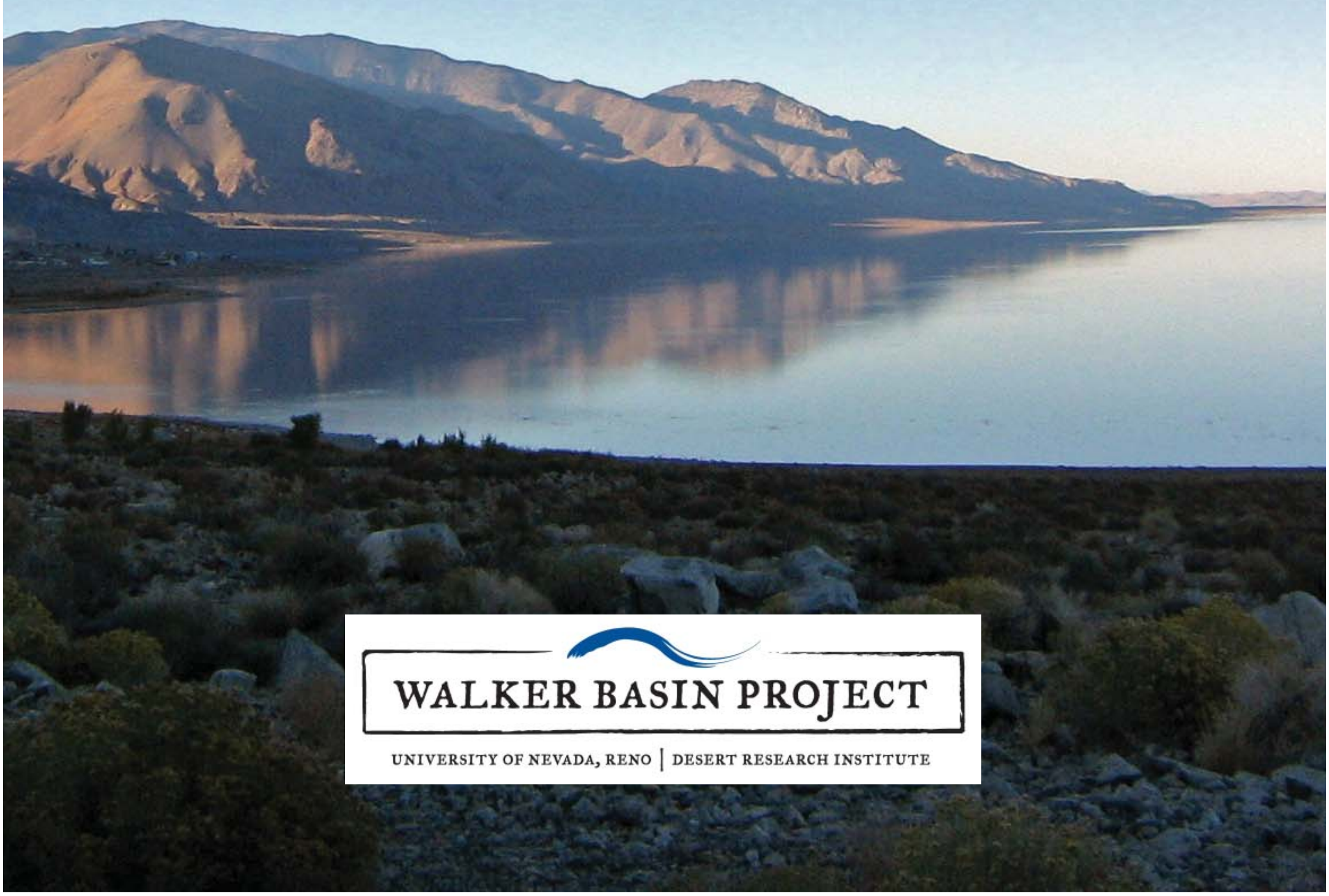
EXHIBIT 86

Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin

Michael W. Collopy and James M. Thomas
Project Directors

April 2010



WALKER BASIN PROJECT

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EXECUTIVE SUMMARY

Walker Lake is one of three desert terminus lakes in the western US that supports a fishery. Desert terminus lakes have no water outflow, so their size depends on the balance between water inflow and evaporation of water from the lake's surface. Over the past 100 years, lake levels have decreased about 150 feet, during which time the volume of the lake has declined from about 10 million to less than 2 million acre feet. During this decline, the total dissolved solids (TDS) of the lake have increased from about 2500 mg/l to greater than 16,000 mg/l. These changes have had far reaching impacts on the health of the lake and its associated ecosystem, such as a significant population decline of threatened Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*), a subspecies that is receiving considerable conservation and restoration attention.

Walker Lake is located in a watershed that supports significant agriculture activity. The primary source of the lake's water is snowmelt runoff from the Sierra Nevada Mountains, which flows through several agricultural valleys before reaching the lake. There are currently no water rights for the lake, so during low water years the lake receives little or no inflow.

In an effort to restore Walker Lake, Congress enacted a law in 2005 that created a program to acquire water rights from willing sellers in the Walker Basin. In order to enact an ecologically and economically sustainable program of water acquisitions, a large-scale integrated research program was established. The primary objective of this research program was to provide the hydrologic, ecologic, economic, and agricultural data needed to inform decisions related to water acquisitions.

LAKE AND RIVER STUDIES

One of the goals of the Walker Basin Project was to evaluate the present status of Walker Lake and Walker River in reference to its existing limnological condition and to evaluate changes in those conditions that may occur in response to changes in water delivery and management practices. The aquatic reports in this volume include summaries for 10 studies conducted by more than 15 scientists, notable because it is the largest study ever conducted examining the ecology of a mid-elevation western Great Basin river and its terminal lake. Each report stands alone, but the strength of this volume lies in the diversity of studies and commonality among findings through divergent methods. The integrated sum of information is vastly greater than the total of the individual parts.

Walker Lake was monitored and sampled during 2007–2008 for the purpose of describing current conditions and to calibrate an ecological model of lake response under different water delivery scenarios. Water quality samples collected from several sites in the lake were used to identify and assess ecological parameters important to lake ecosystem health. Physical, chemical and biological datasets were developed across depth profiles over time to explore factors governing intra-lake circulation and the resulting nutrient cycling, summertime oxygen minima, and accumulations of deleterious substances (e.g., ammonia and hydrogen sulfide). These data were combined with available historical data and used to parameterize the Walker Lake ecological model. Sensitivity analysis of the model was used to identify the factors most important to lake function and its ecological condition. These results, and the professional judgment of participating researchers, have resulted in recommendations for long-term monitoring of the lake to provide a consistent and comprehensive dataset for evaluating environmental conditions in the lake over time. These monitoring recommendations include specific indicators that are vital to improving diagnostic models for Walker Lake assessment and management as future water acquisitions are evaluated.

As Walker Lake level has declined, both the chemistry and biology of the lake have been adversely impacted. The water quality is generally poor and declining with very high total dissolved solids (>16,000 mg/l), alkaline pH (around 9.0), and major-ion chemistry dominated by sodium, sulfate, chloride, and bicarbonate plus carbonate. Despite low lake levels and high salinity from reduced water inflows, Walker Lake still exhibited complete mixing (holomixis) during the winter and stratification during the summer. Anoxic conditions develop in the hypolimnion during the summer, resulting in high concentrations of ammonia. The high ammonia concentrations combined with elevated phosphorus levels in the lake produce large odiferous blooms of phytoplankton during the summer.

Observations and data analysis indicate that large nuisance blooms and deepwater hypoxia will continue in Walker Lake as long as enhanced internal nutrient loading through oxygen depletion in the hypolimnion continues. The volume and areal extent of the hypolimnion oxygen depletion has decreased over time simply due to the reduction in volume of the hypolimnion as lake level has declined. The production of organic matter leading to the hypoxia is sustained by exceedingly high levels of phosphorous (in excess of 20 uM) which sustain the N-fixing *Nodularia* blooms. If the current rate of lake level decline continues the lake may soon transition to a polymictic status. Even if the lake level rises, the hypolimnetic oxygen depleted zone is not likely to disappear any time soon unless the internal loading of nutrients is reduced.

Although fish species diversity is low in the lake, it did at one time support a robust fishery. Prior to lake level decline, Walker Lake supported a large population of Lahontan cutthroat trout, forage fish, tui chub (*Gila bicolor*), as well as other species. Cutthroat trout are currently maintained by an extensive stocking program and tui chub recruitment is limited by the saline conditions in the lake. Studies of the lake foodweb show that both species are mostly dependent on benthic production, which is consistent throughout the season. Pelagic production of edible phytoplankton and zooplankton is highly variable both spatially and temporally.

Paleoecology data for the lake indicate that past fluctuation in lake elevation and salinity occurred rapidly, possibly within several decades, particularly when the Walker River changed course and diverted flow from or returned flow to the lake. When lake levels rapidly recovered, certain taxa quickly colonized the lake. This rapid colonization is evidenced by the sudden occurrence or transition of ostracode and diatom taxa in the sediment record, suggesting that the taxa found in Walker Lake are adapted to rapid recolonization when conditions are favorable. Walker River is the lifeline which many Walker Lake taxa need to survive unfavorable lake conditions and it has served as such for many tens of thousands of years. Little information is available and few studies have been conducted on the Walker River most likely because its tremendous value in sustaining Walker Lake taxa has not been fully recognized.

Walker River studies quantitatively examined its physical characteristics, water chemistry and quality, and ecology (i.e., algae, macrophytes, macroinvertebrates, and fish communities) in different reaches of the river. These studies were designed to:

- define healthy and functioning conditions in the river
- predict changes in riverine ecosystems that can be anticipated from increased flow and change in the timing of delivery from water acquisitions
- integrate this information with future hydrology studies to help develop strategies that maximally increase ecosystem health and recreational opportunities.

Water quality, salient metrics describing physical characteristics of aquatic habitat, periphyton, and benthic macroinvertebrates (BMIs) were sampled at eight river sites during the spring, summer, and autumn of 2007 and 2008.

River water chemistry sampling results were compared to historical data and long-term trends in water quality were identified. Seasonal water quality changes along the length of the river were assessed. Mass loadings of important water quality constituents from the Walker River into Walker Lake were calculated based on measured river flows and constituent concentrations over the sampling period of this study. Results of this monitoring effort provide a basis for comparison for future potential changes in river water quality as new water acquisitions are introduced into the river. An examination of the major ions in the river and lake show that, although the river water becomes more concentrated downstream it is still low in TDS compared to the lake, so that an increase in stream flow would lower the TDS in the lake.

Biomass and community composition of periphyton in the Walker River was evaluated to establish present-day knowledge of algal taxa in different river habitats. Standing stocks of algal biomass were present at levels that often signify eutrophic conditions at the East Fork and Mason Valley sites. The river had high abundances of siltation-tolerant diatom taxa with the most notable abundances (exceeding 60 percent) at site locations farthest down the river towards the lake. The near ubiquitous presence of filamentous green algae (especially *Cladophora* and *Oedogonium*) throughout the system (except the West Walker) is indicative of a system having a high potential for nutrient-algal interactions that produce oxygen slumps during the summer months. Taxonomic richness and the community tolerance values of riffle and woody debris BMIs exhibited spatial and temporal trends. Both metrics show that ecological health of upstream river reaches is generally better than reaches through and below Mason Valley. Multivariate analyses found a strong relationship among water temperature, discharge (and factors that are affected by discharge such as current velocity, wetted width of the stream and water depth), nutrient concentrations, and BMI community structure. These strong relationships indicate that Walker River BMI communities are affected by activities that influence these factors, including water management, flow reduction, and livestock grazing and BMI communities may be useful as indicators of river pollution.

Ten species of fish were collected from eight electroshocking locations in the Walker River. Fifty percent of the species were native, with nonnative coldwater species (brown trout [*Salmo trutta*], rainbow trout [*Oncorhynchus mykiss*], etc.) captured in the upper river reaches and warm water nonnative species (bass [*Micropterus dolomieu*], catfish [*Amereiurus nebulosus*], and carp [*Cyprinus carpio*]) captured in the middle to lower river reaches. Lahontan redside shiner (*Richardsonius egregious*), a forage fish for top predators, was the only native fish captured across most reaches. Otherwise, larger cold water predators (nonnative and native) such as brown trout, rainbow trout, and mountain whitefish, were found in upper, middle, and lower reaches, but they were not necessarily found at the same site.

The drop in Walker Lake level has caused Walker River to extend its length by about 20 km across the former lake bed. In addition to lengthening, the river has also severely down cut in response to lowering of base level (drop in the lake level). A study of the river using rectified aerial photographs from 1938 to the present, in combination with detailed topography from 1995, 1997, and 2005, documented the conditions under which lateral and vertical erosion have occurred. From 1995 to 1997, approximately 1.02 million metric tons (MT) of sediment was eroded from the bed and banks of the lowermost Walker River (about the last 20 km). Over the next seven years (1997 to 2005) about 430,000 MT of sediment was eroded. During the spring 2005 runoff season, approximately 477,000 MT of sediment was eroded and during the spring 2006 runoff season another 936,000 MT of sediment was flushed into the lake from bed and bank erosion.

The amount of erosion in a given year is directly related to the duration of the runoff event as well as peak discharge. A 2-D sediment transport model was used to simulate the amount of sediment transport and vertical erosion that may occur under a variety of flow scenarios. It is difficult to directly compare the estimates of erosion made from aerial photography to those calculated from modeling because the former is better at documenting lateral erosion and the latter focuses on vertical erosion. Nevertheless, the results from both of these approaches indicate that hundreds of thousands of metric tons of sediment are eroded from the bed and banks of the lower Walker River during an "average" runoff year, attesting to the instability of this system. Most of this instability is concentrated in the lowermost reaches of the river. If more flow becomes available in the Walker River in the future and the way that the flow is delivered to the lower Walker River can be controlled, instead of increasing peak flows down the river a more sound approach would be to increase the duration of spring runoff events or to establish minimum base flows that cumulatively would supply the additional water volume to the lake to minimize further erosion.

A pressing issue for the lower Walker River is the poor condition of the siphon. The siphon is holding in place the historic head cut that migrated upstream during the 1997 flood because of the lowering of Walker Lake from its historic high stand position in 1868. The failure of this structure would likely allow the rapid migration of this head cut upstream where it would threaten bridges and other infrastructure in Schurz, in addition to destabilizing the relatively intact Walker River reach that extends from Weber Dam downstream to the siphon. Stabilization of the siphon reach would also allow effective fish passage.

A HEC-RAS model was developed for the upper Walker River to evaluate stream bed and bank erosion for this part of the Walker River system. This model was run for various flow scenarios and constitutes another project related to the river. The predicted hydrodynamic characteristics of the flow (i.e., bed shear stress, mean velocity, water surface elevation, Froude number and maximum channel depth) were obtained from the model. A number of methods were used to determine the susceptibility of sediments in the upper Walker River to be eroded and transported under varying flow conditions, and analyses consistently indicated that the sediments in the upper Walker River would be expected to be actively transported under most of the flow conditions anticipated as a result of the acquisition of additional water along the river. Model results were consistent with what was observed in the field at each of the locations where sediment samples were collected. Even at relatively low flow conditions, active sediment transport was visually observed. Particles were being transported along the surface of the sediment beds. If this particle load was determined to be detrimental to the lake, a potential solution for excessive sediment transport into the lower Walker River would be the installation of settling basins or grit tanks in series throughout the watershed to trap sediments being transported. Periodically, these basins would require cleaning to remove settled materials; these collected materials could potentially be repurposed for different types of building construction or road construction projects.

This modeling study also predicted that most of the upper Walker River can handle flows of up to 400 cfs (cubic feet per second) without excessive flooding, but the average annual maximum flow of 700 cfs would result in localized flooding at a number of locations

WATER FLOW MODELS AND THE DECISION SUPPORT TOOL (DST) MODEL

A computer-based decision support tool (DST) model capable of evaluating the efficacy of proposed water rights acquisitions in the Walker River basin was developed and tested. This DST model represents a major step forward in understanding the complex hydrologic relationships within the real system. Climate, streamflow, upstream storage areas, irrigation practices, crop and non-agricultural ET, groundwater-surface water exchange in the river corridor, groundwater pumping and recharge, and all known existing water rights (decree, storage, and flood; as well as supplemental groundwater) all play a role in the Walker River system and are simulated by the DST. The DST allows users to track water from the headwaters, where streamflow originates, through the complicated deliveries and returns in the heavily irrigated Smith and Mason valleys, to the USGS gauge near Wabuska.

Three different models were integrated to generate results for the DST project. The USGS's Precipitation-Runoff Modeling System (PRMS) was used to model the headwater supply areas of the Walker River basin. It performs well in the West Walker headwaters: timing of the annual hydrograph was well represented, although streamflow peaks were slightly underestimated by the model. The effects of reservoir operations and diversions for agricultural irrigation in the East Walker are not captured by the model, which causes poor representation of annual hydrograph timing as well as overestimation of streamflow peaks for the East Walker River. The East Walker model, or at least estimated inflows to Bridgeport Reservoir, might be improved by simulating additional subbasins utilizing historic streamflow data from discontinued USGS gauges.

MODFLOW is used to model the agricultural demand areas and groundwater-surface water interaction in Mason and Smith valleys. Mason Valley, in particular, is well modeled: low root mean square error (RMSE) values are calculated for water levels, streamflows, and river responses. The Mason Valley groundwater model suggests that groundwater fluxes into the river/drain network account for about 4 percent of the river's water budget during wet periods, but nearly 25 percent during extended drought. Smith Valley is not modeled with the same degree of accuracy as Mason Valley, although contrasting the two provides insight to the system. The groundwater models are limited by their non-unique solutions, poor representation of water levels in parts of Smith Valley, and the unknown errors associated with the simulated groundwater-surface water interaction.

MODSIM simulates reservoir operations, streamflow routing, and water rights allocations in the Walker River basin from the headwaters to the Wabuska gauge. Given the complexity of the water distribution system in the Walker River basin, the results are reasonable. The model is able to maintain target volumes in the reservoirs while supplying water to downstream demands, which indicates that reservoir operations are simulated realistically. Generally, simulated water allocations correspond to historical allocations during the simulation period. In spite of the problems encountered with model calibration, the simulation model allocates the different categories of water reasonably well.

The DST project captures the spatial and temporal complexity of relationships among climate, evaporation, river flows, groundwater-surface water exchange along the river, irrigation practices and groundwater pumping. It uses information gained from other hydrologic modeling studies and incorporates state-of-the-art software and high-resolution spatial products to enhance the accuracy of predicted hydrologic responses. The modeling effort incorporates a geographic information systems (GIS) database of both surface and groundwater data developed by other investigators on the project.

The geographic information system (GIS) database of vector, raster and tabular data, developed as a separate project from the DTS described above, had a principal objective of acquiring, developing and analyzing the requisite spatial and tabular data needed to successfully support many of the Walker Basin Project components. In particular, a majority of the GIS development process focused on providing data for the DST water flow modeling effort described above. In addition to data sets for the DST, a wide variety of other spatial data sets were developed and integrated into the GIS database in support of other Walker projects (alternative agriculture and vegetation management; plant, soil and water interactions; health of Walker River and Lake; economic impacts and strategies; demographics and economic development), as well as outside entities requesting spatial data - the United States Fish and Wildlife Service [USFWS] restoration project; Western Development and Storage, the acquisitions team; and Jones and Stokes, the Environmental Impact Statement [EIS] development team).

Researchers constructed an extensive GIS database of the entire Walker Basin, with data sets from federal, state, and local agencies combined and integrated with derivative data sets. The result is a scalable, georeferenced collection of spatial data (i.e., geodatabases, shapefiles, rasters, and tables) representing a wide variety of spatial and temporal features, as well as tabular information for the entire Walker Basin. The principal base layer for the development, processing and analysis was one-foot natural color aerial photography, complemented by six-inch resolution imagery of the Yerington area. Infrastructure data included the Public Land Survey System (PLSS), land ownership, roads, topography and administrative boundaries. LIDAR imagery and USGS elevational data were integrated for groundwater modeling analysis. USDA agricultural and soils data were also integrated with geo-referenced spatial data and from this information attribute tables were generated.

Acquisition and development of surface and ground water data for the DST was time consuming as information was gathered from many sources, fieldwork was required and much of the data required digitizing or manually entering into digital format. However, the most critical factor in the GIS database was the establishment of a minimum mapping or modeling unit for the primary irrigation. Due to the sensitive nature of mapping at the farm scale, a data set that operated at the scale of each group of fields linked by a common ditch was developed for this project. This dataset is referred to as a Hydrological Response Unit (HRU). Forty-four HRUs were defined for this project and for each HRU water right and historic water diversion data were compiled into associated attribute tables. Tabular and shapefile data for the GIS task are included in the report on a USB flashdrive.

The GIS database includes both surface and groundwater distribution networks and water rights. These data were used as inputs for the DST model described above, providing spatial and tabular data to the supply, demand, and basin management components, as well as calibration data to assist in the validation of the models. The database might be used in the future by resource managers and researchers for investigating hydrologic, ecological and economical phenomena in the Walker Basin.

Another project that contributed to understanding the groundwater inflows and outflows to the Walker River was the distributed temperature sensing project. This project is important for understanding the hydrology of the basin and the accurate assessment and management of its water resources. Distributed temperature sensing analysis showed the groundwater-surface water interaction to be highly variable in both space and time. This project found that ground water inflows and outflows to and from the river were easily identifiable and quantifiable using the combination of the distributed temperate data and vertical temperature measurements. The distributed temperate measurements indicate gaining conditions over short periods of time and long spatial extent. These measurements permitted assessment of where gains to channel flow were occurring during the limited periods with gaining conditions. In agricultural areas, inflow zones to the river can be identified based on temperature differences, permitting efficient sampling for determining potential salinity loading to the river by groundwater at the resolution of individual fields and drains.

LAND USE CHANGE, VEGETATION MANAGEMENT AND PLANT SOIL WATER INTERACTIONS

Over the past 150 years, the Walker River riparian zone has experienced massive land cover conversion from native riparian vegetation to extensive agricultural landscapes characterized by irrigated pastures and alfalfa (*Medicago sativa*) fields. Much of the historical riparian area in the lower river was dominated by wet meadow and emergent wetland habitats. Ninety-five percent of this habitat has been lost, but only 41 percent was directly converted to agriculture. The rest was converted to more xeric communities. Cottonwood (*Populus fremontti)* forests were not as extensive along the Walker River as they were along the Truckee and Carson Rivers. The most extensive forest occurred at the former Walker River delta. Now there are numerous small patches and individual trees scattered around the former riparian zone resulting in more extensive, but also more fragmented forests. The dominant direction of change observed in the historical analysis indicates a riparian environment that has become narrower, more channelized, and with reduced groundwater availability.

Water withdrawals and diversions for agriculture have greatly reduced flows of water to Walker Lake, influencing aquatic ecosystem integrity. River regulation and reduced in-stream flows have altered riparian vegetation even in locations not devoted to agricultural use. In response to recent environmental concerns, purchase of water rights from agricultural producers is under consideration. However, past abandonment of irrigated fields in the region has resulted in ecologically and economically undesirable effects, including surface soil erosion, salinization, and spread of invasive plant species. Careful orchestration is required for land use conversion to result in benefits for ecosystems and society.

The impending impact of water reallocation has stimulated renewed interest among the agricultural sector, not only in terms of alfalfa production but also with respect to alternative agriculture (e.g., biofuel crops and the production of low water use crops) and the restoration of abandoned agricultural lands. A parallel concern is the response of existing ecosystems to future changes in water availability, allocation, and management. About 50,000 acres in Lyon County are currently devoted to irrigated alfalfa production (personal communication; Nevada Cooperative Extension, Yerington, NV). Conversion of high water use alfalfa to lower water use alternative agricultural crops could have a significant impact on water resources, the local economies, and ecosystem stability.

Alternative low water use crops were investigated to determine likely responses by soils and vegetation to changes in water application and consumptive use, water table depth, and soil salinity in three key landscape circumstances: (1) currently irrigated and peripheral lands that may undergo lowering of water tables due to reduced irrigation; (2) the Walker River riparian zone that presumably would undergo an increase in water table levels and a change in the net direction of water movement with increased in-stream flows during the irrigation season; and (3) the lower Walker River, which currently suffers from soil salinization and infestation from invasive species. This investigation was accomplished through the measurement of important soil characteristics and parameters, such as soil moisture depletion and evapotranspiration, susceptibility to wind erosion, salinization, nutrient fluxes, temperature, and organic matter content, as they relate to water treatment and vegetative cover.

Five agricultural crops (teff [*Eragrostis tef*], buckwheat [*Fagopyrum esculentum*], amaranth [*Amaranth hybridus* x *hypochondriacus*], pearl millet [*Pennisetum glaucum*] and alfalfa [*Medicago sativa*]), nine biomass crops (switchgrass [*Panicum virgatum*], sand bluestem [*Andropogon hallii*], Indian grass [*Sorghastrum nutans*], prairie sandreed [*Calamovilfa longifolia*], bluestem [*Bothrichloa ischaemum*], tall wheatgrass [*Elytrigia elongata*], Basin wildrye [*Leymus cinereus*], Mammoth wildrye [*Leymus racemosus*], and tall fescue [*Festuca arundinacea*]) and five native species that can be used for re-vegetation (Indian rice grass, Basin wildrye, Beardless wheat grass [*Pseudoregneria spicata*], Western wheatgrass [*Pascopyrum smithii*], and Inland salt grass [*Distichilis spicata*]) were tested. These alternative crops and native species were planted at five sites under four different water regimes (0, 50, 75, and 100 percent [4 feet]). At each site, physical and chemical soil properties were analyzed and wind erosion, precipitation, and soil moisture were quantified. In addition, riparian zone de-nitrification was measured in the field and modeled. Finally, the ability of an invasive species (for this experiment, tall white top) to use alternative deep water sources and thus out compete native species was investigated.

Of the alternative low water use crops, teff and amaranth were the highest performing annual crops, with seed production comparable to production elsewhere. Additionally, both species produced seeds at the lowest watering levels. Although above ground teff biomass yields were largest of the five crops, no differences in soil carbon content were found. In addition, the higher yields for teff did not translate into increased soil carbon dioxide (CO_2) efflux rates. Effects of vegetation on nitrogen (N) fluxes were not consistent. Perhaps most surprisingly, nitrogen (N) fluxes in alfalfa soils were not much different from switch grass and amaranth, despite alfalfa being an N fixing species.

Warm season biomass crops were generally not as successful as cool season crops, with the exception of old world bluestem. Additionally, bluestem was the top performing warm season grass in the lowest watering treatment. Cool season grasses established and grew well in both sites, and were very competitive with weeds. There was variability in performance of some species between sites, but tall wheatgrass was consistently a top performer, in both high and low water applications.

The establishment of multiple restoration species (a mix of native grasses and shrubs) were evaluated for an application rate of one foot per acre and with no water application. All native grasses established significantly better with water application, though there were differences in rank performance between sites. Indian rice grass was the best performer at one site, with the highest biomass and weed suppression as compared to the other grasses, whereas beardless wheat grass was the top performer at the other restoration site. Sagebrush survived transplanting significantly better than other species, and greasewood, although it had low survival, had the fastest growth rate and responded the most to water addition.

Application of none and 25 percent (one acre feet of normal four acre feet) of water for dust suppression was also evaluated for the plots. Overall, the 25 percent water treatments were far more effective at reducing dust generation and increasing dust deposition than the zero percent water treatments and, in some instances more so than even the controls. The zero percent water treatments were found to be far more erosive than natural conditions.

Groundwater flow modeling, using MODFLOW, showed that the residence time of water and nitrate removal rates are sufficient to remove nearly all nitrate from hypothetical "slugs" of water originating from the agricultural ditches and flowing through the riparian groundwater zone before entering the river.

Experiments with tall white top (*Lepidium latifolium*) show that it is able to utilize deep water sources. This may have impacts on late season surface water availability, but in competition experiments tall white top did not negatively impact the native grass (slender wheat grass [*Elymus trachycaulus*]).

Another project examined alternative crops that would enable producers to remain economically viable while using less water. The main crop grown in Mason and Smith Valleys is alfalfa, which yields high prices but is a high water user. If producers plan to continue growing crops with lower water use and potentially sell a portion of their water rights, they would have to be able to grow a crop that uses less water, yet yields equal or greater profits. Viable crops which merited study offer producers more than one option when considering alternatives. These alternative lower water use crops include onions (*Allium cepa*), leaf lettuce (*Lactuca sativa*), wine grapes (*Vitis interspecific*), teff (*Eragrostis tef*), two-row malt barley (*Hordeum distichum*), Great Basin wildrye (*Leymus cinereus*), and switch grass (*Panicum virgatum*). In addition to different cropping practices a no-till option was also included models for all crops under consideration.

A combination of a crop yield model (WinEPIC) and a risk simulation model (SIMETAR) were used for analysis and to address agronomic and economic questions. Results showed that there are alternative crops that could be economically feasible in the Walker Basin. For producers able to obtain funding for capital investment and who are willing to hire additional labor, growing onions and leaf lettuce under rotation would yield substantial returns. With no additional capital or labor, the study recommended investigating contracts for growing two-row malt barley or Great Basin wildrye. These four crops use half the water needed for alfalfa (two feet rather than four feet), which would potentially allow producers to sell part of their water rights. The study also concluded that teff has potential for profit, but switch grass was not recommended. Wine grapes have a good profit potential, but they are demanding both fiscally and in terms of labor, and therefore require more risk-tolerance than other crops.

ECONOMICS AND SOCIAL HISTORY

In order to quantify any economic impact to the Walker Basin as the result of water right acquisitions, the current economic and demographic characteristics of the communities within the Walker Basin had to be developed and analyzed using local, state, and federal databases and geographic information systems software. Although agriculture is a predominant and traditional industry in the Walker Basin, employment and industry totals indicate a diverse economy. Almost a quarter billion in taxable sales is generated in the Walker Basin, with the majority of sales coming from retail industries. Another $58 million in revenue is estimated to be generated from crop production in Mason and Smith valleys (Lyon County) from production on more than 50,000 acres. Current and future residential and commercial construction activity is mostly targeted for populated areas in the basin and is consistent with the current economic conditions.

The acquisition of water rights that have historically been used for agriculture could have a variety of economic and fiscal impacts in the Walker Basin. Cost and value for a number of crops, including alfalfa and onion, which are the main crops in the Walker Basin, as well as alternative crops (as discussed above), were assessed in conjunction with estimated reliability of water rights offset against hypothetical water rights sale income. Four scenarios related to how water rights might be acquired, along with the resultant potential uses for the land following water rights acquisition, and estimates of economic and fiscal impacts for those scenarios were evaluated. The four scenarios include: (1) agricultural land taken completely out of production (returned to native vegetation); (2) existing crop rotations and farming practices are altered to save water; (3) alternative crops that require less water are cultivated; and (4) other (non-agricultural) sources of water rights are purchased. Based on these scenarios, the study examined the potential economic impacts in the Walker Lake Basin assuming that sufficient water flows into the lake to save and maintain a fishery. Three different scenarios of the overall economic impact in Mason and Smith Valleys were evaluated using different figures for acres taken out of production, modified crop rotations, and alternative low water use crops. Two scenarios indicate a projected loss to the regional domestic product, whereas the third scenario showed a positive economic impact to the region. The study concludes that the economic impact to the region is highly dependent upon where and how water rights are acquired and what happens to the land associated with the water right. A risk fund to assist farmers and reduce the perceived risk of growing alternative crops is suggested, in association with agricultural and business technical assistance programs.

Based on input received at community meetings, this project also makes some recommendations regarding economic development efforts in the Basin that would be consistent with the desire of citizens in the communities and that might tend to offset any economic dislocations that could result from the acquisition of water rights.

A social and political historical account of water rights acquisitions in the Walker Basin for ecosystem restoration will be published as a book when the overall water rights acquisition program is completed. Currently three chapters are completed; "Changing Contexts in Western Water Policy;" "The Past as Prologue—the Walker River Basin;" and "P. L. 109-103 and the Walker Basin Project."

WILD HORSES AND BURROS

Wild horse and burro policy is currently driven by several goals that include the mitigation of damage to rangeland, the commitment to humane treatment of the animals, and the control of regulatory costs.

A study undertaken as part of the Walker Basin Project investigated alternative auction strategies that potentially could increase adoption rates of wild horses. Placing animals with private owners and raising revenue from the distribution of the horses complements all the goals of the current wild horse and burro policy. Forty experimental auctions for three alternative packages of goods were conducted. The auction items were comprised of: (1) hiking equipment, (2) an Apple iPod and speaker system and (3) high quality wines. Auction participants were provided with alternative low and high information about the goods offered. Two types of auctions were evaluated, a sequential or good-by-good method and a right-to-choose method, in which the highest bidder wins the right to choose from among the goods that are available. Results of auction type analysis indicate that revenues from the sequential method were slightly higher, but not statistically different from those generated by the right-to-choose strategy.

The wild horse and burro policy study also employed stochastic simulation procedures to provide wild horse adoption decision makers with a range of potential revenues for wild horse adoptions. This range of revenues combined with capital and operation cost estimates of a potential wild horse and burro interpretive center provides decision makers with information as to potential distribution of net returns. From the distribution of net returns, decision makers could decide on construction and operation of a national wild horse and burro interpretive center in a risk adverse vantage.

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REPORT CONTENTS

Introduction

Walker Lake is one of three desert terminus lakes in the United States that support a fishery. Over the past 100 years, lake levels have declined about 140 feet and the volume of the lake has decreased from, about 10 million to less than 2 million acre feet. During this decline the total dissolved solids (TDS) of the lake have increased from about 2,500 mg/l to greater than 15,000 mg/l. These changes have had far reaching impacts on the health of the lake and its associated ecosystems. High TDS values have resulted in significant population declines of threatened Lahontan cutthroat trout (LCT), a subspecies that is receiving significant conservation and restoration attention.

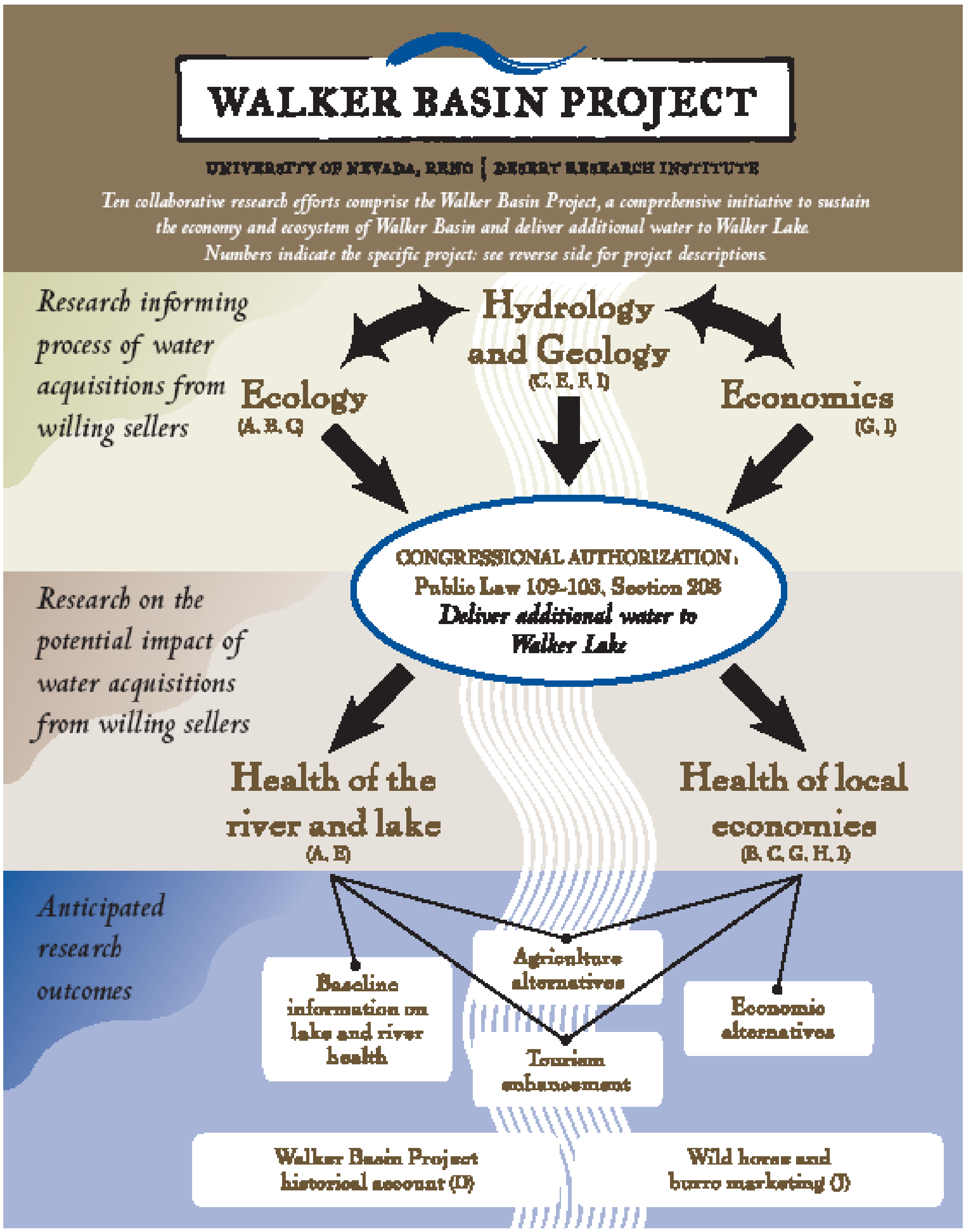
Walker Lake is located in a watershed that supports significant agriculture activity. The source of the lake's water comes primarily from snowmelt runoff from the Sierra Nevada, which flows through several agricultural valleys before reaching the lake. There are currently no water rights for the lake, so during low water years the lake receives little or no inflow from the Walker River.

In an effort to save Walker Lake, Congress enacted a law in 2005 (i.e., H.R. 2419 Energy and Water Development Appropriations Act, 2006, Section 208), that created a program to acquire water rights from willing sellers in the Walker Basin. In order to enact an ecologically and economically sustainable program of water acquisitions, a large-scale integrated research program was established. The goal of the Walker Basin Project was to provide the hydrologic, ecologic, economic, and agricultural data needed to inform decisions related to water acquisitions. This report is the product of the research program that was developed in response to direction provided in this federal legislation Specifically, Desert Research Institute and University of Nevada, Reno faculty were funded to: (1) develop a method to optimize the purchase of water rights in the Walker River Basin, (2) evaluate options for practicing alternative agricultural practices, and (3) evaluate the impacts that water removal from crop-irrigated lands will have on the spread of invasive plants, aquatic and terrestrial ecosystems, and the local economy.

This document is divided into 10 sections, each representing a major research component of the overall project. Throughout the study period, project leaders met monthly to share updates, coordinate logistics, and ensure ongoing integration of the overall research effort. The relationships between these component studies are depicted below, along with a brief description of the activities of each study component.

Once the draft reports were completed by the component study leads, the project co-directors (M. Collopy and J. Thomas) obtained independent external peer reviews from subject matter experts for each of the completed report sections. Then report authors revised their respective documents, based on the review comments provided, and documented how they responded to each of the review comments. The peer reviewer comments and the authors' responses to those comments are compiled in a chapter at the end of this document. The Bureau of Reclamation (BOR) granted two of the studies (Alternative Agriculture; Plant, Soil and Water Interactions) no-cost extensions through December 2009, so data for a second growing season could be obtained prior to finalizing their reports. While a preliminary report for each of these two studies is included in this report, they were not externally peer reviewed. That review will take place in the fall of 2009, in advance of submitting the final reports for these two studies to BOR. It is our intention to submit those documents as an Addendum to this final report.

The component studies of the overall project were developed as standalone reports, thus many of the component study reports contain similar background and introductory material. This material was included so that the individual reports could be read as standalone sections without having to read other parts of the overall report.



PROJECT DESCRIPTIONS

A. HEALTH OF WALKER RIVER AND LAKE. This project will evaluate and establish a benchmark for the environmental and ecological health of Walker Lake and Walker River. Decision tools will be developed to analyze the efficacy of different water acquisitions for improving future ecological integrity of Walker Lake and Walker River.

B. ALTERNATIVE AGRICULTURE AND VEGETATION MANAGEMENT. This project will identify the economic potential and cultural practices necessary for low-water-use crops with the aim of minimizing water use, soil erosion and evaporation from soil surfaces. In addition, the research will evaluate methods to re-establish desirable vegetation in areas that may be affected by changing agricultural practices and to anticipate vegetation responses under scenarios identified through modeling efforts.

C. PLANT, SOIL AND WATER INTERACTIONS. This project will assess likely responses by soils and vegetation to changes in water application and use. Information on the impacts of changes in water table and stream elevation on soil physical and chemical properties, including wind erosion, nutrient cycling and salt accumulation, will aid managers in the preservation of air and water quality adjacent to and within the river and lake itself.

D. PROJECT HISTORICAL ACCOUNT. This project will provide an overview of the political and historical context in which the acquisition of land and associated water rights for ecosystem restoration in the Walker River system occurs. Key components include arid land agriculture, multi-state involvement and urban/rural interface issues.

E. HEALTH OF RIVER CHANNEL AND LAKE WATER WITH INCREASED FLOWS. This project will develop a set of recommendations to minimize further sediment and salt loading to Walker Lake and degradation to the lower Walker River under increased water flows. These recommendations will be made available to land and water managers to assess potential impacts resulting from variations in flow, water quality and channel geometry on the transport of sediments and on the flow capacity of the Walker River.

F. WATER FLOW MODEL. This project will develop a decision-support tool to evaluate the effectiveness of proposed acquisitions of water rights from willing sellers to increase water delivery to Walker Lake. The tool's water flow model will include aspects of climate and evaporation from different water sources.

G. WATER CONSERVATION PRACTICES FOR AGRICULTURE PRODUCERS. The project will determine the most economically effective use of water on agricultural lands and provide producers with an estimate of the potential amount of water rights they may be able to offer to the market for lease or sale.

H. ECONOMIC IMPACT AND STRATEGIES. This project will develop estimates of the economic impacts projected to occur from the acquisition of water rights and changes in agricultural production and land use. The project will also formulate economic development actions to mitigate the projected economic and fiscal dislocations. One benefit of this research will be to identify appropriate sustainable economic development actions and related public policy alternatives.

I. GIS DATABASE DEVELOPMENT. This project will develop a geographic information systems (GIS) framework for linking water rights with water distribution networks and points of diversion for the Walker Basin. The resulting GIS database may be used to assess how water and land acquisitions will affect the entire Walker Basin system. The economic component of this project will develop a GIS database of properties, businesses and local demographics in close proximity to the Walker River and its tributaries.

J. WILD HORSE AND BURRO MARKETING. The project will determine which characteristics of wild horses and burros increase adoption rates. It will also investigate alternative auction procedures which could increase adoption rates and simultaneously increase revenues to support wild horse and burro programs.

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PAST ELEVATIONS AND ECOSYSTEMS OF WALKER LAKE PROVIDE A CONTEXT FOR FUTURE MANAGEMENT DECISIONS

Contributing Author: Saxon E. Sharpe, Desert Research Institute

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Walker Lake became the southernmost embayment of Nevada's Lake Lahontan about 14,000 years ago when waters rose above 4,271 feet (1,302 m) mean sea level (msl) at the Adrian Valley sill north of Wabuska [Figure 1] (Benson and Mifflin 1986). This elevation is corrected for isostatic rebound and tilting. This high stand of Lake Lahontan occurred sometime between 14,500 and 13,000 yr B.P. (before present) and may have lasted less than 200 years (Benson 1991). Climate conditions providing greater effective moisture (precipitation minus evaporation) were responsible for high lake levels at this time.

The elevation of Walker Lake in December 2007 was 3,934 feet msl, a difference of over 337 feet between this highstand and today. Highstand Walker Lake was fresh with a total dissolved solids (TDS) possibly as low as 500 milligrams per liter (mg/L). In December 2007 Walker Lake TDS was ~ 16,000 mg/L. At times during the last 30,000 years, however, Walker Lake was shallow and much more saline than today with TDS possibly as high as 100,000 mg/L (Benson 1991, Benson et al. 1991, Bradbury et al. 1989).

Changes in river volume and, therefore, lake volume can create different river and lake ecosystems. Lopes and Smith (2007) report lake elevation has not exceeded 4,120 ft-msl during the last ~10,000 years. This finding is consistent with Adams (2007) who reports that lake elevations fluctuated about 180 feet during the last ~3,500 years and that during this time period four episodes of deep water occurred. Yuan et al. (2006a) also report deep and shallow lake stands during the last ~2,700 years. Ecosystems resulting from different lake elevations have different physical attributes, processes, and biota. What triggered these substantial fluctuations in Walker Lake's elevation? On what timescales has the lake changed? What ecosystems have resulted from changes in lake and river volume? How can this information be used to aid management decisions?

Decadal to millennial change in the elevation of Walker Lake resulted from three processes: change in climate, change in the course of the Walker River, and modification of the hydrology of the Walker Basin caused by humans. These processes affect lake and river ecology on different timescales.

Climate affects the river and lake on both short and long timescales. Periods of drought can last seasons to centuries. Pluvial (wet) periods can last tens of thousands of years during glacial climates or decades during cool and wet climate episodes within overall drier climate regimes. When climate is cool and wet relative to today precipitation is greater than evaporation and more water is available to lake and river ecosystems. When climate is warm and dry like our current climate has been for the last ~ 10,000 years, precipitation is often less than evaporation and less water is generally available.

Present-day climate at Walker Lake is arid with hot summers. The Sierra Nevada create a rain shadow to their east which decreases precipitation as storms move from west to east across the mountain range. Substantial seasonal and diurnal temperature fluctuation, common to desert environments, occurs at elevations near Walker Lake. Temperatures at Hawthorne, Nevada, (elevation 4,220 feet), range from an average maximum temperature of 71˚ F to an average minimum temperature of 41˚ F. Average annual precipitation at Hawthorne is less than 5 inches (51-year record; WRCC, 2006).

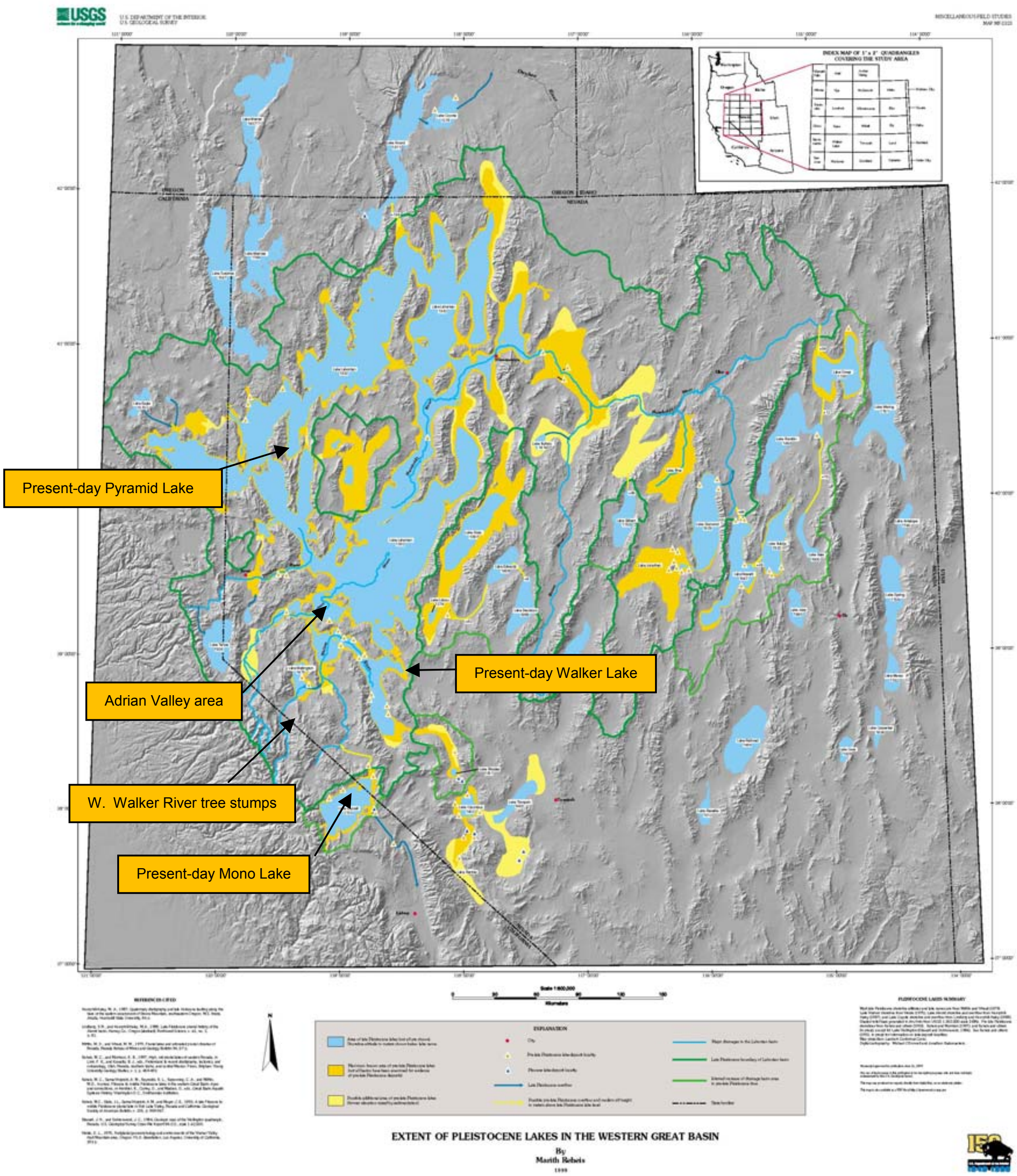

Figure 1. Pleistocene Lakes in the Western Great Basin and other localities mentioned in text (from: Reheis 1999, http://pubs.usgs.gov/mf/1999/mf-2323/mf2323.pdf).

Climate has been responsible for swings of hundreds of feet in the elevation of Walker Lake. Climate influence on Walker Lake is a product of the interplay of snowpack (river discharge) in the Sierra Nevada, and temperature, evaporation, and humidity at Walker Lake. For example, if snowpack in the Sierra Nevada were extensive (creating high river flow in spring and summer) and temperature at Walker Lake were low, lake levels would be high (assuming no agricultural use of water). If snowpack in the Sierra Nevada were moderate (creating moderate or low river flow), but temperature at Walker Lake remained very low, lake levels could remain relatively high because evaporation would be reduced. This last scenario may have occurred in Walker Lake's pre-history.

The course of the Walker River also affects the elevation of Walker Lake. The Walker River makes a 180 degree bend near Wabuska in Mason Valley. An old river channel heading in a northwesterly direction through Adrian Valley (Figure 1), however, likely carried the Walker River away from Walker Lake and into the Carson Sink at times in the past (King 1993, 1996, Yuan et al. 2006a, Adams 2003, 2007). During the time(s) that the Walker River flowed through the Adrian Valley, Walker Lake was very shallow or possibly dry.

For the purposes of this report, the exact timing of lake levels (discussed in Benson 1991, Benson et al. 1991, Bradbury et al. 1989, Adams 2003, 2007, and Yuan et al. 2004, 2006a, 2006b) is secondary to what we can learn about the Walker Lake ecosystem during times of different lake elevations. This discussion will compare what is known about taxa inhabiting low-water-saline to high-water-fresh Walker Lake ecosystems.

Humans began affecting the river and lake in 1852 when Walker River water was diverted for irrigation of agricultural lands (Horton 1996). Lands irrigated for agricultural production increased from 0 acres in 1850 to approximately 110,850 today (Pahl 1999). The operation of Topaz and Bridgeport Reservoirs allows farmers in Smith and Mason valleys to extend their growing season until late September and October which alters the natural hydrograph of the Walker River and the amount of water flowing into Walker Lake. Groundwater pumping in Smith and Mason valleys began in the 1960s and has since depressed the aquifer's water table, resulted in a net increase in recharge from the Walker River to the aquifer, and created a net decrease in stream flow passing the Wabuska stream gage located just upstream from the Walker River Paiute Reservation (Horton 1996, Sharpe et al. 2008). These modifications, not drought, have decreased the elevation of Walker Lake from approximately 4,083 feet in 1882 to 3,934 feet msl in December 2007 (Milne 1987, Beutel et al. 2001). The 149 foot elevation decrease concomitantly decreased lake volume from approximately 9.0 to 1.7 million acre-feet and increased TDS from an estimated 2,500 to approximately 15,995 mg/L.

This chapter will focus on the paleoecology of Walker Lake rather than the Walker River because little information exists on the ecology of the Walker River. The river section of this report is the first comprehensive study on the physical characteristics, biota, and health of the Walker River. Past variability and ecosystem change in Walker Lake, however, indicates that the Walker River is the lifeline for lake taxa. Therefore, a healthy Walker River is the key to long-term species survival in Walker Lake.

PREVIOUS RESEARCH

The first study to collect comprehensive physical and biological data in Walker Lake was conducted by DRI researchers between May 1975 and May 1977 (Koch et al. 1979, Cooper and Koch 1984). Numerous data sets were collected every two weeks or monthly for two years and are extremely valuable because they record Walker Lake biota and processes when the lake TDS were at ~ 10,300 mg/L. Horne et al. (1994) sampled Walker Lake between 1992 and 1994. Horne sampled one day each in July and October 1992, in March, April, July and September 1993, and in February and May 1994. These data, not taken as regularly at the previous study, record Walker Lake at ~ 12,500 mg/L. Subsequent lake studies include Beutel (2001) who sampled water quality and chlorophyll-a monthly at two locations from October 1992 to September 1993 and January 1995 to December 1996. Beutel also monitored zooplankton from 1992 to 1996 at one or more lake locations. In the summer of 1998 water profiles and undisturbed sediment-water interface samples were collected (Beutel 2001).

The Walker Lake Fishery Improvement Team (WLFIT) includes representatives from the Walker River Paiute Tribe, Nevada Department of Wildlife, and U.S. Fish and Wildlife Service. The WLFIT began a 5-year monitoring program in 2006 designed to evaluate the response of water quality, benthic invertebrates, macrophytes, the zooplankton community, tui chub, and Lahontan cutthroat trout to fluctuating lake environment and seasonal inflow to Walker Lake. The WLFIT has been monitoring benthic invertebrates in the near-shore areas quarterly since 2006 and is collecting temporal and spatial data to assess current conditions in the river and lake. Additionally, the six locations monitored and reported on in this report are also monitored monthly by the WLFIT. These studies as well as quarterly monitoring by the Nevada Division of Environmental Protection beginning in 1992, monitoring and reports compiled by the Nevada Department of Wildlife for the Walker Lake fishery beginning in 1958, and Lahontan cutthroat trout data collected by the U.S. Fish and Wildlife Service are crucial to our understanding of lake processes and changes on seasonal to decadal time scales.

Projects focusing on the ecology of the Walker River and its tributaries are few. Samples of water, bottom sediment, and biota were collected during the summers of 1994 and 1995 from sites on the Walker River to assess environmental quality (Thodal and Tuttle 1996). A study of mercury in 12 fish and 29 aquatic invertebrates and sediment from 19 sites in the Walker River Basin was conducted by Wiemeyer (2002). Leach and Benson (USGS) measured chemistry of the river at numerous locations during high and low flow periods and demonstrated the problem with irrigation return as a pollutant. In 2006 the U.S. Fish and Wildlife Service commissioned a study by Otis Bay, Reno, Nevada, to complete surveys for vegetation, avian, herpetological, and aquatic invertebrate abundance and richness and geomorphic and geologic characteristics along the Walker River.

The river and lake, however, operate on many timescales, from diurnal to seasonal to millennial. It is important to become familiar with past environments of Walker Lake and the Walker River because the past provides us with the additional knowledge to make informed management decisions.

THE GEOCHEMICAL HISTORY OF WALKER LAKE

Walker Lake provides a clear example of how solutes (ions) within a water body can change with continued evaporation and, as a result, alter lake environment and habitat. Changes in major ions [Ca, Mg, K, Na, SO_4, Cl, $HCO_3(CO_3)$] can affect the occurrence of certain taxa just like TDS and temperature. Changes in solute composition were called solute evolution by Jones (1966). Eugster and Jones (1979) provide a detailed discussion of solute evolution as a consequence of evaporation and mineral precipitation, as well as other processes. Forester (1983, 1987, 1991) discusses how solute evolution affects the distribution of ostracodes and Sharpe and Forester (2008) discuss how solute evolution affects the distribution of mollusks. Solute evolution may affect other taxa as well.

Briefly, solute evolution occurs as follows. The TDS along a solute evolutionary climate or hydrologic gradient will commonly increase more or less in a linear fashion. As solutes are concentrated in the water column due to processes such as evaporation, calcium (Ca) and bicarbonate/carbonate ([$HCO_3(CO_3)$] referred to as alk, for alkalinity, hereafter) reach saturation at ~ 200-300 mg/L TDS (Figure 2) because each ion is a relatively insoluble mineral compared to halite or gypsum. Note that 200-300 mg/L TDS is the high percentage interval in the Figure 2 data array. After this interval, the Ca and alk in the water column decrease because calcite is precipitating and other ions are concentrating. When calcite precipitates, Ca and alk are removed in equal equivalents. Either Ca or alk are lost (depleted) from solution relative to the other depending on the initial alk to Ca ratio. The colored bars in Figure 2 are discussed below.

Calcium plus alk depletion commonly occurs at TDS levels between ~ 1,000 to 2,000 mg/L (Figure 2). At TDS levels greater than ~2,000 mg/L, Ca plus alk are no longer dominant, therefore higher-TDS waters are dominated by ions other Ca or alk. Note in Figure 2 that Walker Lake is shown in blue triangles and the 1882 value occurs just beyond the Ca plus alk depletion zone of ~ 1,000 to 2,000 mg/L. All other values (1937-2003) occur well after Ca plus alk depletion. These values fall into the zone where Ca plus alk are no longer dominant in the water column. The ions currently dominating Walker Lake are sodium and chloride. In 1882, and in periods of fresher water (lower TDS), Walker Lake had Ca plus alk values over 50% (Figure 2). Between 1941 to ~ 1975, with ongoing evaporation and low inflow, the Ca plus alk value drops to just below 30% and after 1975 the Ca plus alk value drops to less than 20% (Figure 2). This simplified scenario does not account for non-equilibrium processes, species of calcium precipitated, or calcium complexed to other chemical species, but it does illustrate that the ions in Walker Lake have changed over time.

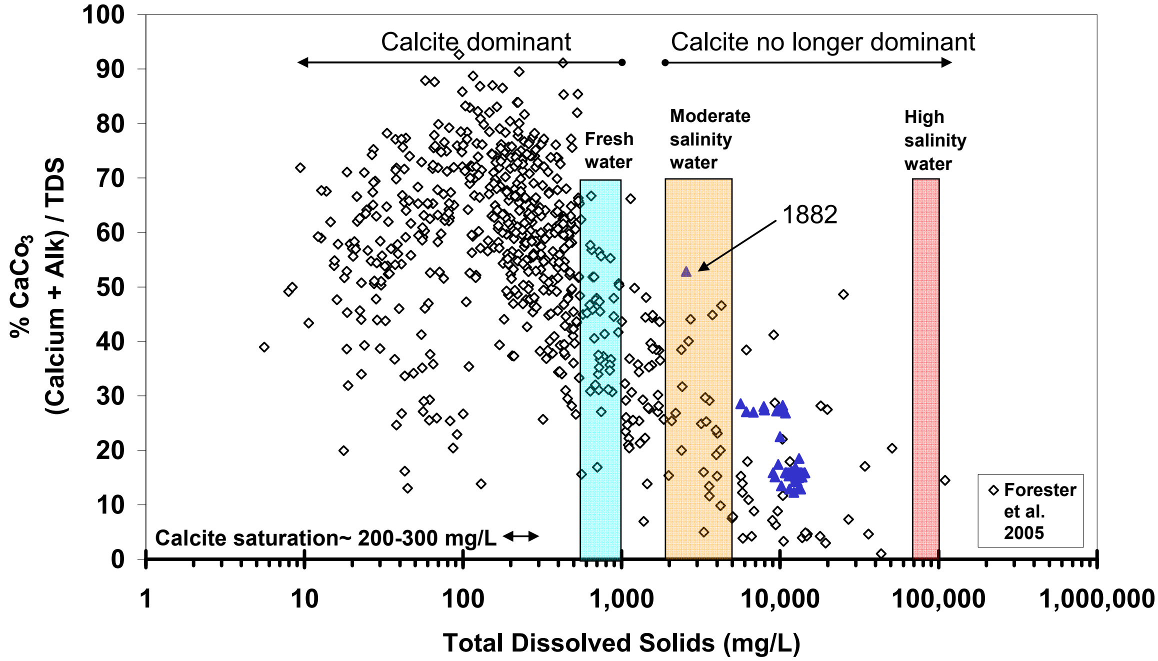

Figure 2. The solute evolution process. Diamonds show the ratio of Ca plus alk to TDS of 631 aquatic locations included in the North American Non-Marine Ostracode Database (NANODe) (Forester et al. 2005). Blue triangles show Walker Lake values. The two clusters of blue Walker Lake triangles are artifacts of the years data were collected (a data gap). Calcite saturation (the maximum percentage of Ca plus alk commonly occurs at about 200 to 300 mg/L TDS, the high-point of the curve. At saturation, Ca and alk are removed in equal equivalents while other ions remain in solution, so it is at this point that the curve begins to decline. As the percent of Ca plus alk to total ions decreases, the concentration of other ions is rising because of evaporative loss of water. Between approximately 1,000 to 2,000 mg/L TDS Ca plus alk (taken together) are no longer dominant solutes. Beyond this TDS range, the solutes are dominated by ions other than Ca or alk and, commonly, either Ca or alk is depleted from solution. Blue bar denotes fresh water, orange bar denotes moderate salinity water, and red bar denotes high salinity water. Bar widths are illustrative; they vary in width and overlap based on biota and water geochemistry specific to location.

Figure 3 tracks individual ions in Walker Lake through time. Note that alk (HCO_3) is always greater than Ca. This is because inflowing Walker River waters contain much greater alk relative to Ca (Humberstone 1999). Because alk and Ca are precipitated first, because they are precipitated in equal equivalents, and because Walker Lake initially had greater alk relative to Ca, Ca will be depleted relative to alk with continued evaporation. Figure 3 shows that over time, calcium is depleted and the remaining ions values increased. Also, the spread among all ions has increased relative to initial values. Therefore, in addition to TDS change, the ionic composition of Walker Lake today is vastly different from 1882 values. The changes noted in Figure 3 are the result of water withdrawn from the Walker River for agricultural use. This solute evolution process however, also occurs naturally with increased or decreased inflow and evaporation based on climate change or river diversion. When fresh water is input, the process reverses.

In 1882 Walker Lake was transitioning from waters dominated by alk and calcium to waters dominated by other ions. This major shift in ionic composition (not just TDS) can be one of the primary factors affecting the occurrence of taxa.

Solute evolution at these TDS concentrations creates three generalized solute fields: (1) Ca and alk in roughly equal proportions below ~ 2,000 mg/L (type 1 solutes); (2) alk enriched and Ca depleted above ~ 2,000 mg/L (type 2 solutes); and (3) alk depleted and Ca enriched above ~ 2,000 mg/L (type 3 solutes) (Figure 4). Type 1 is common to freshwater and types 2 and 3 to saline waters, although dilute waters can have solute compositions common to types 2 and 3 (see Sharpe and Forester 2008). Walker Lake is (and always will be) type 2 because its waters have greater alk relative to Ca (Figure 3). The colored bars in Figure 4 are discussed below.

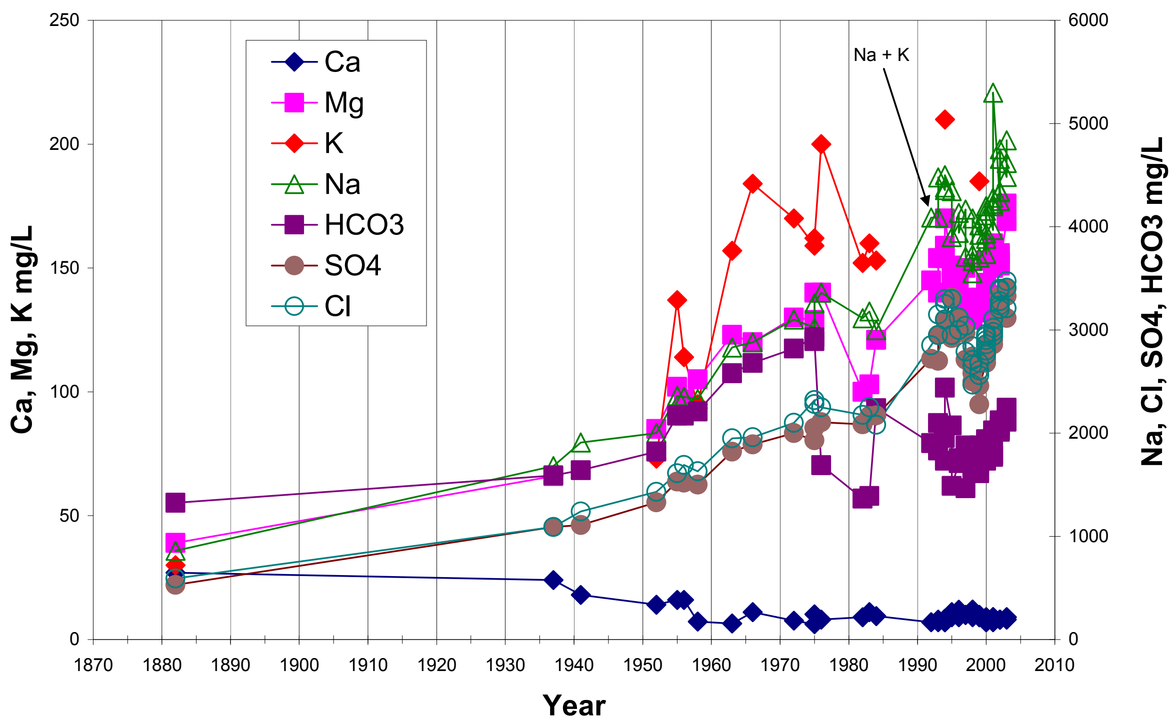

Figure 3. Walker Lake Solute Change 1882-2003. The 1882 HCO_3 and K values are estimated from Russell 1885 (see Rush 1974). Other measurements are taken from Rush (1974), Boyle Engineering (1976), Benson and Spencer (1983), Nevada Department of Wildlife, and Nevada Department of Environmental Protection. Na and K are graphed together beginning in 1992. These data are not collected after 2003. Water samples were taken at different seasons of the year and in different areas of the lake, yet trends are apparent.

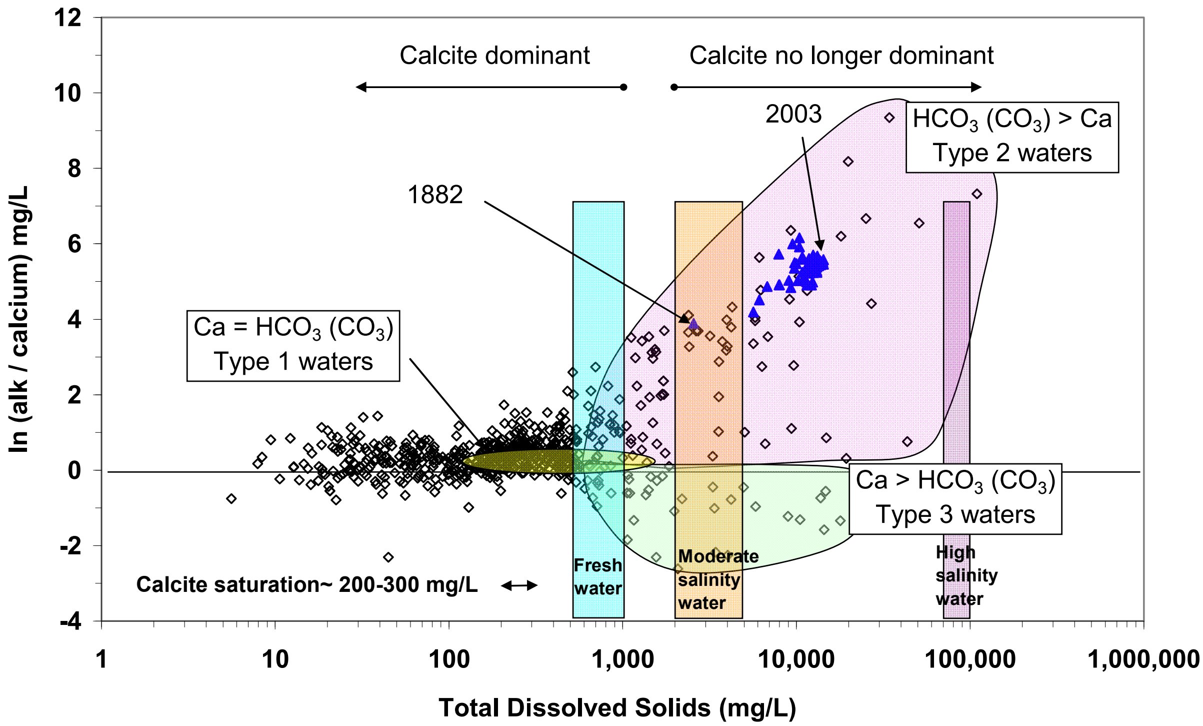

Figure 4. Walker Lake Alkalinity to Calcium Ratio 1882-2003. Diamonds, triangles, calcite saturation, and bars are shown as in Figure 2. These data are not collected after 2003. Three hydrochemical fields result from solute evolution: the alk [$HCO_3(CO_3)$ = Ca] field with a TDS below ~ 2,000 mg/L (type 1 water, yellow); the alk [$HCO_3(CO_3)$ = Ca] > Ca field with a TDS greater than ~ 2,000 mg/L (type 2 water, pink); and the alk [$HCO_3(CO_3)$ = Ca] < Ca field with a TDS greater than ~ 2,000 mg/L (type 3 water, green). Additional hydrochemical fields occur in the solute evolution process at higher TDS levels (Jones, 1966; Eugster and Jones, 1979) but they are not discussed here.

THE TAXA OF WALKER LAKE

Sediment cores taken from Walker Lake by the U.S. Geological Survey during the 1970s and 1980s provide valuable biotic (diatom, ostracode, brine shrimp, and pollen) and abiotic (sediment structure, composition, pore water, stable isotope, and geochemical) data used to reconstruct the past environments of Walker Lake (Benson 1988, Benson 1991, Benson et al. 1991, Bradbury 1987, Bradbury et al. 1989) for the last ~ 30,000 years. Mixing of sediments may have occurred in part of one core and hiatuses in sediment deposition were noted, so the exact timing of certain events is not precisely known. Another set of cores taken in 2000 record the last ~ 2,700 years (Yuan et al. 2004, Yuan et al. 2006a, Yuan et al. 2006b). All in all, these sediment cores provide a relatively robust record for Walker Lake and clearly show that the lake can change relatively rapidly in volume and, thus, from one ecosystem to another.

Changes in inflow to Walker Lake affected the occurrence and abundance of Walker Lake taxa through both geochemical and physical processes. Geochemical processes such as lake water composition (ionic constituents) and concentration (TDS) and physical processes such as temperature, stratification, dissolved oxygen, light penetration and nutrients directly affected the occurrence and distribution of phytoplankton (algae and diatoms), zooplankton, ostracodes, brine shrimp, mollusks, and fishes. Biologic and geochemical evidence from the USGS Walker Lake sediment cores indicate that the lake TDS ranged from ~ 500 to possibly as high as 100,000 mg/L in the past and taxa moved in and out of this system as TDS and lake processes changed.

A listing of selected taxa from published literature is shown in Table 1. If a genus drops from the record in this table, it could mean that (1) it occurred but was not abundant, therefore, not recorded; (2) it was extirpated (no longer exists) in Walker Lake; (3) it was not preserved in the record; or (4) the sampling design was not intended to collect that particular taxon. Therefore, when a particular genus drops out of the record, we cannot be sure of its absence. The taxa in Table 1 are from published peer-reviewed literature only, so this table does not represent other times in the lake's history or other studies. Additionally, the large time blocks (e.g., ~5,000 to historic time) encompass taxa that may have existed during either high or very low lake levels. Taxa within these large time blocks did not all exist at once in the lake. They are included so that a general presence-absence comparison may be made.

Table 1. Selected Walker Lake taxa through time.

TIME PERIOD	**~30,000-25,000 yr B.P.*[1]**	**~25,000-10,000 yr B.P.*[1]**	**~ 10,000-5,000 yr B.P.*[1]**	**~5,000 yr B.P. to historic time*[1,2]**	**Pre-1963[3]**	**1975-1978[4]**	**1992-1996[5]**	**THIS STUDY**
Phytoplankton								
Bluegreen Algae								
Amphithrix janthina						X		
Anabaena inaequalis						X		
Anabaena sp.						X	X	
Anacystis sp.						X		
Calothrix parietina						X		
Calothrix sp.						X		
Chroococcus sp.						X		
Dermacapsa sp.						X		
Entophysalis sp.						X		
Gomphosphaeria sp.						X		
Lyngbya sp.						X		
Microcystis aeruginosa						X		
Microcoleus lynagbyaceus						X		
Nodularia (spumigena) crassa						**X**	**X**	**X**
Nodularia sp.					X			**X**
Schizothrix calcicola						X		

Table 1. Selected Walker Lake taxa through time (continued).

TIME PERIOD	~30,000-25,000 yr B.P.*[1]	~25,000-10,000 yr B.P.*[1]	~ 10,000-5,000 yr B.P.*[1]	~5,000 yr B.P. to historic time*[1,2]	Pre-1963[3]	1975-1978[4]	1992-1996[5]	THIS STUDY
Schizothrix						X		
Spirulina subsalsa						X		
Spirulina						X		
Synechococcus aeruginosa						X		
Synechococcaceae								X
Green Algae								
Botryococcus braunii						**X**		
Botryococcus sp.	X	X	X	X				
Cladophora glomerata						**X**	X	X
Cladophora sp.					X			
Dunalliella sp.						X		
Elakatothrix gelatinosa						X		
Gongrosira						X		
Oocystis sp.						X		X
Planktospheria sp.						X		
Spermatozopsis sp.								X
Ulothrix aequalis						X		
Ulothrix cf. *aequalis*						X		
Ulothrix cylindricum						X		
Diatoms								
Achnanthes sp.						X		
Amphora ovalis						X		
Anomoeoneis costata	X	**X**						
Anomeoneis sphaerophora						X		
Caloneis schumanniana						X		
Ceratoneis (Hannaea) arcus						**X**		
Chaetoceros elmorei				X		**X**		
Chaetoceros sp.					X			X
Cocconeis placentula						**X**		
Coscinodiscus sp.						X		
Cyclotella kutzingiana						**X**		
Cyclotella meneghiniana	X	X	X	X				
Cyclotella quillensis	X		X	X				
Cyclotella ocellata			X	X				
Cymatopleura sp.						X		
Cymbella spp.						**X**		
Diatoma vulgare						**X**		
Diploneis sp.						X		

Table 1. Selected Walker Lake taxa through time (continued).

TIME PERIOD	**~30,000-25,000 yr B.P.*[1]**	**~25,000-10,000 yr B.P.*[1]**	**~ 10,000-5,000 yr B.P.*[1]**	**~5,000 yr B.P. to historic time*[1,2]**	**Pre-1963[3]**	**1975-1978[4]**	**1992-1996[5]**	**THIS STUDY**
Entomoneis sp.						X		
Epithemia turgida						X		
Fragilaria vaucheriae						X		
Frustulia rhomboides						X		
Gomphonema lanceolata						X		
Melosira distans						X		
Meridion circulare						X		
Navicula subinflatoides		**X**		X				
Navicula spp.				X		**X**		
Nitzschia sp.						**X**		
Rhoicosphenia curvata						X		
Rhopalodia musculus						X		
Stephanodiscus excentricus	**X**		**X**	**X**				
Stephanodiscus niagarae		X	X	X				
Stephanodiscus rotula	X		X	X				
Surirella nevadensis	**X**	X	X	X				
Surirella striatula						X		
Synedra ulna						X		
Tabellaria sp.						X		
Zooplankton								
Copepods								
Acanthocyclops (Cyclops)					X	X		X
Ceriodaphnia quadrangular					X			
Diaphanosoma					X			
Leptodiaptomus (Diaptomus)					X	**X**	X	X
Rotifers								
Brachionus spp.							X	
Hexarthra fennica							**X**	
Hexarthra spp.								X
Lucane spp.								X
Cladocera								
Alona guttata							X	X
Moina hutchinsoni					X	**X**	X	X
Ostracodes								
Candona caudata			X	X				
Candona sp.	X	X	X	X				
Limnocythere bradburyi	**X**	X						
Limnocythere ceriotuberosa	**X**	X	**X**	**X**		X		

Table 1. Selected Walker Lake taxa through time (continued).

TIME PERIOD	~30,000-25,000 yr B.P.*[1]	~25,000-10,000 yr B.P.*[1]	~ 10,000-5,000 yr B.P.*[1]	~5,000 yr B.P. to historic time*[1,2]	Pre-1963[3]	1975-1978[4]	1992-1996[5]	THIS STUDY
Limnocythere sappaensis		X		X				
Brine Shrimp								
Artemia		X		X				
Amphipods								
Hyallela azteca						X		
Chironomids								X
Chironomus						X		
Pelopia								
Damselflies/Dragonflies							X	X
Enallazma sp.						X		
Mollusks								
Anodonta sp.				X				
Gyraulus parvus				X				
Helisoma newberryi				X				
Helisoma trivolvus				X				
Physella sp.				X				
Pisidium sp.				X				
Pyrgulopsis nevadensis				X				
Aquatic Grass								
Ruppia sp.				X			X	
Fish				(1885-1910)[6]				
Cyprinus carpio (common carp)**				X				
Archoplites interruptus (Sac.				X				
Oncorhynchus clarki henshawi				X***		stocked	stocked	stocked
Catostomus tahoensis (Tahoe				X		X		
Siphatales (Gila) bicolor (tui chub)				X		X	X	X
Rhinichthys osculus (speckled dace)				X				

X indicates taxa recovered from lake at that time. Bold X indicates taxon was abundant.
*not all species present consistently through entire time period. Time periods encompass many different lake environments.
**introduced.
***native strain extirpated in lake; current LCT are stocked.
1 Bradbury et al. 1989.
2 S.E. Sharpe, unpublished data.
3 Cooper and Koch 1984, Koch et al. 1979, Ting, unpublished data (see Koch et al. 1979).
4Cooper and Koch 1984, Koch et al. 1979, Osborne et al. 1982.
5Horne et al. 1994, Beutel et al. 2001.
6 Brussard et al. 1996.

It is important to remember that the record of taxa recovered in cores is incomplete and not representative of all the taxa in the lake because of differential preservation and sampling techniques. The sediment record favors those taxa with resistant coverings such as diatoms and ostracodes. It is also possible that some taxa recovered from lake cores were transported to the lake from the river and then incorporated into lake sediments. However, Bradbury et al. (1989) compare different climate and environmental proxy data such as geochemical measurements from the same core intervals and climate and hydrology records near Walker Lake to support the conclusion that the taxa listed were living in the lake at that particular time.

No-analog situations between past and present may exist. A no analog situation is one where an assemblage of taxa found in the past is not known to occur together today. For example, the ostracode, *Limnocythere bradburyi*, was recovered in two different intervals in the Walker Lake record. Today this ostracode occurs primarily in central Mexico and is found in the U.S. only in southernmost Arizona (Forester et al. 2005). Climatic, hydrologic, and limnologic conditions very different than today existed for periods allowing this ostracode to live in Walker Lake. Some taxa may be able to recolonize Walker Lake after extirpation but others may not if past physical and geochemical conditions are not recreated.

High Salinity Alkaline Waters

Periods of very high salinity with alkaline (alk relative to Ca) water occurred at ~2,100 and >4,650 ^{14}C age B.P. (Benson 1991, Benson et al. 1991, Bradbury et al. 1989). Diatoms *Anomoeoneis costata* and *Navicula subinflatoides*, ostracode *Limnocythere sappaensis* and pellets of brine shrimp (*Artemia* sp.) were recovered at these same core depths in Walker Lake sediments indicating shallow, saline water (Bradbury et al. 1989). All these taxa are tolerant of high salinity waters and *N. subinflatoides* and *Artemia monica* currently inhabit Mono Lake where TDS can exceed 100,000 mg/L. Walker Lake was likely surrounded by marshes and salt flats during these time periods evidenced by the pollen of Cyperaceae (sedge) and *Sarcobatus* (greasewood) recovered from these same core depths. This shallow, saline lake ecosystem may have experienced rapid fluctuations in depth and in area of open water because of its small volume. The lake, between ~ 2,500 and 2,150 years B.P., may have been less than three feet deep and reduced in volume by 98% and areally by 93% from the 1968 size (see Bradbury et al. 1989). TDS during these low stands may have been as high as 60,000 or 100,000 mg/L, similar to Mono Lake in salinity and ionic composition.

High salinity alkaline Walker Lake waters can result from climate or diversion of the river. The climate scenario for high salinity alkaline waters is nominal snowpack in the Sierra Nevada and low river flow. Nominal precipitation and moderate temperature at Walker Lake likely occurred or alternately, moderate precipitation and high temperature at Walker Lake occurred, resulting in low effective moisture at the lake. The river diversion scenario for these saline waters is extensive snowpack in the Sierra Nevada. Adams (2003) calculates that the inflow to Carson Lake would have to increase by a factor of at least four to produce late Holocene Carson Lake levels even when the Walker River was flowing to Carson Sink. High to moderate precipitation would likely occur at Walker Lake associated with the Sierra storm tracks. Taxa capable of moving upriver as lake conditions became inhospitable likely did so. Taxa living in the river recolonized the lake when inflow once again reduced lake TDS levels.

Figures 2 and 4 (red bar) show the area of high salinity alkaline waters. If Walker Lake were to continue to evaporate it would fall below 10% Ca plus alk and move toward the red bar in Figure 2. With increased TDS the Walker Lake alk to Ca ratio would further increase the amount of alk relative to calcium, thus moving Walker Lake values toward the top right corner of Figure 4.

Moderate Salinity Alkaline Waters

Periods of moderate salinity occurred during transitions from low to high water or vice versa. Diatoms *Stephanodiscus excentricus*, *Surirella nevadensis*, *Cyclotella meneghiniana*, *Chaetoceros elmorei*, and *Cyclotella quillensis* and ostracode *Limnocythere ceriotuberosa* are representative of a moderate-salinity eutrophic lake and inhabited Walker Lake at different intervals from about 4,650 (Bradbury et al. 1989) prior to historic lake drawdown. *Botryococcus*, often common in this type of environment, was recorded by Bradbury et al. (1989) between ~ 4,300 and ~900 ^{14}C age B.P. *Botryococcus* was recorded in 1975-1977 by Cooper and Koch (1984) but is absent or rare in Walker Lake today.

The taxa *S. excentricus*, *S. nevadensis*, and *C. quillensis* occurred in Pyramid Lake in the 1920s when it had a salinity of ~ 3,500 mg/L (see Bradbury et al. 1989). *C. elmorei* was the predominant diatom collected by Koch et al. (1979). They state that *C. elmorei* TDS range is large: from ~ 400-30,000 mg/L. The presence of *L. ceriotuberosa* implies that the lake bottom was at least seasonally oxygenated. *L. ceriotuberosa* is the only abundant ostracode living in Walker Lake sediment today (Bradbury et al. 1989).

The diatom and ostracode taxa suggest that the lake fluctuated between ~ 2,000-5,000 mg/L TDS during this time period (Forester et al. 2005). The high-end range of moderate salinity alkaline waters is greater than 10,000 mg/L TDS and would contain a different assemblage of taxa than the lower TDS value. Based on salinity, geochemistry, and taxa, Walker Lake today is transitioning from a moderately salinity alkaline water (on the high end) to a high salinity alkaline water (on the low end).

The climate scenario for moderate salinity alkaline waters is moderate to low snowpack in the Sierra Nevada, moderate to low river flow, and moderate to low precipitation at Walker Lake. Alternatively, if moderate precipitation occurred in the mountains but temperature at Walker Lake was high, evaporation would increase. These waters could also occur if diversion of the Walker River was not rapid or diversion was partial (as suggested by Yuan et al 2006a), allowing some water to flow into the lake. These waters would also occur on a transition from very saline to fresh water.

Walker Lake currently contains moderate salinity alkaline waters resulting from agricultural diversions. Figure 2 shows moderate salinity alkaline waters to the right of the depletion zone (~1,000-2,000 mg/L) where alk plus calcium are no longer dominant (orange bar). Figure 4 shows moderate salinity alkaline waters (orange bar). Note that the 1882 Walker Lake value is within the orange bar in Figs 2 and 4. Subsequent Walker Lake values are to the right of the orange bar. Geochemically, moderate salinity alkaline waters can encompass much greater TDS values than contained within the orange bars.

The TDS of the orange bars is based on the modern requirements of taxa recovered from Walker Lake core sediments.

Fresh Waters

When Walker Lake is deep and fresh, the diatom *Cyclotella ocellata* and ostracode *Candona caudata* occur. *C. ocellata* is found in Lake Tahoe and in the epilimnion of other cool oligotrophic freshwater lakes. The presence of *C. caudata* implies that TDS was below 2,000 mg/L (Forester et al. 2005). Stable isotope values of unrecrystallized carbonates (Benson et al. 1991) indicate Walker Lake was rising when *C. ocellata* first appeared in the record (~ 4,800 ^{14}C age B.P.), and approached and reached a steady state condition when *C. caudata* entered the record (~ 4,700 ^{14}C age B.P.). Walker Lake TDS was probably below 1,000 mg/L at times during the last 5,000 years (late Holocene highstands) and it may have averaged as low as 500 mg/L during these highstands (R.M. Forester, personal communication). Two diatoms, *Stephanodiscus niagarae* and *Stephanodiscus rotula* occurred in Walker Lake when the lake was slightly more saline, but still considered relatively fresh.

The climate scenario for fresh waters is high snowpack in the Sierra Nevada and high river flow. High to moderate precipitation at Walker Lake would likely occur and evaporation on the lake surface would be offset by inflow. Walker Lake waters have not been fresh during the historic period. Figs. 2 and 4 show where fresh waters occur (blue bar). This area is just after Ca and alk saturation (200-300 mg/L) but before Ca or alk depletion.

Historic Change in Taxa

Blue-green algae and diatoms comprised over 99% of the total phytoplankton numbers sampled in 1975-1977 and blue-green algae alone made up 97% of this sample (Cooper and Koch, 1984). The blue-green algae, *Nodularia (spumigena) crassa*, has dominated the blue-green algae assemblage for more than the last 30 years (Table 1). The green algae, *Cladophora glomerata*, was dominant in the 1975-1977 study and was collected in the 1990s and in the present study. *Chaetoceros* sp. was found in the lake prior to 1963 and was collected in this study. *C. elmorei* was living in Walker Lake during at least seven intervals of moderate salinity water during the last ~ 5,000 years (Bradbury et al. 1989). It was the dominant diatom during the 1970s.

Two species of copepods, *Ceriodaphnia quadrangular* and *Diaphanosoma leuchtenbergianum* no longer live in the lake because of the elevated TDS (Dickerson and Vinyard 1999). *Leptodiaptomus (Diaptomus) sicilis* and *Acanthocyclops (Cyclops) vernalis* have been recorded in the lake prior to 1963 and are recorded in this study. *L. sicilis* declined 50-70% in abundance between 1977 and 1994 (Horne et al. 1994). The rotifer *Hexarthra fennica* was first recovered in the 1990s and was a dominant species at that time. It was also recovered in this study. Cladoceran *Moina hutchinsoni* has lived in the lake for at least the last 45 years and was also recovered in this study. Amphipods were not recovered from the lake in 2003 or 2004 (NDOW, 2005) nor in this study.

Historically, four native species of fish inhabited Walker Lake: Lahontan cutthroat trout, LCT (*Oncorhynchus clarki henshawi*), tui chub (*Gila bicolor*), speckled dace (*Rhinichthys osculus*), and Tahoe sucker (*Catostomus tahoensis*) (Sigler and Sigler

1987, LaRivers 1962, Brussard et al. 1996). Speckled dace have not been collected since before 1963 and Tahoe sucker have not been collected since the mid 1970s. Tui chub is the only native fish (defined as the strain that evolved in Walker Lake) remaining in Walker Lake. LCT are native to Walker Lake, however, the stocked fish are not the original Walker Lake native strain and, so, are considered by many not native. Two introduced fish species, the common carp (*Cyprinus carpio*) and the Sacramento perch (*Archoplites interruptus*) were extirpated from the lake by about 1963 (Cooper and Koch 1984).

DROUGHT CONDITIONS AT WALKER LAKE

Two intervals of low Walker Lake levels are documented during the last 2,000 years (Benson et al. 1991, Yuan et al. 2004, Adams 2003). Bradbury et al. (1989) report two intervals in the last ~2,100 years that contain the saline-tolerant ostracode *Limnocythere sappaensis.* The interval at ~ 2,100 years ago also contains brine shrimp. Bradbury et al. (1989) report an older saline episode containing brine shrimp at slightly greater than 4,700 ^{14}C age B.P. The modern physical tolerances of the other taxa recovered suggest high salinity waters during all three of these intervals.

Low levels and high salinity of Walker Lake have been attributed to both drought conditions and the diversion of the Walker River through the Adrian Valley (Figure 1). Benson et al. (1991) report that Walker Lake was shallow and saline at ~ 2,000 and ~ 1,000 yr B.P. and that desiccations of Walker Lake since 21,000 yr B.P. resulted from the diversion of the Walker River. Adams (2003) reports lowering of Walker Lake levels at ~ 1500-1000 and 500-300 cal yr B.P. associated with the diversion of the Walker River (Adams 2007).

Bradbury et al. (1989) argue that drought conditions, not diversion, caused shallow, saline Walker Lake conditions between ~2,400 and 2,000 yr B.P. They do not report a later low stand. Yuan et al. (2004) report that substantial multicentury droughts occurred between AD 900 and 1100 (1038 and 838 cal yr B.P.) and AD 1200 and 1350 (740 and 550 cal yr B.P). They argue that the Walker River was not diverted from Walker Lake during the last 1,200 years so these droughts were climate controlled. Mensing et al. (2008) report two extended droughts at Pyramid Lake ending at 800 and 550 cal yr B.P. Graham et al. (2007) report generally arid conditions with episodes of severe centennial-scale drought in the western and central U.S. between 500 and 1350 A.D. Although dates of drought from these various climate proxy records are not consistent, they do indicate that severe, long-term drought episodes existed in the past.

Stine (1994, 2004) provides evidence for climate controlled low lake stands in the central Sierra Nevada. Upright and rooted stumps in and adjacent to the West Walker River, Mono Lake (Figure 1), Owens Lake (south of Bishop, California) and Tenaya Lake, Fallen Leaf Lake, Independence Lake, and Osgood Swamp (all located in the central Sierra Nevada) were once trees growing in sites that today are too wet to support their growth. For example, under natural conditions (excluding human drawdown of lake elevation) stumps at Mono Lake would be submerged under 50 feet and stumps at Walker Lake would be submerged under 140 feet of water. Tenaya Lake currently has rooted stumps beneath 70 feet of water and Fallen Leaf Lake has rooted stumps under tens of feet of water. Radiometric dates (Stine 1994, 2004) from these localities are grouped in two intervals in Medieval time: more than 200 years prior to ~ AD 1100 (~ 1038 to 838 cal yr B.P.) and more than 140 years prior to ~ AD 1350 (~ 740 to 550 cal yr B.P.).

Stine documented 104 rooted stumps in the West Walker River Canyon approximately three miles north of the junction of Highway 395 and Highway 108 (Sonora Pass road, Figure 1). These trees date to either of the two medieval drought intervals. Stream flow must have been much less than present to allow these trees to grow in the lowest areas of the narrow canyon floor. Stine ruled out piracy of the West Walker River, so the Walker River likely flowed in near these trees toward Walker Lake during these time periods. It is possible that the Walker River was diverted through Adrian Valley during these low-flow periods. It is also possible that the Walker River flowed into Walker Lake and that inflow was not sufficient to exceed evaporation during these drought periods.

Relatively good concurrence exists for a climate-induced severe, century-scale drought between ~ 1,038-838 and ~ 740-550 cal yr B.P. (Yuan et al. 2004, Stine 1994, Mensing et al. 2008) supporting the hypothesis that low Walker Lake levels at these times were climate controlled. Evidence also exists for drought conditions at ~ 2,000 years ago (Mensing et al. 2008) indicating that this earlier Walker Lake low stand may also have been climate controlled.

The widespread distribution of stumps dating from these two drought periods, as well as other drought proxy data, suggest drought conditions on at least a regional scale. The magnitude of these droughts exceeded both the Dust Bowl and recent drought periods; these droughts lasted from decades to centuries (Stine 1994, Mensing et al. 2008). The evidence for past century-duration drought in the Great Basin suggests that climate-induced, severe, long-term drought will undoubtedly affect future Walker Lake levels and salinity. Given this probability, it is critical that Walker Lake taxa are allowed to move upriver when drought conditions occur or they may be extirpated, even if TDS levels have been lowered relative to current measurements.

RIVER CONDITIONS

The record over the last 30,000 years suggests that many species enter and leave the lake ecosystem depending on their ecological tolerances to the physical conditions of the lake. The taxonomic record indicates that species of phytoplankton, diatoms, zooplankton, ostracodes, brine shrimp, and fishes have been able to move back into a system where they have previously been rare or extirpated. Recolonization mechanisms for these taxa include transport by wind or waterfowl, persisting in refugia such as at a groundwater discharge site within the lake or leaving the lake to live in appropriate reaches of the Walker River.

The Walker River once provided a stable refugium for taxa. Lahontan cutthroat trout and tui chub could inhabit and reproduce in river waters when lake conditions were unfavorable. They could migrate back to the lake when hospitable conditions returned. The river, however, has been modified from its prehistoric conditions by the construction of dams (e.g., introducing barriers, changing the seasonal river hydrograph, and increased water temperature in certain reaches), introduction of non-native fish (competition and predation), introduction of plant species, removal of water for irrigation, and decrease in water quality resulting from agriculture. The river is no longer a healthy, natural ecosystem available to host taxa that must leave the lake or die when conditions are unfavorable. Until the river can again act as a refugium, many taxa, particularly fish, requiring less saline lake conditions will likely not be able to naturally recolonize the lake when salinity decreases.

CONCLUSION

Knowledge of the long-term record of Walker Lake ecosystems can aid current management decisions. The paleoecological record shows:

1. The depth and salinity of Walker Lake naturally fluctuated from fresh and deep to very shallow and saline. Lake elevation fluctuated as much as 180 feet during the last 5,000 years (Adams 2007). The TDS in Walker Lake may have been as high as 100,000 mg/L when brine shrimp inhabited the lake to as low as 500 mg/L when the lake was deep (Bradbury et al. 1989). Currently Walker Lake is 149 feet below its historic high elevation with a salinity of ~16,000 mg/L. The lake environment and many of its taxa are adapted to substantial variation in depth and salinity. This is good news for management because large lake fluctuations resulting from acquisitions should not pose problems to taxa. The natural system, however contained a healthy, unobstructed river which served as an escape route and habitat for many taxa when the lake became inhospitable. Management of the Walker Lake ecosystem must include restoration of the river so that taxa can move upriver when lake conditions deteriorate or they will likely be extirpated from the lake.
2. The geochemistry of Walker Lake changed over time not only in TDS, but also in the relative abundance of ions. This affected the distribution and occurrence of certain taxa. The good news for management is that with increased water flowing to the lake, or greatly decreased evaporation or both, this process will reverse and TDS and ionic strength will decrease. Increased inflow from the Walker River relative to today is needed to help reverse the solute evolution process.
3. Past fluctuation in lake elevation and salinity occurred rapidly, particularly when the Walker River changed course and diverted flow from or returned flow to the lake. Bradbury et al. (1989) suggest that the lake transitioned from low and saline to high and dilute within several decades. This information suggests that if water acquisitions result in substantial inflow in short periods of time, it would not be uncommon to the Walker Lake environment. This is helpful for management and water release decisions because the time frame for acquisitions could be within a short time frame, from years to decades.
4. Certain taxa quickly colonized the lake, evidenced by the sudden occurrence or transition of ostracode and diatom taxa in the sediment record. This suggests that the taxa found in Walker Lake are adapted to rapid recolonization when conditions are favorable. However, it is essential that particular taxa are able to migrate up and live in a healthy Walker River so that they can return to the lake when conditions are favorable. This finding is significant because it underscores

the value of a healthy, passable (e.g., temperature, depth, obstacle, and cover) river that taxa can use as a conduit to provide suitable habitat.

5. Long-term decadal to centennial drought in the future is likely because droughts of this magnitude and duration occurred in the past. The Walker Lake ecosystem will again be compromised if severe, long-term drought conditions occur. The Walker River should be restored to provide a usable escape route and healthy habitat for species until drought conditions abate.

It is ironic that this chapter and almost all previous work have focused on the lake ecosystem because so many different aspects of the past record imply that the Walker River is the key to species survival in Walker Lake. The river, not the lake, is the stable ecosystem that many taxa require in a highly variable environment such as Walker Lake and the river should be the focus of restoration efforts. As river health is restored, lake health will follow. The Walker River currently appears to be considered only a pipeline to deliver more water to Walker Lake. Instead, the river is the lifeline Walker Lake taxa need to survive unfavorable lake conditions and it has served as such for many tens of thousands of years. Little information is available and few studies have been conducted on the Walker River most likely because its tremendous value in sustaining Walker Lake taxa has not been fully recognized.

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PROJECT A: INSTREAM AND LAKE AQUATIC HEALTH INTRODUCTION

Similar to other Great Basin aquatic systems, streams, rivers, and lakes in the Walker River Basin have been altered from historic conditions by a number of factors. Hydrology has been altered by diversion for agriculture, diversions have decreased annual inflow into Walker Lake, and the historic native fish community consisted of eight species, including the threatened Lahontan cutthroat trout, and now includes five additional sport species that have reduced the abundance and distribution of native fishes.

A number of studies have examined Walker Lake fishes, and its ancient, historic and current limnology. In contrast, few biological studies have considered the river and there is little information available to assess how its aquatic life responds to human activity. During 2007 and 2008, a number of studies were conducted by Desert Research Institute and University of Nevada, Reno scientists to compile existing ecological information for Walker Lake, recommend salient factors to monitor Walker Lake limnology and track spatial and temporal variability in its environment and biota, and assess how life in the river is affected by human activity and may respond to increased discharge. These studies provide information to facilitate the decision making process by describing how these systems will respond to increased flow into Walker Lake.

Findings from these studies are presented in two reports, Part I addresses Walker Lake work and Part II discusses Walker River studies. These reports include summaries for 10 studies conducted by more than 15 scientists, and it is notable because it is the largest study ever conducted to examine the ecology of a mid-elevation western Great Basin river and its terminal lake.

Lake studies compiled available water quality and ecological information from existing and previous work to determine appropriate indicators of lake condition. Water quality was sampled to identify relevant ecological aspects of algal, invertebrate, and fish communities to determine a baseline ecological condition (production and food web energetics). This database includes all historical Walker Lake information, and, to facilitate information access to outside agencies and the public, it also includes all Walker River data accumulated during 2007 and 2008. The database includes greater temporal and spatial detail than previous compilations. Also included is a statistical analysis to assess the current lake condition from available indicators. Salient elements of an effective monitoring program to best define current and future lake conditions using appropriate indicators are also presented. A sampling and analysis plan is also included to guide programs that accomplish these goals in a statistically defined framework suitable for modeling predictions of lake condition. Implementing this plan will provide information showing important trends and rates of change in the environmental condition of Walker Lake that can be identified early and statistically tracked over time.

Studies in the river (Part II) quantitatively examined physical characteristics of the river (e.g., discharge, substrate characteristics, depth, current velocity, etc.), its water chemistry and quality, and its ecology (i.e., algae, macrophytes, macroinvertebrates, and fish communities) at eight sites from Schurz to the base of the Sierra Nevada Mountains. This work provides information describing spatial and temporal variability in environments, periphyton, fish, and macroinvertebrates. This work identifies environmental factors that are most important to structuring communities and they show that communities change in response to factors that are associated with discharge (e.g., water depth, current velocity, water temperature, etc.) and elevated nutrients.

PART 1. WALKER LAKE

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EXECUTIVE SUMMARY PART I: WALKER LAKE

Walker Lake is currently experiencing a long-term lake level and volumetric decline due to diminished water delivery. One of the goals of the overall Walker Basin project is to evaluate the present status of the lake in reference to its existing limnological condition and to evaluate changes in those conditions that may occur in response to changes in water delivery and management practices. Therefore, Walker Lake was monitored and sampled during 2007– 2008 for the purpose of describing current conditions and to calibrate an ecological model of lake response under different water delivery scenarios. Water quality samples collected from several sites in Walker Lake were used to identify and assess ecological parameters important to lake ecosystem health. Physical, chemical and biological datasets were developed across depth profiles over time to explore factors governing intra-lake circulation and the resulting nutrient cycling, summertime oxygen minima, and accumulations of deleterious substances (e.g., ammonia and hydrogen sulfide). These data were compiled with available historical data and used to parameterize the Walker Lake ecological model. Sensitivity analysis then identified the factors most important to lake function and its ecological condition. These results and the professional judgment of participating researchers have contributed to recommendations for long-term monitoring that would provide a consistent and comprehensive dataset on environmental conditions in the lake over time, including specific indicators vital to improved diagnostic models for Walker Lake assessment and management as future water acquisitions are introduced.

Data were obtained from sources including: the Nevada Department of Environmental Protection (NDEP), the Nevada Department of Wildlife (NDOW), the US Geological Survey (USGS), the Desert Research Institute (DRI), and the University of Nevada, Reno (UNR). (A special thanks goes to these organizations for their assistance and provision of data.) Some organizations have ongoing sampling programs at Walker Lake; at the time of writing, data in the database were the most currently available.

The overall database structure considered compilation of information and efficient queries. Data for Walker Lake were diverse with respect to factors including: time sampled, location sampled, groups collecting samples, and parameters that were sampled for. Because so many organizations were represented, the format of data varied widely. In order for the data and database to be a useful tool, structure of the database considered questions that users might ask Conducting queries to answer such questions required the database to be relational and for the data to be normalized.

The information collected through historical and contemporary Walker Lake monitoring efforts was incorporated into an ecological model. The objectives of the model were to 1) integrate historical and contemporary monitoring data; 2) inform future monitoring strategies; and 3) provide a tool for testing the impacts of potential water management strategies on the limnology of Walker Lake. This model is summarized in a basic description of the modeling techniques, input data, calibration methods, and results. Recommendations for reducing uncertainty in model forecasts through future monitoring and research activities are also provided.

Observations, data and analysis indicate that large nuisance blooms and deepwater hypoxia will continue as the Walker Lake system is in the midst of the successional processes that enhances internal nutrient loading through oxygen depletion in the hypolimnion that then causes further enhancement of the blooms. The volume and areal extent of the hypolimnion oxygen depletion has decreased simply due to the reduction in the volume of the hypolimnion as water levels have declined. The production of organic matter leading to the hypoxia is sustained by exceedingly high levels of phosphorous (in excess of 20 uM) sustaining the N-fixing *Nodularia* blooms. Given the trajectory of water decline the lake could soon make the transition to a polymictic status. In the event water management creates a situation where water levels may rise, the hypolimnetic oxygen depleted zone is not likely to disappear unless means are found to minimize the internal loading of nutrients.

CONTENTS

LIST OF FIGURES

A.1: CONTEMPORARY LIMNOLOGY OF WALKER LAKE, NEVADA

A.4: WALKER LAKE: HYPOLIMNETIC OXYGEN DEFICIT ASSESSMENT AND ASSOCIATED LIMNOLOGICAL FACTORS

A.5: THE CONTEMPORARY ECOLOGY AND FOOD WEB ENERGETICS OF WALKER LAKE, NEVADA

LIST OF TABLES

A.1: CONTEMPORARY LIMNOLOGY OF WALKER LAKE, NEVADA

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ABSTRACT

Walker Lake is currently experiencing a long-term lake level and volumetric decline due to diminished water delivery. One of the goals of the overall Walker Basin project is to evaluate the present status of the lake in reference to its existing limnological condition and to evaluate changes in those conditions that may occur in response to changes in water delivery and management practices. Therefore, Walker Lake was monitored and sampled during 2007 and 2008 for the purpose of describing current conditions and to calibrate an ecological model of lake response under different water delivery scenarios. Water quality samples collected from several sites in Walker Lake were used to identify and assess ecological parameters important to the lake ecosystem health. Physical, chemical, and biological datasets were developed across depth profiles over time to explore factors governing intra-lake circulation and the resulting nutrient cycling, summertime oxygen minima, and potential accumulations of deleterious substances (e.g., ammonia and hydrogen sulfide). These data were compiled with available historical data and used to parameterize the Walker Lake ecological model. Sensitivity analysis then identified the factors most important to lake function and its ecological condition. These results and the professional judgment of participating researchers have contributed to recommendations for long-term monitoring that would provide a consistent and comprehensive dataset on environmental conditions in the lake over time, including specific indicators vital to improved diagnostic models for Walker Lake assessment and management as future water acquisitions are introduced.

INTRODUCTION

The main goal of the Walker Basin Project is to halt the volumetric decline of Walker Lake (Figure A.1.1) and thereby restore to the greatest extent possible its ecology and fishery to historic conditions. Assuming that increased deliveries of water to the lake are achieved, the existence of a detailed dataset of physical, chemical, and biological variables will be essential for assessing the success of such endeavors. Whereas a great deal is known concerning the physical structure and biogeochemical function of temperate lakes, Walker Lake is unusual in several ways, so additional knowledge may be required to predict the recovery responses of this lake. Most notably, Walker Lake is one of only a few large, moderately saline, terminal lakes in the world, and is therefore more vulnerable to increases in solutes than the more common flow-through type of lake. Higher salinity in Walker Lake resulting from increased desiccation in the last century threatens the survival of native trout (*Oncorhynchus clarki henshawi*), even when stocked into the lake by management agencies, as well as the natural recruitment of native forage fish such as tui chub (*Siphateles bicolor*).

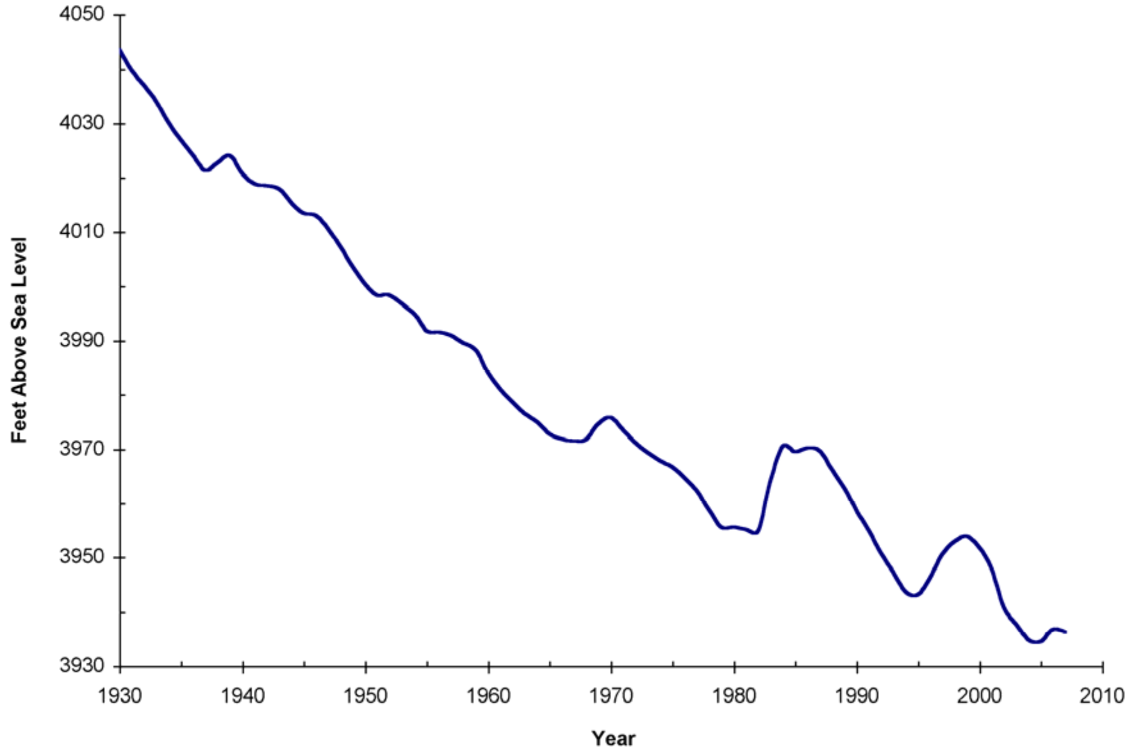


Figure A.1.1. Walker Lake level as measured by the USGS at a location on the west end of the lake, 1930 to 2007. This plot depicts mean annual lake level, based on measurements taken approximately every month.

Although the success of larger organisms at the top of the Walker Lake food web is the benchmark against which success or failure of restoration activities will be judged, the vastly more abundant algae, zooplankton, and microorganisms that form the bulk of the trophic pyramid are the major drivers of ecosystem function. There are more than a million microorganisms per milliliter of Walker Lake water, and as such, their diversity and activity in many ways control the suitability of the lake for higher life forms. The most fundamental impact on any lake from microorganisms is the balance between production and consumption of molecular oxygen. In Walker Lake, following the onset of summer stratification, microbial activity consumes all or most of the dissolved oxygen in deeper portions of the water column (the hypolimnion), rendering most of this otherwise permissively cool region uninhabitable to fish and other aquatic fauna. Additionally, following the onset of anoxia (deficiency in oxygen), other microbial reactions lead to the production and potential accumulation of toxic ammonia and hydrogen sulfide, which can stress fish populations that are already squeezed by temperature constraints into a narrow zone at the bottom of the oxic (oxygenated) layer (Figure A.1.2).

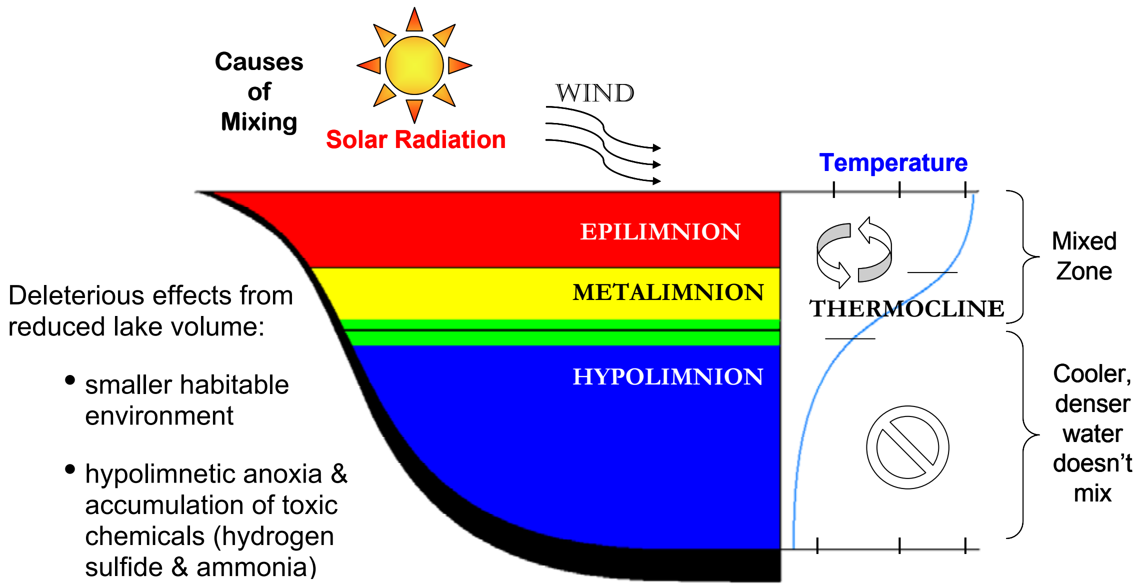


Figure A.1.2. Generalized representation of thermal stratification as it occurs in freshwater lakes. Anoxia in the hypolimnion and increased temperature and salinity in the epilimnion greatly reduces the zone of habitability for fish in Walker Lake. It is estimated that during summer stratification there is an approximately 1-meter deep region of the lake just above the hypolimnion (represented in green) that remains habitable for the lake's indigenous fish populations.

It has been suggested that historically Walker Lake's hypolimnion did not become anaerobic (absence of free oxygen) in the summertime (Beutel and Horne, 1997; Beutel, 2001). In recent decades, however, this condition has become the normal situation. In which case, the interplay between physical and chemical changes to the lake may become more intimately linked to the activity of water-column microorganisms. By triggering a simple shift from oxic/aerobic to anoxic/anaerobic conditions, the oxygen-consuming microorganisms in Walker Lake effectively reduce the (macro)-biologically-available volume (habitat) of the lake by approximately one-half. To date, no significant study of the Walker Lake microbial community has been performed. Thus, almost nothing is known about the microorganisms that consume oxygen in Walker Lake, or about the biogeochemical and limnological conditions likely to result once this change has occurred.

Water rights acquisitions along the Walker River are intended to increase average annual flows into Walker Lake for the purpose of providing a sustainable restoration of the lake's ecological health. As inflow volumes increase, however, many important water quality characteristics are likely to change over time. Therefore, a lake water quality sampling program was implemented by the Desert Research Institute (DRI) and the University of Nevada, Reno (UNR) to help evaluate the current conditions and to help establish a baseline for water quality parameters that may change as inflow volumes increase (Table A.1.1). Data from these studies and from previous monitoring and assessment work at Walker Lake were compiled into a searchable database that was used to calibrate and test an ecological model of the lake. Upon further refinement, the ecological model will ultimately be capable of forecasting limnological conditions under a wide range of future scenarios. Because the development of future streamflow predictions is still ongoing as a deliverable from other work-group units on the Walker Lake Project, only hypothetical flow scenarios were investigated here.

Table A.1.1. Summary of data collected and available in the database, showing overall periods of record and reporting organizations. Additional information and data sources are provided in Appendices to the Walker Lake Database User Manual (Lutz and Heyvaert, this volume).

Begin Date	Most Recent Date	Parameter(s):	Primary Reporting Organization(s):
8-Sep-1882	1-Dec-2007	Lake Level	Various
24-Jun-1999	2-May-2008	Profile Including: Barometric Pressure, Conductivity, DO, ORP, PAR, pH, Salinity, TDS, Temperature, Turbidity	DRI, NDEP, NDOW, USGS, UNR
17-Jan-1995	18-Dec-1996	General Constituents, Nutrients	Beutel
7-Mar-2007	4-Dec-2007	General Constituents, Major Ions, Nutrients, Metals	DRI
29-Aug-1990	4-Mar-2008	General Constituents, Major Ions, Nutrients, Metals	NDEP
8-Sep-1882	26-Jun-1995	General Constituents, Major Ions, Nutrients	Historical

DO: dissolved oxygen; ORP: oxidation-reduction potential; PAR: photosynthetically active radiation; DRI: Desert Research Institute; NDEP: Nevada Division of Environmental Protection; NDOW: Nevada Department of Wildlife; USGS: U.S. Geological Survey; UNR: University of Nevada, Reno.

METHODS/APPROACH

Walker Lake has been sampled at a variety of locations. The most commonly sampled locations are shown on Figure A.1.3. Sportsman's Beach, also known as WL1, has a relatively longer record, having been sampled since 1990. The most frequently sampled site is WL3, representing the center of the lake. Profile monitoring or sampling of the water column has been conducted at a variety of locations, though most commonly at WL2, WL3, and WL4. Site WL6 is located just offshore from where Walker River discharges into the lake.

Available records from the Nevada Department of Environmental Protection (NDEP) reflect sampling events taking place from 1990 into 2008. During that time, NDEP sampled sites WL1, WL2, WL3, WL4, and WL6. Most profiles were conducted at WL2, WL3, and WL4 for conductivity, DO, pH and temperature. NDEP also collected information on general constituents, trace elements, nutrients, bacteria, and major ions. In the Federal Aid Job Progress Reports for Walker Lake, NDEP reports water quantity and quality, limnological and biological conditions, angler use and success, fish population and zooplankton monitoring, and stocking assessment of the Lahontan Cutthroat Trout (LCT). Other available records reflect water column profiling events taking place from 2004 into 2008 by the Nevada Department of Wildlife (NDOW) and intermittent monitoring from 2002 by the U.S. Geological Survey (USGS).

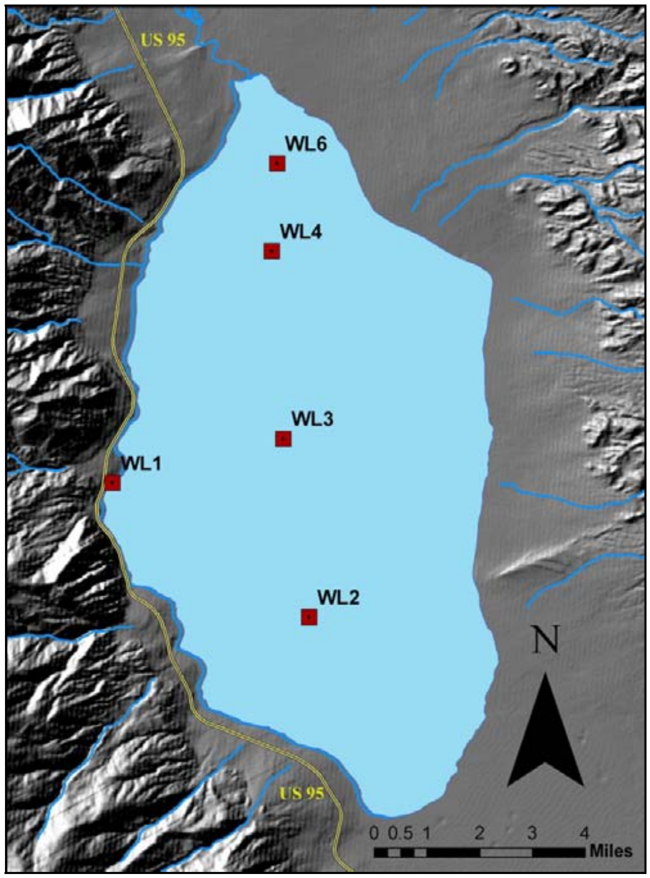


Figure A.1.3. Established Walker Lake limnological sampling points used by various groups represented in the Walker Lake Database (there are no records for sampling at WL5).

Five locations were monitored by DRI and the University of Nevada, Reno at regular intervals (4 to 6 weeks) between March 2007 and December 2007, as well as in May 2008 and September 2008, to capture seasonal variability in water quality and physical conditions. Several of these sampling stations were located at established stations along a transect across the lake from south to north (Figure A.1.3). The sites represent a subset of ten stations monitored regularly by NDEP, NDOW and WLFIT (Walker Lake Fishery Improvement Team). Descriptions of sampling and analytic methods applied by DRI and UNR during their 2007 to 2008 sampling period are summarized below, with additional details available from Fritsen *et al*. (this volume) and from Chandra *et al.* (this volume). Note that analysis and reporting of food web structure and dynamics in Walker Lake have been provided in a separate treatment (Chandra *et al.,* this volume).

All available data from NDEP, NDOW, DRI, and UNR monitoring, as well as from several historical reports, were used in creating the Walker Lake and River Database, which then was queried to support the ecological modeling of Walker Lake.

Physical Characterization

A high-precision, continuous water quality sampler (Seabird Technologies, model SBE 19) was calibrated for conditions at Walker Lake and then used to measure the temperature, photosynthetically active radiation (PAR) and dissolved oxygen (DO) at each location. PAR data were converted to watts/m^2 using a multiplicative factor of 2.5, derived from equation 2 in Morel and Smith (1974). Additional profiles of the water column were obtained with a YSI multiprobe that provided salinity in addition to temperature and DO concentrations near the center of the lake (WL3).

Short-term monitoring also occurred along the western shore of Walker Lake to investigate potential groundwater contributions near Cottonwood Creek and the town of Walker Lake. Previous studies had suggested significant amounts of groundwater could be flowing into Walker Lake in this area (Allander *et al.,* 2006; Lopes and Smith, 2007). Therefore, specific conductance and temperature measurements were collected, along with samples for stable isotope analysis, during nearshore surveys of horizontal and vertical profiles along the western shoreline (0 to 500 m offshore) in April, May, and July 2007.

Sampling and Analysis for Nutrients and Aquatic Chemistry

Samples were collected seasonally (Table A.1.2) from a variety of sites around the lake, including repeated sampling of central vertical profiles near the deepest point in Walker Lake (WL3). Samples were collected for major-ions, nutrients, and trace elements by Van Dorn sampler at 2.5-m intervals from the surface to the bottom, to represent vertical variation during stratified and non-stratified periods. Major-ion and nutrient samples were collected in half-gallon plastic jugs that had been triple rinsed with sample water prior to filling. These samples were stored in the field on ice until transport to the laboratory, where samples were refrigerated in the dark at 4°C until analysis. Trace-element samples were collected in 500-mL low-density polyethylene bottles that were soaked for at least two weeks in dilute nitric acid prior to sample collection; these samples were filtered in the field through laboratory pre-cleaned 0.45-µm cartridge filters. Isotopic samples were collected in 1-oz glass bottles (triple rinsed with sample water) and closed with poly-seal lids.

Major-ion and nutrient samples, as appropriate, were filtered in the laboratory through 0.45-µm filters and analyzed at the Desert Research Institute Analytical Chemistry Laboratory, which is U.S. Environmental Protection Agency and State of Nevada certified. Trace element samples were analyzed by inductively coupled mass spectrometry in the Desert Research Institute Ultra-Trace Chemistry Laboratory. All samples were analyzed using appropriate EPA drinking-water and waste-water procedures. Stable isotopes of δ^2H and $\delta^{18}O$ were analyzed at the University of Nevada, Reno Stable Isotope Laboratory. Additional analyses were conducted by the Desert

Research Institute Environmental Microbiology Laboratory and the University of Nevada, Reno, Limnological Laboratory. Due to the high salinity of Walker Lake samples, some water quality constituents (total phosphorus, orthophosphate, nitrate and ammonia) were analyzed by methods developed as part of the EPA Clean Lakes Grant Program for Nevada lakes (Solórzano, 1969; Liddicoat *et al.,* 1975; Jones, 1984; Reuter and Goldman, 1990). Standard quality assurance and quality control measures were adopted for the Walker Lake sampling program, including regular analysis of field and laboratory blanks and duplicates, as well as the analysis of standard reference materials and matrix spikes (Thomas *et al.,* 2008).

Table A.1.2. Calendar of Walker Lake sampling excursions by DRI and UNR during this project.

Sample Date	Reported By:	General Constituents	Nutrients	Major Ions	Trace Elements	Profile	Microbial
7-Mar-07	DRI	x	x	x	x	x	
27-Apr-07	DRI	x	x	x	x	x	
22-May-07	DRI					x	
30-May-07	DRI	x	x	x	x	x	
28-Aug-07	DRI					x	
29-Aug-07	DRI	x	x	x	x		
2-Oct-07	DRI					x	
3-Oct-07	DRI	x	x	x	x	x	x
4-Dec-07	DRI	x	x	x	x	x	
5-Dec-07	DRI					x	
3-Mar-07	UNR					x	
22-May-07	UNR	x	x	x	x	x	
3-Oct-07	UNR					x	
4-Dec-07	DRI	x	x	x	x	x	
4-Dec-07	UNR					x	
5-Dec-07	DRI					x	
1-May-08	DRI		x			x	
2-May-08	DRI		x			x	
18-Sep-08	DRI	x	x	x			x

See Appendix for a detailed list of parameters in each category

Biological Characterization

Chlorophyll-a pigment concentrations were determined via fluorometry using the Welschmeyer (1994) method in a Turner Designs model 10AU Fluorometer. This method was calibrated with purchased standards (chlorophyll-a from *Anacystis nidulans*, Sigma Corp.). The chlorophyll-a content was checked against a spectrophotometric method (Parsons *et al.,* 1984) for quality assurance. Particulate organic carbon (POC) and particulate organic nitrogen (PON) were determined using the method outlined by Karl *et al*. (1991). Subsamples were filtered onto pre-combusted filters, the filters were acidified through exposure to hydrochloric acid fumes, and the filters were encapsulated in tin discs before analysis with a Perkin-Elmer 2400 series II CHN/O analyzer. Particulate phosphorus subsamples were processed in a manner similar to POC and PON subsamples

(Karl *et al.,* 1991), then digested to extract organic and inorganic fractions using the method outlined by Pardo *et al.* (2003). The phosphorus concentration of the resulting extracts were determined colorimetrically using the Lachat QuikChem® Method 12-115-01-1-F (McKnight and Sardina, 2001) with a Lachat QC8000 FIA.

Phytoplankton samples were preserved by addition of gluteraldehyde to a final concentration of 0.5 percent. Enumeration involved counting a target number of natural units from each sample. The usual target number of natural units was $n \geq 400$. Natural units were deemed appropriate instead of cells, due to the fact that colonial or filamentous cells do not occur singly in nature so individual cells would be inappropriate to portray relative abundances (Mills *et al.,* 2002). Differential interference contrast (DIC) microscopy using an Olympus BX-60 equipped with epiflourescence and digital imaging capabilities was used for enumeration and identification. As outlined by PhycoTech, the magnification used was dependent on the dominant taxa encountered within the sample slide. Overall, the goal was to enumerate and identify taxa present across a range of magnifications. Once the correct magnification was determined for the majority taxa-type, a minimum of 15 fields were viewed and the natural units enumerated under that magnification. In addition, the minority cell types were counted. The minimum observable phytoplankton cell size was approximately 0.5 to 1 micron. All taxa encountered were image-documented for quality assurance and archival purposes. Biovolume estimates for each contributing taxa were determined by assigning formulas outlined in current literature (Hillebrand *et al.,* 1999).

Since very little was known about the microbial portion of the Walker Lake food web, the microbiological investigation of Walker Lake utilized a combined approach that included traditional microscopy and cultivation-based methods as well as several relatively new molecular techniques. Planktonic cell counts were performed on samples preserved in 2% glutaraldehyde using two complementary approaches: epifluorescence microscopy and flow cytometry. Briefly, direct counts were made using an epifluorescent microscope (Zeiss Axioskop 2 plus) after sample filtration onto black 0.2 µm pore size filters (Poretics®, GE Osmonics, Inc.) and staining with 4’6-diamidino-2-phenylindole (DAPI; Porter and Feig, 1980). One hundred fields were counted per depth, and the results averaged and normalized to estimate total numbers of cells per mL. Performing cell counts in parallel with a flow cytometer (Micro PRO™, Advanced Analytical Technology Inc.) proved especially useful because in addition to total cell enumeration this technology enabled quantification of the potentially photosynthetic microorganisms by measuring auto-fluorescent cells (Gasol and Del Giorgio, 2000).

In spite of increasing reliance upon molecular approaches for microbial ecology, cultivation-based approaches remain valuable for quantitative assessments of microbial functional groups. An important early result was that the initial attempts at cultivating microorganisms from Walker Lake were completely unsuccessful. However, utilizing previously determined lake chemistry (Beutel, 2001) enabled the design of specific media capable of supporting Walker Lake’s alkaliphilic halo-tolerant microbes. For example, as H_2S production in the water column was a priority of this study, a synthetic medium was developed to target the major group of environmental micoorganisms capable of producing H_2S: sulfate-reducing bacteria. By enumerating changes in the spatial and temporal distribution of these microorganisms, it was possible to assess the relative importance of this particular physiotype to overall lake function. The same approach was utilized for a range of ecologically-important substrates, including organic carbon (aerobic and anaerobic) and alternative respiratory electron acceptors such as iron oxides, nitrate, elemental sulfur, and arsenate. All told, nine different media were employed to quantify aerobic heterotrophs, nitrate reducers, fermentative microorganisms, sulfur and sulfate reducers, iron reducers, arsenate reducers, arsenite oxidizers, and manganese reducers.

As useful as cultivation-based microbiology has been, it is generally accepted that the vast majority of microorganisms in environmental samples cannot be grown in the laboratory (e.g., Amann *et al.,* 1995). An important implication, therefore, is that most of the microbial diversity in samples analyzed by traditional approaches has been missed. Fortunately, a variety of molecular techniques, mostly focused on the universally-conserved small subunit (SSU) of the 16S ribosomal RNA gene, have been developed that detect microbial DNA in a sample, rather than the subset of microorganisms amenable to growth in particular culture media. Thus, in addition to the functional assessment of microbial diversity in Walker Lake, a DNA-based approach (SSU rRNA fingerprinting and clone libraries) to explore the phylogenetic diversity and breadth of the microbial community was also adopted.

Database Development and Management

The Walker Lake and River Database was developed as a tool for analyzing trends in water quality conditions and to evaluate the ecological state of the lake, with the intent of making recommendations for long-term monitoring that will track changes associated with increased water delivery to the lake. The database contains both historical and contemporary information about lake conditions, as well as some results from river monitoring during 2007 and 2008.

Data were obtained from many sources, including NDEP, NDOW, USGS, DRI, and UNR; in most cases these data came directly from the staff working at these organizations (see Appendix F in the Walker Lake Database User Manual). Some of these groups continue with ongoing sampling programs at Walker Lake, but at the time of this writing, the Walker Lake and River Database represents the most currently available data. These data were diverse with respect to reported factors, including time sampled, location sampled, groups collecting the samples, and the parameters that were measured or analyzed. The format of these data varied widely as well, since many organizations were represented. For these data and the database to be a useful tool, a structure for the database was developed based on a consideration of the types of questions that a user might ask, such as:

- Did DRI collect samples at WL2 in 2007?
- Was chloride sampled and measured in March?
- Has conductivity increased since the lake has been sampled?

Conducting searches to answer such questions requires a relational database, which allows data to be searched by various combinations of factors: for example, by time and parameter (was chloride tested in March?); or by group, location, and time (did DRI collect samples at WL2 in 2007?); or by available records for a specific parameter (what is the long-term record of conductivity in the lake?).

Microsoft^{TM} (MS) Access was used for the construction of the Walker database, and several display forms were created to act as a graphical user interface (GUI). Those familiar with MS Access can operate the database by using the existing tables and building their own queries. Those unfamiliar with MS Access will need to briefly consult the user's manual (Lutz and Heyvaert, this volume) for instructions on how to use the existing tables and queries, and then build their own queries. Data from the Walker database can be exported in various formats for use in other programs. MS Access can also be linked directly to ArcGIS (from within the ArcCatalog program).

Normalization of data was necessary to construct the relational database. This should not be confused with the statistical normalization methods often applied to data. Rather, database normalization is a technique that considers characteristics of data and structure to minimize logical and structural problems, decrease duplication of information and anomalies, and increase database efficiency. This normalization process resulted in a series of tables that are connected by relationships.

Tables for Walker Lake and Walker River data are connected by relationships to the following additional tables: sample sites, instrument and/or method used, qualifiers (e.g., detection limit, calculated, estimated), parameters, reporting units, and reporting organization. These relationships allow users to search Walker Lake and River data by any combination of sample sites, instrument/methods, qualifiers, parameters, reporting units, and reporting organization.

Currently, 140 water quality parameters are recorded in the database. A list of the parameters is given in the appendix. It should be noted that as new parameters are monitored, they can be easily added to the existing database. At present, a total of 95,535 records for samples from Walker Lake and 70,877 records for samples from Walker River are stored in the database.

Ecological Water Quality Modeling

The information collected through monitoring and data management efforts was integrated into an ecological model to inform the monitoring plan and which could ultimately support future decisions with regards to water management. The model consists of hydrodynamic and ecological components represented in the Computational Aquatic Ecosystem Dynamics Model (CAEDYM), developed at the University of Western Australia. CAEDYM consists of a series of mathematical equations representing the major biogeochemical processes influencing water quality. It contains process descriptions for primary production, secondary production, oxygen dynamics, nutrient and metal cycling, and the movement of sediment. Details of modeling features and mechanistic processes are described in the CAEDYM science manual (Hipsey et al., 2006).

In this study, CAEDYM was coupled to the one-dimensional Dynamic Reservoir Simulation Model (DYRESM) to allow investigation of seasonal and annual variations in Walker Lake's physical limnology. The one-dimensional approach assumes that the lake can be represented by a series of homogeneous horizontal planes, which is reasonable when changes are much greater in the vertical dimension than in the horizontal, as at Walker Lake. This assumption is necessary when available data and computational resources are limited, and when longer-term simulations are desired. In part, the one-dimensional model was selected for this study because more advanced two- or three-dimensional approaches were not feasible given the resources allocated to this modeling effort. Furthermore, the one-dimensional model is appropriate for investigating general trends in lake limnology and allows for longer term (i.e. 30 year) simulations with specific river flow scenarios, which would not be feasible with the more advanced models. Also, should additional resources become available in the future, CAEYDM can easily be coupled to a three-dimensional hydrodynamic model.

The ecological model requires several types of input data to properly simulate the processes within Walker Lake. Boundary conditions describe the forces acting on the lake and include meteorological and streamflow data. In this study, daily inflow to Walker Lake from the Walker River was estimated from USGS Gage 10302002 (Walker River at Lateral 2A). Groundwater discharge to the lake was estimated to be 11,000 acre-ft/year (Schaefer, 1980). No long-term meteorological observations currently exist on or adjacent to Walker Lake. Thus, observations from the National Weather Service (NWS) Cooperative Observer Program station at Hawthorne, from the U.S. Forest Service Remote Automated Weather Stations at Brawley Peaks and Benton, and from wind tower data collected by the Western Regional Climate Center at Luning were all compiled to estimate local meteorological conditions. Additionally, daily estimates of shortwave and longwave incident radiation were obtained from the NWS North American Regional Reanalysis (NARR) database. NARR provides a gridded dataset of meteorological data produced from a hindcast simulation based on historical point observations. Initial conditions were also required to describe the vertical distribution of water temperature, dissolved oxygen, nutrients, phytoplankton, and zooplankton in the lake at the outset of model runs. These data were obtained from the monitoring efforts and database compilation described previously in this chapter.

Calibration of CAEDYM was required to ensure that the model was adequately representing existing conditions before it could be used to assess future scenarios. This was accomplished by comparing modeled and observed water surface elevations and the vertical profiles of water temperature and dissolved oxygen for the 2007 simulation. By making adjustments to the various process-based coefficients, good agreement was found with all variables for each of the 2007 sampling dates, except the October 3rd sampling event where the model predicted lake mixing (breakdown of stratification) approximately one week after it was observed. A partial validation of the model was performed by comparing simulated and measured results for the year 1993 as reported by Horne *et al*. (1994). The model performed reasonably well under both 2007 and 1993 conditions but it can be substantially improved based on the recommendations described later in this report.

A series of hypothetical simulations were conducted to test the model's ability to forecast ecological response to water management decisions. Upon further refinement, the model will ultimately be capable of producing impact assessments based on specific streamflow scenarios, which are currently in development by a separate work-group unit of the Walker Basin Project. To demonstrate forecasting techniques with this model, the historical streamflows from 1982 to 1986 (average Walker River discharge: 425 cfs) and from 1989 to 1993 (average Walker River discharge: 30 cfs) were used to represent potential impacts from extended high-flow and low-flow conditions, respectively. Furthermore, recommended minimum annual inputs to the lake of 140,000 acre-ft/yr (Horne *et al.,* 1994) and 112,000 acre-ft/yr (Thomas, 1995) were simulated by assuming a uniform Walker River streamflow distributed over the entire year.

Finally, a sensitivity analysis was conducted to determine how responsive the model would be to changes in the input parameters and model coefficients. These results provide insight into how the model can be improved, by reducing uncertainty associated with the input data and the model coefficients that most strongly influence model results. The model's sensitivity to a wide range of conditions was examined, including modifications to meteorological data, input loads, sediment nutrient concentrations, initial conditions, and hydrodynamic mixing coefficients. The impacts from changing these various conditions were assessed by examining response changes in water temperature and dissolved oxygen vertical profiles (see Stone *et al.,* this volume).

RESULTS AND DISCUSSION

Physical Characteristics

<u>Lake level</u>

Walker Lake level has been generally declining since records began. Figure A.1.1 shows lake level (in mean feet above sea level) recorded between 1930 and 2007. Periodic increases in lake level during the mid 1980s and late 1990s are attributed to increased runoff from higher precipitation years.

<u>Temperature dynamics</u>

Temperature (Figure A.1.4) and dissolved oxygen measurements (Figure A.1.9) showed Walker Lake stratifying during May and remaining stratified through September. During December, the lake became isothermic, as indicated by temperature (average 9.3°C from surface to bottom) and dissolved oxygen (6.7 mg/L from surface to bottom). This was a typical annual cycle, with isothermal conditions generally persisting through January and into February.

<u>Optical properties</u>

Secchi depth measurements were available at WL3 from 1995 until 2008. Since 1999, Secchi measurements have also been made at WL2 and WL4. Figure A.1.5 depicts Secchi measurements from WL3, since this is the site with the most complete record in the database. In general, the Secchi depth is increasing, which reflects a relative increase of clarity in the lake, although the apparent trend could be influenced by greater frequency of measurements in recent years. Profiles of photosynthetically active radiation (PAR) in the water column are shown in Figure A.1.6 for two different times that bracket the sampling period of this project.

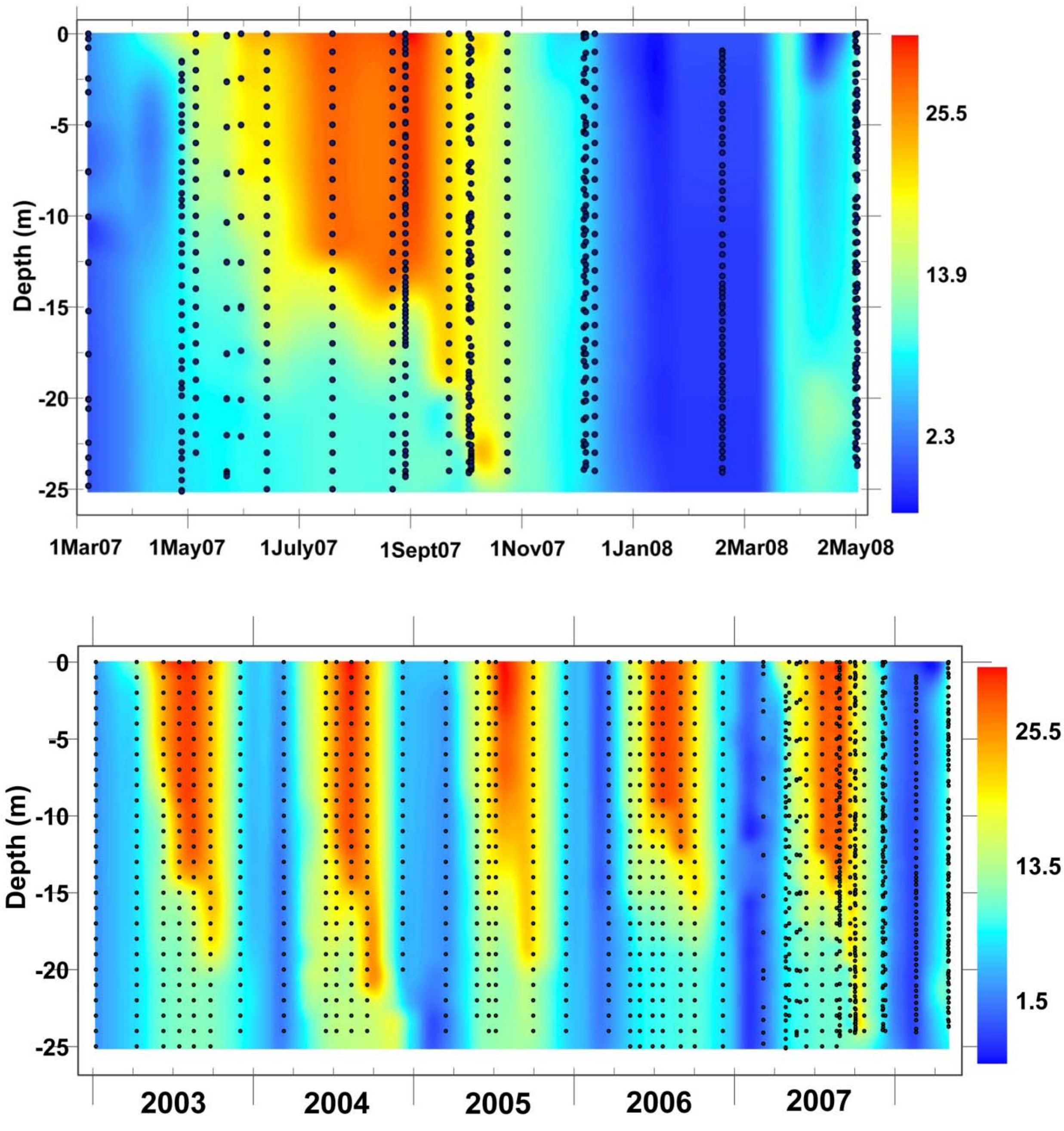


Figure A.1.4. Walker Lake temperature (°C) profile 2002 to 2008. Interpolation of data points was created using the spline tool in 3D Analyst extension of ArcMap 9.2 (ESRI, 2009) with default optional settings.

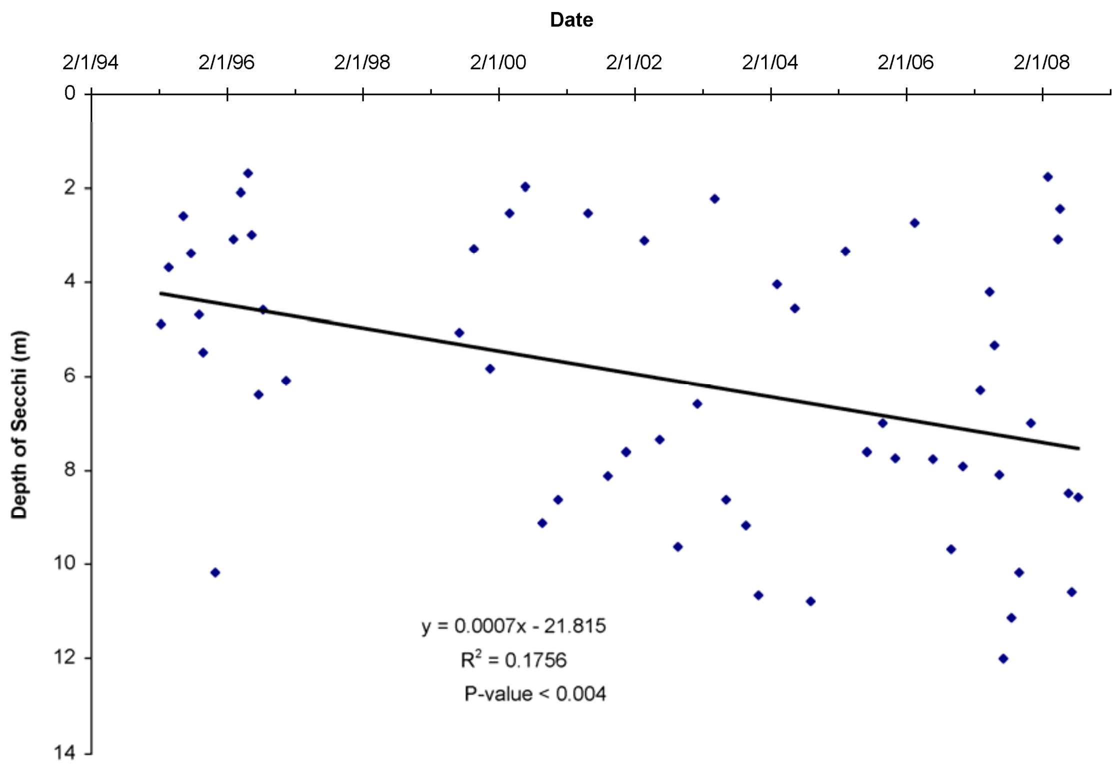


Figure A.1.5. Secchi depth measurements from the Walker Lake and River Database for site WL3 from 1995 to 2008.

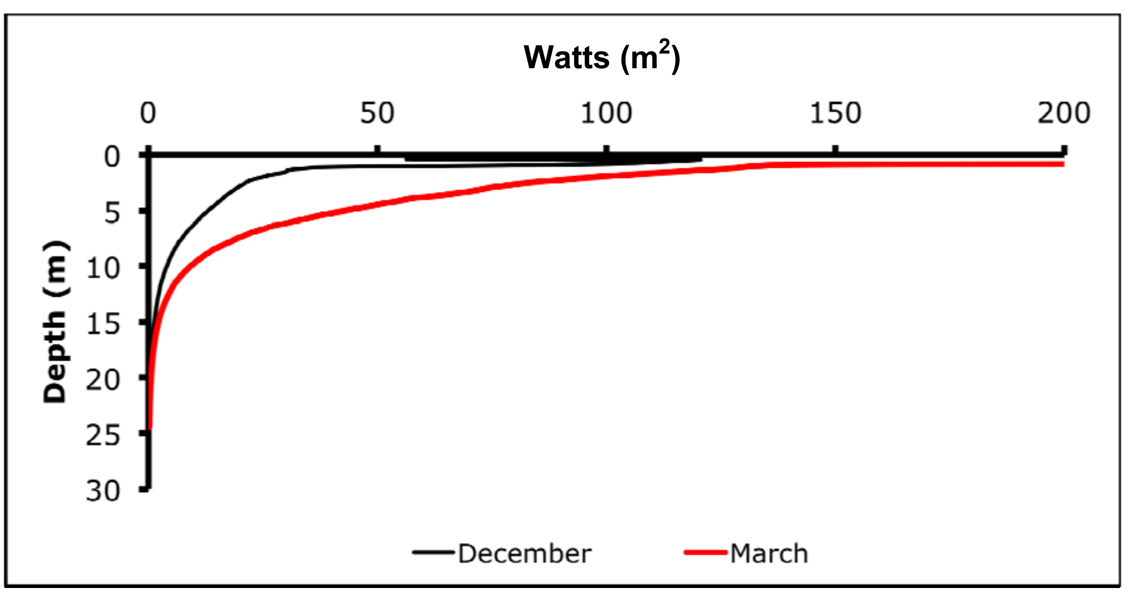


Figure A.1.6. Comparison of photosynthetically active radiation (PAR) measured with Seabird profiler at site WL3 in December 2007 and March 2008, bracketing the sampling period of this project.

Chemical Characteristics

Major ions, TDS, conductivity and pH

Walker Lake has generally poor water quality with very high TDS, alkaline pH (average 9.37), and a sodium–sulfate+chloride+bicarbonate chemical type (Figure A.1.7). All samples collected, regardless of month or depth, have similar ionic character because limnological processes such as thermal stratification do not significantly change the ionic character of the lake. Note, however, that TDS increased from 15,000 mg/L in March and May to 15,900 mg/L in December (Table A.1.3). The increase in TDS resulted from increases in sodium (depths averaged for each sample date: 290 mg/L), carbon (HCO_3 + CO_3: 210 mg/L), chloride (280 mg/L), and sulfate (250 mg/L). The TDS of Walker Lake has been increasing over time as shown by specific conductivity in Figure A.1.8 because of the continual process of evaporation.

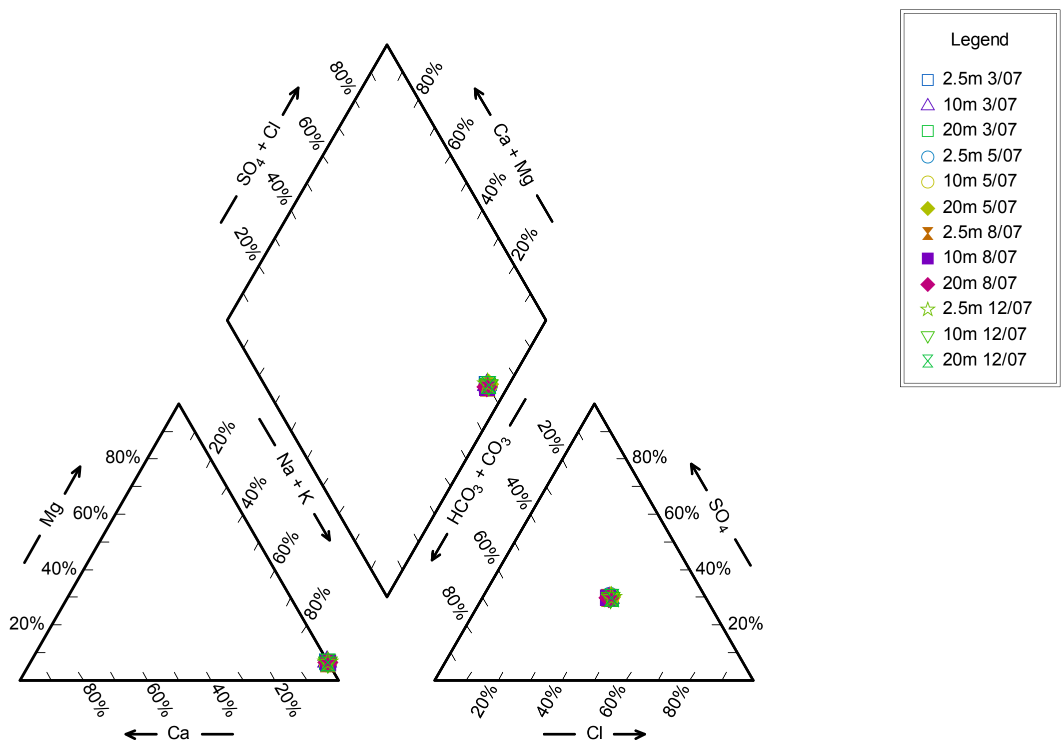


Figure A.1.7. Trilinear diagram of major-ion chemistry of Walker Lake in 2007. Regardless of month or depth, the lake water has similar ionic character (Hershey *et al.,* this volume).

Table A.1.3. Major-ion, pH, and TDS data for Walker Lake collected in 2007.

Sample Name	Sample Date	pH	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	SiO_2 (mg/L)	TDS (mg/L)	EC (µS/cm)
WL3 2.5m	03/07/2007	9.38	10.7	190	4,760	262	2,300	1,060	3,450	3,490	0.30	15,000	20,000
WL3 10m	03/07/2007	9.37	10.5	193	4,870	253	2,310	1,060	3,410	3,460	0.30	15,000	20,000
WL3 20m	03/07/2007	9.38	10.4	186	5,000	255	2,320	1,060	3,480	3,460	0.20	15,000	20,000
WL3 2.5m	05/22/2007	9.37	10.5	183	5,070	256	2,420	1,010	3,460	3,580	0.58	15,100	19,670
WL3 10m	05/22/2007	9.37	10.4	177	4,930	256	2,400	1,010	3,490	3,550	0.54	15,000	19,670
WL3 20m	05/22/2007	9.38	10	187	4,900	250	2,400	1,010	3,500	3,560	0.68	15,000	19,600
WL3 2.5m	08/29/2007	9.40	10.9	191	5,310	288	2,370	1,120	3,520	3,580	0.66	15,700	19,600
WL3 10m	08/29/2007	9.39	10.7	193	5,320	295	2,390	1,130	3,490	3,590	0.58	15,700	19,600
WL3 20m	08/29/2007	9.36	9.71	184	4,820	280	2,360	1,040	3,360	3,420	2.06	15,000	19,700
WL3 2.5m	12/04/2007	9.37	10	197	5,110	284	2,450	1,120	3,730	3,700	1.10	15,900	20,500
WL3 10m	12/04/2007	9.36	10	194	5,230	283	2,440	1,130	3,710	3,720	1.10	15,900	20,500
WL3 20m	12/04/2007	9.36	10.1	192	5,160	279	2,460	1,130	3,750	3,730	1.00	15,900	20,500

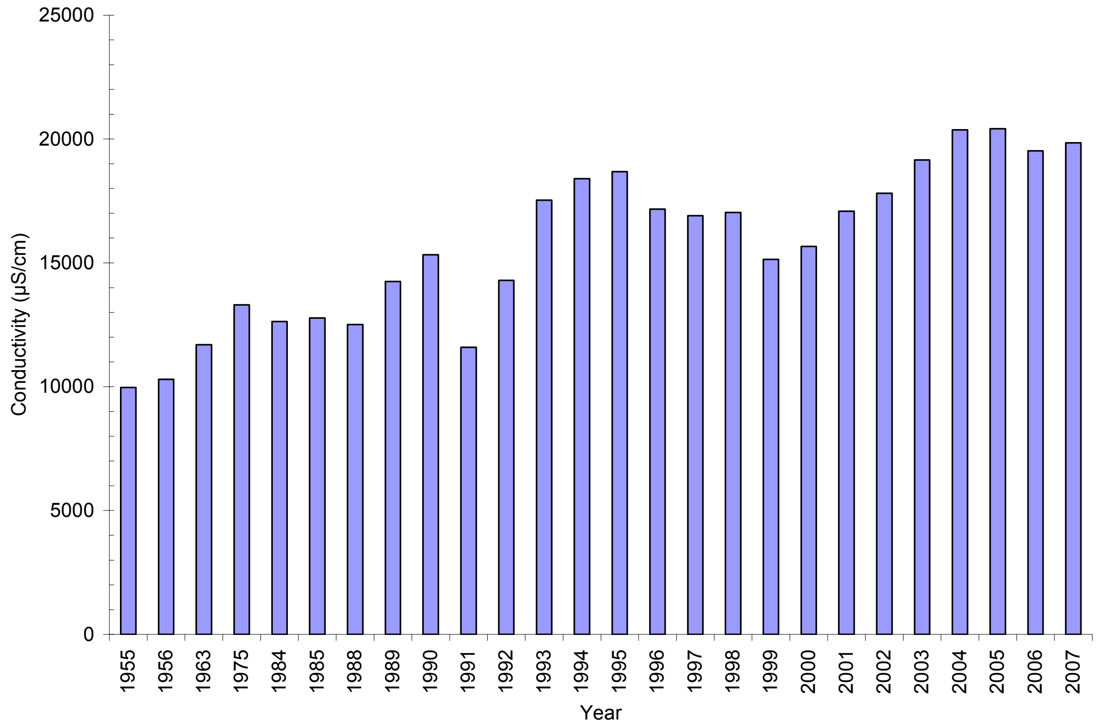


Figure A.1.8. Annually averaged specific conductivity measurements from the Walker Lake and River Database for near-surface samples at site WL3 from 1955 to 2007.

To identify groundwater inflow into Walker Lake, specific conductivity and temperature data and stable isotope samples were collected along the western shoreline on April 27, May 31, and July 6, 2007. During this period of time, increased groundwater inflow from spring snowmelt and runoff could possibly be identified. Unfortunately, these techniques did not provide sufficient measurement resolution to discern any variation in lake water conductance, temperature, or isotopic signature that could be attributed to groundwater inflow (specific conductance, 5 percent; temperature, 0.1 ºC; δ^2H, 1‰; δ^{18}O, 0.2 ‰).

The pH at mid-lake (WL3) ranged from 9.3 to 9.4 from March to December, while conductivity over the same period ranged from 19,600 to 20,550 µS/cm (Table A.1.3). These were measurements conducted on samples in the DRI laboratory, along with analysis of major ions. In-situ measurements of pH were more variable (9.2 to 9.9), likely because of greater sampling frequency and depths, and perhaps affected by inaccurate calibrations or sensor drift.

Dissolved Oxygen

Epilimnetic dissolved oxygen (DO) ranged from 10.4 mg/L in March to 6.0 mg/L in October, with a sharp loss of oxygen around 18 meters after stratification. The hypolimnion became devoid of oxygen at each sampling location by the end of May, and remained anoxic throughout the summer and into early October (Figure A.1.9).

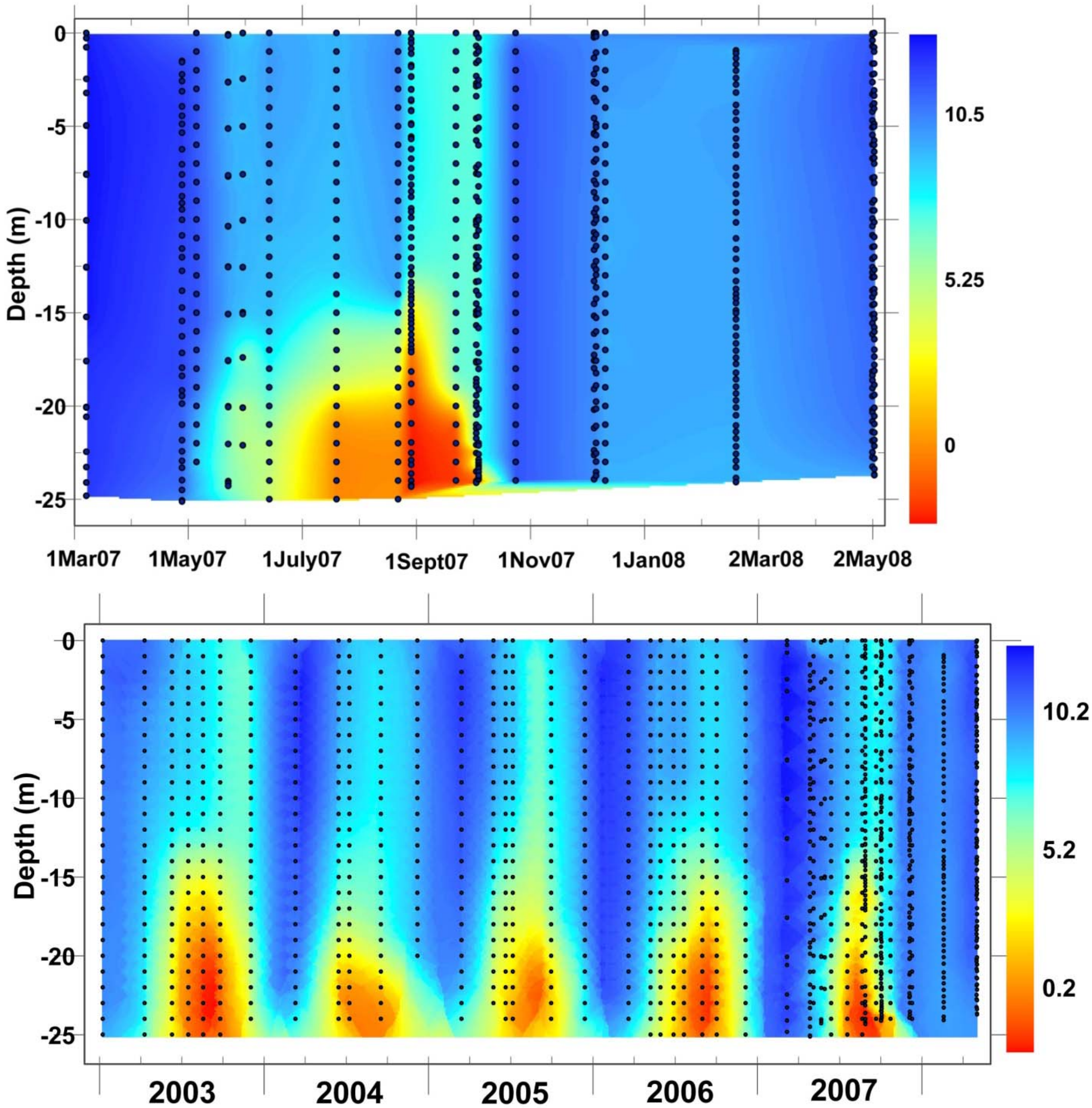


Figure A.1.9. Walker Lake dissolved oxygen (mg/L) profiles at site WL3 during the project sampling period (upper chart) and from 2003 to 2008 (lower chart). Data were collected by DRI and UNR (this report) and by NDOW (Sollberger and Wright, 2002 to 2007). Interpolation of data points for the project sampling period was done with Natural Neighbor tool in 3D Analyst extension of ArcMap 9.2 (ESRI, 2009). Interpolation of data points from 2003 to 2008 was done with Kriging tool in 3D Analyst extension.

During 2007, DRI, NDEP, NDOW and UNR conducted profiles at Walker Lake. Figure A.1.10 shows a comparison of dissolved oxygen measurements reported by the four organizations during profile events at WL3. Measurements are averaged by month, over depth to 24 meters, and are separated by organization. During the months of July, August, and September, DO is relatively low. The lowest measurement was reported by DRI during August. The highest value was reported by DRI during March. The differences within months most likely represent changes in lake condition or location between the different sampling dates for that month, as well as slight variations in instrument calibration and use.

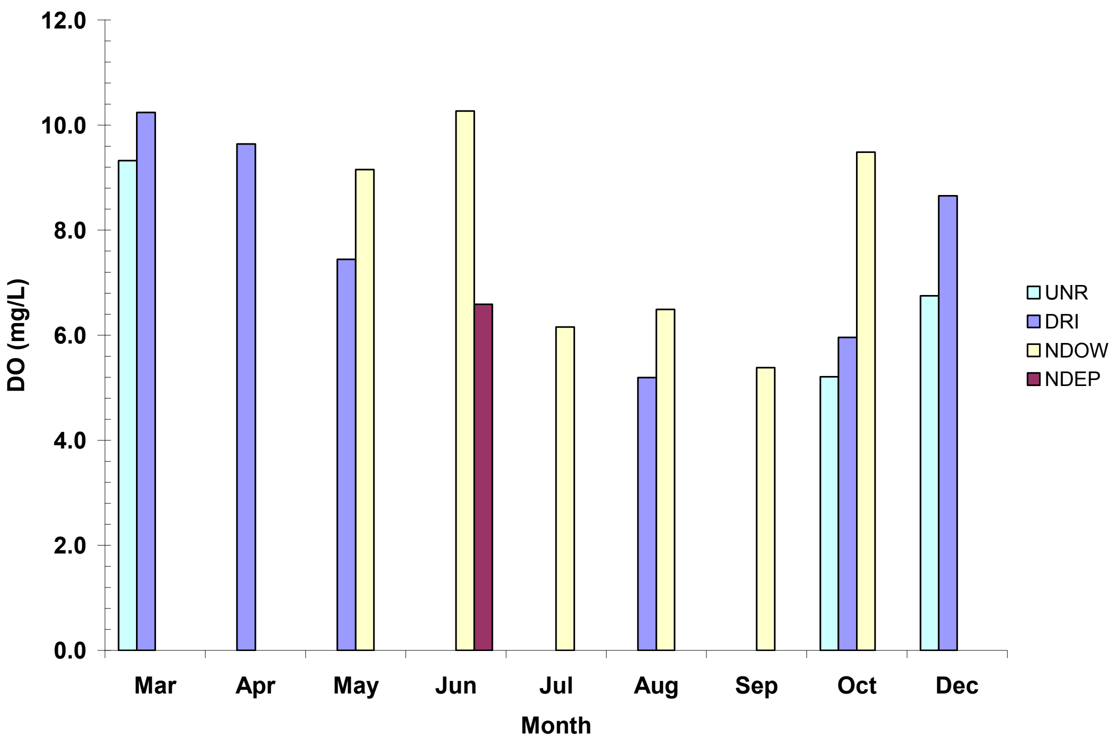


Figure A.1.10. Comparative results for mean dissolved oxygen (mg/L) between the lake surface and 24 meters depth, measured during profile sampling events at site WL3 during 2007.

Nutrients

Phosphorus varied by depth during each sampling period and demonstrated spatial patchiness around the lake. Total phosphorus levels at WL3 were generally high, ranging from 28 µM (860 µg/L) in May, at around 20 m, to 19 µM (600 µg/L) in August near the surface (Figure A.1.11). Orthophosphate-P concentrations were generally high as well, averaging 20 µM (625 µg/L) within the water column for the year.

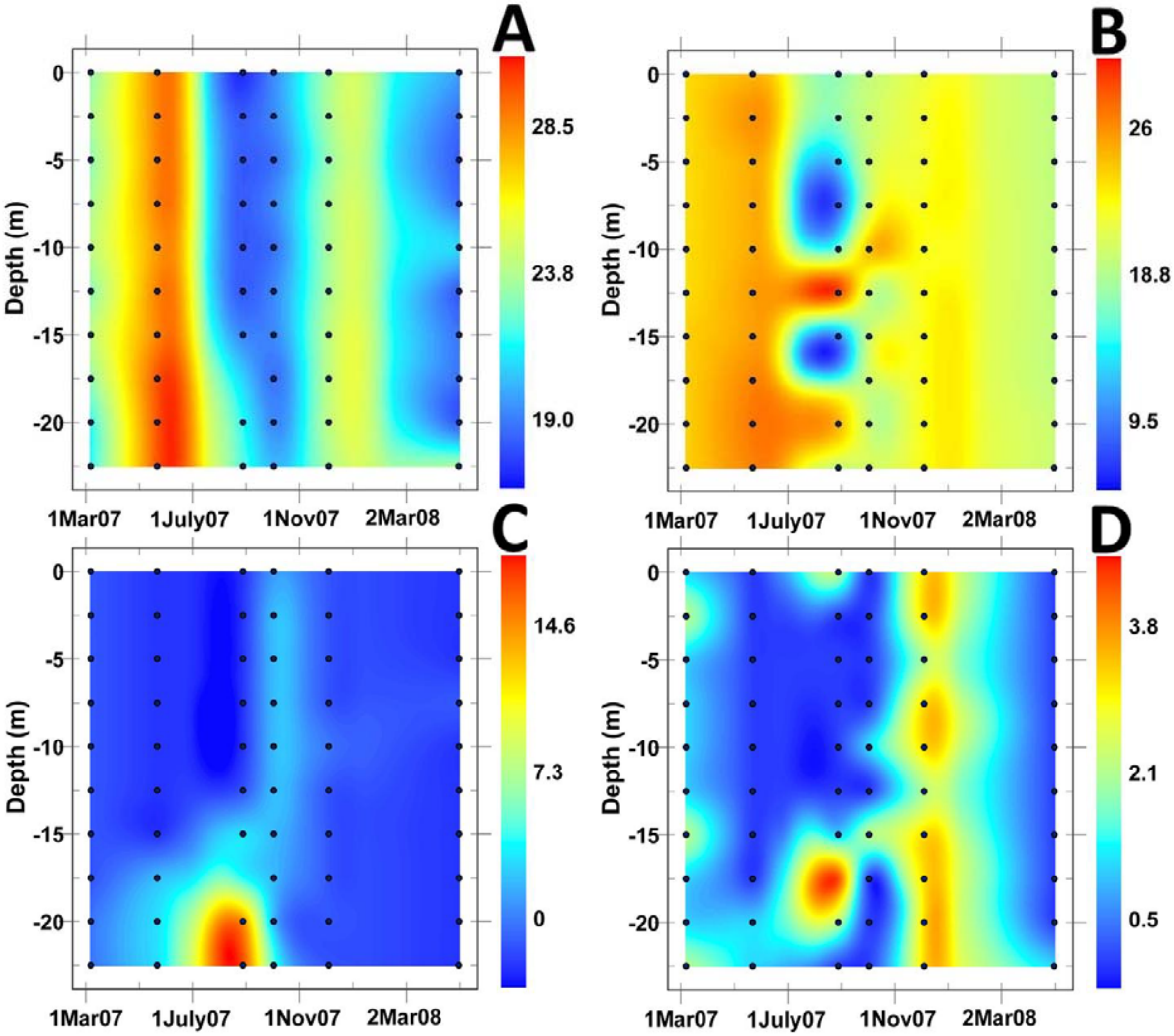


Figure A.1.11. Walker Lake nutrient concentration (µM) profiles from site WL3 for A) total phosphorus, B) orthophosphate, C) ammonia-N, and D) nitrate-N. Interpolation of data points was created using the spline tool in 3D Analyst extension of ArcMap 9.2 with default optional settings.

Inorganic nitrogen concentrations were variable over time. Whereas ammonium-N generally ranged from below detection to about 4 µM (56 µg/L), the concentration in bottom waters at WL3 briefly spiked to above 14 µM (190 µg/L) during August 2007 (Figure A.1.11) and in September 2008. Nitrate concentrations for the year ranged from below detection to about 3.6 µM (50 µg/L), with a distinct spike appearing at 15 to 18 m during August, despite a high abundance of nitrate-reducing bacteria in the bottom waters (10^4/mL, Table A.1.4). Notably, this nitrate layer developed directly above the coincident spike in ammonia; a result consistent with microbial nitrification.

Table A.1.4. Quantification estimates (cells mL^{-1}) for samples obtained at site WL3 on 10/03/07 and 9/18/08.

Depth (m)	Aerobic Heterotrophs		Fermentative		Nitrate reducers		Sulfate Reducers		Sulfur Reducers		Iron (FeNTA) Reducers		Iron (FeCitrate) Reducers		Arsenate Reducers		Arsenite Oxidizers	
0	10^{4}	10^{5}	10^{4}	10^{1}	10^{2}	10^{1}	10^{3}	0	10^{1}	0	10^{4}	0	X	0	X	n/a	X	10^{2}
10	10^{4}	10^{5}	10^{4}	10^{4}	10^{2}	10^{1}	10^{4}	0	10^{1}	0	10^{4}	0	X	10^{1}	X	n/a	X	10^{3}
15	10^{5}	--	10^{4}	--	10^{2}	--	10^{4}	--	0	--	10^{4}	--	X	--	X	--	X	--
17.5	10^{4}	10^{4}	10^{4}	10^{4}	10^{2}	10^{2}	10^{3}	10^{1}	10^{1}	10^{2}	10^{4}	10^{1}	X	10^{1}	X	10^{3}	X	10^{2}
18	--	10^{4}	--	10^{5}	--	10^{3}	--	10^{1}	--	10^{2}	--	10^{2}	X	10^{1}	X	10^{3}	X	10^{2}
19	--	10^{4}	--	10^{5}	--	10^{3}	--	10^{1}	--	10^{2}	--	10^{3}	X	10^{2}	X	10^{1}	X	10^{3-5}
22	--	10^{4}	--	10^{5}	--	10^{4}	--	10^{2}	--	10^{4}	--	10^{4}	X	10^{5}	X	10^{3-4}	X	10^{3-6}
22.5	10^{4}	--	10^{4}	--	10^{3}	--	10^{4}	--	0	--	10^{4}	--	X	--	X	--	X	--
24	10^{5}	--	10^{4}	--	10^{4}	--	10^{5}	--	10^{1}	--	10^{6}	--	X	--	X	--	X	--
Date	2007	2008	'07	'08	'07	'08	'07	'08	'07	'08	'07	'08	'07	'08	'07	'08	'07	'08

*note: different depths were sampled in 2007 and 2008, based on YSI data at the time of sample collection (see Figure A.1.16).

Biological

<u>Chlorophyll-a and algal biomass</u>

Phytoplankton dynamics followed an annual cycle that included a winter minima and a spring bloom, as shown in Figure A.1.12 (Fritsen *et al.,* this volume), which is not unexpected for a moderately-deep, monomictic, temperate lake. The largest biomass concentrations during the study occurred from the end of April to early May 2008. This spring bloom was first observed on April 25 (Figure A.1.13a and A.1.13b) and sampled on May 1. Biomass measured at site WL3 was approximately 10 µg chl-a L^{-1}, but the surface accumulations appeared somewhat dispersed and diminished compared to only a few days earlier. During spring 2007, Walker Lake was sampled on April 27, yielding a peak biomass of 3.2 µg chl-a L^{-1}. Based on observations and photo images from a resident at the town of Walker Lake, however, this sampling occurred a few weeks prior to the major spring bloom of that year, during which extensive surface accumulations were also prevalent (Figure A.1.13c).

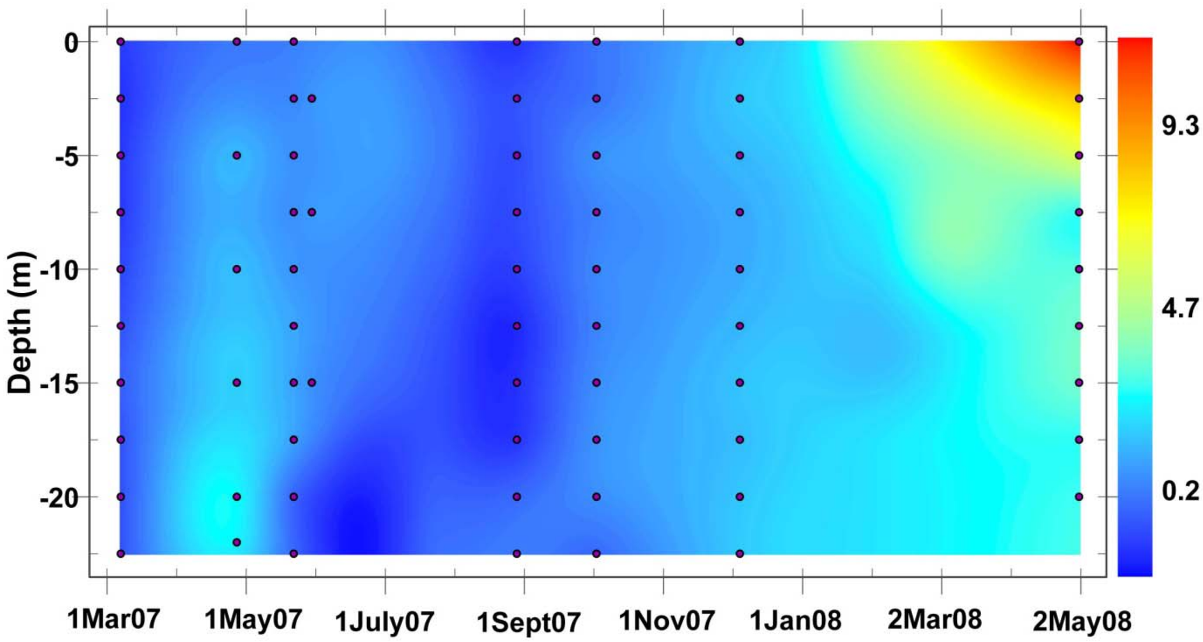


Figure A.1.12. Walker Lake chlorophyll-a (µg/L) profile at site WL3. Interpolation of data points was created using the spline tool in 3D Analyst extension of ArcMap 9.2 with default optional settings.

Figure A.1.13. Images showing A) birds swimming through surface accumulations of the cyanobacterial bloom on April 25, 2008, and their "swimming tracks;" B) C. Fritsen sampling the large cyanobacterial surface accumulations along the shore just north of the town of Walker and south of Sportsmans Beach. (Note that during sampling, pungent noxious odors were prevalent [C. and T. Fritsen, personal observations; images courtesy of Tyler Fritsen]; C) surface accumulations of algae in spring 2007 (image courtesy of B. Ronnald).

The phytoplankton of Walker Lake, although attaining high levels of biomass, was relatively depauperate in regards to richness and diversity, with only a few taxa comprising the plankton assemblage during all seasons (Figure A.1.14). *Nodularia* spp. (cyanobacteria, Figure A.1.15a and A.1.15b) mostly dominated the phytoplankton assemblages in terms of biovolume, with lesser volumes of *Spermatozopsis* (chlorophyte, Figure A.1.15d) and a small autotrophic flagellate (yet to be positively identified) during spring and summer. During winter, other taxa were more prevalent, notably *Chaetocerous* (Figure A.1.15c), a small chain-forming diatom, and chlorophytes. In addition, *Synechococcus*-like microbes (cyanobacteria), detected putatively by flow cytometry (autofluorescence) and definitively by phylogenetic analysis, were abundant throughout the study and numerically dominated several of the samples, particularly in the anaerobic hypolimnion after stratification. Despite this numerical abundance, however (potentially as high as 6.7 x 10^5 cells mL^{-1}), they did not often dominate biovolume assessments, due to their small size (typically ~1.5 µm). Interestingly, the large and morphologically conspicuous *Nodularia* spp. did not appear in the molecular characterization analyses, most likely due to use of a 100 µm pre-filter during microbial sampling to remove the larger zooplankton and their associated microbial gut flora.

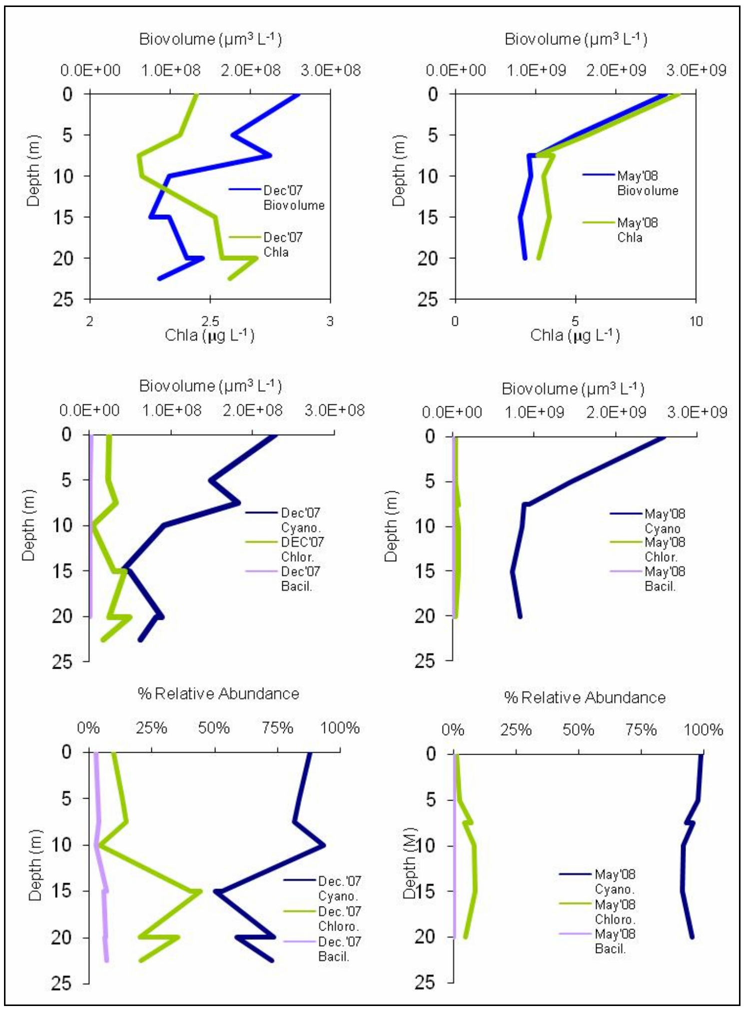


Figure A.1.14. Profiles of phytoplankton total biovolume and chl-a (top two panels), biovolume of cyanobacteria, chlorophytes and bacillariophytes (middle two panels) and their relative numerical abundance during December 2007 and May 2008 (bottom panels).

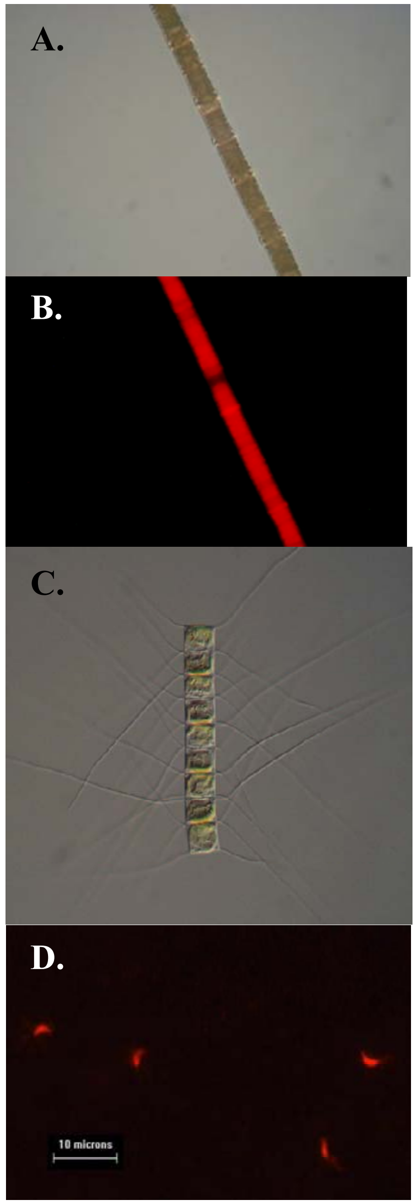


Figure A.1.15. A) *Nodularia* filament viewed with differential interference microscopy (DIC); B) the same *Nodularia* filament viewed with epilflourescence; C) *Chaetocerous* viewed with DIC; and D) *Spermatozopsis* viewed with epifluorescence.

<u>Bacterial communities</u>

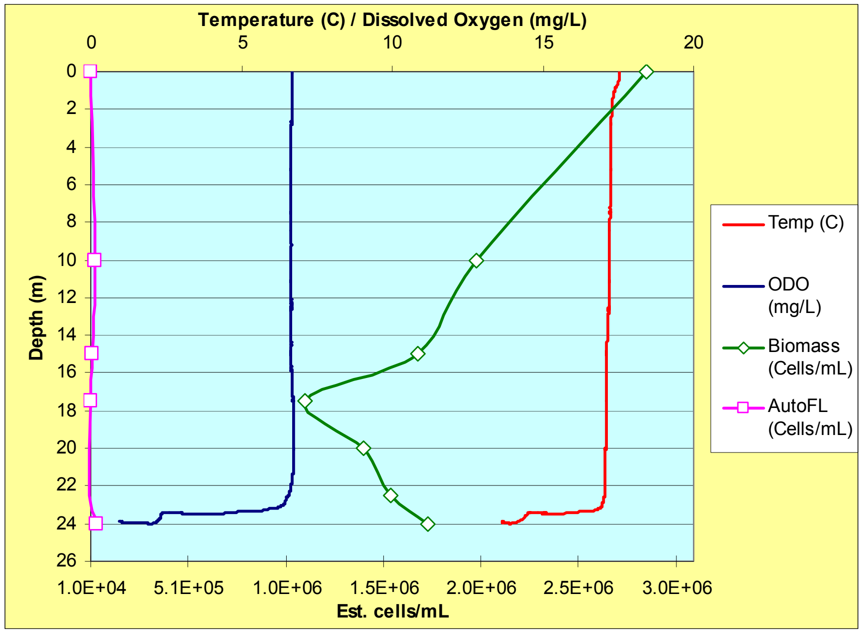
Two detailed evaluations of Walker Lake's microbial communities were performed during this study. The first occurred immediately after, or possibly during, the 2007 autumnal lake turn-over event (10/03/2007 sampling). Fall turn-over events such as this are characterized by a rapid breakdown of summer thermal stratification, and result in a complete top-to-bottom mixing of the lake (see Figure A.1.2 for a generalized representation of thermal stratification). It did appear at the time of sampling, however, that a slight remnant of thermal stratification persisted below 23 m (Figure A.1.16). The second microbial evaluation was performed the following year (09/18/2008 sampling) while the lake still exhibited thermal structure. This enabled a study of the lake's microbial communities during the anoxic conditions that have become typical of its late summer hypolimnion.

Total cell counts using epifluorescence microscopy and flow cytometry both estimated the microbial density to be about 10^6 (i.e., millions of) cells per milliliter, regardless of date or depth of sample (Figure A.1.16). Estimates of autofluorescing cells (e.g., cyanobacterial phytoplankton) were approximately an order of magnitude less than total cell counts. During stratification in 2008, total and autofluorescent cell counts increased sharply at the thermocline (from 10^5 and 10^4 cells per mL, respectively, to 10^6 and 10^5) and remained high throughout the anoxic hypolimnion (Figure A.1.16b). This indicates that a substantial anaerobic phototrophic community was present during thermal stratification.

Cultivation-based studies demonstrated that numerous alkaliphilic physiotypes were present (Table A.1.4). Quantitative estimates (cells/mL) for specific types were largely depth-specific and ranged as follows: 10^4 to 10^5 aerobic heterotrophs; up to 10^5 fermentative microbes and sulfate-reducers; up to10^4 nitrate-reducers and sulfur-reducers; up to 10^6 iron-reducers; and 10^1 to 10^6 microbes capable utilizing arsenic (either through reduction or oxidation pathways). As expected, physiotypes were distributed concurrent with thermal stratification in the 2008 sample (i.e., anaerobic metabolisms were confined to the anoxic hypolimnion), whereas they were found throughout the water column in 2007, further evidence that the lake had just mixed or was mixing during sampling.

Molecular characterization of the microbial communities also demonstrated the influence of thermal stratification. Terminal-Restriction Fragment Length Polymorphism (T-RFLP) analysis (data not shown) indicate that communities were different between samples taken from the epilimnion/mixed layer and the hypolimnion (2008), or the putative hypolimnetic remnant (2007). Based on the presence of unique signatures in the T-RFLP data, molecular cloning was used to examine the microbial communities present in the surface water (0 m) and bottom-most samples from each collection date (24 m and 22 m, chronologically). Phylogenetic analysis of these clone libraries indicated that while the overall diversity of major bacterial groups (phyla and Proteobacterial classes) in Walker Lake was essentially the same during mixed and thermally stratified conditions, there was decidedly more segregation of bacterial groups (both in distribution and abundance) between the individual depths during 2008 (Figure A.1.17). In 2007, the majority of phyla were ubiquitous, with only the Actinobacteria and *Deltaproteobacteria* being depth-specific (comprising 16% and 5% of the 0 m and 24 m libraries, respectively). No depth-specific trends were observed within the individual phyla. In contrast, Actinobacteria and *Deltaproteobacteria* comprised substantially larger portions of the 2008 0 m and 22 m samples (25% and 11%, respectively). Additionally, representatives of the *Gammaproteobacteria* (11% of the total clones) were only found in the 22 m hypolimnetic community.

a) October 3, 2007



b) September 18, 2008

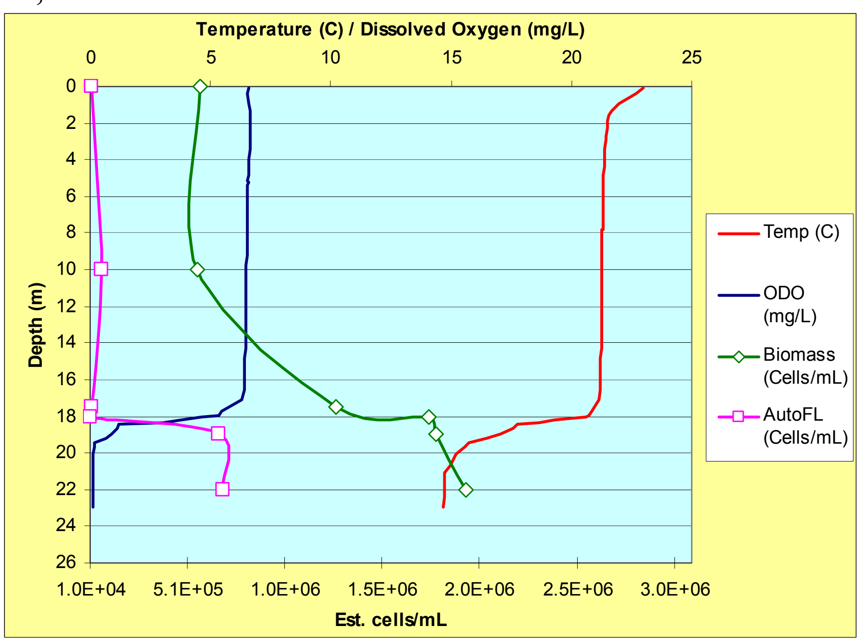
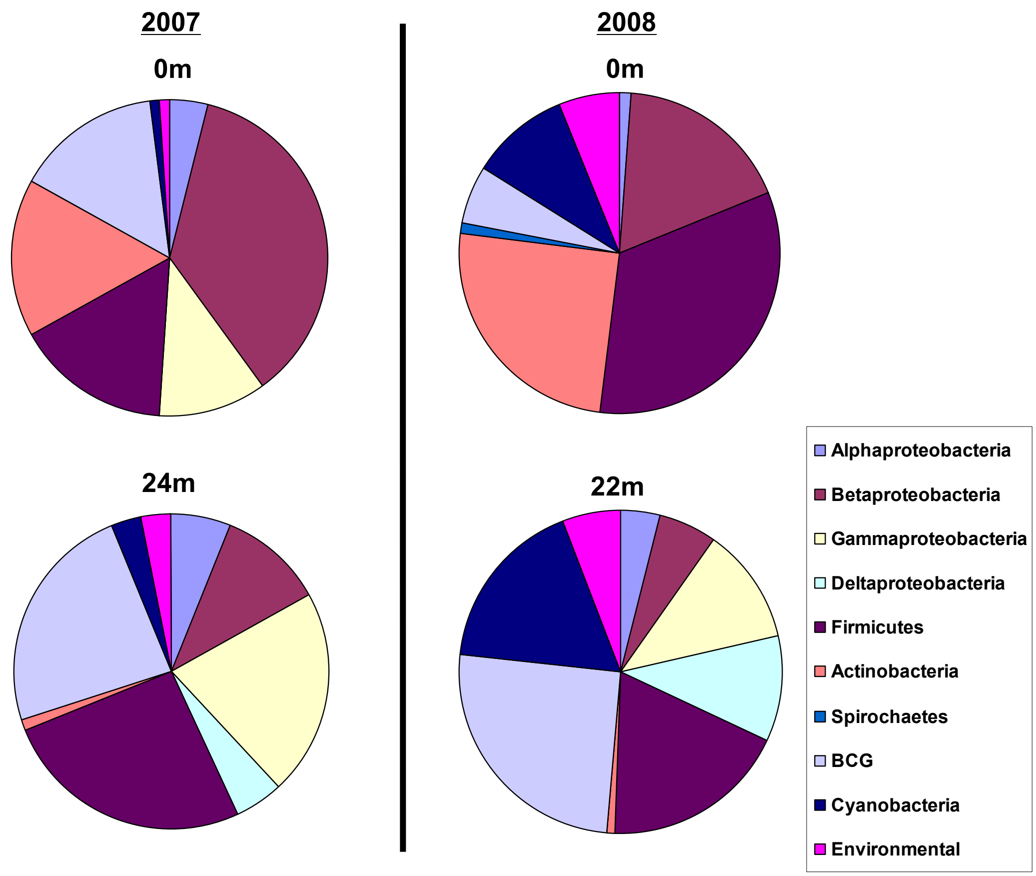


Figure A.1.16. Depth profiles of Walker Lake (WL3) from two different dates indicating temperature and dissolved oxygen (YSI) and total and autofluorescent cells (measured by flow cytometry). a) October 3, 2007: Although the data indicates that the lake was mixing during sampling, a hypolimnetic remnant (HR) appeared to exist below 23 m. b) September 18, 2008: Temperature and dissolved oxygen profiles indicate the lake was stratified. Note the increase in cells, both total and autofluorescing, corresponding to the thermocline.



	October 3, 2007		September 18, 2008	
Bacterial Group	0 m	24 m	0 m	22 m
Alphaproteobacteria	4 %	6 %	1 %	4 %
Betaproteobacteria	36 %	11 %	18 %	6 %
Gammaproteobacteria	11 %	21 %	n/d	12 %
Deltaproteobacteria	n/d	5 %	n/d	11 %
Firmicutes	16 %	26 %	33 %	19 %
Actinobacteria	16 %	1 %	25 %	1 %
Spirochaetes	n/d	n/d	1 %	n/d
BCG	15 %	24 %	6 %	26 %
Cyanobacteria	1 %	3 %	10 %	18 %
Environmental Clones	1 %	3 %	6 %	6 %

Figure A.1.17. Molecular community analysis of Walker Lake for surface and bottom water depths from 10/3/2007 and 9/18/2008. The pie charts indicate relative percentage of the clone library comprised by the individual bacterial groups. Actual percentages are listed in the table. Number of clones per library were as follows: Oct. 2007 – 0 m (73), 24 m (75); Sept. 2008 – 0 m (83), 22 m (85). BCG = Bacteroidetes/Chlorobi Group. Environmental clones refers to non-chimeric sequences not closely related to any cultured isolate but having sequence identity greater than 91% with other environmental sequences present in the National Center for Biotechnology database.

Further segregation was observed within the individual phyla as well. While Firmicutes and Cyanobacteria were present in both 2008 libraries, there were clear phylogenetic divisions between the individual clones. Firmicutes present in the 0 m sample were all in the order Bacilliales, while those present in the 22 m sample were strictly representative of the class Clostridia (not surprising as the Clostridia are often distinguished from the Bacilli by their lack of aerobic respiration). Similarly, there was a distinction between the Cyanobacteria found in oxic (Cyanobium-like microorganisms) and anoxic (*Synechococcus*-like species) waters. The high percentage of *Synechococcus*-like clones in the hypolimnion, and their absence in the mixed-layer sample, mirrors the observed increase in autofluorescent cells below the thermocline, as well as the onsite observation of pink pigmented cells on filters collected from anoxic depths (Figure A.1.18). For both of these two major types of cyanobacteria detected at Walker Lake, the nearest phylogenetic neighbors (about 98% of 16S rRNA sequence identity) were *Cyanobium* and *Synechococcus* strains cultivated from hypersaline Mono Lake in California (Budinoff and Hollibaugh, 2007).

Molecular and cultivation-based datasets indicated a diverse population of obligate alkaliphiles (microbes only capable of growth at high pH) at all depths. Major bacterial types included a variety of Proteobacteria, with relatives of known sulfate- and iron-reducing bacteria (*Deltaproteobacteria*) being found only in the deepest samples (Figure A.1.17). Of particular note is the apparent bloom of *Synechococcus*-like microorganisms in the 2008 anoxic hypolimnion. It has been reported that these cyanobacteria are capable of utilizing hydrogen sulfide through anoxygenic photosynthesis (Imhoff *et al.,* 1979), so it is possible that their numbers represent a response to the increase in *Deltaproteobacteria* species capable of H_2S production (aka, sulfate-reducers). This result may be relevant to the fishery of Walker Lake as it indicates the presence of a novel form of photoautotrophy that could prevent accumulation of toxic H_2S in the hypolimnion.

Also potentially important to ecological functions of this lake are the very high numbers of microorganisms involved in metal cycling, especially in and near the lake's hypolimnion, with up to 10^6 cells per mL for both iron reducers and arsenic oxidizers (Table A.1.4). Since microbial metal cycling is known to be a major factor driving the mineralization of organic carbon in some lakes (Lovely, 1991, Stemmler and Berthelin, 2003), it is possible that much of the water column respiration may be metal-driven in Walker Lake. However, given the lake's high dissolved organic carbon (DOC) concentrations (40.6–42.4 mg/L, Walker Lake Database) and the fact that alkaliphilic iron-reducing bacteria were only recently reported in the literature (Ye et al., 2004), it is clear there remains much to learn concerning the lower trophic structure and microbial dynamics of Walker Lake.

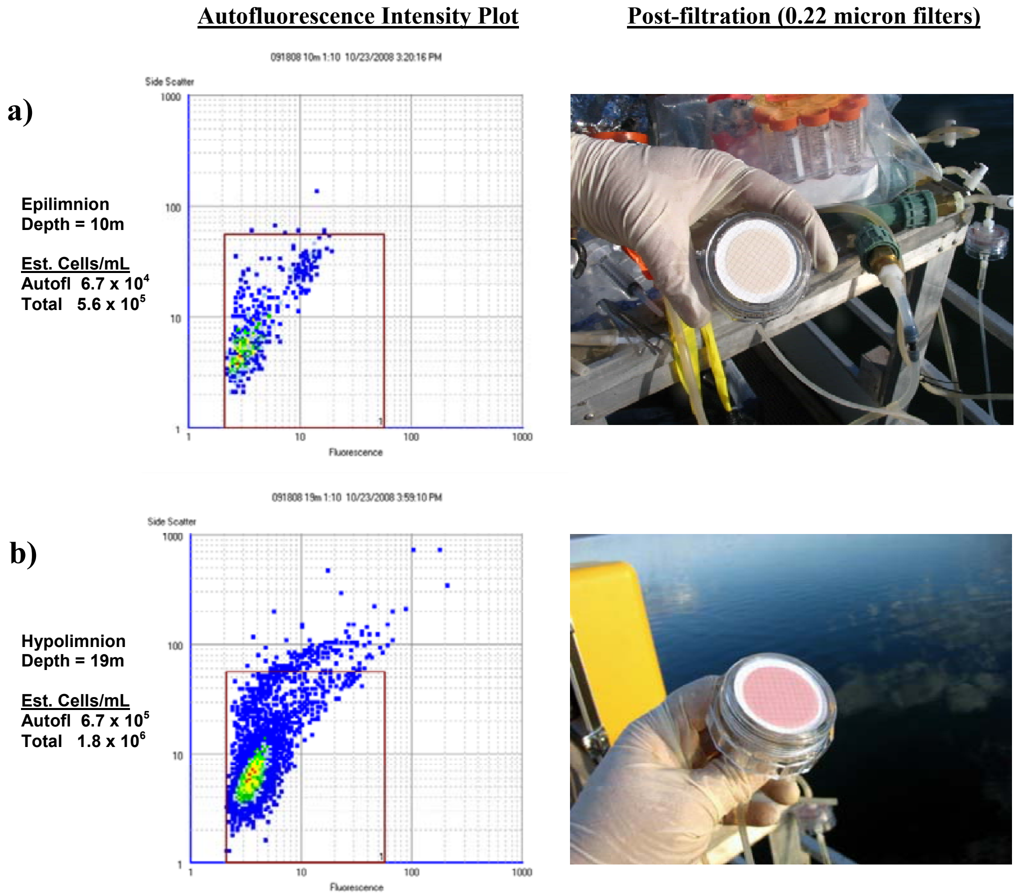


Figure A.1.18. Samples collected on September 18, 2008. Illustrated are autofluorescent intensity plots and pictures taken in the field post filtration from a) the epilimnion (10 m) and b) the hypolimnion (19 m). Note the order of magnitude higher estimated autofluorescent cell count in the hypolimnetic sample and the abundance of pink pigmented cells on the filter.

Ecological Water Quality Modeling

Water-quality conditions and trends in the lake were evaluated relative to historic Walker River inflow volumes, using the river's current geometry, which provided a basis for hypothetical scenario runs with the Walker Lake ecological model. Forecasts developed from this model indicate potential ecological conditions that would result under different streamflow scenarios in the Walker River, as described above. A summary of these results is provided below, with further detail available in a subsequent chapter (Stone *et al.,* this volume).

The ecological model produced forecasted vertical distributions in a number of water quality parameters including temperature, TDS, DO, chlorophyll-a, nutrients and carbon, along with water surface elevations. Figure A.1.19 shows simulated and observed water surface elevations for the calibration period (1/1/2007 to 1/1/2008) as well as for the high- and low-streamflow scenarios and the minimum-flow scenarios suggested by

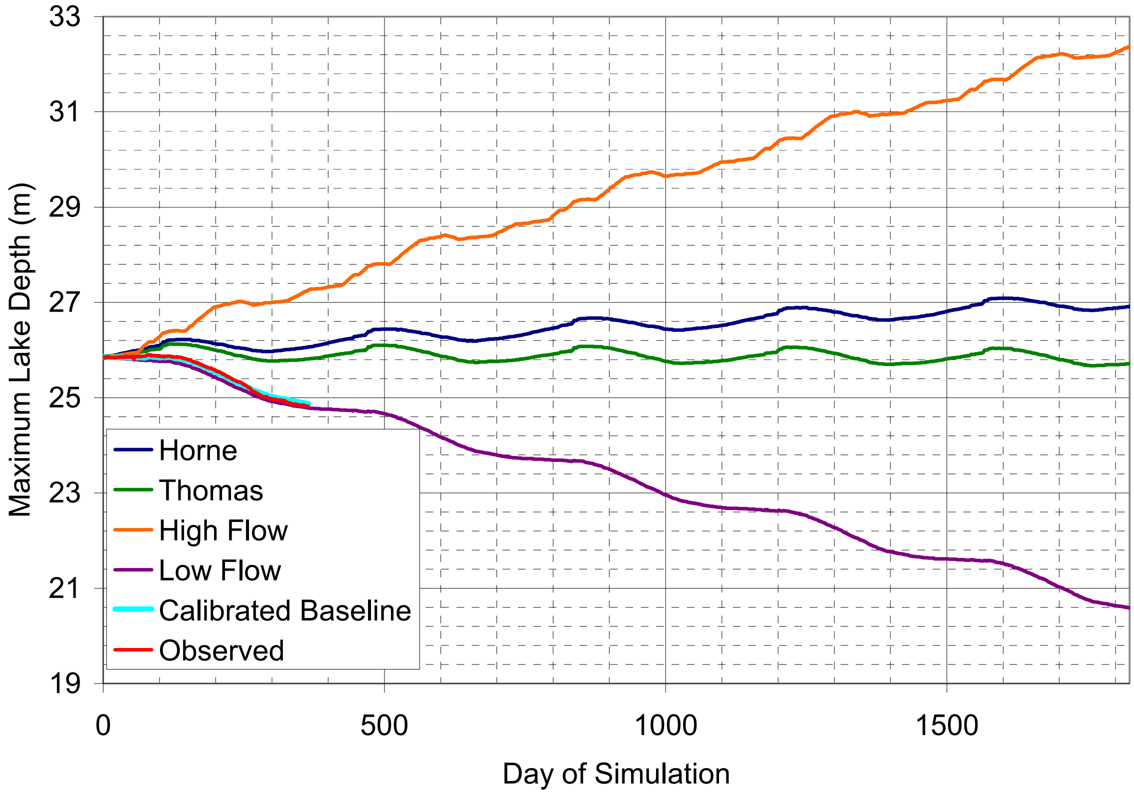


Figure A.1.19. Walker Lake water surface elevations for observed and baseline conditions during 2007 and for several five-year hypothetical Walker River flows under high-flow and low-flow conditions and with minimum flows determined by Horne *et al*. (1994) and Thomas (1995).

Horne *et al*. (1994) and Thomas (1995). This figure illustrates the high degree of agreement between observed and simulated water surface data for the calibrated baseline condition. Under high-flow conditions (based on 1982 to 1986 streamflow data), the water surface elevation was forecasted to increase by approximately 1.3 m per year over the five-year simulation. Under low-flow conditions (based on 1989 to 1993 data), the water surface elevation was forecasted to drop by 1.0 m per year. The water surface elevation was forecasted to increase by 0.20 m per year under a minimum streamflow of 140,000 acre-ft/year, as recommended by Horne *et al*. (1994), and to decrease by only 0.03 m per year under the 112,000 acre-ft/year suggested by Thomas (1995), which is well within the uncertainty of the model predictions. Thus, it can be concluded that the model is performing reasonably well in describing the water balance of the lake. These results were consistent with the results of Thomas (1995), suggesting that a minimum flow of 112,000 acre-ft/year would stabilize the water surface elevation of Walker Lake.

Figure A.1.20 contains a summary of forecasted vertical distributions for water temperature, TDS, and DO under the hypothetical high-flow condition over a five-year simulation period. It is important to note that these scales are different between scenarios, which is necessary to display the full range of variation. Under the high-flow scenario, the hypolimnion is forecasted to extend higher into the water column each summer as a result of increasing water surface elevation. According to the model predictions under these extremely high streamflows (based on 1982 to 1986 measurements), a slight gradient in TDS could occur, with lower-density, low-TDS water not mixing completely with the higher-density, high-TDS water at the bottom of the lake. Dissolved oxygen profiles under the high-flow scenarios are affected by reduced mixing, with elevated DO near the lake surface and depressed DO at the lake bottom. The increased density stratification (TDS) forecasted here is likely a result of the extremely high flows used in this scenario and a consequence of the assumptions inherent to a one-dimensional hydrodynamic model. While it is possible that a three-dimensional simulation would yield different conclusions, these results suggest that some density stratification could occur under extreme flow conditions, which is reasonable based on similar conditions in other systems.

Forecasted results for the hypothetical low-flow scenario are shown in Figure A.1.21. In this case, the extent of the hypolimnion is predicted to be reduced within the water column as the lake grows shallower from year to year. Thus, the cooler water required by Walker Lake fish would become available over an increasingly smaller vertical portion of the lake. Both the temperature and TDS profiles indicate complete mixing of the lake every fall. As a result, DO concentrations are forecasted to be more evenly distributed throughout the vertical profile. However, DO concentrations are shown to drop to anoxic levels near the lakebed during stratification. Under this scenario of extremely low flows over an extended period of time, the TDS levels in the lake are predicted to rise above 21,000 mg/L.

Forecasted vertical profiles for water temperature, TDS and DO concentrations under the minimum annual flow determined by Thomas (1995) are shown in Figure A.1.22. As discussed above, the 112,000 acre-feet/year suggested by Thomas was evenly distributed on a daily basis over the simulation period (equivalent to 155 cfs). Due to the equilibrium state established for the lake water surface, vertical profiles are forecasted to remain stable from year to year. The only noticeable change over the five-year simulation is a slight decrease in the height of the anoxic region with time. Future studies could investigate the influence of streamflow timing.

It is important to note that the Walker Lake ecological model is still in its early stages of development and is not currently capable of producing limnological forecasts with a high degree of confidence sufficient to guide policy decisions. However, the quality of model predictions would be improved by addressing the major areas of uncertainty, as determined through sensitivity analysis. For example, no data is currently available describing the distribution of nutrients within the lake sediments. Also, the model currently uses default rate coefficients for its equations. These are based on published literature values, but could vary greatly for the unique environment found in Walker Lake. Thus, results presented here should be interpreted as a general description of how trends in the lake's limnology are likely to change with the given flow scenarios.

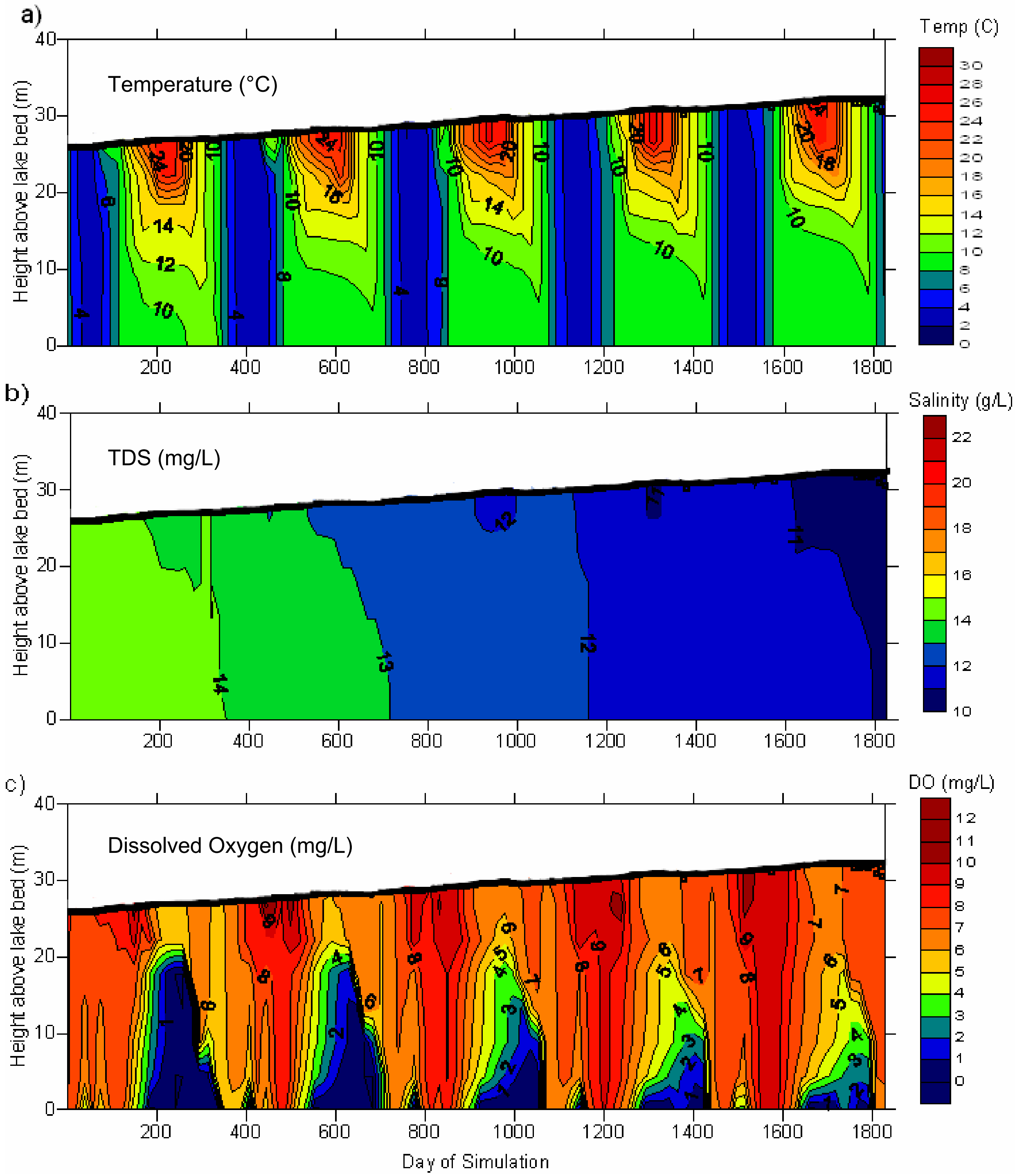


Figure A.1.20. Model results for Walker Lake vertical profiles of temperature, TDS (salinity), and DO under the high-flow scenario (425 cfs).

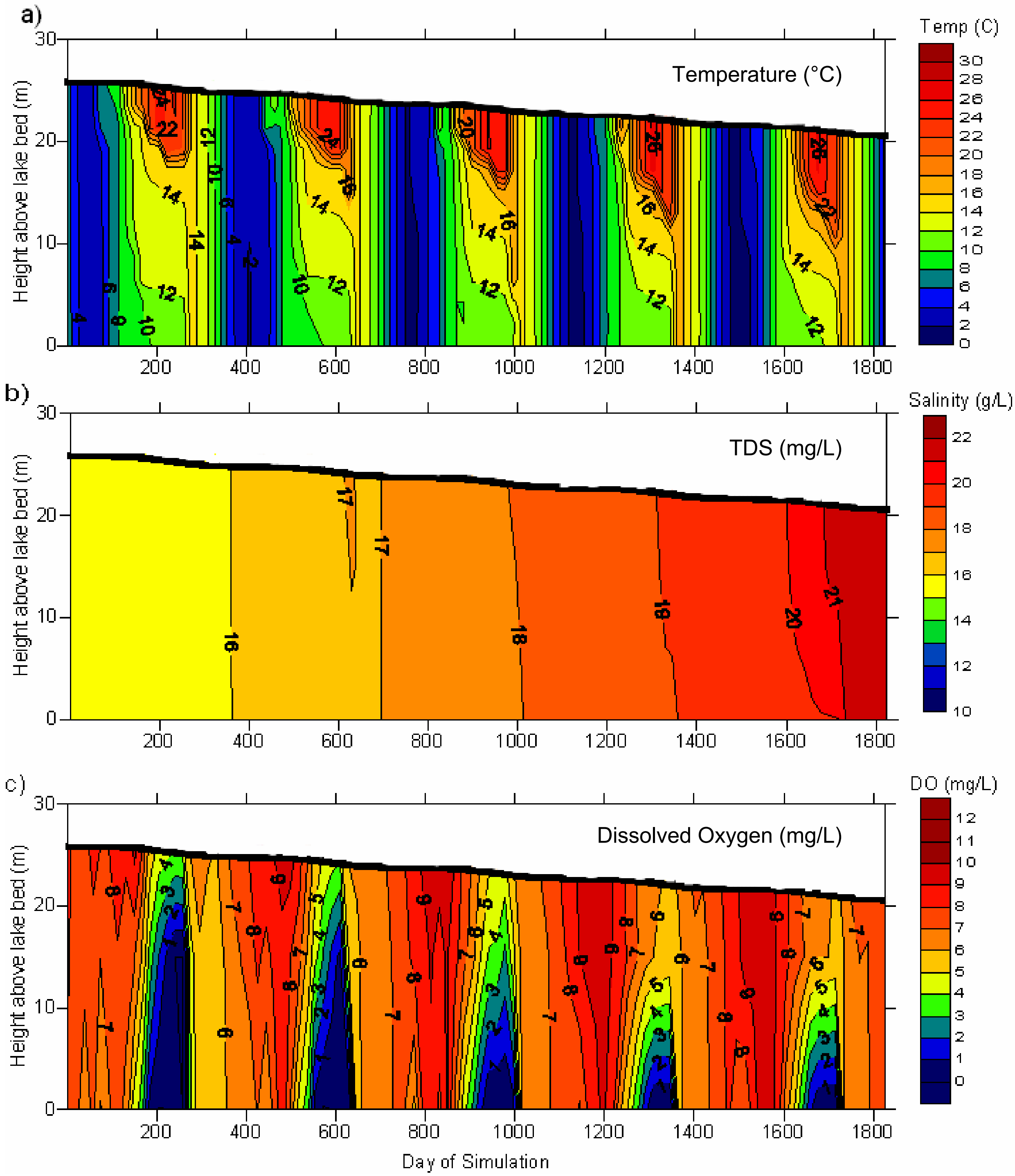


Figure A.1.21. Model results for Walker Lake vertical profiles of temperature, TDS (salinity), and DO under the low-flow scenario (30 cfs).

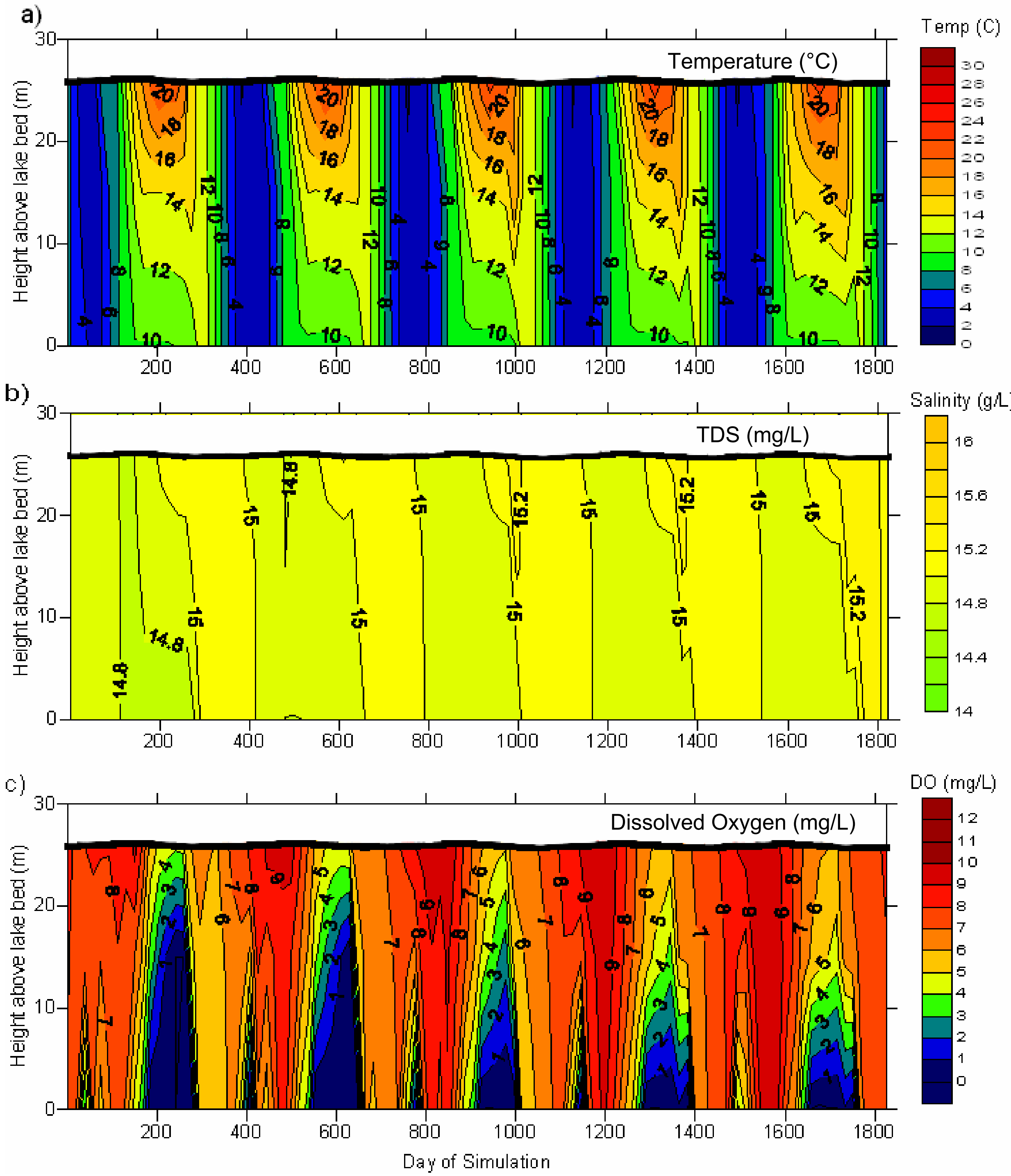


Figure A.1.22. Model results for temperature, TDS (salinity), and DO vertical profiles resulting from an annual Walker River flow of 112,000 acre-ft (note: color scale for TDS is the same as shown in Figures A.1.20 and A.1.21 but the contours have been adjusted to a higher resolution).

Recommendations for Long-term Monitoring

As described in the methods section, the ecological model requires a wide range of data for setting boundary and initial conditions. Additional data collection activities will be necessary to reduce the uncertainty in these estimates and to better describe spatial and temporal patterns. Meteorological data in particular (air temperature, wind speed, solar radiation, and humidity) are needed to drive the lake model hydrodynamic and thermodynamic processes. Therefore, a meteorological monitoring station should be established on or near Walker Lake.

Also, the water quality of the Walker River and groundwater discharge volume, timing, and location are not well known. Therefore, a continuous water quality monitoring station for at least temperature, conductivity, DO, and pH should be established near the mouth of the Walker River.

One boundary condition with high uncertainty is the sediment nutrient concentration and flux characterization. Determination of spatial and temporal patterns in sediment nutrient processes should be conducted as part of any future monitoring plan.

Vertical profile data for temperature, DO, conductivity, pH, nutrients, carbon, chlorophyll-a, and zooplankton were instrumental for model calibration. Therefore, continued monitoring of these properties, supplemented with relevant microbial diversity and activity measurements, will be essential for improving the model performance. In particular, results from Walker Lake monitoring indicate the presence of dynamic, microbially-driven redox, nitrogen, carbon, and metal cycling. Further clarification will be needed on the rates, the spatial and temporal partitioning, and key microbial taxa involved with these processes (e.g., nitrogen fixation, denitrification, and nitrification).

Dynamics of phytoplankton and microbial blooms in Walker Lake appear to be shorter than the return frequency of current quarterly and monthly monitoring programs. Therefore, more frequent sampling may be necessary in early spring to capture the onset, distribution, and dynamics of large blooms as they occur.

Moreover, it is abundantly clear from the present study that a succession of autotrophic and heterotrophic microbial processes operate in Walker Lake. Further determinations of microbial diversity and activity as a function of depth, season, and location on the lake will be required to understand the factors that lead to seasonal anoxia and to determine the potential impacts of newly discovered anaerobic metabolisms in the hypolimnion (e.g., arsenic and iron reduction and non-oxygenic photosynthesis) as well as the effects on these processes from increased water delivery to the lake. As previously mentioned, a study of biogeochemical nutrient cycling would help evaluate the net effect of these microorganisms on lake ecology.

The usual period of lake turn-over and holomixis from November through February is a critical time for evaluating long-term trends in the lake, as this is when spatial and depth variability are minimized. Considerable effort should be taken to collect a complete set of depth profiles and samples from the lake during this period of deepest mixing, perhaps every January, to best represent lake-wide conditions on a regular basis as they reset to an annual baseline before stratification begins, with subsequent onset of blooms and hypolimnetic anoxia.

Given the substantial patchiness of water quality conditions in Walker Lake over time, space and depth, it will be important to characterize this variation by maintaining multiple monitoring stations across the lake. These should include the long-term sites at WL3, WL2, and WL4, as well as additional sites near the inflow and outer edges of the lake. In particular, this monitoring should evaluate the coupling between riverine and lake processes in the nearshore, since fisheries production in contemporary Walker Lake is largely driven by benthic production (see Chandra *et al.,* this volume). Thus, it will be important to understand physical, chemical, and biological coupling of pelagic production (algae and detritus) with the bottom sediments and the sediment water interface. Describing biological diversity, patchiness, production, and fisheries feeding behaviors across spatial habitats and scales will help provide improved predictions of ecosystem response to changes in lake volume and water delivery patterns.

The sampling conducted by NDOW, in collaboration with the Walker Lake Fisheries Improvement Team, has been part of a long term monitoring program on Walker Lake that along with USGS data has contributed substantially to the Walker Lake Database and the Walker Lake modeling effort. These are the longest term monitoring programs on the lake and they should be maintained, with minor modifications and some additional features as noted above, to provide continued support for development of the Walker Lake ecological model and to track the progress of Walker Lake restoration.

CONCLUSIONS

Despite the lower water levels and higher salinity associated with reduced inflows, Walker Lake still exhibits holomixis during winter and stratification during summer. As typical of other lakes and similar to previous studies in Walker Lake a decade earlier, nutrient concentrations varied spatially and temporally. The lake continues to develop anoxic conditions in the hypolimnion during summer, resulting in high concentrations of ammonia. Internal loading of nutrients, due to microbial activity (e.g., water column nitrification) and redox changes in the sediment, continues to be a strong contributor to the nitrogen budget of Walker Lake. Phosphorus levels remained high throughout this study, similar to the findings of previous researchers (Beutel and Horne, 1997; Beutel, 2001). As with previous findings, the nutrient data suggest that Walker Lake is strongly nitrogen-limited, even as water levels have declined in the lake.

Walker Lake has generally poor water quality, with very high TDS, alkaline pH and major-ion chemistry dominated by sodium, sulfate, chloride, and carbonate. The total dissolved solids increased during 2007 from 15,000 mg/L in April to 15,900 mg/L in December.

Phytoplankton blooms continue to reach high biomass levels, as predicted from the elevated nutrient content (total phosphorus) of the lake. High P:N ratios and alkaline conditions are likely to remain primary drivers of cyanobacterial biomass dominance in the phytoplankton. Furthermore, since microbial nitrogenase complexes are sensitive to oxygen, N-limitation may be the major driver supporting dramatic accumulations of *Synechococcus* spp. in the anaerobic hypolimnion.

The large odiferous blooms that have occurred during the past two years are noteworthy, as these surface accumulations are likely to have detrimental affects on the lake's beneficial uses (including recreation and use by waterfowl). Of particular note and concern is that projections of lower lake levels in the face of continued internal nutrient loading sets the stage whereby internal loading provides equivalent or increasing amounts of phosphorus to a decreasing volume of upper mixed-layer water. Thus, large blooms in 2007 and 2008 may be indicative of the beginning stages in a hypereutrophic, positive-feedback process that can detrimentally affect lakes as their volume to benthic-surface-area ratio decreases.

Walker Lake also contains a diverse alkaliphilic microbial community, the activity of which can affect oxygen concentrations and the habitability of portions of the water column for fish. Since microbial and microalgal biogeochemistry controls many of the factors that define ecosystem function and potential—ranging from the availability of limiting nutrients (N), to toxin production (H_2S, NH_3) and trophic status—it is evident that understanding these processes may be essential for predicting effects and developing sound management strategies as lake conditions continue to change.

An ecological model was calibrated and applied to Walker Lake to investigate limnological impacts of different Walker River streamflow scenarios. Because detailed streamflow scenarios based on water acquisition options were not yet available, the utility of the model was demonstrated by simulating high- and low-flow scenarios, based on historical streamflow data. These results provided a basis for assessing the potential changes in lake water quality as new water acquisitions are introduced. However, further model refinement is necessary before forecasts of ecological conditions can be produced for specific flow scenarios. The model results were consistent with the recommended minimum Walker River flow of 112,000 acre-ft (Thomas, 1995) for sustaining the existing water surface elevation.

Data analysis, modeling results and professional judgment each have contributed to several recommendations for longer-term monitoring that would track environmental conditions in the lake over time, including specific indicators important to improve diagnostic models and other decision tools used for Walker Lake assessment and management. This work should be considered the starting point for further considerations of management approaches and it highlights the need for a comprehensive science and monitoring plan to support targeted research. Ultimately, with continued development, the Walker Lake ecological model could help to optimize future water deliveries in terms of lake benefits, which is critical for developing sound management strategies.

Acknowledgements

We would like to thank the Nevada Division of Environmental Protection (NDEP), the Nevada Department of Wildlife (NDOW), the U.S. Geological Survey (USGS), and the Walker Lake Fisher Improvement Team (WLFIT) for their assistance in providing historic and contemporary data for the Walker Lake database and the ecological model. In addition, we appreciate the useful comments from three anonymous reviewers.

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APPENDIX. LIST OF PARAMETERS INCLUDED IN WALKER LAKE DATABASE.

Parameter Name	Parameter Description
General Constituents:	
Baro Press	Barometric pressure
BOD	Biological oxygen demand
COD	Chemical oxygen demand
Color	Color
Conductivity	Conductivity measured in field
Conductivity lab	Conductivity measured in lab
DO	Dissolved oxygen
DO %sat	Dissolved oxygen as % sat
DO chrg	DO qa/qc field parameter
Hardness	Hardness as $CaCO_3$
Hydroxide	Hydroxide
Lake Depth	Approximate depth to bottom
Lake Level	Elevation of lake level above MSL
Lake Volume	Reservoir storage in ac-ft
ORP	Oxidation-reduction potential
pH	pH measured in the field
pH lab	pH measured in the lab
pH mV	pH millivolt from field measurements
Salinity	
SAR TR	Sodium absorption ratio total recoverable
Secchi	Depth of clarity with Secchi disk
SS	Suspended solids
TDS	Total dissolved solids / residue on evaporation
TDScond	TDS from conductivity 0.7811(cond)-1035.4
TDSevap	TDS corrected for evaporation HCO_3 x 0.4917
Temperature	Temperature measured in the field
Temperature lab	Temperature measured in the lab
TSS	Total suspended solids
Turbidity	Turbidity
Major Ions:	
Alk-bicarb-$CaCO_3$	Alkalinity bicarbonate as $CaCO_3$
Alk-carb-$CaCO_3$	Alkalinity carbonate as $CaCO_3$
Alk-Tot-$CaCO_3$	Total alkalinity as $CaCO_3$

Parameter Name	Parameter Description
Br	Bromide
Ca	Calcium
Ca TR	Calcium total recoverable
Cl	Chloride
CO_3	Carbonate
F	Fluoride
F TR	Fluoride total recoverable
Hardness TR	Hardness as $CaCO_3$ total recoverable
HCO_3	Bicarbonate
K	Potassium
Mg	Magnesium
Mg TR	Magnesium total recoverable
Na	Sodium
Na TR	Sodium total recoverable
SAR	Sodium absorption ratio
SiO_2	Silica
SO_4	Sulfate
Trace Elements:	
Ag	Silver
Al	Aluminum
As	Arsenic
As TR	Arsenic total recoverable
B	Boron
B TR	Boron total recoverable
Ba	Barium
Ba TR	Barium total recoverable
Be	Beryllium
Be TR	Beryllium total recoverable
Cd	Cadmium
Cd TR	Cadmium total recoverable
Co	Cobalt
Cr	Chromium
Cr TR	Chromium total recoverable
Cu	Copper
Cu TR	Copper total recoverable
Fe	Iron
Fe TR	Iron total recoverable
Hg	Mercury
Hg TR	Mercury total recoverable
Mn	Manganese
Mn TR	Manganese total recoverable
Mo	Molybdenum
Mo TR	Molybdenum total recoverable
Ni	Nickel
Ni TR	Nickel total recoverable
Pb	Lead
Pb TR	Lead total recoverable
S	Sulfide
Sb	Antimony

Parameter Name	Parameter Description
Sb TR	Antimony total recoverable
Se	Selenium
Se TR	Selenium total recoverable
Sn	Tin
Sr	Strontium
Tl	Thallium
Tl TR	Thallium total recoverable
U	Uranium
U TR	Uranium total recoverable
U238	Uranium 238 isotope
U238 TR	Uranium 238 isotope total recoverable
V	Vanadium
V TR	Vanadium total recoverable
Zn	Zinc
Zn TR	Zinc total recoverable
Nutrients:	
Chl-a	Chlorophyll-a
DKN	Dissolved Kjeldahl nitrogen (TKN soluble)
DOC	Dissolved organic carbon
N T	Total nitrogen
N T max	Maximum total nitrogen
N T min	Minimum total nitrogen
N TIN	Total inorganic nitrogen
N TON	Total organic nitrogen
NH3-N	Un-ionized ammonia as nitrogen
NH4	Ammonia
NH4-N	Ammonia as nitrogen
NO2-N	Nitrite as nitrogen
NO3	Nitrate
NO3+NO2-N	Nitrate+nitrite as nitrogen
NO3-N	Nitrate as nitrogen
OPO4	Dissolved reactive phosphorus
P D	Dissolved phosphorus (total soluble phosphorus)
P T	Total phosphorus
PAR	Photosynthetically active radiation
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
Bacteria:	
Bacteria Total	Total bacteria
Fecal Strep	Fecal strep bacteria
Fecal Coli	Fecal coliform bacteria
T Coli	Total coliform bacteria
E Coli	E coli bacteria
Others:	
MPN-SRB	Sulfate reducing bacteria (most probable number)
Cell counts (DC)	Direct counts w/ DAPI (4',6-diamidino-2-phenylindole)
Cell counts (FC)	Flow cytometry
MPN-AH	Aerobic heterotrophs (most probable number)
MPN-F	Fermenters (most probable number)

Parameter Name	Parameter Description
MPN-FeRB	Iron reducing bacteria (most probable number)
MPN-S	Sulfur reducers (most probable number)
N fixation	Nitrogen fixation µmol
PC-R2A	Aerobic heterotrophs (plate count)
PC-S	Sulfur reducers (plate count)
Phospholipid	Phospholipid fatty acid analysis
Zooplankton E	Enumeration, C and N isotope and fatty acid
Zooplankton Stoi	Stoichiometry (C, N, and P)
Fatty Acid	µg/mg C or µg/mg dw
MPN-NR	Nitrate reducers (most probable number)
Profiles:	
Conductivity	Measured at site during profile
DO	Measured at site during profile
DO % sat	Measured at site during profile
ORP	Measured at site during profile
PAR	Measured at site during profile
pH	Measured at site during profile
Salinity	Measured at site during profile
TDS	Measured at site during profile
Temperature	Measured at site during profile

A.2: USER MANUAL: WALKER LAKE DATABASE VERSION 1.0

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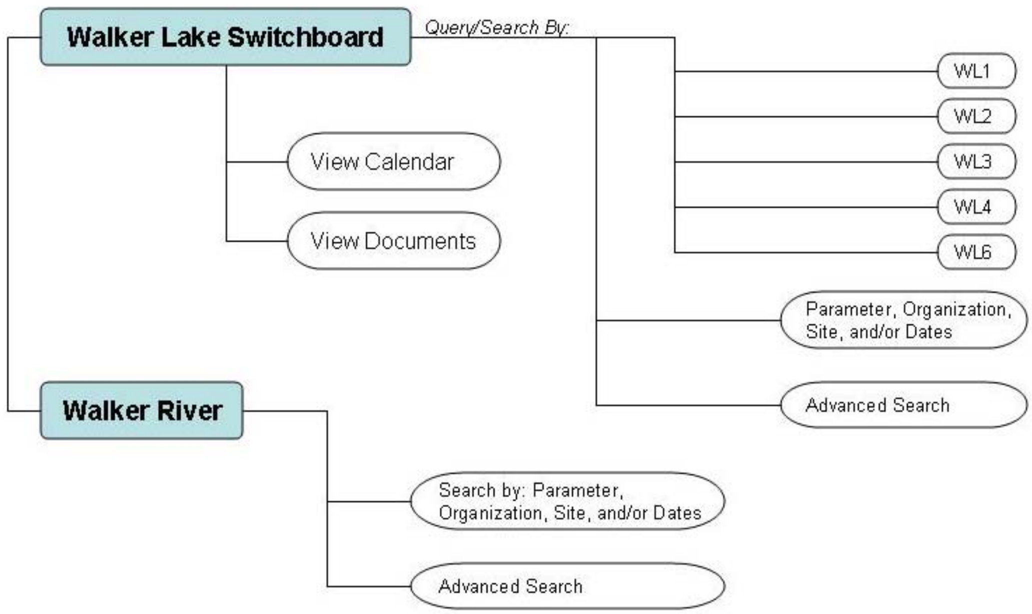
INTRODUCTION

The database and documentation are designed for the Walker Lake Task 6 Implementation Plan. The following documentation is designed to be a simple user's manual of the database as designed for the Walker Basin project. Users familiar with Microsoft Access™ can operate the database by using the existing tables and by building their own queries. Those unfamiliar with Microsoft™ Access will find explanation in the steps below on how to build their own queries.

Data were obtained from sources including: the Nevada Division of Environmental Protection (NDEP), the Nevada Department of Wildlife (NDOW), the U.S. Geological Survey (USGS), the Desert Research Institute (DRI), and the University of Nevada, Reno (UNR). Contact information is given in the appendix. (Special thanks go to these organizations and their staff for their assistance and provision of data.) Some organizations have ongoing sampling programs at Walker Lake; at the time of writing, data in the database were the most currently available. Though the project emphasized data collection for the lake, some data for Walker River were also entered into the database.

The overall database structure considered compilation of information and efficient queries. Data for Walker Lake were diverse with respect to factors including: time sampled, location sampled, groups collecting samples, and physical parameters sampled. Since so many organizations were represented, the format of data varied widely. For the data and database to be a useful tool, structure of the database considered questions that users might ask. Conducting queries to answer such questions required the database to be relational and for the data to be normalized.

A relational database structure allows data to be searched by various combinations of factors, such as time and parameter (was chloride tested in March?); group, location, and time (did DRI collect samples at WL2 in 2007?); or all available records for a parameter (conductivity since the lake has been sampled). Normalization of data is necessary to construct a relational database. Normalization also increases database efficiency, minimizes logical and structural problems, and decreases duplication of information. Figure 1 is a basic flow chart of the database structure.

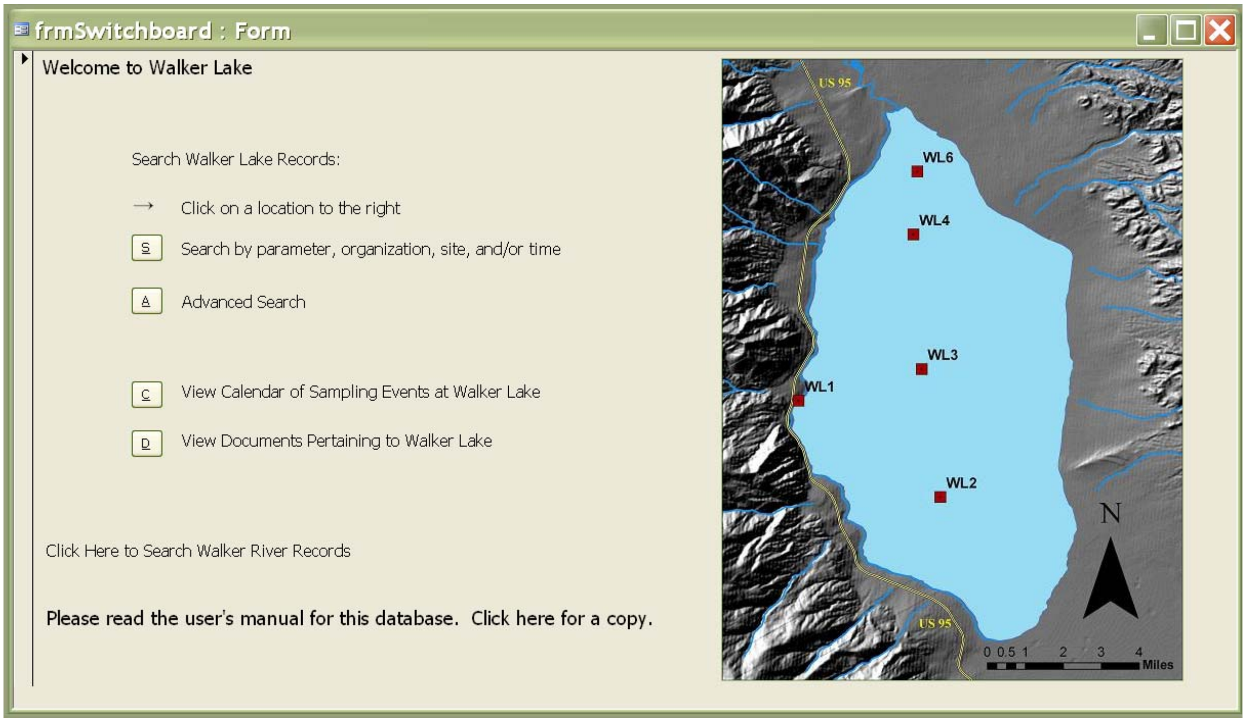


Basic flow chart of the database structure.

SWITCHBOARD

The Switchboard automatically launches when the database is opened. From the switchboard, the following can be done:

- Query for WL1, WL2, WL3, WL4, and/or WL6 by clicking on those sites
- Launch a form to query by parameter, organization, site and/or time
- Launch an advanced query
- View a calendar of sampling events
- View documents pertaining to the lake
- Click to search Walker River Records



QUERIES/SEARCHES

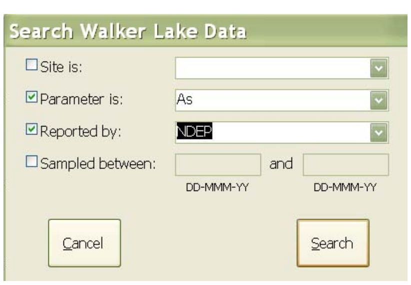
Search by Parameter, Organization, Site, and/or Time

Clicking the *Search by Parameter, Organization, Site, and/or Time* button will launch the search form seen below. The user checks the relevant boxes and makes selections from corresponding drop-down menus. In the case of searching by a date, the user must enter the date in the format DD-MMM-YY. The following example depicts a search for all arsenic (As) records reported by NDEP:

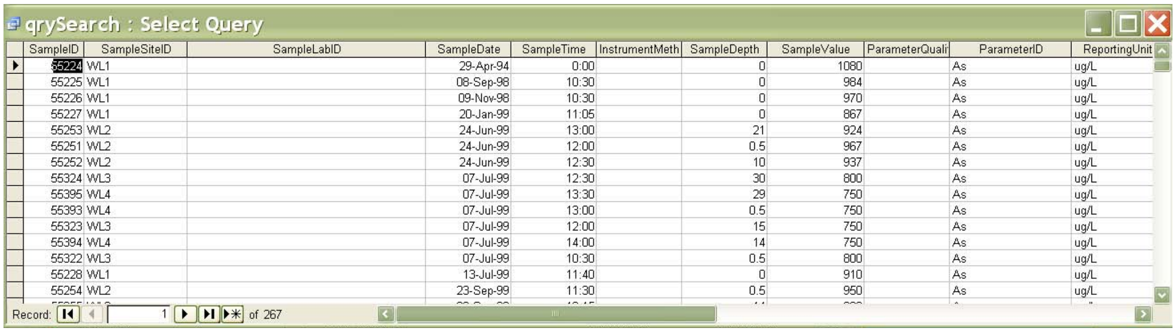
Check *Parameter is* box; select *As* from drop-down menu

Check *Reported by* box; select *NDEP* from drop-down menu

Click *Search*



The search yields the following records.



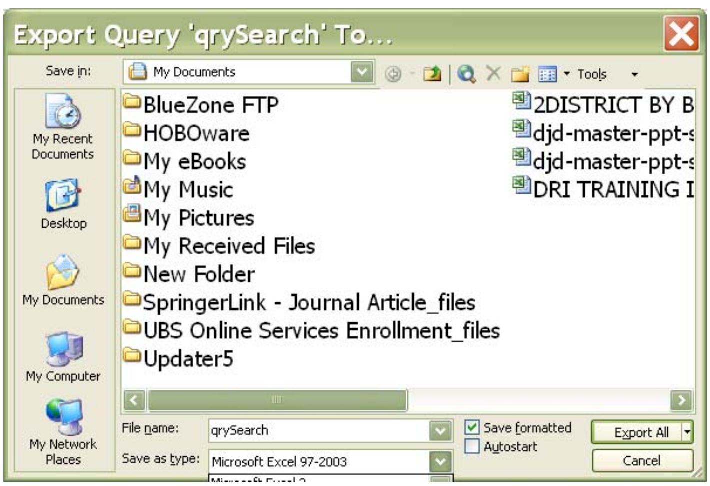
SampleID	SampleSiteID	SampleLabID	SampleDate	SampleTime	InstrumentMeth	SampleDepth	SampleValue	ParameterQuali	ParameterID	ReportingUnit
55224	WL1		29-Apr-94	0:00		0	1080		As	ug/L
55225	WL1		08-Sep-98	10:30		0	984		As	ug/L
55226	WL1		09-Nov-98	10:30		0	970		As	ug/L
55227	WL1		20-Jan-99	11:05		0	867		As	ug/L
55253	WL2		24-Jun-99	13:00		21	924		As	ug/L
55251	WL2		24-Jun-99	12:00		0.5	967		As	ug/L
55252	WL2		24-Jun-99	12:30		10	937		As	ug/L
55324	WL3		07-Jul-99	12:30		30	800		As	ug/L
55395	WL4		07-Jul-99	13:30		29	750		As	ug/L
55393	WL4		07-Jul-99	13:00		0.5	750		As	ug/L
55323	WL3		07-Jul-99	12:00		15	750		As	ug/L
55394	WL4		07-Jul-99	14:00		14	750		As	ug/L
55322	WL3		07-Jul-99	10:30		0.5	800		As	ug/L
55228	WL1		13-Jul-99	11:40		0	910		As	ug/L
55254	WL2		23-Sep-99	11:30		0.5	950		As	ug/L

To export these records (or any records resulting from any query), go to the *File* menu.

Click *Export*.

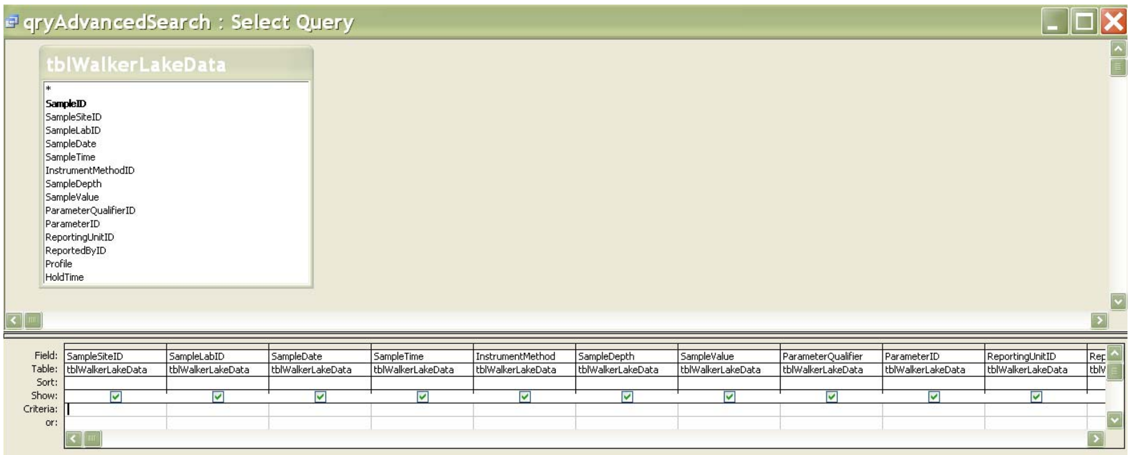
Under *Save as Type* choose Microsoft Excel 97-2003 (or other format) and be sure to check the box *Save Formatted*.

Note: The date field exports a two-digit year. The user may highlight the date column and select “Format, Cells” and choose a date format with four digits.



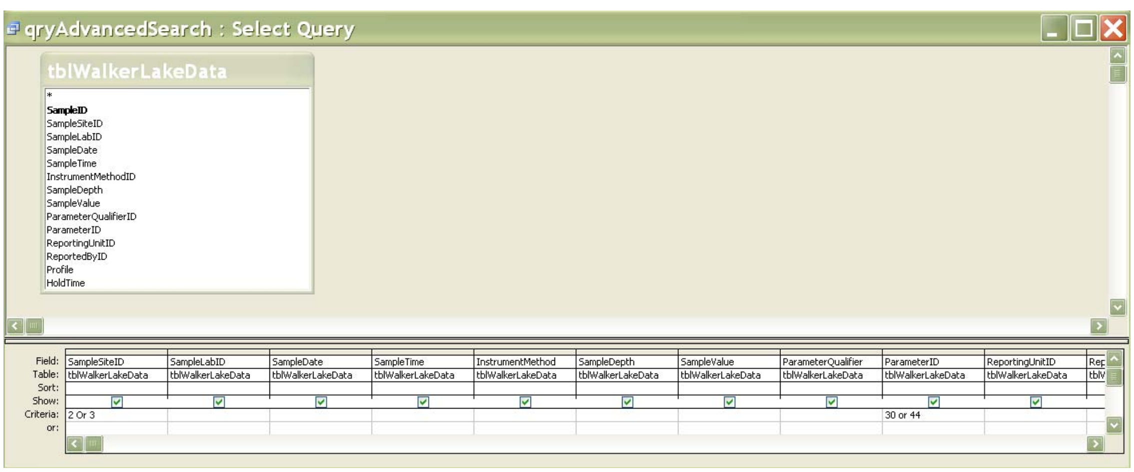
Advanced Query/Search

In an advanced search query, the user can enter multiple choices in search fields. Clicking the *Advanced Search* button launches the query seen below. The following example depicts a search for records from WL2 and WL3 for both fluoride (F) and conductivity.

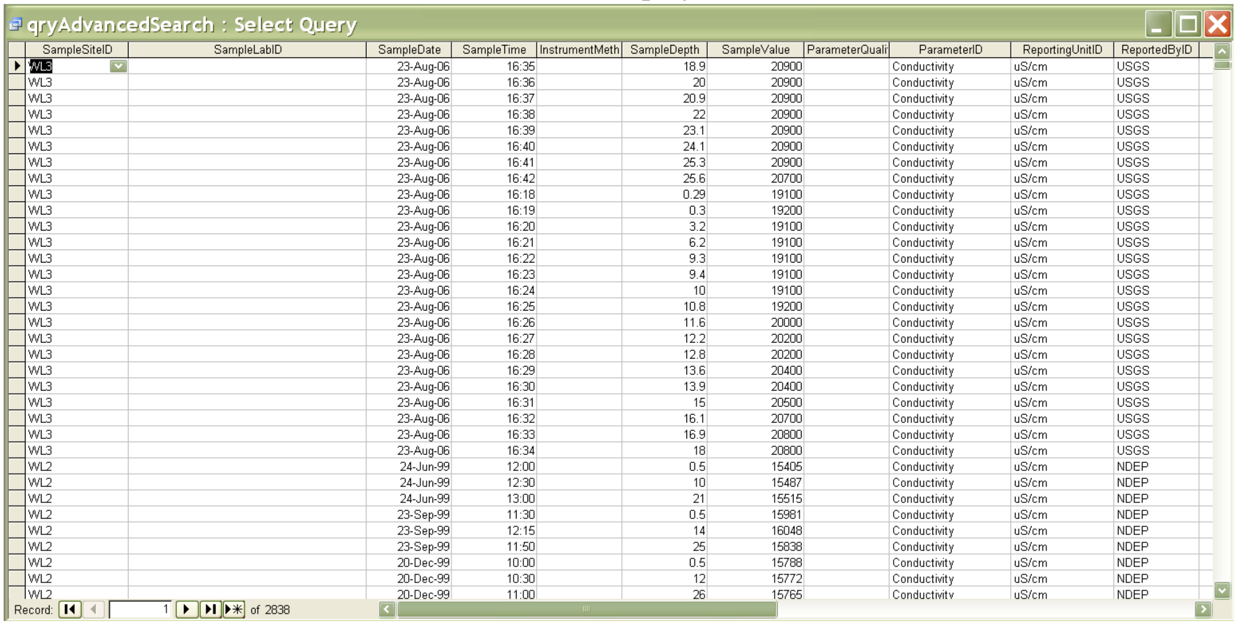


In the criteria space for SampleSiteID, enter "2 or 3" (see numerical list of sites in the Appendix) to represent WL2 and WL3.

In the criteria space for ParameterID, enter "30 or 44" (see numerical list of parameters in the Appendix) to represent conductivity and fluoride.



Under the *View* menu, click *Datasheet view* to display the search results.



qryAdvancedSearch : Select Query

SampleSiteID	SampleLabID	SampleDate	SampleTime	InstrumentMeth	SampleDepth	SampleValue	ParameterQuali	ParameterID	ReportingUnitID	ReportedByID
WL3		23-Aug-06	16:35		18.9	20900		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:36		20	20900		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:37		20.9	20900		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:38		22	20900		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:39		23.1	20900		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:40		24.1	20900		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:41		25.3	20900		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:42		25.6	20700		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:18		0.29	19100		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:19		0.3	19200		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:20		3.2	19100		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:21		6.2	19100		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:22		9.3	19100		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:23		9.4	19100		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:24		10	19100		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:25		10.8	19200		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:26		11.6	20000		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:27		12.2	20200		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:28		12.8	20200		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:29		13.6	20400		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:30		13.9	20400		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:31		15	20500		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:32		16.1	20700		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:33		16.9	20800		Conductivity	uS/cm	USGS
WL3		23-Aug-06	16:34		18	20800		Conductivity	uS/cm	USGS
WL2		24-Jun-99	12:00		0.5	15405		Conductivity	uS/cm	NDEP
WL2		24-Jun-99	12:30		10	15487		Conductivity	uS/cm	NDEP
WL2		24-Jun-99	13:00		21	15515		Conductivity	uS/cm	NDEP
WL2		23-Sep-99	11:30		0.5	15981		Conductivity	uS/cm	NDEP
WL2		23-Sep-99	12:15		14	16048		Conductivity	uS/cm	NDEP
WL2		23-Sep-99	11:50		25	15838		Conductivity	uS/cm	NDEP
WL2		20-Dec-99	10:00		0.5	15788		Conductivity	uS/cm	NDEP
WL2		20-Dec-99	10:30		12	15772		Conductivity	uS/cm	NDEP
WL2		20-Dec-99	11:00		26	15765		Conductivity	uS/cm	NDEP

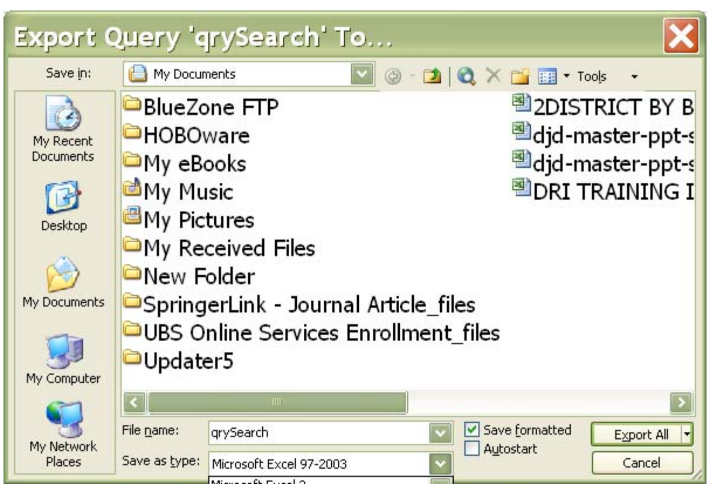
Record: 1 of 2838

To export these records (or any records resulting from any query), go to the *File* menu.

Click *Export*.

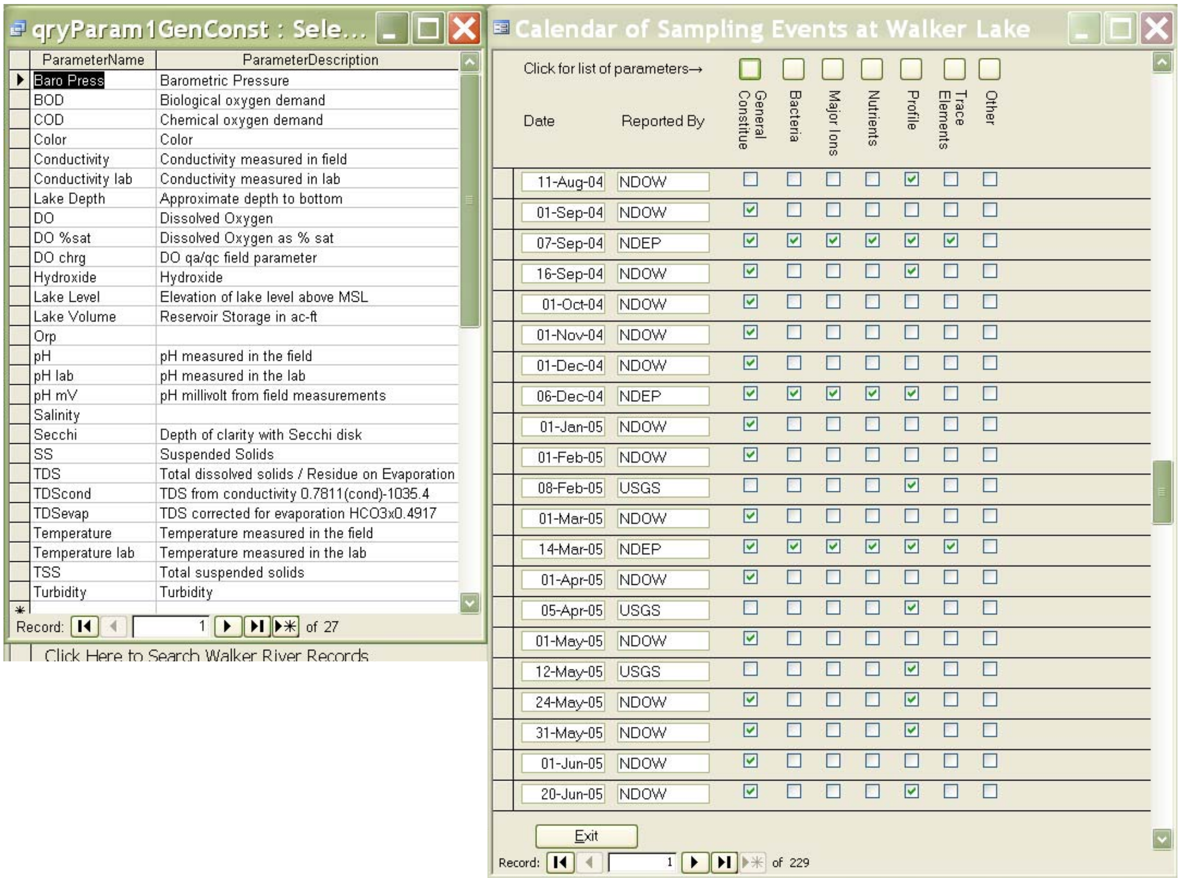
Under *Save as Type* choose Microsoft Excel 97-2003 (or other format) and be sure to check the box *Save Formatted*.

Note: The date field exports a two-digit year. The user may highlight the date column and select "Format, Cells" and choose a date format with four digits.



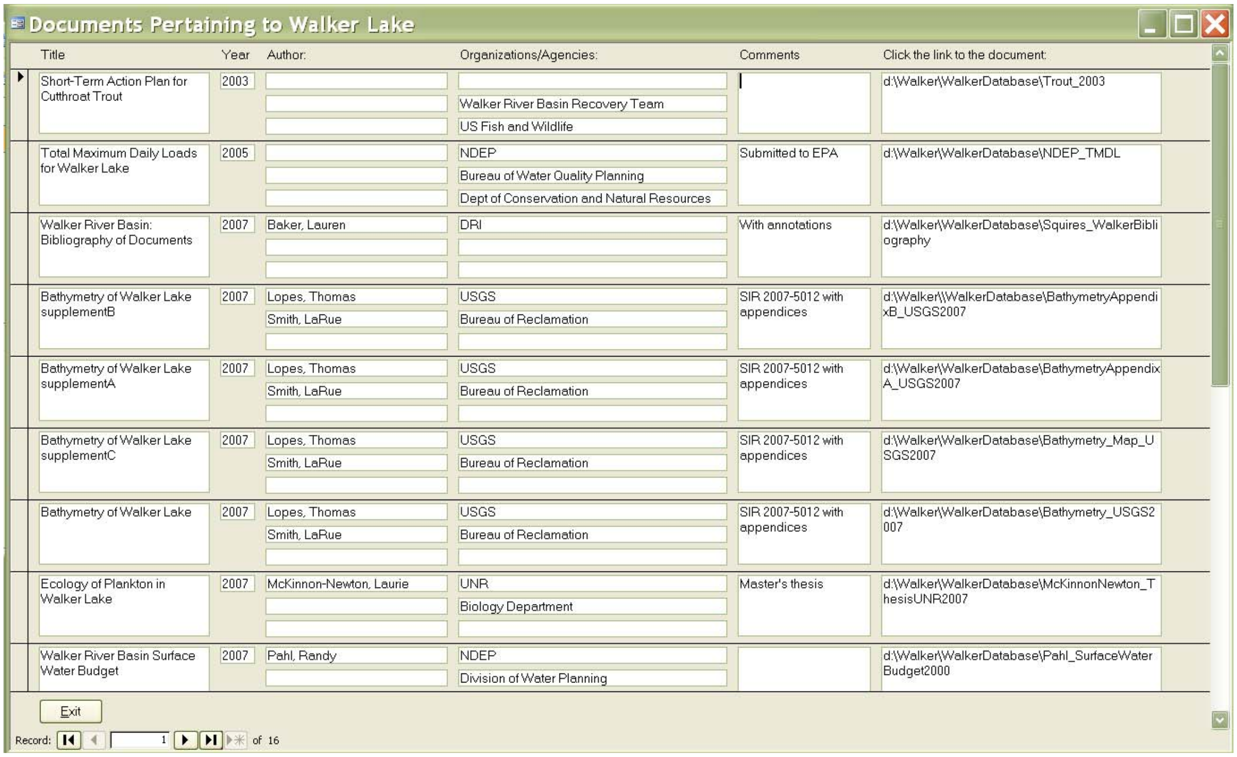
CALENDAR

Clicking the calendar button launches the calendar form. In the interest of brevity, parameters were organized into groups: general constituents, bacteria, major ions, nutrients, trace elements, and other. The user can view lists of parameters included in groups by clicking on the relevant button. The example below shows the list of general constituents. All lists are included in the appendix to this report.



DOCUMENTS PERTAINING TO WALKER LAKE

Clicking the *View Documents Pertaining to Walker Lake* button launches a list of documents included with the database. Clicking the link opens the document outside of the database.


Documents Pertaining to Walker Lake

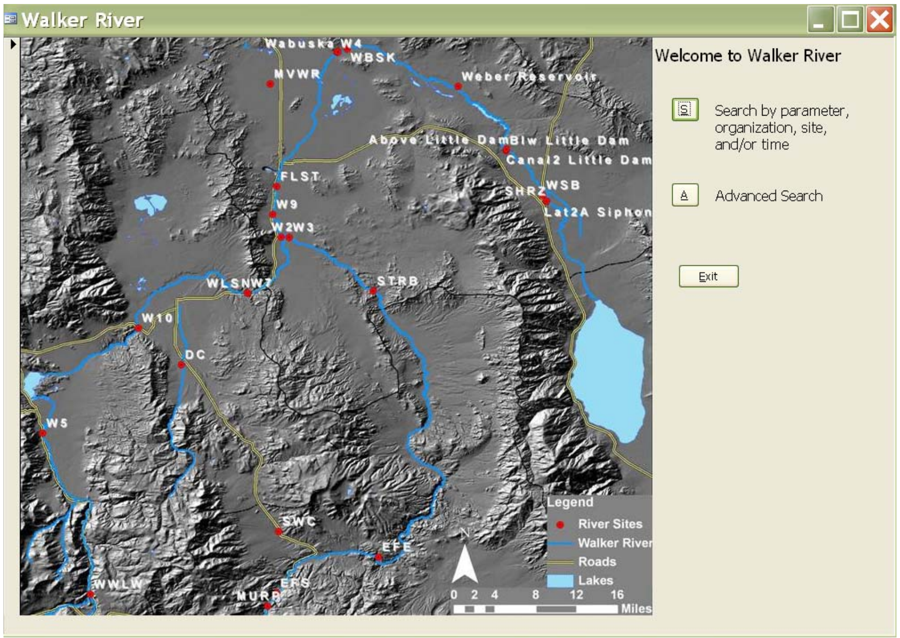
Title	Year	Author:	Organizations/Agencies:	Comments	Click the link to the document:
Short-Term Action Plan for Cutthroat Trout	2003		Walker River Basin Recovery Team; US Fish and Wildlife		d:\Walker\WalkerDatabase\Trout_2003
Total Maximum Daily Loads for Walker Lake	2005		NDEP; Bureau of Water Quality Planning; Dept of Conservation and Natural Resources	Submitted to EPA	d:\Walker\WalkerDatabase\NDEP_TMDL
Walker River Basin: Bibliography of Documents	2007	Baker, Lauren	DRI	With annotations	d:\Walker\WalkerDatabase\Squires_WalkerBibliography
Bathymetry of Walker Lake supplementB	2007	Lopes, Thomas; Smith, LaRue	USGS; Bureau of Reclamation	SIR 2007-5012 with appendices	d:\Walker\\WalkerDatabase\BathymetryAppendixB_USGS2007
Bathymetry of Walker Lake supplementA	2007	Lopes, Thomas; Smith, LaRue	USGS; Bureau of Reclamation	SIR 2007-5012 with appendices	d:\Walker\WalkerDatabase\BathymetryAppendixA_USGS2007
Bathymetry of Walker Lake supplementC	2007	Lopes, Thomas; Smith, LaRue	USGS; Bureau of Reclamation	SIR 2007-5012 with appendices	d:\Walker\WalkerDatabase\Bathymetry_Map_USGS2007
Bathymetry of Walker Lake	2007	Lopes, Thomas; Smith, LaRue	USGS; Bureau of Reclamation	SIR 2007-5012 with appendices	d:\Walker\WalkerDatabase\Bathymetry_USGS2007
Ecology of Plankton in Walker Lake	2007	McKinnon-Newton, Laurie	UNR; Biology Department	Master's thesis	d:\Walker\WalkerDatabase\McKinnonNewton_ThesisUNR2007
Walker River Basin Surface Water Budget	2007	Pahl, Randy	NDEP; Division of Water Planning		d:\Walker\WalkerDatabase\Pahl_SurfaceWaterBudget2000

Exit

Record: 1 of 16

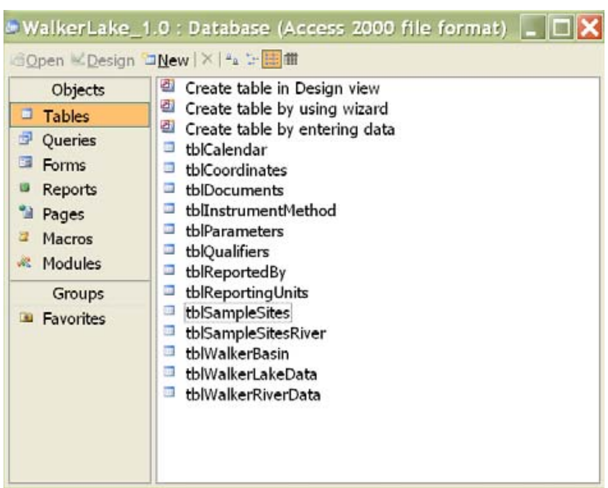
WALKER RIVER RECORDS

By clicking anywhere on the text *Click Here to Search Walker River Records*, the user will open a new form. Shown below, the form has two options for searching Walker River records (clicking on sites is not an option for Walker River Records). These searches operate similarly to those for Walker Lake, so please see previous sections as to their use.



TABLES

Users can also peruse records by viewing the tables. This can be done by selecting *Tables* on the main menu of Microsoft™ Access. This is typically found to the left and behind the Switchboard in the Microsoft™ Access desktop, or by going to the *Window* menu and selecting "WalkerLake1.0: Database (Access 2000 file format).



Open the table "tblSampleSites" by double-clicking on its name. Additional information, including comments, site description, and location (GPS coordinates), is listed.

tblSampleSites : Table

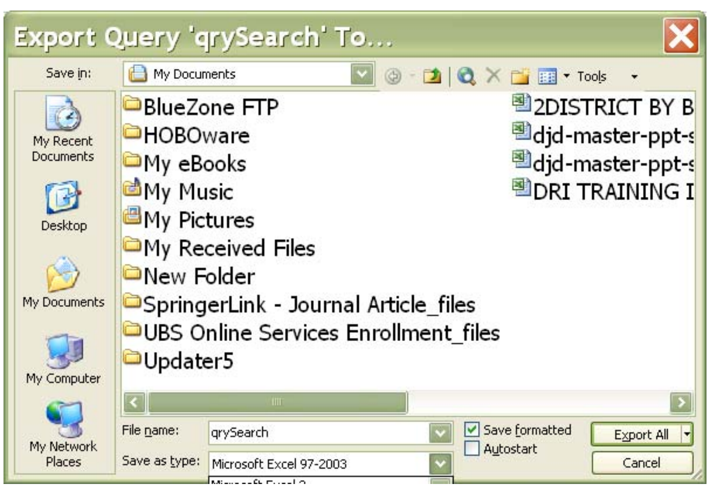
SampleSiteID	LocationID	SampleSite	SampleSiteDescription	LatDD	LongDD	utmE	utmN	SampleSiteComments
1	Walker Lake	WL1	Walker Lake Sportsman's Beach Boat Dock	38.687833	-118.768833	346158	4283621	NDEP coordinates, NAD83 UT
2	Walker Lake	WL2	Walker Lake 2 south	38.650833	-118.714702	350789	4279425	NDEP coordinates, NAD83 UT
3	Walker Lake	WL3	Walker Lake 3 center	38.7	-118.721798	350274	4284893	NDEP coordinates, NAD83 UT
4	Walker Lake	WL4	Walker Lake 4 north	38.751703	-118.724996	350104	4290636	NDEP coordinates, NAD83 UT
5	Walker Lake	WL5	Walker Lake 5					
6	Walker Lake	WL6	Walker Lake 6 river mouth	38.7759	-118.72353	350282	4293319	NDEP coordinates, NAD83 UT
7	Walker Lake	WLET	Walker Lake ET Station (1m depth)	38.745222	-118.719167	350697	4289907	USGS coordinates, NAD83 UT
8	Walker Lake	WLLS	Walker Lake near Hawthorne	38.676667	-118.771111	345935	4282385	USGS coordinates, NAD83 UT
11	Walker Lake	WLWC	Walker Lake - West Side Cliffs	38.672389	-118.767917	346204	4281905	USGS coordinates, NAD83 UT
12	Walker Lake	WLP1	Walker Lake - Observation Point 1 USGS	38.665083	-118.726278	349811	4281025	USGS coordinates, NAD83 UT
13	Walker Lake	WLP2	Walker Lake - Observation Point 2	38.660306	-118.722806	350104	4280490	USGS coordinates, NAD83 UT
14	Walker Lake	WLP3	Walker Lake – Observation Point 3	38.671194	-118.712722	351004	4281681	USGS coordinates, NAD83 UT
15	Walker Lake	WLP4	Walker Lake – Observation Point 4	38.701083	-118.691333	352926	4284964	USGS coordinates, NAD83 UT
16	Walker Lake	WLWL	Walker Lake - Town of Walker Lake	38.648472	-118.747639	347918	4279217	USGS coordinates, NAD83 UT
17	Walker Lake	WLRC	Walker Lake - Rose Creek Alluvial Fan	38.614944	-118.708389	351264	4275432	USGS coordinates, NAD83 UT
18	Walker Lake	WLR2	Walker Lake – Rose Creek Alluvial Fan 2	38.61125	-118.705083	351544	4275017	USGS coordinates, NAD83 UT
19	Walker Lake	WLSE	Walker Lake - South End	38.614028	-118.701889	351828	4275320	USGS coordinates, NAD83 UT
20	Walker Lake	WLBR	Walker Lake - Bullrush very South End	38.608056	-118.701444	351855	4274656	USGS coordinates, NAD83 UT
21	Walker Lake	WLVB	Walker Lake - Cottonwood Valve Box 14	38.622639	-118.733361	349106	4276327	USGS coordinates, NAD83 UT
22	Walker Lake	WLA		38.783867	-118.722967	350347	4294202	DRI coordinates, NAD83 UTM1
23	Walker Lake	WLB		38.7823	-118.721067	350509	4294025	DRI coordinates, NAD83 UTM1
24	Walker Lake	WLC		38.7642	-118.725767	350063	4292024	DRI coordinates, NAD83 UTM1
25	Walker Lake	WLD		38.777583	-118.72205	350414	4293504	DRI coordinates, NAD83 UTM1
26	Walker Lake	WLE		38.775167	-118.7201	350578	4293233	DRI coordinates, NAD83 UTM1
27	Walker Lake	WLF		38.780133	-118.720933	350517	4293784	DRI coordinates, NAD83 UTM1
28	Walker Lake	WLG		38.782067	-118.721167	350499	4293999	DRI coordinates, NAD83 UTM1
29	Walker Lake	WLH		38.783717	-118.718367	350747	4294179	DRI coordinates, NAD83 UTM1
30	Walker Lake	WLI		38.780883	-118.715933	350953	4293860	DRI coordinates, NAD83 UTM1
31	Walker Lake	WLJ		38.7793	-118.712917	351210	4293680	DRI coordinates, NAD83 UTM1
32	Walker Lake	WLK		38.783333	-118.725267	350147	4294147	DRI coordinates, NAD83 UTM1
33	Walker Lake	WLL		38.7809	-118.728383	349872	4293881	DRI coordinates, NAD83 UTM1
34	Walker Lake	WLM		38.778833	-118.72975	349748	4293656	DRI coordinates, NAD83 UTM1
35	Walker Lake	WLPE		38.718367	-118.7212	350364	4286930	DRI coordinates, NAD83 UTM1
46	Walker Lake	NDOW_Station	Beutel- approx btwn WL3 and WL1					No known coordinates
47	Walker Lake	WL01_042707	DRI site on 04/27/2007	38.6837	-118.768067	346215	4283160	DRI coordinates, NAD83 UTM1
49	Walker Lake	WL02_042707	DRI site on 04/27/2007	38.66365	-118.757	347135	4280917	DRI coordinates, NAD83 UTM1
50	Walker Lake	WL03_042707	DRI site on 04/27/2007	38.661017	-118.753317	347450	4280619	DRI coordinates, NAD83 UTM1
51	Walker Lake	WL04_042707	DRI site on 04/27/2007	38.65785	-118.750283	347707	4280263	DRI coordinates, NAD83 UTM1
52	Walker Lake	WL05_042707	DRI site on 04/27/2007	38.648783	-118.7461	348052	4279249	DRI coordinates, NAD83 UTM1
53	Walker Lake	WL06_042707	DRI site on 04/27/2007	38.643567	-118.749117	347778	4278675	DRI coordinates, NAD83 UTM1

Record: 1 of 44

To export these records (or any records depicted in any table), go to the *File* menu.

Click *Export*.

Under *Save as Type* choose Microsoft Excel 97-2003 (or other format) and be sure to check the box *Save Formatted*.



More information can be obtained by clicking on the + symbol on the left column of *tblSampleSites*. The example below is for WLVB, Cottonwood Valve Box 14, and shows samples collected at that site.

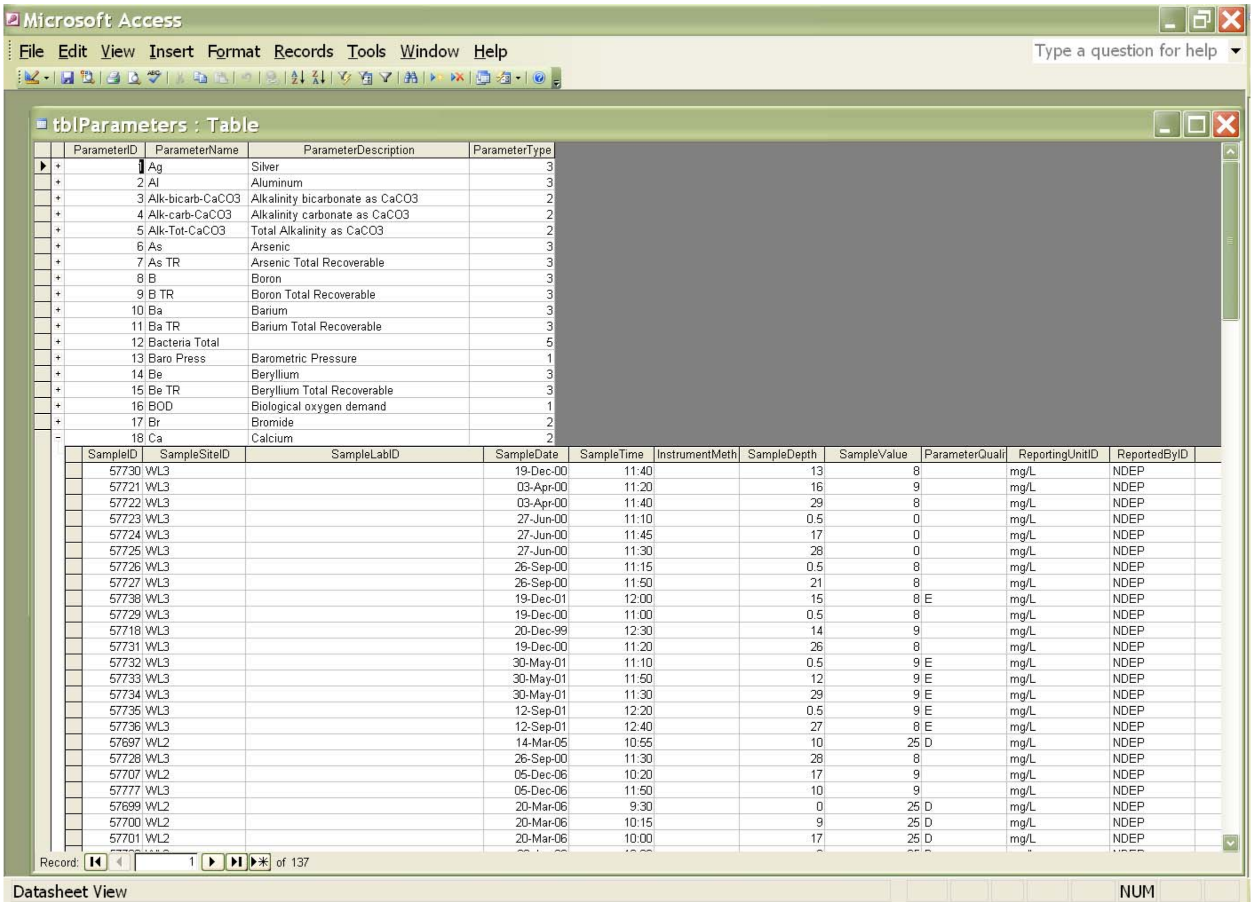
tblSampleSites : Table

	SampleSiteID	LocationID	SampleSite	SampleSiteDescription	LatDD	LongDD	utmE	utmN	SampleSiteComments
+	1	Walker Lake	WL1	Walker Lake Sportsman's Beach Boat Dock	38.687833	-118.768833	346158	4283621	NDEP coordinates, NAD83 UTM
+	2	Walker Lake	WL2	Walker Lake 2 south	38.650833	-118.714702	350789	4279425	NDEP coordinates, NAD83 UTM
+	3	Walker Lake	WL3	Walker Lake 3 center	38.7	-118.721798	350274	4284893	NDEP coordinates, NAD83 UTM
+	4	Walker Lake	WL4	Walker Lake 4 north	38.751703	-118.724996	350104	4290636	NDEP coordinates, NAD83 UTM
+	5	Walker Lake	WL5	Walker Lake 5					
+	6	Walker Lake	WL6	Walker Lake 6 river mouth	38.7759	-118.72353	350282	4293319	NDEP coordinates, NAD83 UTM
+	7	Walker Lake	WLET	Walker Lake ET Station (1m depth)	38.745222	-118.719167	350597	4289907	USGS coordinates, NAD83 UTM
+	8	Walker Lake	WLLS	Walker Lake near Hawthorne	38.676667	-118.771111	345935	4282385	USGS coordinates, NAD83 UTM
+	11	Walker Lake	WLWC	Walker Lake - West Side Cliffs	38.672389	-118.767917	346204	4281905	USGS coordinates, NAD83 UTM
+	12	Walker Lake	WLP1	Walker Lake - Observation Point 1 USGS	38.665083	-118.726278	349811	4281025	USGS coordinates, NAD83 UTM
+	13	Walker Lake	WLP2	Walker Lake - Observation Point 2	38.660306	-118.722806	350104	4280490	USGS coordinates, NAD83 UTM
+	14	Walker Lake	WLP3	Walker Lake – Observation Point 3	38.671194	-118.712722	351004	4281681	USGS coordinates, NAD83 UTM
+	15	Walker Lake	WLP4	Walker Lake – Observation Point 4	38.701083	-118.691333	352926	4284964	USGS coordinates, NAD83 UTM
+	16	Walker Lake	WLWL	Walker Lake - Town of Walker Lake	38.648472	-118.747639	347918	4279217	USGS coordinates, NAD83 UTM
+	17	Walker Lake	WLRC	Walker Lake - Rose Creek Alluvial Fan	38.614944	-118.708389	351264	4275432	USGS coordinates, NAD83 UTM
+	18	Walker Lake	WLR2	Walker Lake – Rose Creek Alluvial Fan 2	38.61125	-118.705083	351544	4275017	USGS coordinates, NAD83 UTM
+	19	Walker Lake	WLSE	Walker Lake - South End	38.614028	-118.701889	351828	4275320	USGS coordinates, NAD83 UTM
+	20	Walker Lake	WLBR	Walker Lake - Bullrush very South End	38.608056	-118.701444	351855	4274656	USGS coordinates, NAD83 UTM
-	21	Walker Lake	WLVB	Walker Lake - Cottonwood Valve Box 14	38.622639	-118.733361	349106	4276327	USGS coordinates, NAD83 UTM

SampleDate	SampleTime	InstrumentMeth	SampleDepth	SampleValue	ParameterQuali	ParameterID	ReportingUnitID	ReportedByID	Profile	HoldTime
23-Aug-06	11:52		0.32	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	11:53		0.32	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	11:54		0.34	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	11:55		1.3	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	11:56		1.3	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	11:57		1.3	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	11:58		2.3	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	11:59		2.3	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:00		3.3	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:01		3.3	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:02		4.2	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:03		4.2	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:04		5	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:05		5	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:06		6	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:07		6.8	665		Baro Press	mm Hg	USGS	☑	☐
23-Aug-06	12:08		6.8	665		Baro Press	mm Hg	USGS	☑	☐
08-Mar-07	15:07		0.1	667		Baro Press	mm Hg	USGS	☑	☐
08-Mar-07	15:08		0.5	667		Baro Press	mm Hg	USGS	☑	☐
08-Mar-07	15:09		1	667		Baro Press	mm Hg	USGS	☑	☐

Record: 15 of 156

Another example opens the table “*tblParameters*” to view all calcium (Ca) records stored within the database.



ParameterID	ParameterName	ParameterDescription	ParameterType
1	Ag	Silver	3
2	Al	Aluminum	3
3	Alk-bicarb-CaCO3	Alkalinity bicarbonate as CaCO3	2
4	Alk-carb-CaCO3	Alkalinity carbonate as CaCO3	2
5	Alk-Tot-CaCO3	Total Alkalinity as CaCO3	2
6	As	Arsenic	3
7	As TR	Arsenic Total Recoverable	3
8	B	Boron	3
9	B TR	Boron Total Recoverable	3
10	Ba	Barium	3
11	Ba TR	Barium Total Recoverable	3
12	Bacteria Total		5
13	Baro Press	Barometric Pressure	1
14	Be	Beryllium	3
15	Be TR	Beryllium Total Recoverable	3
16	BOD	Biological oxygen demand	1
17	Br	Bromide	2
18	Ca	Calcium	2

SampleID	SampleSiteID	SampleLabID	SampleDate	SampleTime	InstrumentMeth	SampleDepth	SampleValue	ParameterQuali	ReportingUnitID	ReportedByID
57730	WL3		19-Dec-00	11:40		13	8		mg/L	NDEP
57721	WL3		03-Apr-00	11:20		16	9		mg/L	NDEP
57722	WL3		03-Apr-00	11:40		29	8		mg/L	NDEP
57723	WL3		27-Jun-00	11:10		0.5	0		mg/L	NDEP
57724	WL3		27-Jun-00	11:45		17	0		mg/L	NDEP
57725	WL3		27-Jun-00	11:30		28	0		mg/L	NDEP
57726	WL3		26-Sep-00	11:15		0.5	8		mg/L	NDEP
57727	WL3		26-Sep-00	11:50		21	8		mg/L	NDEP
57738	WL3		19-Dec-01	12:00		15	8	E	mg/L	NDEP
57729	WL3		19-Dec-00	11:00		0.5	8		mg/L	NDEP
57718	WL3		20-Dec-99	12:30		14	9		mg/L	NDEP
57731	WL3		19-Dec-00	11:20		26	8		mg/L	NDEP
57732	WL3		30-May-01	11:10		0.5	9	E	mg/L	NDEP
57733	WL3		30-May-01	11:50		12	9	E	mg/L	NDEP
57734	WL3		30-May-01	11:30		29	9	E	mg/L	NDEP
57735	WL3		12-Sep-01	12:20		0.5	9	E	mg/L	NDEP
57736	WL3		12-Sep-01	12:40		27	8	E	mg/L	NDEP
57697	WL2		14-Mar-05	10:55		10	25	D	mg/L	NDEP
57728	WL3		26-Sep-00	11:30		28	8		mg/L	NDEP
57707	WL2		05-Dec-06	10:20		17	9		mg/L	NDEP
57777	WL3		05-Dec-06	11:50		10	9		mg/L	NDEP
57699	WL2		20-Mar-06	9:30		0	25	D	mg/L	NDEP
57700	WL2		20-Mar-06	10:15		9	25	D	mg/L	NDEP
57701	WL2		20-Mar-06	10:00		17	25	D	mg/L	NDEP

APPENDIX A.2.1. LIST OF CONTACTS FOR DATA INCLUDED IN THE WALKER LAKE AND RIVER DATABASE.

University of Nevada, Reno. Department of Natural Resources & Environmental Science. Mailstop 186. Knudtsen Resource Center, 1000 Valley Road, Reno, NV, 89512. (775) 784-6763 or (775) 784-4020. Fax; (775) 784-4583.

Desert Research Institute. Department of Hydrologic Sciences and Department of Earth and Ecosystem Sciences. 2215 Raggio Parkway, Reno, NV, 89512. (775) 673-7300

U.S. Geological Survey, Nevada Water Science Center. 2730 N. Deer Run Rd, Carson City, NV, 89701. (775) 887-7600. http://nevada.usgs.gov/walker/contactus.htm.

Nevada Division of Environmental Protection, Bureau of Water Quality Planning. 901 S Stewart Street, Suite 4001, Carson City, NV, 89701-5249. (775) 687-9444 http://ndep.nv.gov/bwqp/staff.htm.

Nevada Department of Wildlife, Headquarters. 1100 Valley road, Reno, NV 89512. (775) 688-1500. Fax: (775) 423-8171. ndowinfo@ndow.org .

APPENDIX A.2.2. LIST OF PARAMETERS AND CORRESPONDING NUMBERS FOR ADVANCED QUERIES.

Parameter ID	Parameter Name	Parameter Description
1	Ag	Silver
2	Al	Aluminum
3	Alk-bicarb-$CaCO_3$	Alkalinity bicarbonate as $CaCO_3$
4	Alk-carb-$CaCO_3$	Alkalinity carbonate as $CaCO_3$
5	Alk-Tot-$CaCO_3$	Total alkalinity as $CaCO_3$
6	As	Arsenic
7	As TR	Arsenic total recoverable
8	B	Boron
9	B TR	Boron total recoverable
10	Ba	Barium
11	Ba TR	Barium total recoverable
12	Bacteria Total	
13	Baro Press	Barometric pressure
14	Be	Beryllium
15	Be TR	Beryllium total recoverable
16	BOD	Biological oxygen demand
17	Br	Bromide
18	Ca	Calcium
19	Ca TR	Calcium total recoverable
20	Cd	Cadmium
21	Cd TR	Cadmium total recoverable
22	Cell counts (DC)	Direct counts w/ DAPI
23	Cell counts (FC)	Flow cytometry
24	Chl-a	Chlorophyll-a
25	Cl	Chloride
26	Co	Cobalt
27	CO3	Carbonate
28	COD	Chemical oxygen demand
29	Color	Color
30	Conductivity	Conductivity measured in field
31	Conductivity lab	Conductivity measured in lab
32	Cr	Chromium
33	Cr TR	Chromium total recoverable
34	Cu	Copper
35	Cu TR	Copper total recoverable
37	DKN	Dissolved Kjeldahl nitrogen (TKN soluble)
38	DO	Dissolved oxygen
39	DO %sat	Dissolved oxygen as % sat
40	DO chrg	DO qa/qc field parameter
41	DOC	Dissolved organic carbon
43	E Coli	E coli bacteria
44	F	Fluoride
45	F TR	Fluoride total recoverable
136	Fatty Acid	µg/mg C or µg/mg dw
46	Fe	Iron

Parameter ID	Parameter Name	Parameter Description
47	Fe TR	Iron total recoverable
48	Fecal Coli	Fecal coliform bacteria
49	Fecal Strep	Fecal strep bacteria
139	Flow	Surface flow measured at gage
50	Hardness	Hardness as $CaCO_3$
51	Hardness TR	Hardness as $CaCO_3$ total recoverable
52	HCO3	Bicarbonate
53	Hg	Mercury
54	Hg TR	Mercury total recoverable
55	Hydroxide	Hydroxide
56	K	Potassium
36	Lake Depth	Approximate depth to bottom
57	Lake Level	Elevation of lake level above MSL
58	Lake Volume	Reservoir storage in ac-ft
59	Mg	Magnesium
60	Mg TR	Magnesium total recoverable
61	Mn	Manganese
62	Mn TR	Manganese total recoverable
63	Mo	Molybdenum
64	Mo TR	Molybdenum total recoverable
65	MPN-AH	Aerobic heterotrophs (most probable number)
66	MPN-F	Fermenters (most probable number)
67	MPN-FeRB	Iron reducing bacteria (most probable number)
68	MPN-NR	Nitrate reducers (most probable number)
69	MPN-S	Sulfur reducers (most probable number)
70	MPN-SRB	Sulfate-reducing bacteria (most probable number)
71	N fixation	Nitrogen fixation μmol
72	N T	Total nitrogen
73	N T max	Maximum total nitrogen
74	N T min	Minimum total nitrogen
75	N TIN	Total inorganic nitrogen TIN
76	N TON	Total organic nitrogen
77	Na	Sodium
78	Na TR	Sodium total recoverable
79	NH3-N	Un-ionized ammonia as nitrogen
80	NH4	Ammonia
81	NH4-N	Ammonia as nitrogen
82	Ni	Nickel
83	Ni TR	Nickel total recoverable
84	NO2-N	Nitrite as nitrogen
85	NO3	Nitrate
86	NO3+NO2-N	Nitrate+nitrite as nitrogen
87	NO3-N	Nitrate as nitrogen
88	OPO4	Dissolved reactive phosphorus
89	ORP	Oxidation-reduction potential
42	P D	Dissolved phosphorus (total soluble phosphorus)
90	P T	Total phosphorus

Parameter ID	Parameter Name	Parameter Description
91	PAR	Photosynthetically active radiation
92	Pb	Lead
93	Pb TR	Lead total recoverable
94	PC-R2A	Aerobic heterotrophs (plate count)
95	PC-S	Sulfur reducers (plate count)
96	pH	pH measured in the field
97	pH lab	pH measured in the lab
98	pH mV	pH millivolt from field measurements
99	Phospholipid	Phospholipid fatty acid analysis
100	S	Sulfide
101	Salinity	
102	SAR	Sodium absorption ratio
103	SAR TR	Sodium absorption ratio total recoverable
104	Sb	Antimony
105	Sb TR	Antimony total recoverable
106	Se	Selenium
107	Se TR	Selenium total recoverable
108	Secchi	Depth of clarity with Secchi disk
109	SiO2	Silica
110	Sn	Tin
111	SO4	Sulfate
112	Sr	Strontium
113	SS	Suspended solids
114	T Coli	Total coliform bacteria
115	TDS	Total dissolved solids / residue on evaporation
116	TDScond	TDS from conductivity 0.7811(cond)-1035.4
117	TDSevap	TDS corrected for evaporation HCO_3 x 0.4917
118	Temperature	Temperature measured in the field
119	Temperature lab	Temperature measured in the lab
120	TKN	Total Kjeldahl nitrogen
121	Tl	Thallium
122	Tl TR	Thallium total recoverable
123	TOC	Total organic carbon
124	TSS	Total suspended solids
125	Turbidity	Turbidity
126	U	Uranium
127	U TR	Uranium total recoverable
128	U238	Uranium 238 isotope
129	U238 TR	Uranium 238 isotope total recoverable
130	V	Vanadium
131	V TR	Vanadium total recoverable
132	Zn	Zinc
133	Zn TR	Zinc total recoverable
134	Zooplankton E	Enumeration, C and N isotope and fatty acid
135	Zooplankton Stoi	Stoichiometry (C, N, and P)

APPENDIX A.2.3. LIST OF WALKER LAKE SITES AND CORRESPONDING NUMBERS FOR ADVANCED QUERIES.

SampleSiteID	SampleSite	SampleSiteDescription
1	WL1	Walker Lake Sportsman's Beach Boat Dock
2	WL2	Walker Lake 2 south
3	WL3	Walker Lake 3 center
4	WL4	Walker Lake 4 north
5	WL5	Walker Lake 5
6	WL6	Walker Lake 6 river mouth
7	WLET	Walker Lake ET Station (1-m depth)
8	WLLS	Walker Lake near Hawthorne
11	WLWC	Walker Lake - West Side Cliffs
12	WLP1	Walker Lake - Observation Point 1 USGS
13	WLP2	Walker Lake - Observation Point 2
14	WLP3	Walker Lake – Observation Point 3
15	WLP4	Walker Lake – Observation Point 4
16	WLWL	Walker Lake - Town of Walker Lake
17	WLRC	Walker Lake - Rose Creek Alluvial Fan
18	WLR2	Walker Lake – Rose Creek Alluvial Fan 2
19	WLSE	Walker Lake - South End
20	WLBR	Walker Lake - Bullrush very South End
21	WLVB	Walker Lake - Cottonwood Valve Box 14
22	WLA	DRI site
23	WLB	DRI site
24	WLC	DRI site
25	WLD	DRI site
26	WLE	DRI site
27	WLF	DRI site
28	WLG	DRI site
29	WLH	DRI site
30	WLI	DRI site
31	WLJ	DRI site
32	WLK	DRI site
33	WLL	DRI site
34	WLM	DRI site
35	WLPE	DRI site
46	NDOW_Station	Beutel- approx btwn WL3 and WL1
47	WL01_042707	DRI site on 04/27/2007
49	WL02_042707	DRI site on 04/27/2007
50	WL03_042707	DRI site on 04/27/2007
51	WL04_042707	DRI site on 04/27/2007
52	WL05_042707	DRI site on 04/27/2007
53	WL06_042707	DRI site on 04/27/2007
54	WL07_042707	DRI site on 04/27/2007
55	WL08_042707	DRI site on 04/27/2007
56	WL09_042707	DRI site on 04/27/2007
57	WL10_042707	DRI site on 04/27/2007

APPENDIX A.2.4. LIST OF REPORTING ORGANIZATIONS AND CORRESPONDING NUMBERS FOR ADVANCED QUERIES.

ReportedByID	ReportedBy	ReportedByDescription
1	USGS	U.S. Geological Survey
2	NDEP	Nevada Division of Environmental Protection
3	NDOW	Nevada Department of Wildlife
4	DRI	Desert Research Institutevision
5	UNR	University of Nevada, Reno
6	Beutel	State of the Lake
7	Historical	USGS historical records

APPENDIX A.2.5. LIST OF WALKER RIVER SITES AND CORRESPONDING NUMBERS FOR ADVANCED QUERIES.

RiverSiteID	RiverSiteName	RiverSiteDescription
1	US-395	WWLW US 395 Site
2	Murphy Rvr	MURP Murphy River Site
3	Wilson	WLSN Wilson Site
4	E Fork	STRB East Fork
5	Mason	MVWR Mason Site
6	Fulston	FLST Fulston Site
7	Wabuska	WBSK Wabuska Site
8	Schurz	SHRZ Schurz Site
9	Wabuska Geotherm	Wabuska Geothermal Well
10	Desert Crk	DC Desert Creek
11	E Fork @ Elbow	EFE: E Fork Walker River @ Elbow
12	E Fork @ Stateline	EFS: E Fork Walker River @ Stateline
13	Sweet Water Crk	SWC: Sweet Water Creek
14	W Fork @ Wellington	W10: W Fork Walker River @ Wellington
15	W Fork @ Nordyke	W2: W Fork Walker River @ Nordyke West
16	E Fork @ Nordyke	W3: E Fork Walker River @ Nordyke East
17	Rvr @ Wabuska	W4: Walker River @ Wabuska
18	Rvr @ Topaz Ln	W Fork Walker River @ Topaz Lane
19	Rvr @ Hudson	W Fork Walker River @ Hudson Gage
20	Rvr @ Snyder	Walker River @ Mason Gage @ Snyder Lane
21	Rvr @ Schurz	Walker River @ Schurz Bridge
22	Gage Lat2A Siphon	River gage @ Schurz Lat2A siphon
23	Gage Blw Little Dam	River gage @ Schurz below Little Dam
24	Gage Above Little Dam	River gage @ Schurz above Little Dam
25	Gage Canal2 Little Dam	River gage @ Schurz Canal2 near Little Dam
26	Gage Weber Reservoir	River gage @ Schurz Weber Reservoir
27	Gage Wabuska	River gage @ Wabuska

APPENDIX A.2.6. CALENDAR OF SAMPLING EVENTS AT WALKER LAKE FROM 2000 THROUGH 2009 REPRESENTED IN THE DATABASE.

Date	Reported By	General Constituents	Bacteria	Major ions	Nutrients	Profile	Trace Element	Other
1-Jan-00	NDOW	x						
25-Jan-00	NDEP	x	x	x	x		x	
1-Feb-00	NDOW	x						
1-Mar-00	NDOW	x						
7-Mar-00	NDEP	x	x	x	x			
1-Apr-00	NDOW	x						
3-Apr-00	NDEP	x	x	x	x	x	x	
1-May-00	NDOW	x						
9-May-00	NDEP	x	x	x	x			
1-Jun-00	NDOW	x						
27-Jun-00	NDEP	x	x	x	x	x	x	
1-Jul-00	NDOW	x						
5-Jul-00	NDEP	x	x	x	x		x	
1-Aug-00	NDOW	x						
1-Sep-00	NDOW	x						
5-Sep-00	NDEP	x	x	x	x			
26-Sep-00	NDEP	x	x	x	x	x	x	
1-Oct-00	NDOW	x						
1-Nov-00	NDOW	x						
14-Nov-00	NDEP	x	x	x	x			
1-Dec-00	NDOW	x						
19-Dec-00	NDEP	x	x	x	x	x	x	
1-Jan-01	NDOW	x						
16-Jan-01	NDEP	x	x	x	x		x	
1-Feb-01	NDOW	x						
1-Mar-01	NDOW	x						
13-Mar-01	NDEP	x	x	x	x			
1-Apr-01	NDOW	x						
1-May-01	NDOW	x						
30-May-01	NDEP	x	x	x	x	x	x	
1-Jun-01	NDOW	x						
5-Jun-01	NDEP	x	x	x	x			
1-Jul-01	NDOW	x						
31-Jul-01	NDEP	x	x	x	x		x	
1-Aug-01	NDOW	x						
1-Sep-01	NDOW	x						

Date	Reported By	General Constituents	Bacteria	Major ions	Nutrients	Profile	Trace Element	Other
11-Sep-01	NDEP	x	x	x	x			
12-Sep-01	NDEP	x	x	x	x		x	
12-Sep-01	NDEP					x		
1-Oct-01	NDOW	x						
1-Nov-01	NDOW	x						
13-Nov-01	NDEP	x	x	x	x			
1-Dec-01	NDOW	x						
19-Dec-01	NDEP	x	x	x	x	x	x	
1-Jan-02	NDOW	x						
22-Jan-02	NDEP	x	x	x	x		x	
1-Mar-02	NDOW	x						
12-Mar-02	NDEP	x	x	x	x			
28-Mar-02	NDEP	x		x	x	x	x	
1-Apr-02	NDOW	x						
1-May-02	NDOW	x						
20-May-02	NDEP	x	x	x	x			
1-Jun-02	NDOW	x						
18-Jun-02	NDEP	x	x	x	x	x	x	
1-Jul-02	NDOW	x						
13-Jul-02	USGS	x						
28-Jul-02	USGS	x						
1-Aug-02	NDOW	x						
1-Sep-02	NDOW	x						
24-Sep-02	NDEP	x	x	x	x	x	x	
1-Oct-02	NDOW	x						
6-Oct-02	USGS	x						
16-Oct-02	USGS	x						
26-Oct-02	USGS	x						
31-Oct-02	USGS	x						
1-Nov-02	NDOW	x						
10-Nov-02	USGS	x						
15-Nov-02	USGS	x						
1-Dec-02	NDOW	x						
1-Jan-03	NDOW	x						
4-Jan-03	USGS	x						
7-Jan-03	NDEP	x	x	x	x	x	x	
14-Jan-03	USGS	x						
19-Jan-03	USGS	x						
1-Feb-03	NDOW	x						
3-Feb-03	USGS	x						

Date	Reported By	General Constituents	Bacteria	Major ions	Nutrients	Profile	Trace Element	Other
18-Feb-03	USGS	x						
23-Feb-03	USGS	x						
28-Feb-03	USGS	x						
1-Mar-03	NDOW	x						
1-Apr-03	NDOW	x						
10-Apr-03	NDEP	x	x	x	x	x	x	
14-Apr-03	USGS	x						
19-Apr-03	USGS	x						
1-May-03	NDOW	x						
1-Jun-03	NDOW	x						
10-Jun-03	NDEP	x	x	x	x		x	
10-Jun-03	NDEP					x		
1-Jul-03	NDOW	x						
1-Aug-03	NDOW	x						
7-Aug-03	USGS	x						
1-Sep-03	NDOW	x						
1-Sep-03	USGS	x						
16-Sep-03	USGS	x						
25-Sep-03	NDEP	x	x	x	x	x	x	
1-Oct-03	NDOW	x						
1-Nov-03	NDOW	x						
5-Nov-03	USGS	x						
20-Nov-03	USGS	x						
1-Dec-03	NDOW	x						
2-Dec-03	NDEP	x	x	x	x	x		
1-Jan-04	NDOW	x						
1-Feb-04	NDOW	x						
23-Feb-04	USGS	x						
28-Feb-04	USGS	x						
1-Mar-04	NDOW	x						
10-Mar-04	NDEP	x	x	x	x	x	x	
1-Apr-04	NDOW	x						
1-May-04	NDOW	x						
1-Jun-04	NDOW	x						
9-Jun-04	NDEP	x	x	x	x	x		
14-Jun-04	NDEP	x	x	x	x	x		
17-Jun-04	USGS	x						
1-Jul-04	NDOW	x						
2-Jul-04	USGS	x						
8-Jul-04	NDOW					x		

Date	Reported By	General Constituents	Bacteria	Major ions	Nutrients	Profile	Trace Element	Other
1-Aug-04	NDOW	x						
11-Aug-04	NDOW					x		
1-Sep-04	NDOW	x						
7-Sep-04	NDEP	x	x	x	x	x	x	
16-Sep-04	NDOW	x				x		
1-Oct-04	NDOW	x						
1-Nov-04	NDOW	x						
1-Dec-04	NDOW	x						
6-Dec-04	NDEP	x	x	x	x	x		
1-Jan-05	NDOW	x						
1-Feb-05	NDOW	x						
8-Feb-05	USGS					x		
1-Mar-05	NDOW	x						
14-Mar-05	NDEP	x	x	x	x	x	x	
1-Apr-05	NDOW	x						
5-Apr-05	USGS					x		
1-May-05	NDOW	x						
12-May-05	USGS					x		
24-May-05	NDOW	x				x		
31-May-05	NDOW	x				x		
1-Jun-05	NDOW	x						
20-Jun-05	NDOW	x				x		
1-Jul-05	NDOW	x						
6-Jul-05	NDEP	x	x	x	x	x		
13-Jul-05	USGS					x		
1-Aug-05	NDOW	x						
17-Aug-05	USGS					x		
1-Sep-05	NDOW	x						
29-Sep-05	NDEP	x	x	x	x	x		
1-Oct-05	NDOW	x						
25-Oct-05	USGS					x		
1-Nov-05	NDOW	x						
1-Dec-05	NDOW	x						
6-Dec-05	NDEP	x	x	x	x	x		
13-Dec-05	NDEP					x		
13-Dec-05	NDOW	x				x		
1-Jan-06	NDOW	x						
19-Jan-06	USGS					x		
1-Feb-06	NDOW	x						
1-Mar-06	NDOW	x						

Date	Reported By	General Constituents	Bacteria	Major ions	Nutrients	Profile	Trace Element	Other
8-Mar-06	USGS					x		
20-Mar-06	NDEP	x	x	x	x	x	x	
30-Mar-06	USGS					x		
1-Apr-06	NDOW	x						
1-May-06	NDOW	x						
8-May-06	NDOW					x		
16-May-06	USGS					x		
30-May-06	NDOW					x		
1-Jun-06	NDOW	x						
21-Jun-06	USGS					x		
26-Jun-06	NDEP	x	x	x	x	x	x	
28-Jun-06	NDOW					x		
1-Jul-06	NDOW	x						
21-Jul-06	NDOW					x		
1-Aug-06	NDOW	x						
1-Aug-06	USGS					x		
22-Aug-06	USGS					x		
23-Aug-06	USGS					x		
31-Aug-06	NDOW					x		
1-Sep-06	NDOW	x						
6-Sep-06	USGS					x		
1-Oct-06	NDOW	x						
3-Oct-06	NDEP	x	x	x	x	x		
19-Oct-06	USGS					x		
1-Nov-06	NDOW	x						
15-Nov-06	USGS					x		
1-Dec-06	NDOW	x						
5-Dec-06	NDEP	x	x	x	x	x	x	
1-Jan-07	NDOW	x						
1-Feb-07	NDOW	x						
1-Mar-07	NDOW	x						
3-Mar-07	UNR					x		
7-Mar-07	DRI	x		x	x	x	x	
7-Mar-07	NDEP	x	x	x	x		x	
7-Mar-07	UNR	x						
8-Mar-07	USGS					x		
1-Apr-07	NDOW	x						
27-Apr-07	DRI				x	x		
1-May-07	NDOW	x						
5-May-07	NDOW					x		

Date	Reported By	General Constituent	Bacteria	Major ions	Nutrients	Profile	Trace Element	Other
22-May-07	DRI	x		x	x	x	x	x
22-May-07	UNR	x				x		
30-May-07	DRI				x	x		
1-Jun-07	NDOW	x						
13-Jun-07	NDOW					x		
19-Jun-07	NDEP	x	x	x	x	x	x	
1-Jul-07	NDOW	x						
10-Jul-07	UNR	x						
19-Jul-07	NDOW					x		
1-Aug-07	NDOW	x						
20-Aug-07	UNR	x						
21-Aug-07	NDOW					x		
28-Aug-07	DRI				x	x		
29-Aug-07	DRI	x		x	x		x	
1-Sep-07	NDOW	x						
18-Sep-07	NDEP	x	x	x	x	x		
21-Sep-07	NDOW					x		
1-Oct-07	NDOW	x						
2-Oct-07	DRI				x	x		
3-Oct-07	DRI				x	x	x	x
3-Oct-07	UNR	x						
3-Oct-07	UNR					x		
23-Oct-07	NDOW					x		
1-Nov-07	NDOW	x						
1-Dec-07	NDOW	x						
4-Dec-07	DRI	x		x	x	x	x	x
4-Dec-07	UNR	x				x		
5-Dec-07	DRI				x	x		
10-Dec-07	NDEP	x	x	x	x		x	
11-Dec-07	NDEP	x	x	x	x	x	x	
4-Mar-08	NDEP	x	x	x	x	x	x	
1-May-08	DRI				x	x		
2-May-08	DRI				x	x		

APPENDIX A.2.7. DESCRIPTION OF PARAMETER NAMES USED IN THE DATABASE.

General Constituents includes:

ParameterName	ParameterDescription
Baro Press	Barometric pressure
BOD	Biological oxygen demand
COD	Chemical oxygen demand
Color	Color
Conductivity	Conductivity measured in field
Conductivity lab	Conductivity measured in lab
DO	Dissolved oxygen
DO % sat	Dissolved oxygen as % sat
DO chrg	DO qa/qc field parameter
Hydroxide	Hydroxide
ORP	Oxidation reduction potential
pH	pH measured in the field
pH lab	pH measured in the lab
pH mV	pH millivolt from field measurements
Salinity	
Secchi	Depth of clarity with Secchi disk
SS	Suspended solids
TDS	Total dissolved solids / residue on evaporation
TDScond	TDS from conductivity 0.7811(cond) - 1035.4
TDSevap	TDS corrected for evaporation HCO_3 x 0.4917
Temperature	Temperature measured in the field
Temperature lab	Temperature measured in the lab
TSS	Total suspended solids
Turbidity	Turbidity

Bacteria includes:

ParameterName	ParameterDescription
Bacteria Total	
E Coli	E coli bacteria
Fecal Coli	Fecal coliform bacteria
Fecal Strep	Fecal strep bacteria
T Coli	Total coliform bacteria

Major Ions includes:

ParameterName	ParameterDescription
Alk-bicarb-CaCO3	Alkalinity bicarbonate as $CaCO_3$
Alk-carb-CaCO3	Alkalinity carbonate as $CaCO_3$
Alk-Tot-CaCO3	Total alkalinity as $CaCO_3$
Br	Bromide
Ca	Calcium
Ca TR	Calcium total recoverable
Cl	Chloride
CO3	Carbonate
F	Fluoride
F TR	Fluoride total recoverable
Hardness	Hardness as $CaCO_3$
Hardness TR	Hardness as $CaCO_3$ total recoverable
HCO3	Bicarbonate
K	Potassium
Mg	Magnesium
Mg TR	Magnesium total recoverable
Na	Sodium
Na TR	Sodium total recoverable
SAR	Sodium absorption ratio
SAR TR	Sodium absorption ratio total recoverable
SiO2	Silica
SO4	Sulfate

Nutrients includes:

ParameterName	ParameterDescription
DKN	Dissolved Kjeldahl nitrogen (TKN soluble)
DOC	Dissolved organic carbon
P D	Dissolved phosphorus (total soluble phosphorus)
N fixation	Nitrogen fixation μmol
N T	Total nitrogen
N T max	Maximum total nitrogen
N T min	Minimum total nitrogen
N TIN	Total inorganic nitrogen
N TON	Total organic nitrogen
NH3-N	Ammonia as nitrogen
NH4	Ammonia
NH4-N	Ammonia as nitrogen
NO2-N	Nitrite as nitrogen
NO3	Nitrate
NO3+NO2-N	Nitrate+nitrite as nitrogen
NO3-N	Nitrate as nitrogen
oPO4	Dissolved reactive phosphorus
P T	Total phosphorus
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon

Profile includes:

ParameterName	ParameterDescription
Baro Press	Barometric pressure
Conductivity	Conductivity measured in field
DO	Dissolved Oxygen
DO % sat	Dissolved oxygen as % saturation
ORP	Oxidation reduction potential
PAR	Photosynthetically active radiation
pH	pH measured in the field
Salinity	
TDS	Total dissolved solids / Residue on Evaporation
Temperature	Temperature measured in the field
Turbidity	Turbidity

Trace Element includes:

ParameterName	ParameterDescription
Ag	Silver
Al	Aluminum
As	Arsenic
As TR	Arsenic total recoverable
B	Boron
B TR	Boron total recoverable
Ba	Barium
Ba TR	Barium total recoverable
Be	Beryllium
Be TR	Beryllium total recoverable
Cd	Cadmium
Cd TR	Cadmium total recoverable
Co	Cobalt
Cr	Chromium
Cr TR	Chromium total recoverable
Cu	Copper
Cu TR	Copper total recoverable
Fe	Iron
Fe TR	Iron total recoverable
Hg	Mercury
Hg TR	Mercury total recoverable
Mn	Manganese
Mn TR	Manganese total recoverable
Mo	Molybdenum
Mo TR	Molybdenum total recoverable
Ni	Nickel
Ni TR	Nickel total recoverable
Pb	Lead
Pb TR	Lead total recoverable
S	Sulfide
Sb	Antimony
Sb TR	Antimony total recoverable
Se	Selenium
Se TR	Selenium total recoverable
Sn	Tin
Sr	Strontium
Tl	Thallium
Tl TR	Thallium total recoverable
U	Uranium
U TR	Uranium total recoverable
U238	Uranium 238 isotope
U238 TR	Uranium 238 isotope total recoverable

ParameterName	ParameterDescription
V	Vanadium
V TR	Vanadium total recoverable
Zn	Zinc
Zn TR	Zinc total recoverable

Other Includes:

ParameterName	ParameterDescription
Cell counts (DC)	Direct counts w/ DAPI
Cell counts (FC)	Flow cytometry
MPN-AH	Aerobic heterotrophs (most probable number)
MPN-F	Fermenters (most probable number)
MPN-FeRB	Iron reducing bacteria (most probable number)
MPN-NR	Nitrate reducers (most probable number)
MPN-S	Sulfur reducers (most probable number)
MPN-SRB	Sulfate reducing bacteria (most probable number)
PC-R2A	Aerobic heterotrophs (plate count)
PC-S	Sulfur reducers (plate count)
Phospholipid	Phospholipid fatty acid analysis
Zooplankton E	Enumeration, C and N isotope and fatty acid
Zooplankton Stoi	Stoichiometry (C, N, and P)
Fatty Acid	Concentration as µg/mg C or µg/mg dw

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A.3: ECOLOGICAL MODEL FOR WALKER LAKE, NEVADA

Contributing Authors: Mark Stone, Alan Heyvaert, Sudeep Chandra, Chris Fritsen, Ron Hershey, Duane Moser, James Bruckner, Alexandra Lutz, Jeramie Memmott, and Kumud Acharya

ABSTRACT

The information collected through historical and contemporary Walker Lake monitoring efforts was incorporated into an ecological model. The objectives of the model were to 1) integrate historical and contemporary monitoring data; 2) inform future monitoring strategies; and 3) to provide a tool for testing the impacts of potential water management strategies on the limnology of Walker Lake. The purpose of this addendum is to provide a basic description of the modeling techniques, input data, calibration methods, and results. Recommendations for reducing uncertainty in model forecasts through future monitoring and research activities are also provided.

The Walker Lake model was developed using coupled hydrodynamic and ecological components based on the Computational Aquatic Ecosystem Dynamics Model (CAEDYM). The model was customized to describe the general characteristics (e.g. bathymetry, water and nutrient inflows, nutrient concentrations, algae and zooplankton abundance, etc.) of Walker Lake. The model was calibrated using data collected by DRI and UNR in 2007 and early 2008. The model was then partially validated using historical data collected by Dr. Alex Horne in 1993 (Horne et al. 1994). A sensitivity analysis was also conducted to investigate the influence of data and parameter uncertainty on model predictions. Finally, a series of hypothetical streamflow scenarios were simulated to test the model's robustness and to provide initial guidance for water management decisions. The current model is still in its early stages of development. Ultimately, a refined model would be capable of forecasting ecological responses to specific Walker River flow scenarios, as they become available.

MODEL BACKGROUND

CAEDYM was developed at the Center for Water Research (CWR) at the University of Western Australia (http://www.cwr.uwa.edu.au). The model consists of a series of mathematical equations representing the major biogeochemical processes influencing water quality. It contains process descriptions for primary production, secondary production, nutrient and metal cycling, and oxygen dynamics. In this study, CAEDYM was dynamically coupled to the one-dimensional Dynamic Reservoir Simulation Model (DYRESM) to allow investigation of seasonal and annual variations in Walker Lake physical limnology. The one-dimensional approach assumes that the lake can be represented by a series of homogeneous horizontal plans. This assumption is necessary when available data and computational resources are limited and when long-term simulations are desired.

Hydrodynamic Model

Vertical temperature, salinity, and mixing patterns in Walker Lake were simulated using DYRESM. DYRESM was developed at the Center for Water Research (CWR) at the University of Western Australia (http://www.cwr.uwa.edu.au). The software is available free of charge and the source code is provided to the research community. DYRESM models the lake as a vertical stack of horizontal layers of uniform temperature and salinity. The model dynamically adjusts the number and thickness of each vertical layer as necessary to maintain numerical stability. The surface mixed layer, in which temperature and conductivity are relatively uniform, is simulated as relatively course layers, while the thermocline and chemocline are simulated at a finer vertical resolution. The vertical resolution dynamically adjusts as a function of water depth and vertical gradients. A brief description of the required model inputs and outputs are given below.

Ecological Model

The ecological component of the Walker Lake Model was developed using CAEDYM, which was also developed by CWR. CAEDYM is a process-based model of the major biogeochemical processes influencing water quality. It optionally models inorganic particles, oxygen, organic and inorganic nutrients, multiple phytoplankton and zooplankton groups, pH, aqueous speciation (including metals), precipitation/dissolution reactions, fish and bacteria. Configuration is flexible so that the model can be applied at the appropriate level of sophistication for available data and project objectives. The model has been applied to lakes and reservoirs, rivers, estuaries, wetlands, and the coastal ocean. It has been coupled to several hydrodynamic drivers by CWR (including DYRESM), and also may be coupled to other hydrodynamic codes. CAEDYM is more advanced than most traditional nutrient-phytoplankton-zooplankton models in that it is a general biogeochemical model that also can resolve species or group specific ecological interactions. An important component of CAEDYM for the simulation of Walker Lake is the models ability to simulate salinity dependence. Full technical details and documentation for CAEDYM can be accessed at: http://www.cwr.uwa.edu.au/services/models.php?mdid=3.

INPUT DATA

Bathymetric Data

Walker Lake's bathymetry was described in a study completed by the USGS in 2007 (USGS 2007). According to the USGS study, the minimum altitude occurs near the center of the lake at 1173.3 m above mean sea level (MSL). At the time of the USGS measurement in 2005, the water surface elevation was 1199.57 m MSL, the maximum depth was 26.3 m, the storage volume was 2.19 km^3 (1,779,000 acre-ft), and the surface area was 13,026 hectares (32,190 acres). The USGS reported relationships to describe the storage volume and surface area as a function of elevation (Figure A.3.1). These relationships were used to describe Walker Lake in the DYRESM model through the bathymetric tables contained in the Walker.stg file.

The DYRESM model uses variable layer depths within a maximum and a minimum layer thickness as specified in the Walker.cfg file. The resulting temperature and salinity patterns are output for each model layer at a specified time step, which is equal to or greater than the computational time step. The model calculations are made several times within each day, although the boundary conditions of inflow and meteorology were daily average values. The computational time step for the WLM was set at two hours.

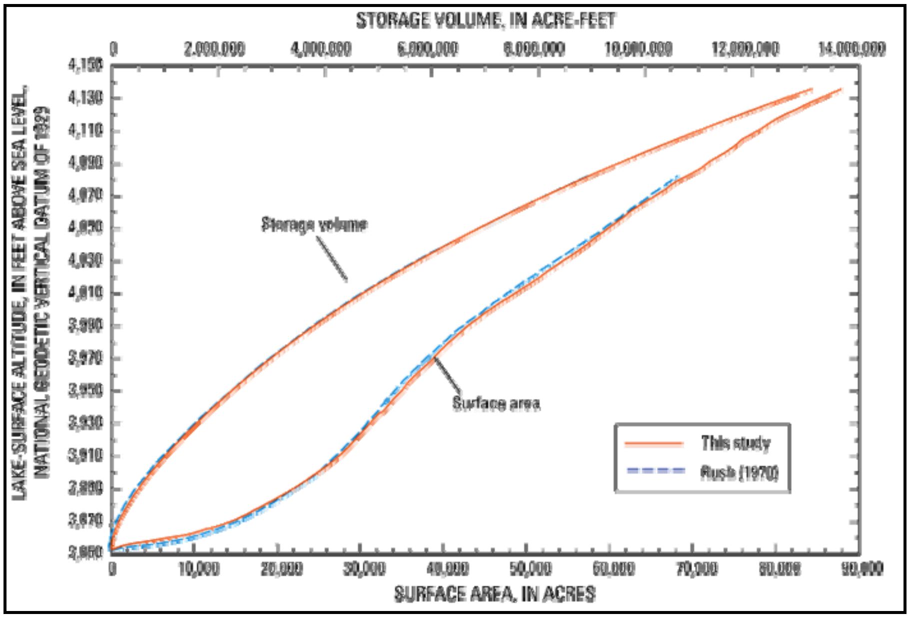

Figure A.3.1. Storage and surface area relationships developed by the USGS (2007).

Surface Water and Groundwater Inputs

In this study the daily inflow to Walker Lake from the Walker River was estimated from USGS Gage 10302002 (Walker River at Lateral 2A). Daily streamflow data is available for the gage through the USGS National Water Information System. As described below, streamflow data was required for the calibration period (2007) and the validation period (1993). Further, historical data were used to produce two hypothetical streamflow scenarios. Streamflow data from 1982-1986 were used as input for the *high-flow* scenario and 1989-1993 data were used for the *low-flow* scenario.

In addition to streamflow volume, DYRESM also requires data describing water temperature and TDS concentrations for all inputs. Occasional measurements of water temperature near the mouth of Walker River are available from the USGS and the Nevada Division of Environmental Protection. A simple regression analysis showed that stream water temperature was reasonably estimated as the average air temperature from the previous three days. TDS values varied between 100 and 500 mg/L, with most values between 300 and 400 mg/L. TDS concentrations were not highly correlated with stream discharge. Thus, an average value of 350 mg/L was used throughout the study with the exception of the sensitivity analysis.

CAEDYM requires inputs loads of all simulated water quality parameters including total phosphorus, phosphate, total nitrogen, ammonia, nitrate, pH, and DO. Because regular water quality monitoring data are not available for the lower reach of the Walker River, the loads were estimated from the intermittent data provided by the USGS and NDEP. For each parameter, typical values were estimated based on the statistical mean and a visual investigation of recent data. The sensitivity of the model to the uncertainty of input loads was investigated in the sensitivity analysis described below.

Groundwater discharge to the lake was estimated to be 13,568,300 m^3/year (11,000 acre-ft/year)(Thomas 1995). Groundwater discharge was distributed evenly throughout the year and throughout the vertical profile. Evaporation from the lake surface was calculated directly by the model.

Meteorological Data

The model required daily descriptions of local meteorological conditions including air temperature, incoming shortwave and longwave radiation (or cloud cover), wind speed, vapor pressure (or relative humidity), and precipitation. No long-term meteorological stations exist on or immediately adjacent to Walker Lake. Thus, observations from the National Weather Service (NWS) Cooperative Observer Program (COOP) station at Hawthorne, the U.S. Forest Service Remote Automated Weather Station (RAWS) at Brawley Peaks and Benton, and wind tower data collected by the Western Regional Climate Center (WRCC) at Luning were compiled to estimate local meteorological conditions. Additionally, daily estimates of shortwave and longwave incident radiation and air temperature were obtained from the NWS North American Regional Reanalysis (NARR). NARR provides a gridded dataset of meteorological data produced from a hindcast simulation based on historical point observations. These data sources were combined to produce the required meteorological dataset in the Walker.met file. An example of the meteorological data used for the year 2007 is shown in Figure A.3.2.

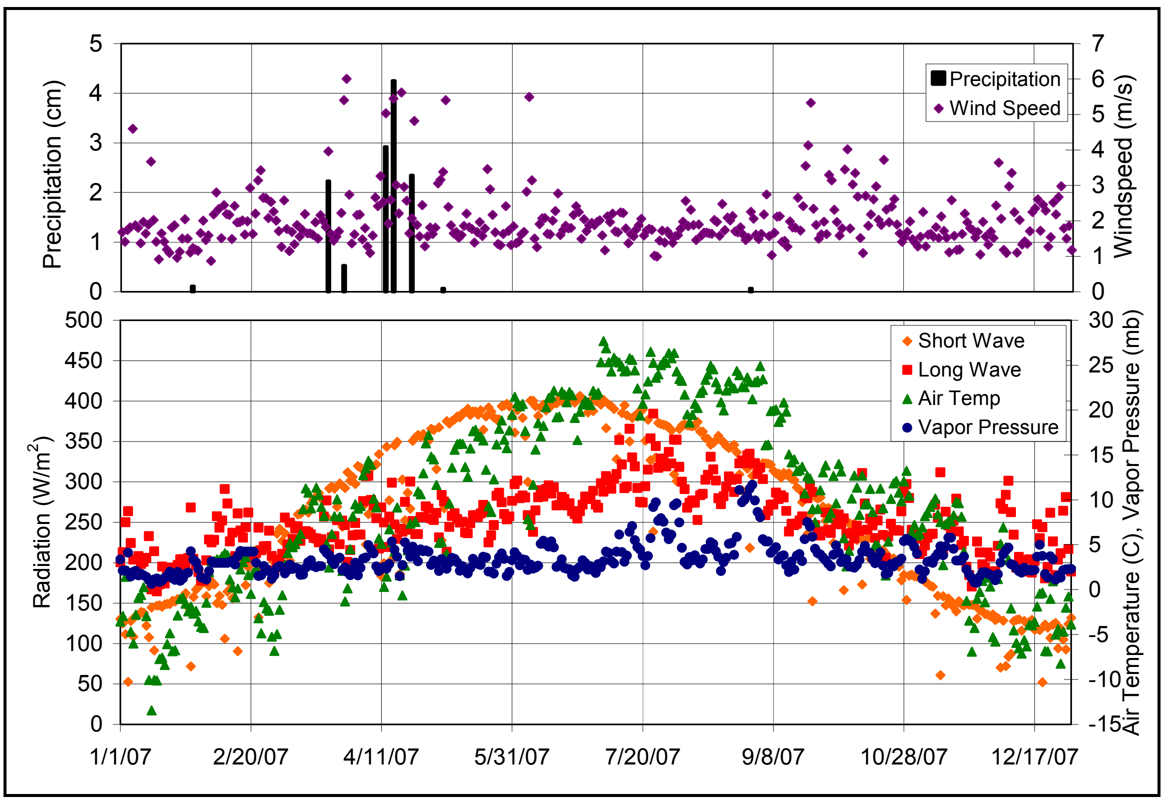

Figure A.3.2.   Meteorological data for the calibration year 2007.

Initial Conditions

Initial conditions must also be provided to the model to describe the vertical distributions of water temperature, dissolved oxygen, nutrients, algae, and zooplankton at the outset of the model. For the calibration simulation (2007) the initialization data were obtained from the monitoring efforts performed by DRI and UNR. Likewise, the validation simulation (1993) was initialized using monitoring data reported by Horne in 1993 (Horne et al. 1994). Because each simulation was initiated on January 1 of its respective year, the lake was assumed to be fully mixed and the parameters were set to be constant throughout the water column. No data is available describing the nutrient concentrations associated with the lakebed sediments (particulate or dissolved). Thus, initial conditions for sediment nutrients were estimated based on data from Pyramid Lake and from typical ratios between water column and sediment nutrients in other lakes. Due to the high level of uncertainty associated with estimates of sediment nutrients, a wide range of conditions were tested in the sensitivity analysis described below.

CAEDYM is capable of simulating up to seven phytoplankton groups and five zooplankton groups. For the Walker Lake model, we only simulated the dominant groups which included three phytoplankton groups (nodularia, cyanobacteria, and diatoms) and three zooplankton groups (cladocerans, copepods, and rotifers).

MODEL CALIBRATION

Model calibration is a necessary step in any model application. For most models, calibr Model calibration is a necessary step in any model application. For most models, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. Calibration of the Walker Lake model was accomplished by comparing modeled and observed water surface elevations and vertical profiles of water temperature and dissolved oxygen for the year of 2007. A preliminary validation was conducted using 1993 data as described below.

The hydrodynamic model (DYRESM) was calibrated first to ensure the proper representation of physical features, which in term influence the CAEDYM model. DYRESM is designed to be relatively calibration free and therefore very few calibration coefficients are available for adjustments (Hipsey et al. 2006). One by one we tested the influence of the bulk aerodynamic momentum transport coefficient, shear production efficiency coefficient, energy mixing efficiency coefficient, wind stirring efficiency coefficient, and vertical mixing coefficient on the vertical temperature profile over the simulation period. The model was relatively insensitive to most of the coefficients within their typical ranges. The best agreement with measured data was found by setting the shear production efficiency, energy mixing efficiency, and wind stirring efficiency coefficients all to one and the vertical mixing coefficient equal to 4000 (default=2000). An example of a vertical temperature profile before and after calibration as compared with measured data is shown in Figure A.3.3.

A more basic measure of the models ability to describe the physical processes of the lake is in the simulation of water surface elevations. An inability to reproduce the measured water surface elevation would represent an error in the lake's water budget (e.g. from inaccurate streamflow, groundwater flow, or evaporation). A comparison between the measured and simulated water surface elevations for 2007 is shown in Figure

A.3.4. The simulated and measured water surface elevations were nearly identical throughout the calibration period.

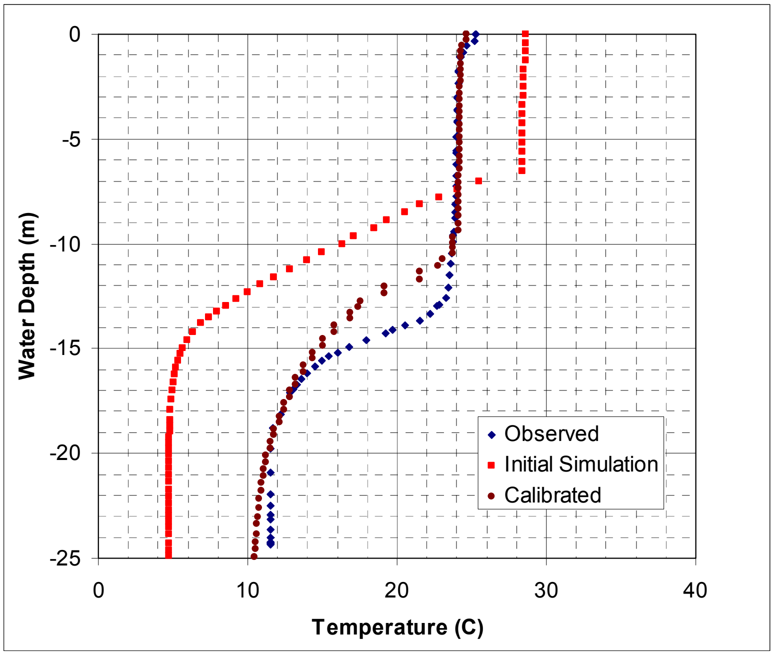

Figure A.3.3. Vertical temperature profiles for the initial and calibrated simulations compared with the observed data on August 28, 2007.

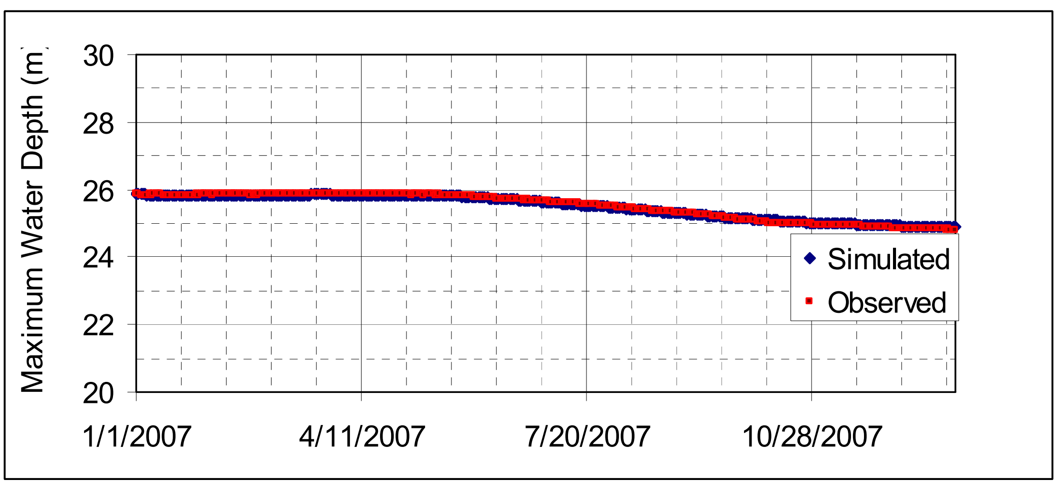

Figure A.3.4. Simulated and observed lake water depth.

The final stage of the calibration involved an analysis of the CAEYDM results. CAEDYM is designed to require little or no calibration (Hipsey et al. 2006). An example of a typical DO vertical profile is shown in Figure A.3.5. No additional calibration was performed due to the reasonable agreement between simulated and measured data under the default conditions. However, the discrepancy between simulated and observed DO concentrations suggest that the model performance could be improved through further refinements as outlined below.

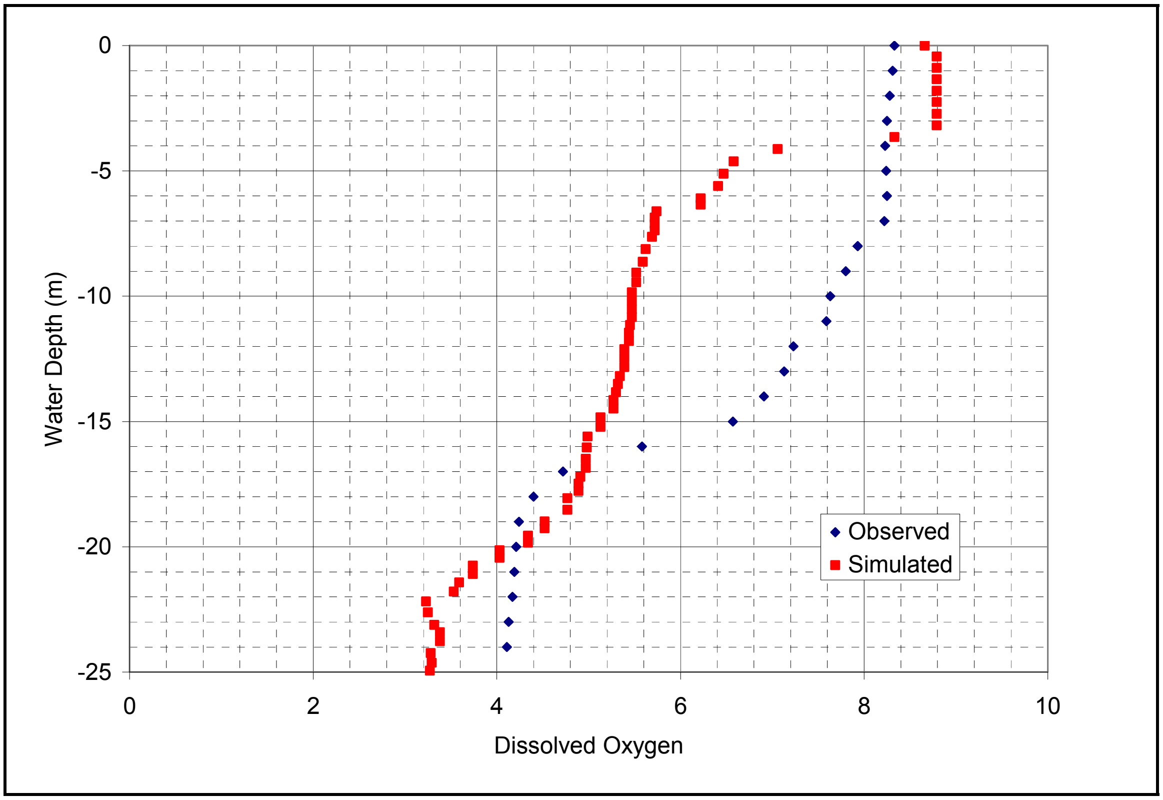

Figure A.3.5. Vertical dissolved oxygen profiles for the calibrated simulations compared with the observed data on June 19, 2007.

Validating a model requires an evaluation of model performance using an independent dataset. The Walker Lake model was partially validated using data collected by Dr. Alex Horne in 1993 (Horne et. al. 1994). The model's boundary conditions and initial conditions were adjusted to match 1993 conditions. Meteorological and streamflow data were obtained from the same data sources listed above. The initial water surface elevation and water temperature, ph, DO, TDS, nutrients, chlorophyll-a, and zooplankton concentrations were all obtained from Horne et al. (1994). As with the calibration routine, the results of the simulation were compared with monitoring data to evaluate model performance. However, specific numerical values for the 1993 dataset were only available for a limited number of observations. Thus, this preliminary validation was limited to a qualitative comparison of observed and simulated trends in water temperature and dissolved oxygen. The final vertical profiles for water temperature, TDS, and DO as functions of time, for the validation year of 1993, are shown in Figure A.3.6. The temporal patterns were very similar to those reported by Horne.

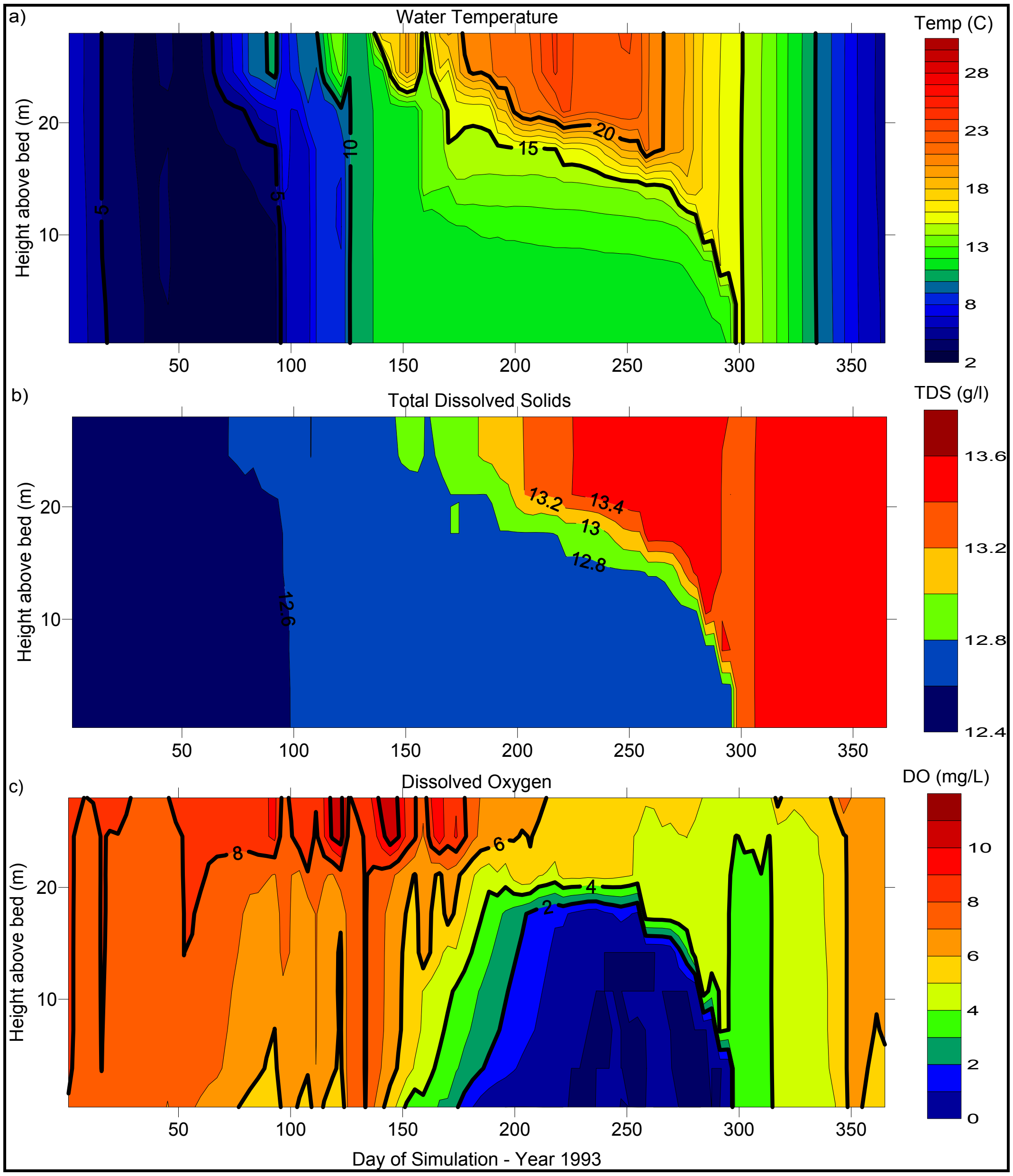

Figure A.3.6. Vertical temperature, TDS, and DO profiles over the 1993 validation period.

SENSITIVITY ANALYSIS

A sensitivity analysis was used to determine how responsive the model was to changes in the value of boundary conditions, initial conditions, and model parameters. By showing how the model responds to changes in parameter values and input data uncertainty, the sensitivity analysis is a useful tool in model building as well as in model evaluation. Further, the results provide insight into how the model can be improved by reducing uncertainty in the data and parameters which most strongly influence the model results. We examined the models sensitivity to a wide range of conditions including modifications to the meteorological data, input loads from the Walker River, sediment nutrient concentrations, initial conditions, and hydrodynamic mixing coefficients. The impacts of the various conditions were primarily determined by examining changes in temperature distributions for DYRESM parameters and DO for CAEDYM parameters.

Meteorological Uncertainty

The first group of sensitivity tests involved manipulations of the meteorological inputs. This was necessary because, as describe above, meteorological data was not available in the vicinity of the lake. Each parameter was adjusted to a high and low value independently and the impacts on water temperature profiles were observed. The range of values was based roughly on the average monthly standard deviation of the observed data. The air temperature was adjusted over a range of +/- ±5º C. Thus each daily record was increased by 5º C for the high air temperature simulation and decreased by 5º C for the low temperature simulation. Additionally, both shortwave and longwave radiation were adjusted by ±50 W/m^2; wind speed by ±1 m/s; vapor pressure by ± 0.5 mb; and precipitation was multiplied by two and divided by two.

The model was found to be insensitive to the changes in precipitation and vapor pressure over the calibration period of 2007 and thus the results are not shown here. The expected trends were observed for changes in air temperature, solar radiation, and wind speed. Figure A.3.7 shows the vertical temperature profiles for the (a) baseline condition along with the (b) reduced and (c) increased temperature conditions. The cooler temperature condition showed the expected cooling of the lake surface temperature and a slightly shallower thermocline in the summer. Conversely, the warmer air temperatures caused warmer water temperatures at the surface and a deeper summer thermocline. The vertical temperature profiles resulting under (b) increased and (c) decreased shortwave and longwave radiation intensity are shown in Figure A.3.8. The solar radiation was shown to have a strong influence on both the lake surface temperatures and on the depth of the summer thermocline. As expected, increasing the magnitude of the wind speed increased mixing, reduced the epilimnion temperature, and increased the epilimnion depth. The influence on epilimnetic temperatures was even stronger than the influences of solar radiation and air temperature. The results from the (b) increased winds and (c) decreased winds are shown in Figure A.3.9.

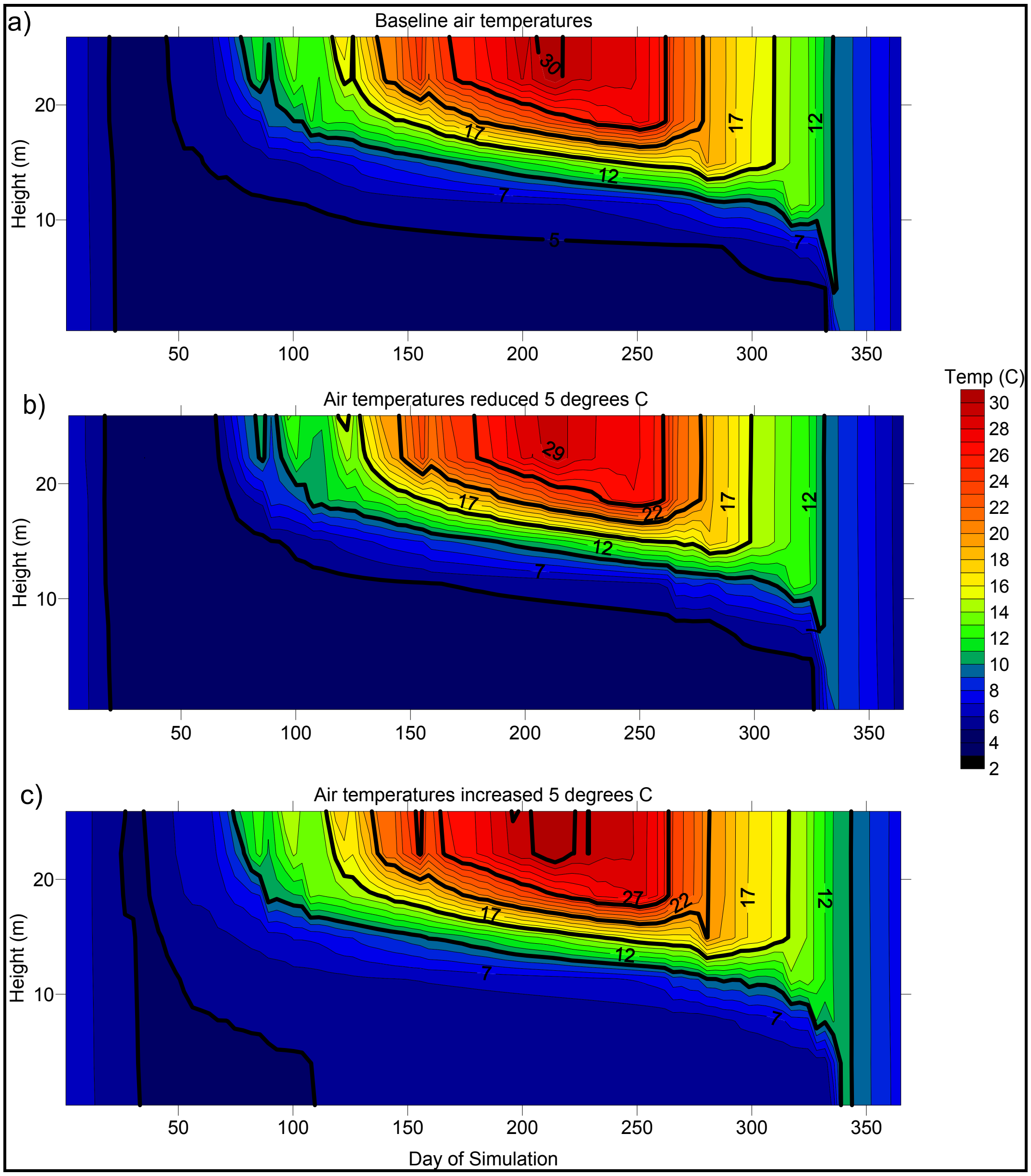

Figure A.3.7. Influence of atmospheric temperature on vertical water temperature profiles.

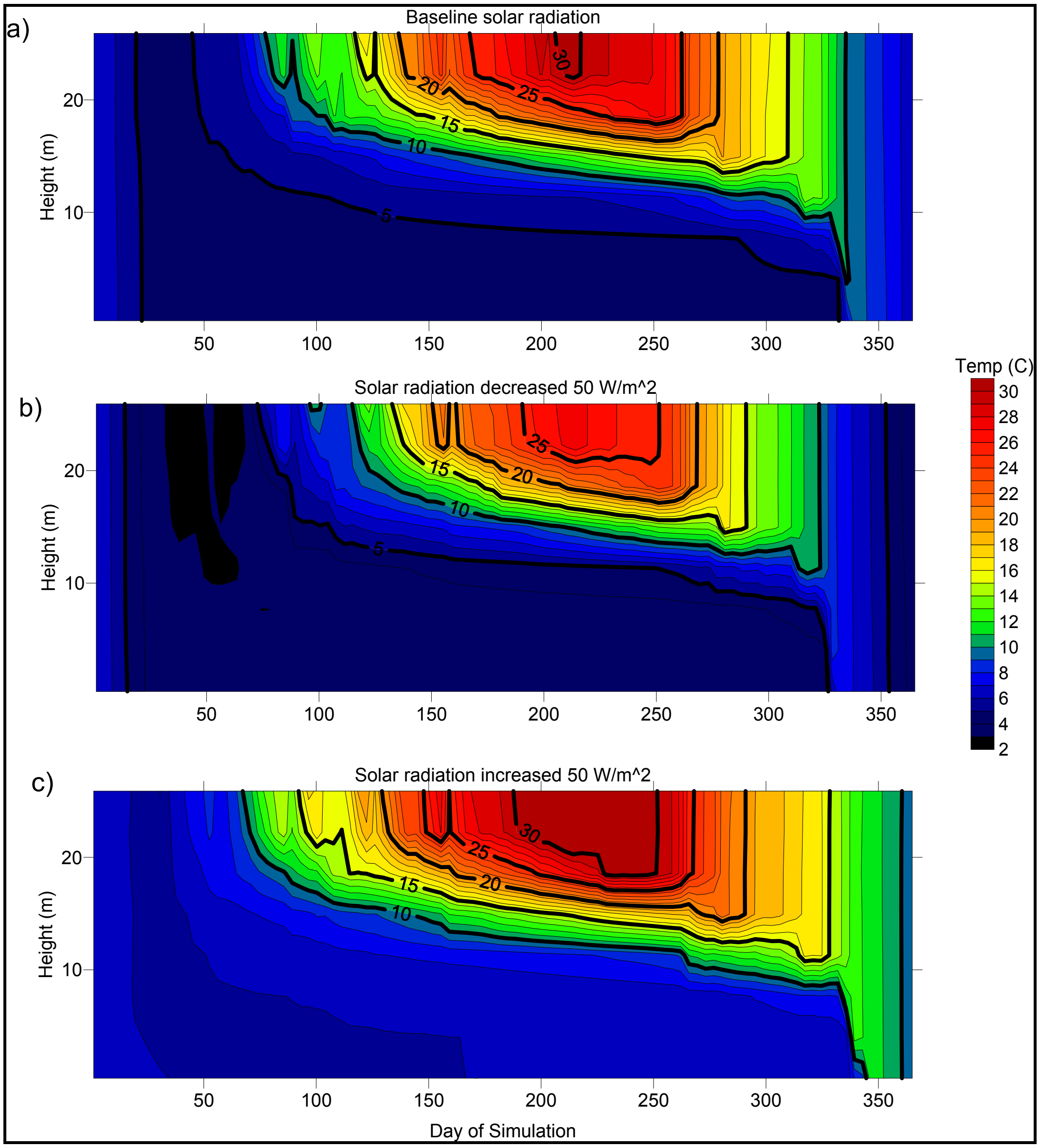

Figure A.3.8. Influence of solar radiation on vertical water temperature profiles.

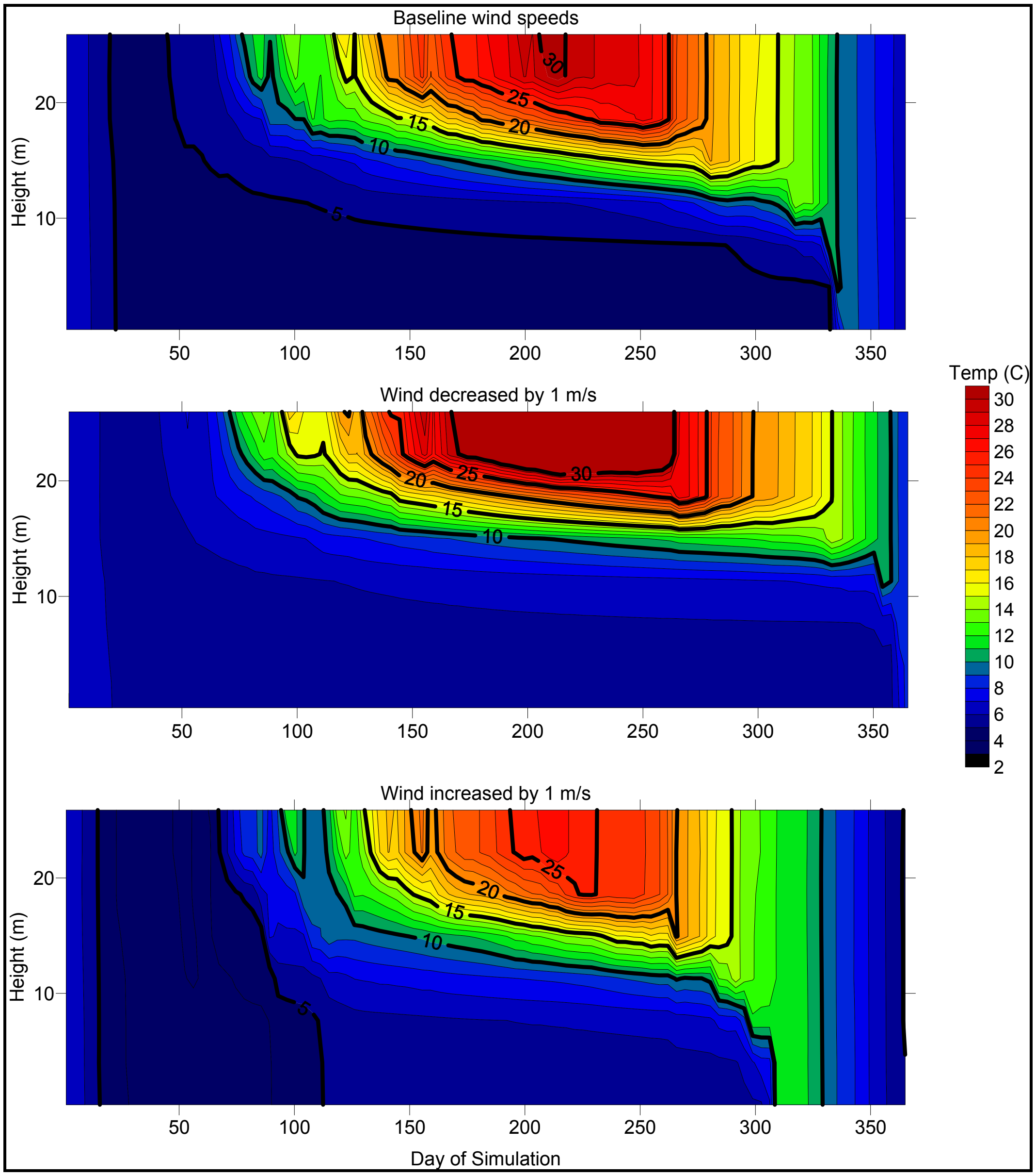

Figure A.3.9. Influence of wind speed on vertical water temperature profiles.

Initial Condition Uncertainty

The next group of sensitivity tests focused on the initial conditions. These tests can be further divided into initial physical limnology conditions, water column constituents, and sediment constituents. We first examined the influence of the initial water temperature profile by increasing and decreasing the temperature by 2º C from a baseline condition of 7º C. Figure A.3.10 shows that changing the initial condition has a strong influence in the first several months of the simulation. The influence of the initial temperature becomes less pronounced but is still noticeable throughout the 1-year simulation.

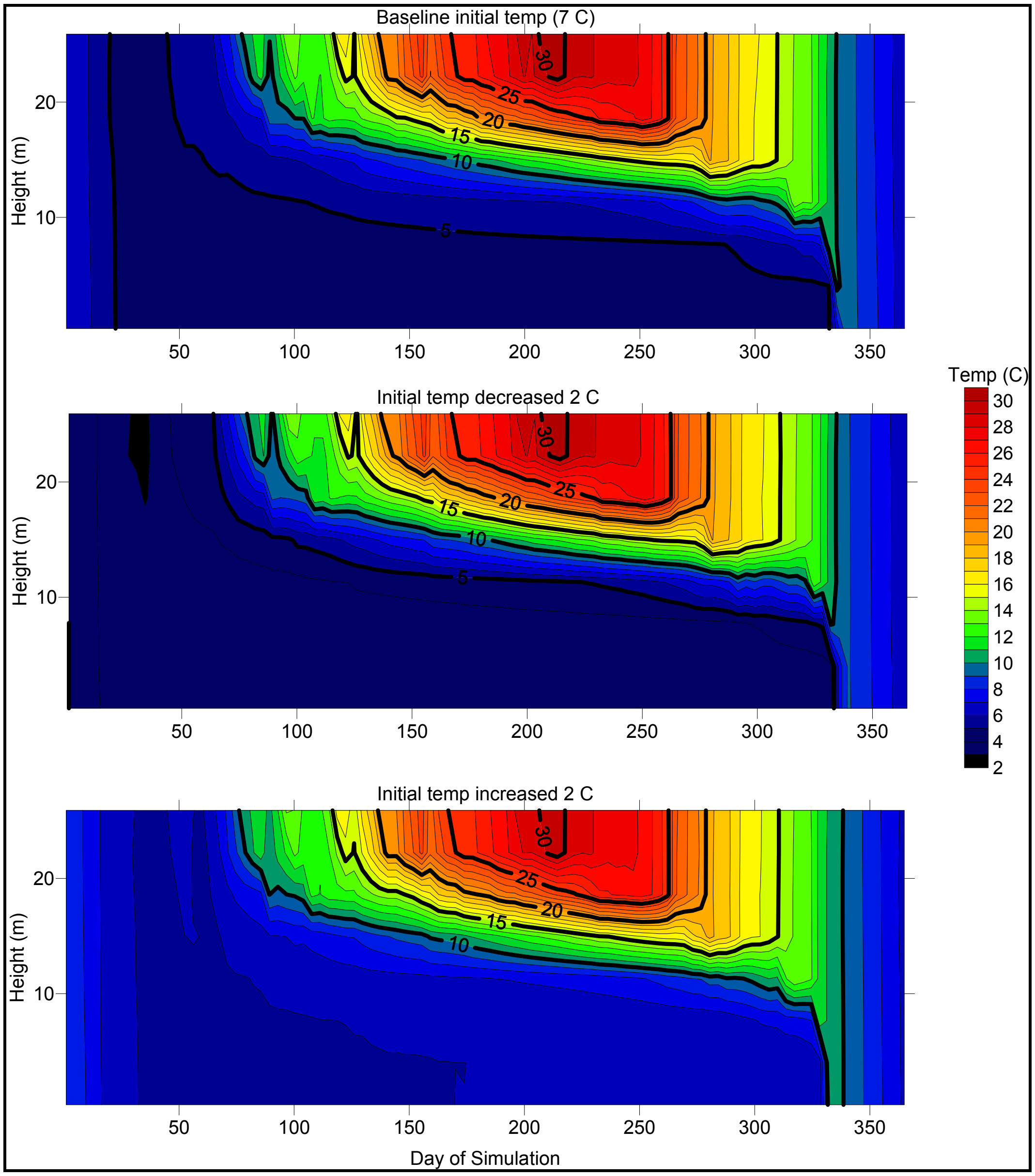

Figure A.3.10. Influence of the initial water temperature on vertical water temperature profiles.

One of the greatest sources of uncertainty in the model configuration was in the initial conditions of nutrients associated with the lake bed sediments because no data for Walker Lake sediments was available. The high nutrients condition was produced by setting all concentrations one order of magnitude higher than the baseline condition. The low nutrient condition was produced by setting all concentrations equal to zero. In spite of the extreme range of conditions used to test model sensitivity, no noticeable change in DO profiles was observed from the (a) baseline conditions for the (b) decreased (zero) or (c) increased initial nutrient concentrations, as shown in Figure A.3.11. Careful examination of near-bed data did reveal moderate changes in water column nutrient concentrations. In spite of this apparent lake of sensitivity, it is still recommended that sediment sampling for nutrients be conduced because at this point no such data exists for Walker Lake.

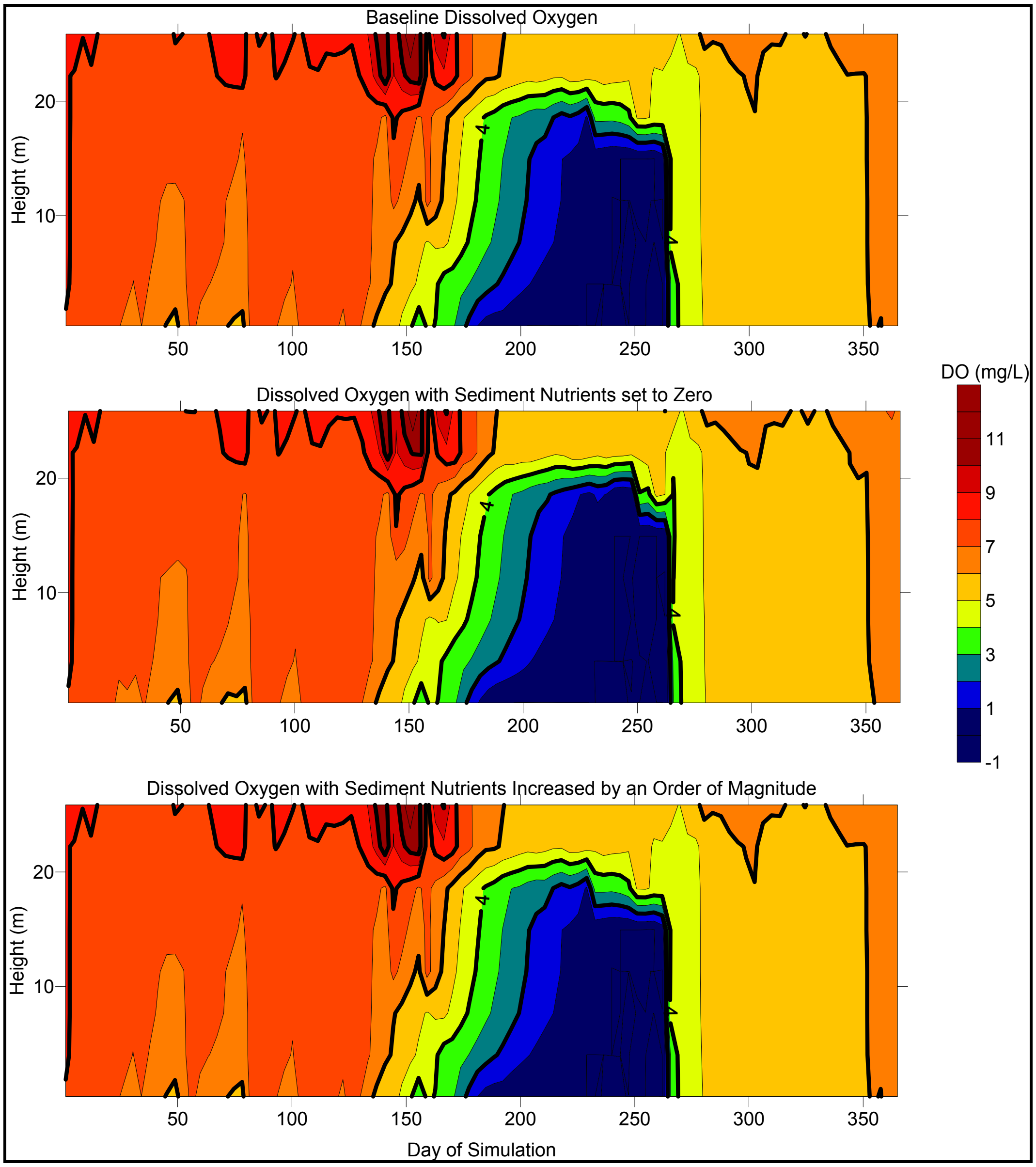

Figure A.3.11. Influence of initial lake bed sediment nutrient concentrations on vertical DO profiles.

Lake Input Uncertainty

The next source of uncertainty examined through the sensitivity analysis was that attributed to nutrient and TDS loads from the Walker River. As described above, only occasional water quality data is available for the lower reach of the Walker River and no data is available just above the confluence with Walker Lake. For the baseline condition, typical nutrient and TDS loads were estimated by examining the range of values observed within the Walker River with an emphasis on recent monitoring data. However, a substantial range in values (usually around one order of magnitude) was observed for much of the data. For the sensitivity analysis, a simulation was repeated with each nutrient and TDS load at both the high and low ends of the historical observed values. The range of values included: total phosphorus, 0.05 to 0.2 mg/L; phosphate, 0.1 to 0.8; ammonia, 0.01 to 0.1 mg/L; nitrate, 0.2 to 2.0 mg/L; and TDS, 100 to 500 mg/L. The model was insensitive to individual manipulations in nutrient and TDS loads. A final simulation was completed to examine overall nutrient load sensitivity by setting all nutrient and TDS concentrations to first their lowest and then their highest values, as listed above. Figure A.3.12 shows the simulated DO profiles under the (a) decreased and (b) increased nutrient load conditions. The changes resulted in only minor changes in DO profiles over the 1-year simulation. The model was likely insensitive to the changes do relatively small contribution of the river to the lake, in terms of flows and constituents, over the modeled period. As with bed sediments, it is still recommended that occasional sampling of nutrient loads to the lake is necessary because of the great shortage of information in this area.

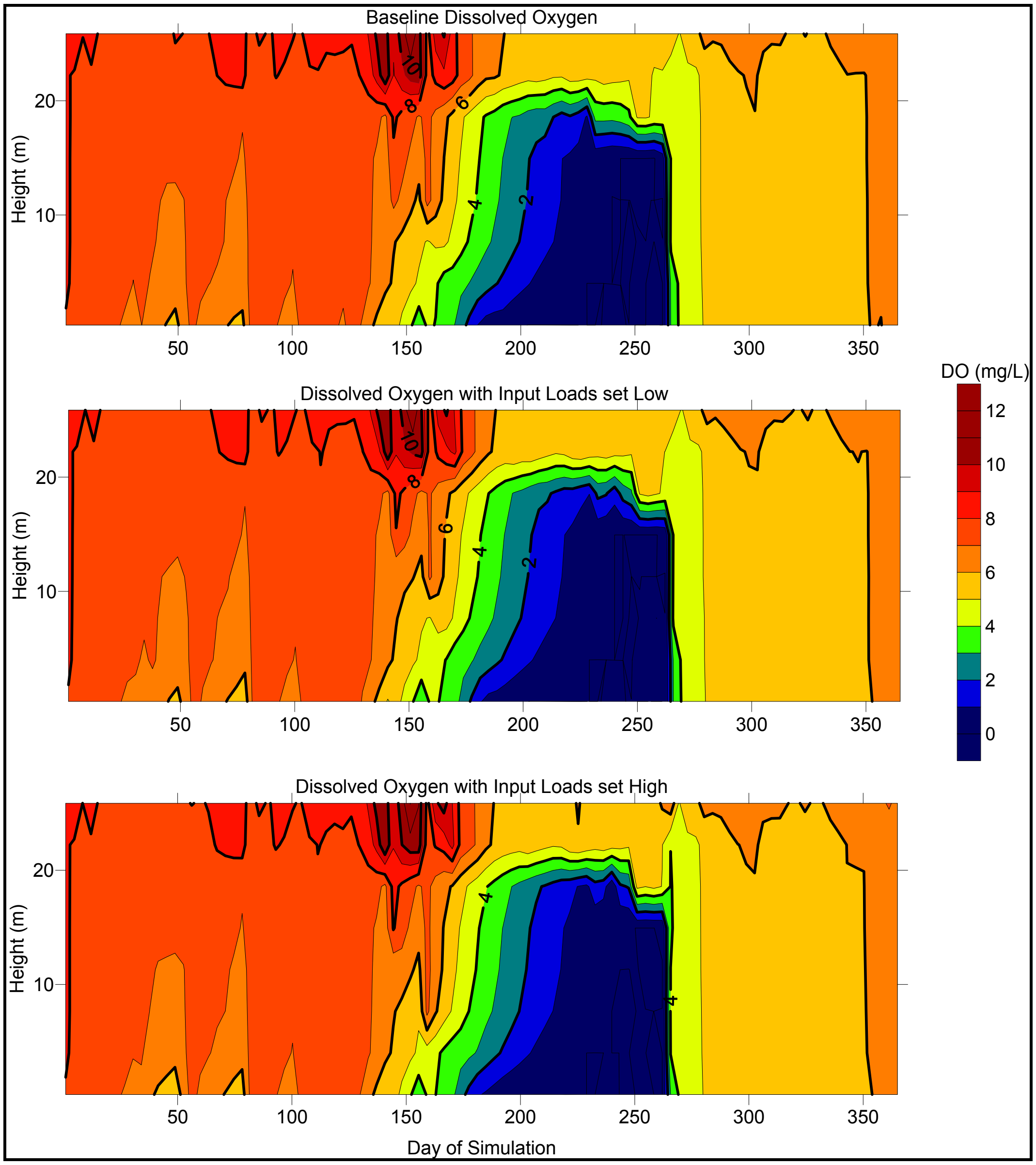

Figure A.3.12. Influence of Walker River nutrient loads on vertical DO profiles.

Parameter Uncertainty

The final component of the uncertainty analysis was an investigation of the sensitivity of the model to the various model parameters described in the calibration section above. The bulk aerodynamic momentum transport, shear production efficiency, energy mixing efficiency, wind stirring efficiency, and vertical mixing coefficients were all examined one-by-one to reveal model sensitivity to the suggested range of settings. The sensitivity analysis revealed that the model is insensitive to changes in the shear production efficiency, energy mixing efficiency, and wind stirring efficiency coefficients. Changes to the bulk aerodynamic momentum transport coefficient also resulted in very small changes in the simulated temperature profiles.

SCENARIO RESULTS

The Walker Lake model provides a tool for investigating the limnological impacts of various watershed management decisions on Walker Lake. Streamflow scenarios resulting from watershed management decisions will become available at the conclusion of this research and also in the future as additional water becomes available. Here we demonstrate the ability of the model using several hypothetical streamflow scenarios. We first investigate the models predictions of water surface elevations under a range of Walker River flow conditions. We then take a closer look at the lake dynamics under each scenario. The scenarios considered included the *Baseline* condition, which was the result of the 2007 model calibration simulation; a *High-Flow* scenario, which was based on period of 1982 to 1986 (the wettest five consecutive years in the gage record); a *Low-Flow* scenario, based on the period of 1989 to 1993 (the driest five consecutive years in the gage record; the minimum annual input from the Walker River to maintain the lake's water surface elevation as determined by Horne et al. (1994); and the minimum flow recommended by Thomas (1995).

Water-Surface Elevation

Figure A.3.13 shows simulated and observed water surface elevations for the calibration period (1/1/2007 to 1/1/2008) as well as for the high- and low-streamflow scenarios and the minimum flow scenarios suggested by Horne et al. (1994) and Thomas (1995). Under high-flow conditions (based on 1982–1986 streamflow data) the water surface elevation was forecasted to increase by approximately 1.3 m per year over the five year simulation. Under low-flow conditions (based on 1989–1993 data) the water surface elevation was forecasted to drop by 1.0 m per year. The water surface elevation was forecasted to increase by 0.20 m per year under the minimum streamflow of 140,000 acre-ft/year recommended by Horne et al. (1994) and to decrease by only 0.03 m per year under the 112,000 acre-ft/year suggested by Thomas (1995) (which is well within the uncertainty of the model predictions). Thus we can conclude that the model is performing well in describing the water balance of the lake. The results also corroborate the results of Thomas (1995), who suggested a minimum flow of 112,000 acre-ft/year to stabilize the water surface elevation of Walker Lake.

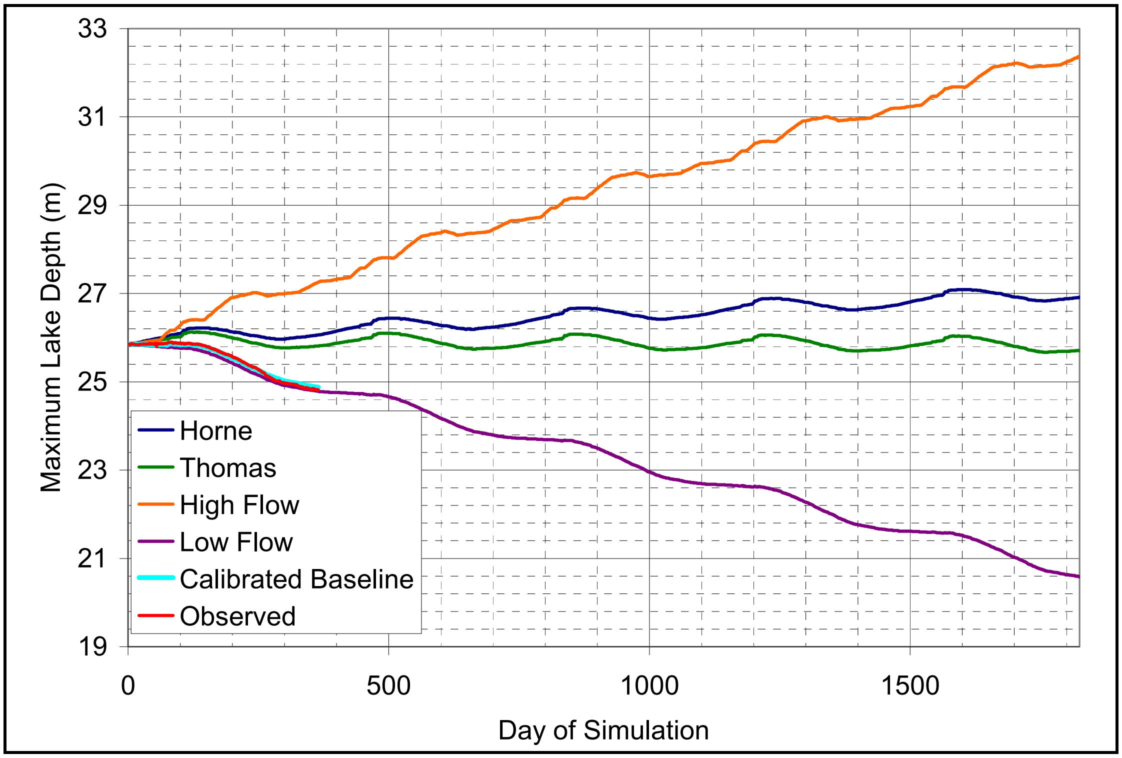

Figure A.3.13. Walker Lake water surface elevations for the observed and baseline conditions for the year 2007 and five-year hypothetical Walker River flows under high-flow and low-flow conditions and with the minimum flows determined by Horne *et al*. (1994) and Thomas (1995).

Baseline Scenario

The *Baseline* scenario was defined as the 2007 simulation period, which represents the contemporary status of Walker Lake. Figure A.3.14 contains the vertical profiles of temperature, salinity, and DO over the simulated period. The simulated results successfully reproduced the development and dissipation of a thermocline and the onset and dissipation of a hypolimnetic oxygen deficit.

Hypothetical High-Flow Scenario

Figure A.3.15 contains a summary of forecasted vertical distributions for water temperature, TDS, and DO under the high-flow condition over a 5-year simulation period. Under the high-flow scenario, the hypolimnion is forecasted to extend higher into the water column each summer as a result of increasing water surface elevation. According to the model predictions under these extremely high stream flows, a slight gradient in TDS could occur; with lower-density, low-TDS water not mixing completely with the higher-density, high-TDS water at the bottom of the lake. DO profiles under the high-flow scenarios are affected by reduced mixing, with elevated DO near the lake surface and depressed DO at the lake bottom. The increased density stratification forecasted here is likely a result of extremely high flows used in this scenario and a consequence of the assumptions inherent to a one-dimensional hydrodynamic model.

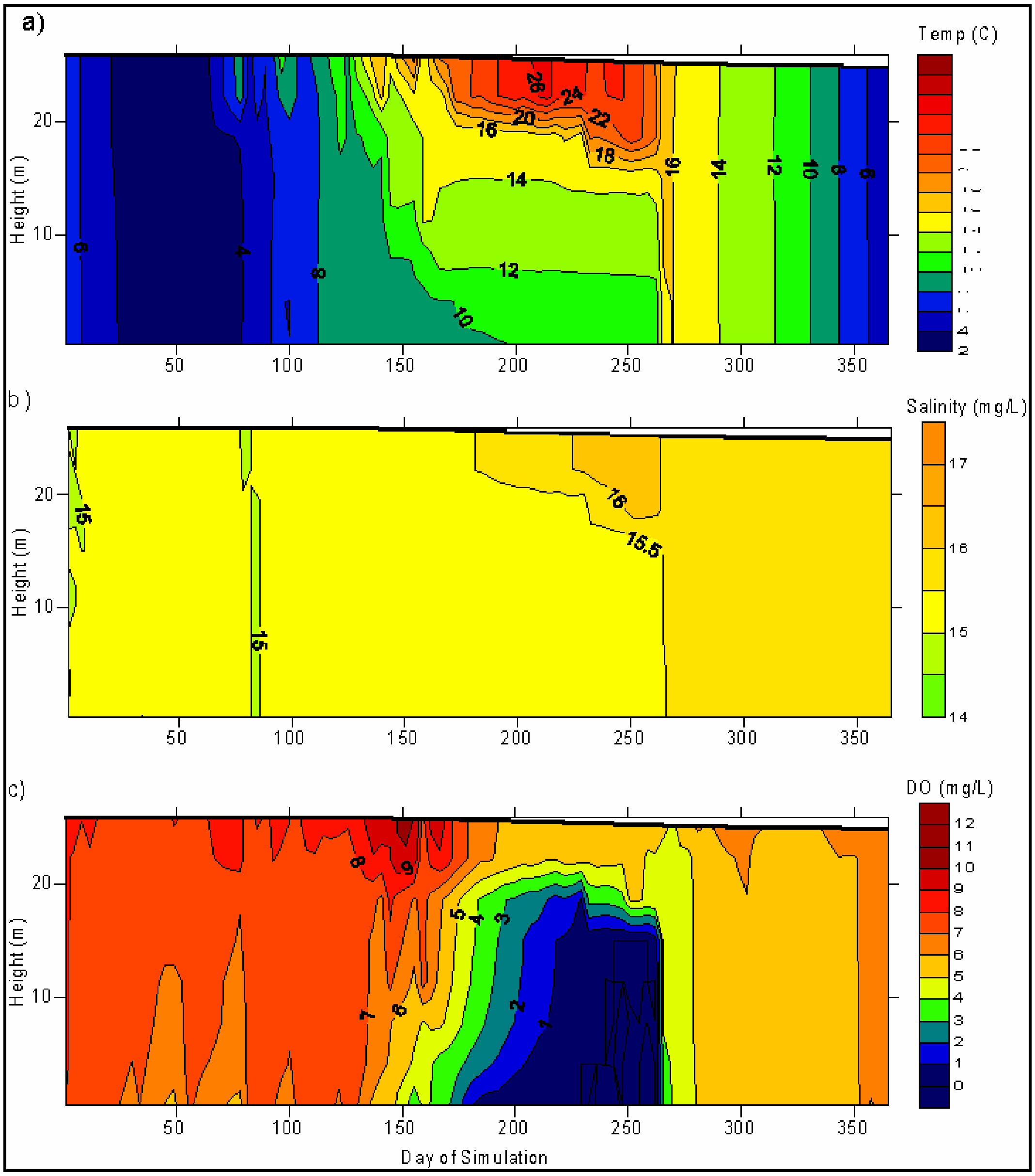

Figure A.3.14. Temperature, TDS, and DO vertical profiles under the baseline scenario (2007).

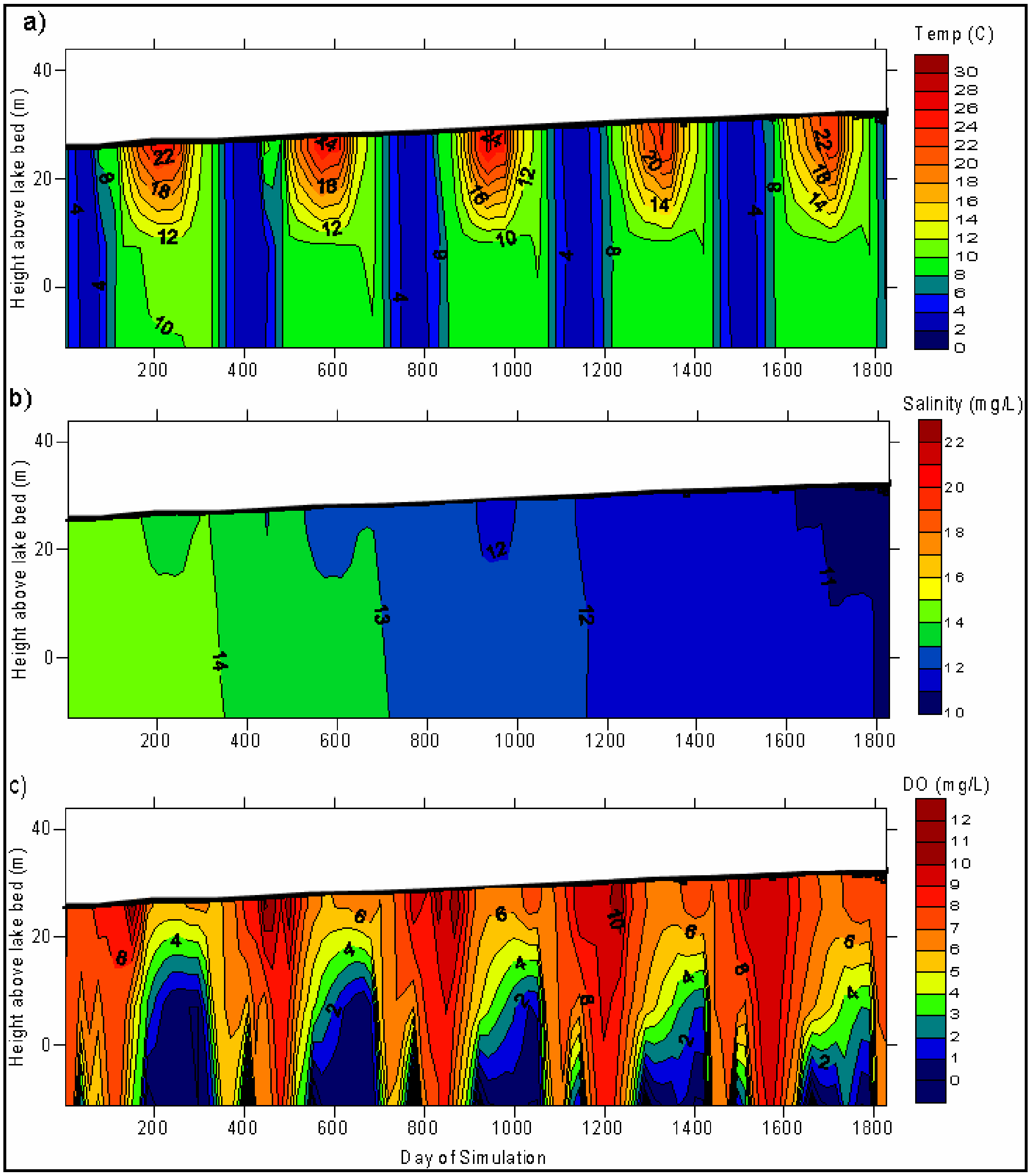

Figure A.3.15. Temperature, TDS, and DO vertical profiles under the high-flow scenario (2007).

Hypothetical Low-Flow Scenario

Forecasted results for the low-flow scenario are shown in Figure A.3.16. In this case, the extent of the hypolimnion is predicted to be reduced within the water column as the lake grows shallower from year-to-year. Thus, the cooler water required by Walker Lake fish would become available over an increasingly smaller vertical portion of the lake. Both the temperature and TDS profiles indicate complete mixing of the lake every fall. As a result, DO concentrations are forecasted to be more evenly distributed throughout the vertical profile. However, DO concentrations are shown to drop to anoxic levels near the lakebed during stratification. Under this scenario of extremely low flows over an extended period of time, the TDS levels in the lake are predicted to rise above 21,000 mg/L.

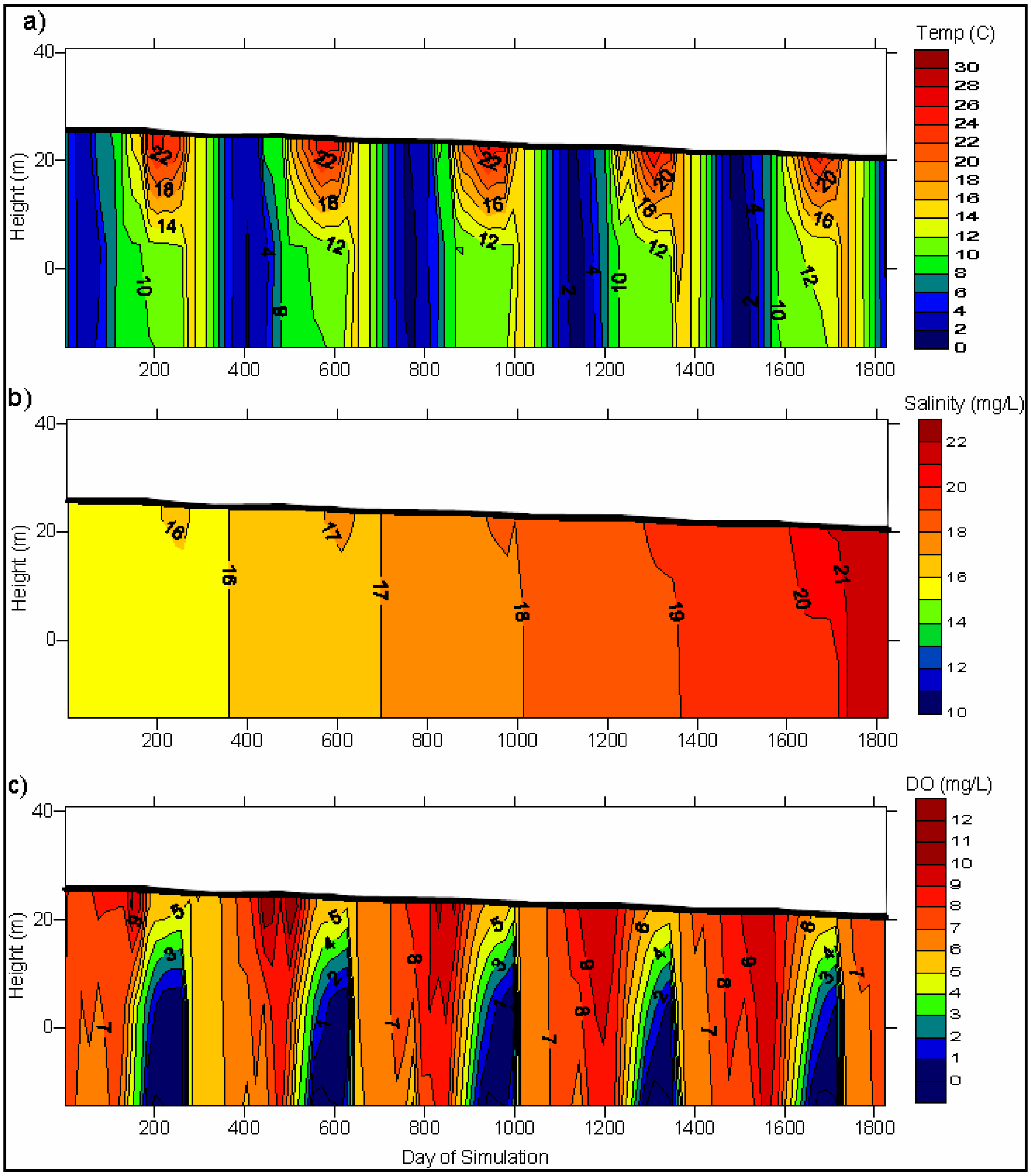

Figure A.3.16. Temperature, TDS, and DO vertical profiles under the low-flow scenario (2007).

Sustainable Flow

Forecasted vertical profiles for water temperature, TDS, and DO concentrations under the minimum annual flow determined by Thomas (1995) are shown in Figure A.3.17. As discussed above, the 112,000 acre-feet/year suggested by Thomas was evenly distributed on a daily basis over the simulation period. Future studies could also investigate the influence of streamflow timing on Walker Lake limnology. Due to the equilibrium state established for the lake water surface under this condition, the vertical profiles also are forecasted to remain stable from year-to-year. The only noticeable change over the five year simulation is a slight decrease in the height of the anoxic region with time.

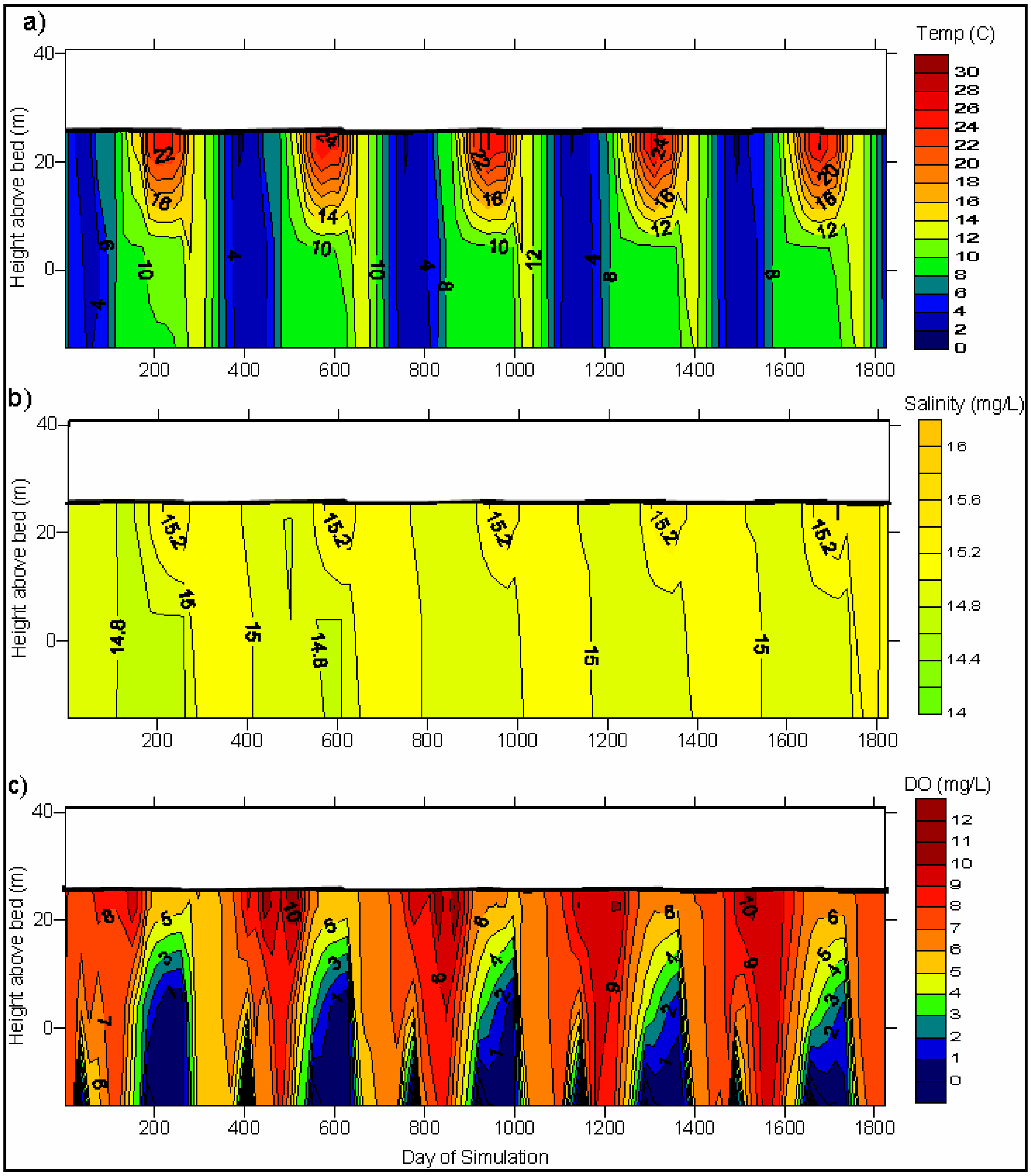

Figure A.3.17. Temperature, TDS, and DO vertical profiles with an annual Walker River flow of 112,000 acre-ft (Note: the color scale for TDS is the same as in Figures A.3.15 and A.3.16 but the contours have been adjusted to a higher resolution).

CONCLUSIONS AND RECOMMENDATIONS

An ecological model was calibrated and validated for Walker Lake. The model integrates the results from historical and contemporary limnological investigations within a tool that is capable of forecasting the influence of water management decisions on the lake's ecosystem. Although specific stream flow scenarios are not yet available, the hypothetical scenarios discussed above demonstrate the model's ability to forecast an overall water budget, along with internal dynamics, over a range of conditions. Simulations of the minimum flows recommended by Horne et al. (1994) and Thomas (1995) revealed that 130,000 acre-feet/year would result in a slight recovery of the lake's water surface elevation while 112,000 acre-feet/year would maintain the current condition. A comprehensive sensitivity analysis revealed which input data and model coefficients most strongly influence model predictions. The results are summarized below as recommendations for future monitoring efforts. Finally, the flexible nature of CAEDYM allowed us to apply the model to Walker Lake in a rather simplistic fashion. Model performance can be greatly improved by increasing the sophistication of the model through steps suggested below.

Data Needs for Improving the Ecological Model

- Local meteorological conditions: air temperature, wind speed, relative humidity, atmospheric pressure, shortwave radiation, longwave radiation, and precipitation
- Regular monitoring at the river mouth: continuous sampling of water temperature, TDS/conductivity, pH, and DO and regular sampling of TN, NH_3, NO_3, TON, TP, PO_4, TOP, TC, TOC
- Sediment characterization: particulate and porewater TN, NH_3, NO_3, TON, TP, PO_4, TOP, TC, TOC, H_2S and metals to improve descriptions of nutrient and metals fluxes at the sediment/water interface
- Algal characterization – seasonal characterization of major taxonomic groups
- Zooplankton characterization – seasonal characterization of major taxonomic groups

Future Steps for Improved Model Performance

- The model can be improved by incorporating a fish component. The data requirements would include dominant fish species, growth characteristics, and feeding preferences
- The model would also benefit from Walker Lake specific growth experiments for dominant algal and zooplankton species - especially for salinity related coefficients
- Improvement of the sophistication of the TDS routines to account for mineral precipitates should also be a priority

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A.4: WALKER LAKE: HYPOLIMNETIC OXYGEN DEFICIT ASSESSMENT AND ASSOCIATED LIMNOLOGICAL FACTORS

Contributing Authors: Chris Fritsen, Jeramie Memmott, Clinton Davis, and E. Wirthlin

ABSTRACT

All observations, data, and analysis continue to indicate that large nuisance blooms (rapid increases in algal population, typically by a small number of species) and deepwater hypoxia (low dissolved oxygen) will continue as the Walker Lake system is in the midst of the successional processes that enhance internal nutrient loading through oxygen depletion in the hypolimnion (water stratum below the mixed layer) leading to further enhancement of the blooms. The volume and areal extent of the hypolimnion oxygen depletion has decreased simply due to the reduction in the volume of the hypolimnion as water levels have declined. The production of organic matter leading to the hypoxia is sustained by exceedingly high levels of phosphorous (in excess of 20 µM) sustaining the N-fixing *Nodularia* blooms. Given the trajectory of water decline, the lake could soon make the transition to a polymictic status (frequent or continuous mixing throughout). In the event water management creates a situation where water levels may rise, the hypolimnetic oxygen-depleted zone is not likely to disappear unless means are found to minimize the internal loading of nutrients.

INTRODUCTION

Walker Lake presently is in a state of volumetric decline due to the lack of water delivery. One of the goals of the overall Walker Basin Project is to evaluate the present status of the lake regarding its overall limnological condition and re-evaluate best practices for assessing changes in the ecological condition over time that may occur in response to changes in management practices. Embedded within the project's overall goal was a specific objective to determine the present-day spatial and temporal extent of the lake's low-oxygen zones and evaluate limnological factors contributing to excess organic matter production, loading, and export into the deeper hypolimnetic waters where decay/respiration leads to oxygen depletion. To meet this objective, Walker Lake was surveyed and sampled between March 2007 and September 2008 for temperature, conductivity, and dissolved oxygen profiles. This information showed the extent of the lake's mixed layer, hypolimnion, and oxygen content. Profiles of algal biomass were obtained to assess organic matter content in the lake and the lake's potential for annual new production. Evaluations of these measures in conjunction with the measures of the lake's geochemistry and an evaluation of these in context of historical data and contemporary studies are contributing to the overall project's aims. These aims include assessing the present-day geochemical and foodweb status and parameterizing new food web and biogeochemical models for Walker Lake in an efforts to assess the effects of potential lake management strategies (including the delivery of more water to the lake). An overall compilation of these combined studies has been presented in Heyvaert *et al.* (this volume). Reported below are relevant data and data analyses that were specific to the aim of evaluating the lake's hypolimnetic oxygen deficit.

METHODS

Sample collection and *in situ* data collection were underway from March 7, 2007, to September 18, 2008. The majority of data was collected from three sites running north to south across the length of the Lake (WL2, WL3, and WL4), with the focus at WL3. Samples were collected using a 21-ft pontoon boat launched from Sportsman's Beach boat ramp (WL1) (Figure A.4.1).

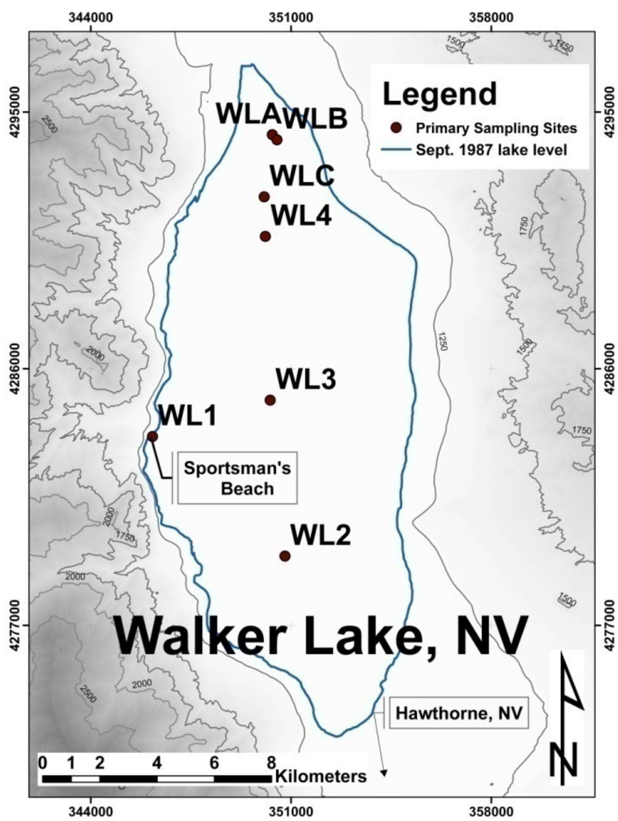

Figure A.4.1. Site map with sampling locations and main access point (Sportsman's Beach).

The structure of the lake was evaluated using a YSI 6600V2 multi-parameter probe with an attached downwelling photosynthetically active radiation (PAR) sensor. The multi-probe was configured to simultaneously measure and record *in situ* temperature, dissolved oxygen, specific conductivity, pH, oxidation-reduction potential, and PAR. The dissolved oxygen and depth sensors on the multi-probe were calibrated on site prior to data collection to ensure proper compensation for altitude and barometric pressure. The remaining probes were calibrated in the laboratory on the day prior to sample collection.

Following the initiation of the profiling, discrete sample collections were routinely taken at 2.5-m intervals from just below the water surface to greater than 1 m above the lake bottom. The depth at WL3 varied from approximately 25 m during the first sampling to approximately 23 m during the final sampling. At WL3, samples were collected at 0, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, and 22.5 m using a 5-L Niskin bottle. The samples were immediately placed in 1- or 2-L amber HDPE bottles and placed on ice in a dark cooler for transport to the DRI Reno Laboratory for processing. Simultaneously, water samples for nutrient and metals chemistry analysis were collected using a peristaltic pump. Secchi depth was determined using a 20-cm white Secchi disk from Wildco®. Next, vertically integrated zooplankton tows from near the bottom to the surface were collected using a 50-cm-diameter zooplankton net with 80-micron mesh. Samples were rinsed from the net with Walker Lake water into 1-L clear HDPE bottles and placed on ice in a dark cooler for transport to the laboratory. Zooplankton samples were collected on March 7, 2007, May 22, 2007, September 28, 2007, October 3, 2007, and December 4, 2007, and then sent via overnight carrier to the DRI Las Vegas laboratory for quantitative analysis.

This sampling protocol was followed for each sampling trip with the exception of August 23, 2008, when wind prevented sampling on the lake and samples were collected only from WL1. Additional sampling was carried out to augment this basic plan. Samples collected for primary production assays (March and December 2007) were placed in 2-L amber HDPE bottles, filled to overflowing, and placed in a cooler containing lake water. The lake water in the cooler was monitored and held at the mean epilimnetic temperature through small ice additions until back in the laboratory. Mini-Winkler samples were collected in 20-mL scintillation vials with poly-cone caps and fixed through the addition of Mn^{2+} solution and alkali-iodide-azide solution immediately after collection. These samples were then kept cool in the dark until analysis. All samples were transported back to the DRI Reno Laboratory the day of sample collection for processing or shipping to the DRI Las Vegas Laboratory.

Once samples were in the laboratory, samples were promptly processed according to standard operating procedures. The sample transport containers were homogenized through agitation and subsampled for chlorophyll *a* (chl-a), particulate organic carbon/nitrogen (POC/N), particulate phosphorus (PP), algal pigments, bacterial enumeration, and algal identification/enumeration. Chlorophyll *a* and pigment samples were vacuum filtered onto Whatman GF/F glass fiber filters, which were placed into 20-ml borosilicate glass scintillation vials and immediately into a -80°C freezer until analysis. The POC/N samples were vacuum filtered onto pre-combusted GF/F filters, promptly placed in a drying oven for more than 24 hours and stored in a container with desiccant until analysis using a Perkin Elmer 2400 Series II CHNS/O system. The PP samples were filtered onto acid-rinsed GF/F filters, dried, and stored with POC/N filters. The concentrations of PP extracts were determined colorimetrically.

Duplicates and blanks were prepared for each ten samples processed for each analyte conducted. These quality assurance samples were analyzed with the other samples and analytical blanks were also incorporated in the analysis. The mean percent difference for duplicates of environmental samples were less than 30 percent and much lower for analytical duplicates. Analytical results from procedural and analytical blanks were well below sample results, typically near or below the level of detection for each analyte. The ratios of analytical results (e.g. particulate carbon to particulate nitrogen) were plotted to identify analytical results that fell outside the pattern of values observed, and then the identified samples were investigated for errors in calculation or to determine the validity of the result.

Chlorophyll *a* pigment concentrations were determined via fluorometry using the Welschmeyer (1994) method in a Turner Designs model 10AU fluorometer calibrated with purchased standards (i.e., chlorophyll *a* from *Anacystis nidulans*, Sigma Corp.). Chlorophyll *a* content was checked against a spectrophotometric (Parson *et al*. 1984) method for quality assurance. The POC/N concentrations were determined using the method outlined by Karl *et al*. (1991). Subsamples were filtered onto pre-combusted filters, which were acidified through exposure to hydrochloric acid fumes, and then encapsulated in tin discs before analysis with a Perkin-Elmer 2400 series II CHN/O analyzer. Subsamples for PP were processed in a manner similar to POC/N subsamples (Karl *et al*. 1991), then digested to extract organic and inorganic fractions using the method outlined by Pardo *et al.* (2003). The phosphorus concentration of the resulting extracts were determined colorimetrically using the Lachat QuikChem® Method 12-115-01-1-F (McKnight and Sardina 2001) with a Lachat QC8000 F.IA.

Phytoplankton (freely floating algae or bacteria) subsamples were preserved by addition of gluteraldehyde to a final concentration of 0.5 percent. Enumeration involved counting a target number of natural units from each sample. The usual target number of natural units was n equal to or greater than 400. Natural units were deemed appropriate instead of cells, due to the fact that colonial or filamentous cells do not occur singly in nature, so individual cells would be inappropriate to portray relative abundances (Mills *et al*. 2002). Differential interference contrast (DIC) microscopy using an Olympus BX-60 equipped with epiflourescence and digital imaging capabilities was used for enumeration and identification. As outlined by PhycoTech, the magnification used was dependent on the dominant taxa encountered within the sample slide. Overall, the goal was to enumerate and identify taxa present across a range of magnifications. Once the correct magnification was determined for the majority taxa-type, a minimum of 15 fields were viewed and the natural units enumerated under that magnification. In addition, the minority cell types were counted. All taxa encountered were image-documented for quality assurance and archival purposes. Biovolume estimates for each contributing taxa were determined by assigning formulas outlined in current literature (Hillebrand and Sommer 1999).

Profile data and sample analysis data have been integrated into the DRI Walker Microsoft™ Access database and the overall description of this database is reported in Hayevert *et al.* (submitted) and in the technical reports on the database compilation.

RESULTS

Walker Lake has been declining since the mid 1800s (Figure A.4.2). Periodic increases in lake level during the mid 1980s and late 1990s are attributed to increased runoff from higher precipitation years. In spring 2007, the lake elevation was at 1,200 m above sea level. The Walker Lake drainage basin depth-surface area and depth-volume relationships from the lake bottom are given in Figure A.4.3, and at that elevation, the lake's maximum depth was at 28.5 m (Sollberger and Wright 2002 to 2007, Lopes and Smith 2007), which indicates the mean depth of the lake was at approximately 16.5 m.

The surface area was 1.31 x 10^8 m^2 (32,280 acres) and the storage volume was 2.21 x 10^8 m^3 (1.792 x 10^6 acre ft).

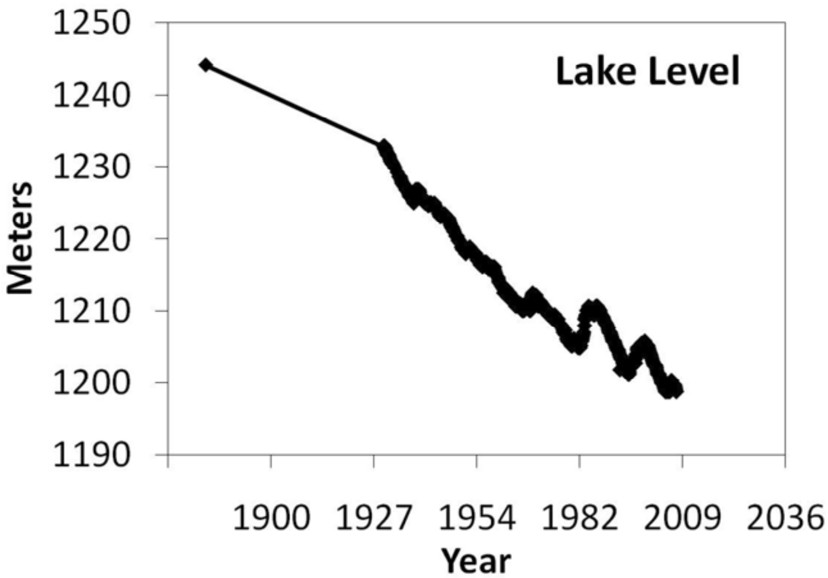

Figure A.4.2. Historical lake elevation changes (Russell 1885, Koch *et al*. 1979, U.S. Geological Survey 2001, Sollberger and Wright 2002 to 2007).

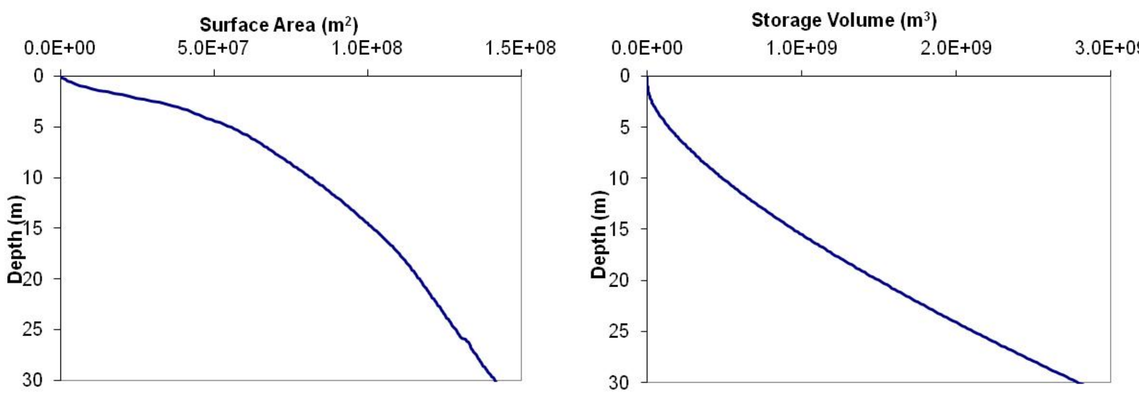

Figure A.4.3. Depth-area and depth-volume relationships for the Walker Lake basin. In 2005, the maximum depth was 28 m (Lopes and Smith 2007).

Walker Lake has been sampled at a variety of locations in the past. The most commonly sampled locations are shown on Figure A.4.1. Sportsman's Beach (WL1), has a relatively longer record, having been sampled since 1990. The most frequently sampled site is WL3, approximately in the center of the lake. This is the most sampled site in the study because of its being close to the maximum depth and because it offers the means to assess the physical and chemical conditions of all the lake's layers. Profiling and sampling also occurred at other locations by both DRI and UNR, most commonly at WL2 and WL4, and additional sites near the entrance of Walker River (Figure A.4.1).

Temperature Dynamics

Temperature profiles taken throughout 2007 and into 2008 showed Walker Lake thermally stratifying during the end of April and early May, with additional surface heating through September (Figure A.4.4). Surface water temperatures ranged from 3 to 4^{o}C in the winter and up to 25 (25.28 maximum) ^{o}C by late summer. Density stratification in Walker Lake is primarily driven by thermal stratification and as the lake cools and becomes isothermal during winter, it mixes. There is not presently an indication of layering due to dissolved solids (i.e., TDS or conductivity).

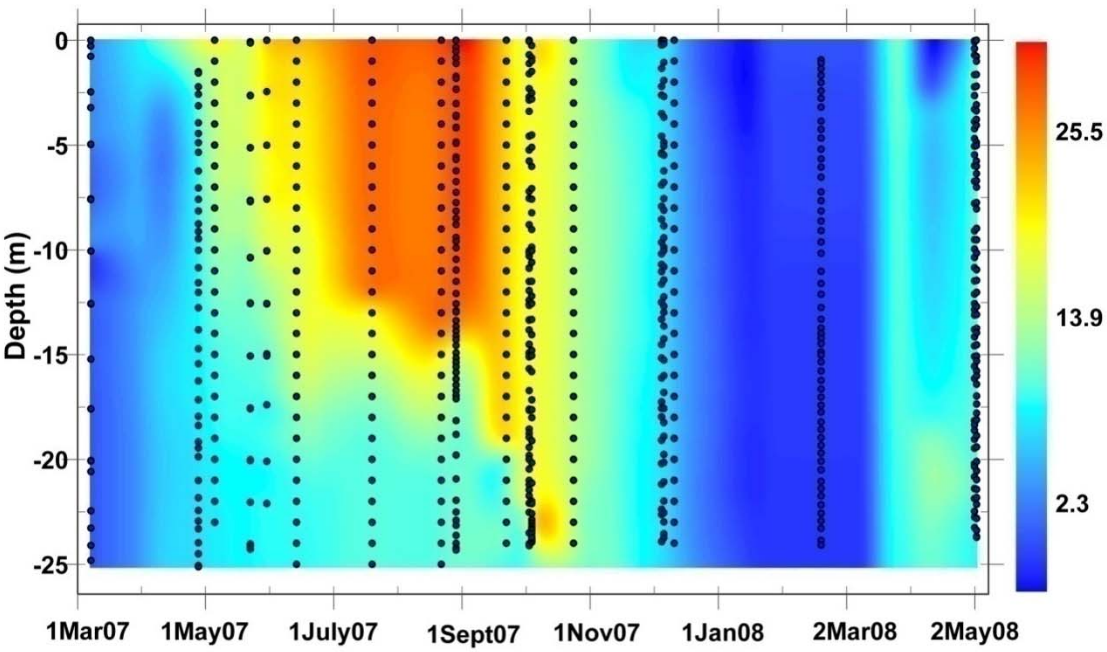

Figure A.4.4. Temperature-depth dynamics from 2007 to May 2008 derived from data collected by DRI, UNR and NDOW (Sollberger and Wright 2002 to 2007). The interpolation of data points was created using the Spline tool in the 3D Analyst extension of ArcMap 9.2 (ESRI 2009) with default optional settings.

Seasonal heating led to a surface mixed layer of approximately 13 to 15 m in 2007. This summer mixed layer depth (MLD) was comparable to that in 2006 (as derived from historical data; Figure A.4.5) yet appeared to be slightly shallower than in 2003 to 2005 (when summer MLDs appeared to be approximately 1 m deeper). All of the annual thermal profiles captured the extension of warmer water (approximately 18 to 20^{o}C) to depths exceeding 20 m in association with the seasonal cooling and destratification of the lake. In October 2007, relatively warm water (15^{o}C) extended almost to the bottom of the lake. The timing of this destratification generally occurred in October of each year. Any apparent differences in summer MLDs, temperatures, and/or the timing of the deepening of the MLD/destratification should not yet be interpreted as indications of changes in the overall lake condition, as these dynamics are largely controlled by local air temperature, wind conditions, and the lake's prior seasonal thermal history. A much longer term compilation of a time series of temperature profiles would be needed to assess any significant changes in the lake's thermal mixing regimes.

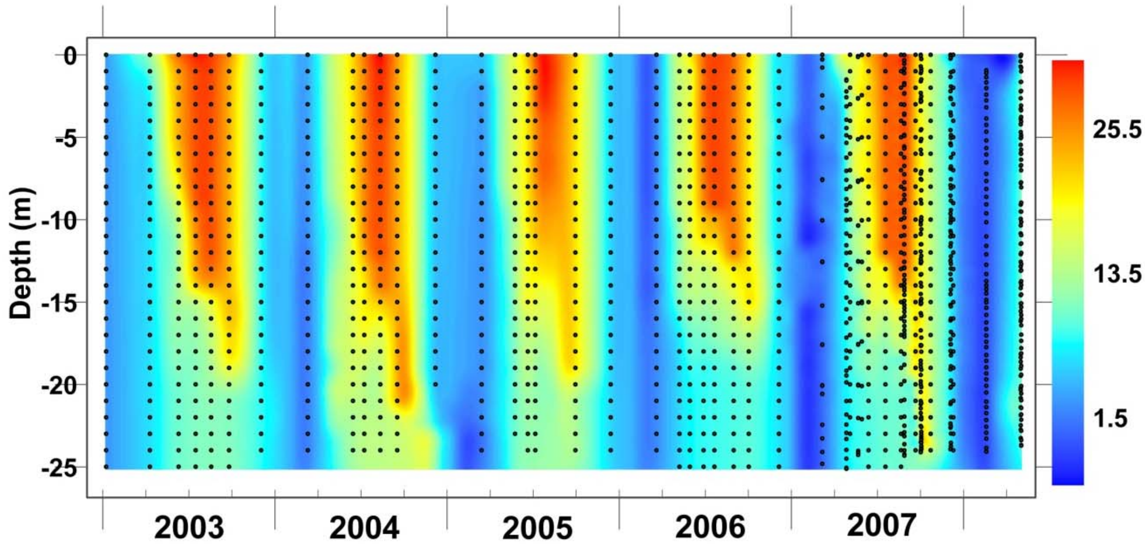

Figure A.4.5. Walker Lake's annual temperature dynamics from 2003 through spring of 2008 derived from data collected by DRI, UNR and NDOW (Sollberger and Wright 2002 to 2007). The interpolation of data points was created using the Spline tool in the 3D Analyst extension of ArcMap 9.2 (ESRI 2009) with default optional settings.

Dissolved Oxygen

Surface water dissolved oxygen (DO) ranged from a high of 12 mg/L in March to a low of 6.4 mg/L in October. Deepwater hypolimnetic oxygen ranged from a high of 12 mg/L during the early spring to being anoxic during the summer stratification. Hypoxia or dissolved oxygen concentrations less than 2 mg/L (USGS 2006) started at approximately 17 m and the depth at which DO levels were below 5 mg/L was at 14 m. This oxygen-depleted hypolimnion persisted throughout the summer and into early October, when the MLD began its seasonal deepening (Figure A.4.6). The lake's deepwater hypoxia has been known since the late 1960s and early 1970s (Koch *et al* 1979) and has been repeatedly documented in the monitoring programs in the past several years in addition to those reported since the early 1970s and 1990s (Figure A.4.7; Horne *et al.* 1994; Beutel and Horne 1997; Sollberger and Wright 2002 to 2007).

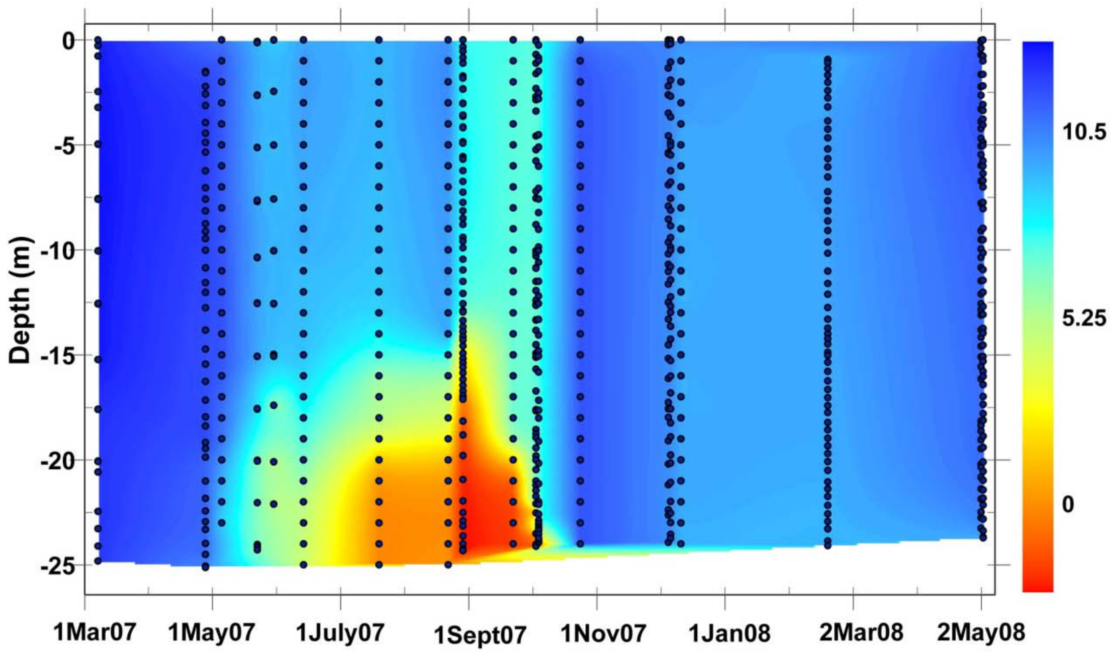

Figure A.4.6. Dissolved oxygen dynamics in Walker Lake during study showing extent of oxygen depletion in deepwater. The data were collected by DRI, UNR and NDOW (Sollberger and Wright 2002 to 2007). The interpolation of data points was created using the Natural Neighbor tool in the 3D Analyst extension of ArcMap 9.2 (ESRI 2009).

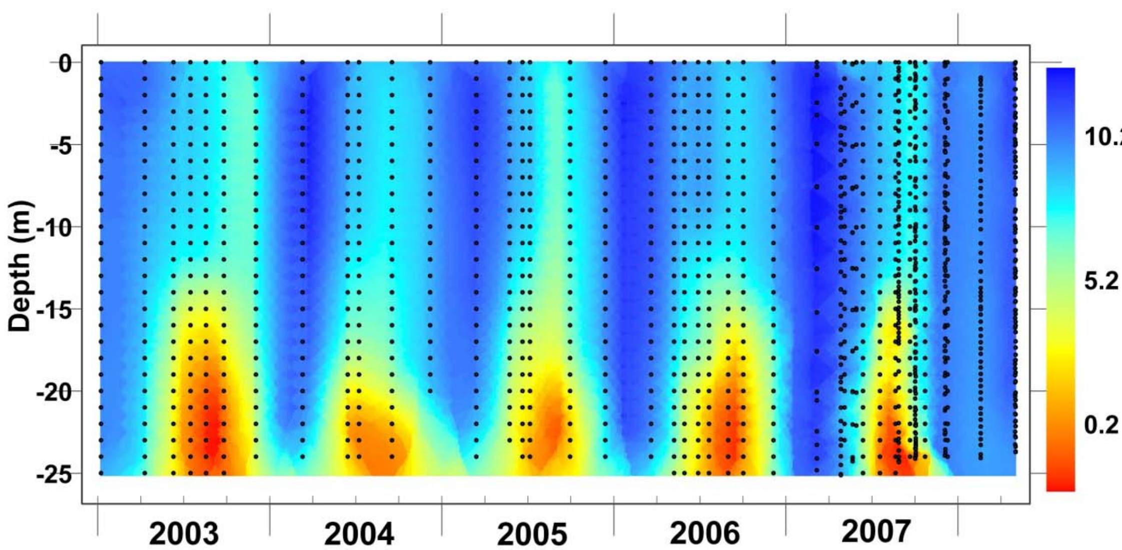

Figure A.4.7. Dissolved oxygen dynamics in Walker Lake from 2003 to 2008 illustrating extent and duration of oxygen depletion in the hypolimnion. The data were collected by DRI, UNR and NDOW (Sollberger and Wright 2002 to 2007). The interpolation of data points was created using the Kriging tool in the 3D Analyst extension of ArcMap 9.2 (ESRI 2009).

The hypolimnetic oxygen deficit (HOD) is a means for estimating the autotrophic productivity of a lake based on the oxygen consumed during decomposition of autochthanous organic material in the hypolimnion of lakes where thermal stratification is evident (Wetzel and Likens, 2000). The HOD is calculated through monitoring the oxygen concentration in the hypolimnion throughout the period of stratification. The total HOD during 2007 was calculated at 3.77 x 10^9 g of oxygen, given the deficit of oxygen in the bottom 8 m of the lake (i.e. depth at the top of the hypolimnion of 17 m). With a surface area at the top of the hypolimnion of 1.09 x 10^8 m^2 (Lopes and Smith 2007), the areal HOD was on the order of 34.5 g O_2 m^{-2}. Because the hypolimnion oxygen concentrations were depleted to anoxia and the oxidation of reduced organic matter proceeds via alternative electron acceptors and fermentive processes, the HOD only represents the very minimum estimate of the net productivity of the lake (i.e., the calculation is likely to represent a large underestimate).

When the DO in the hypolimnion is not depleted to the point of anoxia, the HOD becomes a more accurate tool for calculating the net productivity of the system as the use of alternative electron acceptors and fermentative processes are reduced. When the lake has sufficient volume, the amount of oxygen in the hypolimnion at the onset of stratification is more likely to be sufficient to supply decomposition through the period of stratification without causing anoxia. But, as the lake level decreased and the gross oxygen content of the hypolimnion at the onset of stratification decreases, the net oxygen deficit during stratification grows (assuming productivity and subsequent decomposition stays the same or increases). The analysis of the net HOD is instructive when compared to the past extent of oxygen deficits in the lake.

In 1976, the lake was 35 m deep and had a hypolimnetic oxygen depleted zone that extended from the depths in excess of 13 m to the bottom of the lake at the end of July (Koch *et al*. 1979). This extent of hypoxia leads to an estimated total HOD of 2.54 x 10^{10} g O_2 and an areal HOD of 208 g O_2 m^{-2}. In 1993, the oxygen-depleted zone extended about 15 m from the bottom (Horne *et al*. 1994) and the total HOD was estimated at 1.26 x 10^{10} g O_2 with an areal HOD of 120 g O_2 m^{-2}. From these past studies, it is readily apparent that the productivity of the lake is sufficient to overwhelmingly drive and create extensive anoxia even when the lake was approximately 10 m deeper. However, this comparison also hints at a decrease in the net areal oxygen deficit as the lake level has decreased and emphasizes that the morphometric scaling of these processes changes as the lake levels change. Specifically, it is worth noting that the ratio of the hypolimnion volume to total lake volume decreased three-fold (from 0.6 to 0.2) and the ratio of the hypolimnion's surface area to the lake's epilimnion volume decreased 2.3-fold (from 0.095 to 0.04) between 1976 and 2007.

Some of the changes in these ratios are due to the summer MLD remaining relatively constant at about 13 to 15 m even as the lake levels change. Due to this progression over the years, the concern for coldwater fisheries has been the decrease in the volume of water at depths below the warm surface water layers that also has sufficient oxygen for respiration. During 2007, it is apparent that there were approximately two weeks in which the lake may have been deficient of water less than 20^{o}C and had oxygen in excess of 5 mg/L (which are boundary conditions considered to be restrictive for Lahontan cutthroat trout survival) (Cooper and Koch 1984).

The change in the ratio of the hypolimnetic anoxic zone surface area to the surface mixed layer is particularly noteworthy because it indicates that the relative magnitude of internal geochemical processes and habitat distributions is likely to be changing relative to the lake volume changes simply due to morphometric scaling. For instance, if internal nutrient loading were to remain constant in proportion to the surface area of the hypolimnetic zone, then the relative loading to the lake's overall volume may actually be decreasing as the lake level becomes shallower. In addition, as the lake shallows, the relative proportion of the lake volume illuminated by solar radiation also changes.

Euphotic Zone and Optical Properties

Relative changes in fraction of the lake's volume and surface areas of benthos within the euphotic zone (traditionally defined as the 1-percent light penetration depth) are influenced not only by the morphometric changes but also by the changes in the water constituents that absorb and scatter light. Profiles of photosynthetic radiation taken during the study indicate the penetration of the 1-percent light level to depths of 24 m in the winter months, decreasing to depths between 13 and 19 m during spring and summer seasons (Figure A.4.8). The nominal 1-percent light level was measured at 9 m on May 1, 2008, when phytoplankton biomass was measured at its highest during the study (at about 10 μg/L).

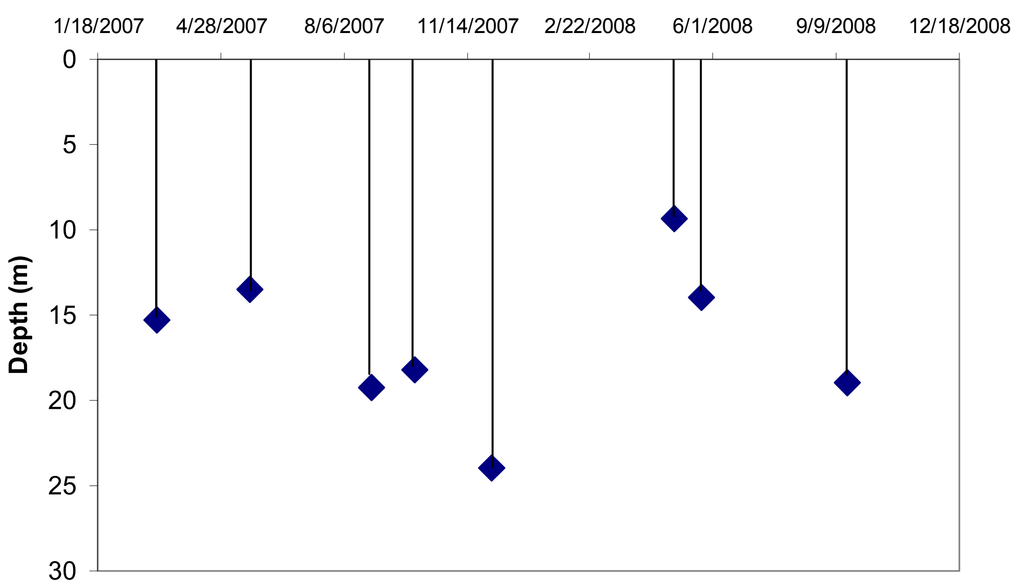

Figure A.4.8. Depth of the measured 1-percent light penetration (a surrogate approximation of the euphotic zone) during the study. PAR data were collected using a LI-COR Biosciences LI-192 Underwater Quantum Sensor.

The euphotic zone depths were reported as being 7 to 9 m during the mid 1970s (Koch *et al*. 1979). The differences in reported light penetration between that time and 2007 may be an indication of an increase in the overall clarity of the lake since that time.

Maximum Secchi depths reported in 1975 to 1976 were approximately 33 percent of that recorded in 2007 and 2008 (Figure A.4.9) and additional data collected in the 1990s and 2007 seem to indicate that the clarity may indeed be increasing, especially during winter (Koch *et al*. 1979, Horne *et al*. 1994, Beutel and Horne 1997, Sollberger and Wright 2002 to 2007). One of the potential implications of this increase when coupled with the decreasing water level could be a change in the amount of time and area over which the benthos receives more than one percent light and the amount of radiation penetrating the anoxic hypolimnion. In 1975, with a euphotic zone depth of approximately 8 m, the projected benthic surface area would have been on the order of 2.0 x 10^7 m^2; in 2007, using the same calculations (and assuming an average euphotic zone depth of 12 m), the projected benthic area in the euphotic zone would be on the order of 2.3 x10^7 m^2, which represents only a slight increase in the very roughly calculated area for benthic production. However, this area represents a substantially larger fraction of the lake's surface area (approximately 18 percent in 2007 compared to about 12 percent in 1975). Thus, the relative contribution of primary production in littoral zones may be on the increase as the lake level continues to decline. It is unclear from the literature whether or not this would in turn lead to an increase or decrease in the productivity of the fishery.

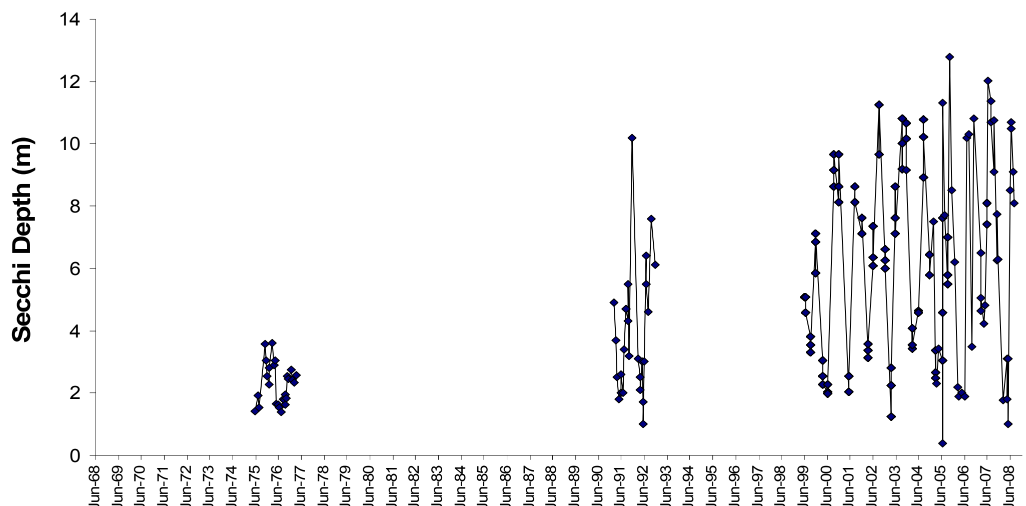

Figure A.4.9. Measured Secchi depth frome the current study and over the past 33 years at Walker Lake near the WL3 monitoring location (Koch *et al*. 1979, Horne *et al*. 1994, Beutel and Horne 1997, Sollberger and Wright 2002 to 2007).

Chlorophyll-*a* and Algal Biomass

Phytoplankton dynamics followed an annual cycle that included a winter minima and a spring bloom, which is not unexpected from a moderately deep monolithic temperate lake. The largest biomass measured during the study occurred at the end of April and in early May 2008. This spring bloom was observed on April 25 (Figure A.4.11) and sampled on May 1, only a few days later. Biomass at the WL3 site was measured at about 10 µg chl-a/L and, based purely on visual observations, the surface accumulations did not appear to be as large as they had been only a few days earlier (Figure A.4.10). During spring 2007, the lake was sampled on April 27, and the peak biomass measured during this time was only 1.5 to 3.2 µg chl-a/L. However, based on the observations and images taken by a resident of the town of Walker, this sampling occurred a few weeks prior to the major spring bloom of that year, when surface accumulations were also prevalent and easily notable. Based on these observations, it is highly likely that sampling on a monthly or quarterly basis is not effective in documenting the peaks of the spring blooms (e.g., like those observed in 2007 and 2008).

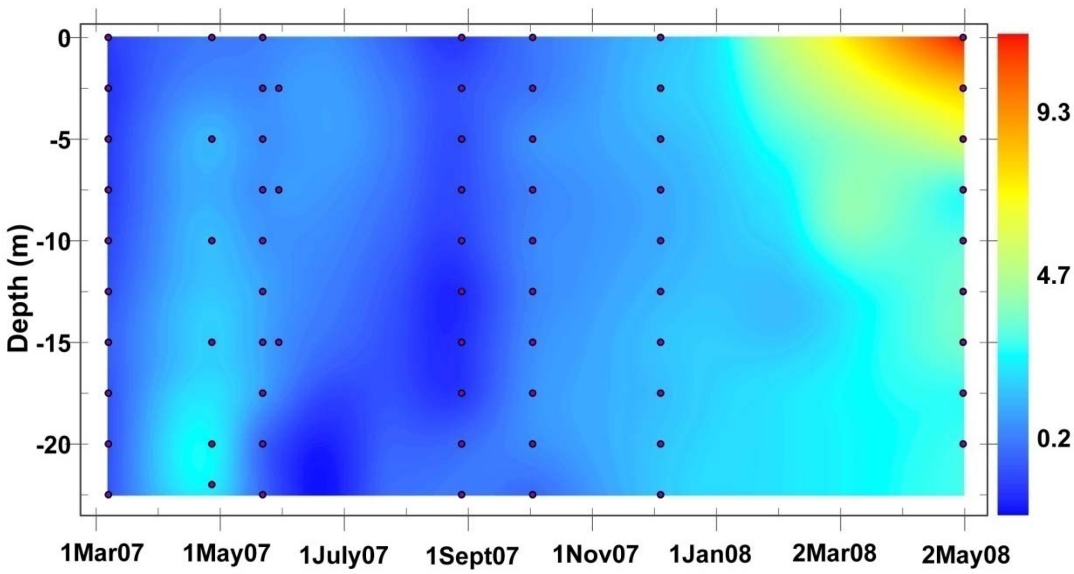

Figure A.4.10. Contours of chlorophyll-*a* concentrations during the study. Maximum biomass was 10 µg/L during the May 2008 sampling. The interpolation of data points was created using the Spline tool in the 3D Analyst extension of ArcMap 9.2 (ESRI 2009).

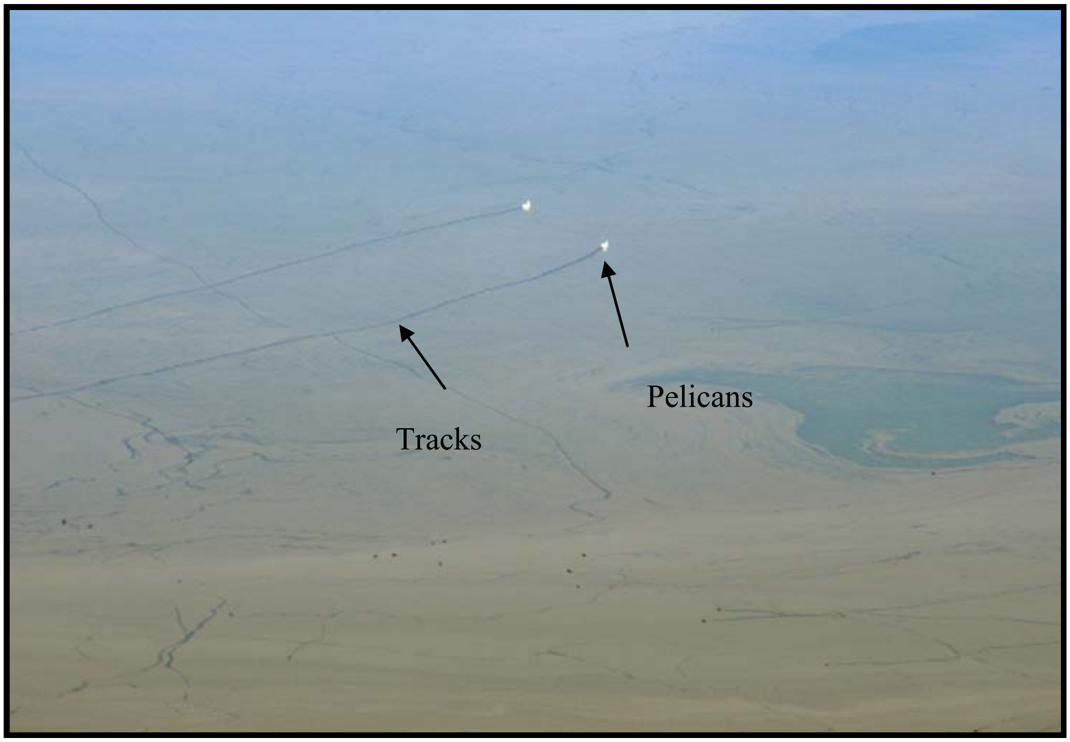

Figure A.4.11. Images showing birds (pelicans and coots) swimming through surface accumulations of the cyanobacterial bloom (*Nodularia*) on April 25, 2008, and their "swimming tracks".

Phytoplankton

The phytoplankton of Walker Lake—although attaining high levels of biomass—was relatively depauperate in regards to richness and diversity, with only a few taxa comprising the plankton assemblage during all seasons (Figure A.4.12). *Nodularia* spp. mostly dominated the phytoplankton assemblages in terms of biovolume, with lesser volumes of *Spermatozopsis* and a small autotrophic flagellate (yet to be positively identified) during spring and summer. During winter, other taxa were more prevalent, notably *Chaetocerous*, a small chain-forming diatom, and Chlorophytes. Synechoccocea were also prevalent and abundant throughout the study. Yet due to their small size (typically ~1.5 µm) they did not often dominate the biovolume.

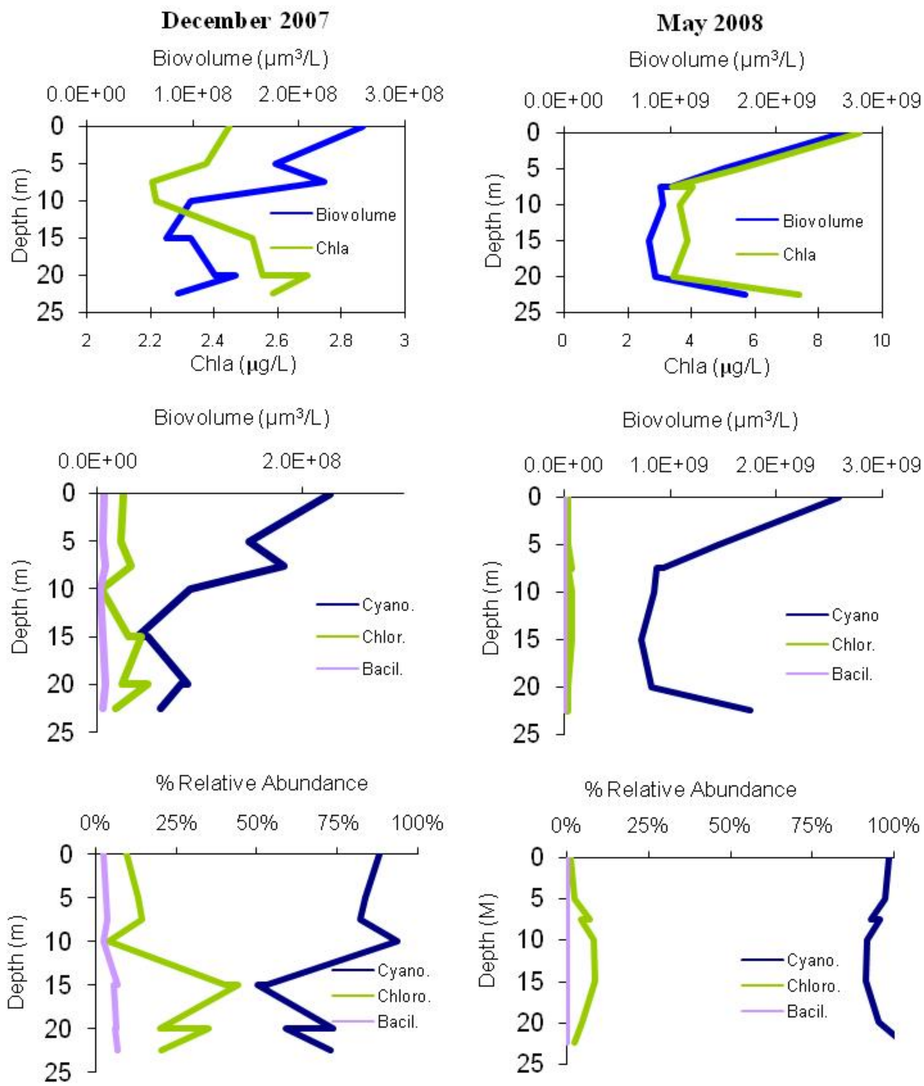

Figure A.4.12. Profiles of phytoplankton total biovolume and chl-a (top two panels), biovolume of Cyanobacteria, Chlorophytes and Bacillariophytes (middle two panels) and their relative numerical abundance during December 2007 and May 2008 (bottom panels).

Productivity

Assays for assessing productivity verses irradiance functions of the lake phytoplankton (whereby lake water samples are incubated at high concentrations of carbon-14 (^{14}C) for a brief time period and then water samples are killed and dried) were attempted on two separate occasions. This method drives off unincorporated ^{14}C and dries the entire sample to capture all of the ^{14}C fixed into organic matter (soluble and particulate) during the incubation. During these assays, the salt in the small volume of dried lake water (2 to 5 ml) precipitated in the scintillation cocktails and readings of the radioactivity proved unsuccessful. Utilization of different ratios of water and cocktail and changes in cocktail (Ecolume/Cytoscint) proved unsuccessful as well. Hence, alternative approaches at productivity assays were evaluated. Discrete samples were incubated in the laboratory with ^{14}C $NaCO_3$ and then these samples were filtered rather than being dried. This approach was successful, but the use of this technique *in situ* as a part of the sampling regime similar to that carried out in other lakes in the region (Goldman 1988, Lebo *et. al.* 1992) was not implemented. The filtration method could be incorporated in the future, but only after an evaluation of the risks involved with using radioisotopes in a closed system. We determined that the risks outweighed the benefits for this particular study.

Assessments of the diurnal changes in the DO content of the lake (Wetzel and Likens 2000) were attempted on two separate occasions (October 2 and December 2, 2007). Profiles at WL3 were taken roughly three to four hours apart from 1030 hours to 1400 hours the following day for the October outing. These profiles showed changes in DO on the order of 0.065 mg O_2/L/hr during the daylight hours on October 2 and decreases up to 0.03 mg O_2/L/hr during the night. The DO values in the evening exhibited a decrease of ~0.1 mg/L. Some of these fluctuations in the DO could possibly be attributed to the patches of phytoplankton and water properties that are often apparent. The vertical profiles from the study on that day illustrate the intermittent presence of layers of water with lower and higher DO contents (Figure A.4.13). As these layered patches of water intermix and wander, the determination of DO dynamics at a set sampling location can become confounded. Despite the apparent challenges associated with this technique, it is apparent that production in the lake is on the level that can be measured on a daily basis, at least when biomass is high, yet the patchiness imparted by the phytoplankton may be a confounding factor. Additional higher time-resolving profiling capabilities may offer a better means for this approach in the future.

A YSI sonde (600 xlm) was deployed at six m depth on a buoy for 26 hours during December. DO fluctuated only slightly from 8.69 to 8.78 mg/L during this outing and production and respiration rates were not detectable. The primary differences in December compared to October were the water temperature, which was 9.3 to 9.4 ^{o}C, and the shortened day length. Phytoplankton biomass was low but comparable to that measured in October (Chl-a of 1.5 to 2.1 μg Chl-a/L). Discrete samples incubated in the laboratory with ^{14}C $NaCO_3$ (where large volumes were incubated and filtered rather than dried) yielded primary production rates of 18 to 50 μg C/L/hr. These rates are just below the levels that are generally detectable by oxygen–based methods (Wetzel and Likens 2000).

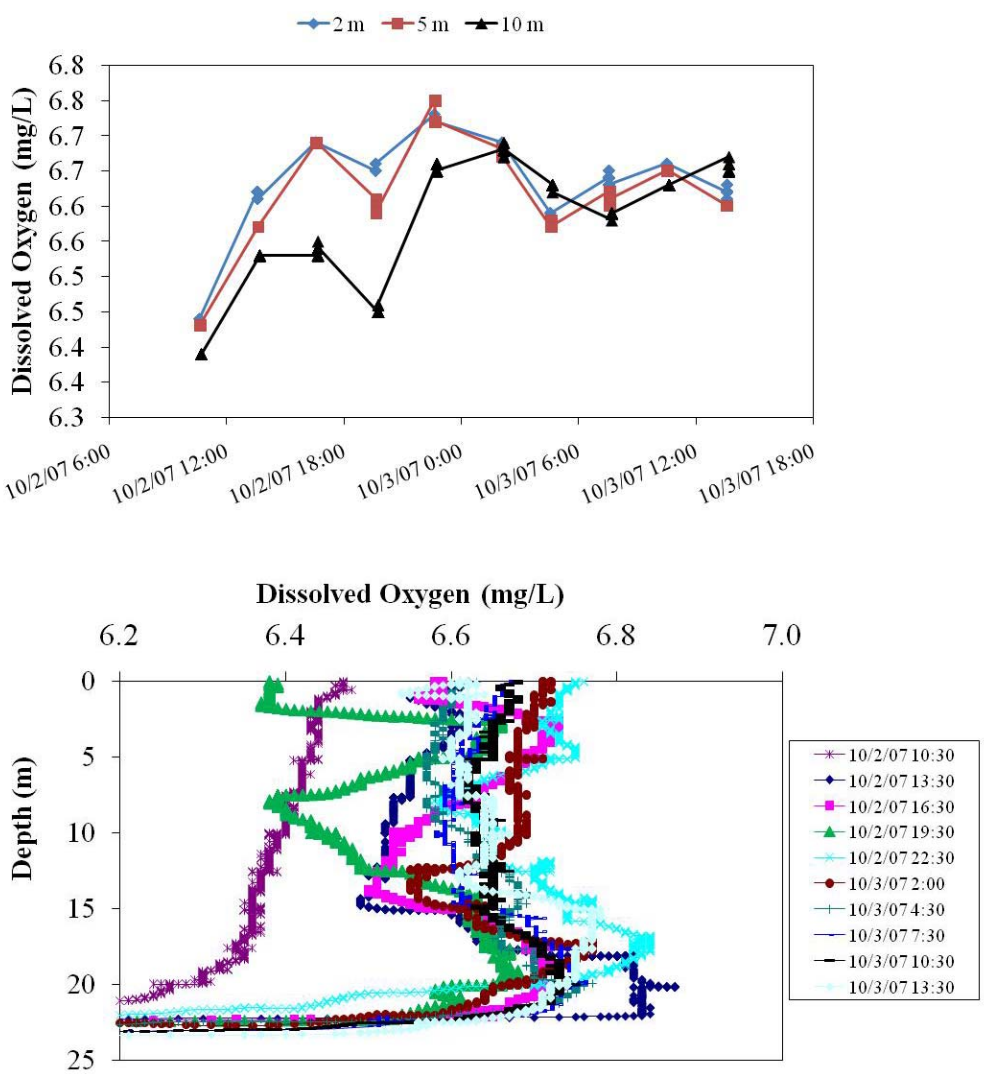

Figure A.4.13. Diurnal time series of dissolved oxygen at 2, 5, and 10 m during the October 2007 sampling (upper panel) and associated depth profiles (lower panel).

DISCUSSION

It is apparent that continued lowering of the lake level will continue to diminish the volume of the hypolimnion and the lake will eventually make the transition to a polymictic body of water. Among the conditions associated with that transition is an overall increase in the relative proportion of the littoral zones, increases in the overall lake oxygen content with large diurnal oxygen swings, higher overall temperatures, increased sediment resuspension events, and the overall loss of habitat for cold-water fisheries. Presently, the habitat for cold-water species is likely to be minimal during the late summer when most all of the cold water in the lake is oxygen deficient.

The lake has an exceedingly large amount of phosphorus (with total phosphorus being in excess of 20 μM) that overwhelmingly promotes the growth of the N-fixing cyanobacterial blooms (e.g., Koch *et al*. 1979, Beutel and Horne 1997, Beutel *et al.* 2001). The trophic status indices developed for lakes worldwide (the Carlson Trophic Status index) places Walker Lake at the high end of the Hypereutrophic class. Overall, the beneficial uses in this category of lakes are highly impaired and this is likely to be a fair assessment of the lake in its present condition, whereby sustained fisheries and ecological health are at risk, drinking water supply potential is minimal, and recreational uses (such as boating and swimming) are compromised when the blooms are occurring.

All observations, data, and analysis indicate that large nuisance blooms and deepwater hypoxia will continue or increase in occurrence and magnitude as the Walker Lake system is in the midst of the successional phenomena that enhances internal nutrient loading through oxygen depletion in the hypolimnion, which causes further enhancement of the blooms (Whitton and Potts 2000). This positive-feedback phenomenon is known for eutrophic and hypertrophic lakes throughout the world (Kalff 2002) and the strategies for mitigating the phenomena are varied.

The general approaches that have exhibited successes for mitigation involve the control of nutrients with aims of lowering the nutrient content of the lake to the point where nutrient loading (both internal and external) does not produce blooms that lead to deepwater hypoxia.

Among the measures that can be implemented for nutrient control is the removal of nutrients in the form of biomass with a net loss of the nutrient content of the lake. This approach is generally not utilized as a sustained practice for lake management because the cost of harvesting can be prohibitive, and more encompassing best management practices for watershed nutrient controls are more often favored. However, the management practices for nutrient controls in terminal lakes in arid regions with a limited amount of water delivery may be more limited. Therefore, all management approaches may deserve feasibility assessments.

Harvesting of biomass may be more readily sustainable if beneficial uses can be found for the harvested material. Use of phytoplankton from lakes has been demonstrated on occasion (e.g., in the harvesting and commercialization of *Amphanizomenon flos-aquae* blooms for blue green algae supplements) and assessments of some cyanobacteria as natural fertilizer has occurred (Banjeree *et al*. 1997, Costa *et al*. 1999, Carmichael *et al*. 2000). The phytoplankton bloom that has occurred in Walker Lake is primarily composed of *Nodularia*, an N-fixing cyanobacteria (nitrogen-fixing algae in Walker Lake are favored due to the extremely low water N:P ratio as well as the high pH). Presently, agricultural practices within the Walker Lake watershed employ some degree of importing nitrogen fertilizers into the basin (since nutrient supplies from coarse, low organic matter soils are limited). Hence, the utilization of the nitrogen-fixing algae within the Walker basin itself presents an intriguing potential for internal sustenance of agriculture without importing new materials from outside the basin. The lake's water column presently has an estimated phosphorous content in excess 1,000 metric tons and estimated nitrogen content in excess of 3,000 metric tons (estimates based on the average Total Phosphorous and Total Kejhdal Nitrogen measured in the winter; see the combined Heyvaert *et al.,* this volume). The total amount that ends up in the phytoplankton bloom in the summer has not been sufficiently resolved, however, based on biomass data from May 2008, the phytoplankton biomass may only attain 2 to 15 percent of these materials in the lake. Therefore, biomass harvesting alone is not likely to mitigate the present nutrient condition.

Additional mitigation measures for nutrient controls may also warrant discussion and future evaluation. For instance, treatments that bind phosphorous or cap phosphorous-leaching sediments are known. Under certain conditions, these treatments can offer a means to lower the internal loading of nutrients to a lake. Implementation of any of these strategies, however, would require scrutiny and feasibility assessments, as some of these techniques (e.g., Fe) would not work in the oxygen-depleted hypolimnion and others (e.g., alum) may have enhanced toxicities to fish at the high pH within this lake. However, directed treatments of a limited amount and duration delivered into the oxygen-deficient hypolimnion (during mid-summer stratification, where fish will not be found) could possibly be considered. The shrinking of the lake level and the reduction in the size/area of the deoxygenated hypolimnion may offer an advantage over the earlier condition, as treatments would have to be applied over smaller areas than in the past. Because this is a terminal lake, the more drastic mitigation measures like whole lake flushing or dredging of the bottom sediments are not management options.

Oxygenation of the hypolimnion remains an alternative that may help decrease the internal nutrient load (Horne *et al*. 1994; Beutel and Horne 1997). Oxygenation (as opposed to aeration) is a means to more efficiently inject oxygen into the deep waters and therefore reduces the vertical mixing and the risk of destratification and general warming of the cold deep water (desirable for cold water fisheries). The challenge for oxygenation (or aeration) at this stage in the lake's progression is the small vertical scale over which the hypolimnion extends, and therefore the potential for kinetic energy dissipation is greatly reduced and the risk of destratification is increased. Implementation of this approach may work; it could also be considered if the lake levels are increased.

Enhancing the delivery of water to Walker Lake may impart beneficial changes in the lake that could mitigate the degradation of the lake's overall beneficial uses (e.g., TDS would go down and water would get deeper and colder). However, raising the level of the lake alone without the management of the nutrient conditions may only result in nominal changes in the lake condition, as the amount of nutrients presently within the lake are exceedingly high and are likely to continue to promote nuisance blooms and hypoxic conditions even when lake level rises.

Regardless of the management strategies affected, monitoring for the assessment of the lake's condition should continue. Nominally, the quarterly monitoring that NDEP and others have employed has great value. However, in addition to this standard monitoring, alternative cost-effective approaches for assessment of short-term and long-term affects of management actions should be employed. For instance, in a scenario where water delivery was increased during brief high-flow periods, the limnological conditions should be monitored in the localized river plume and lake-wide as this water is distributed throughout the lake. Thus, the adaptive systems management strategies could be affected during the overall process.

In addition, monitoring strategies that help in resolving the timing and the magnitude of the peak of the bloom should aid in determining the true extent of the biomass in the lake and the challenges and potential that this bloom represents in regards to management options. Instrumented buoys (of varying complexities and cost) can offer better time-resolving data without the dedicated use of personnel and should aid in determining the actual timing and extent of the bloom. Lake color data, derived from satellites or with airborne hyperspectral sensors, may offer an additional means to better determine the areal patchiness and extent of the phytoplankton bloom.

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A.5: THE CONTEMPORARY ECOLOGY AND FOOD WEB ENERGETICS OF WALKER LAKE, NEVADA

Contributing Authors: Sudeep Chandra, John Umek, Chris, Fritsen, Laurie McKinnon-Newton, Alan Heyvaert, Don Sada, Kumud Acharya, and Mark Stone

ABSTRACT

A remnant of Lake Lahontan, Walker Lake is a large, terminal lake in western Nevada. To document the contemporary ecological condition of Walker Lake after decades of water diversions and reduction in lake level, we conducted a snapshot investigation of the lake's pelagic primary production, and primary and secondary consumers between March 2007 and September 2008. The phytoplankton community displayed a distinct seasonal variability in both winter and spring seasons with patchiness spatially and temporally. Zooplankton showed similar patterns of temporal patchiness with the greatest abundance occurring in late spring and fall. Benthic invertebrates along a transect from the shallow to the deepest part of the lake, had a similar mean biomass from early summer, midsummer, and fall indicating a relatively stable biomass available for fishes over time. Gut content and stable isotope analysis taken from cutthroat trout revealed an energetic reliance on the benthic community indicating that in order to assess the potential recovery of native trout and forage fish, benthic consumers and production should be evaluated and monitored in future investigations. These findings of benthic reliance are similar for other large terminal lakes such as Pyramid and Eagle lakes.

INTRODUCTION

Terminal and saline lake ecosystems comprise nearly half of the inland water ecosystems globally by volume. While many of these lakes are small in size, large terminal lakes generally occur in semi arid and arid climates on nearly every continent. The Western United States is home to 6 large, natural terminal lakes (Eagle Lake, Walker Lake, Pyramid Lake, Crater Lake, The Great Salt Lake, and Mono Lake). Three of these lakes (Eagle Lake, Walker Lake, Pyramid Lake) contain endemic trout species and nearly all have an assemblage consisting entirely of native species which is rare for limnetic ecosystems in the Western United States. One of these terminal lakes, Walker Lake is a remnant of Lake Lahontan, a large lake from the Pleistocene era that began to desiccate roughly 10,000 years ago (Benson, 1978), it was located in the rain shadow of the Sierra Nevada and Cascade ranges to the west and the Rocky Mountains to the east.

Similar to other terminal ecosystems, the ecology of Walker Lake has been largely impacted due to a reduction of freshwater inflows (Beutel 2001, Hammer, 1986). The lake's volume decreased by almost 75% between 1892 to 1996 with a 99.9% reduction in river flow reaching the lake between 1979 and 2005. As a result of these anthropogenic influences salinity has increased over time (Beutel *et al*. 2001) with large consequences for the biodiversity and production of the lake.

Although species diversity is low in the lake, it did at one time support a robust fishery. Prior to desiccation, Walker Lake supported a large population of Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*), forage fish, tui chub (*Gila bicolor*), as well as other species. However dam construction on the Walker River stopped spawning runs and in conjunction with other environmental factors the Walker Lake cutthroat trout strain is now extinct and is maintained by an intensive stocking program with non-Walker strains of Lahontan cutthroat trout (Elliot, 1995). The benefits of increasing river flow will depend upon water quantity and quality, and timing of release. Fish are limited by high salinity and ion concentrations and if there is not an increase in flow to Walker Lake over the next ten years it may be unable to support a fishery in the future as the lake increases in salinity (Beutel *et al*. 2001). Increased river annual flow could off set the desiccation and decrease levels of salinity in Walker Lake.

The goal of this study was to characterize the contemporary ecological condition of Walker Lake. The specific objectives were to determine the 1) seasonal changes of algal biomass and composition in pelagic primary producers, 2) spatial distribution of pelagic primary production, 3) primary consumer abundance, composition (zooplankton and zoobenthos) and biomass (zoobenthos), as well as 3) fish composition and food web structure.

MATERIALS AND METHODS

Walker Lake is located in the desert region of west-central Nevada southeast of Reno Nevada (N38 42.012, W118 42.948). In 2007 the lake had a surface elevation of approximately 1200 m with a max depth of 27.0 m (USGS 2007). There is one primary inflow to the lake, the Walker River, which discharges into the north end of the lake.

Primary Producers

In order to determine seasonal changes in primary producer biomass and composition, primary producers were sampled from an index station (Site 11 on Figure A.5.1) located at deepest part of the lake from March 7, 2007 to September 18, 2008 approximately every 8 weeks. A vertical profile was collected from the surface to depth at 2.5 meter increments. Chlorophyll *a* was used as a surrogate measure for algal biomass. Pigment concentrations were determined via fluorometry using the Welschmeyer (1994) method in a Turner Designs model 10AU Fluorometer calibrated with purchased standards (i.e., chlorophyll *a* from *Anacystis nidulans*, Sigma Corp.). Chlorophyll *a* content was checked against a spectrophotometric (Parson *et al*. 1984) method for quality assurance.

Phytoplankton subsamples from the vertical profiles collected in 2007-08 were preserved by addition of gluteraldehyde to a final concentration of 0.5%. Enumeration involved counting a target number of natural units from each sample. The usual target number of natural units was n $\geq$ 400. Natural units were deemed appropriate instead of cells, due to the fact that colonial or filamentous cells do not occur singly in nature so individual cells would be inappropriate to portray relative abundances (Mills *et al*. 2002). Differential interference contrast microscopy using an Olympus BX-60 equipped with epiflourescence and digital imaging capabilities was used for enumeration and identification. As outlined by PhycoTech, the magnification used was dependent on the dominant taxa encountered within the sample slide. Overall, the goal was to enumerate and identify taxa present across a range of magnifications. Once the correct magnification was determined for the majority taxa-type, a minimum of fifteen fields were viewed and

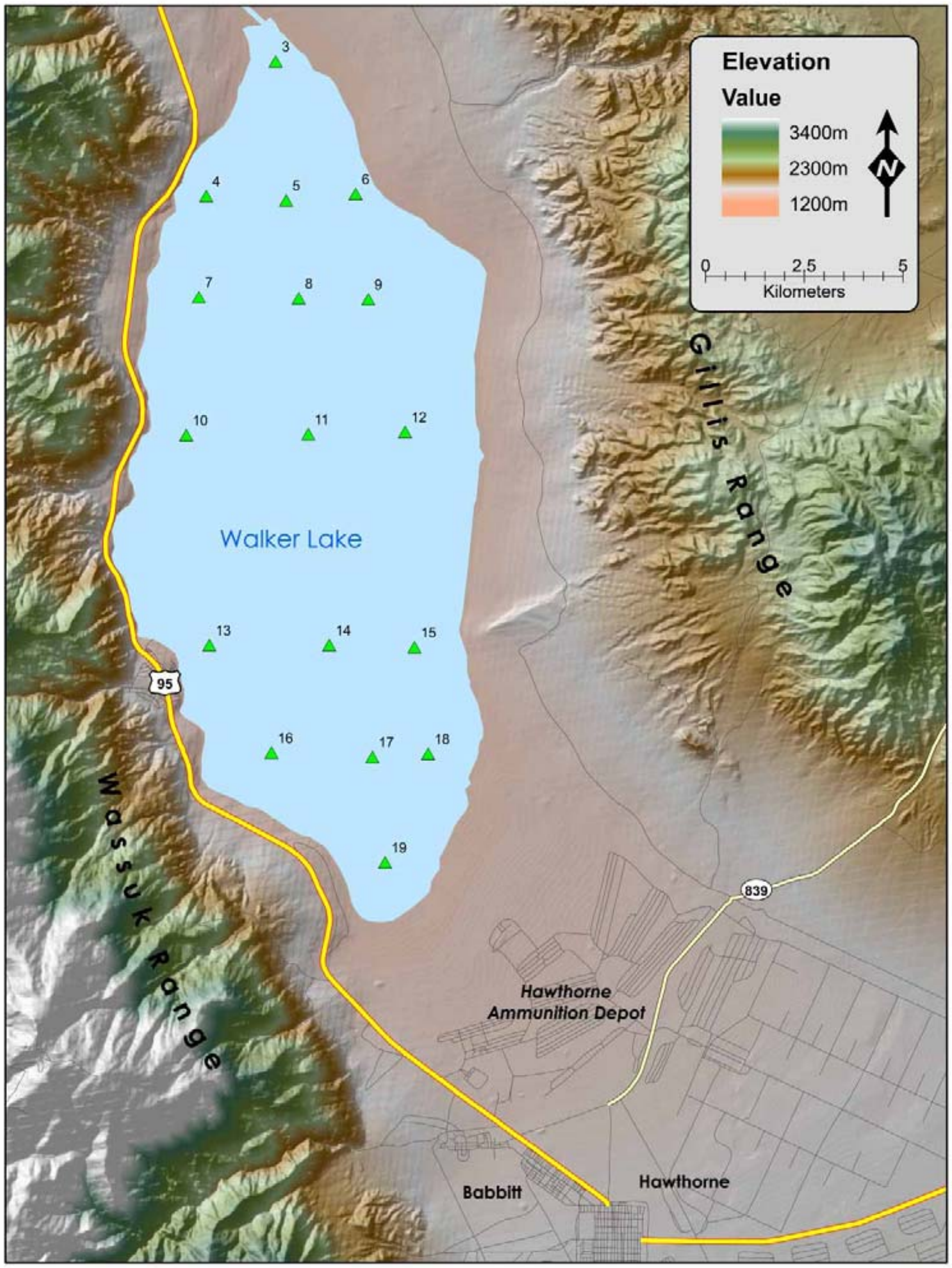

Figure A.5.1. Walker Lake, Nevada, the surrounding geologic and landmark features and the 17 sampling locations used to determine the phytoplankton patchiness and changes over time.

the natural units enumerated under that magnification. In addition, the minority cell types were counted. All taxa encountered were image-documented for quality assurance and archival purposes. Biovolume estimates for each contributing taxa were determined by assigning formulas outlined in current literature (Hillebrand and Sommer 1999).

The patchiness and spatial distribution of phytoplankton during two seasons (summer and winter) were determined from 17 sampling stations evenly distributed around the lake from 4 time periods (17 July 2003 & Apr 2004) (Table 1). At each location, phytoplankton samples were collected using a horizontal Van Dorn sampler from the surface to depth at 5 meter intervals preserved with Lugol's solution. Phytoplankton cells were identified to family using various taxonomic keys (C. Boyer (1916), G.M Smith (1950, 1920), G. W. Prescott (1964), and I. La Rivers (1978), and personnel communications with Dr. Ann St. Amand, (Phycotech, St. Joseph, MI). Each group was enumerated and measured for size using standard methods (APHA 1999). Phytoplankton were grouped into two categories 1) *Nodularia,* the dominant algal species in the lake and 2) edible phytoplankton. The mean density of each group is presented. Interpolated surface maps for phytoplankton and zooplankton (cells/mL and organisms/L, respectively) were created in ArcGIS 9.x by Rich Inman, Biology Department, University of Nevada, Reno. Kriging with tension spline was used at a 30 m grid cell resolution to predict cells/mL or organisms/L throughout the lake from the closest 12 sampling sites.

Table A.5.1. Locations where phytoplankton and zooplankton were collected from the lake to determine spatial patchiness and distribution.

Site	Latitude (N)	Longitude (W)
3	38°47′164″	118°43′54′
4	38°45′537″	118°44′543″
5	38°45′60"	118°43′27″
6	38°45′636″	118°42′36″
7	38°44′250″	118°44′700″
8	38°44′25″	118°43′085″
9	38°44′274″	118°41′820″
10	38°42′33″	118°44′940″
11	38°42′39″	118°42′83″
12	38°42′486″	118°41′22″
13	33°39′456″	118°44′400″
14	38°39′48″	118°42′41″
15	38°39′528″	118°40′920″
16	38°38′016″	118°43′440″
17	38°37′96″	118°41′66″
18	38°38′40″	118°40′680″
19	38°36′867″	118°41′404″

Primary and Secondary Consumers

In order to determine seasonal changes in zooplankton composition and abundance, zooplankton were collected from the central index station at regular intervals (4-6 weeks from March 2007 to April 2008 using a vertical, zooplankton tow (153 um mesh), from the bottom to the surface. Samples were preserved in a sucrose-Lugol's solution until identification and enumeration. In order to capture changes zoobenthic consumer distribution, zoobenthos were collected in the spring, summer, and fall using multiple (3 to 5) Petite ponar grabs at 5 meter intervals from the inlet of Walker Lake (1-5m) to 30 meters (deepest part of the lake). Samples were screened through a 500 um mesh bucket for each location, stored in 70% ethanol and identified to the lowest taxonomy possible (species for most taxa and family for oligochaetes and chironomids). Invertebrates were weighed to determine biomass at each depth.

Through coordination with the Nevada Department of Wildlife and the US Fish and Wildlife Service, fish were collected using overnight, experimental gill nets (38m x 1.8m with mesh size starting at 1.27 cm and increasing by .64 cm until reaching 15.24 cm) set on the west side of the lake and via creel census. Fishes were collected during early summer to fall in 2007. Fish were identified to species with tui chub morphotypes (benthic or pelagic) identified by counting gill rakers. Total length and weight were measured for each fish. Fish condition was calculated using the Fulton's condition index, common measure used to assess fish condition and health.

Stable Isotope and Food Web Structure

Fish and primary consumer tissue samples were dried at 60 °C for at least 24 hours and ground into a fine powder using a mortar and pestle. After being packed into tin capsules (8 x 5 mm), a continuous flow isotope ratio mass spectrometer (IRMS) (20-20, PDZEuropa Scientific Sandbach, United Kingdom) analyzed the samples for carbon and nitrogen. Sample combustion to CO^2 and N^2 occurred at 1000 °C in an inline elemental analyzer (PDZEuropa Scientific, ANCA-GSL). A Carbosieve G column (Supelco, Bellefonte, PA, USA) separated the gas before introduction to the IRMS. Standard gases (Pee Dee Belemnite for $\delta^{13}C$ and N_2 gas for $\delta^{15}N$) were injected directly into the IRMS before and after the sample peaks.

Isotopic ratio was expressed as a per mil (‰) notation. Using $\delta^{13}C$ as an example, it was defined by the following equation:

$$\boldsymbol{\delta^{13}C = [(^{13}C/^{12}C)_{sample} / (^{13}C/^{12}C)_{standard} - 1] * 1000}$$

A more positive $\delta^{13}C$ indicated isotopic enrichment, or contained proportionally higher concentrations of heavier ^{13}C isotope. After every twenty samples a replicate and a standard were added to the analysis sequence. Replicate variation was less than 3% and machine analytical variation was within .2 ‰.

To facilitate feeding comparisons between fish species, the dependence of individual fish and zoobenthos on pelagic energy was determined by the following equation:

$$\boldsymbol{\%\ Pelagic = [(\delta^{13}C_{consumer} - \delta^{13}C_{littoral}) / (\delta^{13}C_{pelagic} - \delta^{13}C_{littoral})] * 100}$$

where $\delta^{13}C_{consumer}$ was the individual value for fish or invertebrate. The littoral endpoint, $\delta^{13}C_{littoral}$ (oligochaete, chironomidae), represented the benthic primary production signal. The pelagic endpoint, $\delta^{13}C_{pelagic}$ (mean of all zooplankton from the Index represented the pelagic primary production signal. Fish trophic position was estimated from fish $\delta^{15}N$ values. Individual fish signatures were corrected for baseline variation using invertebrate primary consumer $\delta^{15}N$ similar to Vander Zanden and Rasmussen (1999). In this case a baseline linear regression equation ($\delta^{13}C$ v $\delta^{15}N$) determined from the littoral benthic and pelagic invertebrate samples was used to adjust fish isotope nitrogen signature to their corresponding $\delta^{13}C$ signature to determine their trophic position (Vander Zanden *et al*. 2003, Chandra *et al*. 2005). Trophic position was calculated as $TP = ((\delta^{15}N_{fish} - \delta^{15}N_{baseline})/3.4) + 2$, where 3.4 is the trophic level enrichment factor (Minagawa and Wada 1984; Vander Zanden and Rasmussen 2001).

RESULTS AND DISCUSSION

Phytoplankton dynamics followed an annual cycle that included a winter minima and a spring bloom which is not unexpected from a moderately deep monolithic temperate lake. The largest biomass measured during our study occurred at the end of April and in early May of 2008. This spring bloom was observed on April 25th and sampled on May 1st – only a few days later. Biomass was measured at ca. 10 µg chl-a L^{-1} and, based purely on visual observations, the surface accumulations did not appear to be as large as they had been only a few days earlier (Figure A.5.2). During the spring of 2007 the lake was sampled on April 27th, and the peak biomass measured during this time was only 1.5 to 3.2 µg chl-a L^{-1}. However, based on the observations and images take by a resident of the town of Walker, this sampling occurred a few weeks prior to the major spring bloom of that year, when surface accumulations were also prevalent and easily notable. Based on these observations it is highly likely that sampling on a monthly or quarterly basis is not effective in documenting the peaks of the spring blooms (e.g., like those observed in 2007 and 2008).

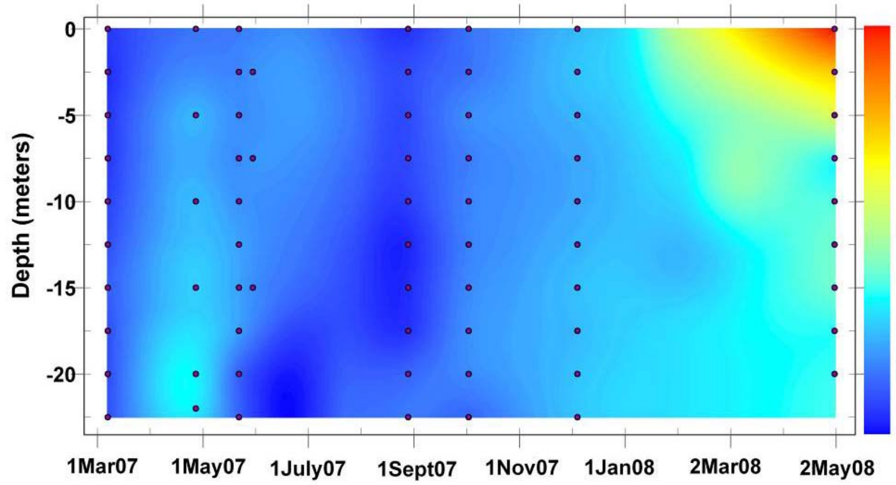

Figure A.5.2. Contours of chlorophyll *a* concentrations during the study. Maximum biomass was 10 µg L^{-1} during the May 2008 sampling.

The phytoplankton of Walker Lake—although attaining high levels of biomass—was relatively depauperate in regards to richness and diversity, with only a few taxa comprising the plankton assemblage during all seasons (Figure A.5.3). *N. crassa* mostly dominated the phytoplankton assemblages in terms of biovolume, with lesser volumes of *Spermatozopsis* and a small autotrophic flagellate (yet to be positively identified) during spring and summer. During winter other taxa were more prevalent, notably *Chaetocerous*, a small chain-forming diatom, and Chlorophytes. Synechoccocea were also prevalent and abundant throughout the study. Yet due to their small size (typically ~1.5 um) they did not often dominate the biovolume.

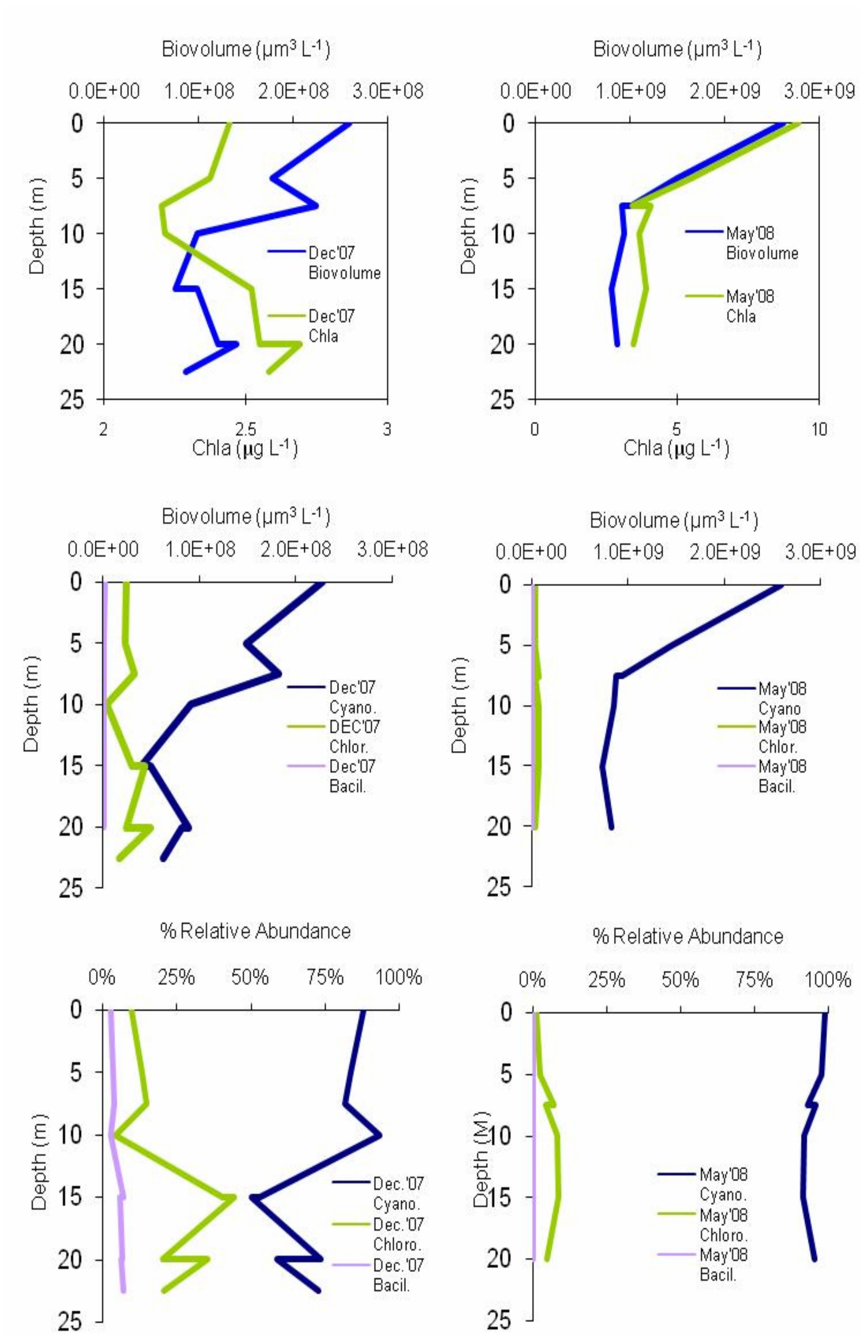

Figure A.5.3. Profiles of phytoplankton total biovolume and chl-a (top two panels), biovolume of Cyanobacteria, Chlorophytes and Bacillariophytes (middle two panels) and their relative numerical abundance during December 2007 and May of 2008 (bottom panels).

In a spatial context, the phytoplankton community was dominated by the cyanobacteria, *Nodularia crassa* which is the same dominant phytoplankton that has undergone taxonomic changes since it was described in previous studies at Walker Lake. *N. crassa* formed large mats on the lake's surface in summer with and average of 7000 cells/mL and lower concentrations at all other depths at <1000 cells/mL. Some sites had high concentrations while the adjoining sites had few if any, and overall the distribution of plankton was very patchy within the water column and across the lake (Figure A.5.4). During the winter, the cell counts throughout the water column were equal or greater than the concentrations at the surface in the summer collections at collection sites. Averaged throughout the year, *N. crassa* counts ranged from <500 cells/mL to > 10,000 cells/mL, but were not significantly different among sites, and site 19 had the highest mean concentrations (Figures A.5.4 and A.5.5). With the exception of the site 19 count in July, collections in July and January generally had lower concentrations of *N. crassa* than in February (Figure A.5.5). Variability among sites was greater in February than in the other three months resulting in a higher mean concentration of *N crassa*. Overall there was distinct seasonal variability in both winter and spring seasons with patchiness in space and time (between months). It is believed that wind driven, internal wave action is the primary distributor of phytoplankton within the lake.

More edible phytoplankton were counted in the summer than in winter (Figure A.5.6). Unlike *N. crassa,* edible phytoplankton were most abundant in the beginning of July and least abundant in winter. Counts of edible phytoplankton ranged from <150 cells/mL to >1300 cells/mL among sites. Site 3 had the highest concentration of edible phytoplankton, significantly greater than sites 10,12,14,16, and 17 ($p<0.04$) (Figures A.5.6 and A.5.7). Summer collections showed more variability by site than winter collections (Figure A.5.6). Greater numbers of edible phytoplankton cells were counted when water temperature reached about 20ºC. Less than 1000 cells/mL were counted at any site (except site 7 in February) during the winter when the water temperature was about 5ºC.

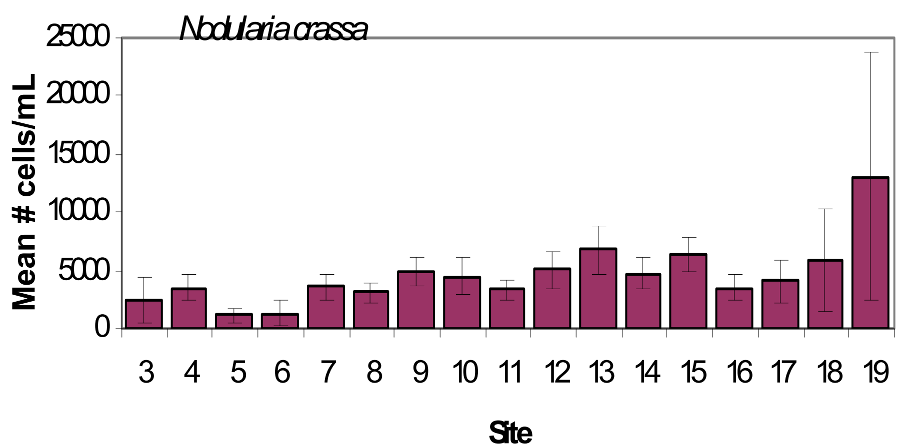

Figure A.5.4. Mean number of *Nodularia crassa* cells mL^{-1} at all 17 sites. Each bar represents an average of two collection dates in winter and two collection dates in summer in 2003-2004. Error bars are standard error of the mean.

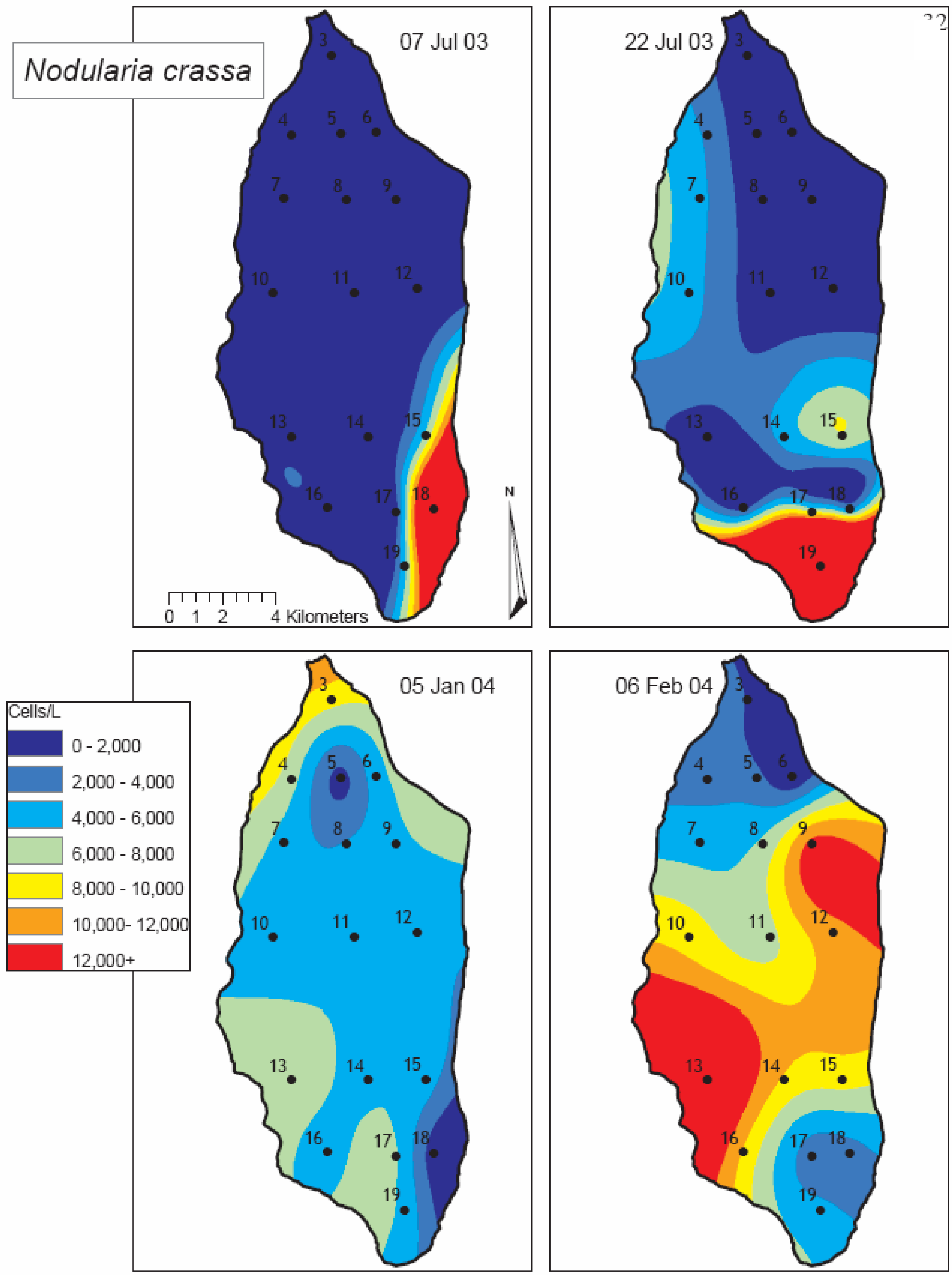

Figure A.5.5. Total *Nodularia crassa* (cells/L) for two seasons in Walker lake. Note the variability and distribution within each season (winter versus early summer).

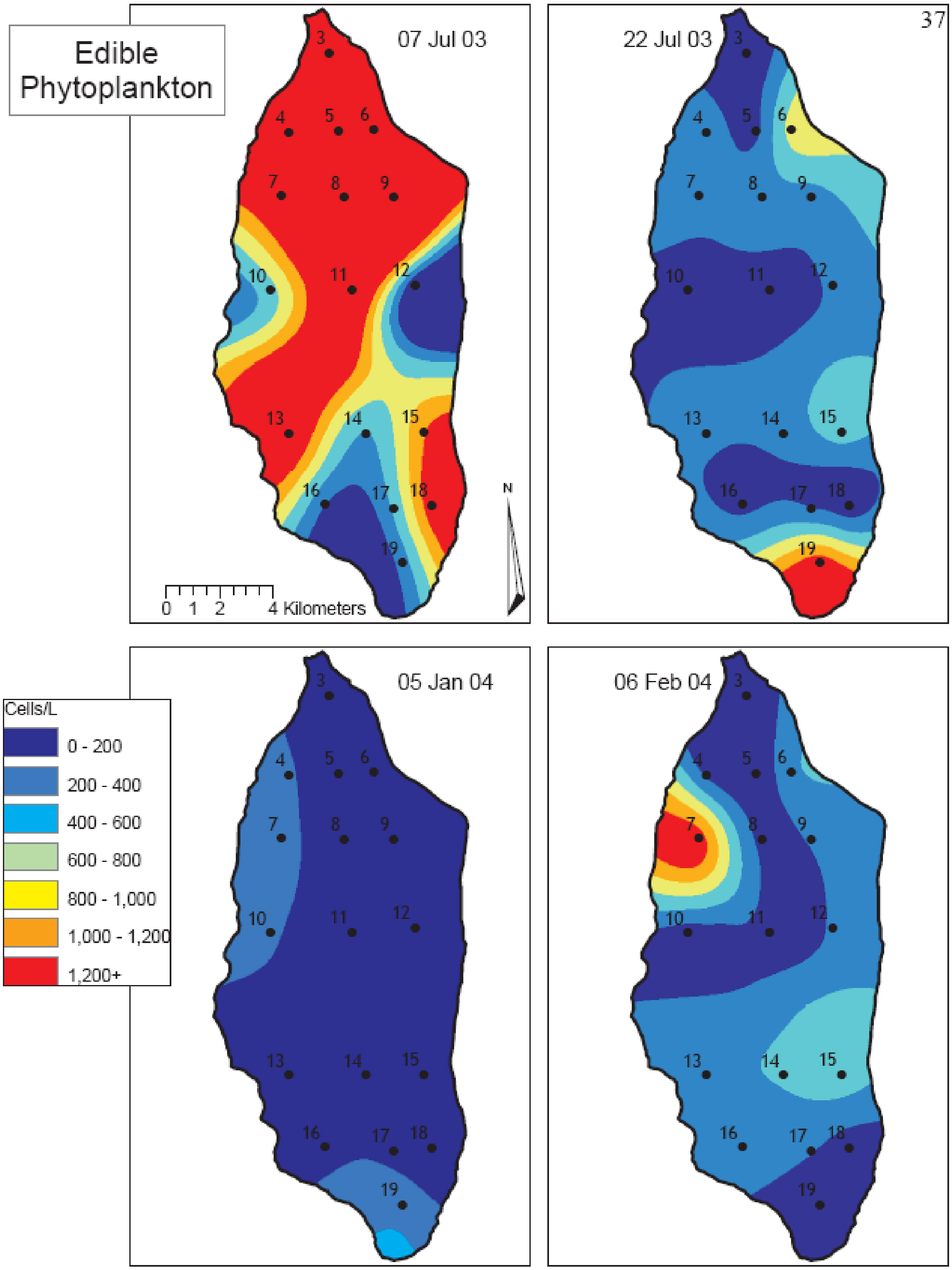

Figure A.5.6. Total edible phytoplankton (cells/mL) for two seasons in Walker Lake comprised of four collection dates. Note the variability and distribution within each season, particularly in summer.

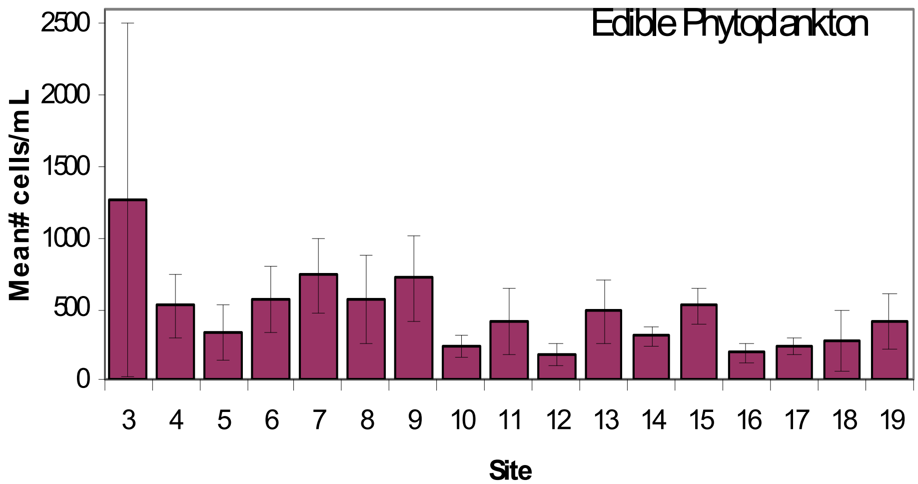

Figure A.5.7. Mean number of edible phytoplankton cells per mL at all 17 sites. Each bar represents an average of all collection dates in 2003-2004. Error bars are standard error of the mean.

Overall, the concentration of *N. crassa* was greatest in the winter (Feb) and was generally much higher than edible phytoplankton at all dates, depths and sites. As such, *N. crassa* concentrations have disproportionately influenced total phytoplankton counts. The edible phytoplankton concentrations were greatest in summer (07 July 03 collection) although, even at peak levels, edible phytoplankton concentrations were far less by an order of magnitude, than the concentrations of *N. crassa.*

The zooplankton community consisted of 3 dominant species (Hexartha spp, Moina hutchinsoni, Leptdiaptomus sicilis) during 2007. The abundance was highly variable in time with the greatest abundance occurring in the late spring and fall (Figure A.5.8). Leptodiamtomus had the highest abundance in June (59 indivudals/L) and low in the October (9 individuals/L). Moina hutchinsoni exhibited the second greatest abundance but varied over time with the highest abundance during the summer (approximately 19 individuals/L) and a low in winter and spring (1 individuals/L). Hexartha populations are in smaller numbers with little variation but an increase winter (November).

Oligochaeta, diptera, and odonata were the only major zoobenthic axonomic groups found in this study. Biomass and diversity was highest during June in the littoral zone (52 mg dw/ m^2), then gradually decreasing throughout the summer. Oligochaeta were only found during the June sampling period at 3 meters of (12.9 mg dw/ m^2) (Figures A.5.9 and 10). Two odonata were identified in our samples, coenagrion and zoniagron. Coenagrion was only found in the littoral zone and in our June (13.3 mg dw/ m^2) and August (12.7 mg dw/ m^2) sampling periods. Zoniagron was only found at out 30 meters sampling depth in June (9.5 mg dw/ m^2). However in our last sampling period in October zoniagron was found in the littoral and profundal zones at each depth sampled up to 18 meters (12.9 mg dw/ m^2). The chironomidae, tanypodinae, had the highest overall abundance during each sampling period and was also present at each depth. The highest abundance of tanypodinae was found in August at 4 meters (13.5 mg dw/ m^2) and in October at 13 meters (12.9 mg dw/m^2). Overall, mean biomass from early summer (June, midsummer (August) and Fall (October) remains constant but seemingly available for fish (8.6 to 10 mg dw/ sq m).

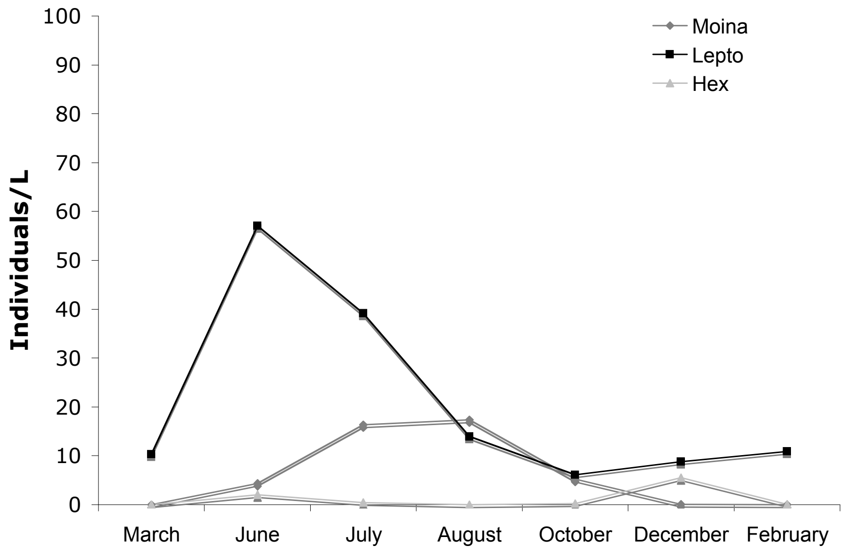

Figure A.5.8. Mean zooplankton densities from the index sampling station (near site 11) over time from 2007 to 2008.

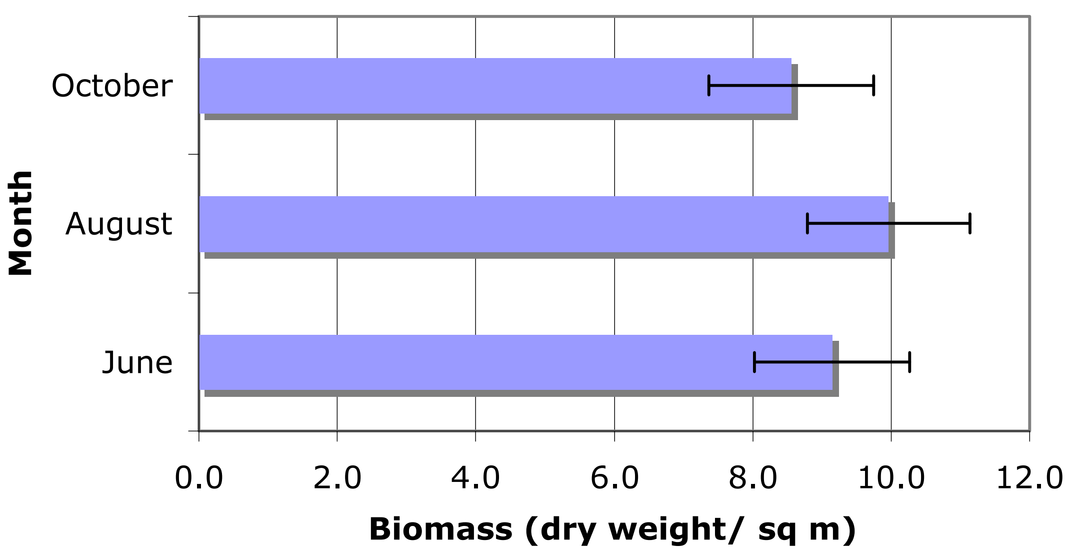

Figure A.5.9. Mean invertebrate biomass for the whole lake during three different sampling periods (late Spring- June, Summer- August, and early Fall- October) in 2007.

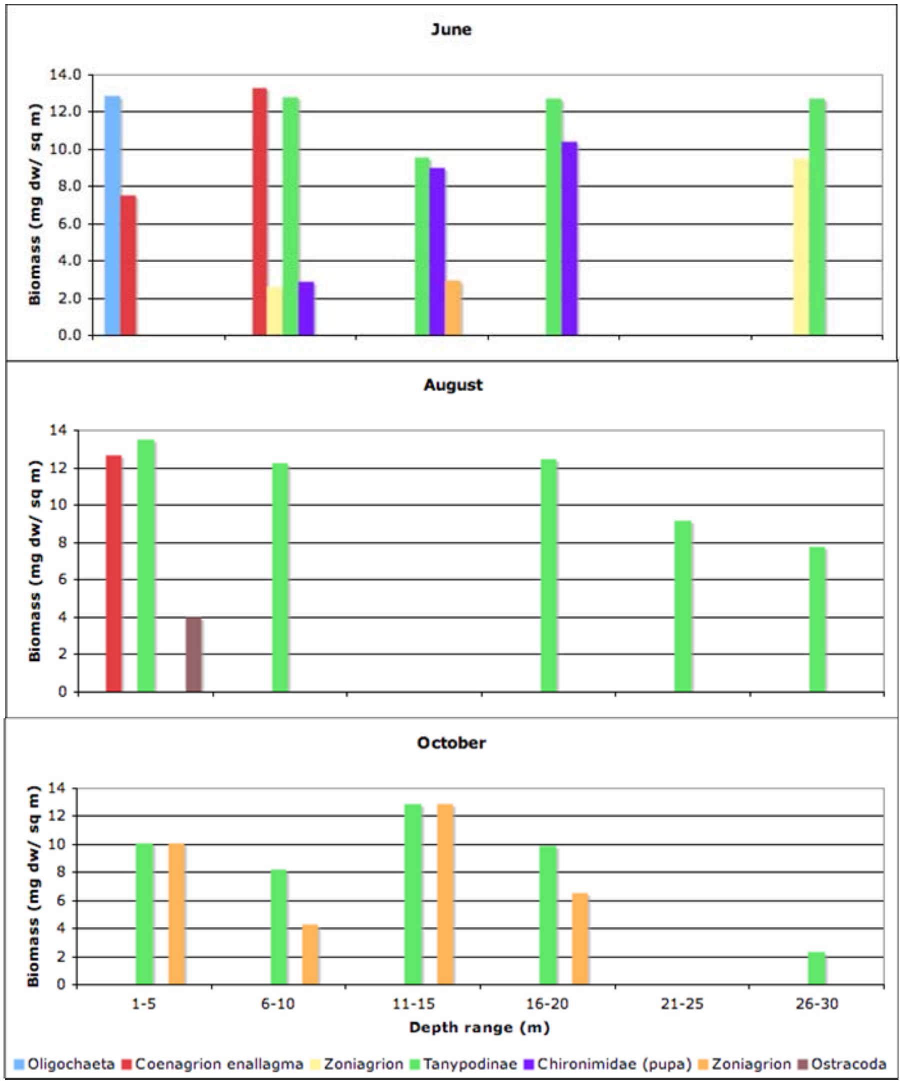

Figure A.5.10. Zoobenthic biomass for specific taxonomic groups over time in 2007.

Mean zooplankton isotope values of $\delta^{13}C$ and $\delta^{15}N$ were -22.8‰ and 11.0‰, respectively. Mean benthic primary consumers isotopes for $\delta^{13}C$ and $\delta^{15}N$ were -19.9‰ and 9.4‰, respectively. However, there was a difference in the benthic invertebrate $\delta^{15}N$ signature in the littoral (8.3‰) and profundal zones (10.0‰). Only two fish species were caught in the lake. The tui chub (pelagic morphotype) and the top predator Lahontan cutthroat trout currently maintained by hatchery processes by the Nevada Department Wildlife and the US Fish and Wildllife Service. Pelagic tui chub $\delta^{13}C$ and $\delta^{15}N$ concentrations were -20.5‰ and 12.6‰, respectively. Cutthroat trout $\delta^{13}C$ and $\delta^{15}N$ concentrations were -19.8‰ and 15.7‰, respectively (Figure A.5.11).

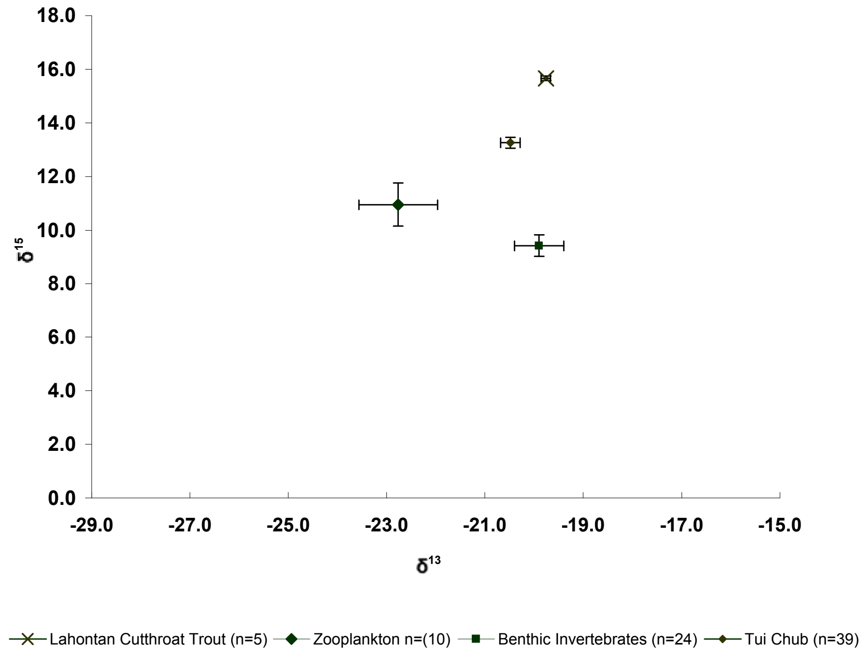

Figure A.5.11. Stable isotope (carbon and nitrogen) concentration of the dominant food web from Walker Lake.

Only two fish species were caught in Walker Lake compared to 5 native fish taxa in neighboring Pyramid Lake and terminal Eagle Lake in California (Table 2). Only the pelagic morphotype of tui chub (Lahontan lake tui chub) was identified and no benthic creek tui chubs were caught despite a large netting effort to collect fishes. It is believed that other fish species common to this region (Tahoe sucker, Lahontan redside, speckled dace, benthic creek tui chub morphotype) could exist in the lake given more freshwater circumstances.

Table A.5.2. Mean size (length and weight) and standard deviations of the two different fish species caught within Walker Lake.

Species	Length (mm)	Weight (g)
Lahontan cutthroat trout (n=17)	470.35 ± 10.4	1,199.12 ± 317.5
Tui chub (n=183)	152.7 ± 0.48	148.1 ± 12.57

Some of these fish are caught within the Walker River, the lake's primary inflow (Chandra and Umek, unpublished data). The mean size of both cutthroat trout and tui chub are similar to those found in nearby lake environments (Table 2). Despite stressors to the lake environment through increased total dissolved concentrations over time (see limnology Chapter), cutthroat trout condition factor in Walker Lake (1.15) are in the higher range compared with other limnetic ecosystems (Table 3) (Carlander 1969, Chandra et al., 2006). The levels are much greater than conditions scores measured from lakes in the regional Fallen Leaf Lake (0.67) where efforts have been underway to restore cutthroat trout and Pyramid Lake (1.02) where populations are maintained due to hatchery processes (Allen *et al.,* 2004, Chandra et al., 2006). It may be that the higher trout condition scores from Walker Lake are due to the fish feeding behavior and benthic resource utilization available under current lake conditions (see above and below).

Table A.5.3. The body condition of cutthroat trout from Walker lake compared with other limnetic ecosystems obtained from Carlander (1969), Chandra et al., (2006), and Allen *et al*. (2004).

Location	Mean K (TL)
Trapper's Lake, Colorado	1.52
Pathfinder River, Wyoming	1.06
Upper No name Lake, Wyoming	1.05
West Gallatin River, Montana	0.99
Lower No name Lake, Wyoming	0.79
Fallen Leaf Lake, California	0.67
Walker Lake, Nevada	1.15

Stable isotope information suggests cutthroat trout, while maintained through hatchery processes is the top predator feeding on tui chubs and primary consumers. Pelagic tui chubs are the second dominant consumer feeding mostly on primary consumers. A continuous monitoring program by the state of Nevada's Department of Wildlife suggests limited recruitment of young of the year tui chub due to increasing saline condition and low freshwater flows entering the lake (Solberger personal communication). There may be 3 cohorts of tui chub within the lake with recruitment occurring within the last year (Figure A.5.12). Moreover small and large stages seem to live in the deeper part of the lakes while medium size chubs live in the shallow water. It is unclear if the lack of tui chub recruitment impacts cutthroat energetics and maintenance of their population however these fish comprise a significant amount of diet for cutthroat trout in neighboring Pyramid Lake (Chandra et al., 2006). Thus it is likely that alterations to populations of this food base could affect cutthroat dynamics and recovery. Future effort should be placed into understand tui chub recruitment and production.

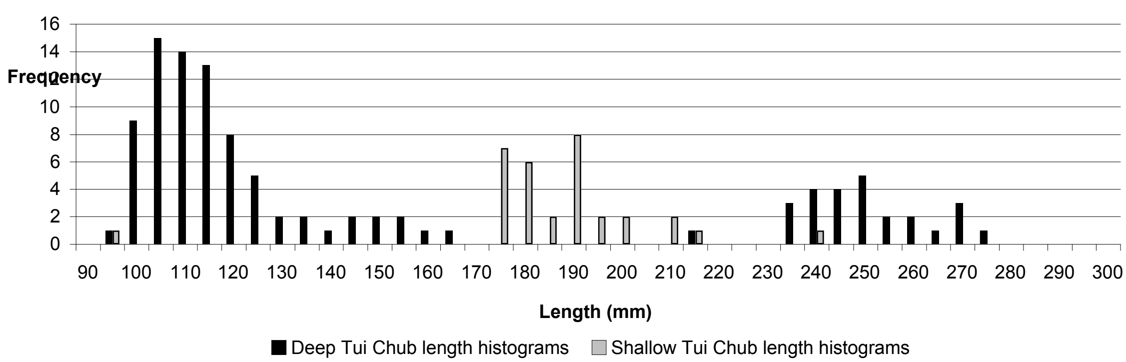

Figure A.5.12. Histogram of tui chub from Walker Lake indicating three distinct cohorts surviving in the lake.

Stable isotope carbon information also strongly suggests the Walker lakes fishery is not supported by pelagic production (Figure A.5.11). Benthic resources rather are the dominant contributor to fish energy balance. Pelagic zooplankton are highly patch in the lake environment and may not be available for fish consumption (see above). Qualitative stomach analysis support the stable isotope finding for both pelagic tui chub and cutthroat trout. It indicated that benthic invertebrate were the dominant food source during all sampling periods (Umek and Chandra unpublished data) with a dominance of zoniagron and coeniagron in the stomachs. Calculations based on stable isotope measurements suggest cutthroat trout are indeed the top predator feeding at a trophic position of approximately 3.4 and utilizing very little energy from pelagic carbon sources (11%). The pelagic tui chub morphotype slightly more energy from pelagic sources (32%) thus eating mostly benthic derived carbon and feeding at a trophic position of 3.1. All physical, chemical, and biological (lower food web only) limnological monitoring programs by state and federal agencies to date has focused on monitoring conditions in the open water. It is critical to develop a comprehensive benthic (littoral and profundal) monitoring program to determine the mechanisms contributing to alterations in the fisheries if freshwater is returned to the lake.

CONCLUSIONS

Previous data collected on Walker Lake has focused on the physical, chemical, and biological conditions in the pelagic zone. Recently, studies have suggested that benthic production can be important for fisheries energetics in Walker and other terminal lakes (Chandra et al. 2006). In this study we also determined that benthic rather than pelagic productions supports fisheries energetics. The benefits of increasing the water flow into Walker Lake and the affects it will have on the ecological community will depend upon the timing of release and the quantity and quality of the water. To determine the impacts of increased water flow on the food web and the energetics of the fish community, monitoring the phytoplankton, zooplankton, and benthic invertebrate community will be critical. While this study does provide a seasonal snap shot of the lake there is likely interannual variability that has not been captured in this study. Based on our observations of the phytoplankton community, quarterly and monthly sampling may not be effective in documenting the peak spring blooms as observed in 2007 and 2008. This suggests that a comprehensive monitory plan that captures intra and interannual variability of pelagic and benthic ecological components of the food web needs to be developed to determine the mechanisms contributing to the health of the fisheries in Walker Lake.

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PROJECT A: INSTREAM AND LAKE AQUATIC HEALTH INTRODUCTION

PART II. WALKER RIVER

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EXECUTIVE SUMMARY PART II: WALKER RIVER

Studies in the Walker River were conducted to quantitatively examine physical characteristics of the river, its water chemistry and quality, and its ecology (i.e., algae (periphyton), macrophytes, macroinvertebrates, and fish communities) at eight sites from the base of the Sierra Nevada to Walker Lake. This information was used to gain insight into relationships between different physico-chemical environments and characteristics of periphyton, benthic macroinvertebrate, and fish communities. This information can be used to predict changes in riverine ecosystems that can be anticipated from increased flow and change in the timing of delivery from water acquisitions. It can also be integrated with hydrology studies to reveal strategies that maximally increase ecosystem health and recreational opportunities in the Walker River.

Water quality samples were collected from eight river sites and one central vertical profile at the deepest part of Walker Lake. Sampling results were compared to historical data and long-term trends in water quality were identified. Seasonal water-quality changes along the length of the river were assessed. Water-quality changes along several reaches of the river were compared to ecological parameters and the general river health was evaluated. Mass loadings of important water-quality constituents from the Walker River into Walker Lake were calculated based upon measured river flows and constituent concentrations over the sampling period of this study. Results provided a basis for comparison to potential changes in river water quality as new water acquisitions are introduced into the river.

Biomass and community composition of periphyton in the Walker River was evaluated to establish a present-day knowledge of algal taxa in different river habitats. Standing stocks of algal biomass were present at levels the often signify eutrophic conditions at East Fork and Mason Valley sites. The river had high abundances of siltation-tolerant diatom taxa- with the most notable abundances (exceeding 60%) at lower site locations. The near ubiquitous presence of filamentous green algae (especially *Cladophora* and *Oedogonium*) throughout the system (excepting the West Fork) is indicative of a system having a high potential for nutrient-algal interactions that produce oxygen slumps during the summer months. Several community-based metrics (N-fixing diatoms, motile diatoms and % *Cymbella*) correlated with Total Dissolved Solids (TDS) (which increased downstream). These relationships can be used with additional indictors to provide the tools to assess how ecosystem health may change with in response to different management strategies.

Taxonomic richness and the community tolerance values of riffle and woody debris benthic macroinvertebrates (BMIs) exhibited spatial and temporal trends. Both metrics show that ecological health of upstream reaches is generally better than reaches through and below Mason Valley. Multivariate analyses found a strong relationship between water temperature, discharge, and BMI community structure, which indicates that that ecological integrity of the Walker River is affected by activities that influence these factors. Conversely, actions that increase discharge and reduce water temperature and nutrients would improve river conditions and have a concomitant affect on BMI communities. Runoff during 2007 and 2008 was less than 50 percent of normal in the

Walker River. Additional sampling during years with higher runoff is needed to gain insight into the response of river ecological health to incremental increases in discharge.

These studies included the first examination of Walker River BMI elemental composition and stoichiometry in relatively large scale. Our results indicated that some BMIs taxa were relatively invariable in their elemental composition, however, considerable differences were also found among taxa. Many of these variations were explained by regional and seasonal variation in water quality. More targeted biomonitoring involving BMI and primary productivity is suggested in the future to tease out stresses on particular organisms in the area. We also suggest that a precautionary approach be taken when Water Rights Acquisitions are allotted specially in areas of higher pollution levels.

CONTENTS

LIST OF FIGURES

A.6: MAJOR-ION AND TRACE-ELEMENT CHEMISTRY OF WALKER RIVER AND WALKER LAKE, NEVADA

A.7: WALKER RIVER PERIPHYTON

A.9: SPATIAL AND TEMPORAL VARIABILITY IN ELEMENTAL COMPOSITION AND STOICHIOMETRY OF BENTHIC MACROINVERTEBRATE COMMUNITIES IN THE WALKER RIVER, NEVADA AND CALIFORNIA

A.10: FISHES OF WALKER RIVER: PRESENT COMPOSITION AND BASIC ECOLOGY

LIST OF TABLES

A.6: MAJOR-ION AND TRACE-ELEMENT CHEMISTRY OF WALKER RIVER AND WALKER LAKE, NEVADA

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ABSTRACT

Water-quality samples were collected from eight river sites and one central vertical profile at the deepest part of Walker Lake. Sampling results were evaluated to identify changes in water chemistry along the river and during different seasons. Major ions show that the Walker River has very low total dissolved solids (TDS) concentrations relative to Walker Lake's very high TDS. The river is composed predominantly of Ca^{2+}, Na^{+}, and HCO_3^{2-}, while the lake is composed predominantly of Na^{+} and a mixture of relatively equal proportions of HCO_3^{2-}, SO_4^{2-}, and Cl^{-}. Trace elements are very low in the river except for Mo and low in the lake except for Mo and As. Stable isotopes show that river water becomes increasingly evaporated as it flows downstream, and becomes increasingly evaporated in the lake. Because the river water is very low in TDS, increased river flow over a sufficiently long period of time should lower Walker Lake TDS.

INTRODUCTION

Increasing water inputs to the Walker River and Walker Lake will improve the ecosystems for both river and lake biota. Improving these ecosystems can partially be accomplished by improving the overall quality of water flowing in the river and into the lake. For example, lowering the total dissolved solids (TDS) content of Walker Lake will lower the osmotic stress on fish. Major-ion and trace element chemistry samples were collected from the Walker River and Walker Lake to establish present baseline conditions so the impact of future water-chemistry changes can be assessed.

Major-ion and trace-element sampling was conducted in conjunction with limnological and river ecological sampling. Analyses included ionic composition, nutrients, and trace elements; the results of changes in nutrients are addressed in other chapters as they relate to the river and lake ecosystems. Changes in major-ion and trace element chemistry along the river are discussed as is the overall chemistry of the lake. Samples were also collected for isotopic analyses of $\delta^{2}H$ and $\delta^{18}O$ to identify different sources of river water, to identify any groundwater inputs directly to the lake, and to assist in characterizing lake dynamics such as mixing and evaporative losses.

METHODS

Major-ion and nutrient samples were collected in half-gallon plastic jugs that were triple rinsed with sample water before being filled. These samples were stored in the field on ice until transport to the Desert Research Institute Analytical Chemistry Laboratory; samples were refrigerated until analysis. Major-ion and nutrient samples, as appropriate, were filtered in the laboratory through l0.45-μm filters. Trace-element samples were collected in 500-mL low-density polyethylene bottles that were soaked for at least two weeks in dilute nitric acid prior to sample collection; samples were filtered in the field through laboratory pre-cleaned 0.45-µm cartridge filters. Trace element samples were analyzed by inductively coupled mass spectrometry in the Desert Research Institute Ultra-Trace Chemistry Laboratory. Isotopic samples were collected in 1-oz glass bottles (triple rinsed with sample water) with poly-seal lids. Stable isotopes of δ^2H and δ^{18}O were analyzed at the University of Nevada, Reno Stable Isotope Laboratory. All samples, except for isotopic samples, were analyzed using the appropriate U.S. Environmental Protection Agency drinking-water and waste-water analytical procedures.

Samples were collected from eight different river locations and one lake location (Figure A.6.1). Two river locations were on the East Walker River, two locations were on the West Walker River, and four locations were on the main stem Walker River. River samples were collected seven times starting in April 2007 and ending in September 2008. Walker River sampling locations were selected to represent the variety of aquatic river environments in higher order Walker Basin streams and were located close to U.S. Geological Survey (USGS) stream gauges. Lake samples were collected roughly quarterly from March 2007 to December 2007.

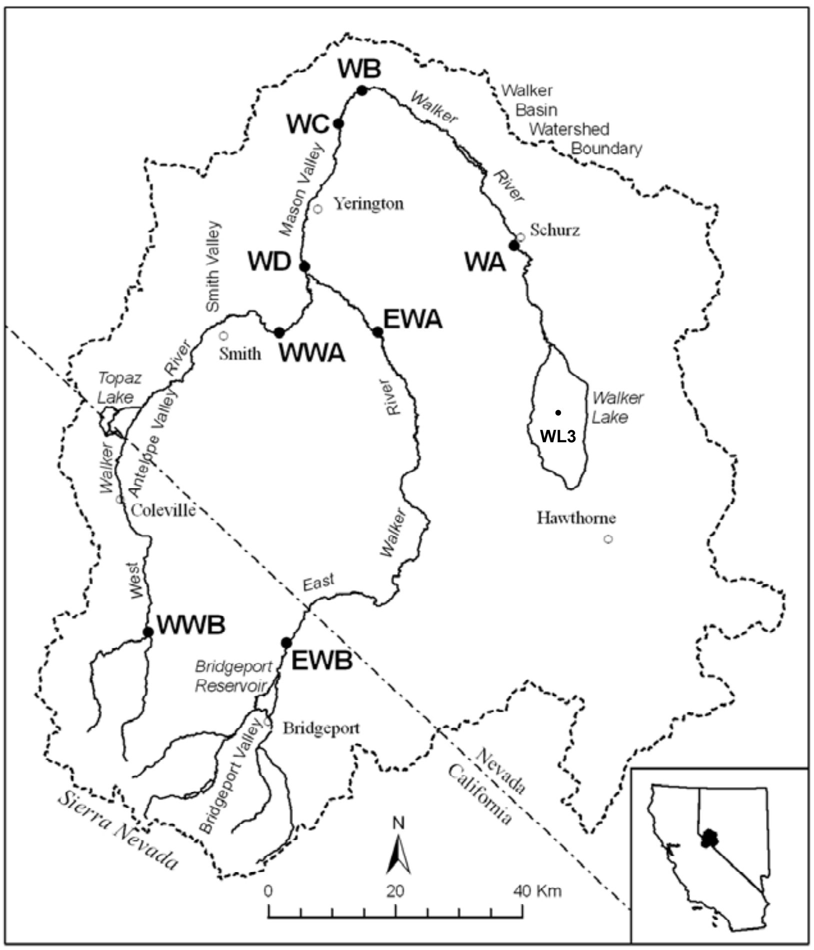

Figure A.6.1. Location of major-ion, trace-element, and stable isotopic samples collected for the Walker River and Walker Lake study.

RESULTS AND DISCUSSION

Walker River

Analytical results for major ions, minor ions, other parameters, and stable isotopes (δ^2H and $\delta^{18}O$) for the Walker River are listed in Table A.6.1. Trace-element analytical results are listed in Table A.6.2. A trilinear diagram of major-ion chemistry during base-flow conditions (low flow conditions during winter months when reservoirs are collecting and storing water) in February 2008 shows that the water chemistry of the river is predominantly composed of Ca^{2+}, Na^{+}, and HCO_3^{2-} with the contribution of SO_4^{2-} increasing downstream relative to the other major ions (Figure A.6.2).

<u>Water chemistry changes along the river</u>

Total dissolved solids (TDS) in the river, for base-flow conditions in February 2008, ranged from a low of 90 mg/L for the WWB sampling location in the upper reach of the West Fork to a high of 334 mg/L for the WA location at Schurz, NV, 15 km upstream from Walker Lake (Figure A.6.3, Table A.6.1). These concentrations are very low relative to the high TDS (15,900 mg/L, Table A.6.3) in Walker Lake. Total suspended solids (TSS) concentrations are very low in the upper reaches of the east and west forks of the Walker River during base-flow conditions, but increase in concentration in the lower reaches of the east and west forks (Figure A.6.4), similar to TDS. Total suspended solids also increase from sampling locations WD to WC along the upper reach of the main stem of the Walker River, but decrease in the lower reach of the main stem as the river slows and loses energy as it nears Weber Reservoir. Total suspended solids are also low in water exiting Weber Reservoir.

Trace-element concentrations for the Walker River during base-flow conditions in February 2008 are generally very low (Table A.6.2) with only Mo exceeding Nevada Aquatic Life standards (19 µg/L, NAC 445A.144; note that the units µg/L are approximately equal to ppb) at sampling location WA. For many, but not all, of the trace elements analyzed, concentrations generally increase downstream under base-flow conditions.

Stable isotopic compositions for the Walker River during base flow in February 2008 plot off the global meteoric water line (Craig, 1961) indicating that the river waters have been evaporated (Figure A.6.5). Isotopic compositions become progressively enriched (or isotopically heavier or have less negative compositions) downstream and follow an increasing evaporation as river water flows downstream toward Walker Lake.

Table A.6.1. Major ions, minor ions, other parameters, and stable isotopic (δ^2H and $\delta^{18}O$) data generated for the Walker River.

Location	Date	pH	EC (µS/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3 as N (mg/L)	SiO_2 (mg/L)	F (mg/L)	Br (mg/L)	TDS (mg/L)	TSS (mg/L)	Turbidity (mg/L)	Hg (mg/L)	δ^2H (‰)	$\delta^{18}O$ (‰)
WWB	4/26/2007	7.65	62	6.74	1.50	3.08	0.68	32.8	NA	0.44	1.78	0.003	8.4	<0.05	<0.02	40	3.1	1.43	<0.2	-110	-15.0
EWB	4/26/2007	8.06	199	19.4	3.92	15.1	3.23	99.6	NA	2.61	12.6	0.009	15.1	0.24	<0.02	125	14.6	5.01	<0.2	-109	-14.2
WWA	4/26/2007	8.61	405	30.9	8.26	39.5	4.29	151	6.1	19.9	34.0	0.143	16.3	0.69	0.06	218	12.3	6.91	<0.2	-107	-14.1
EWA	4/27/2007	8.05	282	26.9	5.76	21.4	4.00	129	NA	4.35	26.2	0.004	19.2	0.36	<0.02	171	27.0	8.54	<0.2	-109	-13.9
WD	4/27/2007	8.18	442	34.7	8.44	41.1	4.35	176	NA	17.8	44.7	0.124	17.9	0.66	0.05	258	16.2	7.79	<0.2	-108	-14.0
WC	4/27/2007	8.17	453	36.2	8.94	42.4	4.50	182	NA	17.8	48.8	0.161	20.2	0.60	0.04	248	32.9	12.7	<0.2	-107	-14.1
WWB	8/13/2007	8.16	174	12.5	2.80	19.7	2.05	85.1	NA	4.7	10.8	0.005	13.8	0.17	0.01	92	1.0	0.82	<0.2	-110	-14.5
EWB	8/13/2007	9.33	197	19.3	4.22	16.8	3.44	73.4	17.8	2.6	9.7	0.103	17.5	0.30	0.02	116	5.0	4.09	<0.2	-95	-11.6
WWA	8/13/2007	8.59	273	20.4	5.16	27.5	2.71	114	3.8	11.4	20.1	0.002	9.0	0.51	0.04	146	4.5	2.91	<0.2	-104	-13.5
EWA	8/14/2007	8.27	238	21.7	4.85	19.8	3.89	125	NA	3.2	15.1	0.007	16.6	0.37	0.04	135	35.8	12.5	<0.2	-97	-11.7
WD	8/14/2007	8.41	304	23.1	5.51	31.4	3.56	131	2.0	10.7	27.6	0.023	14.3	0.55	0.04	170	11.5	5.73	<0.2	-102	-12.8
WC	8/14/2007	8.30	326	25.3	6.30	31.6	3.93	142	NA	11.0	31.6	0.021	18.2	0.54	0.02	190	9.3	4.88	<0.2	-104	-13.0
WB	8/14/2007	8.33	353	27.5	6.75	35.1	4.08	146	1.3	12.6	37.8	0.010	18.0	0.59	0.05	207	8.1	4.77	<0.2	-102	-12.7
WA	8/14/2007	8.82	561	35.5	10.3	73.3	7.18	208	16	25.1	63.8	0.008	19.1	0.91	0.07	340	3.5	1.44	<0.2	-85	-8.4
WWB	9/20/2007	8.06	203	13.9	3.38	22.4	2.41	97.1	NA	5.9	13.3	0.008	14.7	0.19	0.03	115	1.6	1.15	<0.2	-110	-14.8
EWB	9/20/2007	9.29	198	18.7	3.9	17.6	3.56	65.6	18.6	3.0	11.5	0.080	28.7	0.35	<0.02	131	9.8	7.67	<0.2	-93	-10.9
WWA	9/20/2007	8.37	327	25.6	6.54	31.7	3.31	126	1.9	18.8	27.7	0.006	11.6	0.59	0.03	181	2.7	1.70	<0.2	-105	-13.5
EWA	9/21/2007	8.15	252	23.3	5.07	21.5	4.02	124	NA	4.0	19.7	0.005	25.3	0.42	<0.02	165	38.2	11.7	<0.2	-94	-11.2
WD	9/21/2007	8.23	328	26.5	6.29	32.2	3.88	139	NA	12.4	31.9	0.009	19.4	0.54	<0.02	200	14.8	5.75	<0.2	-98	-12.2
WC	9/21/2007	8.25	336	27.0	6.56	32.5	4.08	140	NA	13.0	34.6	0.006	20.0	0.55	0.03	202	16.3	7.52	<0.2	-101	-12.4
WB	9/21/2007	8.28	343	27.7	6.78	33.3	4.2	142	NA	13.2	35.4	0.005	20.0	0.57	0.03	206	19.8	10.2	<0.2	-100	-12.3
WA	9/21/2007	8.19	556	41.0	9.52	65.0	6.98	237	NA	23.6	59.4	0.005	23.2	0.78	0.06	342	12.2	3.06	<0.2	-93	-10.6
WWB	2/13/2008	7.71	136	13.2	3.26	9.86	1.65	77.4	NA	2.49	7.07	0.030	14.2	0.07	<0.02	90	0.6	0.86	<0.2	-114	-15.4
EWB	2/13/2008	8.10	250	24.3	5.06	19.7	4.55	124	NA	3.64	23.3	0.097	19.3	0.25	<0.02	168	4.2	4.4	<0.2	-111	-14.4
WWA	2/13/2008	8.52	571	44.5	11.5	60.0	5.49	200	6.5	38.1	63.8	0.062	13.7	1.00	0.12	345	4.7	2.33	<0.2	-109	-14.3
EWA	2/14/2008	8.09	317	30.8	6.73	25.3	4.59	136	NA	5.87	43.7	0.021	20.8	0.42	0.07	206	23.2	11.3	<0.2	-110	-14.0
WD	2/14/2008	8.19	502	40.6	9.52	51.0	5.21	188	NA	26.9	64.7	0.044	16.8	0.79	0.05	308	13.6	7.11	<0.2	-109	-14.1
WC	2/14/2008	8.20	467	38.5	9.25	47.1	5.14	179	NA	23.7	61.4	0.031	16.1	0.73	0.05	295	27.8	14.5	<0.2	-109	-14.0
WB	2/14/2008	8.20	513	39.9	9.46	53.8	5.58	189	NA	25.1	69.6	0.024	16.7	0.85	0.05	316	18.8	12.6	<0.2	-108	-13.6
WA	2/14/2008	8.25	514	41.6	10.1	54.2	6.60	215	NA	23.7	58.8	0.005	21.2	0.82	0.07	334	9.8	9.11	<0.2	-94	-11.0

Table A.6.1. Major ions, minor ions, other parameters, and stable isotopic (δ^2H and $\delta^{18}O$) data generated for the Walker River (continued).

Location	Date	pH	EC (µS/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3 as N (mg/L)	SiO_2 (mg/L)	F (mg/L)	Br (mg/L)	TDS (mg/L)	TSS (mg/L)	Turbidity (mg/L)	Hg (mg/L)	δ^2H (‰)	$\delta^{18}O$ (‰)
WWB	4/18/2008	7.75	66	7.42	1.59	2.94	0.71	35.4	NA	0.5	2.9	0.02	8.7	0.03	<0.02	45	14.5	3.22	<0.2	-112	-15.2
EWB	4/18/2008	8.24	238	20.6	4.67	20.4	4.01	110	NA	4.1	23.0	0.01	17.8	0.28	<0.02	151	7.6	4.01	<0.2	-111	-14.4
WWA	4/18/2008	8.25	311	25.4	6.84	28.5	3.51	133	NA	14.2	25.3	0.20	9.3	0.54	0.04	189	42.4	23.5	<0.2	-105	-13.3
EWA	4/17/2008	8.18	276	24.4	5.62	23.2	4.24	123	NA	5.1	30.6	0.01	19.8	0.34	<0.02	176	73.6	26.5	<0.2	-111	-14.2
WD	4/17/2008	8.28	427	32.8	8.46	42.1	4.65	165	NA	19.6	49.5	0.02	16.4	0.62	0.05	272	59.0	24.4	<0.2	-107	-13.5
WC	4/17/2008	8.26	445	36.2	9.23	41.9	4.75	175	NA	18.5	54.7	0.02	20.8	0.57	0.05	299	25.7	14.2	<0.2	-109	-13.6
WB	4/17/2008	8.34	475	36.5	9.19	48.9	5.42	179	1.3	20.1	61.9	0.01	20.2	0.73	0.06	300	53.9	24.5	<0.2	-107	-13.3
WA	4/17/2008	8.05	644	50.7	12.2	68.1	5.96	264	NA	26.4	79.2	<0.01	19.0	0.62	0.07	394	6.0	2.36	<0.2	-96	-10.9
WWB	7/10/2008	7.64	63	6.72	1.43	2.82	0.61	32.9	NA	0.43	1.91	0.005	7.38	0.02	<0.02	34	17.9	12.5	<0.2	-106	-14.6
EWB	7/10/2008	8.93	192	20.1	4.24	15.0	3.62	86.2	8.6	2.31	12.7	0.117	16.3	0.26	<0.02	129	4.2	3.87	<0.2	-105	-13.2
WWA	7/10/2008	7.90	196	17.1	4.46	16.6	2.48	91.0	NA	6.37	15.0	0.135	10.9	0.33	0.02	127	67.0	81.4	<0.2	-107	-14.1
EWA	7/10/2008	8.07	231	22.7	5.12	18.1	4.15	118	NA	3.36	18.8	0.026	18.0	0.33	<0.02	151	50.4	18.6	<0.2	-105	-13.1
WD	7/10/2008	8.03	235	20.1	4.88	21.4	3.43	110	NA	8.30	22.5	0.048	14.5	0.39	0.02	150	41.6	20.1	<0.2	-107	-13.6
WC	7/10/2008	8.09	276	23.1	5.75	25.8	3.81	125	NA	8.86	26.8	0.052	16.3	0.47	0.03	175	37.4	18.3	<0.2	-107	-13.6
WB	7/10/2008	8.13	303	25.2	6.28	28.7	4.02	136	NA	10.2	31.1	0.024	15.3	0.50	0.03	191	27.4	13.4	<0.2	-106	-13.3
WA	7/10/2008	8.06	472	30.4	10.1	55.8	6.54	202	NA	23.9	51.7	0.015	4.82	0.85	0.06	283	1.1	2.15	<0.2	-92	-9.8
WWB	9/11/2008	7.94	164	16.1	3.51	12.8	1.57	84.0	NA	2.91	10.6	0.006	12.7	0.09	<0.02	108	1.2	1.28	NA	-109	-14.7
EWB	9/11/2008	8.94	202	21.1	4.36	15.9	3.84	85.8	11.3	2.49	11.8	0.089	33.0	0.30	<0.02	160	6.7	5.88	NA	-98	-11.6
WWA	9/11/2008	8.36	280	23.5	6.24	25.3	3.12	121	1.40	11.8	23.4	0.005	9.89	0.43	0.04	170	2.5	2.13	NA	-107	-13.7
EWA	9/11/2008	8.08	250	24.3	5.32	20.2	4.07	125	NA	3.92	20.3	0.009	29.7	0.36	<0.02	169	15.5	7.37	NA	-100	-12.0
WD	9/11/2008	8.14	312	25.8	6.25	29.8	3.69	135	NA	10.7	33.0	0.051	19.2	0.48	0.02	202	9.2	5.08	NA	-104	-12.9
WC	9/11/2008	8.11	320	26.4	6.72	29.5	3.82	137	NA	11.1	34.2	0.029	21.0	0.47	0.03	209	8.3	5.60	NA	-104	-13.1
WB	9/11/2008	8.11	334	26.8	6.81	31.9	3.95	138	NA	12.7	38.0	0.014	20.2	0.50	0.03	213	8.8	5.70	NA	-105	-13.0
WA	9/11/2008	8.28	521	39.2	10.9	58.3	6.75	240	NA	23.7	45.0	0.013	9.34	0.88	0.06	314	2.8	3.01	NA	-87	-8.9

Table A.6.2. Trace-element data generated for the Walker River.

Sample	Date	Be (ppb)	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	Sr (ppb)	Mo (ppb)	Ag (ppb)	Cd (ppb)	Sn (ppb)	Sb (ppb)	Ba (ppb)	TI (ppb)	Pb (ppb)	U (ppb)	As (ppb)	Se (ppb)
WWB	4/26/2007	<1.0	14.8	<1.0	<1.0	2.6	18.1	<1.0	<1.0	<1.0	<1.0	74.8	<1.0	<1.0	<1.0	NA	<1.0	9.5	<1.0	<1.0	<1.0	1.2	<5.0
EWB	4/26/2007	<1.0	2.2	1.2	<1.0	17.1	49.7	<1.0	<1.0	<1.0	<1.0	204.2	3.9	<1.0	<1.0	NA	<1.0	23.2	<1.0	<1.0	1.8	3.9	<5.0
WWA	4/26/2007	<1.0	1.2	5.2	<1.0	25.9	25.1	<1.0	<1.0	1.1	<1.0	329.7	8.7	<1.0	<1.0	NA	<1.0	40.6	<1.0	<1.0	14.3	12.9	<5.0
EWA	4/27/2007	<1.0	1.9	2.3	<1.0	20.1	21.2	<1.0	<1.0	<1.0	<1.0	262.1	6.4	<1.0	<1.0	NA	<1.0	42.9	<1.0	<1.0	2.3	8.5	<5.0
WD	4/27/2007	<1.0	10.1	3.4	<1.0	10.0	24.7	<1.0	<1.0	1.1	<1.0	356.8	7.9	<1.0	<1.0	NA	<1.0	48.4	<1.0	<1.0	10.4	11.4	<5.0
WC	4/27/2007	<1.0	1.8	3.9	<1.0	9.1	4.0	<1.0	<1.0	<1.0	<1.0	372.6	8.5	<1.0	<1.0	NA	<1.0	51.1	<1.0	<1.0	14.7	11.5	<5.0
WWB	8/13/2007	<1.0	2.4	1.2	<1.0	5.9	22.0	<1.0	<1.0	<1.0	<1.0	164.8	2.0	<1.0	<1.0	NA	<1.0	23.2	<1.0	<1.0	<1.0	27.0	<5.0
EWB	8/13/2007	<1.0	7.3	3.1	<1.0	11.9	51.1	<1.0	<1.0	<1.0	<1.0	207.5	5.0	<1.0	<1.0	NA	<1.0	20.8	<1.0	<1.0	2.1	19.5	<5.0
WWA	8/13/2007	<1.0	8.8	2.5	<1.0	11.1	14.5	<1.0	<1.0	<1.0	<1.0	224.1	5.6	<1.0	<1.0	NA	<1.0	27.8	<1.0	<1.0	6.6	8.1	<5.0
EWA	8/14/2007	<1.0	9.3	3.1	<1.0	12.4	33.6	<1.0	<1.0	<1.0	<1.0	236.3	6.4	<1.0	<1.0	NA	<1.0	31.3	<1.0	<1.0	2.1	17.2	<5.0
WD	8/14/2007	<1.0	12.9	3.6	<1.0	9.9	17.1	<1.0	<1.0	<1.0	<1.0	249.8	7.5	<1.0	<1.0	NA	<1.0	30.5	<1.0	<1.0	6.5	13.4	<5.0
WC	8/14/2007	<1.0	14.3	4.1	<1.0	9.5	12.6	<1.0	<1.0	<1.0	<1.0	262.4	7.6	<1.0	<1.0	NA	<1.0	32.4	<1.0	<1.0	6.6	13.1	<5.0
WB	8/14/2007	<1.0	22.0	4.2	<1.0	15.1	20.8	<1.0	<1.0	<1.0	<1.0	286.8	8.9	<1.0	<1.0	NA	<1.0	32.1	<1.0	<1.0	7.8	14.0	<5.0
WA	8/14/2007	<1.0	<1.0	7.7	<1.0	59.6	5.2	<1.0	<1.0	<1.0	<1.0	441.6	28.3	<1.0	<1.0	NA	<1.0	39.3	<1.0	<1.0	17.5	36.2	<5.0
WWB	9/20/2007	<1.0	1.6	1.0	<1.0	6.6	32.4	<1.0	<1.0	<1.0	<1.0	138.0	2.3	<1.0	<1.0	<1.0	<1.0	23.9	<1.0	<1.0	<1.0	29.6	<5.0
EWB	9/20/2007	<1.0	35.2	4.9	<1.0	17.2	98.5	<1.0	<1.0	<1.0	<1.0	165.1	6.3	<1.0	<1.0	<1.0	<1.0	24.8	<1.0	<1.0	3.7	19.1	<5.0
WWA	9/20/2007	<1.0	8.5	2.2	<1.0	13.4	22.9	<1.0	<1.0	<1.0	<1.0	212.9	7.1	<1.0	<1.0	<1.0	<1.0	32.1	<1.0	<1.0	10.9	8.9	<5.0
EWA	9/20/2007	<1.0	2.2	3.5	<1.0	8.3	19.4	<1.0	<1.0	<1.0	<1.0	192.9	7.6	<1.0	<1.0	<1.0	<1.0	31.6	<1.0	<1.0	3.6	16.4	<5.0
WD	9/21/2007	<1.0	39.0	3.0	<1.0	15.3	42.9	<1.0	<1.0	<1.0	<1.0	207.7	8.1	<1.0	<1.0	<1.0	<1.0	32.6	<1.0	<1.0	9.1	12.4	<5.0
WC	9/21/2007	<1.0	16.3	4.0	<1.0	6.6	17.8	<1.0	<1.0	<1.0	<1.0	242.6	8.9	<1.0	<1.0	<1.0	<1.0	30.4	<1.0	<1.0	10.8	13.0	<5.0
WB	9/21/2007	<1.0	27.6	3.9	<1.0	9.7	26.9	<1.0	<1.0	<1.0	<1.0	222.4	8.7	<1.0	<1.0	<1.0	<1.0	29.8	<1.0	<1.0	11.0	13.6	<5.0
WA	9/21/2007	<1.0	1.6	4.6	<1.0	158.9	6.3	<1.0	<1.0	<1.0	<1.0	378.1	23.2	<1.0	<1.0	<1.0	<1.0	64.0	<1.0	<1.0	13.2	17.7	<5.0
WWB	2/13/2008	<1.0	1.1	<1.0	<1.0	6.5	17.0	<1.0	<1.0	<1.0	<1.0	118.0	1.2	<1.0	<1.0	<1.0	<1.0	16.5	<1.0	<1.0	<1.0	6.7	<5.0
EWB	2/13/2008	<1.0	1.7	<1.0	<1.0	324.1	54.1	<1.0	<1.0	<1.0	<1.0	202.1	5.6	<1.0	<1.0	<1.0	<1.0	33.8	<1.0	<1.0	2.8	3.8	<5.0
WWA	2/13/2008	<1.0	<1.0	4.0	<1.0	193.8	15.0	<1.0	<1.0	<1.0	<1.0	383.0	12.7	<1.0	<1.0	<1.0	<1.0	52.6	<1.0	<1.0	28.9	13.7	<5.0
EWA	2/14/2008	<1.0	1.1	1.6	<1.0	47.0	20.5	<1.0	<1.0	<1.0	<1.0	242.7	8.7	<1.0	<1.0	<1.0	<1.0	45.3	<1.0	<1.0	4.5	8.6	<5.0
WD	2/14/2008	<1.0	33.4	2.5	<1.0	21.9	58.1	<1.0	<1.0	<1.0	<1.0	342.1	10.5	<1.0	<1.0	<1.0	<1.0	47.5	<1.0	<1.0	20.4	10.9	<5.0
WC	2/14/2008	<1.0	2.1	2.6	<1.0	11.1	6.6	<1.0	<1.0	<1.0	<1.0	326.1	10.4	<1.0	<1.0	<1.0	<1.0	46.0	<1.0	<1.0	19.1	10.2	<5.0
WB	2/14/2008	<1.0	8.5	2.8	<1.0	17.4	13.5	<1.0	<1.0	<1.0	<1.0	334.1	11.2	<1.0	<1.0	<1.0	<1.0	45.1	<1.0	<1.0	19.7	13.3	<5.0
WA	2/14/2008	<1.0	40.3	4.4	<1.0	21.0	45.4	<1.0	<1.0	1.1	<1.0	339.4	12.1	<1.0	<1.0	<1.0	<1.0	47.6	<1.0	<1.0	17.5	19.2	<5.0

Table A.6.2. Trace-element data generated for the Walker River (continued).

Sample	Date	Be (ppb)	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	Sr (ppb)	Mo (ppb)	Ag (ppb)	Cd (ppb)	Sn (ppb)	Sb (ppb)	Ba (ppb)	TI (ppb)	Pb (ppb)	U (ppb)	As (ppb)	Se (ppb)
WWB	4/18/2008	<0.1	19.8	0.6	<0.1	3.1	25.0	<0.1	0.8	0.4	2.0	81.5	0.6	<0.1	<0.1	NA	<0.1	10.3	<0.1	<0.1	0.3	0.6	<1.0
EWB	4/18/2008	<0.1	3.9	1.1	<0.1	26.7	52.6	<0.1	1.0	0.6	2.4	201.2	4.6	<0.1	<0.1	NA	<0.1	30.7	<0.1	<0.1	2.3	4.2	<1.0
WWA	4/18/2008	<0.1	97.1	3.4	<0.1	51.4	97.2	0.2	1.2	1.4	2.7	245.6	7.4	<0.1	<0.1	NA	0.2	40.6	<0.1	0.2	11.2	7.8	<1.0
EWA	4/17/2008	<0.1	102.0	2.4	<0.1	19.8	120.2	0.2	0.5	1.0	0.5	240.9	6.4	<0.1	<0.1	NA	0.2	39.4	<0.1	<0.1	2.6	7.9	<1.0
WD	4/17/2008	<0.1	57.0	3.4	<0.1	17.6	59.2	0.1	0.5	0.9	0.3	308.2	8.8	<0.1	<0.1	NA	0.1	44.0	<0.1	<0.1	12.4	10.1	<1.0
WC	4/17/2008	<0.1	18.7	3.7	1.1	20.2	24.1	0.1	0.8	1.0	0.4	338.8	9.3	<0.1	<0.1	NA	0.2	49.0	<0.1	<0.1	13.7	11.0	<1.0
WB	4/17/2008	<0.1	2.3	4.5	<0.1	22.6	4.8	<0.1	0.5	0.9	0.3	345.9	10.4	<0.1	<0.1	NA	0.2	44.9	<0.1	<0.1	14.5	14.8	<1.0
WA	4/17/2008	<0.1	2.7	5.8	<0.1	214.5	9.4	0.1	0.7	0.6	0.4	487.7	14.7	<0.1	<0.1	NA	0.1	67.2	<0.1	<0.1	24.1	13.1	<1.0
WWB	7/17/2008	<0.1	16.2	0.6	<0.1	4.4	13.4	<0.1	<0.1	0.3	0.3	71.2	0.6	<0.1	<0.1	NA	<0.1	11.4	<0.1	<0.1	0.2	1.2	<1.0
EWB	7/17/2008	<0.1	2.3	1.7	<0.1	32.0	69.2	0.1	0.3	0.6	0.5	189.8	4.6	<0.1	<0.1	NA	<0.1	20.9	<0.1	<0.1	1.6	14.5	<1.0
WWA	7/17/2008	<0.1	234.2	2.4	0.2	18.0	212.3	0.2	2.3	1.7	4.3	172.5	4.2	<0.1	<0.1	NA	<0.1	28.2	<0.1	0.2	4.0	6.4	<1.0
EWA	7/17/2008	<0.1	206.7	2.9	0.1	30.8	233.6	0.2	0.7	1.2	0.7	223.5	5.9	<0.1	<0.1	NA	0.1	37.6	<0.1	0.2	1.8	12.6	<1.0
WD	7/17/2008	<0.1	39.3	2.9	<0.1	8.8	47.4	<0.1	0.5	1.0	1.2	193.5	5.7	<0.1	<0.1	NA	0.1	28.2	<0.1	<0.1	3.6	9.6	<1.0
WC	7/17/2008	<0.1	10.1	3.5	<0.1	8.4	13.4	<0.1	0.4	1.0	1.1	220.2	7.1	<0.1	<0.1	NA	0.1	30.3	<0.1	<0.1	5.8	10.6	<1.0
WB	7/17/2008	<0.1	47.7	3.7	<0.1	10.5	48.4	<0.1	0.5	1.1	1.4	241.5	7.6	<0.1	<0.1	NA	0.1	30.6	<0.1	<0.1	6.9	11.3	<1.0
WA	7/17/2008	<0.1	1.9	3.2	<0.1	23.3	6.5	0.2	0.7	0.8	0.3	341.7	11.8	<0.1	<0.1	NA	0.2	37.5	<0.1	<0.1	9.8	20.2	<1.0
WWB	9/11/2008	<0.1	2.4	1.0	<0.1	5.7	15.8	<0.1	0.3	0.3	2.3	199.4	1.8	<0.1	<0.1	NA	0.1	26.0	<0.1	<0.1	0.6	11.1	<1.0
EWB	9/11/2008	<0.1	8.2	3.8	<0.1	24.5	45.9	0.2	4.5	0.9	6.8	209.4	5.6	<0.1	<0.1	NA	0.2	27.8	<0.1	0.3	2.3	16.1	<1.0
WWA	9/11/2008	<0.1	8.0	2.3	<0.1	10.1	16.7	<0.1	0.3	0.6	0.4	231.8	5.9	<0.1	<0.1	NA	0.1	31.9	<0.1	<0.1	9.3	8.3	<1.0
EWA	9/11/2008	<0.1	29.2	3.3	<0.1	20.3	70.4	0.1	0.5	0.8	0.6	233.3	6.8	<0.1	<0.1	NA	0.1	34.2	<0.1	<0.1	2.7	15.7	<1.0
WD	9/11/2008	<0.1	20.4	2.8	<0.1	14.1	27.8	<0.1	0.4	0.8	0.3	244.2	7.2	<0.1	<0.1	NA	0.1	33.2	<0.1	<0.1	7.4	11.6	<1.0
WC	9/11/2008	<0.1	4.0	3.3	<0.1	13.5	6.5	<0.1	0.4	0.8	0.2	258.6	7.7	<0.1	<0.1	NA	0.1	33.4	<0.1	<0.1	8.7	11.7	<1.0
WB	9/11/2008	<0.1	6.9	3.3	<0.1	7.4	8.7	<0.1	0.3	0.8	0.2	254.0	8.3	<0.1	<0.1	NA	0.1	30.2	<0.1	<0.1	8.9	11.6	<1.0
WA	9/11/2008	<0.1	1.0	3.8	<0.1	36.8	7.4	0.3	0.5	0.7	0.3	409.9	13.1	<0.1	<0.1	NA	0.3	43.3	<0.1	<0.1	9.5	27.9	<1.0

Table A.6.3. Major ions, minor ions, other parameters, and stable isotopic (δ^2H and $\delta^{18}O$) data generated for Walker Lake.

Location	Date	pH	EC (µS/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3 as N (mg/L)	SiO_2 (mg/L)	TP (mg/L)	F (mg/L)	Br (mg/L)	TDS (mg/L)	TSS (mg/L)	Turbidity (mg/L)	Hg (mg/L)	δ^2H (‰)	$\delta^{18}O$ (‰)
WL3 2.5m	3/7/2007	9.38	20,000	10.7	190	4,760	262	2,300	1,060	3,450	3,490	0.03	0.30	0.73	22.9	8.93	15,000	1.8	1.05	<0.2	-31	0.6
WL3 10m	3/7/2007	9.37	20,000	10.5	193	4,870	253	2,310	1,060	3,410	3,460	0.02	0.30	0.74	22.9	8.60	15,000	5.4	1.30	<0.2	-31	0.6
WL3 20m	3/7/2007	9.38	20,000	10.4	186	5,000	255	2,320	1,060	3,480	3,460	0.02	0.20	0.69	24.0	8.32	15,000	2.8	1.10	<0.2	-31	0.5
WL3 2.5m	5/22/2007	9.37	19,670	10.5	183	5,070	256	2,420	1,010	3,460	3,580	<0.01	0.58	0.84	23.0	9.08	15,100	8.8	0.62	<0.2	-32	0.6
WL3 10m	5/22/2007	9.37	19,670	10.4	177	4,930	256	2,400	1,010	3,490	3,550	<0.01	0.54	0.83	22.9	8.15	15,000	5.2	1.34	<0.2	-31	0.5
WL3 20m	5/22/2007	9.38	19,600	10	187	4,900	250	2,400	1,010	3,500	3,560	0.02	0.68	0.86	22.8	8.65	15,000	6.6	1.35	<0.2	-31	0.5
WL3 2.5m	8/29/2007	9.40	20,400	10.9	191	5,310	288	2,370	1,120	3,520	3,580	0.01	0.66	0.62	26.1	8.70	15,700	1.8	0.78	<0.2	-28	1.1
WL3 10m	8/29/2007	9.39	20,400	10.7	193	5,320	295	2,390	1,130	3,490	3,590	0.01	0.58	0.62	26.0	7.60	15,700	1.0	0.75	<0.2	-29	1.1
WL3 20m	8/29/2007	9.36	19,700	9.71	184	4,820	280	2,360	1,040	3,360	3,420	0.03	2.06	0.69	25.0	7.50	15,000	0.4	1.07	<0.2	-31	0.5
WL3 2.5m	12/4/2007	9.37	20,500	10	197	5,110	284	2,450	1,120	3,730	3,700	0.04	1.10	0.73	26.2	7.62	15,900	0.8	0.80	<0.2	-28	1.2
WL3 10m	12/4/2007	9.36	20,500	10	194	5,230	283	2,440	1,130	3,710	3,720	0.04	1.10	0.73	25.8	8.49	15,900	1.5	0.75	<0.2	-28	1.2
WL3 20m	12/4/2007	9.36	20,500	10.1	192	5,160	279	2,460	1,130	3,750	3,730	0.04	1.00	0.74	26.2	8.00	15,900	1.5	0.90	<0.2	-27	1.2

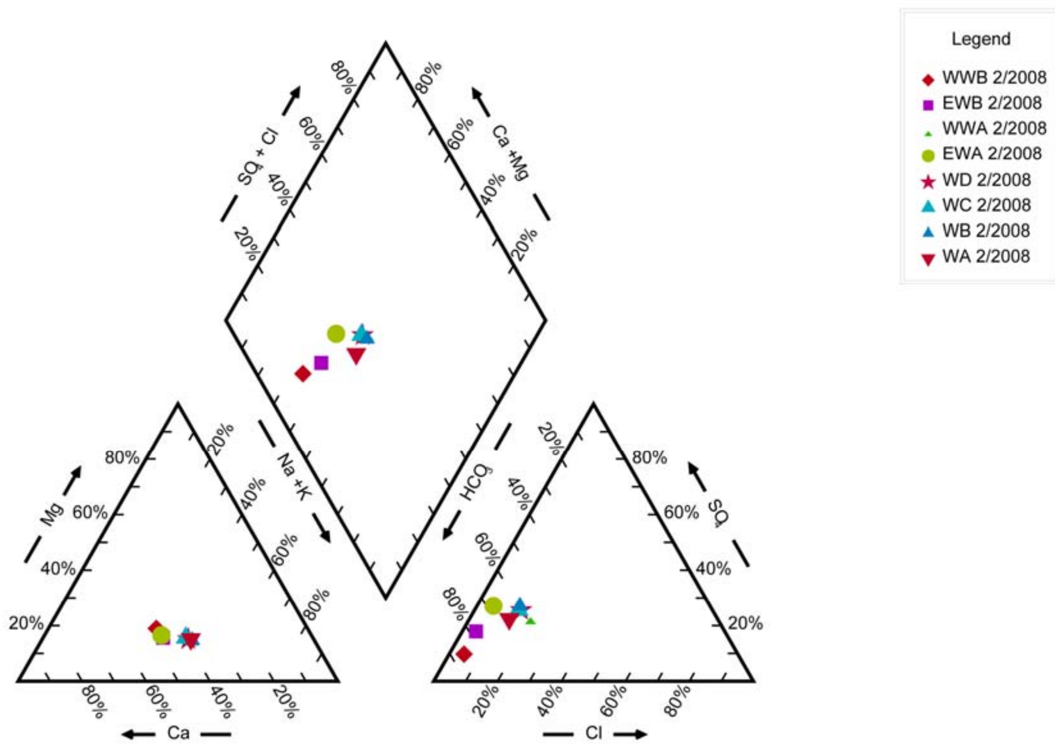

Figure A.6.2. Major-ion trilinear diagram for the Walker River for samples collected during base-flow conditions in February 2008. Diagram shows that the river chemistry is composed predominantly of Ca^{2+}, Na^{+}, and HCO_3^{2+}. The contribution of SO_4^{2-} relative to the other major ions increases downstream.

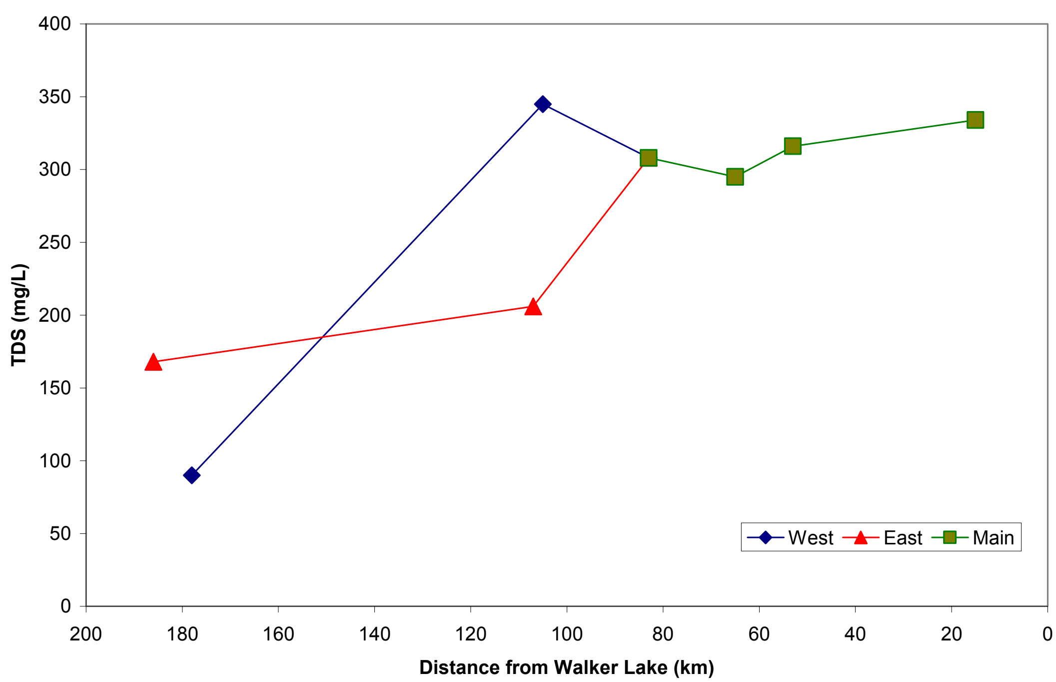

Figure A.6.3. Variations in total dissolved solids (TDS, mg/L) along the Walker River during base-flow conditions in February 2008.

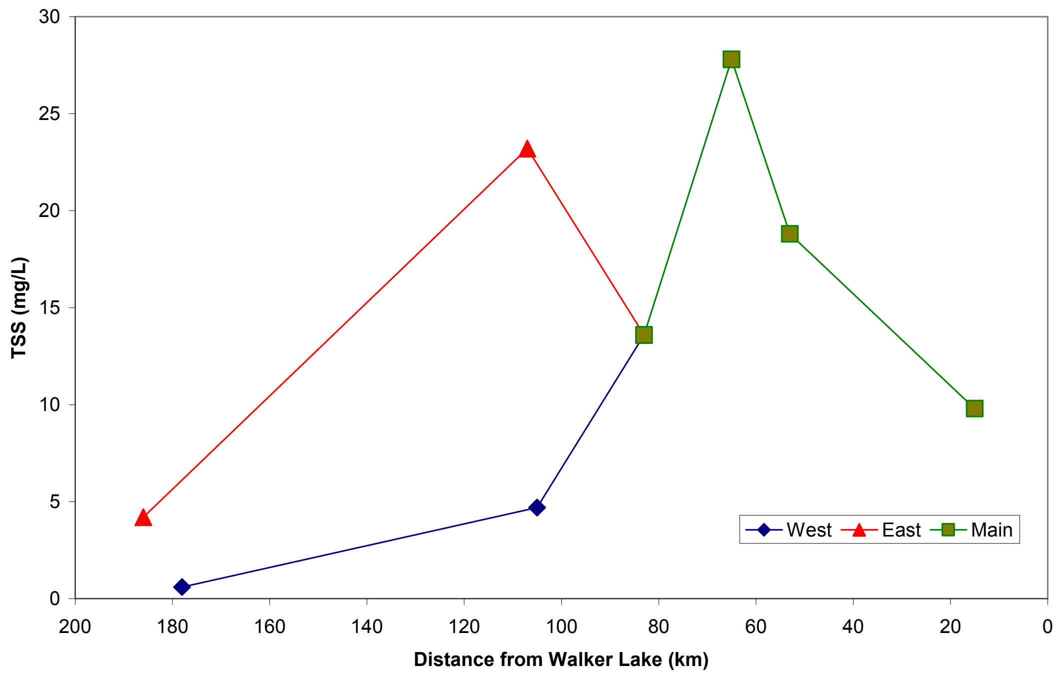

Figure A.6.4. Variations in total suspended solids (TSS, mg/L) along the Walker River during base-flow conditions in February 2008.

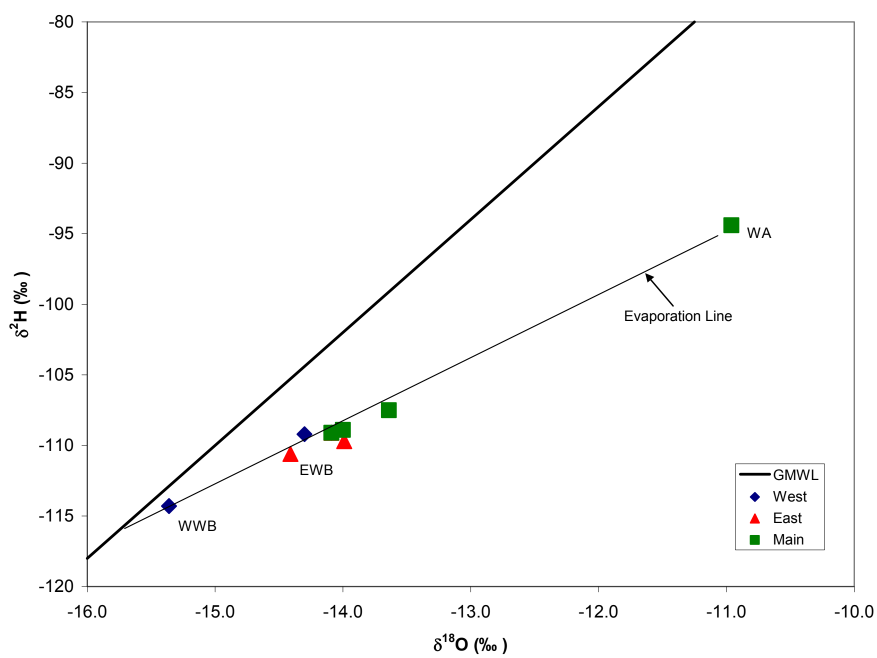

Figure A.6.5. Variations in stable isotope composition along the Walker River during base-flow conditions in February 2008.

Seasonal Water Chemistry Variations

From base-flow conditions in February 2008, river water becomes progressively more dilute from April 2008 to July 2008 (Figure A.6.6) as TDS concentrations decrease with increased flows from spring snow melt in the watershed and reservoir releases. By September 2008, river water increased in TDS concentrations, but still less than base-flow conditions.

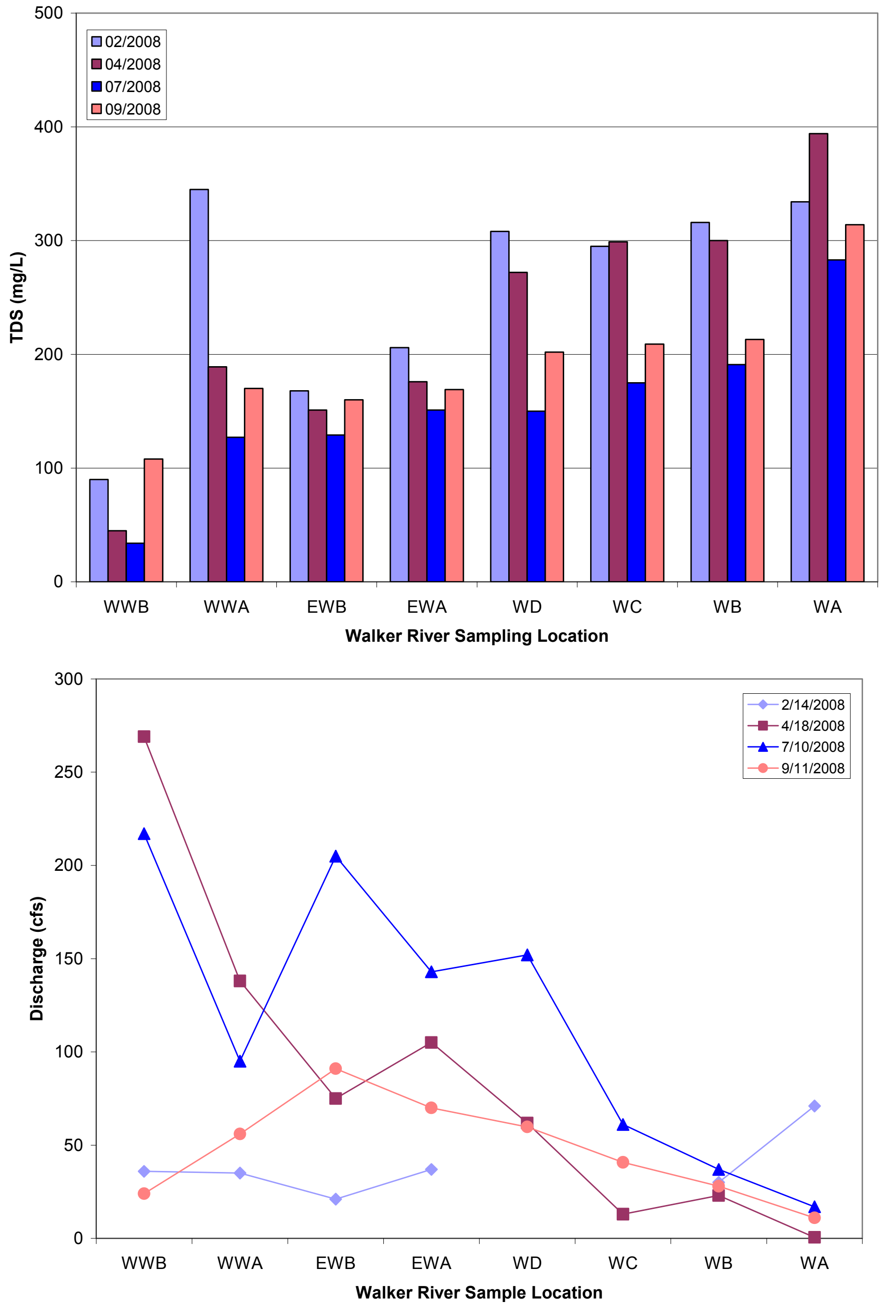

Figure A.6.6. Seasonal variations in TDS along the Walker River. Base-flow conditions in February 2008 have the highest concentrations in TDS. July 2008 has the most dilute concentrations at all locations.

Trace elements generally increase downstream, and for most elements, concentrations are higher for base-flow conditions in February 2008 (Figure A.6.7); however, there are exceptions to these general observations. For example, Mn concentrations at two upstream locations (WWA, EWB) are much higher than downstream during base-flow conditions. As another example, Fe concentrations are higher at several locations in July 2008, which is in contrast to the TDS trends described above. Some trace elements, such as Mn and Fe, are sensitive to oxidation-reduction and/or other geochemical processes (e.g., pH, sorption), and these processes likely vary at different locations and times of the year.

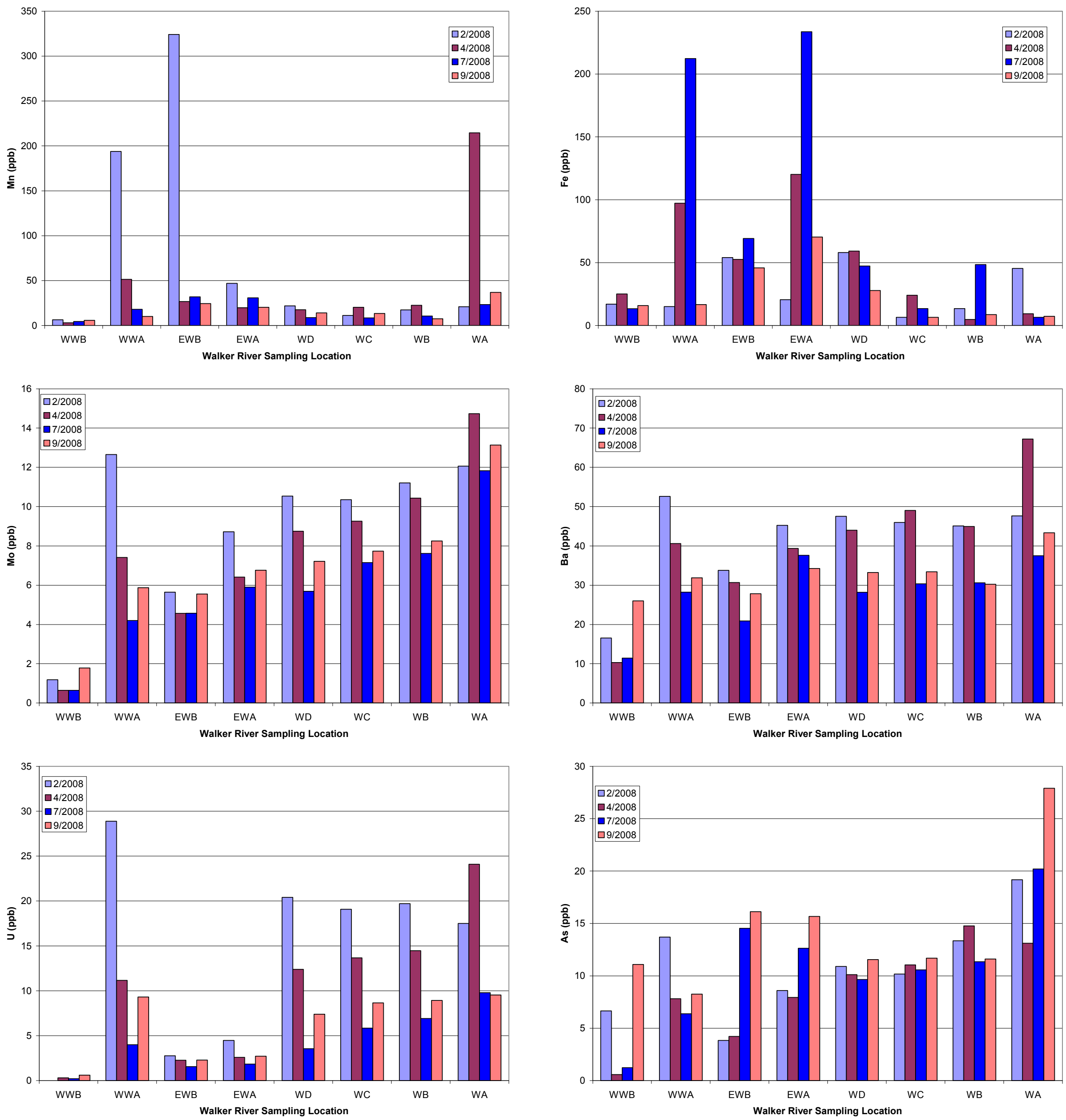

Figure A.6.7. Seasonal variations in select trace-element concentrations (Mn, Fe, Mo, Ba, U, As) along the Walker River.

Stable isotopic compositions varied seasonally along the Walker River during 2008. Isotopic compositions became progressively enriched (or isotopically heavier or have less negative values) and increasingly evaporated downstream and as the year progressed (Figure A.6.8). $\delta^{18}O$ values along the Walker River during 2008 (Figure A.6.9) have the greatest seasonal enrichment from evaporation at sampling locations EWA and WA as these sampling locations are downstream of Bridgeport Reservoir and Weber Reservoir, respectively.

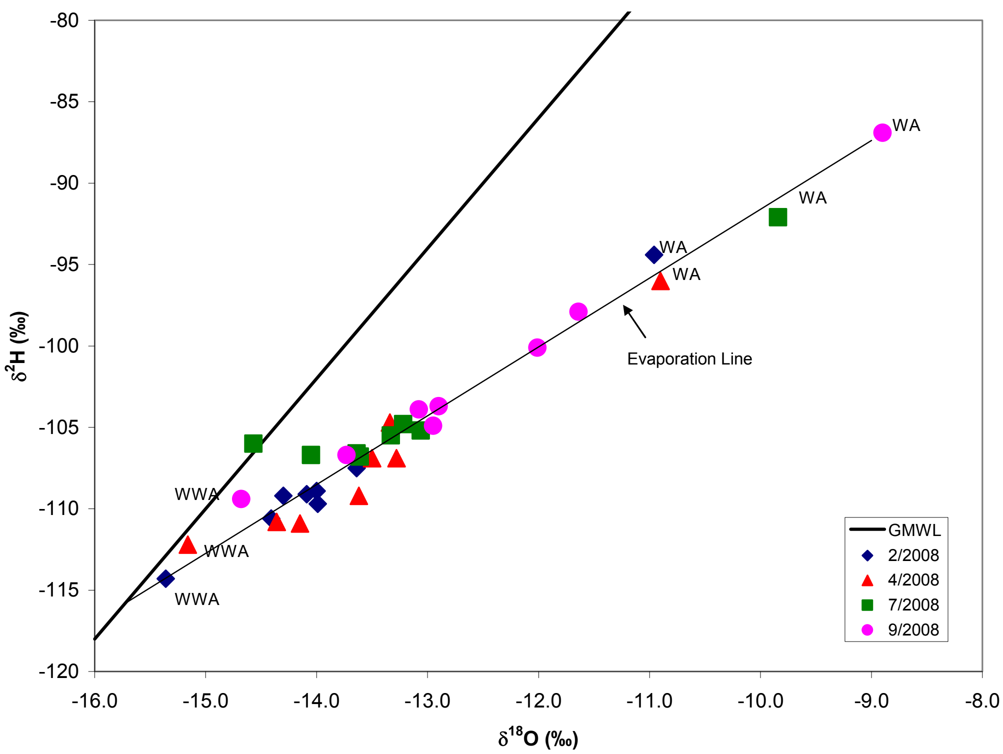

Figure A.6.8. Seasonal variations in stable isotope composition along the Walker River during 2008.

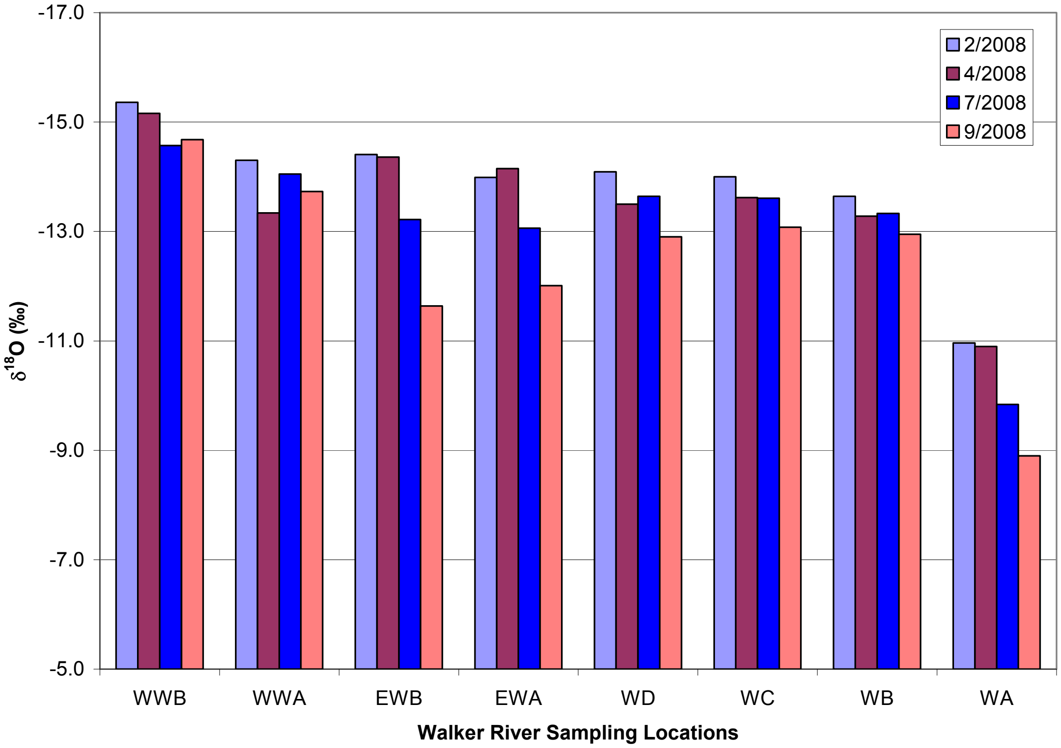

Figure A.6.9. Seasonal variations in $\delta^{18}O$ along the Walker River during 2008.

Walker Lake

Analytical results for major ions, minor ions, other parameters, and stable isotopes (δ^2H and $\delta^{18}O$) for Walker Lake are listed in Table A.6.3. Trace-element analytical results are listed in Table A.6.4. A trilinear diagram of major-ion chemistry (Figure A.6.10) shows that the water chemistry of the lake is predominantly composed of Na^+ and a mixture of relatively equal proportions of HCO_3^{2-} (30 percent), SO_4^{2-} (30 percent), and Cl^- (40 percent). Regardless of depth or time of sampling, the relative proportions of the major ions do not change substantially.

Table A.6.4. Trace-element data generated for the Walker Lake.

Sample	Date	Be (ppb)	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	Sr (ppb)	Mo (ppb)	Ag (ppb)	Cd (ppb)	Sn (ppb)	Sb (ppb)	Ba (ppb)	Tl (ppb)	Pb (ppb)	U (ppb)	As (ppb)	Se (ppb)
WL3 2.5m	3/7/2007	<10	<10	11.6	<10	<10	14.1	<10	<10	<10	<10	6,291	475	<10	<10	NA	<10	209	<10	<10	278	1,551	<50
WL3 10m	3/7/2007	<10	<10	11.4	<10	<10	14.2	<10	<10	<10	<10	6,261	477	<10	<10	NA	<10	206	<10	<10	273	1,530	<50
WL3 20m	3/7/2007	<10	<10	11.7	<10	<10	13.4	<10	<10	<10	<10	6,292	472	<10	<10	NA	<10	204	<10	<10	266	1,599	<50
WL3 2.5m	5/22/2007	<10	<10	12.1	<10	10.4	23.0	<10	<10	<10	<10	6,432	474	<10	<10	NA	<10	210	<10	<10	264	1,590	<50
WL3 10m	5/22/2007	<10	<10	11.2	<10	<10	18.7	<10	<10	<10	<10	6,100	457	<10	<10	NA	<10	200	<10	<10	261	1,546	<50
WL3 20m	5/22/2007	<10	<10	10.6	<10	11.1	14.8	<10	<10	<10	<10	6,227	428	<10	<10	NA	<10	204	<10	<10	218	1,532	<50
WL3 2.5m	8/28/2007	<10	27.5	11.7	<10	<10	29.7	<10	<10	<10	<10	6,417	479	<10	<10	NA	<10	207	<10	<10	266	1,634	<50
WL3 10m	8/28/2007	<10	<10	<10	<10	31.4	13.8	<10	<10	<10	<10	6,434	445	<10	<10	NA	<10	203	<10	<10	223	1,646	<50
WL3 20m	8/28/2007	<10	33.0	13.0	<10	<10	31.8	<10	<10	<10	<10	7,212	512	<10	<10	NA	<10	230	<10	<10	275	1,764	<50
WL3 2.5m	12/4/2007	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	5,023	420	<10	<10	<10	<10	168	<10	<10	274	1,323	<200
WL3 10m	12/4/2007	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	4,986	429	<10	<10	<10	<10	169	<10	<10	282	1,341	<200
WL3 20m	12/4/2007	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	4,865	442	<10	<10	<10	<10	168	<10	<10	292	1,368	<200

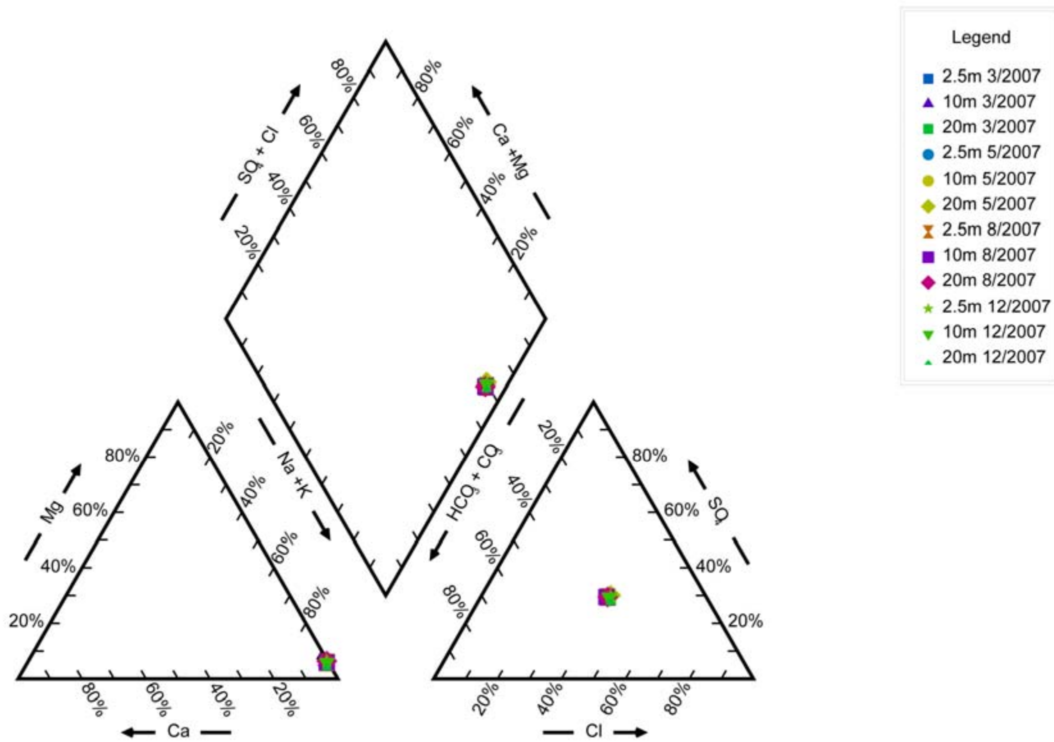

Figure A.6.10. Major-ion trilinear diagram for Walker Lake for samples collected March through December 2007.

Water Chemistry Variations

Total dissolved solids in the lake, 15,900 mg/L (Table A.6.3), are substantially higher than in the river (90 to 334 mg/L). The TDS of the lake has increased since 1882 (2,500 mg/L, http://www.unce.unr.edu/publications/files/nr/2008/fs0808.pdf) because of reduced river flow and evaporative concentration. Over the course of sampling from April to December 2007, the TDS of the lake increased by 900 mg/L. The increased TDS resulted primarily from increases in Na^+, Cl^-, and SO_4^{2-} (Figure A.6.11) and correlated with a decrease in lake elevation (http://waterdata.usgs.gov/nv/nwis/dv/?site_no=10288500&referred_module=sw, accessed March 17, 2009).

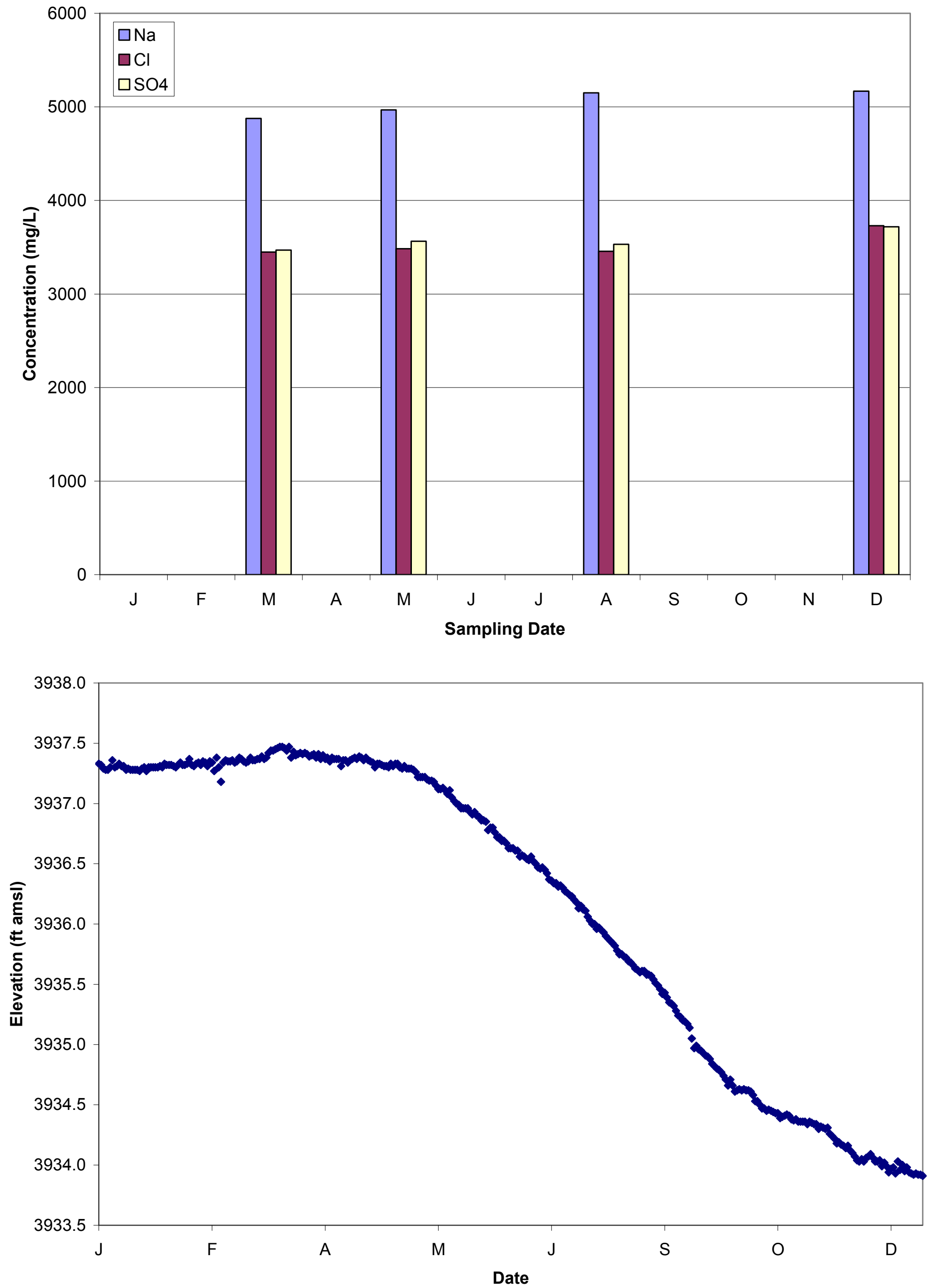

Figure A.6.11. Increases in Na^{+}, SO_4^{2-}, and Cl^{-} in Walker Lake from March through December 2007. Plotted concentrations are averages of three different depths for each sampling date. Also shown is the Walker Lake surface elevation changes during 2007.

A study of sediment delivery to Walker Lake as a result of historic erosion from the lowering of lake level (Adams and Chen, this report) showed a large amount of channel down cutting and sediment loading to Walker Lake. It is impossible to ascertain from limited sampling in 2007 at the main lake sampling location (WL3) how this historical erosion and sediment loading may have impacted Walker Lake water chemistry. An analysis of historical lake water chemistry changes in relation to water-level changes and sediment loading could provide insight into this question, but was beyond the scope of this study and would require substantially more detailed sampling at the mouth of the river over one or more years.

Most trace-element concentrations in Walker Lake are relatively low except for Fe, Mo, Ba, U, and As (Table A.6.4). Only Mo concentrations are above Nevada Aquatic Life standards (19 µg/L, NAC 445A.144). Total As concentrations are also very high (1,535 ppb average for three depths and four sampling events), well above Nevada Municipal or Domestic Supply standards (50 µg/L, NAC 445A.144). Note however, there is only a Nevada Aquatic Life standard for the reduced species of As, As(III) (1-hr average 342 µg/L, 96-hr average 180 µg/L, NAC 445A.144). As(III) concentrations were not measured during this study, but is likely to be present at depth during lake stratification and hypolimnion hypoxia.

Stable isotopic compositions for Walker Lake are highly enriched (or isotopically heavier or have less negative values to positive values), increased during lake sampling from March to December 2007 (Table A.6.3), and are highly evaporated and plot well off the global meteoric water line (Figure A.6.12).

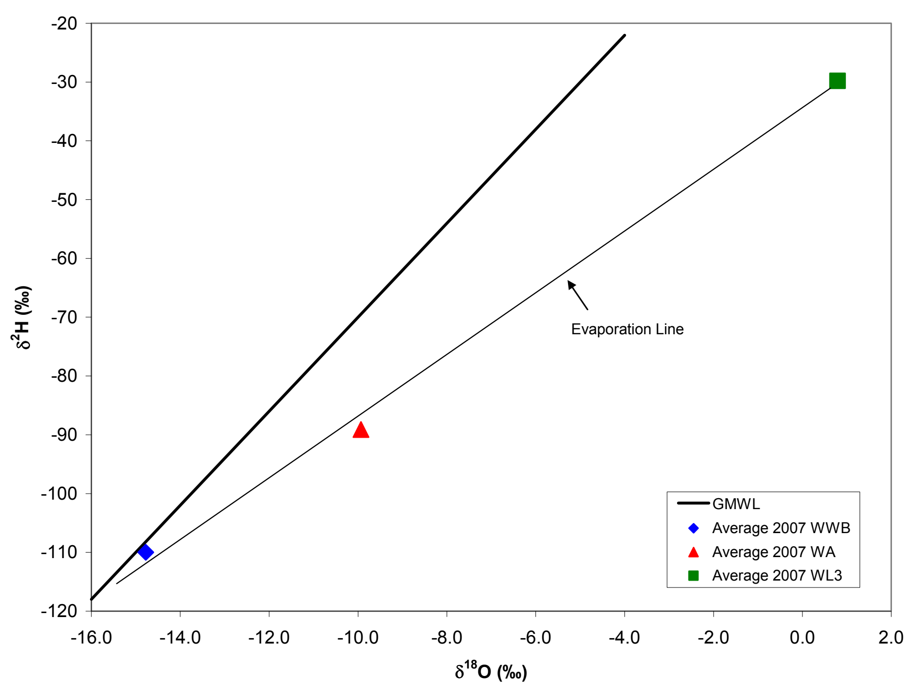

Figure A.6.12. Average stable isotopic composition of Walker Lake and select Walker River sampling locations.

Groundwater inflow

Lopes and Smith (2007) reported lake-bottom anomalies (possibly tufa) underwater near Cottonwood Creek, which may indicate present-day or past groundwater discharge. Also, recently estimated higher evaporation rate (6 ft/yr, Allander *et al*., 2006; 4.1 ft/yr, Harding 1965) suggests that more water is flowing into the lake from sources other than the Walker River than previously reported.

To evaluate groundwater inflow to Walker Lake near Cottonwood Creek, electrical conductivity (EC), temperature, and isotopic surveys were conducted on April 27, May 31, and July 6, 2007. Zigzag near-shore transects coupled with vertical profiles were conducted (Figure A.6.13). In addition to continuous measurements of EC and T at 1- and 2-m depths, periodic samples for δ^2H and δ^{18}O were collected. Isotopic samples were also collected for vertical profiles.

Unfortunately, these data were inconclusive in identifying groundwater inflow into Walker Lake near Cottonwood Creek. Variations in measured EC were less than probe error and δ^2H and δ^{18}O values showed little variation, less than analytical error. Therefore, it is likely that any groundwater that flows into Walker Lake near Cottonwood Creek is quickly mixed with lake water.

CONCLUSIONS

Major ions have shown that the Walker River has very low TDS relative to Walker Lake's very high TDS; the river is composed predominantly of Ca^{2+}, Na^+, and HCO_3^{2-}, while the lake is composed predominantly of Na^+ and a mixture of relatively equal proportions of HCO_3^{2-}, SO_4^{2-}, and Cl^-. Trace elements are very low in the river except for Mo and low in the lake except for Mo and As. Stable isotopes have shown that river water becomes increasingly evaporated as it flows downstream, and becomes increasingly evaporated in the lake. Because the river water is very low in TDS, increased river flow over a sufficiently long period of time should lower lake TDS.

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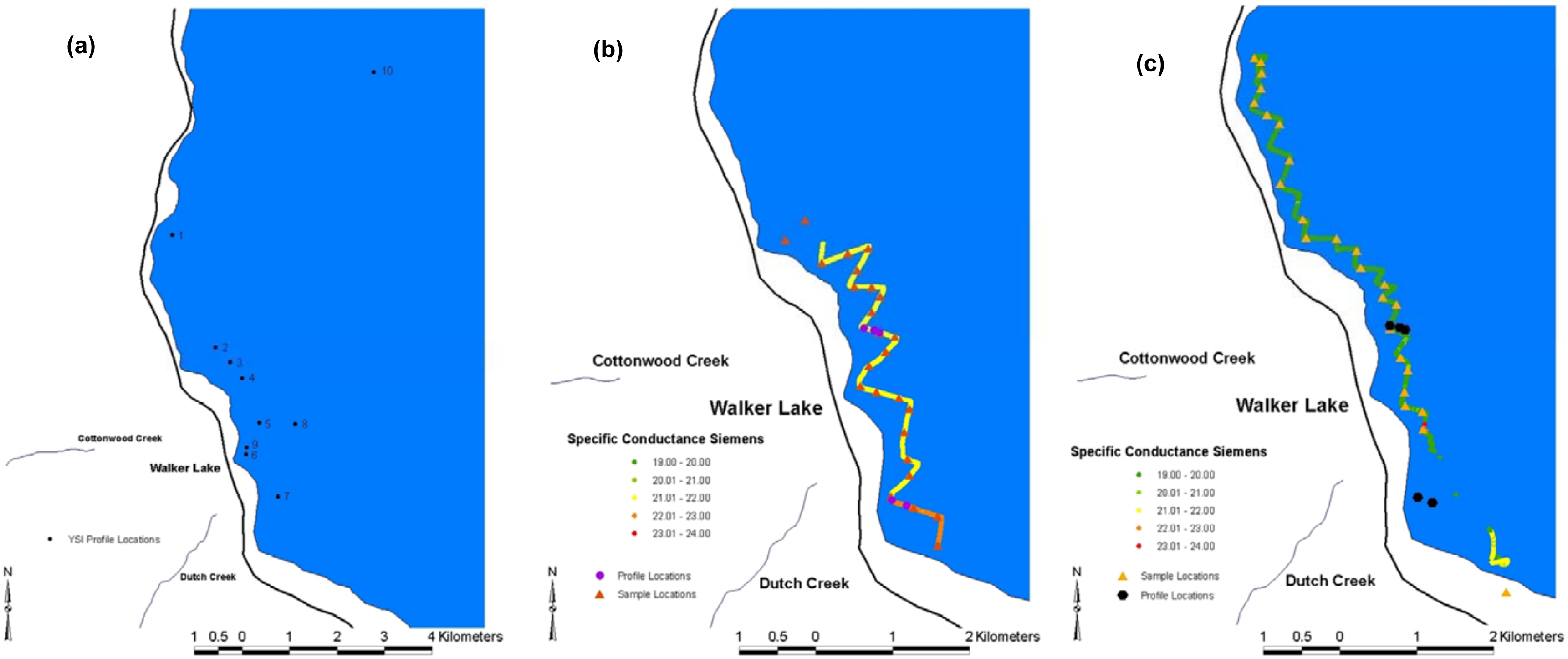

Figure A.6.13. Electrical conductivity, temperature, and stable isotopic surveys near Cottonwood Creek conducted to identify groundwater inflow to Walker Lake. Zigzag transects (B, C) and vertical profiles (A, B, C) are shown. These surveys were inconclusive because groundwater inflow mixes quickly with lake water.

A.7: WALKER RIVER PERIPHYTON

Contributing Authors: Clinton Davis, Jeramie Memmott, Christian Fritsen

ABSTRACT

Periphyton (attached algae) in rivers often provides an important energy source to the system whenever the supply of terrestrial materials (e.g., leaves) may be depleted. Such a scenario often exists in low-gradient streams in arid lands and hence these algal communities often form the basis of the stream's food web and help structure the ecosystem through bottom-up influences. Evaluations of the abundance/biomass of periphyton and community composition can also be used to aid in the evaluation of a stream's productivity, water quality, and environmental conditions. The biomass and community composition of periphyton in the Walker River were evaluated to establish a present-day knowledge of the algal taxa found within different habitats of the Walker River. Standing stocks of algal biomass were present at levels often considered to signify eutrophic conditions (greater than 5 to 15 µg chl *a*/cm^2) in the sites along the East Walker and into Mason Valley. Overall, the river had high abundances of siltation-tolerant diatom taxa, with the most notable abundances (exceeding 60%) at the lower sites. The near ubiquitous presence of filamentous green algae (especially *Cladophora* and *Oedogonium*) throughout the system (except the West Walker) is indicative of a system having a high potential for nutrient-algal interactions that produce oxygen slumps during the summer months. Several community-based metrics (N-fixing diatoms, motile diatoms and % *Cymbella*) correlated with changes in total dissolved solids (TDS) within the system (which increased downstream). These relationships, data, and knowledge base will likely be used in conjunction with additional indicators of ecosystem "health" and be compared to those in other streams to provide the tools for assessments of the stream's overall ecosystem functioning and health and how this may change with the implementation of management strategies.

INTRODUCTION

In comparison to other ecoregions, the ecology of benthic habitats in aquatic systems of desert regions has been understudied. Current understanding mostly stems from research on Australia's dryland river networks (e.g., Murray-Darling Basin) and a few streams in the southwestern U.S. (e.g., Sycamore Creek, AZ) (Kingsford and Thompson 2006). Furthermore, most of these lotic systems are unregulated, so the ecological knowledge base for benthic community dynamics is generally lacking for regulated rivers in arid regions (although see Blinn *et al.* 1998). Rivers and streams within the U.S.'s Great Basin offer a unique opportunity to investigate benthic community dynamics under regulated conditions in a semi-arid environment.

Three ecologically and anthropogenically important basins exist along the western extent of the Great Basin: Truckee, Carson, and Walker. All three have relatively pristine headwaters originating in the eastern Sierra that transition into the low-gradient reaches in the harsher, xeric environment of the Great Basin. Additionally, these lower elevations are subject to increased anthropogenic influences such as agriculture and municipal uses. The Walker River is of particular interest as increased drought conditions in the last decade combined with agricultural use in the surrounding area have increased the pressures on the system at the watershed scale (Sharpe *et al*. 2007). Beyond using physical and chemical descriptions of river reaches, the biological communities (fish, macroinvertebrates, and algae) can be used to infer the current ecological condition of the Walker basin.

Biological assessments (bioassessments) are an essential component for evaluating aquatic ecosystems health (Karr and Chu 1999, Norris and Hawkins 2000, Barbour *et al*. 1999, Marchant *et al*. 2006). These surveys provide an integrated measure of the chemical, physical, and biological functioning state of the system. Fish and benthic macroinvertebrates have usually been the communities targeted in bioassessment efforts within the U.S. (Karr 1981, Karr *et al*. 1986, Plafkin 1989, Ohio EPA 1987, Southerland and Stribling 1995) however, European countries have helped in formalizing periphyton as a monitoring tool by developing and testing various community based indices or metrics (Prygiel and Coste 1993, Kelly *et al*. 1995, Kelly and Whitton 1998). More recently, Porter (2008) compiled these European indices with more recent metrics developed in studies in the U.S.

Attributes of the stream periphyton communities that argue for their inclusion are the crucial status that they occupy within biogeochemical cycles, overall position within context of food webs, and the necessity of periphyton information to develop a truly "integrated assessment" of the stream's ecosystem 'health" in conjunction with the fish and macroinvertebrate communities. Algae's inherent growth kinetics operate on the time scale of hours to days, compared to weeks/months for macroinvertebrates and years for fish, allowing for an almost immediate indicator of changing conditions within the system. Algal assemblages respond to environmental gradients strongly influenced by land use activities that affect water chemistry and habitat (Leland 1995, Pan *et al*. 1996, Cuffney *et al*. 1997, Carpenter and Waite 2000). Land uses such as agriculture (Munn *et al*. 2002), deforestation (Naymik and Pan 2005), and urbanization (Sonneman *et al* 2001, Walker and Pan 2006) are particularly influential on algal assemblages. Thus, periphyton community dynamics offer some potential for assisting management efforts with regard to differentiating anthropogenic impacts from natural variation. Making the distinction between these impacts is particularly important in semi-arid streams where naturally harsh conditions coupled with human impacts can drastically affect these ecosystems.

The goal of the current work is to describe the seasonal and longitudinal dynamics of algae in the Walker River Basin in the context of the present-day environmental conditions. These data, in conjunction with macroinvertebrate and fish communities, help provide a baseline evaluation of ecological condition for future land and water management opportunities as well as future assessments of ecological condition under differing physical, chemical, and operational regimes within the basin.

METHODS

Environmental and biological samples were collected at eight sites spread longitudinally along the Walker River, with two sites each on the East Walker and West Walker and four sites located downstream of the confluence (Figure A.7.1). The sites were selected based on their distribution throughout the watershed, proximity to U.S. Geological Survey (USGS) gages, and accessibility.

These sites encompassed high-elevation, high-gradient reaches to low-elevation, low-gradient reaches (Figure A.7.2 and Figure A.7.3) which are typical of eastern Sierra rivers and streams that flow to the terminal basins within the Great Basin.

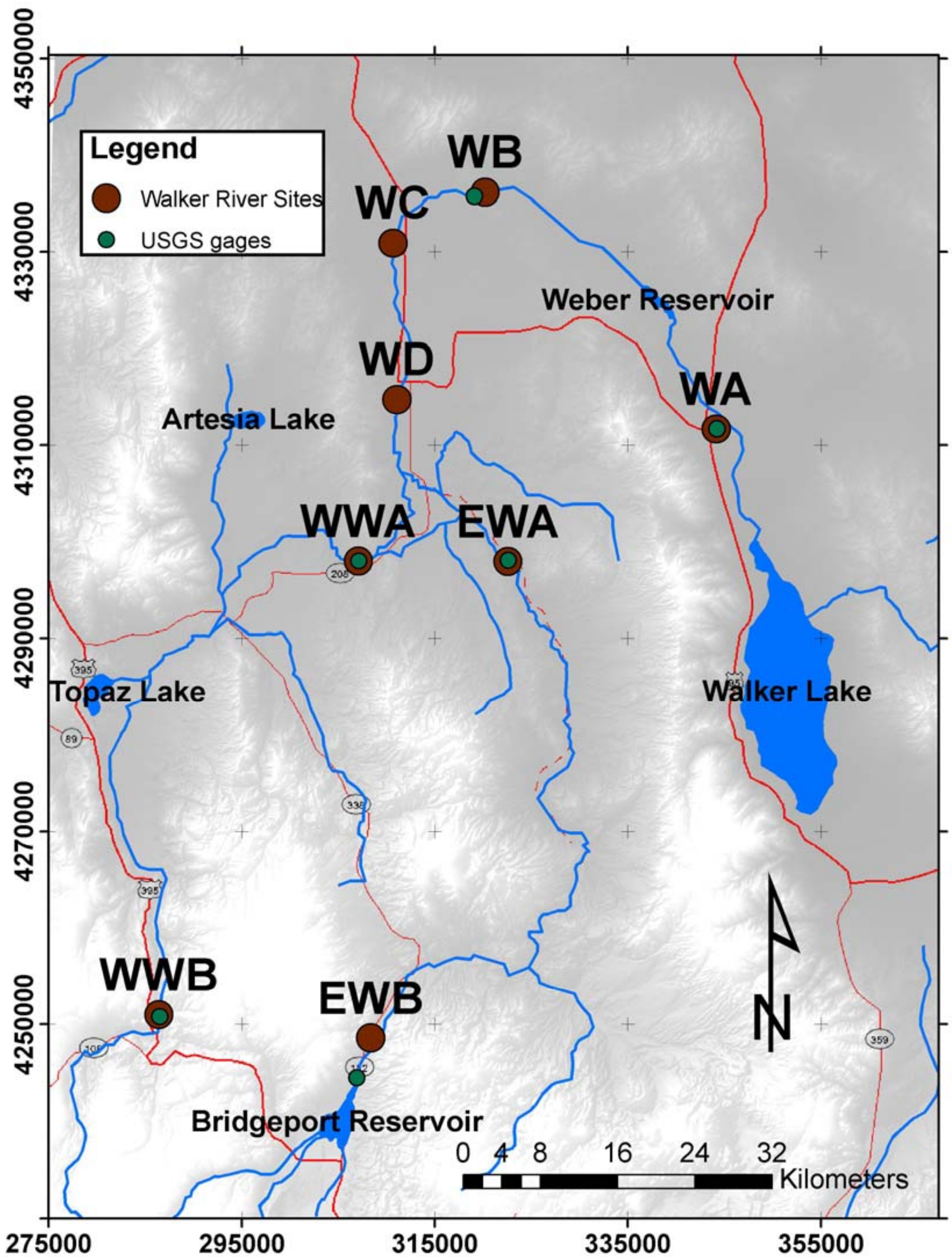

Figure A.7.1. Map of sampling sites in Walker basin (UTM zone 11).

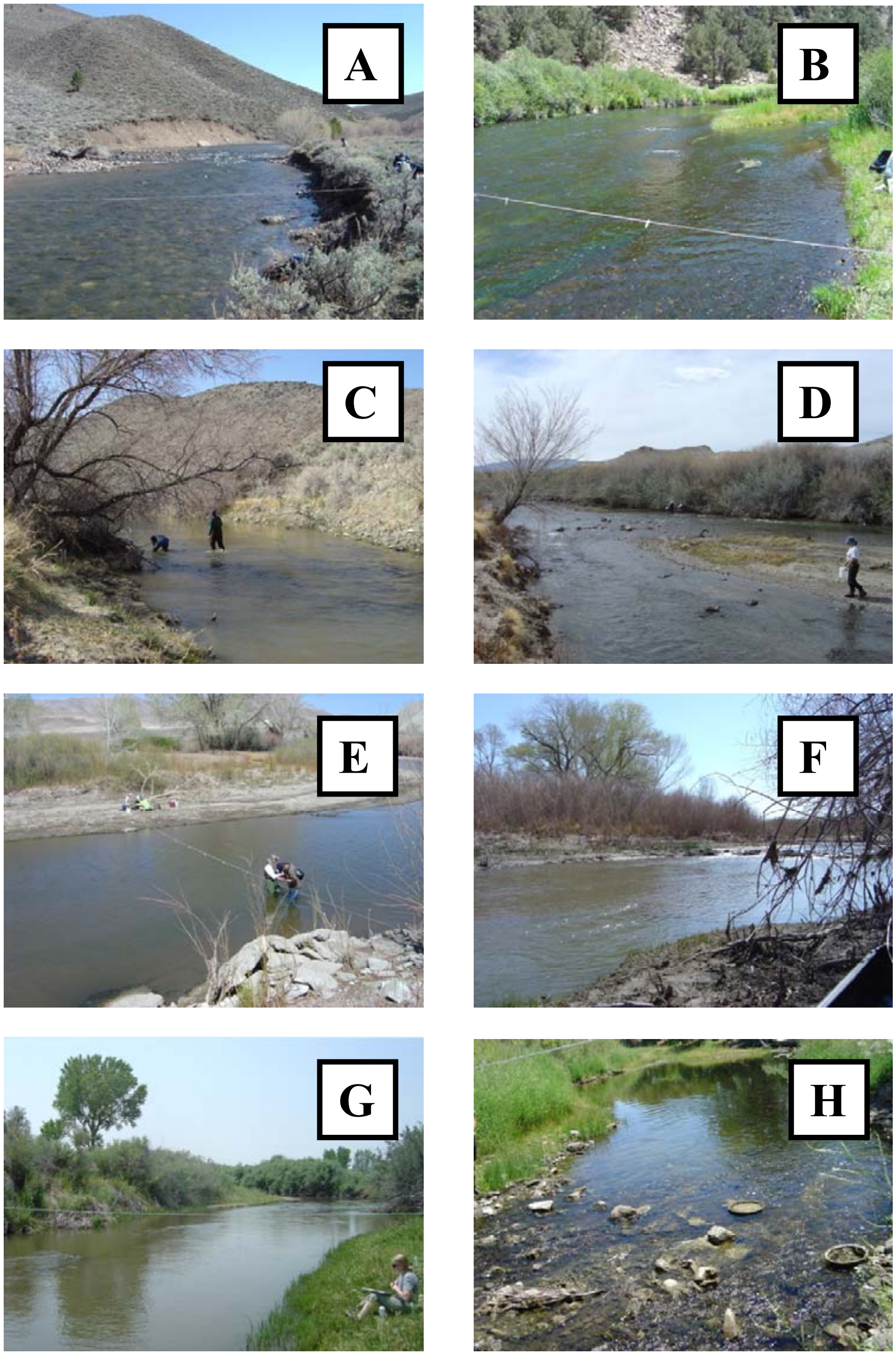

Figure A.7.2. Periphyton sampling sites on Walker River. WWB (A), EWB (B), EWA (C), WWA (D), WD (E), WC (F), WB (G), and WA (H).

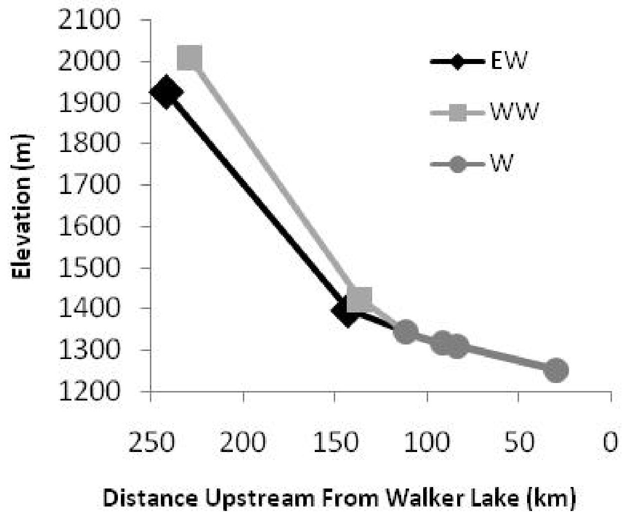

Figure A.7.3. Elevation at sampling sites.

Sampling of the richest targeted habitat (RTH), i.e. the in-stream habitat type that supports the taxonomically richest assemblage of organisms within a sampling reach at each sampling location, helped in identifying differences in periphyton communities in relation to water quality. This approach yielded transects and sampling that had habitats that were mostly typical of the habitats present within the reaches of the river being sampled (Table A.7.1). However, RTH at the WA site was atypical of the lower river as the RTH was a rare cobble riffle that was within an area of the river that had more of a low gradient reach with sand substrates, cut river banks and some willow riparian vegetation.

Water chemistry, periphyton, benthic macroinvertebrates, and fish sampling were conducted simultaneously by Desert Research Institute (DRI) and University of Nevada Reno (UNR) laboratories. Environmental and biological samples were collected in 2007 (April, August, September) and 2008 (April, July, September). Periphyton samples were collected by the Systems Microbial Ecology Laboratory (SMEL) at DRI in close coordination with the Benthic Macroinvertebrate Laboratory at DRI and the Aquatic Ecosystems Analysis Laboratory (AEAL) at UNR.

Table A.7.1. Physical habitat data from periphyton sampling points.

Sample Date	Sample Site	Substrate Size (cm)	% Embedded	Depth (m)	Velocity (m s^{-1})
4/24/2007	EWB	80.9±95.7 (4)	36.3±44.2 (4)	0.2±0.1 (5)	0.4±0.1 (5)
4/25/2007	EWA	51.1±55.2 (4)	45±37 (4)	0.2±0.1 (5)	0.5±0.3 (5)
4/26/2007	WWB	183.8±70.9 (4)	2.5±5 (4)	0.3±0.2 (5)	0.5±0.3 (5)
4/25/2007	WWA	39.9±53.6 (5)	70±41.2 (5)	0.3±0.1 (5)	0.5±0.1 (5)
4/27/2007	WD	8.2±8.9 (3)	53.3±45.1 (3)	0.2±0.1 (4)	0.2±0.3 (4)
4/26/2007	WC	0.5±0 (2)	100±0 (2)	0.2±0.1 (3)	0.2±0.2 (3)
8/9/2007	EWB	70.6±57.5 (5)	10±17.3 (5)	0.3±0.1 (6)	0.6±0.3 (6)
8/8/2007	EWA	52.4±44.5 (5)	20±7.1 (5)	0.3±0.1 (5)	0.7±0.4 (5)
8/9/2007	WWB	111±94.4 (6)	31.7±35 (6)	0.2±0.1 (6)	0.2±0.1 (6)
8/8/2007	WWA	17.4±22.9 (5)	52±44.2 (5)	0.3±0.1 (6)	0.4±0.1 (6)
8/7/2007	WD	4.6±2.6 (5)	60±22.4 (5)	0.2±0.1 (6)	0.3±0.3 (6)
8/7/2007	WC	0.8±0.4 (2)	100±0 (2)	0.1±0 (3)	0±0 (3)
8/9/2007	WB	0.5±0 (3)	100±0 (3)	0.2±0 (4)	0±0 (4)
8/9/2007	WA	106±96.1 (3)	30±26.5 (3)	0.1±0.1 (4)	0.2±0.2 (4)
9/18/2007	EWB	65±49 (6)	10±11 (6)	0.2±0.1 (7)	0.5±0.2 (7)
9/20/2007	EWA	47.5±23.4 (6)	28.3±42.2 (6)	0.2±0.1 (7)	0.6±0.4 (7)
9/18/2007	WWB	75.1±81.8 (5)	28±40.2 (5)	0.2±0.1 (5)	0.2±0.1 (5)
9/18/2007	WWA	49.4±59.1 (6)	50±45.2 (6)	0.3±0.1 (7)	0.5±0.2 (7)
9/19/2007	WD	7.7±7.5 (3)	43.3±49.3 (3)	0.3±0.1 (4)	0.5±0.3 (4)
9/20/2007	WC	0.8±0.4 (2)	100±0 (2)	0.3±0.1 (3)	0.2±0.2 (3)
9/21/2007	WB	0.5±0 (2)	100±0 (2)	0.2±0 (3)	0.1±0.1 (3)
9/21/2007	WA	86.9±18.5 (2)	17.5±7.1 (2)	0.1±0 (2)	0±0 (2)
4/17/2008	EWB	43.3±43 (6)	30.8±39.3 (6)	0.3±0.1 (7)	0.6±0.1 (7)
4/16/2008	EWA	41.3±24.5 (6)	28.3±40.2 (6)	0.3±0.1 (7)	0.6±0.3 (7)
4/17/2008	WWB	153.6±124.7 (5)	1±2.2 (5)	0.4±0.1 (6)	0.5±0.3 (6)
4/15/2008	WWA	17.8±16.3 (5)	62±36.3 (5)	0.3±0.1 (6)	0.3±0.1 (6)
4/16/2008	WD	10.6±15.1 (5)	52±45.5 (5)	0.2±0.1 (6)	0.5±0.3 (6)
4/14/2008	WC	4.3±3.5 (3)	60±36.1 (3)	0.2±0 (4)	0.1±0.2 (4)
4/14/2008	WB	2.1±2.8 (2)	80±28.3 (2)	0.2±0.1 (3)	0.1±0.1 (2)
4/15/2008	WA	40±14.1 (2)	0±0 (2)	0.1±0 (2)	0±0 (2)
7/15/2008	EWB	84.5±76.5 (6)	21.7±21.4 (6)	0.4±0.2 (7)	0.8±0.2 (7)
7/15/2008	EWA	85.3±117.3 (5)	47±48.7 (5)	0.5±0.1 (6)	0.6±0.3 (6)
7/15/2008	WWB	84.7±101.9 (6)	19.2±39.7 (6)	0.4±0.2 (7)	0.6±0.3 (7)
7/16/2008	WWA	23.7±25.9 (4)	45±38.7 (4)	0.4±0.1 (5)	0.4±0.3 (5)
7/17/2008	WD	27.2±45.7 (3)	86.7±23.1 (3)	0.4±0.1 (4)	0.5±0.4 (3)
7/14/2008	WC	1±0.7 (2)	100±0 (2)	0.4±0.1 (3)	0.2±0.3 (3)
7/14/2008	WB	2.9±3 (2)	60±56.6 (2)	0.3±0.2 (2)	0.1±0.1 (2)
7/17/2008	WA	80.5±61.1 (4)	0±0 (4)	0.2±0.1 (4)	0.4±0.2 (4)
9/10/2008	EWB	107.5±75.9 (6)	4.2±4.9 (6)	0.3±0.2 (7)	0.6±0.2 (7)
9/11/2008	EWA	65.6±88.4 (7)	36.4±31.2 (7)	0.3±0.1 (8)	0.4±0.3 (8)
9/10/2008	WWB	36±26.6 (5)	24.3±43.2 (5)	0.3±0 (6)	0.6±0.3 (6)
9/11/2008	WWA	13±28 (5)	82±40.2 (5)	0.3±0.1 (6)	0.4±0.1 (6)
9/9/2008	WD	11.5±13.3 (3)	62.5±36.3 (3)	0.4±0.1 (4)	0.4±0.2 (4)
9/8/2008	WC	0.5±0 (2)	100±0 (2)	0.3±0.1 (3)	0.1±0.1 (3)
9/8/2008	WB	2.1±2.7 (2)	55±63.6 (2)	0.2±0 (3)	0±0 (3)
9/9/2008	WA	55.7±94.7 (3)	68.3±54.8 (3)	0.2±0.1 (4)	0.5±0.4 (4)

As sampling sites were identified and occupied, rebar was pounded into the left and right banks at high-bank locations. These rebar were left in place throughout the study period as reference markers. Each site was sampled using a standard protocol, minimizing bias. A tape was stretched across the river perpendicular to the channel and attached to rebar marking the sample transect. Care was taken to ensure that the water and substrates two meters downstream and greater than 20 meters upstream of the transect were not disturbed.

A YSI 600xlm was used to determine temperature, dissolve oxygen, specific conductivity, pH, and oxidation-reduction potential (ORP) on site. A suite of environmental data was collected at each site (substrate size, substrate embeddedness, depth, mean velocity of water column, and the depth of debris, vegetation and periphyton on the substrate).

ALGAL SAMPLE COLLECTIONS

If the sample unit was epilithic (cobble), epidendric (wood), or epiphytic (vegetation) in nature, a scraping method similar to that outlined in Porter *et al.* (1993, page 18) and Mills *et al*. (2002, page 32) was used. In the case of epidendric and epiphytic samples, the scraping was carried out is such a way that the periphyton could be collected while leaving intact the plant material to which the periphyton was attached. If the sample unit was episammic (sand) or epipelic (silt), a petri dish template method was used as outlined in Mills *et al*. (2002). The epilithic samples were selected from a point one meter upstream of the transect line.

Filtered stream water (FSW), collected the day of sampling at each site and filtered through a 47-mm Whatman GF/F filter with approximately 180 mm Hg vacuum, was used as the transporting medium (solvent) for the periphyton that was scraped from the cobble. The FSW was placed in an FSW-rinsed HDPE wash bottle and used to rinse the periphyton into the sample collection bottle, to keep periphyton moist during the scraping process, and to rinse the brushes into the sample container after scraping was completed. A steel wire brush and/or scalpel was used to scrape all of the periphyton from the sample unit into a tub, which was subsequently rinsed into an amber HDPE sample bottle with FSW. The sample bottle was then sealed tightly and placed in the shaded interior of an ice chest with ice for transport to the laboratory for processing. A measurement of the average length, width, and height (cm) of each item scrapped (e.g., cobble) in the sample unit was recorded.

Sample units requiring episammic sampling required a substrate of sand or silt with a thickness of at least one cm for proper sampling. Sampling of the episammic biota was carried out using Gelman Sciences 50-mm sterile petri dishes and a spatula according to the method outlined by Mills *et al*. (2002). A petri dish was opened and pushed into the substrate with the open end down so that the walls of the petri dish cut into the sediments. A steel spatula was then slid under the petri dish to hold the sediments inside as the petri dish was lifted out of the water and capped using the petri dish lid. The sample was then placed in the shaded interior of an ice chest with ice for transport to the laboratory for processing.

Depth and flow velocity was then measured at the algal sampling site using a wading stick and digital flow meter (FlowMate® model 2000) from Marsh-McBerney, Inc. The location and depth of sample unit boundaries were also recorded with total width from bank to bank along the transect line.

Water Chemistry

Water-quality samples were collected in half-gallon plastic jugs that were triple rinsed with sample water before being filled. Samples were stored in the field on ice in ice chests until transported to DRI-Reno; samples were refrigerated until analysis. Analyses were conducted by the DRI Analytical Chemistry Laboratory, which is a U.S. Environmental Protection Agency (EPA) and State of Nevada certified laboratory. Appropriate EPA drinking-water and waste-water procedures were followed.

Algal Subsample Analysis

Chlorophyll *a* concentrations were determined via fluorometry using the Weslschmeyer (1994) method in a Turner Designs model 10AU fluorometer. This method was calibrated with purchased standards (i.e., chlorophyll *a* from *Anacystis nidulans*, Sigma Corp.). The chlorophyll *a* content was checked against a spectrophotometric (Parson *et al*. 1984) method for quality assurance. The ash-free dry mass (AFDM) was determined using the method outlined in the American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF) Standard Methods (Clesceri *et al*. 1998). Particulate organic carbon (POC) and particulate organic nitrogen (PON) were determined using the method outlined by Karl *et al*. (1991). Subsamples were filtered onto pre-combusted filters, the filters were acidified through exposure to hydrochloric acid fumes, and encapsulated in tin discs before analysis with a Perkin Elmer 2400 series II CHN/O analyzer.

The periphyton samples often contained considerable amounts of sediment that could add to the phosphorus concentration during extraction. This possibility was minimized by using the phosphorus fractionation method (Pardo *et al*. 2003) to determine particulate organic phosphorus. The phosphorus concentration of the resulting extracts was determined colorimetrically using the Lachat QuikChem® Method 12-115-01-1-F (Mcknight and Sardina 2001) with a Lachat QC8000 flow injection analyzer. The Lachat method was selected after experimentation revealed that some of the samples from Walker River developed insoluble precipitates as the extracts were neutralized (a necessary step when using more common methods of phosphorus determination). This method eliminated the need for the neutralization step and allowed for all the remaining extracts to be analyzed.

Microscopic analysis of many 0.5-percent glutaraldehyde-preserved subsamples included enumeration, biovolume determination, identification, archival slide preparation, and digital image documentation. The contents of the petri dishes collected for epissamic and epipelic samples were homogenized, weighed and placed in containers as outlined for each analytical process.

Enumeration and identification of algae genera was done using differential interference contrast (DIC) microscopy on an Olympus BX-60 outfitted with epifluorescence capabilities. Methods followed a modified USGS National Water-Quality Assessment (NAWQA) Program protocol (Clason *et al*. 2002, Acker 2002). In short, a minimum of 200 valves of diatom genera were identified on Naphrax mounts after being acid washed (nitric acid ~50-percent v/v) or oven baked for an hour at 500 Celsius. Soft-algae (non-diatom) genera were identified and counted in a Palmer-Maloney cell using a tiered counting method that entails scanning the whole chamber for large taxa (>200 µm) at 100x magnification, scanning 10 views for medium-size soft taxa (200-50 µm) at 200x, and 15 views for small taxa (<50 µm) at 400x. Natural units were deemed appropriate instead of cells due to the fact that colonial or filamentous cells do not occur singly in nature thus individual cells would be inappropriate to portray relative abundances (Mills *et al*. 2002). All counts were standardized to the cobble area sampled (per square centimeter of substrate).

All taxa encountered were image documented for quality assurance and archival purposes. Biovolume estimates for each contributing taxa were determined by assigning formulas outlined in current literature (Hillebrand *et al*. 1999).

Metrics were calculated based on the Porter (2008) application of metric scores for diatom species in the USGS NAWQA dataset. All metrics in the current study are based on the relative abundance (RA) of genera present in the sampled assemblages, thus generalizations were made regarding the commonality of all species within a genera having similar autecology, tolerance, or sensitivity. Specifically, the following metrics were calculated: % N-fixing diatoms, % Motile diatoms, % Eutrophic diatoms, % Eutrophic soft-algae, % Cyanobacteria, and % *Cymbella* + *Encyonema.* Most of these metrics were previously applied to the Truckee River (Davis 2007), thus deemed applicable to the Walker River for capturing impairments of concern. The Truckee is not being used as a "reference" system in our analysis of the Walker River periphyton. It is referred to for comparison as it is the only eastern Sierra river for which there are adequate studies of periphyton dynamics. The Truckee basin is largely impacted by urban and municipal land uses (Truckee, CA and Reno/Sparks, NV) while the Walker basin is mostly developed for agricultural uses. Also, the Truckee is tightly regulated to maintain fairly constant flows throughout the year while the Walker resembles a more natural hydrograph.

Spearman's ranked correlation coefficients (rho) were derived for exploratory analysis of correlations between environmental conditions and periphyton metrics.

Results

The USGS gauging stations throughout the Walker basin provide a network that allowed tracking of the river's longitudinal flow regimes and the means to evaluate the flows during the study relative to the last decade (Figure A.7.4). In general, peak discharge occurs during early May all along the river, with the highest discharge being at the upper study site of the West Walker (peak values being on the order of 700 to 1,000 cfs). Discharge at the WWA site (on the West Walker) are often 300 cfs lower than at the WWB site (with peak flows reaching 200 to 700 cfs) while flows continue to decrease downstream (e.g., WB and WA) as a result of water utilization and storage within Smith and Mason valleys. Discharge on the East Walker is typically lower than that on the West Walker and peaks at 300 to 400 cfs. The annual hydrograph on the East Walker is less heavily tailed, most likely as a result of water utilization and storage in upstream reservoirs.

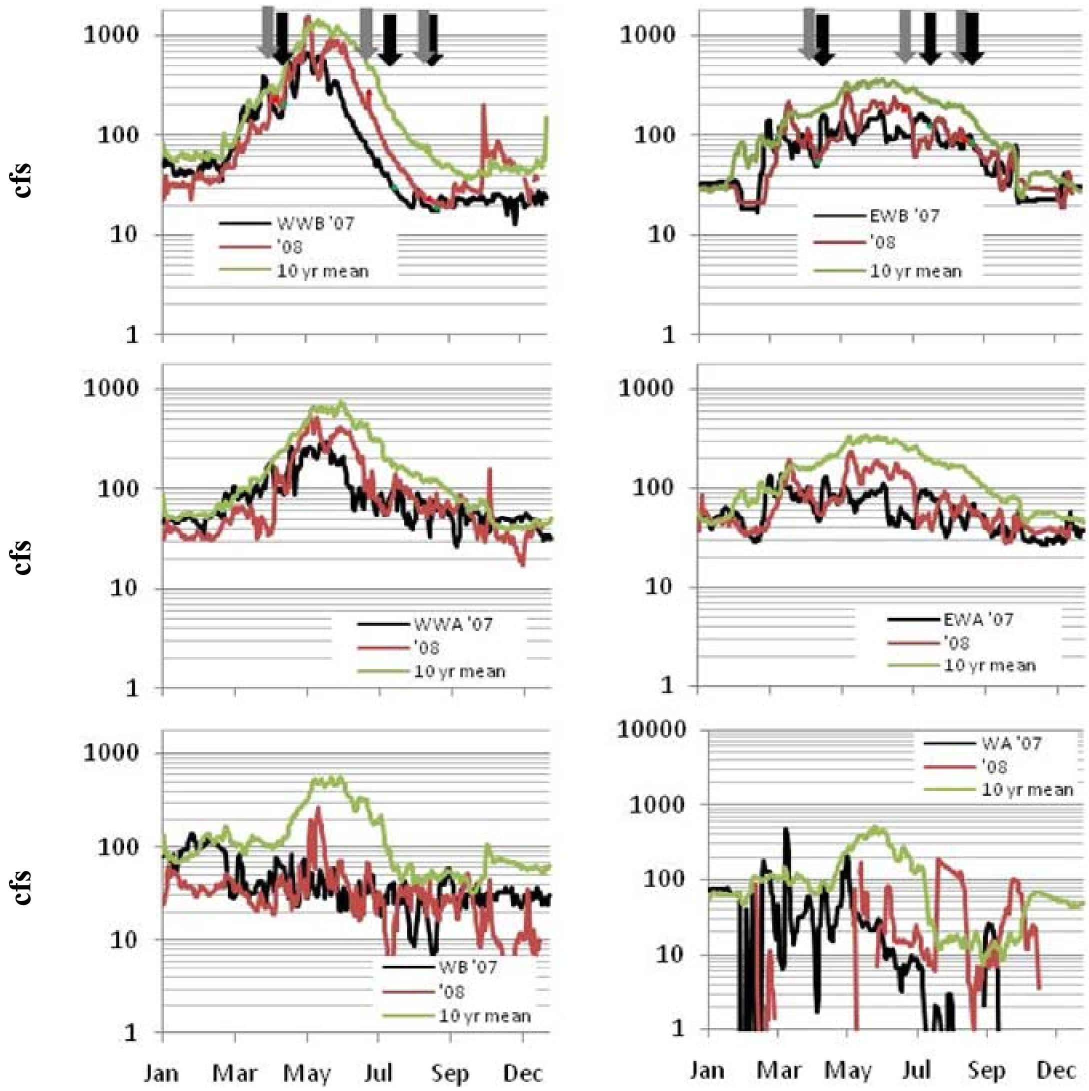

Figure A.7.4. Hydrograph at sampling sites from USGS. Arrows denote time of sampling.

Base flows during summer along the river typically increase from upstream to downstream, with base flows at the WWB site being 40 cfs, while discharge downstream is typically 20 to 30 cfs higher. Maintenance of higher base flows during summer months is common along regulated rivers where water storage and utilization tend to decrease downstream peak flows and increase downstream annual summer base flows. Due to drought conditions the discharge during this study (2007 to 2008) was typically 40 to 60 percent lower all along the river than the means for the last decade.

Discrete measurements of temperature at the time of periphyton collection generally showed a gradual increase in downstream sites during all seasons. The exceptions were the upper East Walker site, EWB, which displayed slightly warmer temperatures in spring and colder during summer and fall (Figure A.7.5) due to the upstream release of reservoir bottom water.

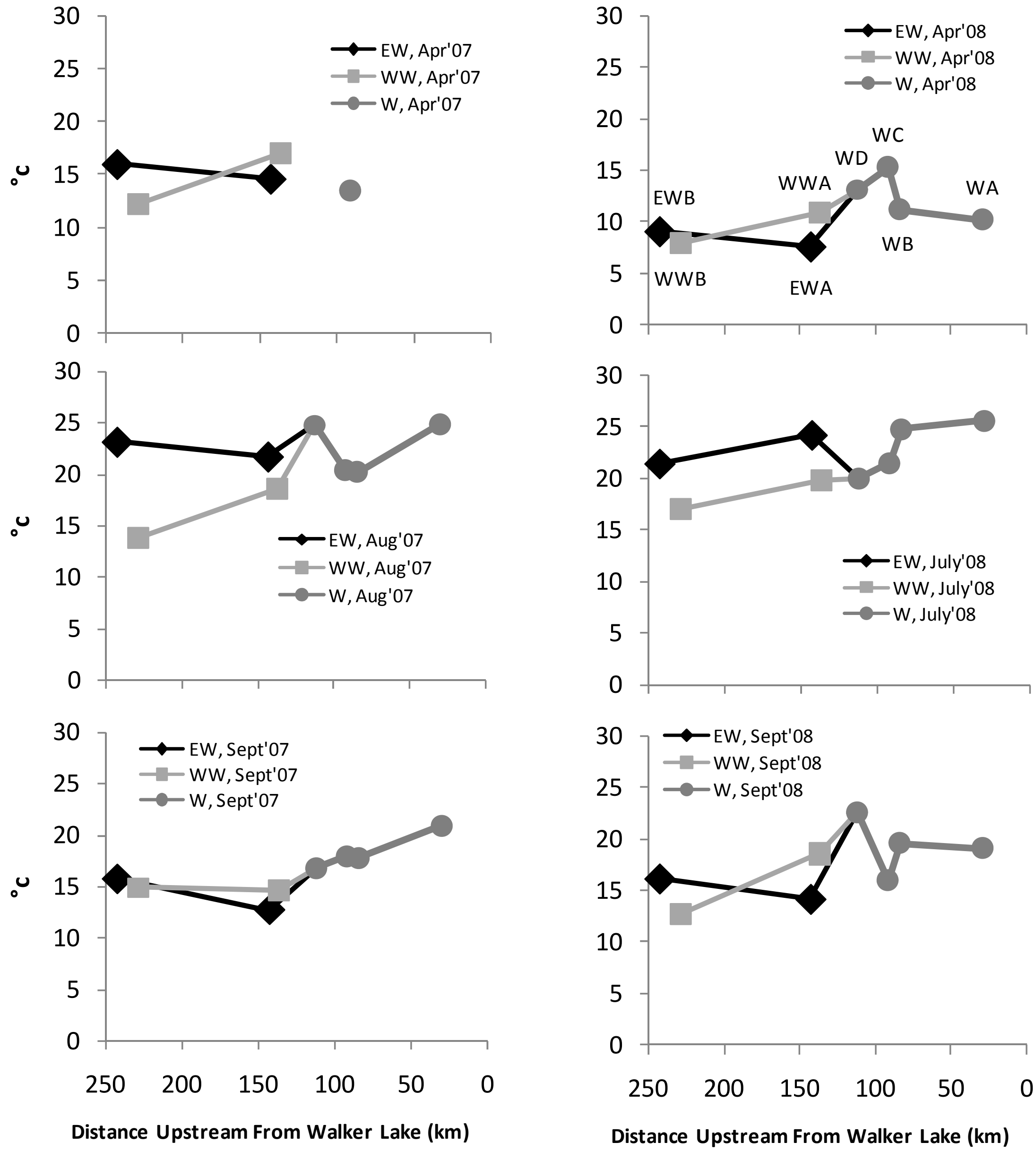

Figure A.7.5. Temperature collected with YSI sonde at time of sample collection.

CHEMISTRY

Electrical conductivity increased over two-fold from the most upstream to the most downstream location during all seasons (Figure A.7.6), which is indicative of total dissolved salts increasing as the water migrates through the basin river and reservoirs. Conductivities at the sites within Smith and Mason valleys were higher during the springs of both 2007 and 2008 (at approximately 300 µS/cm) relative to the conductivities measured during late summer and autumn 2007 (at 400 to 500 µS/cm). The rise in specific conductivity is a direct result of the increases in total dissolved solids (as measured from discrete samples) (Table A.7.2).

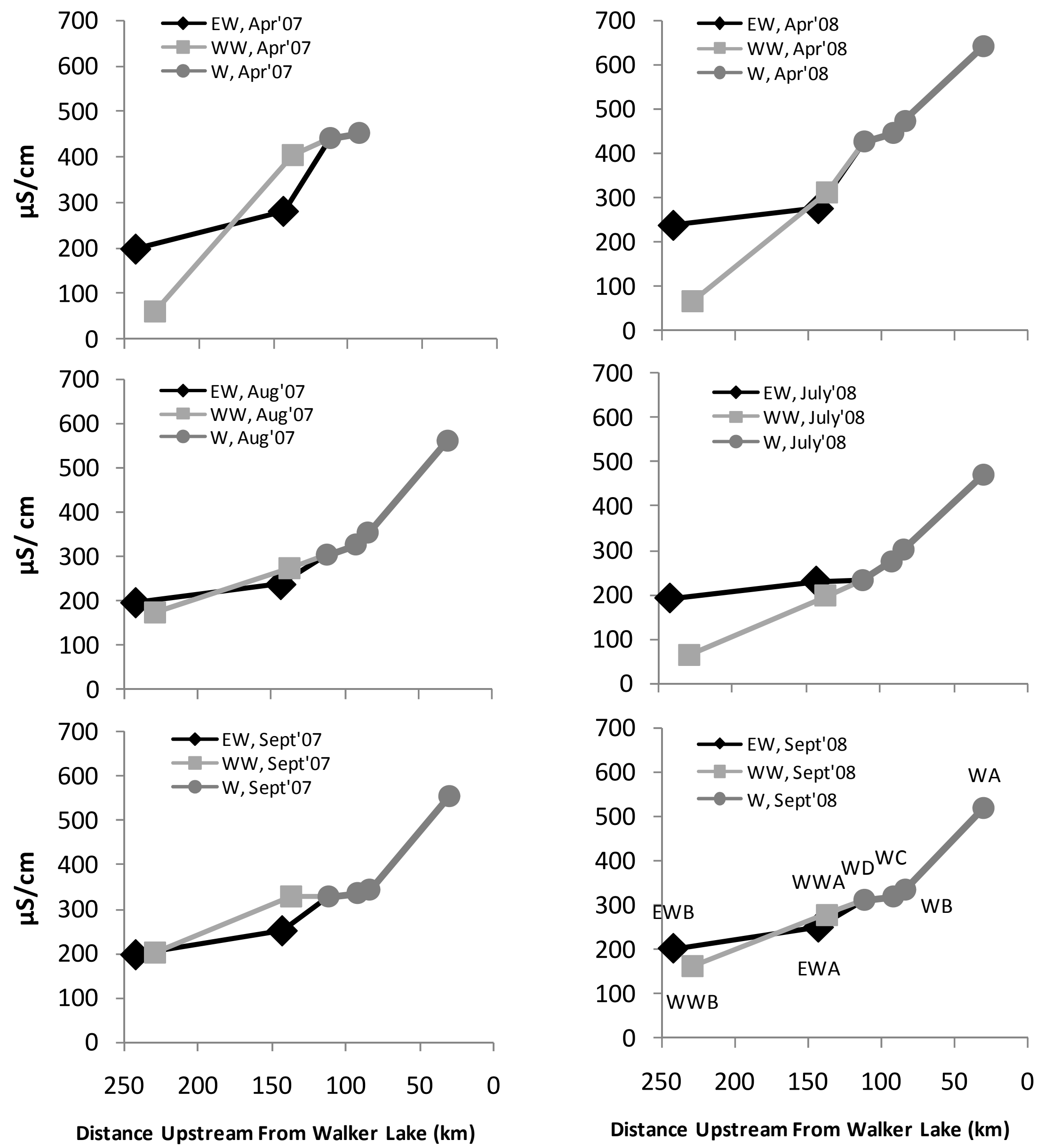

Figure A.7.6. Specific conductivity measured on discrete samples collected at study sites.

Table A.7.2. Water quality constituents measured on discreet samples at sampling sites.

Sample Site	Sample Date	pH	EC ($\mu S\ cm^{-1}$)	TDS ($mg\ L^{-1}$)	SiO_2 (µM)	TOC (µM)	DOC (µM)	TKN (µM)	DKN (µM)	NH_3 (µM)	NO_3 (µM)	NO_2 (µM)	TP (µM)	DP (µM)	OPO_4 (µM)
MURP	4/26/2007	8.06	199	125	251	358	350	25.7	18.6	1.1	0.6	0.07	1.5	0.5	0.2
STRB	4/27/2007	8.05	282	171	320	275	275	20.0	15.0	0.4	0.3	<0.07	2.5	1.4	1.1
WWLW	4/26/2007	7.65	62	40	140	133	133	3.6	2.9	0.4	0.2	<0.07	0.4	0.1	0.1
WLSN	4/26/2007	8.61	405	218	271	400	391	24.3	21.4	1.6	10.2	0.36	2.5	1.5	1.0
FLST	4/27/2007	8.18	442	258	298	325	325	27.1	17.1	0.9	8.9	0.29	2.6	1.7	1.4
MVWR	4/27/2007	8.17	453	248	336	266	275	36.4	14.3	0.8	11.5	0.14	3.5	2.2	1.7
MURP	8/13/2007	9.33	197	116	291	599	599	58.5	34.3	2.0	7.4	2.5	7.6	6.8	4.1
STRB	8/14/2007	8.27	238	135	276	433	450	21.4	22.1	0.9	0.5	0.07	6.1	4.3	3.7
WWLW	8/13/2007	8.16	174	92	230	100	100	4.3	3.6	0.6	0.4	<0.07	0.5	0.4	0.2
WLSN	8/13/2007	8.59	273	146	150	241	250	15.0	10.7	0.7	0.1	0.07	0.8	0.5	0.2
FLST	8/14/2007	8.41	304	170	238	283	283	40.0	15.7	0.8	1.6	0.07	2.6	1.9	1.3
MVWR	8/14/2007	8.30	326	190	303	208	208	12.9	12.1	0.6	1.5	<0.07	2.4	1.8	1.5
WABU	8/14/2007	8.33	353	207	300	225	225	12.1	10.7	0.6	0.7	0.07	2.6	2.1	1.6
SHRZ	8/14/2007	8.82	561	340	318	450	466	26.4	23.6	0.9	0.6	0.07	5.3	5.0	2.9
MURP	9/20/2007	9.29	198	131	478	716	691	96.4	44.3	3.2	5.7	0.64	8.2	6.1	4.9
STRB	9/21/2007	8.15	252	165	421	516	508	44.3	25.7	0.7	0.4	<0.07	5.6	4.2	3.8
WWLW	9/20/2007	8.06	203	115	245	117	125	6.4	4.3	0.3	0.6	<0.07	0.4	0.3	0.2
WLSN	9/20/2007	8.37	327	181	193	258	258	14.3	12.1	0.5	0.4	<0.07	0.5	0.3	0.3
FLST	9/21/2007	8.23	328	200	323	375	366	32.1	17.8	0.5	0.6	<0.07	3.2	2.3	2.0
MVWR	9/21/2007	8.25	336	202	333	316	308	25.7	15.7	0.4	0.4	<0.07	3.0	2.0	1.7
WABU	9/21/2007	8.28	343	206	333	316	300	26.4	15.7	0.5	0.4	<0.07	2.2	2.1	1.7
SHRZ	9/21/2007	8.19	556	342	386	300	291	21.4	15.0	0.5	0.4	<0.07	3.4	2.9	2.4
MURP	2/13/2008	8.10	250	168	321	358	358	30.7	24.3	6.1	6.9	0.57	1.8	0.8	0.6
STRB	2/14/2008	8.09	317	206	346	275	275	21.4	15.7	1.0	1.5	0.07	2.5	1.3	0.9
WWLW	2/13/2008	7.71	136	90	236	108	108	2.9	3.6	0.6	2.1	<0.07	0.4	0.3	0.3
WLSN	2/13/2008	8.52	571	345	228	366	300	23.6	15.0	0.9	4.4	0.21	1.3	0.5	0.2
FLST	2/14/2008	8.19	502	308	280	266	266	17.8	14.3	0.7	3.1	0.07	1.4	0.7	0.5
MVWR	2/14/2008	8.20	467	295	268	250	250	17.8	12.9	0.8	2.2	0.07	2.1	0.8	0.6
WABU	2/14/2008	8.20	513	316	278	291	275	18.6	16.4	0.9	1.7	0.07	2.3	1.3	1.1
SHRZ	2/14/2008	8.25	514	334	353	466	458	35.7	28.6	0.9	0.4	<0.07	6.2	5.0	4.5
MURP	4/18/2008	8.24	238	151	296	416	425	38.6	30.7	1.1	0.7	0.07	1.5	0.7	0.4
STRB	4/17/2008	8.18	276	176	330	366	375	40.7	25.0	0.6	0.7	<0.07	4.0	1.2	0.9
WWLW	4/18/2008	7.75	66	45	145	216	216	15.0	11.4	0.4	1.4	<0.07	0.6	0.2	0.1
WLSN	4/18/2008	8.25	311	189	155	366	375	50.0	30.0	2.8	14.3	0.5	3.5	0.9	0.5
FLST	4/17/2008	8.28	427	272	273	350	358	41.4	25.0	0.7	1.4	0.07	3.8	1.1	0.8
MVWR	4/17/2008	8.26	445	299	346	275	283	32.8	18.6	0.6	1.4	0.07	2.6	1.2	0.9
WABU	4/17/2008	8.34	475	300	336	300	308	33.6	22.8	0.6	0.7	0.07	4.5	1.9	1.6
SHRZ	4/17/2008	8.05	644	394	316	225	233	22.1	17.1	0.4	0.7	0.07	2.1	1.5	0.8
MURP	7/10/2008	8.93	192	129	271	533	516	45.0	45.0	4.9	8.4	3.5	4.1	3.7	3.0
STRB	7/10/2008	8.07	231	151	300	641	649	41.4	30.0	0.9	1.9	0.07	4.6	2.5	2.3
WWLW	7/10/2008	7.64	63	34	123	541	550	3.6	7.9	0.3	0.4	<0.07	1.7	0.2	0.1
WLSN	7/10/2008	7.90	196	127	181	341	316	22.1	17.8	1.4	9.6	0.29	7.2	1.1	1.0
FLST	7/10/2008	8.03	235	150	241	266	225	29.3	21.4	0.6	3.4	0.07	3.5	1.5	1.6
MVWR	7/10/2008	8.09	276	175	271	300	291	24.3	20.7	0.5	3.7	0.07	7.2	1.8	1.7
WABU	7/10/2008	8.13	303	191	255	291	283	20.7	20.0	0.6	1.7	0.07	3.2	1.9	1.8
SHRZ	7/10/2008	8.06	472	283	80	100	92	35.0	36.4	1.1	1.1	0.14	3.7	3.7	3.3
MURP	9/11/2008	8.94	202	160	549	666	674	67.1	45.0	2.1	6.4	0.86	5.3	4.1	3.4
STRB	9/11/2008	8.08	250	169	494	500	508	44.3	31.4	0.9	0.6	<0.07	4.3	3.3	2.9
WWLW	9/11/2008	7.94	164	108	211	100	108	5.0	5.7	0.5	0.4	<0.07	0.4	0.3	0.1
WLSN	9/11/2008	8.36	280	170	165	275	266	15.7	13.6	0.6	0.4	0.07	0.7	0.4	0.2
FLST	9/11/2008	8.14	312	202	320	333	325	25.0	17.1	0.8	3.6	<0.07	2.3	1.7	1.4
MVWR	9/11/2008	8.11	320	209	350	266	258	18.6	13.6	0.5	2.1	<0.07	2.0	1.5	1.4
WABU	9/11/2008	8.11	334	213	336	266	258	18.6	13.6	0.6	1.0	<0.07	2.2	1.6	1.5
SHRZ	9/11/2008	8.28	521	314	155	633	616	55.7	41.4	1.7	0.9	0.14	8.3	7.7	6.7

Phosphorus concentrations were relatively low in both the West Walker and East Walker (less than 1 µM) and increased over two-fold downstream of the confluence during spring. This general pattern remained similar along the West Walker during the late summer months. In contrast to the West Walker, the East Walker had very high total phosphorus concentrations (up to 9 µM) during the late summer and early autumn that tended to decrease downstream (Figure A.7.7). The phosphorus in the East Walker during the autumn was largely comprised of dissolved phosphate (Table A.7.2; as opposed to particulate P) with orthophosphate being the major fraction (at 4 to 5 µM; Table A.7.2).

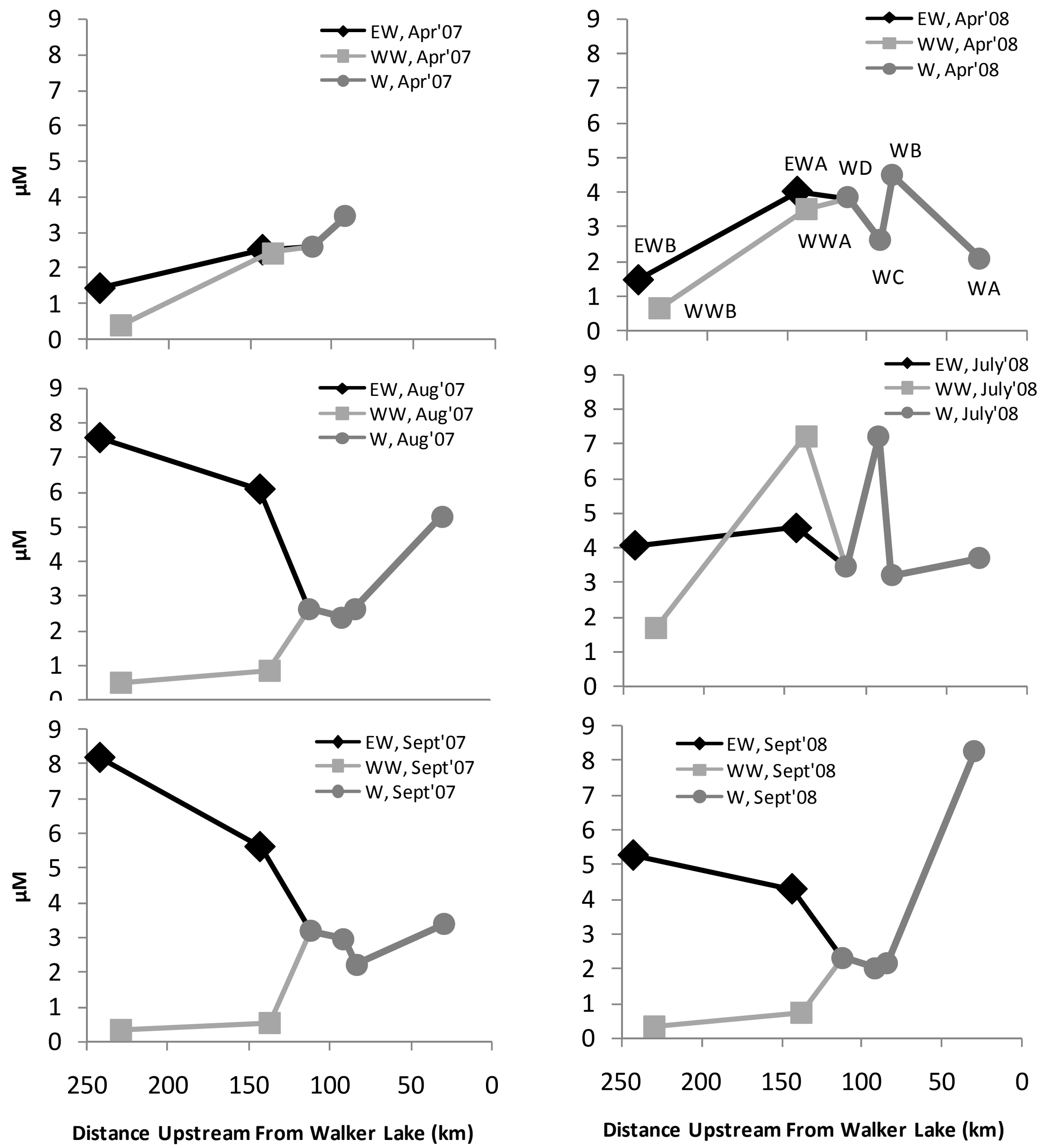

Figure A.7.7. Total phosphorus (TP) along the Walker River during 2007 and 2008 sampling.

The spatial and temporal changes in total Kjeldahl nitrogen (TKN) (Figure A.7.8) were similar in some regards to that of phosphorus. Specifically, TKN was relatively low in the upper river (2 to 25 µM) and increased downstream during spring (reaching values of 30 to 40 µM). Soluble Kjeldahl nitrogen (DKN) during spring comprised the largest portion of the TKN (comprising 65 to 80 percent on average along the river), while NH_4 ranged between 0.3 and 2.0 µM and only comprised a very small (3 to 7 percent) of the DKN (Table A.7.2). In late summer, the East Walker also had high values for TKN that decreased downriver. In contrast to the phosphorous, however, a large fraction of the nitrogen was not generally comprised of dissolved inorganic forms (specifically nitrate, nitrite, and ammonium). Rather, a larger portion (40 to 50 percent) of the TKN in the EF during summer was comprised of filterable particulate matter (Table A.7.2).

The ratio of TN to TP (Figure A.7.9) ranged between 5 and 25 (mol:mol), averaged 12.64, and tended to decrease from upstream to downstream. The ratio did not appear to display as evident or as strong a gradient as has been documented in the Truckee River (Green and Fritsen 2006). However, it should be noted that the sampling sites in the Walker basin did not extend to the higher elevations in the Sierra Nevada as did that particular study of nutrient balance within the Truckee River.

BIOMASS

Periphyton biomass was low in spring at the upstream sites of both West Walker and East Walker (Figure A.7.10), which is consistent with low temperatures, low fluxes of radiation in the winter, as well as the short period of time that followed the high (scouring) flows. However, biomass was rather high (25 µg chl *a*/cm^2) at the WD sampling site in April 2007 and relatively high (15 µg chl *a*/cm^2) at WWA in April 2008. Similarly high values for algal biomass were documented at the EWB site during both August and September 2007, with values of 32 to 47 µg chl *a*/cm^2. The following year, EWB had reduced standing stocks in July (13 µg chl *a*/cm^2) and reduced stocks in September 2008. Although there were large biomass accumulations at some locations (EWB, WWA, and WA), this was not the condition throughout the entire system. For instance, benthic chl *a* was always low at the high-elevation site of the West Walker (WWB, Figure A.7.10) and moderately high (5 to 10 µg chl *a*/cm^2) at the remainder of the sampling sites.

Values of benthic chl *a* exceeding 5 to 15 µg chl *a*/cm^2 have been suggested as the maximum levels to avoid problems for recreational and aesthetic use of streams (e.g., Welch *et al.* 1988, Horner *et al*. 1983) and values in excess of this level could be considered nuisance blooms (Dodds *et al*. 1998). If the trophic criteria are applicable to the Walker River, it is readily apparent that the EWB, WWA, WD and WA sites had algal biomass accumulations that could be regarded as nuisance blooms or even perhaps disruptive blooms.

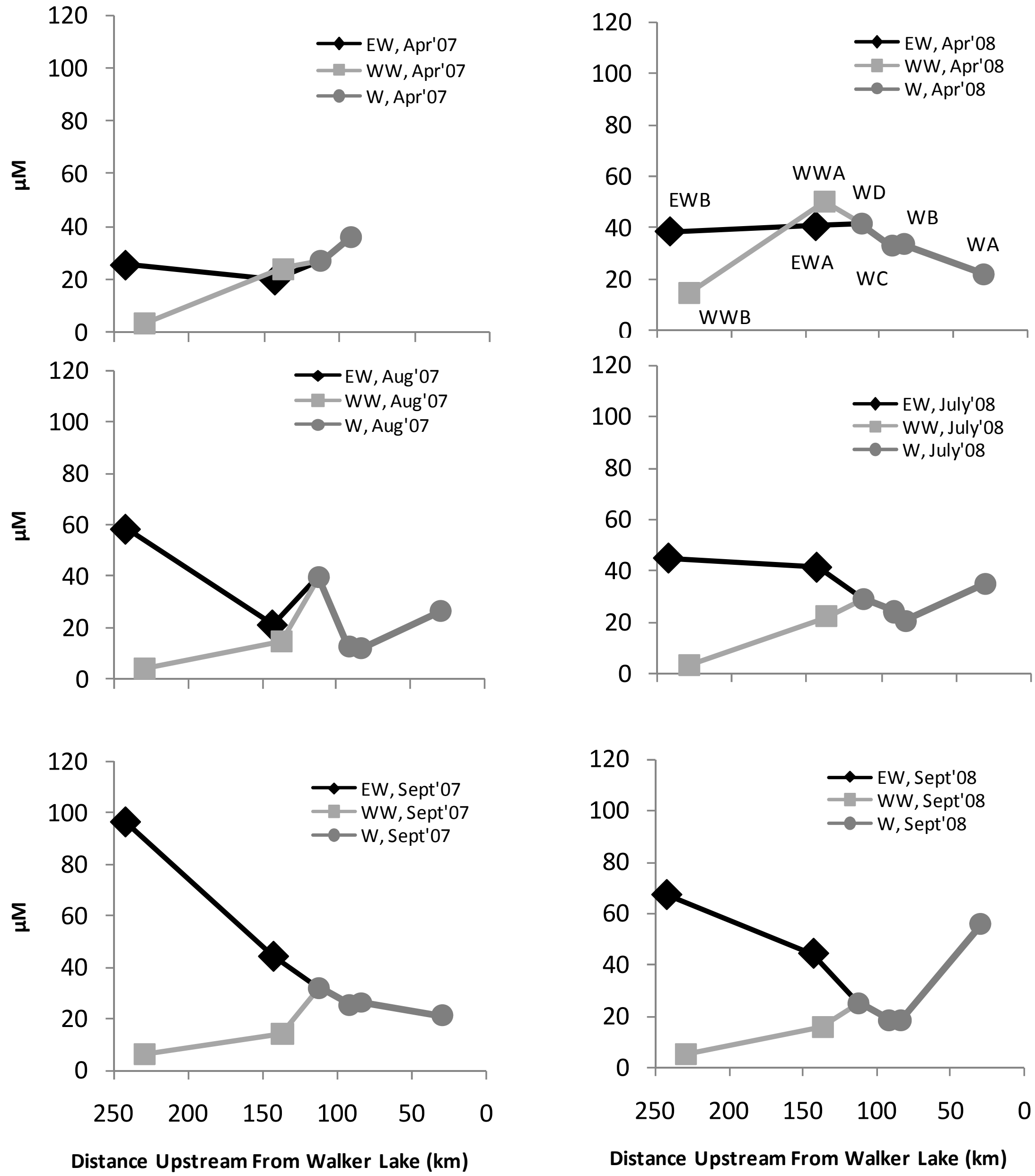

Figure A.7.8. Total Kjeldahl nitrogen (TKN) along the Walker River during 2007 and 2008 sampling periods.

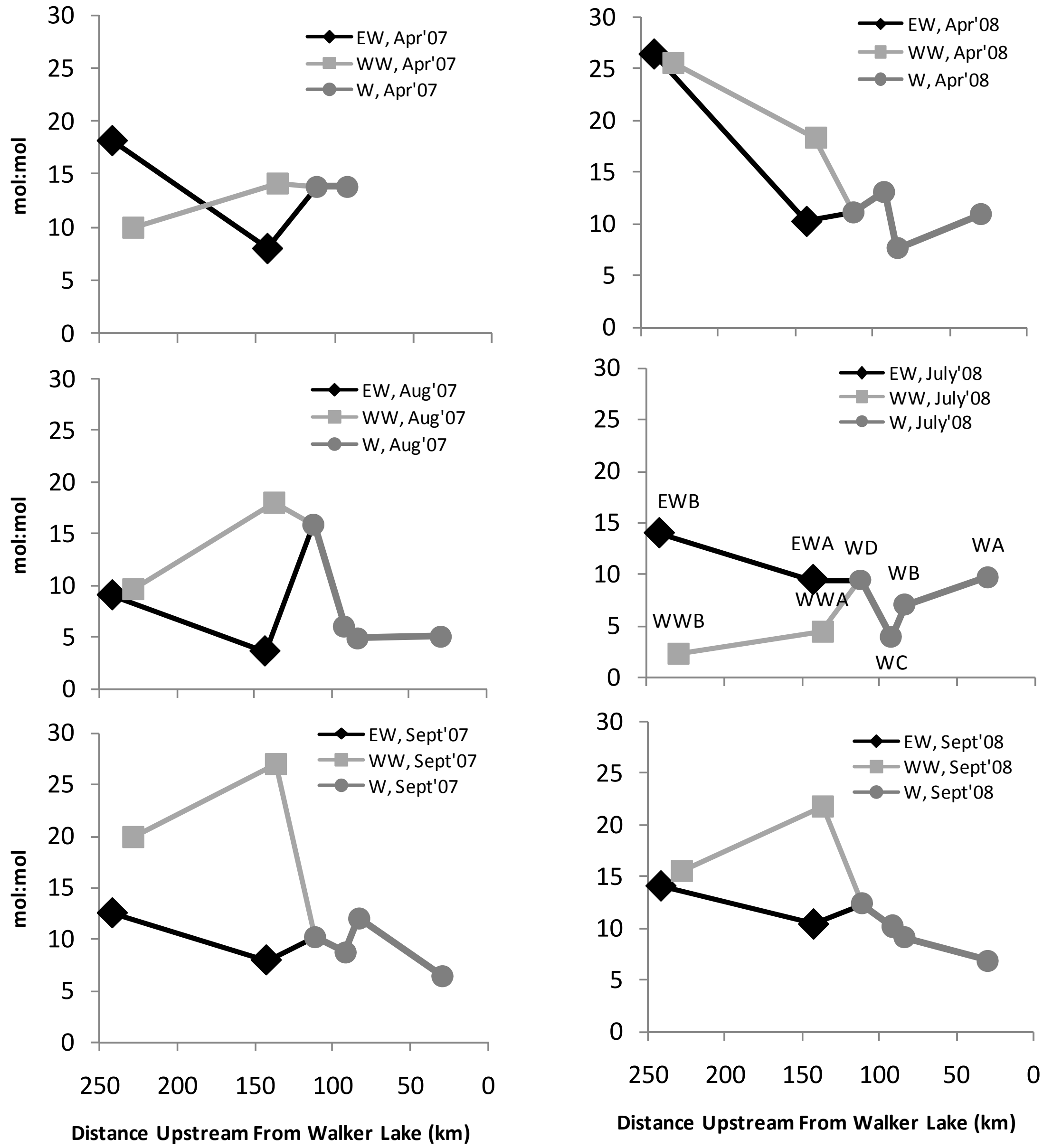

Figure A.7.9. Ratio of total nitrogen to total phosphorus, mol:mol.

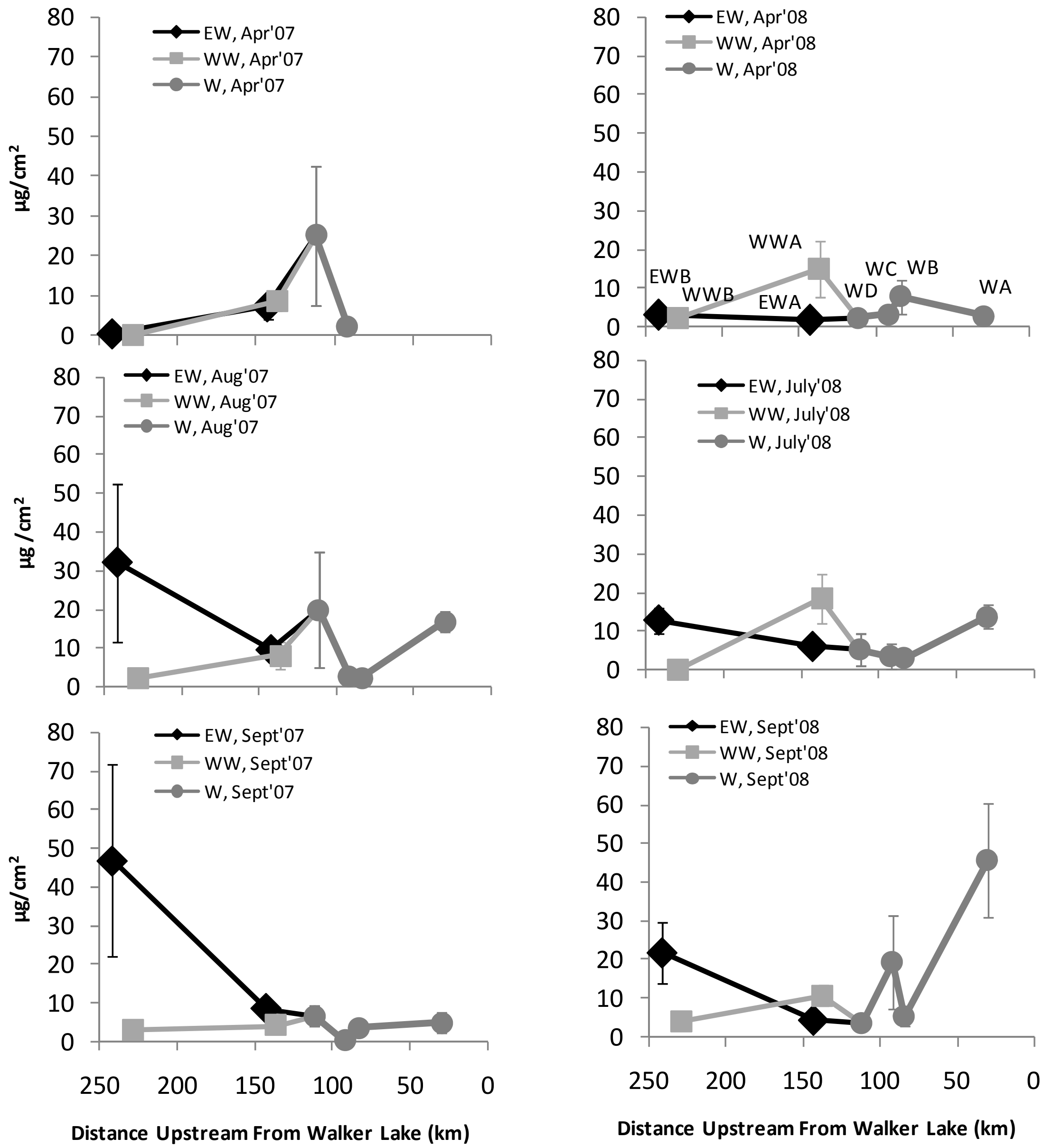

Figure A.7.10. Chlorophyll *a* concentrations for all samples. Error bars = 1 standard error.

In combination with the high nutrient concentrations measured in the East Walker at the EWB site, it is apparent that the stream system was in a eutrophic condition at select sites. Such eutrophic conditions may lead to large oxygen fluctuations and high export or loading of organic matter to downstream locations, especially during summer (Dodds and Gudder 1992). Despite the high biomass (Figure A.7.11) and nutrient concentrations in some locations, portions of the river exhibited more meso- or even oligotrophic characteristics. For instance, the West Walker that exhibits both low biomass (Figures A.7.11 and A.7.12) and low nutrient concentrations (and more unrestricted/regulated water discharges) appeared to be in a condition that could be considered oligotrophic (based on TP being less than 0.8 µM and benthic chl *a* being less than 2 µg chl *a*/cm^2; Dodds *et al.* 1998).

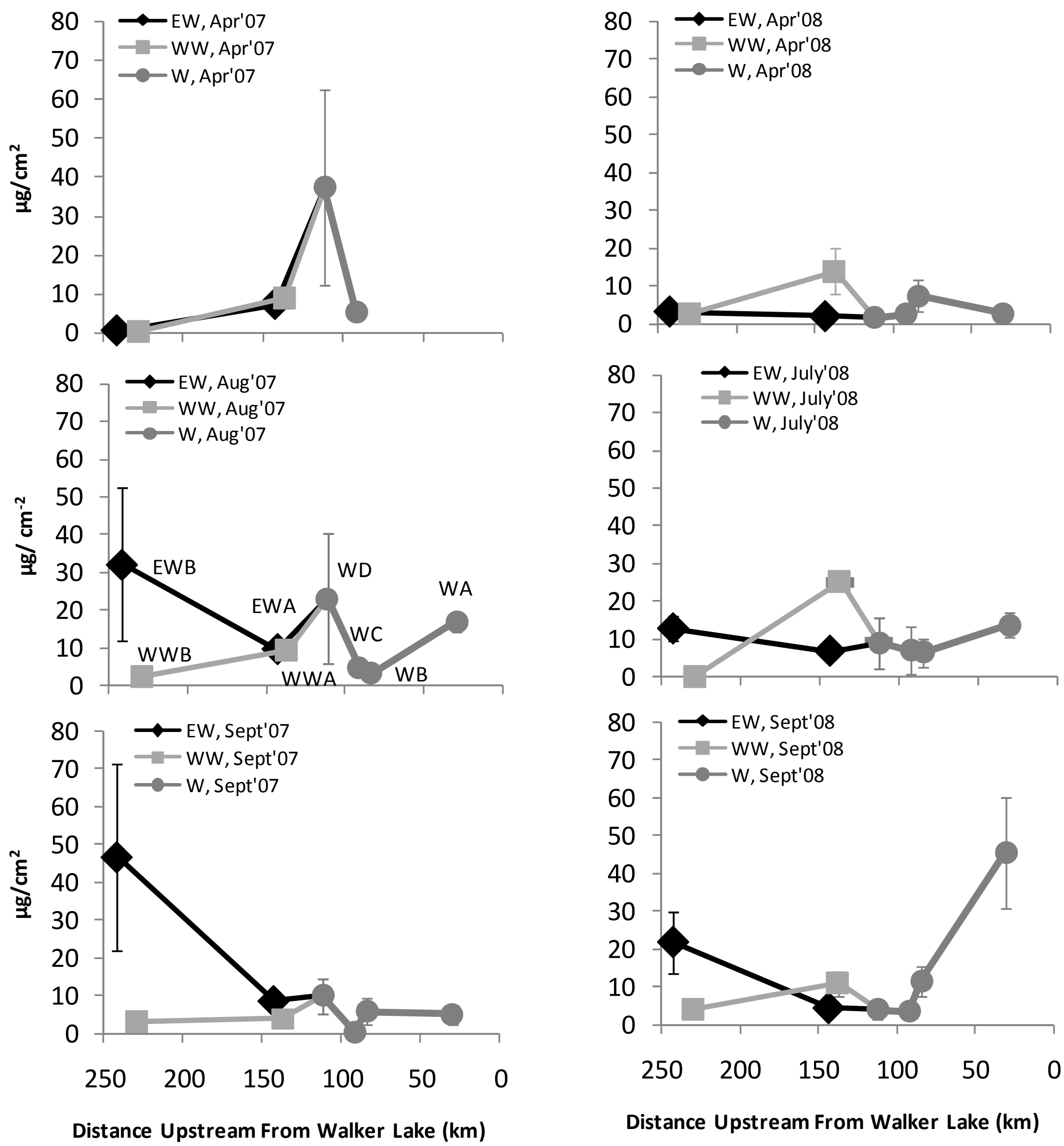

Figure A.7.11. Chlorophyll *a* samples for non-epissamic samples only. Error bars = 1 standard error.

The biogeochemical composition of periphyton indicates a general trend of chl *a* becoming a larger fraction of the total biomass (as indicated by the autotrophic index, Figure A.7.12) from upstream to downstream sites. Carbon to nitrogen (Figure A.7.13) and nitrogen to phosphorus ratios (Figure A.7.14) indicate a general trend for the periphytic mass to have less nitrogen relative to carbon and phosphorous from upstream to downstream locations.

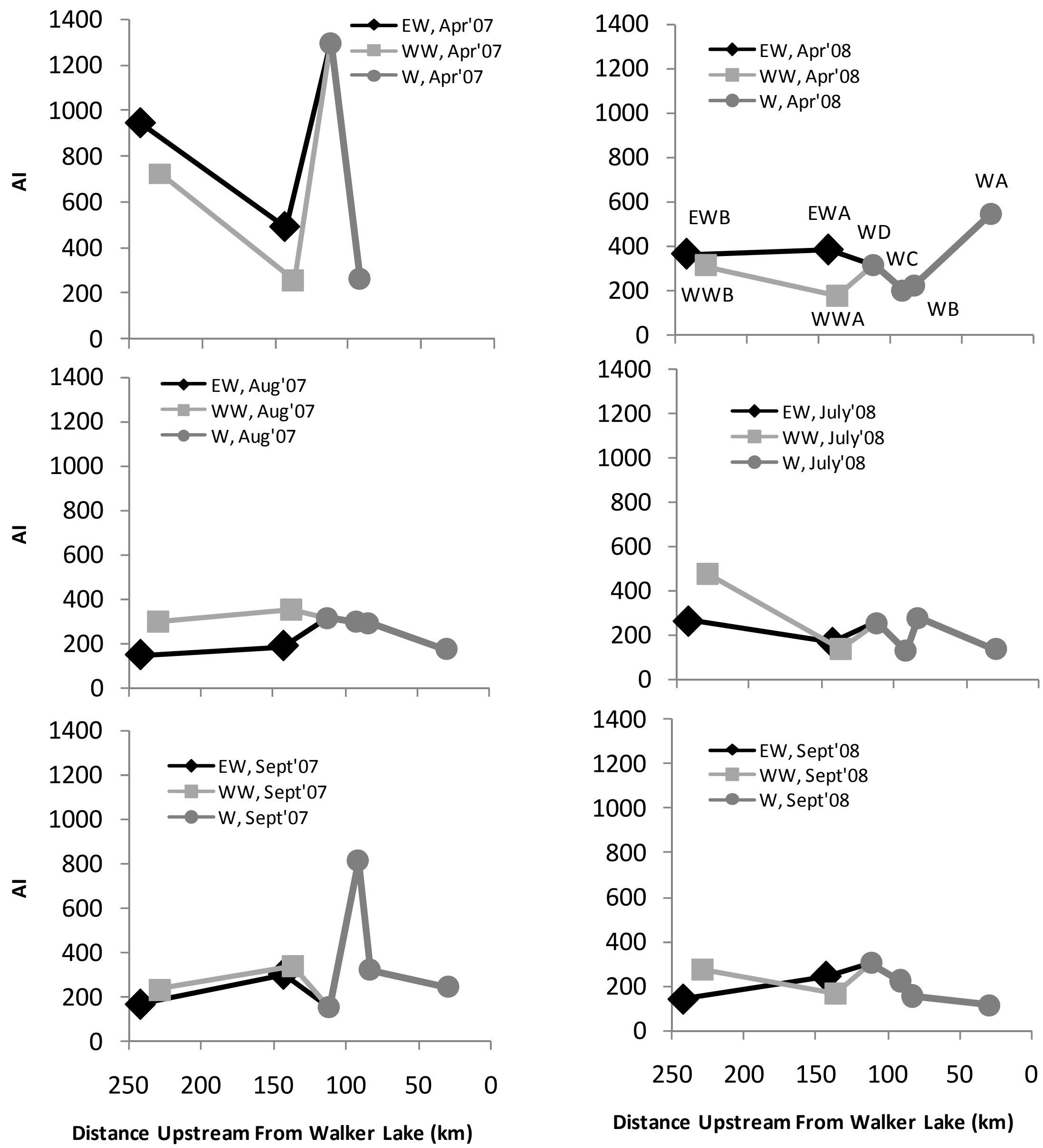

Figure A.7.12. Autotrophic index (AFDW μg/cm^2: chl *a* μg/cm^2).

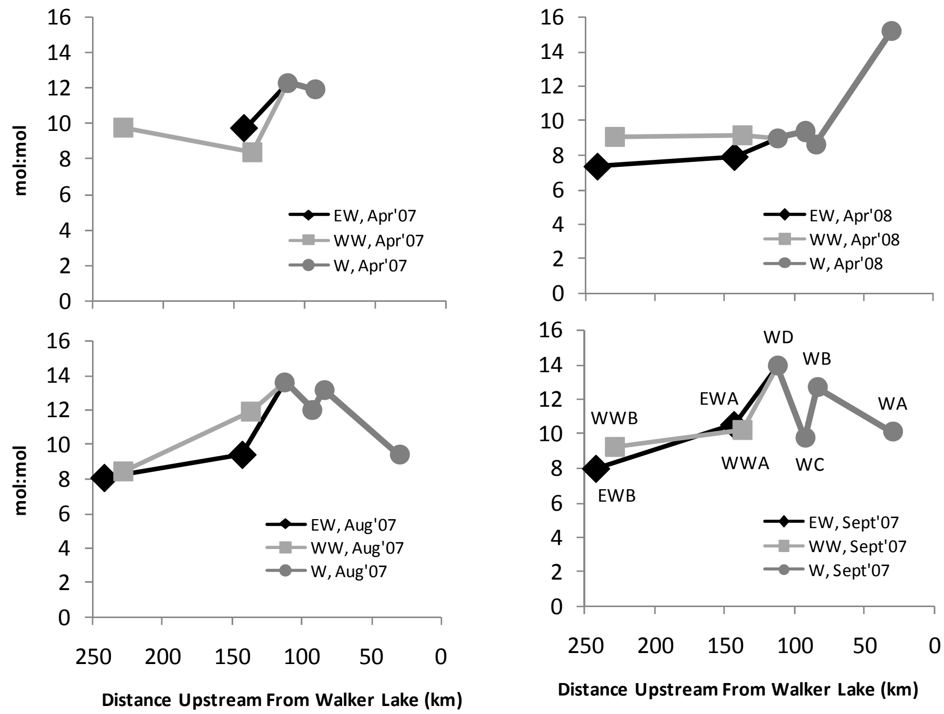

Figure A.7.13. Particulate organic carbon to particulate organic nitrogen ratios.

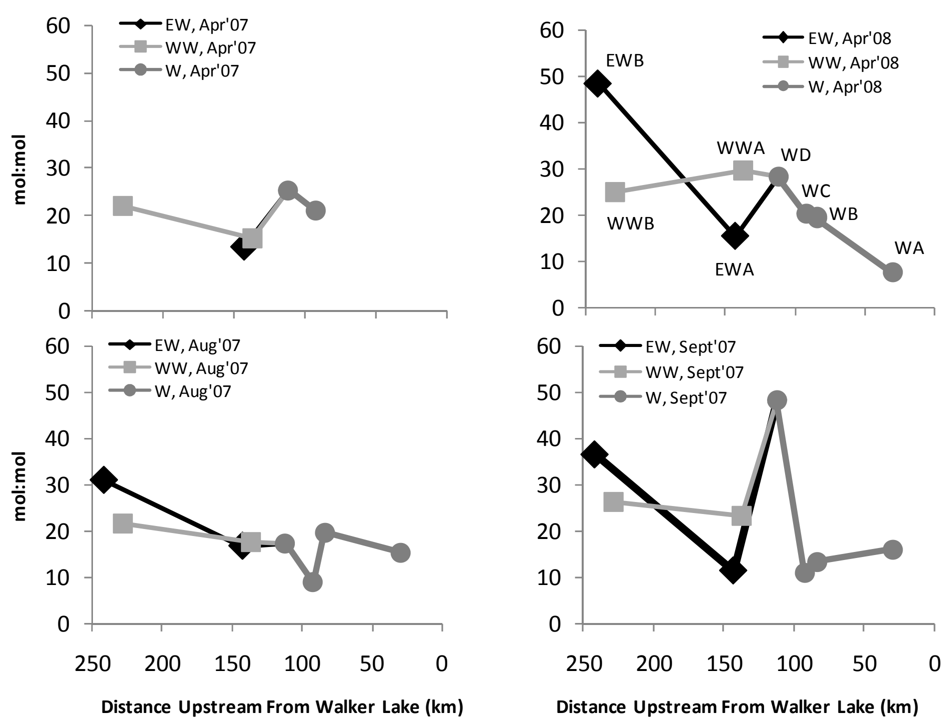

Figure A.7.14. Particulate organic nitrogen to total particulate phosphorus ratios.

COMMUNITY COMPOSITION

Macroalgae

Macroalgae are the types of algae that are readily observed in the field (i.e., macroscopic). *Cladophora*, *Oedogonium*, *Spirogyra*, and *Hydrodicyton* were the main macroalgae collected throughout the Walker Basin. The upstream site on the East Walker, EWB, had copious amounts of *Cladophora* (Figure A.7.15) and *Oedogonium*, with a decline occurring in spring. These genera were consistently associated with the high biomass documented on various substrates (wood, cobble). The most upstream site of the West Walker (WWB) was almost completely absent of these filamentous greens over the sampling period except for August 2007 when small amounts of *Spirogrya* were present. Instead, the colony forming cyanobacteria, *Nostoc*, was the macroscopic form most often observed at WWB (Figure A.7.16).

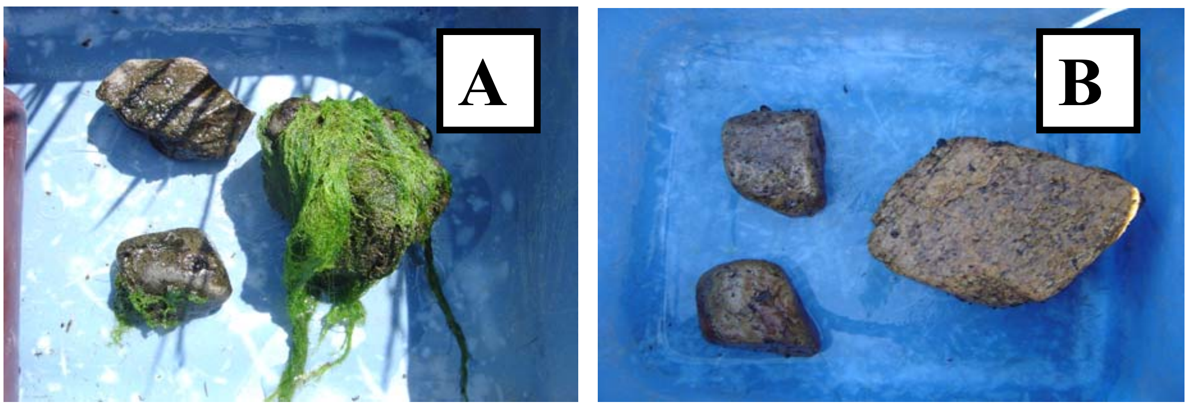

Figure A.7.15. Example of cobble with high biomass (A) and low biomass (B).

Figure A.7.16. Cobble with *Nostoc spp.*

Blinn and Herbst (2003) described the filamentous Chlorophyte *Stigeoclonium* as indicative of low ecological integrity of Lahontan Basin streams, though in particular, the high-nutrient (nitrogen and phosphorus) reaches in their survey. *Stigeoclonium* was only present at the middle reach of the East Walker (EWA) in spring. *Spirogyra* (a pollution sensitive taxa, though adapted for nutrient-rich conditions) was frequently observed at the lower river sites (WC, WB, WA).

Harmful Algal Blooms

During the 2008 sampling in fall (September), researchers noted the visible bloom of floating colonies of potentially toxin-producing cyanobacteria, most notably *Microcystis spp.*, at EWB and WA. The source of the planktonic colonies observed at EWB was confirmed to be drift from Bridgeport Reservoir. The colonies observed at WA were also attributed to fall blooms in a nearby reservoir (Weber). Though no macroscopic blooms were noted in 2007, the microscopic analysis of EWB and WA samples did identify *Microcystis spp*. in the assemblages. Sites downstream from EWB (WD, WC, WB) also had *Microcystis* cells present in fall 2007 and 2008. It is likely that these potentially toxic algae blooms are an annually occurring fall event that could readily affect the water quality and ecological integrity of these tailwater reaches until the collapse and flushing out of the blooms in upstream reservoirs.

Community Composition by Site

All algal genera encountered during microscopic analysis of Walker River periphyton collected in 2007 and 2008 are listed in Table A.7.3.

Table A.7.3. Walker River algal taxa list.

Diatoms	**Cyanophyte**	**Chlorophyte**	**Charophyte**
Achnanthes	*Anabaena*	*Cladophora*	*Cosmarium*
Achnanthidium	Synechococcaceae	*Gloeocystis*	*Spirogyra*
Amphipleura	*Calothrix*	*Hydrodictyon*	
Amphora	*Chamaesiphon*	*Microspora*	
Asterionella	*Dichothrix*	*Monoraphidium*	
Aulacoseira	*Eucapsis*	*Oedogonium*	
Bacillaria	*Fischerella*	*Pediastrum*	
Caloneis	*Homoeothrix*	*Protoderma*	
Cocconeis	*Lyngbya*	*Scenedesmus*	
Cyclotella	*Microcystis*	*Stigeoclonium*	
Cymbella	*Nostoc*	Unidentfied Chlorophyte, Colonial Coccoid	
Cymatopleura	*Nostochopsis*		
Denticula	*Oscillatoria*		
Diadesmis	*Phormidium*		
Diatoma	*Pseudoanabaena*		
Diploneis	Unidentfied Cyanophyte, Coccoid Colonial		
Encyonema			
Epithemia			
Eunotia			
Fallacia			
Fragilaria			
Frustulia			
Gomphoneis			
Gomphonema			
Gyrosigma			
Hannaea			
Hantzschia			
Karayevia			
Luticola			
Melosira			
Meridion			
Navicula			
Neidium			
Nitzschia			
Pinnularia			
Planothidium			
Reimeria			
Rhoicosphenia			
Rhopalodia			
Sellaphora			
Stauroneis			
Staurosira			
Staurosirella			
Stephanodiscus			
Surirella			
Synedra			
Tryblionella			

EWB

Periphyton communities at EWB appeared to be quite similar throughout all seasons in 2007 and 2008. Diatoms were clearly the most abundant (70 to 90 percent total RA) in the assemblages year round. However, the macroscopically detectable filamentous greens (Chlorophyta) *Cladophora* and *Oedogonium* were also associated with the high abundance of diatoms. These large green filaments (often several feet long) offer additional surface area for attachment. The low-profile growth form of the adnate diatom *Cocconeis* (Figure A.7.17A) clearly dominated the assemblages (more than 20 percent total RA in over 50 percent of the EWB samples). The motile adapted genera, *Nitzschia* (Figure A.7.17B) and *Navicula,* also contributed more than 10 percent in the majority of EWB samples. A higher-profile taxa, *Gomphonema*, and tight chain-forming genus, *Staurosira*, also contributed a notable fraction (5 to 20 percent RA) in a large portion of EWB samples. Spring assemblages had a greater abundance (5 to 10 percent RA) of two different genera of erect diatoms, *Achnanthidium* (April 2007) and *Planothidium* (April 2008). Summer (July) 2007 assemblages also had a large fraction of planktonic (drifting) chain-forming *Fragilaria* (10 to 20 percent), which was the largest contribution by this taxa at any site throughout the study period. It is very likely that the source population of these planktonic *Fragilaria* came from the phytoplankton assemblages in the upstream reservoir.

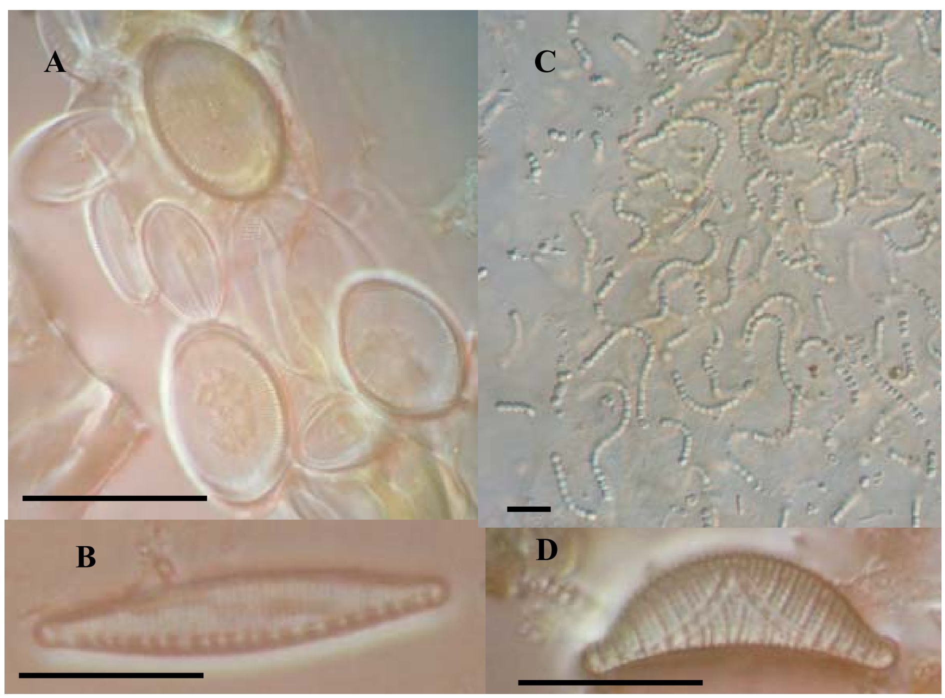

Figure A.7.17. Microscopy images of Walker River algae. A) *Cocconeis*, B) *Nostoc,* C) *Nitzschia*, D) *Epithemia*. Scale bars = 10 µm.

WWB

WWB had periphyton communities that were also dominated by diatoms throughout 2007 and 2008. The exception occurred in spring assemblages that had large fractions of macroscopic, colonial cyanobacteria. Most notable of these were colonies of *Nostoc* (Figure A.7.17C), a filamentous, di-nitrogen-fixer, that formed macroscopic growths on cobble at WWB. The diatom genera *Navicula*, *Nitzschia*, and *Gomphonema* each contributed the most to assemblages year round. *Cocconeis* and *Achnanthidium* also were relatively abundant the majority of the time at WWB. Species of *Diatoma* became more abundant in spring, especially in 2008. Late summer and fall communities shifted toward assemblages dominated by *Epithemia* (Figure A.7.17D), which, similar to *Nostoc,* are also capable of using atmospheric di-nitrogen as a nitrogen source. Additionally, summer exhibited an abundance of colonial, filamentous cyanobacteria (*Homoeothrix*) and solitary, coccoid cyanobacteria (*Synechococcus*).

EWA

Diatoms were the most dominate algal division at EWA throughout both years, though filaments of *Cladophora* were present both years. Assemblages were largely made up of *Cocconeis*, *Navicula*, and *Nitzschia* during all seasons, though some seasonal shifts in the communities were observed. Spring 2007 showed almost complete dominance (40 to 80 percent) of the loose chain-forming genus, *Diatoma*. Summer assemblages were largely composed of epiphytic taxa such as *Achnanthidium*, *Gomphonema*, *Rhoicosphenia*, and *Epithemia. Epithemia* continued to be abundant into the late summer/fall season. Also notable was the year-round abundance of *Cymbella*, a taxa often associated with reference conditions in the eastern U.S and the Truckee River in Nevada.

WWA

The periphyton assemblage at WWA during summer was largely composed of diatoms, however *Cladophora* constituted the macroscopic growths at the site. An epiphytic taxa, *Rhoicosphenia,* was present in more than 95 percent of samples, with the greatest contributions (greater than 10 percent) in 2008. *Nitzschia* and *Navicula* each contributed largely (5 to 35 percent) to WWA periphyton, with the exception of summer and fall 2008. *Cocconeis* and *Diatoma* contributed largely in the summer and fall periods. *Epithemia* made up a large proportion in summer and fall 2007. *Achnanthidium* and *Gomphonema* also contributed largely all year to the WWA assemblage, as well as *Cymbella.* The assemblages in April 2007 also had notable fractions of coccoid cyanobacteria (*Chaemeosiphon*) and filamentous cyanobacteria (*Lyngbya*).

WD

The filamentous greens, *Cladophora* and *Oedogonium*, were the macroscopic growths at the WD site throughout all seasons in both years, with the exception of April 2007. Diatoms continued to dominate the periphyton assemblages year round, especially *Cocconeis*, *Navicula*, *Nitzschia*, *Gomphonema*, and *Rhoicosphenia*. *Achnanthidium* also contributed largely to WD periphyton, though exhibited the greatest proportions in August 2007. *Diatoma*, *Planothidium*, and *Pseudostaurosira* were rare; however, when present, they made notable contributions. April 2007 also had the highest proportion of *Amphora* reported in the study (40 percent).

WC

The filamentous greens, *Cladophora* and *Oedogonium*, were the macroscopic algae on wood at the WC site throughout 2007 and 2008. Similar to WD, the diatoms dominated the periphyton at WC as *Cocconeis*, *Nitzschia*, and *Navicula* were the most abundant taxa. Spring assemblages had large fractions (10 to 20 percent) of stalk-forming species of *Gomphonema*, as well as *Rhoicosphenia*. WC also had comparable proportions of *Amphora* to WD. *Pseudostaurosira* and *Staurosira* also made rare but significant contributions to the periphyton attached to wood at WC.

WB

Similar to WC, *Cladophora* and *Oedogonium* contributed to the macroscopic algae growing on wood at the WB site throughout 2007 and 2008. *Cocconeis, Navicula,* and *Nitzschia* made up the largest portions of the diatom dominated assemblages at WB. The chain-former *Staurosira* continually showed the highest relative abundances throughout both years at the WB site, as well as the chains of *Staurosirella* that did not dominate at any other sites. *Amphora* and *Planothidium* also made notable contributions throughout both years to the periphyton communities associated with wood at WB.

WA

Cladophora composed the major macroscopic taxa at WA during all seasons in 2007 and 2008 (Figure A.7.18). Though the microscopic assemblages were largely diatom dominated, obvious differences appeared by year and seasonally. Diatom assemblages in spring 2007 were largely composed of *Staurosira*, while summer and fall of that year were almost completely dominated (25 to 40 percent) by a unique sub-aerially adapted diatom genus, *Diadesmis*. *Diadesmis* was not collected from any other reaches in the Walker basin during the study. *Fragilaria* and *Rhopalodia* also contributed significantly to the summer 2007 assemblages, with the former relatively abundant in fall 2007. In contrast, summer 2008 had larger proportions of *Gomphonema* and *Rhoicosphenia*, followed by a shift to almost complete dominance by *Synedra* (82 percent) in fall 2008. *Amphor*a was also somewhat abundant in September 2008. Similar to upstream sites, *Cocconeis* continued to contribute to WA periphyton throughout the year, however, unique to the WA site, *Navicula* and *Nitzschia* rarely contributed proportions greater than 5 percent. WA also had several unique cyanobacteria types that were not documented in other reaches such as *Nostochopsis* and an unidentified colonial, coccoid type, which were present year round.

COMMUNITY METRICS

For the following discussion of periphyton metrics please refer to Table A.7.4.

Figure A.7.18. Condition of the WA site during September 2008. Substrates covered by macroscopic growths of *Cladophora*.

% Motile Diatoms

The percentage of the diatom assemblage composed of motile adapted genera (e.g., *Nitzschia*, *Navicula*, *Surirella*, *Hantzschia*) showed a similar range (5 to 59 percent) to that documented on the Truckee River (0-78 percent, Davis 2007). The relatively high percentage of these genera in the diatom populations at some locations indicates siltation and sedimentation may be a low-to-moderate impairment of the of the river benthic habitats in the Walker basin. One hundred-forty NAWQA sites that have applied this metric showed the most degraded streams (usually agriculturally influenced) scored greater than 60 percent, while streams with lower siltation (25th percentile) scored less than 20 percent (Kleiss *et al*. 2000). With a mean of 35% across all samples the Walker River appears to be in the middle this broad nation-derived siltation spectrum. The % Motile metric also showed significant correlation with electrical conductivity and total dissolved solids (Table A.7.5).

Table A.7.4. Walker River metric scores.

Site	Sampling Date	Sample Type	N-fixing Diatoms	Eutrophic Diatoms	Eutrophic Soft Algae	Motile Diatoms	Cyanobacteria	Cymbella and Encyonema
EWB	4/24/2007	Epilithic	0.00%	76.00%	0.04%	51.17%	14.36%	4.00%
		Epilithic	0.00%	73.78%	0.01%	48.04%	29.54%	3.45%
		Epilithic	0.00%	77.38%	16.72%	45.25%	4.70%	6.79%
		Epilithic	0.00%	83.87%	13.96%	61.29%	13.51%	0.92%
		Epidendric	0.00%	86.76%	21.64%	54.79%	0.14%	0.91%
	8/9/2007	Epilithic	0.49%	95.76%	10.34%	17.94%	3.60%	0.82%
		Epilithic	0.98%	92.20%	41.00%	45.85%	21.53%	0.98%
		Epilithic	0.00%	91.18%	23.71%	26.47%	6.43%	4.41%
		Epidendric	0.15%	90.66%	24.49%	20.37%	0.15%	0.31%
	9/18/2007	Epilithic	0.00%	95.31%	4.57%	18.44%	62.20%	1.72%
		Epilithic	0.48%	93.72%	13.47%	16.43%	20.81%	1.93%
		Epidendric	0.47%	99.53%	10.23%	13.68%	42.92%	0.00%
	4/17/2008	Epilithic	0.00%	83.25%	11.24%	41.63%	23.61%	0.00%
		Epidendric	0.00%	80.10%	6.98%	54.23%	6.12%	1.99%
	7/15/2008	Epilithic	0.50%	86.63%	10.88%	47.03%	7.68%	0.99%
		Epilithic	0.49%	90.24%	3.21%	37.56%	0.73%	1.46%
		Epilithic	0.00%	93.33%	21.09%	41.43%	1.31%	0.95%
		Epilithic	0.45%	93.67%	22.73%	44.80%	0.65%	0.45%
		Epidendric	0.00%	96.52%	23.39%	47.76%	0.36%	1.00%
	9/10/2008	Epilithic	0.00%	93.53%	11.21%	17.91%	5.39%	0.00%
		Epidendric	0.00%	96.08%	15.41%	31.86%	4.92%	0.00%
WWB	4/26/2007	Epilithic	1.95%	72.31%	0.95%	30.62%	39.36%	2.12%
		Epilithic	1.48%	78.47%	0.06%	26.79%	31.83%	1.15%
	8/9/2007	Epilithic	5.36%	81.49%	16.04%	21.75%	3.22%	2.11%
		Epilithic	17.14%	83.33%	8.20%	36.67%	16.31%	1.43%
		Epilithic	14.62%	84.43%	6.63%	33.49%	21.78%	1.89%
		Epidendric	0.49%	81.55%	9.01%	47.57%	17.26%	1.46%
	9/18/2007	Epilithic	21.52%	88.19%	2.27%	41.75%	4.04%	1.78%
		Epilithic	18.22%	91.56%	7.39%	32.00%	1.93%	1.78%
		Epidendric	6.40%	84.73%	15.81%	45.81%	1.32%	2.46%
	4/17/2008	Epilithic	0.49%	40.29%	24.54%	19.90%	32.84%	1.94%
		Epidendric	3.37%	66.83%	12.93%	35.58%	2.05%	3.37%
	7/15/2008	Epilithic	0.50%	55.50%	43.27%	25.50%	18.65%	4.00%
		Epilithic	0.00%	44.28%	13.03%	17.91%	19.91%	3.48%
		Epilithic	0.50%	48.51%	15.36%	19.80%	9.48%	5.94%
		Epilithic	1.42%	63.03%	10.67%	17.06%	15.46%	4.74%
		Epidendric	0.49%	52.71%	17.04%	17.73%	41.17%	5.42%
	9/10/2008	Epilithic	10.42%	78.76%	11.60%	43.24%	0.40%	3.47%
		Epidendric	6.25%	76.92%	12.47%	38.94%	2.03%	3.85%

Table A.7.4. Walker River metric scores (continued).

Site	Sampling Date	Sample Type	N-fixing Diatoms	Eutrophic Diatoms	Eutrophic Soft Algae	Motile Diatoms	Cyanobacteria	Cymbella and Encyonema
EWA	4/25/2007	Epilithic	0.99%	10.87%	1.55%	3.95%	2.60%	2.80%
		Epilithic	0.33%	25.98%	1.33%	18.79%	0.24%	6.70%
		Epilithic	2.31%	14.81%	0.15%	7.87%	0.73%	9.72%
		Epidendric	0.00%	44.96%	0.00%	33.61%	0.23%	8.40%
	8/8/2007	Epilithic	6.09%	75.80%	0.01%	41.70%	3.00%	10.35%
		Epilithic	20.40%	80.10%	5.72%	32.84%	30.44%	5.47%
		Epilithic	5.47%	69.65%	3.78%	40.80%	19.08%	12.44%
		Epidendric	6.41%	78.95%	8.78%	47.70%	8.87%	6.91%
	9/20/2007	Epilithic	6.16%	40.19%	0.56%	24.96%	0.18%	4.70%
		Epidendric	4.50%	76.00%	15.34%	48.00%	11.03%	5.00%
	4/16/2008	Epilithic	3.98%	90.55%	0.15%	53.73%	9.31%	0.50%
		Epidendric	0.95%	87.20%	72.75%	49.76%	0.30%	0.95%
	7/15/2008	Epilithic	8.84%	70.23%	4.98%	23.72%	2.89%	5.12%
		Epilithic	6.16%	71.56%	5.18%	33.18%	10.49%	6.16%
		Epilithic	5.88%	69.61%	4.91%	25.98%	3.88%	6.86%
		Epidendric	3.79%	74.88%	3.21%	42.65%	0.80%	4.74%
	9/11/2008	Epilithic	26.42%	65.57%	37.74%	26.89%	15.97%	7.55%
		Epidendric	4.83%	76.33%	2.38%	53.14%	0.19%	5.31%
WWA	4/25/2007	Epilithic	0.00%	86.76%	0.01%	58.45%	17.71%	0.91%
		Epilithic	0.00%	83.17%	0.00%	56.73%	18.66%	0.00%
		Epilithic	0.00%	91.98%	0.00%	61.32%	34.68%	1.89%
		Epidendric	0.00%	87.16%	1.40%	66.97%	18.29%	0.92%
	8/8/2007	Epilithic	13.53%	72.94%	0.27%	24.92%	1.43%	9.74%
		Epilithic	15.82%	75.12%	0.21%	24.88%	1.36%	9.72%
		Epilithic	15.46%	64.73%	5.35%	14.98%	4.13%	11.11%
		Epilithic	7.92%	72.77%	9.36%	18.32%	4.22%	3.96%
		Epidendric	1.23%	86.27%	13.88%	30.12%	3.98%	2.05%
	9/18/2007	Epilithic	7.32%	75.28%	1.63%	20.00%	18.77%	7.48%
		Epilithic	23.33%	70.67%	1.23%	21.33%	15.46%	12.00%
		Epidendric	2.90%	84.06%	36.54%	24.15%	14.00%	3.38%
	4/15/2008	Epilithic	0.33%	82.71%	10.44%	39.48%	16.84%	2.61%
		Epilithic	4.29%	85.71%	13.14%	33.33%	5.45%	4.29%
		Epidendric	0.00%	89.05%	15.07%	36.19%	19.14%	2.86%
	7/16/2008	Epilithic	0.00%	66.50%	0.70%	5.42%	1.38%	6.40%
		Epilithic	0.00%	67.00%	0.58%	4.50%	0.47%	2.00%
		Epilithic	0.48%	67.62%	18.66%	10.48%	1.45%	5.24%
		Epilithic	0.00%	55.11%	26.64%	10.67%	4.64%	5.33%
		Epidendric	1.81%	83.71%	8.87%	18.55%	2.04%	3.62%
	9/11/2008	Epilithic	2.44%	49.27%	23.18%	15.12%	2.18%	2.93%
		Epidendric	3.67%	86.24%	18.20%	18.81%	0.08%	2.29%

Table A.7.4. Walker River metric scores (continued).

Site	Sampling Date	Sample Type	N-fixing Diatoms	Eutrophic Diatoms	Eutrophic Soft Algae	Motile Diatoms	Cyanobacteria	Cymbella and Encyonema
WD	4/27/2007	Epilithic	0.00%	83.33%	0.00%	40.00%	0.00%	0.00%
		Epilithic	0.00%	91.63%	100.00%	33.99%	2.42%	0.49%
		Epidendric	0.00%	90.50%	0.00%	22.00%	1.28%	2.00%
		Epidendric	0.00%	92.13%	11.47%	12.60%	0.13%	0.79%
	8/7/2007	Epilithic	0.85%	61.02%	3.85%	20.76%	1.19%	2.97%
		Epilithic	0.50%	62.38%	9.18%	28.22%	3.93%	1.49%
		Epidendric	1.58%	78.13%	4.05%	29.48%	2.21%	3.33%
	9/19/2007	Epilithic	1.12%	50.48%	18.45%	12.30%	0.04%	3.83%
		Epilithic	0.50%	76.00%	10.14%	32.50%	3.68%	3.00%
		Epidendric	2.33%	71.16%	9.49%	31.16%	6.63%	6.05%
	4/16/2008	Epissamic	0.00%	76.24%	47.82%	32.18%	2.01%	2.48%
		Epissamic	3.38%	67.93%	30.83%	44.73%	11.53%	1.69%
		Epidendric	0.97%	88.83%	16.26%	51.94%	5.87%	0.49%
	7/17/2008	Epilithic	0.00%	91.47%	27.58%	18.01%	5.12%	0.47%
		Epissamic	0.00%	94.50%	46.38%	5.00%	9.65%	0.00%
	9/9/2008	Epilithic	2.94%	75.49%	11.82%	32.35%	0.95%	3.43%
		Epidendric	2.76%	73.27%	4.50%	26.73%	1.25%	3.69%
WC	4/26/2007	Epidendric	0.00%	84.30%	11.74%	35.87%	3.01%	2.69%
		Epidendric	0.00%	82.61%	1.15%	38.65%	0.37%	0.00%
	8/7/2007	Epidendric	2.36%	87.15%	9.00%	40.90%	9.65%	0.64%
		Epidendric	0.98%	81.95%	8.42%	45.85%	2.94%	0.00%
	9/20/2007	Epidendric	1.37%	90.87%	13.32%	68.95%	4.58%	0.46%
	4/14/2008	Epilithic	0.00%	90.38%	24.00%	56.73%	0.02%	1.60%
	7/14/2008	Epidendric	0.50%	86.14%	5.58%	41.58%	1.55%	1.49%
	9/8/2008	Epissamic	0.00%	90.20%	46.89%	9.31%	3.09%	0.00%

Table A.7.4. Walker River metric scores (continued).

Site	Sampling Date	Sample Type	N-fixing Diatoms	Eutrophic Diatoms	Eutrophic Soft Algae	Motile Diatoms	Cyanobacteria	Cymbella and Encyonema
WB	8/9/2007	Epissamic	0.48%	85.58%	25.01%	62.02%	8.19%	0.00%
		Epidendric	0.50%	88.47%	6.55%	53.13%	17.77%	0.50%
	9/21/2007	Epissamic	0.00%	88.74%	13.47%	49.55%	3.42%	0.45%
		Epidendric	0.00%	86.07%	10.09%	45.27%	1.53%	1.49%
	4/14/2008	Epissamic	0.00%	89.35%	21.99%	61.11%	1.06%	0.46%
		Epidendric	0.76%	84.39%	22.00%	57.14%	3.87%	2.01%
		Epidendric	0.00%	75.57%	7.23%	30.77%	5.57%	1.36%
	7/14/2008	Epidendric	0.50%	89.05%	4.56%	45.27%	0.09%	0.00%
		Epidendric	0.92%	84.79%	5.23%	51.61%	0.06%	0.00%
		Epidendric	0.46%	88.02%	5.85%	50.23%	4.08%	0.00%
	9/8/2008	Epissamic	0.00%	87.25%	46.56%	4.41%	1.29%	0.00%
		Epidendric	0.00%	91.67%	6.72%	64.71%	0.61%	0.00%
WA	8/9/2007	Epilithic	2.89%	60.61%	6.09%	54.18%	11.22%	0.00%
		Epilithic	0.47%	37.44%	5.66%	58.29%	17.95%	0.00%
		Epidendric	10.55%	55.05%	3.59%	60.09%	14.33%	0.00%
	9/21/2007	Epilithic	8.49%	38.21%	5.15%	70.75%	29.16%	0.00%
	4/15/2008	Epilithic	1.91%	86.30%	4.13%	73.57%	13.52%	0.16%
	7/17/2008	Epilithic	0.99%	92.61%	12.24%	15.76%	3.74%	0.00%
	9/9/2008	Epilithic	3.38%	62.32%	7.11%	19.32%	18.59%	0.00%
		Epidendric	2.97%	10.89%	10.00%	3.47%	5.68%	0.00%

% Cymbella + Encyonema

The relative abundance of the diatom genera, *Cymbella* and *Encyonema*, within the sampled diatom population also exhibited a similar range (0 to 12 percent) to what has been observed in similar habitats in the Truckee River (Davis 2007). A high proportion of these genera usually correlate with “good” water quality (i.e. low concentrations of phosphorus, nitrogen, and chloride) (Wang *et al*. 2005). The metric scores for the Truckee River were largely driven by the relative abundance of *Encyonema* versus the Walker River’s scores being driven by *Cymbella*. Both of the lower sites on the East and West Walker had consistently the largest fractions of this metric of good integrity. Most of the downstream reaches had very low scores for this metric, likely indicating the decreased habitat quality. Correlation analysis revealed the strongest correlation (negative) with nitrate (Table A.7.5).

% Eutrophic Diatoms

The eutrophic conditions of the low-gradient reaches of the river yielded a high proportion (mean = 77 percent) of diatoms in Walker periphyton assemblages adapted to high-nutrient conditions. *Cocconeis*, *Nitzschia*, and *Rhoicosphenia* contributed large fractions to the assemblages, thus driving the scores of the eutrophic metric. The diatom assemblages of the Truckee River exhibit a comparable proportion (over 80 percent) of eutrophic genera (Davis 2007). The consistently high values at the upstream sites on the East Walker (EWB, EWA) are likely driven by the release of nutrients from the hypolimnion of Bridgeport Reservoir. This is supported by the relatively strong (positive) correlation with nitrate (Table A.7.5).

% Eutrophic Soft Algae

An average of 14 percent of the assemblages was composed of eutrophic soft-algae. The highest values reported for % eutrophic soft-algae occurred at WD (100 percent) in April 2007. The conservative identification for some of the soft-algae, particularly the cyanobacteria, may have limited the response of this metric in capturing shifts in nutrient concentrations. If the metric were calculated using biovolumes instead of abundances, *Cladophora* would likely drive the metric scores up in the lower-elevation reaches, thus indicating significant nutrient inputs in these reaches. For example, the relative abundance of *Cladophora* on April 2007 at EWA was 0.19 percent (extremely low abundance), however, the average biovolume per natural unit of *Cladophora* was 360,000 cubic µm compared to 200 to 2,000 for diatom taxa. The relative biovolume would be 90 percent *Cladophora* and 10 percent all other taxa. Although many environmental assessments using periphyton assemblages apply the relative abundance to calculate algal metrics, relative biovolumes may actually be more appropriate when large, filamentous taxa such as *Cladophora* are present in the system of interest (Porter 2008).

Table A.7.5. Spearman ranked correlation coefficients and significance (below rho) for the relationship between water chemistry and periphyton-based metrics. P-values greater than 0.05 omitted. Bold indicates rho > 0.30.

	pH	EC	TDS	SiO_2	TOC	DOC	TKN	DKN	NH_3	NO_3	TP	DP
N-fixing Diatoms			-0.27	**-0.34**	**-0.30**	**-0.30**	**-0.45**	**-0.37**	-0.27	**-0.45**	**-0.30**	-0.28
			0.02	**0.00**	**0.01**	**0.01**	**0.00**	**0.00**	0.01	**0.00**	**0.01**	0.01
Eutrophic Diatoms	0.28								0.29	**0.39**		
	0.01								0.01	**0.00**		
Eutrophic Softs												
Motile Diatoms		**0.36**	**0.38**									
		0.00	**0.00**									
Cyanobacteria		-0.26	-0.21						0.25			
		0.02	0.06						0.02			
Cymbella + Encyonema		-0.22	-0.25	-0.25			-0.23			**-0.46**		
		0.05	0.02	0.02			0.04			**0.00**		

% Cyanobacteria

Increased composition of this algal division within the assemblage has been correlated with increased nutrient and organic enrichment, as well as toxic materials, to the system (Hill *et al.* 2000). Cyanobacteria metric scores were generally much lower (less than 25 percent) than that reported at comparable sites on the Truckee River (more than 50 percent). Higher scores for this metric were consistently observed, though spatially and temporally variable, at EWB (mostly colonial, coccoid types) and WWB (largely *Nostoc*) throughout both years.

% Nitrogen-fixing Diatoms

It was anticipated that due to the low concentration of bioavailable, inorganic nitrogen that generally characterizes the river system, a large fraction of the diatom assemblages would be composed of diatoms that house di-nitrogen-fixing endosymbionts (*Epithemia* and *Rhopalodia*). Mid-elevation sites (EWA and WWA) and the uppermost West Walker site (WWB) consistently had the highest relative abundances (5 to 20 percent) in late summer and fall. These scores are comparable with the upper and lower reaches of the Truckee River that also have extremely low nitrogen concentrations (Davis 2007). The absence of N-fixing diatoms at the EWB site is most likely due to the relatively high concentrations of nitrogen that are released from the hypolimnion of the upstream reservoir. In contrast, the lower reaches of the Walker River generally show trace levels of dissolved nitrogen and thus would seem a likely habitat for N-fixing diatoms to dominate, however, this is not the case. Only the lowermost reach, WA, exhibited an increase in N-fixing diatoms during late summer and fall. Evidence of the strong relationship with nitrogen species and this metric was demonstrated in the strong, negative correlations with NO_3 and TKN (Table A.7.5).

DISCUSSION

The assessment of the Walker River's algal communities shows site and seasonal differences in biomass and community composition. Typical of most rivers and streams, the highest biomass was documented in summer during low-flow conditions. Increased light and warmer water temperatures combined with stable-flow conditions usually allow for prolific algae accumulation given adequate nutrient supply and substrate availability (Biggs 1996). Eutrophic levels of algal biomass occurred at select locations, most notably on the East Walker downstream from Bridgeport Reservoir (EWB), middle reach of the West Walker (WWA), and the lower most reach, Schurz (WA).

The upper sites of the forks were particularly different with regard to their algal communities. A high biomass of filamentous green algae was attained in summer on the East Walker that was most likely driven by nutrient inputs from Bridgeport Reservoir, while colonial cyanobacteria and low-profile diatoms composed the low biomass that consistently characterized the upper West Walker.

The high-standing stocks of algae at select sites on the Walker River could induce large diurnal swings in dissolved oxygen concentrations. Copious amounts of algae can create high concentrations of dissolved oxygen (DO) during daytime hours (through photosynthesis), but lower DO concentrations at night (through excessive respiration). Large diel DO variations can put the health of aquatic life within a river system at risk and DO is one of the primary water-quality constituents that can be used as an indicator of the ecological health of a water body (Ruhl and Jarrett 1999; Feaster and Conrads 2000). Summer deployment of sondes at an East Walker (EWB), West Walker (WWA), and Walker River (WC) locations could prove very informative with regard to how much these high-standing stocks of algae are influencing ecosystem metabolism in these reaches. Additionally, deployments of sondes at lower sites (WB and WA) would allow an assessment of how even these moderate to high levels of algal biomass (Figure A.7.10) affect the oxygen dynamics under the more restrictive variable and low-flow (0 to 20 cfs) regimes. The application of whole-stream metabolism measurement is a method of integrating ecosystem function and is commonly overlooked as a good indicator of stream "health" (Izagirre *et al*. 2008). Furthermore, continued monitoring of biomass and community composition in conjunction with knowledge about the dynamics of whole-stream metabolism would yield a more complete view of the ecological structure and function of the Walker River.

The fluctuation of flows at the lowermost reach (WA) throughout the study period likely drove the variable composition of the periphyton at that site. Unique to this reach was the diatom taxa that are indicative of fluctuating flows (aerophilic diatom, *Diadesmis*) as well as overall reduced flows creating more stagnate, pool-like habitat (planktonic, chain-forming diatoms) that were observed in 2007. These taxa were reduced or absent at WA during the 2008 season when the reach had flowing water.

The longitudinal comparison of the sites is highlighted by the site differences in dominant substrate type. The higher-gradient reaches in the upper watershed (EWB, WWB, EWA, WWA) are cobble-based benthic habitats, while the remaining low-gradient sites are sand dominated. Algal assemblages that are associated with sandy substrates are not preferred for biological assessments because they are inherently dynamic habitats. Epidendric (wood) and epilithic (cobble) periphyton assemblages are thus given preference, with the latter commonly targeted when conducting assessments by using the criteria of richest targeted habitat. Diatom assemblages have been shown to be similar on both substrates, thus both should be used to increase the sample pool (Townsend and Gell 2005). Due to the lack of cobbles at the lower sites, greater emphasis on epidendric samples may prove more appropriate when wanting to conduct longitudinal comparisons within the Walker basin.

It is difficult to specifically predict how periphyton communities in rivers will respond to increases in base-flow discharges. One could speculate that dramatic shifts in community composition would likely occur as was seen at WA in 2008 although the exact composition is not necessarily predictable. Additionally, the higher volume of water would further dilute nutrients in the lower reaches (particularly phosphorus), perhaps leading to dominance by non-eutrophic taxa. The higher flows would also tend to decrease the TDS and the electrical conductivity of the water in the lower reaches. Recent work by Stevenson *et al*. (2008) showed strong correlations between their calculations of diatom weighted-averages indicators (sensitive and tolerant taxa) and measured conductivity in Western U.S. streams. Similarly, a Lahontan regional study by Blinn and Herbst (2003) indicated that conductivity was associated with shifts in diatom communities. In the current study, the % Motile diatoms was correlated with conductivity, thus the taxa that mostly make up this metric, *Navicula* and *Nitzschia*, could be affected.

Additional delivery of water, especially to the WB and WA sites will likely result in a measurable shift in the algal biomass and taxa, and in the ratio of biomass to water-volume that would affect the in-stream oxygen conditions. Modeling studies parameterized with specific river-bed hydraulic characteristics for these reaches (for instance using WASP or equivalent routines) could be a first quantitative approximation of the potential impacts/benefits of increased flows. These routines would not predict algal community changes but would help in the evaluation of the impacts that the present-day algal biomass may have on the in-stream conditions.

Finally, if water management would allow for flushing flows, these could scour embedded substrate (cobble) that in turn could be colonized by periphyton, if substrate availability is, in fact, a limiting factor. Substrate availability is not generally addressed as a limiting factor for periphyton growth. However, excessive accumulation of algae requires suitable substrate for sustained attachment. Thus, the areas on the Walker River that have hard, stable substrates (cobble or woody debris) that allow the development of these excessive growths are more likely to be at risk of impairment due to low DO concentrations than those without suitable substrates for periphyton attachment. This hypothesis could be readily tested by deploying artificial substrates (bricks) at sites of interest (e.g., WC, WB). In essence, this hypothesis is likely to have already been demonstrated at the WA site, where artificial substrate has been introduced in to the river and had large biomass accumulations during the study when water was present (Figure A.7.10 and A.7.18).

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A.8: RELATIONSHIPS BETWEEN AQUATIC ENVIRONMENTS AND WALKER RIVER BENTHIC MACROINVERTEBRATE COMMUNITIES, NEVADA AND CALIFORNIA

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ABSTRACT

A number of studies have examined Walker Lake fishes, and its ancient, historic and current limnology. Few studies have examined river ecology, and there is little information available to assess its ecological health or how its aquatic life differs from headwaters to its terminus in Walker Lake. Characteristics of river physical habitat, water chemistry, and benthic macroinvertebrates (BMIs) were quantified during the spring, summer, and autumn of 2007 and 2008 in riffles and woody debris at eight sites from Walker Lake to the Sierra Nevada base. Physicochemical characteristics of the river differed spatially and temporally. Spring was distinguished by cool temperatures, high discharge (and related factors such as deep water, high current velocities, and wider stream channels), low nutrients and TDS. Summer and autumn were characterized by high temperatures and TDS, and low discharge. Downstream sties (Mason Valley and below) were relatively narrow, substrates were small, and summer and autumn water temperatures were relatively high. Mean substrate size and discharge increased, and temperatures decreased, among sites along an elevation gradient toward the Sierra Nevada.

Taxonomic richness and the community tolerance values of riffle and woody debris BMIs exhibited spatial and temporal trends. Both metrics show that ecological health of upstream reaches is generally better than reaches through and below Mason Valley. Lowest taxonomic diversity typically occurred during spring and at the lowest site. Riffle taxonomic richness was generally highest during summer at all sites but timing of the highest richness in woody debris was variable and occurred during all seasons. Riffle diversity was highest in the upper site of West Walker River during all seasons, which is the only site retaining a natural hydrograph and that is unaffected by upstream agriculture. Community tolerance values were highest downstream, in the harshest environment, and generally decreased upstream along an elevational gradient. Lowest tolerance values occurred at the upper West Walker site.

Multivariate analyses found a strong relationship between water temperature, discharge, and BMI community structure, which indicates that that ecological integrity of the Walker River is affected by activities that influence these factors. Conversely, actions that increase discharge and reduce water temperature and nutrients would improve river conditions and have a concomitant affect on BMI communities. Runoff during 2007 and 2008 was less than 50 percent of normal in the Walker River. Additional sampling during years with higher runoff is needed to gain insight into the response of river ecological health to incremental increases in discharge.

INTRODUCTION

The hydrographic Great Basin is an expanse of endorehic basins that encompass approximately 20 percent of the US between the Sierra Nevada on the west, the Wasatch Range on the east, and south of the Snake River Plain to the Colorado River drainage (Grayson 1993). It is the most arid region in the US and includes more than 150 north-south oriented mountain ranges that receive most precipitation during winter storms. Water flows from mountains into intervening valleys where it ends in terminal lakes or percolates into the soil as ground water. Aridity restricts humans and economies to small areas with adequate surface or ground water. Aridity also affects vegetation and animal life. Mountains support coniferous forests, most valleys are sagebrush, and riparian and aquatic communities are limited to narrow ribbons along streams, rivers, and springs brooks Studies examining Great Basin aquatic life have focused on lake limnology (e.g., Galat *et al*. 1981), fish biogeography, genetics (e.g., Smith *et al*. 2002), and physiology (Feldmeth *et al*. 1974), and invertebrate taxonomy and biogeography (e.g., Hershler 1998, Hershler and Sada 2002, Polhemus and Polhemus 2002). Few studies have considered lotic aquatic macroinvertebrate ecology. During 2007 and 2008 we examined spatial and temporal variability in the western Great Basin riverine macroinvertebrate communities, and how they differ with in context of water chemistry and temperature, discharge, and characteristics of the physical habitat (e.g., substrate composition, water depth, current velocity, etc.).

The Walker Basin encompasses approximately 1,075847 hec (2,658,420 ac) of the eastern Sierra Nevada Mountains and western Great Basin (Figure A.8.1). Headwaters originate higher than 3,500 m (11,000 ft) elevation, cascade through canyons, and meander through valleys before terminating in Walker Lake at approximately 1,188 m (3,900 ft) elevation. The basin's climate varies along a gradient from cold winters with heavy winter precipitation at higher elevations to arid, hot summers below 1,800 m (6,000 ft) elevation. The basin lies in the Sierra Nevada rain shadow where precipitation decreases as storms move eastward across the mountain range. Most flooding in the basin is associated with rain on snow during occasional warm storms in December and January and historic low flow periods are during late summer. Average annual precipitation exceeds 75 cm (30 in) at high elevations and is less than 7 cm (3 in) at Walker Lake (Western Regional Climate Center 2006). Air temperature at Walker Lake ranges from an average maximum temperature of 21.7 ˚C (71˚ F) to an average minimum of 5˚C (41˚ F) and at 1,950 m (6,400 ft) elevation the average maximum and minimum temperatures are 16.7˚C (62˚ F) and -4˚C (24˚ F), respectively.

Similar to other Great Basin waters, Walker River basin lotic systems have been altered from historic conditions by a number of factors (e.g., Sada and Vinyard 2002, Chambers *et al*. 2008). Hydrology and water quality have been affected by diversion for agriculture since the mid-1880s (Horton 1996) and approximately 44,859 hec (110,850 ac) are currently irrigated in the basin (Pahl 1999). Diversions have decreased annual inflow into Walker Lake from approximately 370,046,556 m^3 (300,000 ac-ft) in the mid-1800s to 145,551,645 m^3 (118,000 ac-ft) currently (Sharpe *et al*. 2007). This has lowered lake levels by more than 43 m (150 ft), increased concentrations of total dissolved solids from 2,500 to almost 16,000 (Horton 1996, Sharpe *et al*. 2008), and caused lower reaches of the river to erode downward to meet the lowering lake level. The historic native fish community in the basin consisted of eight species, and now includes five additional species introduced for sport (Sada 2000, Moyle 2002).

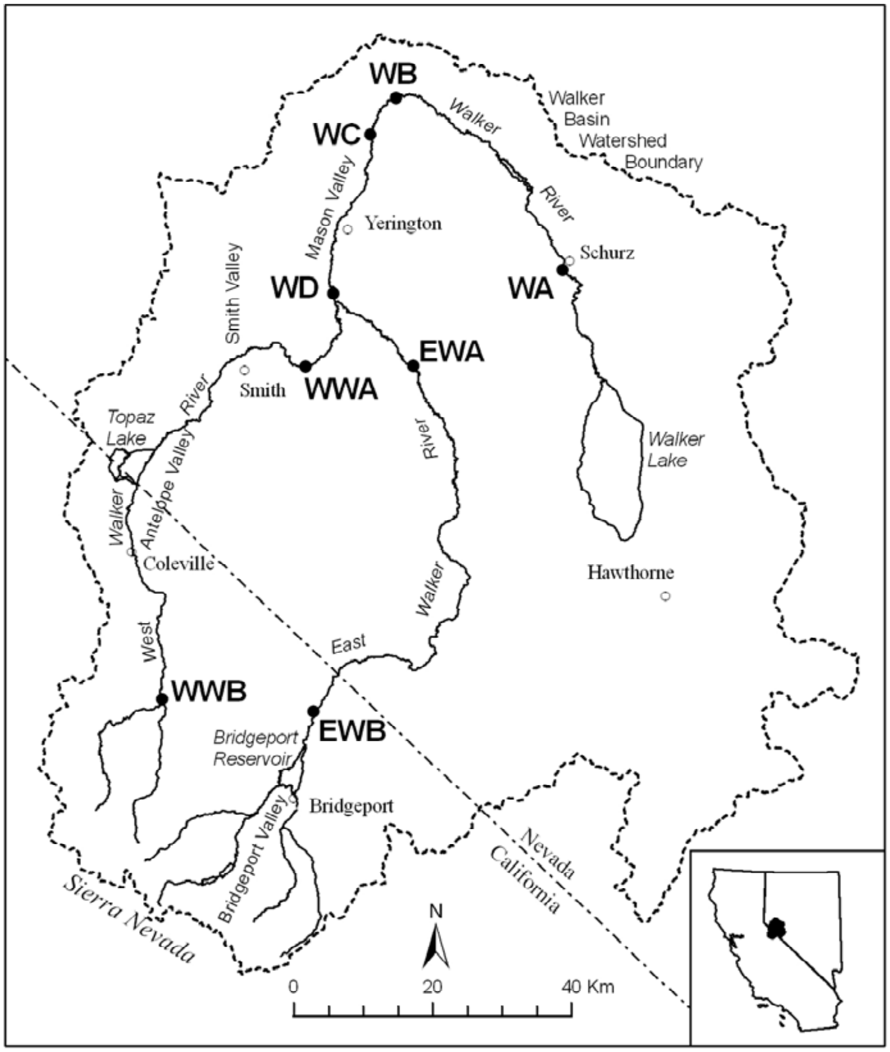

Figure A.8.1. Walker River Basin and the location of 2007 and 2008 BMI, water chemistry, and physical habitat sampling sites. WA, WB, WC and WD = Walker River sites, EFA and EFB = East Walker sites, and WFA and WFB = West Walker sites.

A number of studies have examined Walker Lake fishes, and its ancient, historic and current limnology (e.g., La Rivers 1962, Cooper and Koch 1984, Benson *et al*. 1991, Dickerson and Vinyard 1999, Buetel 2001). In contrast, few biological studies have considered the river and there is little information available to assess how its aquatic life differs from headwaters to its terminous in Walker Lake. Lotic studies in the Walker Basin have been limited to work fish population estimates by California Department of Fish and Game (CDFG) personnel in the East Walker River from 1985 to 2007 summarized by Mehalick and Weaver (2007). Benthic macroinvertebrate (BMI) communities in East Walker River have been sampled by CDFG for several years following a spill of toxic chemicals in 2001, but a report has not been prepared (A. Montalvo, CDFG, pers. comm., August 27, 2008). The Nevada Department of Environmental Protection as periodically sampled benthic macroinvertebrates at several sites, but little information exists to examine river communities and assess the response of these communities to changing environmental conditions.

Physico-chemical characteristics of the Walker River and its tributaries are affected by natural and human factors. Many of its natural features have been altered by human activity such that characteristics of the hydrograph, water chemistry, fish communities, and channel morphology often bear little resemblance to historical condition. The hydrograph is altered by impoundment which alters the timing and magnitude of runoff and base flow, and its water chemistry is affected by agricultural return and the influences of the altered hydrograph on water temperature and other factors. Its fish community has been affected by introduction of a variety of non-native competing and predatory species (Sada 2000), and channel morphology has been affected by diversion, livestock practices, and the altered hydrograph. Information collected by this study provides insight into the response of benthic communities to different natural and human-influenced environmental conditions in the Walker River from the Sierra Nevada base to Walker Lake.

Site Description

Walker basin headwater streams flow off the Sierra Nevada and form the East and West Walker rivers that combine to the Walker River near Yerington, Nevada (Figure A.8.1). The length of river from its headwaters to its terminus at Walker Lake is approximately 250 km (160 mi). With exception of several small headwater reservoirs, both forks of the river are free-flowing before entering Antelope (West Walker) and Bridgeport valleys (East Walker) where they are diverted into low-gradient irrigation ditches. Only sites WWB is unaffected by diversion or upstream influences of agriculture. The river hydrograph is also altered by Bridgeport Reservoir (East Walker) and Topaz Lake (West Walker) that impound water for agriculture in Mason Valley. Low gradients, slow water, and small substrates characterize valley reaches of both forks, and both forks cascade off of the Sierra Nevada and through steep, narrow canyons where they transition between valleys. River volume increases from melting snow in the spring time and usually peaks in May or June. Flows are typically the lowest from November through February. The magnitude of flows during peak and minima periods is influenced by water management practices. Average inflow to Walker Lake was estimated to be 76,000 acre-feet by Thomas (1995). Sample sites were located to represent the variety of river environments in higher order Walker Basin streams. All sites were located close to and downstream of USGS stream gauges (except sites WC and WD that were located in ungaged reaches in the center of Mason Valley; discharge at these sites was calculated from depth and velocity measurements during sampling or interpolation from nearby gauges).

METHODS

Physical Habitat Characteristics and BMIs

Characteristics of the physical habitat and BMIs were quantified during the spring, summer, and autumn of 2007 and 2008 in riffles and woody debris (the two most common habitat types at each site) at eight sites (Figure A.8.1) from approximately 30 km upstream of Walker Lake (approximately 1,250 m elevation) to the Sierra Nevada base (approximately 1,800 m elevation). Sites WA and WB were not sampled during spring 2007 because permission to sample had not granted by landowners. Map coordinates locating each site and USGS stream discharge gages closest to each site are shown in Table A.8.1. Riffle BMIs were collected at each site as composites of six, 0.11-m^2 (1-ft^2) quadrats where substrate was roiled and scrubbed by hand to dislodge organisms into a 250-micron, hand- held, 30 cm D-frame net. Quadrats were aligned parallel to a transect crossing the river and equally-spaced to span the riffle. Woody debris BMI samples were collected in the same manner. Woody debris samples were not collected at site WA during the spring and summer of 2008 due the absence of woody debris during these sample periods.

Physical and chemical characteristics of each reach were recorded by collecting water samples for water chemistry analysis (these analyses were conducted by the DRI Analytical Chemistry Laboratory) and measuring water depth, mean water column velocity, the depth of submerged vegetation and woody debris, and substrate size and embeddedness at 25 equally-spaced points at four transects spaced 1 m apart oriented perpendicular to the thalweg (Table A.8.2). Wetted width at each site was measured as the watered distance between banks across transects. Temperature for each reach was measured using Hobotemp™ thermographs recording data every 15 minutes. Temperature data were not continuously collected from sites WA and WC due to equipment malfunction and vandals. These temperatures were calculated from regression equations using other thermograph records for each site and nearby daily air temperature data compiled by the Western Regional Climate Center (*http://www.wrrc.dri.edu*). Discharge for most sites was recorded by nearby USGS gages. Since no gages are located near sites WC and WD, discharge at these sites was calculated by averaging the sum of discharge recorded for the east and west forks where they entered Mason Valley and records for the Wabuska gage (site WB). Although these estimates may weakly reflect discharge through these reaches results using these calculations closely approximated the discharge calculated at each reach using depth and velocity data collected during BMI surveys.

Physical habitat characteristics of each BMI riffle quadrat were quantified by measuring water depth, and mean water column velocity at the center of each quadrat. Depth of vegetation (categorized as emergent, macrophytes, periphyton) and debris, and substrate size and embededdness were measured at the corner of each quadrat. The depth and current velocity of each BMI woody debris habitat were also recorded.

Table A.8.1. U.S. Geological gage numbers associated with the location and elevation (meters) of reaches where BMIs were sampled in the Walker River during spring, summer, and autumn of 2007 and 2008. Reach names as shown in Figure A.8.1.

Reach Name	USGS Gage	Latitude	Longitude	Elevation
WA	10302002	38 56' 25"	118 48' 12"	1251
WB	10301500	39 09' 23"	119 05' 09"	1310
WC	No Gage	39,06' 30"	119, 07' 38"	1320
WD	No Gage	38, 54' 15"	119, 10' 59"	1335
EWA	10293500	38, 48' 50"	119, 02' 53"	1394
EWB	10293000	38, 22' 07"	119, 11' 59"	1935
WWA	10300000	38, 48', 35"	119, 13' 35"	1417
WWB	10296000	38, 22', 47"	119, 26' 57"	2008

Table A.8.2. Measured and categorical environmental variables used for CCA. Abbreviations shown only for statistically significant variables used for final CCA. Abbreviations as shown in CCA figures.

Variable	Abbrev.	Variable	Abbrev.
Sample Season1	SEASON	Vegetation Presence	VEG
Mean Water Column Velocity	MnWV	Woody Debris Presence	
Mean Water Depth	MnWD	Wetted Width at Transect	WW
Max. Temperature2	MT	Site Elevation	ELEV
Min. Temperature2	MIT	pH	
Max. Discharge2	MD	Nitrate	
Min. Discharge2	MID	Nitrite	NO2
Mean Embeddedness	MnEmb	Total Nitrogen	TN
Mean Substrate Size	MnSUB	Total Dissolved Solids	TDS
Proportion Fines	F	Total Phosphorus	
Proportion Sand	SA	Total Suspended Solids	TSS
Proportion Gravel	G		
Proportion Cobble	CO		
Proportion Boulder	BO		

[1] Season coded 1 = spring, 2 = summer, 3 = autumn; [2] maxima and minima recorded during the period 60 days before each sample

BMI samples were preserved in the field with 90 Percent ethyl alcohol and returned to the Desert Research Institute (DRI) Aquatic Ecology Laboratory for sorting, identification, enumeration, and archiving. Laboratory processing and quality assurance/quality control followed DRI's Standard Operating Procedures, which are on file in the DRI laboratory. All samples are archived in the DRI laboratory.

The BMI community for riffle and woody debris habitats was determined by identifying a minimum of 300 individuals from each sample taken using random methods. Additional taxa were identified using a rare-large search. Vinson and Hawkins (1996) reported that characteristics of the community composition are accurately represented using this sample method. Although samples of this size are inadequate to identify all rare taxa, these methods are adequate to assess differences in BMI community structure along the length of the Walker River. Macroinvertebrates were identified to the lowest possible taxonomic level for insects, and to lowest reasonable level for non-insect taxa. Insect taxa were generally keyed to genus and, when possible, to lower levels. Non-distinct taxa (e.g., organisms too damaged or small to determine with certainty) were not counted, and samples were normalized to 300 individuals for analysis.

ANALYTIC METHODS

Community Metrics

Taxonomic richness and the Hilsenhofff Biotic Index (HBI) (Hilsenhoff 1987) were calculated to assess BMI community health. These metrics are used during bioassessment analyses in freshwaters throughout North America to assess the pollution tolerance of BMI communities (e.g., Rosenberg and Resh, 1993, Barbour *et al*., 1999). Taxonomic richness, or the number of distinct taxa present in a sample, is an important metric because it is typically inversely correlated to the severity of human impacts, pollution, and harshness (Karr and Chu 1999). BMIs were identified to the lowest taxonomic resolution to minimize effects of sampling on richness calculations. Identification at higher resolution identifies fewer taxa and produces lower richness values than obtained with lower resolution. The HBI is the most commonly used sediment (Relyea *et al*. 2000) and pollution tolerance metric. It is used to calculate a community tolerance value using a scoring system that ranks BMI taxa and communities in context of their tolerance to organic pollutants. Calculations were standardized for the western U.S. using Ode *et al*. (2003), and organisms intolerant of pollutants are ranked 0 and highly tolerant organisms are ranked 10. Communities occupying harsh, polluted, or sediment-laden systems are characterized by community tolerance values greater than approximately 5.5.

Multivariate Analysis

Canonical correspondence analysis (CCA) and detrended correspondence analysis (DCA) were multivariate gradient analyses used to examine BMI communities. The CCA is a direct gradient analysis that identifies environmental variables that most influence biotic community structure and DCA is an indirect gradient analysis to examine similarities and differences in community structure (Jongman *et al*., 1987; ter Braak and Prentice, 1988; Palmer, 1993). Data were analyzed using CANOCO v. 4.55 (ter Braak and Šmilauer, 1998). To minimize effects of rare species on results, only taxa with more than 50 individuals or occurring in at least five samples were considered.

Prior to CCA, the proportion of each substrate type and substrate embeddedness were categorized into 12 classes to avoid violation of covariate assumptions (1 < 1%, 3 = 1 - 4.9%, 10 = 5 - 14.9%, 20 = 15 - 24.9%, 30 = 25 - 34.9%, 40 = 35 - 44.9%, 50 = 45 - 54.9%, 60 = 55 - 64.9%, 70 = 65 - 74.9%, 80 = 75 - 84.9%, 90 = 85 - 94.9%, 98 > 95%). All data were log transformed and rare species were down weighted. For CCA, inter-species distance was tested, and smoothing was by Hill's scaling through Monte Carlo simulation with 999 unrestricted permutations. Habitat variables analyzed for final consideration included only the statistically significant ($p < 0.05$) environmental variables as determined by forward selection (Table A.8.2). For DCA, data were detrended by segments, rare species down weighted, and species data were log (X+1) transformed.

RESULTS

Habitat Characteristics

There were spatial and temporal differences in physicochemical characteristics of each site (Appendix I). Spring was distinguished by cool temperatures, high discharge (and related factors such as deep water, high current velocities, and wider stream channels), low nutrients and TDS. Summer and autumn were characterized by high temperatures and TDS, and low discharge (and related factors such as shallow, slow moving water, narrow wetted width, high temperatures, and high nutrients in the East Fork Walker River).

Differences between sites were also notable, with site WA being the most distinct. This site is located below the historic level of Walker Lake, which is an eroding reach of river that frequently dries because of upstream diversions. Through Mason Valley, the river was relatively narrow, substrates small, and summer and autumn water temperatures were relatively high. Mean substrate size increased, and temperatures decreased, along an elevation gradient toward the Sierra Nevada (Appendix I).

<u>Benthic Macroinvertebrates</u>

A total of 308 benthic taxa were identified from 28,206 individuals sampled from 46 riffle and 44 woody debris samples. Approximately 34 and 30 percent of riffle and woody debris communities, respectively, were midges (Family Chironomidae), respectively. The most abundant taxa are shown in Table A.8.3.

Table A.8.3. Walker River Benthic macroinvertebrates occurring in more than five samples or more 50 individuals in benthic and woody debris samples during 2007 and 2008.

Taxon	Abbreviation	No.	Habitat	TV
	AME	34	R	0
Apobaetis sp.	APO	48	R	4
Acentrella sp.	ACE	126	R	4
Baetis bicaudatus	BBI	504	R,W	5
Baetis tricaudatus	BTR	1238	R,W	5
Callibaetis sp.	CAL	135	R,W	9
Camelobaetidius sp.	CAM	68	R	4
Centroptilum/Procloeon sp.	CP	28	R	3
Fallceon quilleri	FCQ	1829	R,W	4
Labiobaetis sp.	LAB	268	R,W	6
Paracloeodes sp.	PRC	871	R,W	4
Caenis sp.	CAE	26	R	7
Ephemerella sp.	EPH	496	R,W	1
Heptageniidae sp.	HP	31	R	4
Cinygmula sp.	CI	117	R,W	4
Herptagenia sp.	HEP	71	R,W	4
Tricorythodes sp.	TRI	1202	R,W	4
Paraleptophlebia sp.	PLP	7	R	4
Isoperla sp.	ISO	580	R,W	2
Brachycentrus sp.	BRC	180	R,W	1
Hydropshche sp.	HYD	643	R,W	4
Hydroptila sp.	HYT	509	R,W	6
Nectopsyche sp.	NEC	187	R,W	3
Oecetis sp.	OEC	39	R	8
Optiservis sp.	OPT	402	R	4
Ochthebius sp.	OCH	30	R	5
Bezzia/Palpomyia sp.	BEZA	143	R,W	6
Culicicoides sp.	CUL	121	R	6
Polypedium cf. *fallax*	PPFL	45	R	6
Polypedium cf. *flavum*	PPF	921	R,W	6
Robackia claviger	ROB	121	R	6
Cladotanytarsus (type A)	CLA	57	R	7
Cladotanytarsus (Vanderwulpi gr.)	CLV	590	R	7
Paratanytarsus sp.	PAT	128	R,W	6
Tanytarsus sp.	TAN	347	R,W	6
Rheotanytarsus sp.	RHT	172	R,W	6

BMI = genus or species, Abbreviation = acronym used for DCA and CCA, No. = number of individuals tallied, Habitat = R for riffle and W for woody debris, and TV = tolerance value.

Table A.8.3. Walker River Benthic macroinvertebrates occurring in more than five samples or more 50 individuals in benthic and woody debris samples during 2007 and 2008 (continued).

Taxon	Abbreviation	No.	Occurrence	TV
Stempelinella sp.	STE	200	R,W	2
Corynoneura sp.	COR	489	R,W	7
Cricotopus(cf. *Bicinctus*)	CRB	486	R,W	8
Cricotopus/Orthocladius distinct A	CROA	287	R	7
Cricotopus/Orthocladius Type V	CROB	63	R	7
Cricotopus cf. *triannulatus* sp.	CRT	87	R	7
Cricotopus trifascia	CRTR	112	R	7
Eukiefferiella (Brehmi gr)	EUKB	16	R	8
Eukieferiella (Gracei gr)	EUKG	186	R,W	8
Lopescladius sp.	LO	84	R	6
Parametriocnemus sp.	PRT	20	R	5
Rheocricotopus sp.	RHE	336	R,W	6
Rheosmittia sp.	RHEC	154	R	5
Thienemaniella sp.	THI	492	R,W	6
Ablaesmyia sp.	AB	33	R	8
Pentanura sp.	PET	113	R,W	6
Thienemannimyia gr	THIE	197	R,W	7
Hemerodromia sp.	HE	27	R	6
Simulium sp.	SIM	1096	R,W	6
Hygrobaytes sp.	HY	19	R	8
Oribatei sp.	OR	35	R	5
Sperchon sp.	SP	169	R	8
Candonidae	CAN	445	R,W	8
Cyprididae	CYP	654	R,W	8
Illocyprididae	IL	73	R	8
Corbicula sp. (invasive)	COB	76	R	10
Pisidium sp.	PIS	125	R	8
Planariidae	PLN	371	R,W	4
Phylum Nematoda	NEM	80	R	5
Lumbriculidae	LUM	68	R	5
Enchytraediae	EN	29	R	10
Pristina sp.	PRS	275	R,W	8
Pristinella sp.	PRT	1763	R,W	8
Nais sp.	NAI	1273	R,W	8
Tubificidae	TUB	751	R,W	10

BMI = genus or species, Abbreviation = acronym used for DCA and CCA, No. = number of individuals tallied, Habitat = R for riffle and W for woody debris, and TV = tolerance value.

Community Metrics

Taxonomic richness and the community tolerance values in riffles and woody debris exhibited spatial and temporal trends. Trends were most evident in riffle communities, which suggest that these communities may be more responsive to changing environments. Figures A.8.2 through A.8.5 show riffle results for each season and year, and Figures A.8.6 and A.8.7 show means (N = 2) calculated for each season (except for WA where N = 1 because it was not sampled during the spring of 2007). Figures A.8.8 through A.8.11 show seasonal and annual results for woody debris, and Figures A.8.12 and A.8.13 show mean values for this habitat calculated for each season. Lowest taxonomic diversity typically occurred during spring and at site WA (Figures A.8.2, A.8.3, A.8.8, and A.8.9). Riffle taxonomic richness was generally highest during summer at all sites in both years (Figures A.8.2 and A.8.4) but highest woody debris richness was less consistent and occurred during all seasons (Figures A.8.8 and A.8.9). Riffle diversity was highest at WWB during all seasons, which is the only site retaining a natural hydrograph and that is unaffected by upstream agriculture. Diversity in woody debris communities was also lowest at site WA but similar at all other sites (Figures A.8.8, A.8.9, and A.8.12).

Community tolerance values were highest downstream and they generally decreased along the elevational gradient (Figures A.8.4, A.8.5, A.8.7, A.8.10, A.8.11, and A.8.13). Consistent with richness, the pattern was more evident in riffles than in woody debris where was little pattern. In riffles, values were highest in the river (sites WA, WB, WC, and WD) (indicating a tolerant BMI community) and decreased slightly upstream through Mason Valley. Seasonal values were generally lower in both forks than in Walker River and lowest values were associated with upstream sample sites (Sites EWB, WWA, and WWB). Lowest values occurred at WWB, which is the only reach of river with a natural hydrograph. This site was also distinguished by higher seasonal variability in tolerance values than at all other sites, which may be more indicative of a naturally fluctuating system that is unaffected by flow regulation. These results indicate that environmental harshness is lowest upstream and increases along the gradient to the harshest conditions that occur in the eroding channel below Schurz.

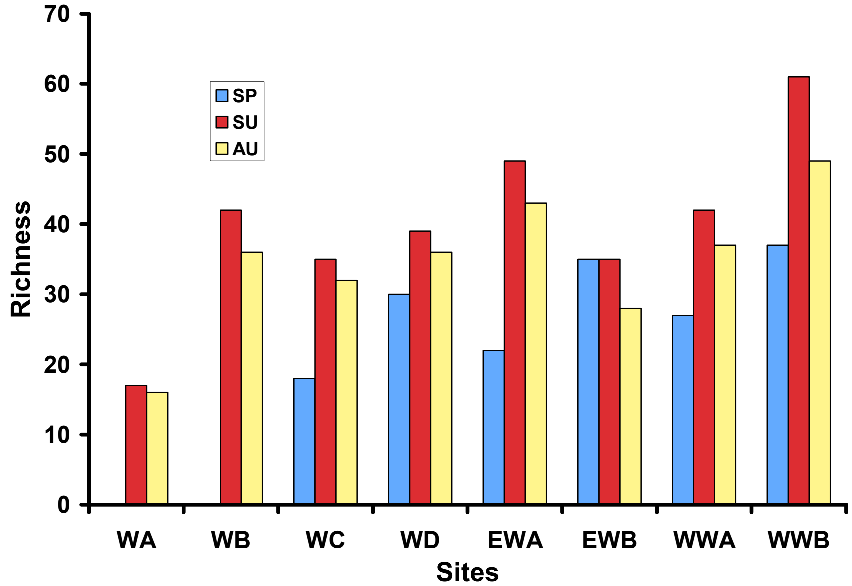

Figure A.8.2. Taxonomic richness of riffle BMI communities at Walker River samples sited during the spring, summer and autumn of 2007 (spring samples at WA and WB not collected). Sample site abbreviations as shown in Figure A.8.1.

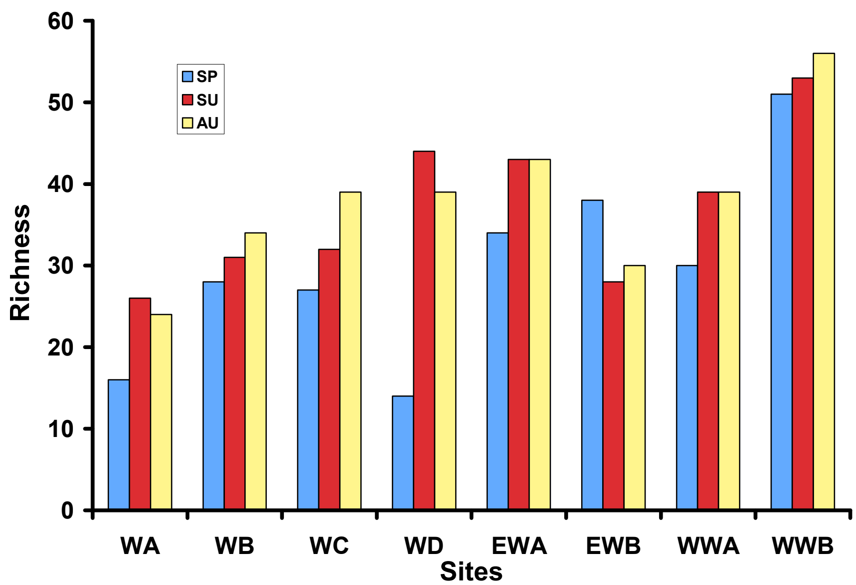

Figure A.8.3. Taxonomic richness of riffle BMI riffle communities at Walker River samples sited during the spring, summer and autumn of 2008. Sample site abbreviations as shown in Figure A.8.1.

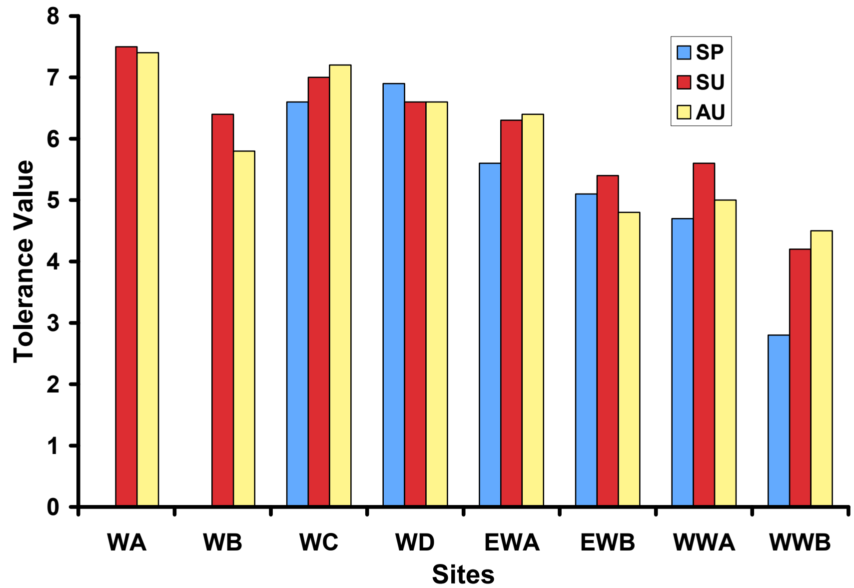

Figure A.8.4. Community tolerance values for Walker River riffle BMI communities sampled during the spring, summer and autumn of 2007 (spring samples at WA and WB not collected). Values calculated using methods of Hilsenhoff (1987). Sample site abbreviations as shown in Figure A.8.1.

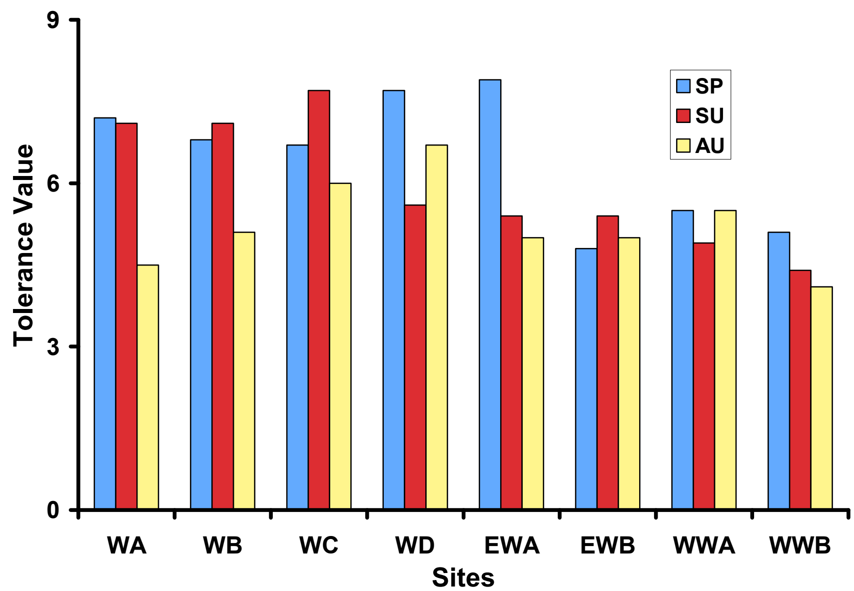

Figure A.8.5. Community tolerance values for Walker River riffle BMI communities sampled during the spring, summer and autumn of 2008. Values calculated using methods of Hilsenhoff (1987). Sample site abbreviations as shown in Figure A.8.1.

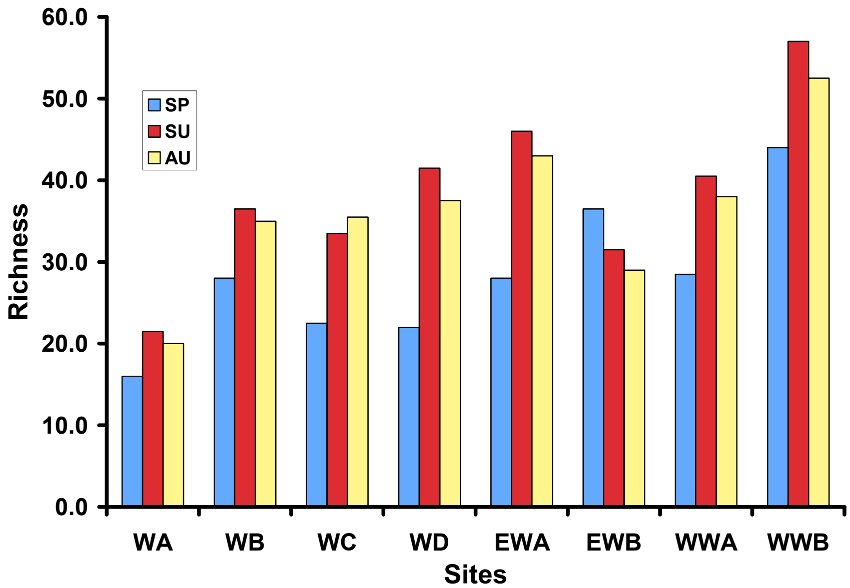

Figure A.8.6. Mean taxonomic richness of Walker River riffle BMI communities sampled during the spring, summer and autumn of 2007 and 2008. Values calculated using methods of Hilsenhoff (1987). Sample site abbreviations as shown in Figure A.8.1.

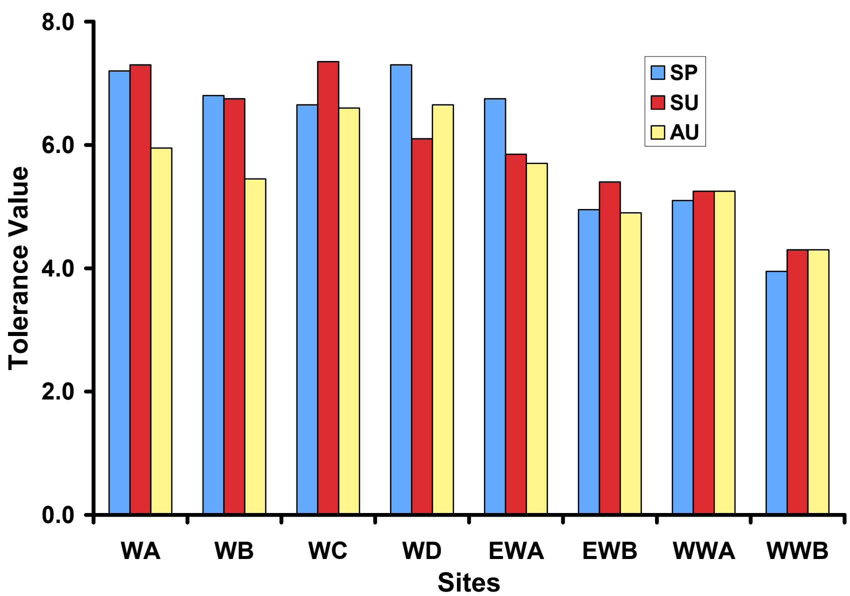

Figure A.8.7. Mean community tolerance values for Walker River riffle BMI communities sampled during the spring, summer and autumn of 2007 and 2008. Values calculated using methods of Hilsenhoff (1987). Sample site abbreviations as shown in Figure A.8.1.

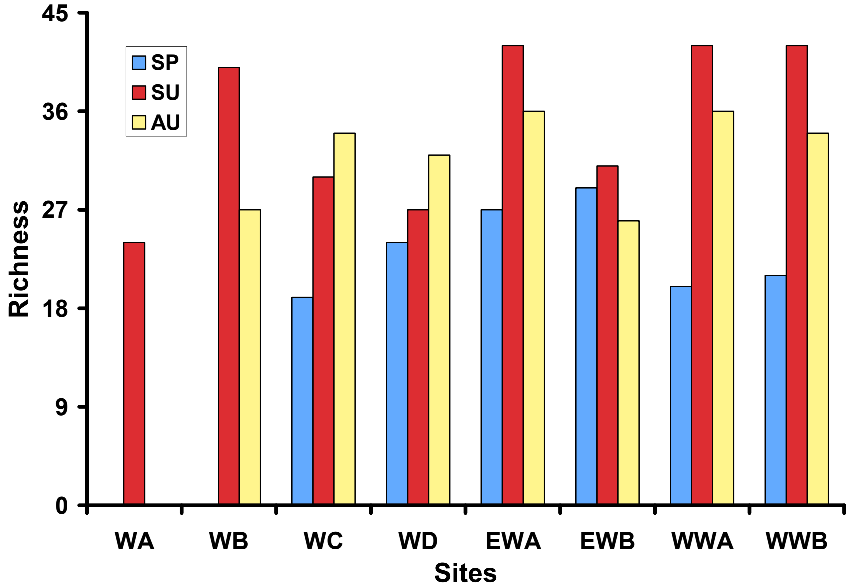

Figure A.8.8. Taxonomic richness of Walker River woody debris BMI communities during the spring, summer and autumn of 2007 (spring samples at WA and WB not collected; woody debris not present at WA during autumn). Sample site abbreviations as shown in Figure A.8.1.

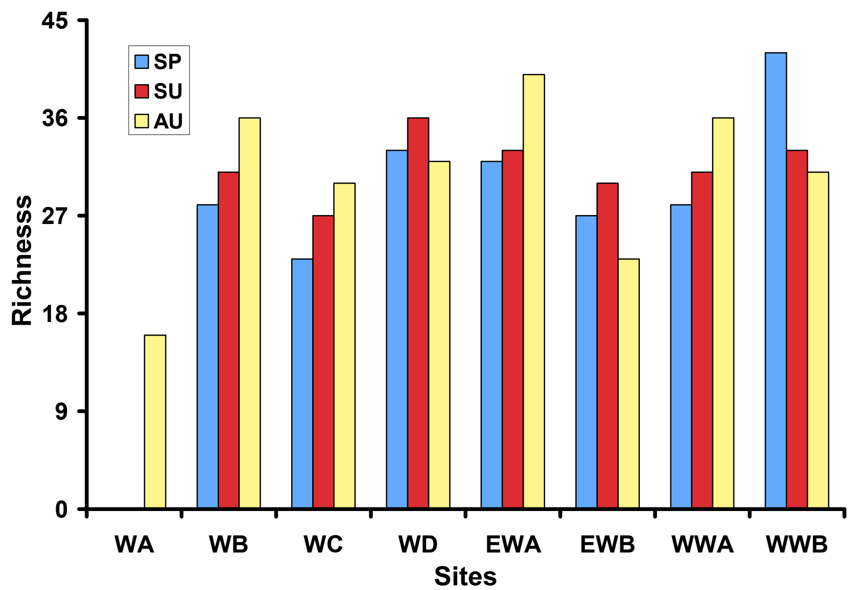

Figure A.8.9. Taxonomic richness of Walker River woody debris BMI communities during the spring, summer and autumn of 2008 (woody debris was absent from WA during spring and summer). Sample site abbreviations as shown in Figure A.8.1.

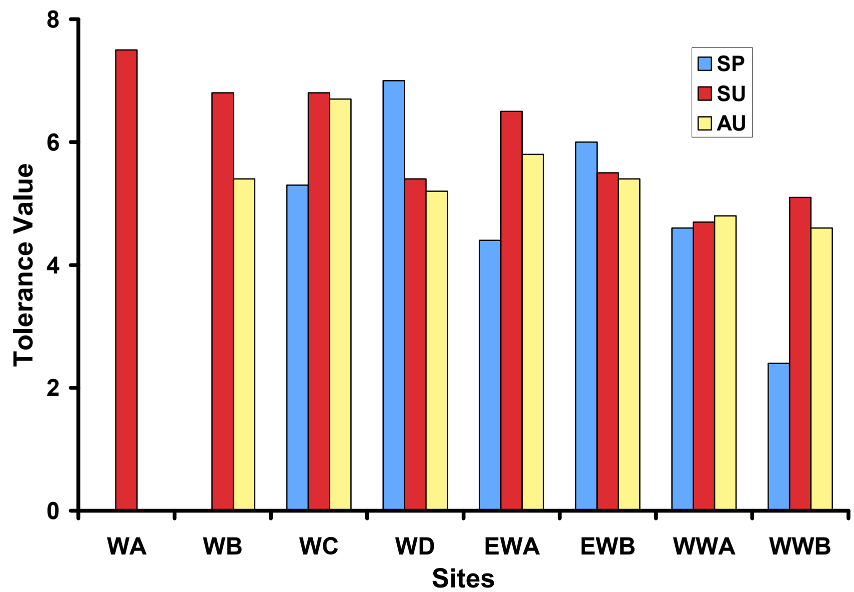

Figure A.8.10. Community tolerance values for woody debris BMI communities sampled during the spring, summer and autumn of 2007. Values calculated using methods of Hilsenhoff (1987). Sample site abbreviations as shown in Figure A.8.1.

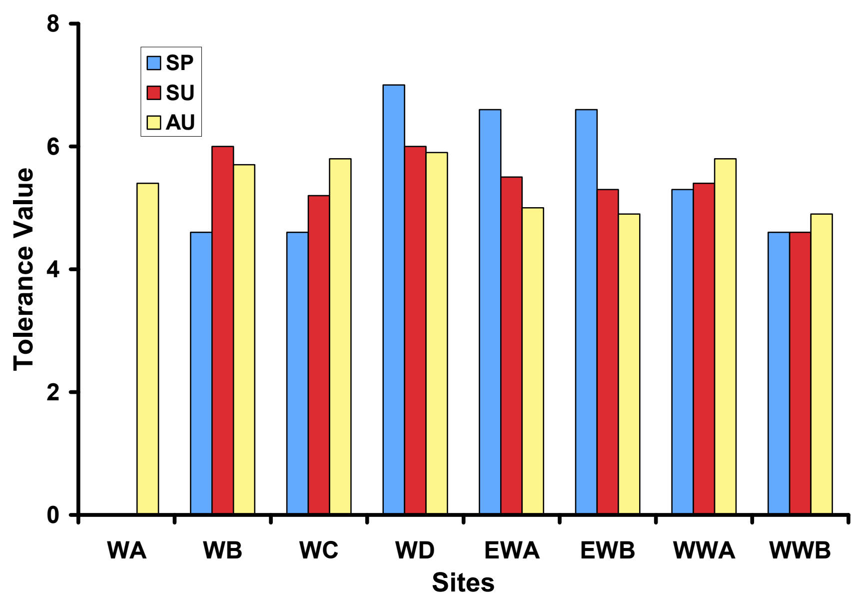

Figure A.8.11. Community tolerance values for woody debris BMI communities sampled during the spring, summer and autumn of 2008. Values calculated using methods of Hilsenhoff (1987). Sample site abbreviations as shown in Figure A.8.1.

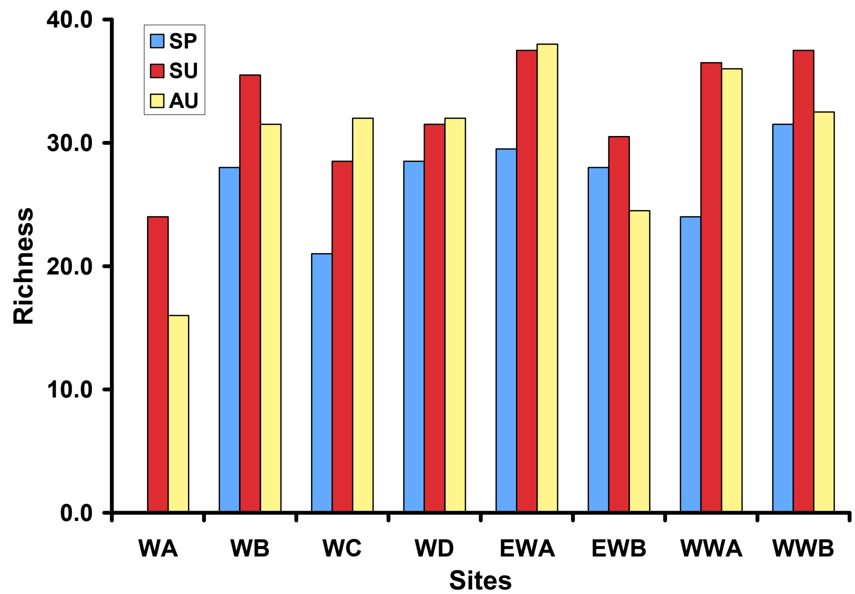

Figure A.8.12. Mean taxonomic richness of Walker River woody debris BMI communities during the spring, summer and autumn of 2007 and 2008. Sample site abbreviations as shown in Figure A.8.1.

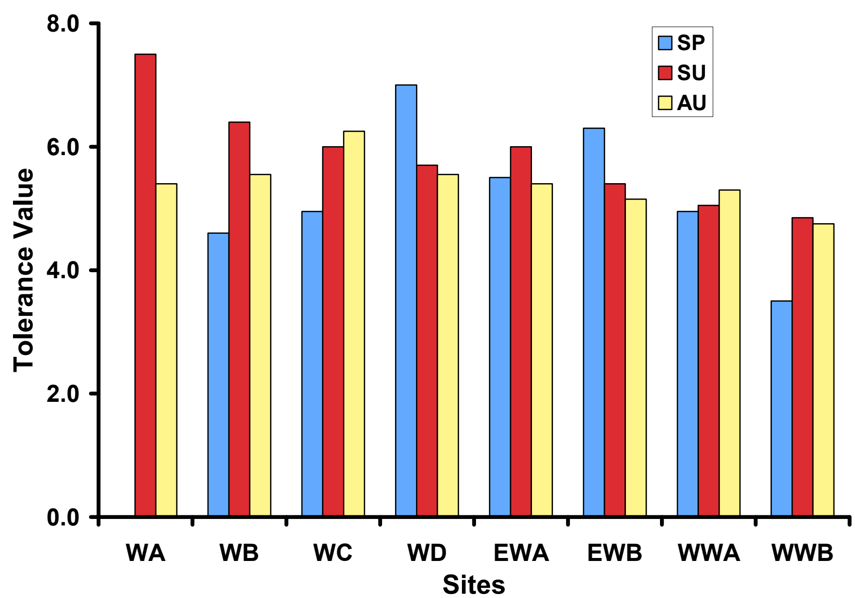

Figure A.8.13. Mean community tolerance values for woody debris BMI communities sampled during the spring, summer and autumn of 2007 and 2008. Values calculated using methods of Hilsenhoff (1987). Sample site abbreviations as shown in Figure A.8.1.

Multivariate Analysis—Detrended Correspondence Analysis

Rare species were not included in multivariate analyses and were categorized as species occurring in fewer than five samples or whose abundance was less than 50 individuals. Excluding these, multivariate analyses included 12,253 riffle BMIs in 71 taxa (for DCA and CCA) and 11,271 woody debris BMIs in 36 taxa (for DCA) (Table A.8.3).

Detrended correspondence analysis of riffle and woody debris communities showed similar results (Figures A.8.14 through A.8.17) and largely confirmed indications suggested by community tolerance values. For riffle communities, the first three axes explained 33.1 of the variance (Table A.8.4) and 38.5 percent for woody debris (Table A.8.5). Site WA was separated from other sites in both analyses and was placed in the upper center portion of the plots (Figures A.8.14 and A.8.16). For riffles, the site was mostly characterized by communities that were dominated by *Paratanytarsus* sp. (PAT, a midge, TV =6), Cyprididae (CYP, an ostracode, TV =8), worms (LUM, TV = 8), flatworms (PLN, TV =4), mites (OR, TV = 5), and nematodes (NEM, a worm, TV =5), which are all tolerant species (Table A.8.3). The woody debris community at WA was also dominated by most of these organisms, with exception of worms and mites (OR) that occupied only riffles (Figures A.8.16 and A.8.17, and Table A.8.3). Most summer and autumn samples in Mason Valley (and some from EWA) were clustered along the left side, center portion of riffle and woody debris plots (Figures A.8.14 and A.8.16). These riffle communities were dominated by *Caenis* sp. (CAE, a mayfly, tolerance value [TV] = 7), *Apobaetis* sp. (APO, a mayfly, TV = 4), *Labiobaetis* sp. (LAB, a mayfly, TV = 6), *Ablabesmyia* sp. (AB, a midge, TV = 8), *Cricotopus* (cf. *Bicinctus*) sp. (CRB, a midge, TV = 7), and *Pristina* sp. (PRS, a worm, TV = 8) among other species (Figure A.8.15). These woody debris communities included CRB, LAB, PRC, and PRS, in addition to *Callibaetis* sp. (CAL, a mayfly, TV = 9) and *Bezzia/Palpoymia* sp. (BEZA, a midge, TV = 6) (Figure A.8.17). All of these species are tolerant of harsh environments.

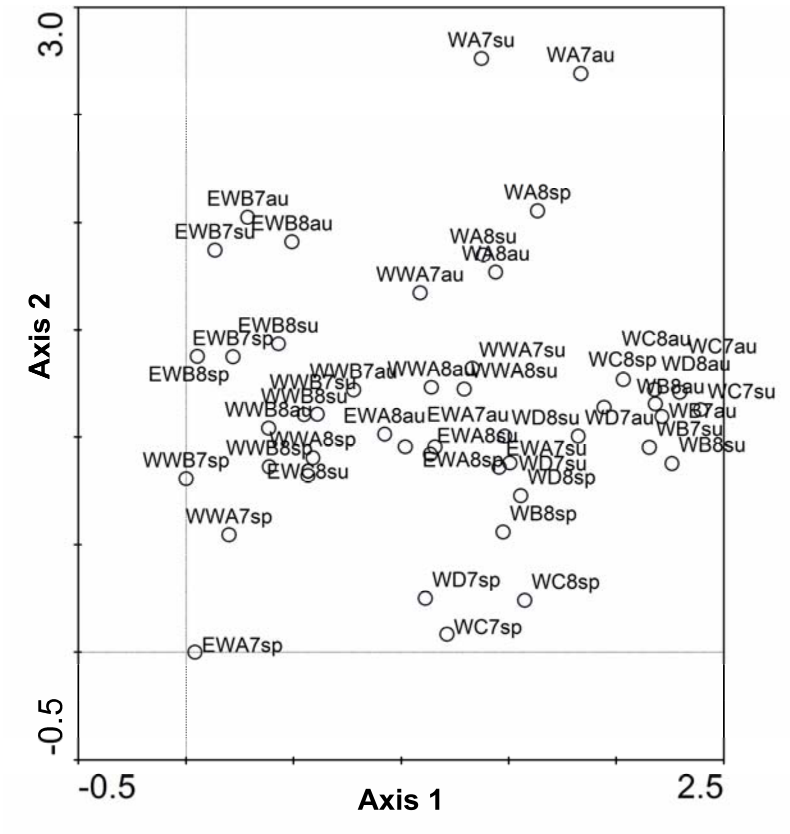

Figure A.8.14. DCA scatter plot illustrating the relationship among 2007 and 2008 Walker River riffle samples and sites as indicated by BMI community structure. Sample sites as shown in Figure A.8.1, and sp = spring samples, su = summer samples, au = autumn samples.

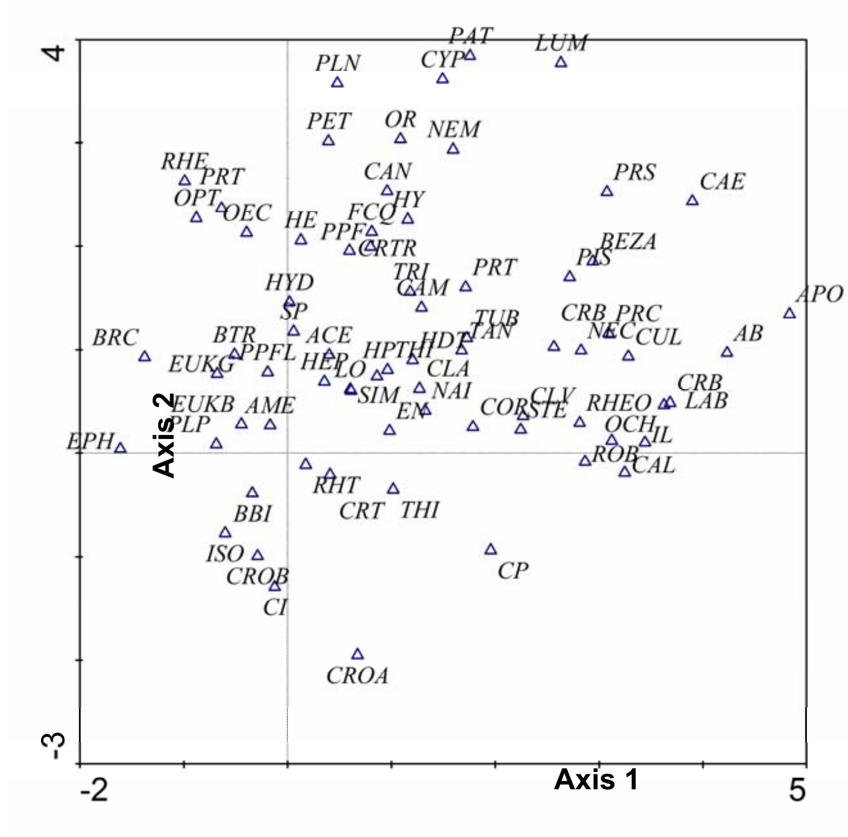

Figure A.8.15. DCA scatterplot illustrating the relationships among species in Walker River riffle BMI communities during 2007 and 2008. Species abbreviated as shown in Table A.8.3.

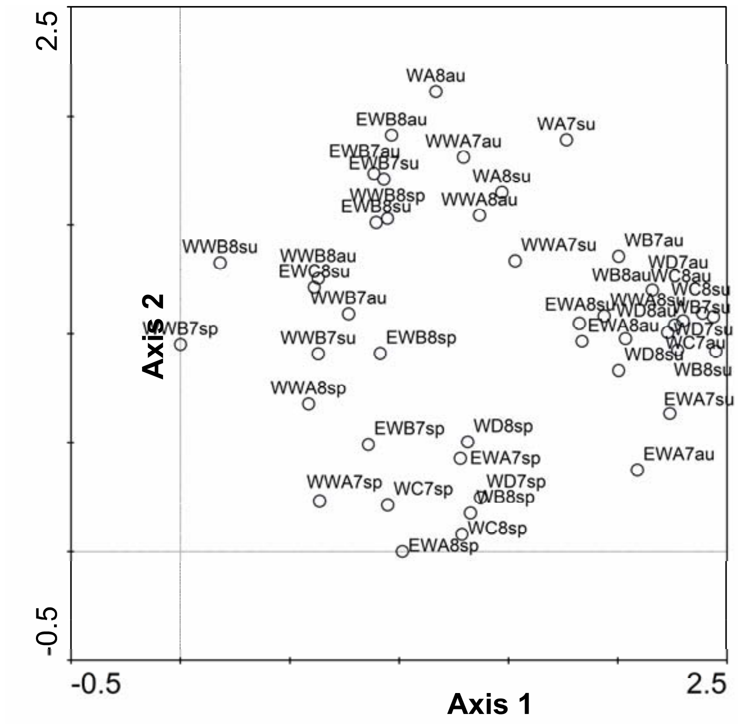

Figure A.8.16. DCA scatter plot illustrating the relationship among 2007 and 2008 Walker River riffle samples and sites as indicated by BMI community structure. Sample sites as shown in Figure A.8.1, and sp = spring samples, su = summer samples, au = autumn samples.

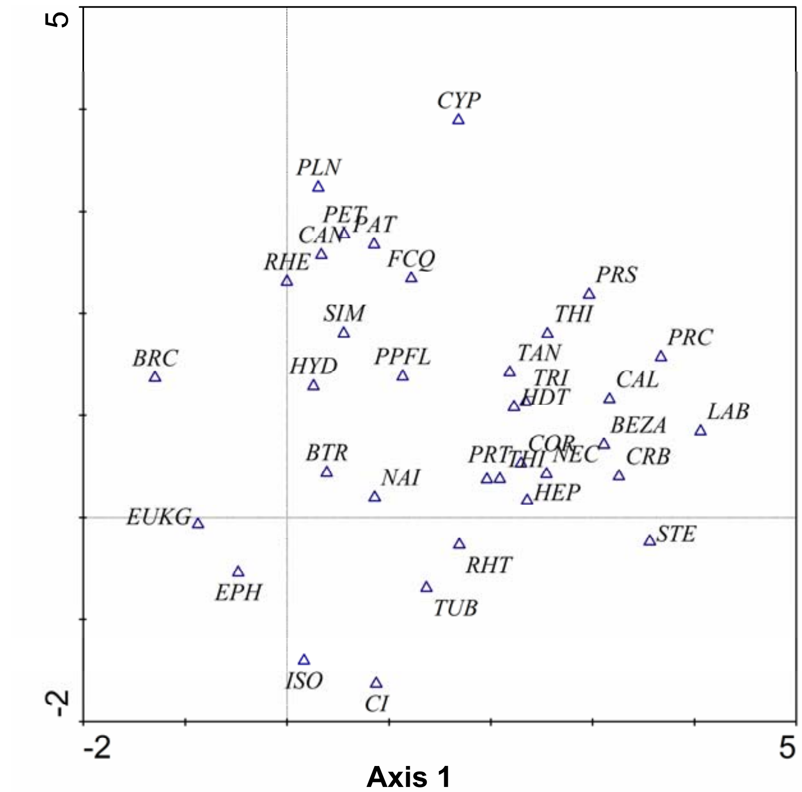

Figure A.8.17. DCA scatter plot illustrating the relationships among species in Walker River woody debris BMI communities during 2007 and 2008. Species abbreviated as shown in Table A.8.3.

Table A.8.4. Eigenvalues and percentage variance explained by the first three axes from DCA assessing similarities among 47 samples (including 71 species; Table A.8.3) of riffle BMI communities at eight Walker River sites during 2007 and 2008. Sum of all eigenvalues = 2.250. Figures A.8.14 and A.8.15 show scatter plots illustrating results.

	AXES		
	1	2	3
Eigenvalues	0.335	0.212	0.082
Length of Gradient	2.393	2.762	1.599
Cumulative Percentage of Variance of Species Data	14.9	24.3	33.1

Table A.8.5. Eigenvalues and percentage variance explained by the first three axes from DCA assessing similarities among 46 samples (including 36 species; Table A.8.3) of woody debris BMI communities at eight Walker River sites during 2007 and 2008. Sum of all eigenvalues = 1.607. Figures A.8.16 and A.8.17 show scatter plots illustrating results.

	AXES		
	1	2	3
Eigenvalues	0.313	0.212	0.095
Length of Gradient	2.448	2.113	1.572
Cumulative Percentage of Variance of Species Data	19.5	32.6	38.5

Most springtime riffle and woody debris communities are associated with lower portions of scatter plots (Figures A.8.14 and A.8.16). For riffles, they are characterized by *Criotopus/Orthocladius* Type A (CROA, a midge, TV = 7), *Criotopus/Orthocladius* Type V (CROB, a midge, TV = 7), *Centroptilium/Procloeon* sp. (CP, a mayfly, TV = 3), *Thienemaniella* sp. (THI, a midge, TV = 6), *Cinygmula* sp. (CI, a mayfly, TV = 4), *Isoperla* sp. (ISO, a mayfly), and others that are less tolerant of harsh conditions that characterize species in the upper center and left side of the scatter plot (Figure A.8.15). Woody debris communities in this portion of the scatter plot include ISO, CI, in addition to Tubificidae (TUB, a worm, TV = 10), *Rheotanytarsus* sp. (RHT, a midge, TV = 6), *Ephemerella* sp. (EPH, a midge, TV = 1), *Eukieferiella* (Gracei gr) (EUKG, a midge, TV = 8), and *Nais* sp. (NAI, an oligocheate worm TV = 8), *Baetis tricaudatus* (BTR, a mayfly, TV = 5).

Most higher elevation riffle and woody debris communities during summer and autumn are clustered near the center/left portion of scatter plots. As with trends indicated by community tolerance values, these communities included several intolerant species, including *Brachycentrus* sp. (BRC, a mayfly, TV = 1), *Ephemerella* sp. (EPH, a mayfly, TV = 1), and Isoperla sp. (ISO, a mayfly, TV = 2). Riffle communities also included *Baetis tricaudatus* (BTR, a mayfly, TV = 5), *Optiservis* sp. (OPT, a beetle, TV = 4), *Oecetis* sp. (OEC, a caddisfly, TV = 8), *Parametriocnemus* sp. (PRT, a midge, TV = 5), and *Hemerodromia* sp. (HE, TV = 6), among other species. Woody debris communities in this portion of the scatter plot also included OPT, RHE OEC, BRC, EPH, and BTR, but not ISO.

Multivariate Analysis—Canonical Correspondence Analysis

Canonical correspondence analysis (CCA) was performed on riffle communities (46 samples of 71 species, Table A.8.3) and environments. Twenty-six measured and categorical environmental variables were initially tested and final analysis included only the 21 statistically significant ($p < 0.05$) variables as determined by forward selection (Table A.8.2).

Only the presence of woody debris, pH, dissolved organic carbon, nitrate, and total phosphorus were non-significant. The first three canonical axes were highly significant ($P = 0.001$), explained 46.6 percent of the species-environment relation, and total inertia of species data was 2.231 (Table A.8.6). The CCA biplot (Figure A.8.18) and the species scatter plot (Figure A.8.19) provide insight into environmental variables that are important to structuring riffle communities defined by DCA (Figures A.8.14 and A.8.15).

Table A.8.6. Eigenvalues and percentage variance explained by the first three axes from CCA assessing BMI-habitat relationships from 46 samples at eight Walker River sample sites during 2007 and 2008. Sum of all eigenvalues = 2.231.

	AXES		
	1	2	3
Eigenvalues	0.314	0.193	0.156
Species-Environment Correlations	0.970	.916	0.922
Cumulative Percentage of Variance of:			
Species Data	14.1	22.8	29.8
Species-Environment Relations	22.1	35.7	46.6

Significant environmental variables ($p < 0.05$) that structured these communities are shown graphically in the CCA biplot (Figure A.8.18). The relative importance of each factor is indicated by vector length. Vectors are longest for the most significant variables, and direction is indicative of increasing magnitude of the parameter (i.e., temperature increases along a plane that is indicated by an arrow). In Figure A.8.18, vector length of elevation, water temperature, total dissolved solids, substrate size, and factors related to discharge (ergo wetted width, minimum discharge and maximum temperature) and their horizontal orientation indicates that variability in these factors are most fully explained along Axis 1. In a similar manner, variability along Axis 2 can be attributed to season, total suspended solids, water depth, and the presence of vegetation.

Results of the CCA show that riffle BMI communities were associated with sites and seasons, as indicated by DCA. The CCA also shows that differences were attributed to environmental conditions that varied spatially and temporally. When the biplot (Figure A.8.18), the scatter plot of species calculated by CCA (Figure A.8.19), and DCA results are considered together, BMIs and communities that are associated with different sites, samples, and environmental conditions can be determined. In most instances, seasonal differences in communities and environments at each site exceeded those observed between years. Spatial and temporal differences in environments and communities calculated by CCA can be broadly categorized into five groups that are associated with distinct portions of the biplot (Table A.8.7). The first group consists of springtime communities located in the lower right and center portion of Figure A.8.18, that were most associated with low temperature and total suspended solids, deeper water, wide wetted width, and high current velocities (most of these factors may be attributed to high springtime discharge). Figure A.8.19 shows that most of these communities are characterized by BMIs with relatively high tolerance values, which is consistent with community tolerance values for these samples (Figure A.8.7). It is notable that springtime WA communities are not associated with other springtime communities due to low flows. Site WWB is also somewhat distinct among springtime samples because it included relatively large proportions of two intolerant species, Brachycentrus sp. (BRC, a mayfly, TV = 1) and Ephemerella sp. (EPH, a mayfly, TV = 1), which may reflect the absence of upstream diversions and other uses of water. The presence of these species is also consistent with low community tolerance values for this site (see Figure7). Similarity among most springtime communities (occurring during both 2007 and 2008) is somewhat surprising because differences in environments that typically influence BMI community structure (such as substrate size, embeddedness, and elevation) were weakly influential during this season. Their similarity may be attributed to early springtime hatching the BMIs characterizing these communities and their relatively rapid colonization of the river following high spring flows. It is also possible that environmental differences between sites may be minor during springtime and that structure of these communities may be influenced more by cool water and high discharge (and related factors such as water depth, current velocity, and wetted width) than by factors structuring communities in summer an autumn.

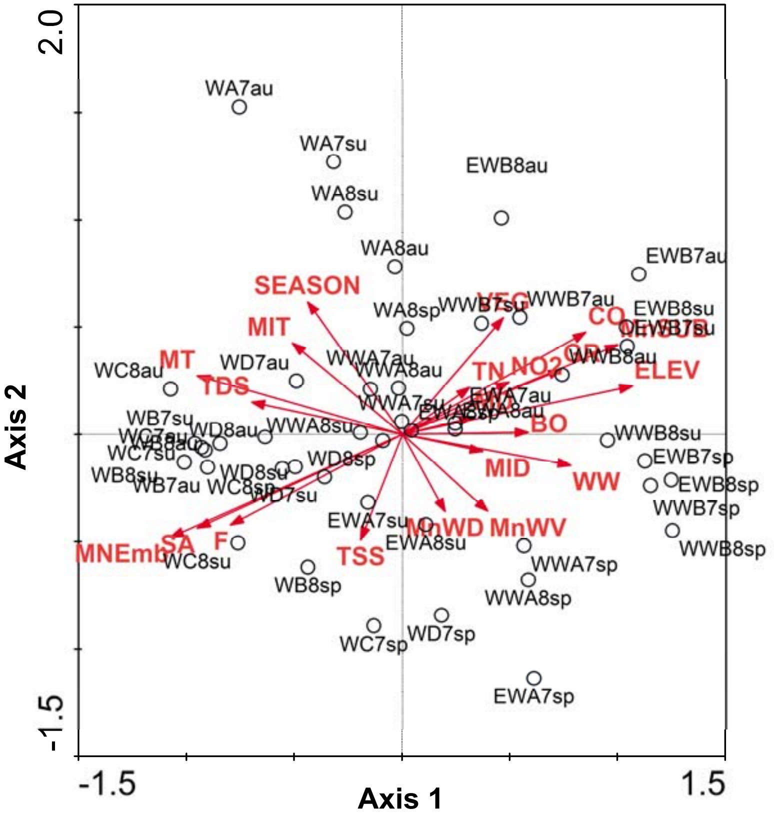

Figure A.8.18. Canonical correspondence analysis biplot showing relationships between Walker River Basin aquatic environment parameters and BMI communities during spring, summer, and autumn 2007 and 2008. Abbreviations for environmental parameters are shown in Table A.8.2. Sample sites as shown in Figure A.8.1, and sp = spring samples, su = summer samples, au = autumn samples.

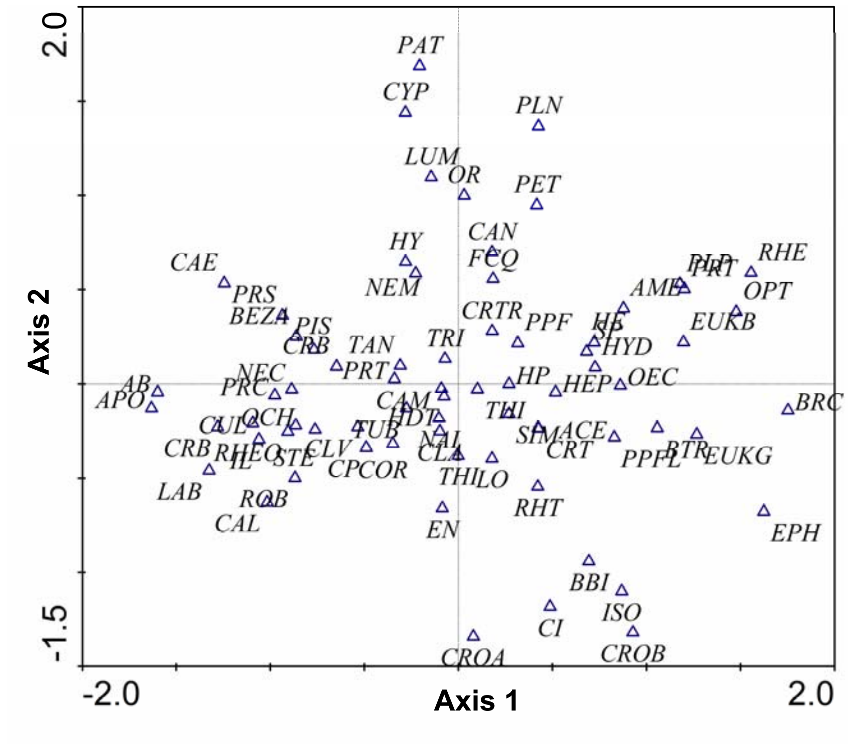

Figure A.8.19. Canonical correspondence analysis scatte rplot showing the distribution of riffle BMI species during spring, summer, and autumn 2007 and 2008. Integrating this with Figure A.8.14 provides insight relationships between species, environments, and sample sites. Abbreviations for species are shown in Table A.8.3.

Site WA samples are in the upper center of the biplot and comprise the second cluster. As shown by DCA, these communities change seasonally and were comprised of highly tolerant BMIs. Its environments also change seasonally and communities were most influenced by low current velocity, shallow water, and high minimum temperature (Table A.8.7).

Table A.8.7.The CCA biplot sector, cluster of samples, five characteristic taxa, and primary environmental factors distinguishing Walker River BMI samples during 2007 and 2008. Taxa abbreviation as shown in Table A.8.3.

Sector	Cluster of Samples	Taxa	Environments
Lower center and right	WB, WC, WD, EWA, EWB, WWA, WWB springtime	BBI, CROA, CROB, EN, ISO	Deep water, swift current, wide wetted width, high TSS, cold temperature, low TDS
Upper center	All WA	PAT, CY, LUM, OR, PET	Shallow water, slow current, high minimum temperature
Center left	WB, WC, & WD summer and autumn	CAE, APO, LAB, AB, CRB	Shallow water, slow current, high TDS, high temperature, small substrate
Center	EWA, WWA	TRI, CAM, THI, PRT, HDT	Moderate substrate, discharge, temperatures, elevation, and nutrients
Middle center right	EWA, EWB, WWA, and WWB summer and autumn	AME, OPT, EUKB, HYD, HE	Large substrate, high discharge and elevation, high nutrients, vegetation

During summer and autumn BMI communities segregated into three additional clusters and CCA shows these changes were influenced by factors associated with Axis 1 (Table A.8.7). Sites in Mason Valley (WB, WC, and WD) are clustered in the left side of the biplot and generally segregated from West Walker and East Walker sites (clustered in the center and upper right portions of the biplot). Environmental factors affecting Mason Valley sites include elevated water temperature, high substrate embeddedness and the presence of sand and fines, low minimum discharge, and high total dissolved solids (Figure A.8.18). Tolerance values of most BMIs in these communities are relatively high (Figure A.8.19, Tables A.8.3 and A.8.7).

There was a transition in communities and environments upstream from the Mason Valley sites through EWA and WWA to WWB then EWB, respectively. East and West Walker sites had larger substrates (cobble and boulder), more vegetation, higher maximum and minimum discharge, and EWB had higher nutrients (primarily total and nitrogen and nitrates) (see Appendix I). Communities at EWA and WWA (the fourth cluster, which is at biplot center) included taxa less tolerant than at the Mason Valley sites (Figure A.8.19, Tables A.8.3 and A.8.7). Their location near biplot center indicates that these environments were moderate in temperature, substrate size, etc., relative to the gradient extremes between Mason Valley and the most upstream sites (WWA and EWB).

Sites WWB and EWB comprise the fifth cluster. Site WWB is distinguished by the lowest tolerance value of all sites (see Figure A.8.7) and its higher elevation elevation included large substrates (cobble and boulder), low embeddedness, and more vegetation. Its communities and environment were distinct from most EWB samples by their lower tolerance value BMIs and by higher nutrient concentrations (see Tables AI-6 and AI-8). It appears that nutrients may enter the river as runoff from livestock in Bridgeport Valley, which alter conditions and affect these communities and cause differences between EWB and WWB BMI communities.

DISCUSSION

Allogenic river environments and biota often follow many predictable patterns summarized by Vannote *et al*. (1980) and Hynes (1970). Headwaters are steep, cold, and low in turbidity, nutrients, and chemical constituents. Substrates are large and currents are swift. There is a downstream gradient in rivers as they increase in size and water becomes slower, deeper, and more turbid, and substrate size decreases. Summer temperatures and chemical content are also higher in downstream reaches. Aquatic life changes along the gradient in response to environmental differences. Headwater fish and benthic communities are adapted to high dissolved oxygen, cold, swift water, and they are intolerant of harsh conditions. Communities change as environmental harshness increases and intolerant species are replaced by organisms that can withstand turbid water, small substrates, low dissolved oxygen, and high water temperature.

Most waters in the US have been altered and few maintain either their natural hydrograph, water quality, sediment transport, nor channel morphology and dynamics (e.g., Naiman *et al*. 1995, Wilson and Carpenter 1999). Increased public interest in healthy rivers is changing management direction from the focused construction of dams, bank stabilization, and grade control structures to projects that accomplish flood control goals while maintaining healthy, naturally functioning aquatic and riparian ecosystems. The challenge is to maintain ecological integrity by moderating the compounding influences of climate change, drought, and deleterious land use activities to retain the economic, environmental, and societal benefits of healthy ecosystems.

Physical, chemical, and hydrological characteristics of streams and rivers are environmental factors that influence their aquatic life. Since this life is specifically adapted to these conditions, changes in the environment influence the composition of fish, BMI, and periphyton communities. The influence of human activity on these communities can be assessed by community structure, calculating community tolerance values, and quantifying characteristics of healthy communities that function as standards to compare with other systems. Much of this work has been accomplished in mesic regions of North America where precipitation is relatively high and is occurs throughout the year. Less is known about benchmarks for arid land aquatic systems where community tolerance values are naturally high because streams and rivers are smaller and warmer, due to low precipitation and high summer temperatures, and chemical constituents are relatively high. Communities in these systems are naturally dominated by species characterizing harsh environments that occur in systems in mesic environments.

Walker River Basin riffle and woody debris BMI communities varied primarily in response to season, discharge, temperature, substrate size, and nutrients in 2007 and 2008. Since runoff during both of these years was less than 50 percent of average, it is difficult to discern how these communities and environments may compare to those occurring during normal or high runoff conditions. This information may be accumulated by continued sampling that includes years with higher precipitation.

With exception of site WA, other springtime communities were similar and included intolerant BMIs at all sites sampled during this season. As summer and autumn temperatures and nutrients increased and discharge decreased, all BMI communities became numerically dominated by more tolerant taxa adapted to harsh conditions. These trends characterize changes in BMI communities that accompany degrading habitat conditions in waters throughout the US (e.g., Barbour *et al*. 1999). The strong relationship between water temperature, discharge, and BMI community structure suggests that ecological integrity of the Walker River is affected by activities that influence these factors. Conversely, actions that increase discharge and reduce water temperature and nutrients would improve river conditions and have a concomitant affect on BMI communities.

There was a strong seasonal variation in species abundance in riffle and woody debris BMI communities. Taxa that were abundant in spring were missing in summer and fall, and taxa found in summer or fall were uncommon in other seasons. This is perhaps due to the food abundance as well as growing season. Spring and summer generally have higher primary productivity and hence the abundance of grazers but fall have higher foliage and other terrestrial input into the system which provide a strong food base for the functional group of shredders and collectors. Annual differences within each season were less, which suggests that the basic structure of BMI communities may be seasonally predictable in different reaches.

Information accumulated during 2007 and 2008 provides evidence showing how Walker Basin riverine BMI communities are influenced by environments that can be attributed to natural and human factors. It is difficult to discern the relative influence of natural and human factors on these communities because baseline information is lacking, knowledge of historical conditions is weak, and there was little environmental variability between 2007 and 2008 because they were drought years. Walker Basin prehistoric and historic environmental conditions have varied dramatically in response to drought and climate change. Changes have been extreme over the past 15,000 years and ranged between with the lower river course changing, Walker Lake drying, and glaciers covering the upper basin. These changes had a demonstrable effect on aquatic life in the basin. The upper basin was historically fishless due to glaciers, and cui-ui (*Chasmistes cujus*) and the Nevada springsnail (*Pyrgulopsis nevadensis*) were extirpated when Walker Lake dried (Hubbs and Miller 1948, Smith and Miller 1981, Hershler 1994). All aquatic life was not extirpated from the basin during these changes, which affected only the distribution of many other species. All aquatic life disappeared from Walker Lake when it dried and BMI communities changed in response to varying cold and warm conditions, and to low and high flow periods. During moist periods the distribution of intolerant BMI communities extended further downstream than during droughts when they were limited to higher elevations. These types of change can be expected to continue into the future, and the ability of the biological system to retain its integrity relies on how effectively human uses can be directed toward maintaining an integrated river and lake system within the limits of biological tolerance. Additional studies are needed to determine how Walker River benthic communities vary in response to higher discharge rates.

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APPENDIX A.8. SUMMARY OF ENVIRONMENTAL CHARACTERISTICS, AND UNITS OF MEASURE, FOR BMI HABITATS SAMPLED AT WALKER RIVER SAMPLE SITES DURING 2007 AND 2008 (IN TABLES FOR EACH SITE, THE SUMMARY OF ENVIRONMENTAL CHARACTERISTICS IN THE REACH DURING EACH SAMPLE ARE IN PARENTHESES)

Appendix Table A.8.1. Samples measurement of wetted width, water temperature, discharge, total dissolved solids, total suspended solids, and nutrients were not different for BMI samples and reach characteristics. In each table, SP07 = spring 2007, SU07 = summer 2007, AU07 = autumn 2007, SP08 = spring 2008, SU08 = summer 2008, AU08 = autumn 2008. Environmental parameters in tables are abbreviated as:

Parameter	Units	Abbreviation
Wetted Width	Meters	WW
Mean Water Depth (cm)	Centimeters	WD
Mean Water Column Velocity	Centimeters/second	WV
Mean Substrate Size	Millimeters	MnSUB
Proportion of Substrate as Fines	< 1mm	Fines
Proportion of Substrate as Sand	1 mm– 4.9 mm	Sand
Proportion of Substrate as Gravel	5 mm – 79.9 mm	Gravel
Proportion of Substrate as Cobble	80 mm – 299.9 mm	Cobble
Proportion of Substrate as Boulder	> 300 mm	Boulder
Embeddedness	Percent	Embed
Maximum Temperature	^{o}C	MaxT
Minimum Temperature	^{o}C	MinT
Minimum Discharge w/in 6 Weeks of Sample	Cubic-feet/sec	MinD
Maximum Discharge w/in 6 Weeks of Sample	Cubic-feet/sec	MaxD
Total Phosphorus Concentration	Milligrams/liter	TP
Total Suspended Solids	Milligrams/liter	TSS
Total Dissolved Solids	Milligrams/liter	TDS
Nitrate Concentration	Milligrams/liter	NO_3
Nitrite Concentration	Milligrams/liter	NO_2

Appendix Table A.8.2. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'WA' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses. BMI and reach substrate composition were the same during AU07.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	ND	5.7	3.6	2.1	7.3	6.5
WD	ND	7.2 (6.5)	(1.9)	3.9 (3.8)	19.7(19.2)	21.8 (27.5)
WV	ND	20 (70)	(0)	0(0)	22 (22)	39 (35)
MnSUB	ND	57.6 (66.1)	(66.3)	51.9 (45.4)	91.5 (83.0)	86.3 (74.3)
Fines	ND	0.0 (0.0)	(0.0)	0.0 (0.0)	.10 (0.0)	.10 (.11)
Sand	ND	0.08 (.08)	(0.0)	.10 (.10)	0.0 (0.0)	0.0 (.08)
Gravel	ND	.58 (.53)	(.73)	.80 (.85)	.40 (.50)	.13 (.31)
Cobble	ND	.34 (.37)	(.27)	.10 (.40)	.50 (.50)	.77 (.50)
Boulder	ND	0.0 (.02)	(0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Embed	ND	20.1 (17.2)	(15.0)	17.4 (9.0)	15.0 (22.3)	34.0 (32.2)
TP	ND	0.164	0.0105	0.065	0.115	0.256
NO_3	ND	0.012	0.007	0.0	0.015	0.013
NO_2	ND	0.001	0.0	0.001	0.002	0.002
TN	ND	0.37	0.30	0.31	0.49	0.78
TDS	ND	340	342	394	283	314
TSS	ND	3.5	12.2	6.0	1.1	2.8
MaxT	ND	29.7	27.2	18.4	29.6	29
MinT	ND	22.2	14.7	0	11.9	7.9
MaxD	ND	30	7.2	88	171	188
MinD	ND	0.0	0.0	0	0	6

Appendix Table A.8.3. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'WB' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	ND	11.7	12.0	11.5	12.2	11.6
WD	ND	12.5 (13.1)	23.8 (23.8)	13.6 (13.2)	34.6 (31.6)	19.1 (18.2)
WV	ND	30 (28)	39 (38)	24 (33)	42 (41)	33 (34)
MnSUB	ND	1.2 (1.1)	1.0 (0.8)	1.0 (1.0)	1.4 (1.1)	2.2 (1.9)
Fines	ND	.48 (.47)	.58 (.34)	.43 (.50)	.45 (.48)	.55 (.87)
Sand	ND	.52 (.53)	.42 (.65)	.57 (.47)	.55 (.50)	.30 (.13)
Gravel	ND	0.0 (0.0)	0.0 (0.0)	0.0 (.03)	0.0 (.02)	.15 (0.0)
Cobble	ND	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Boulder	ND	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Embed	ND	91.0 (95.0)	96.5 (98.7)	96.3 (97.5)	91.0 (95.1)	82.8 (89.0)
TP	ND	0.081	0.069	0.139	0.099	0.067
NO_3	ND	0.009	0.007	0.01	0.024	0.014
NO_2	ND	0.001	0.0	0.001	0.001	0.0
TN	ND	0.17	0.37	0.47	0.29	0.26
TDS	ND	207	206	300	191	213
TSS	ND	8.1	19.8	53.9	27.4	8.8
MaxT	ND	27.4	32.1	22.9	33.4	37.9
MinT	ND	20.9	8.9	0.0	11.9	7.9
MaxD	ND	59	45	51	262	67
MinD	ND	18	6.3	2000	16	4.4

Appendix Table A.8.4. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'WC' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	10.3	10.2	10.4	9.4	11.0	10.3
WD	21.7 (22.0)	12.7 (12.4)	27.8 (28.0)	12.2 (12.5)	31.5 (29.0)	24.8 (23.8)
WV	50 (44)	38 (39)	46 (46)	29 (27)	52 (51)	48 (47)
MnSUB	1.4 (1.4)	1.1 (1.3)	1.7 (1.4)	3.0 (4.2)	1.5 (1.4)	2.6 (2.2)
Fines	.53 (.57)	.10 (.05)	.35 (.47)	.22 (.23)	.25 (.37)	.25 (.31)
Sand	.45 (.34)	.90 (.94)	.58 (.45)	.56 (.59)	.73 (.59)	.58 (.56)
Gravel	.02 (.09)	0.0 (.01)	.07 (.08)	.22 (.18)	.02 (.04)	.20 (.13)
Cobble	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Boulder	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Embed	91.8 (91.4)	100 (99.5)	88.8 (91.0)	79.5 (79.4)	93.0 (93.0)	73.3 (84.3)
TP	0.107	0.074	0.092	0.081	0.224	0.063
NO_3	0.011	0.009	0.006	0.02	0.052	0.029
NO_2	0.002	0.0	0.0	.0001	0.001	0.0
TN	0.51	0.18	0.36	0.46	0.34	0.26
TDS	248	190	202	299	175	209
TSS	32.9	9.3	16.3	25.7	37.4	8.3
MaxT	16.5	27.3	31.3	32.7	29.7	38.2
MinT	3.0	19.5	10.3	1.8	11.5	12.4
MaxD	48.9	34.1	62.3	16.5	211.8	73.3
MinD	27.5	11.6	19.6	8.7	41.2	18.6

Appendix Table A.8.5. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'WD' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	14.9	15.0	15.0	14.3	15.2	14.7
WD	29.0 (27.8)	31.3 (29.2)	27.5 (26.0)	21.9 (23.0)	49.1 (46.6)	26.8 (25.7)
WV	50 (50)	56 (52)	51 (50)	55 (53)	63 (58)	40 (36)
MnSUB	6.2 (6.1)	4.2 (4.6)	14.8 (6.5)	12.5 (20.5)	17.5 (25.9)	7.8 (18.7)
Fines	.20 (.11)	0.0 (.02)	.05 (.11)	.05 (.18)	.13 (.17)	.35 (.37)
Sand	.45 (.50)	.68 (.75)	.45 (.46)	.22 (.22)	.55 (.56)	.38 (.41)
Gravel	.35 (.34)	.32 (.23)	.47 (.43)	.73 (.67)	.25 (.20)	.25 (.16)
Cobble	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (.02)	.05 (.03)	.02 (.03)
Boulder	0.0 (0.0)	0.0 (0.0)	0.03 (0.0)	0.0 (.01)	.02 (.04)	0.0 (.03)
Embed	63.8 (68.3)	69.5 (84.0)	48.8 (54.5)	37.5 (41.3)	68.4 (72.8)	69.8 (77.9)
TP	0.081	0.081	0.099	0.119	0.107	0.072
NO_3	0.013	0.011	0.007	0.02	0.048	0.051
NO_2	0.004	0.001	0.0	0.001	0.001	0.0
TN	0.38	0.56	0.45	0.58	0.41	0.35
TDS	258	170	200	272	150	202
TSS	16.2	11.5	14.8	59.0	41.6	9.2
MaxT	19.2	31.6	29.6	32.3	28.2	29.4
MinT	5.2	15.8	12.3	2.0	11.6	11.5
MaxD	307.4	406.2	99.1	99.4	697.5	164.1
MinD	156.5	137.9	30.4	56.1	110	33.6

Appendix Table A.8.6. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'EWA' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	10.2	10.9	10.5	11.0	11.1	10.7
WD	23.3 (22.2)	37.6 (35.6)	26.0 (23.7)	36.5 (34.7)	49.1 (49.4)	27.5 (26.2)
WV	70 (68)	72 (70)	70 (65)	66 (60)	80 (79)	62 (58)
MnSUB	41.4 (42.5)	56.5 (35.7)	48.4 (63.3)	47.1 (64.0)	60.7 (47.9)	56.3 (68.8)
Fines	.18 (.05)	.25 (.14)	.02 (.05)	.10 (.12)	.10 (.17)	.05 (.05)
Sand	.15 (.09)	.05 (.13)	.08 (.08)	.25 (.15)	.25 (.17)	.13(.16)
Gravel	.55 (.72)	.40 (.60)	.75 (.67)	.48 (.48)	.38 (.51)	.62 (.54)
Cobble	.12 (.14)	.28 (.13)	.15 (.16)	.15 (.23)	.27 (.11)	.20 (.17)
Boulder	0.0 (0.0)	.02 (0.0)	0.0 (.04)	0.02 (.02)	0.0 (.04)	0.0 (.08)
Embed	52.6 (42.7)	42.4 (44.5)	24.0 (27.0)	46.7 (36.7)	43.1 (46.0)	31.6 (30.8)
TP	0.078	0.188	0.174	0.125	0.142	0.133
NO_3	0.006	0.013	0.010	0.01	0.026	0.009
NO_2	0.0	0.001	0.0	0.0	0.001	0.0
TN	0.28	0.30	0.62	0.57	0.58	0.62
TDS	171	135	165	176	151	169
TSS	27.0	35.8	38.2	73.6	50.4	15.5
MaxT	16.5	28.8	26.3	19.2	25.4	27.4
MinT	3.7	17.6	12.7	26.3	11.1	12.5
MaxD	140	113	97	191	231	150
MinD	29	40	32	33	75	37

Appendix Table A.8.7. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'EWB' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	17.4	19.3	18.6	18.1	19.8	18.4
WD	18.6 (17.6)	27.8 (26.0)	22.9 (22.0)	22.0 (21.8)	35.5 (35.5)	25.3 (25.0)
WV	50 (45)	67 (67)	60 (57)	61 (58)	72 (69)	54 (36)
MnSUB	97.9 (59.6)	68.3 (57.4)	75.0 (52.6)	64.2 (59.4)	71.5 (64.7)	45.9 (61.3)
Fines	0.0 (.10)	.08 (.09)	0.0 (.07)	.08 (.06)	.08 (.13)	.10 (.06)
Sand	.08 (.10)	.05 (.06)	.02 (.09)	.05 (.08)	0.0 (.07)	.05 (.11)
Gravel	.48 (.55)	.57 (.63)	.63 (.58)	.62 (.62)	.58 (.53)	.47 (.57)
Cobble	.39 (.25)	.28 (.22)	.35 (.25)	.25 (.24)	.34 (.26)	.38 (.26)
Boulder	.05 (0.0)	.02 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (.01)	0.0 (0.0)
Embed	23.4 (39.4)	16.9 (44.3)	13.9 (20.4)	24.0 (23.7)	19.5 (28.6)	17.3 (46.9)
TP	0.045	0.234	0.254	0.046	0.126	0.163
NO_3	0.016	0.028	0.045	0.01	0.117	0.089
NO_2	0.001	0.035	0.009	0.001	0.049	0.012
TN	0.36	0.82	1.35	0.54	0.63	0.94
TDS	125	116	131	151	129	160
TSS	14.6	5.0	9.8	7.6	4.2	6.7
MaxT	13.4	25.6	23.7	13.5	23.0	30.9
MinT	2.7	17.2	14.1	-0.2	11.0	13.9
MaxD	140	174	160	220	274	205
MinD	17	84	73	21	93	62

Appendix Table A.8.8. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'WWA' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	20.9	21.7	20.9	19.9	21.0	19.9
WD	31.9 (30.6)	30.6 (28.7)	26.5 (27.0)	22.2 (22.0)	38.0 (36.8)	27.5 (25.1)
WV	50 (48)	42 (31)	36 (40)	35 (40)	67 (59)	37 (36)
MnSUB	35.3 (35.4)	34.6 (23.2)	30.9 (37.4)	34.5 (55.3)	55.8 (37.3)	45.1 (56.9)
Fines	.28 (.20)	.25 (.29)	.20 (.19)	.18 (.19)	.09 (.21)	.18 (.24)
Sand	.10 (.12)	.08 (.19)	.18 (.22)	.13 (.13)	.23 (.28)	.09 (.12)
Gravel	.53 (.57)	.63 (.52)	.48 (.48)	.59 (.50)	.45 (.38)	.56 (.44)
Cobble	.09 (.10)	.04 (0.0)	.14 (.11)	.10 (.14)	.23 (.12)	.14 (.17)
Boulder	0.0 (.01)	0.0 (0.0)	0.0 (0.0)	0.0 (.04)	0.0 (.01)	.03 (.03)
Embed	53.6 (49.5)	48.1 (57.9)	48.5 (48.2)	44.0 (50.0)	46.9 (62.7)	41.3 (46.9)
TP	0.076	0.017	0.026	0.109	0.223	0.023
NO_3	0.023	0.007	0.010	0.20	0.135	0.005
NO_2	0.005	0.0	0.001	0.007	0.004	0.001
TN	0.34	0.20	0.21	0.70	0.31	0.22
TDS	218	181	146	189	127	170
TSS	12.3	2.7	4.5	42.4	67.0	2.5
MaxT	19.7	26.1	25.4	22.9	34.9	30.2
MinT	2.8	13.3	19.4	2.0	7.8	13.6
MaxD	181	219	107	68	549	147
MinD	51	54	32	30	82	50

Appendix Table A.8.9. Summary of environmental characteristics of BMI habitats sampled at Walker River site 'WWB' during 2007 and 2008 (these data used in CCA). Summary of environmental characteristics of the reach during each sample shown in parentheses.

Parameter	SP07	SU07	AU07	SP08	SU08	AU08
WW	25.0	16.7	16.3	25.2	26.7	16.6
WD	37.1 (34.2)	21.0 (18.6)	17.8 (18.1)	38.8 (37.0)	35.1 (32.7)	22.1 (19.8)
WV	50 (49)	23 (23)	17 (16)	61 (61)	52 (56)	20 (19)
MnSUB	158.7 (112.6)	124.2 (76.7)	119.4 (97.1)	98.2 (78.2)	99.4 (108.6)	108.5 (105.2)
Fines	.03 (0.0)	.05 (.08)	.03 (0.0)	.01 (0.0)	.13 (0.0)	0.0 (.04)
Sand	0.0 (.08)	.08 (.08)	.13 (.11)	.14 (.11)	0.0 (.11)	.14 (.18)
Gravel	.10 (.36)	.25 (.37)	.40 (.49)	.41 (.49)	.40 (.45)	.35 (.29)
Cobble	.83 (.54)	.60 (.45)	.43 (.39)	.44 (.39)	.45 (.38)	.50 (.43)
Boulder	.04 (.02)	.01 (.02)	.01 (.01)	.01 (.01)	.02 (.05)	.01 (.06)
Embed	14.0 (16.5)	29.8 (39.8)	30.0 (34.1)	24.1 (18.3)	22.9 (21.0)	27.6 (28.9)
TP	0.012	0.015	0.011	0.020	0.052	0.011
NO_3	0.005	0.008	0.004	0.02	0.005	0.006
NO_2	0.0	0.0	0.0	0.0	0.0	0.0
TN	0.05	0.06	0.09	0.21	0.05	0.07
TDS	40	92	115	45	34	108
TSS	3.1	1.0	1.6	14.5	17.9	1.2
MaxT	10.3	22.3	23.1	25.9	13.2	13.2
MinT	1.4	8.9	6.5	-0.1	2.8	2.8
MaxD	385	340	59	279	1600	274
MinD	36	30	18	34	191	23

A.9: SPATIAL AND TEMPORAL VARIABILITY IN ELEMENTAL COMPOSITION AND STOICHIOMETRY OF BENTHIC MACROINVERTEBRATE COMMUNITIES IN THE WALKER RIVER, NEVADA AND CALIFORNIA

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ABSTRACT

Human activities are blamed for nutrient enrichment of ecosystems globally, and are strongly affecting the structure, production and stability of recipient food webs. Specifically, Walker River, NV, which serves as the principal inflow to Walker Lake, has been undergoing rapid changes in water level due to diversions for various water uses. Changes in water level result in nutrient fluxes to the system which may be affecting the consumer benthic macroinvertebrates (BMI) species of Walker River Basin. Here, ecosystem food web theory through elemental imbalance between food sources and consumers is used to explain if the impact of human activities can be indentified using BMIs and their food sources. This is done by understanding where and when consumers may be limited by essential elements which in turn are reflected by consumer diversity, both in terms of taxonomic richness and functional feeding group (FFG) variety. This study tests three hypotheses to understand body nutrient conditions of Walker River BMIs: 1) varies based on seasonal and spatial changes, 2) varies inter-specifically, intra-specifically, and based on FFGs, and 3) correlates directly with water quality data especially total phosphorus (TP) and total nitrogen (TN). Results indicate that certain species and FFGs may be more prone to changes in the region and it is suggested that they be used as bioindicators. It is also suggested that more study be dedicated to the area to identify river reaches that are more vulnerable to ecosystem degradation before water rights acquisitions are allotted.

BACKGROUND

Ecological Stoichiometry and BMIs

Freshwater benthic macroinvertebrate (BMIs) species vary in sensitivity to pollution and, thus, relative abundances have been used to make inferences about pollution loads (Azrina *et al.* 2006). High species richness is often found in natural pristine rivers, however, recently increased human activities have been found to have caused changes to the biodiversity of the river fauna (Nedeau *et al.* 2004). Human activities are blamed for nutrient enrichment of ecosystems globally, and are strongly affecting the structure, production, and stability of recipient food webs (Vitousek *et al*. 1997). Such nutrient enrichment and fluxes in littoral benthic zones are not very well understood with regard to their direct effects on BMI communities. Evidence suggests that BMI body nutrient composition may vary based on the nutrient composition of the food source (Cross *et al*. 2003). The concept of BMI body composition adjustment due to environmental conditions is known as rheostasis and was first introduced by Villar-Argaiz *et al*. (2002). Rheostasis is best supported by intra-specific variations in body

Carbon (C), Nitrogen (N), and Phosphorus (P) body composition due to spatial and/or seasonal changes. Other researchers such as Frost *et al*. (2005) argue against the theory of rheostasis by finding no significant intra-specific variation in BMI elemental composition across lakes. Similarly, Bowman *et al*. (2005) found that BMI elemental composition remains static despite sampling upstream and downstream of a point-source nutrient discharge.

Empirical evidence is partial toward the idea that homeostasis regulates consistent macronutrient compositions within one genus (little intra-specific variation) despite environmental changes (Hensen and Lyche 1991; Elser *et al*. 2000; Sterner and Elser 2002; Evans-White *et al.* 2005). Studies suggest that somatic macronutrient concentrations within BMIs remain static during elemental fluxes because animals egest or excrete excess macronutrients (Corss *et al*. 2007). Body C, N, and P are usually the macronutrients of main concern because they are essential for growth and abundance. Particularly, P somatic content is the most susceptible to change due to environmental deficiency or excess (Liess 2005). Ecological stoichiometry of C, N, and P addresses the consequences and constraints of mass balance of multiple chemical elements in ecological interactions (Reiners 1986). Trophic interactions and those between organisms and their abiotic environment can be influenced by the elemental requirement of these organism's relative supply in their environment (Elser and Urabe 1999). Ecologists are beginning to apply this theory to the benthic ecology of lakes and streams (Frost and Elser 2002; Cross *et al*. 2007). Stoichiometric theory can explain through elemental imbalance between food sources and consumers, where and when consumers may be limited by essential elements which in turn is reflected by consumer diversity, both in terms of taxonomic richness and functional feeding group variety (Merritt *et al*. 1996).

Walker River BMI

Walker River, which serves as the principal inflow to Walker Lake, has been undergoing rapid changes in water level due to diversions for agricultural uses. Diversions have decreased annual inflow into not only Walker Lake, but also caused a significant change in water chemistry, water depth, velocity and physical habitats to BMIs, fish and other aquatic biota (see the preceding section by Sada *et al*. for more details) in the river itself. A number of studies have examined the impact on Walker Lake, and its ancient, historic, and current limnology (e.g., La Rivers 1962; Cooper and Koch 1984; Benson *et al*. 1991; Dickerson and Vinyard 1999; Beutel 2001; Sharpe *et al*. 2007), few biological studies have considered the river, and there is little information available to assess how its aquatic life has been impacted by these changes in water diversions and altered environmental and physical conditions. As a part of long-term strategies of restoring Walker Lake, concerned agencies are looking into a possibility of water rights acquisitions along the Walker River to increase flows into Walker Lake for restoration of the lake's ecological health. In the wake of this development, it is critical to understand and establish a database of the existing environmental, physical, and limnological conditions to understand the health of the river. If more water is retained in the river after water rights acquisitions, this will not only impact river ecology but also have an indirect impact on the lake food web because of interdependencies of many fish and benthic invertebrate species that migrate between the lotic and lentic habitats.

As a part of the ongoing Walker Basin project, BMI communities in the Walker River Basin, eastern California, and western Nevada were examined during 2007 and 2008 to determine how they vary spatially and temporally in context of water chemistry, temperature, discharge, and characteristics of the physical habitat (e.g., substrate composition, water depth, current velocity, etc.), as well as BMI body carbon (C), nitrogen (N), and phosphorus (P) contents and their stoichiometric ratios. These techniques examine the fluxes and ratios between multiple elements to reveal how differences in water chemistry attributed to natural conditions and human activity may affect ecosystem processes. Benthic macroinvertebrates are an integral part of riverine food webs where the contents of C, N and P in all levels of the food chain (periphyton, BMIs, fish, etc.) vary relative to concentrations of these elements in water. As a consequence, changes in nutrient availability reflect BMI stoichiometry, which is indicative of changes in community composition, food web structure, ecosystem processes, and other factors such as fish yield and water quality (Ptacnik *et al*. 2005). Also tested were three hypotheses to understand nutrient stoichiometry of Walker River BMIs: 1) varies based on seasonal and spatial changes, 2) varies inter-specifically, intra-specifically, and based on FFG's, and 3) correlates directly with water quality data, specifically total phosphorus (TP) and total nitrogen (TN).

METHOD

Site description and physical habitat characteristics have been described in detail in the preceding section. Sample sites were located to represent the variety of river environments in higher-order Walker Basin streams and most of them are close to or downstream of USGS stream gauges. Characteristics of the physical habitat and BMIs were quantified during the spring, summer, and fall of 2007 and all four seasons in 2008. Data were collected in all four habitats (riffles, woody, pool and glide) at eight sites (Figure A.9.1) from approximately 30 km (approximately 1,250 m elevation) upstream of Walker Lake to the base of the base of the Sierra Nevada Mountains (approximately 1,800 m elevation). Sites WA and WB were not sampled during spring 2007 because permission to sample had not been granted by landowners. Protocol used for BMIs and physical habitat parameters as described in the previous section includes collection from at each habitat as composites of six, 0.11-m^2 (1-ft^2) quadrates where substrate was roiled and scrubbed by hand to dislodge organisms into a 250-micron, hand-held, 30 cm D-frame net, temperature using Hobotemp thermographs, and substrate embededdness among others.

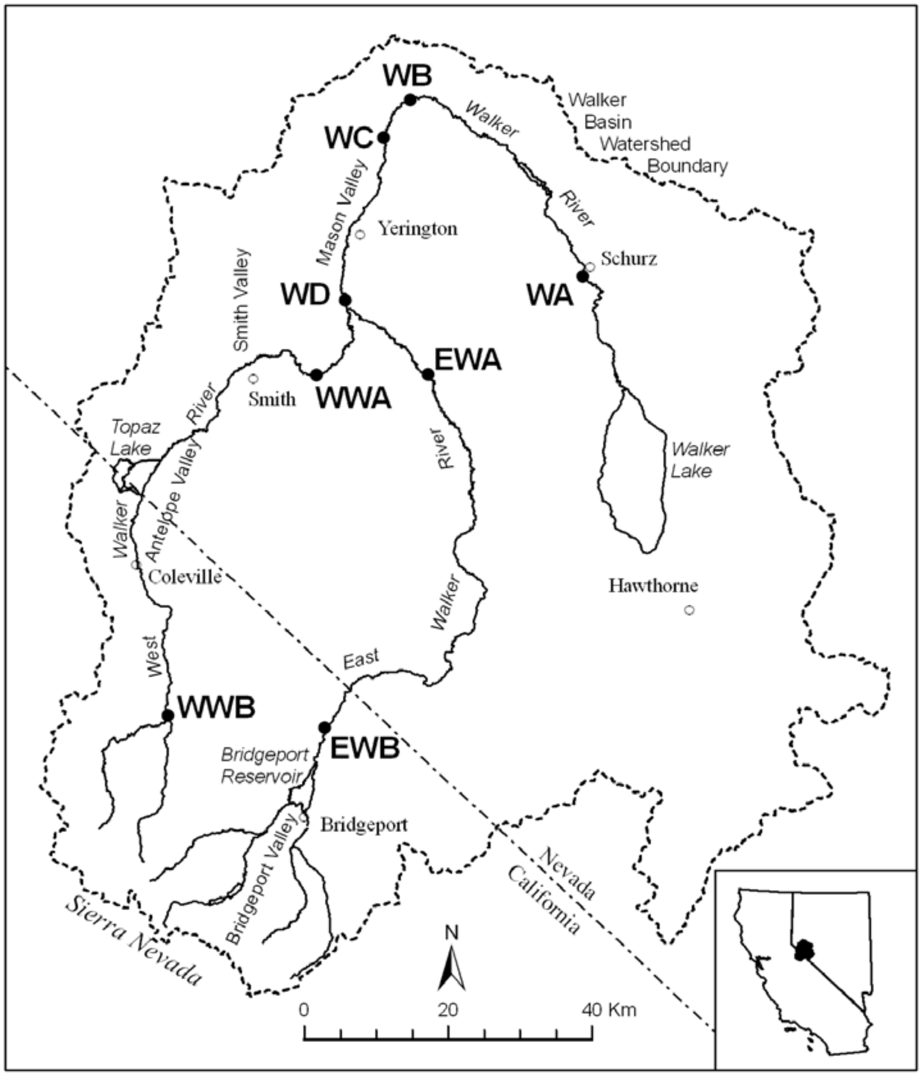

Figure A.9.1. Walker River Basin and the location of 2007 BMI, water chemistry and physical habitat sampling sites. WA, WB, WC and WD = Walker River sites, EWA and EWB = East Walker sites, and WWA and WWB = West Walker sites.

Water-quality samples were collected in half gallon plastic jugs that were triple rinsed with sample water before being filled. Samples were stored in the field on ice in ice chests until transported to DRI-Reno; samples were refrigerated until analysis (pers. Comm. Ron Hershey). Analyses were conducted by the DRI Analytical Chemistry Laboratory, which is a U.S. Environmental Protection Agency (EPA) and state of Nevada certified laboratory. Appropriate U.S. EPA drinking-water and waste-water procedures were followed.

BMI samples for elemental analysis were maintained in dry ice and transported to the laboratory without chemical fixing. Samples were stored in a laboratory freezer until processing by thawing¸ photographing representative species (two to four pictures), and drying in a convection oven for at least 24 hours. Dried material was weighed (individual or subset depending on the size of the invertebrate) and held in test tubes for P analysis and in aluminum capsules for C and N analysis. There were two replicates for C and N, and three for P. Prepared C and N samples were held in a desiccator until transported to Arizona State University for processing. Body carbon and nitrogen samples were analyzed using the Perkin-Elmer model 2400 elemental analyzer. Phosphorus analysis was done at DRI using persulfate oxidation followed by the acid molybdate technique using a UV-vis spectrophotometer. The BMI samples used for enumeration, sorting, identification, and archiving were collected according to the standard protocol developed and practiced by the DRI Aquatic Ecology Laboratory (see previous section for more details).

ANALYTICAL METHODS

Multivariate analysis of variance (MANOVA) was used to test for the effects of season, site, and taxonomic group on invertebrate for C, N, P and C: N, C: P, and N: P ratios, because these ratios are interdependent. The BMI community stoichiometry was examined by pooling a composite collection to analyze C, N, and P at various sites, habitats, and seasons. Due to the large number of samples and very high taxonomic richness in many sites, a finer approach was needed. Therefore, BMIs were also analyzed for differences in genus and species stoichiometry to assess spatial and temporal differences as well as the impact of water quality, if any. Both one-way and two-way analysis of variance (ANOVA) and Tukey LSD Pair-wise Comparison methods were also used, if needed, to analyze the spatial and temporal variation of elemental compositions between various genus, species, functional feeding groups, and habitats. Results within 95 percent confidence intervals were considered significant.

RESULTS

Physicochemical characteristics of the river differed among some sites. Temperatures decreased along an elevation gradient and substrates were larger at higher elevations. Water quality parameters, especially overall mean total phosphorus (TP) and total nitrogen (TN) varied significantly between sites ($p<0.001$, ANOVA; Figure A.9.2). Site EWB had the highest TN concentration (~1.3 mg/L) followed by sites WA (~0.9 mg/L) and EWA (~0.8 mg/L). Site WWB had the lowest TN (<0.2 mg/L; $p<0.05$, ANOVA) of all sites. Similarly, sites WA, EWB, and EWA had higher TP concentrations (> 0.12 mg/L) than rest of the sites. Like TN, site WWB had the lowest TP concentration (< 0.02 mg/L, ANOVA, $p<0.05$). The general seasonal trend for the sites was low TN and TP levels in winter that got progressively higher in spring and summer and reached highest levels in fall, particularly pronounced in the upstream sites, perhaps due to higher flow in winter and smaller flow mixed with higher agricultural runoff containing fertilizers in spring and summer. Temporal variations of both TN and TP were not uniform among all sites. Sites at lower elevations had peak TN and TP in spring and summer and dropped quite a bit in fall (Figure A.9.3).

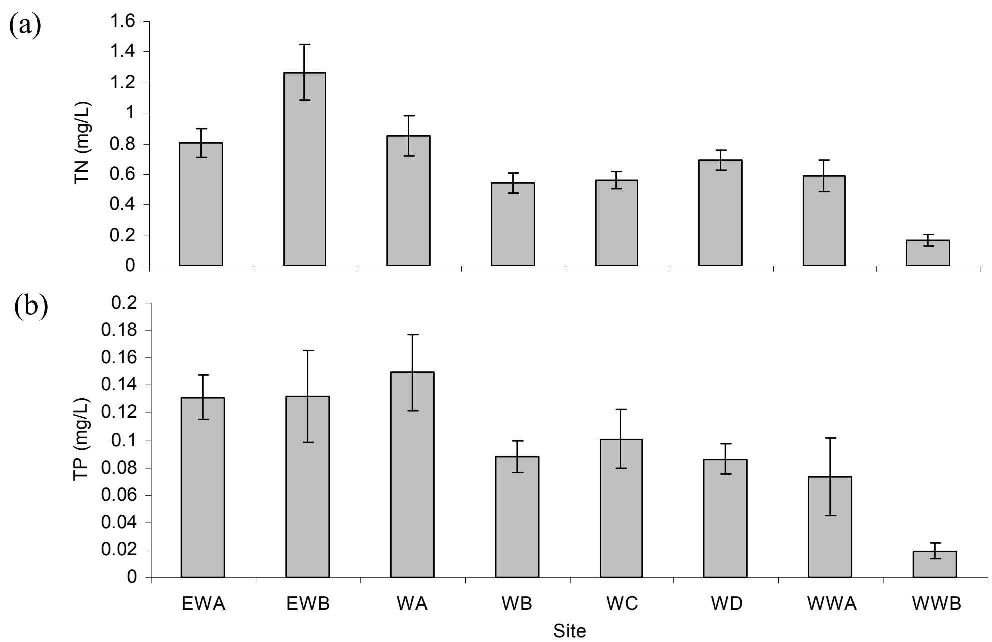

Figure A.9.2. Average water column (a) total nitrogen (TN) and (b) total phosphorus (TP) in mg/L for Walker River sites sampled during 2007 and 2008.

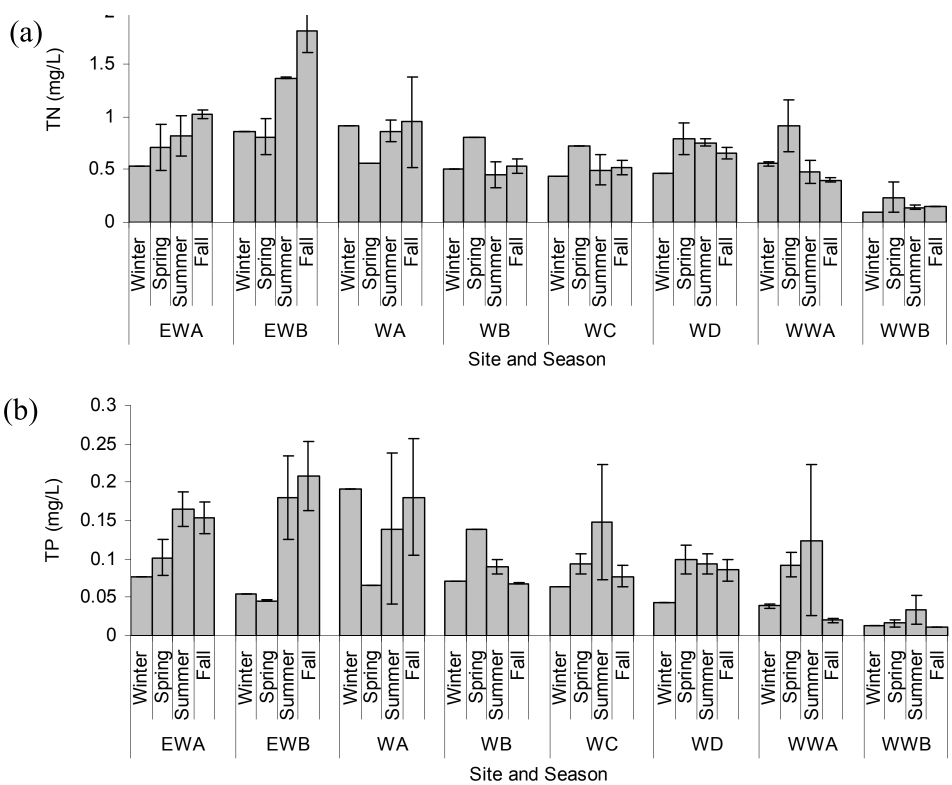

Figure A.9.3. Seasonal (winter, spring, summer and fall) averages of water column (a) TN and (b) TP (mg/L) of Walker River sites sampled during 2007 and 2008.

Walker Basin invertebrate stoichiometry as a whole revealed the complexity and variety within the system (Figure A.9.4). Differences in variation among body elemental concentrations of BMI between sites were minimal and no overarching trend was found when assessed as a whole. For example, when the mean body C, N, and P contents of BMI are assessed on a site-to-site basis, there are no observable significant trends or differences (Figure A.9.5). Of the micronutrients, P tended to be more variable than N, and N more variable than C, both across sites and seasons (Figure A.9.5). This is hardly unexpected considering the fact that the high-elevation streams are highly diverse in terms of taxa and richness. Not all taxa, genus, or species can behave the same way under environmental stress and harshness. Some genus or species are definitely more vulnerable than the others, which cannot be detected by lumping together all the groups.

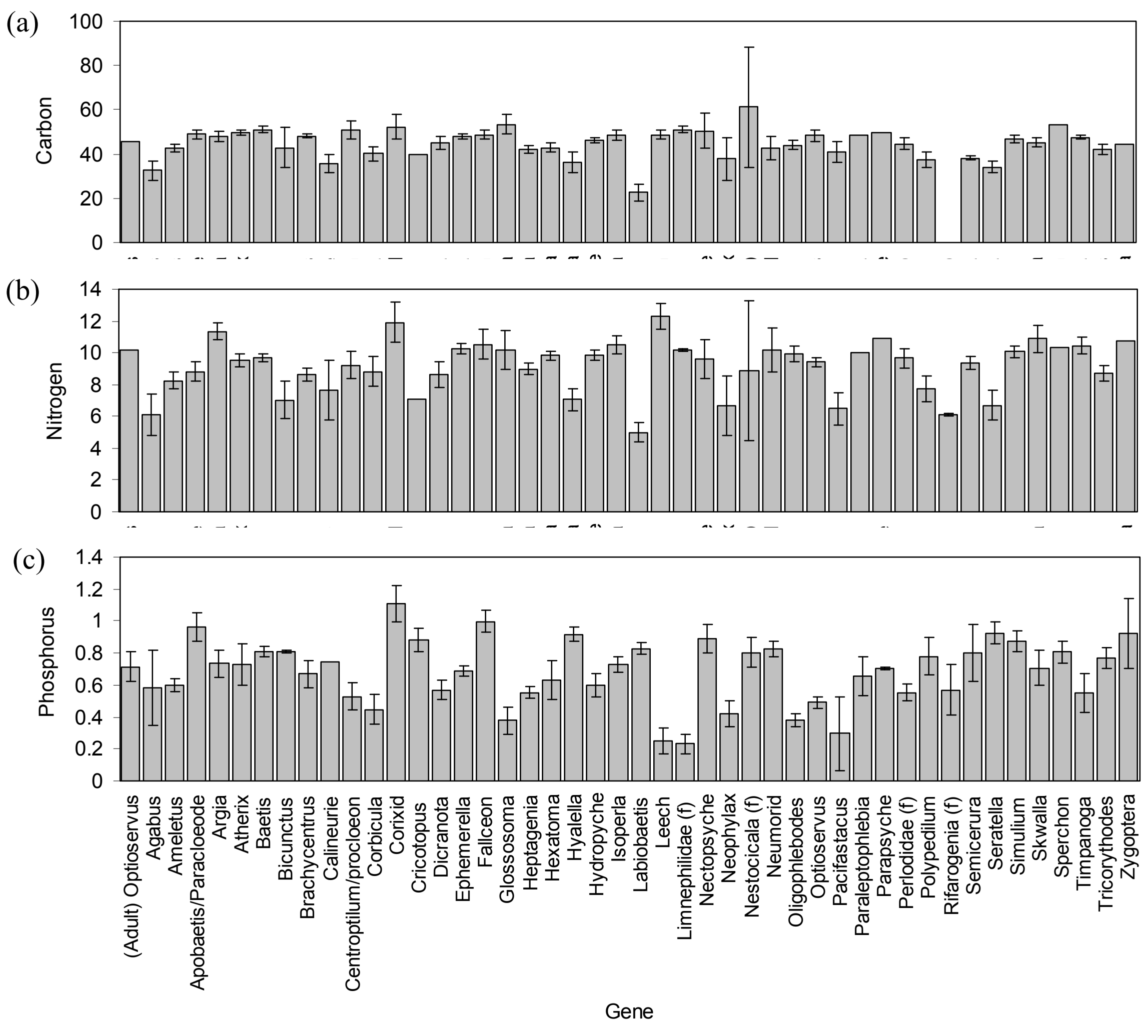

Figure A.9.4. Average percent (%) body mass contents of (a) carbon (C), (b) nitrogen (N), and (c) phosphorus (P) in BMI communities. X axis represent the genus of BMIs. (Note: only samples with replicates have been included).

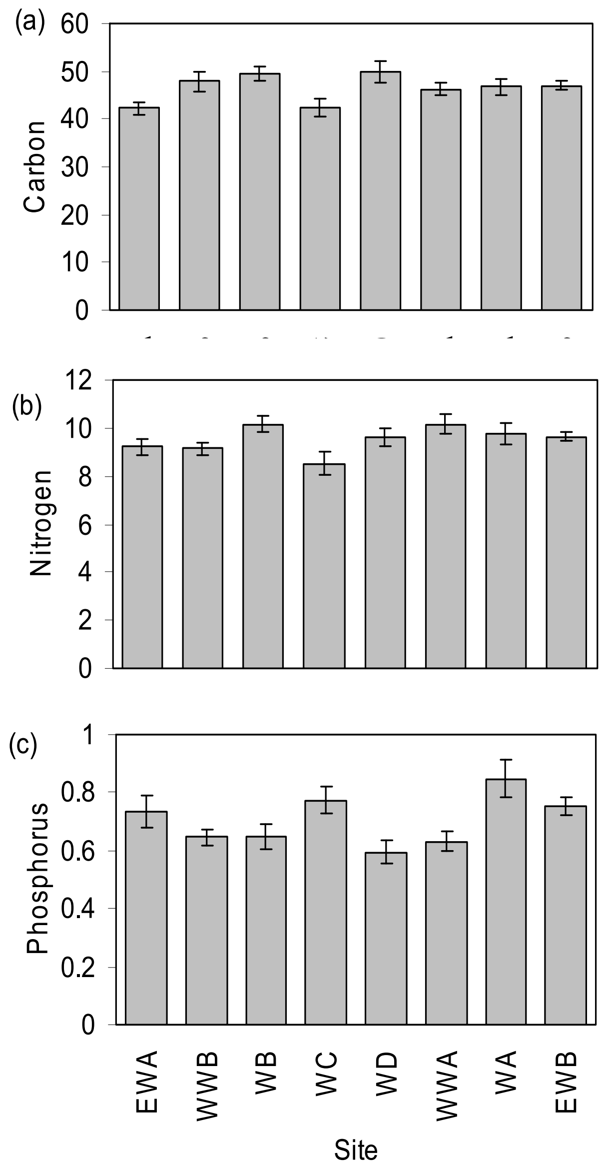

Figure A.9.5. Mean percent (%) body mass contents of (a) carbon (C), (b) nitrogen (N), and (c) phosphorus (P) BMI communities at selected Walker Basin River sites sampled during 2007 and 2008.

However, assessing Walker Basin BMI stoichiometry carefully in finer scale reveals the complexity and variety within the system. For example, mean C, N, and P contents of BMIs varied significantly between genuses. So, it is necessary to examine these cases using a narrower approach, which prevents a reflection of cancellations that may occur due to the significantly different C, N, and P contents of the genus and seasonal and spatial variations. A narrower and finer approach also yields a better understanding of which species or functional feeding group (FFG) would be significantly impacted by changes in human activities and future water rights acquisitions that alter the chemical composition of the system. These same species of concern should be examined and identified, as they often serve as pollutant indicators, and tend to be the least amenable to changes in environmental stress.

Therefore, the next stage of the data analysis involves an attempt to isolate or single out BMI genus, species, or FFG for any variations in body elemental compositions and stoichiometry as a function of their habitat, reach, food, or nutrient levels of the environment. Of the many genuses investigated, the P composition of Skwala and Ephemerella (Figure A.9.6b and A.9.7c) significantly differed between sites ($p<0.05$, Tukey LSD Pair-wise Comparison). Ephemerella P concentration on site WWB was apparently 0.59 percent but on site EWB it was about 0.71 percent A similar trend was found for Skwala, with P concentration on site WWB being about 0.62 percent and for site EWB about 0.89 percent. In terms of habitat, there was a significant difference ($p <0.05$, Tukey LSD Pair-wise Comparison) in body P content of Heptagenia (Figure A.9.6a) of the woody habitat (approximately 0.43 percent) versus riffle (approximately 0.78 percent) habitat.

Similar to the spatial variation, temporal analysis of an individual genus revealed a significant difference ($p<.05$, Tukey LSD Pair-wise Comparison) for Brachycentrus (Figure A.9.6a) body P content in summer (about 0.42 percent) versus spring (about 1.03 percent). Significant seasonal difference in percent P composition was also found in Skwala (Figure A.9.6b) in fall (approximately 0.82 percent) versus spring (approximately 0.41 percent). Seasonal analysis done on site-by-site basis suggested that, in fall (Figure A.9.8), mean (composite) BMI body P content at site WWB (about 0.63 percent) was significantly different ($p <0.05$, Tukey LSD Pair-wise Comparison) than at site EWB (about 0.91 percent). Similar assessment showed that sites WWB (approximately 0.60 percent) and WC (approximately 0.90 percent) yielded significantly different BMI body P contents in summer (Figure A.9.8b).

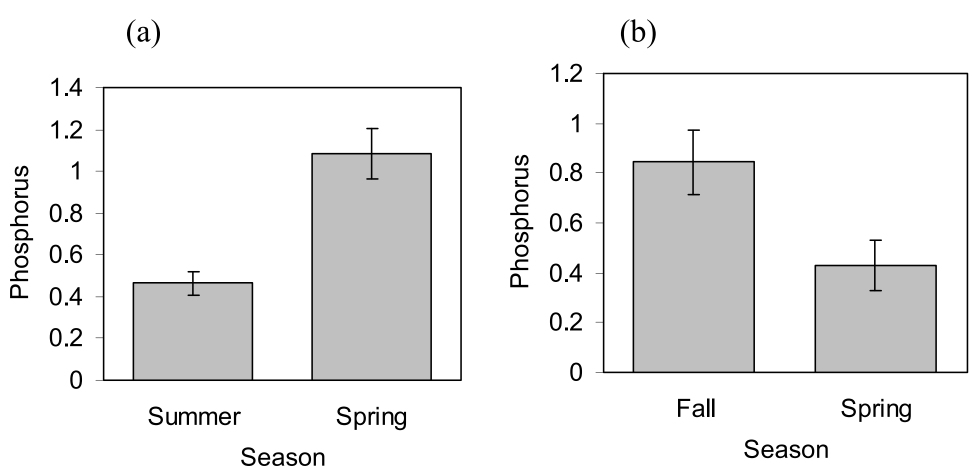

Figure A.9.6. Average percent body mass P in select genus: seasonal variation (a) average percent body mass P in Brachycentrus in summer and spring (b) and average percent body mass P in Skwala in fall and spring.

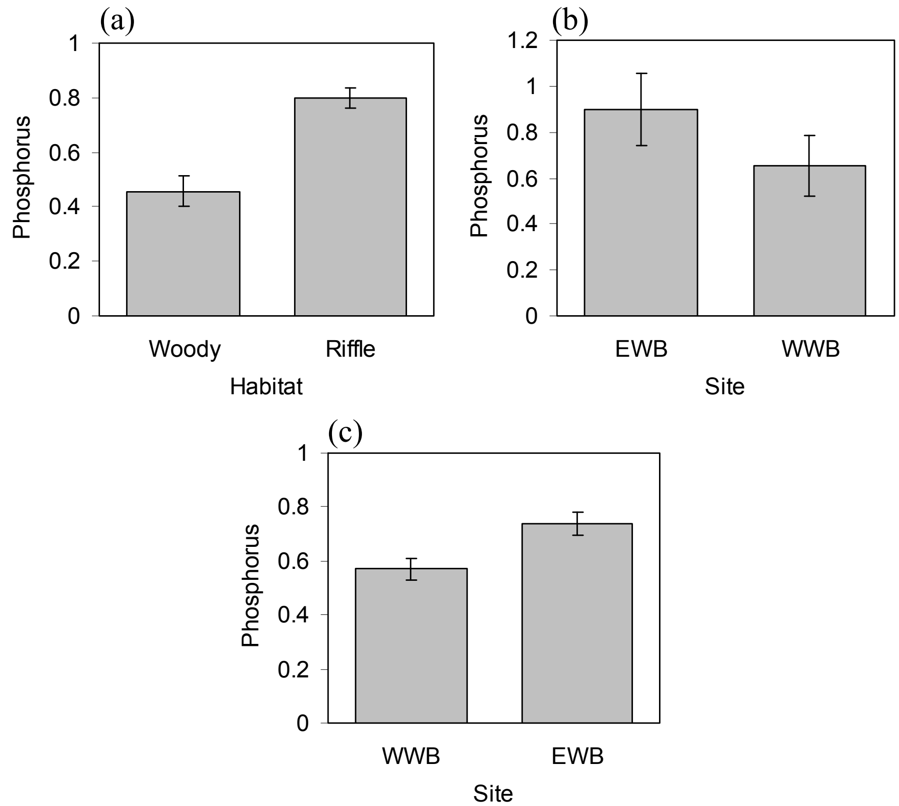

Figure A.9.7. Average percent body mass contents of phosphorus (P) in select genus: spatial variation (a) Heptagenia at sites EWB and WWB, (b) Skwala at sites WWB and EWB, and (c) Ephemerella at woody and riffle habitats.

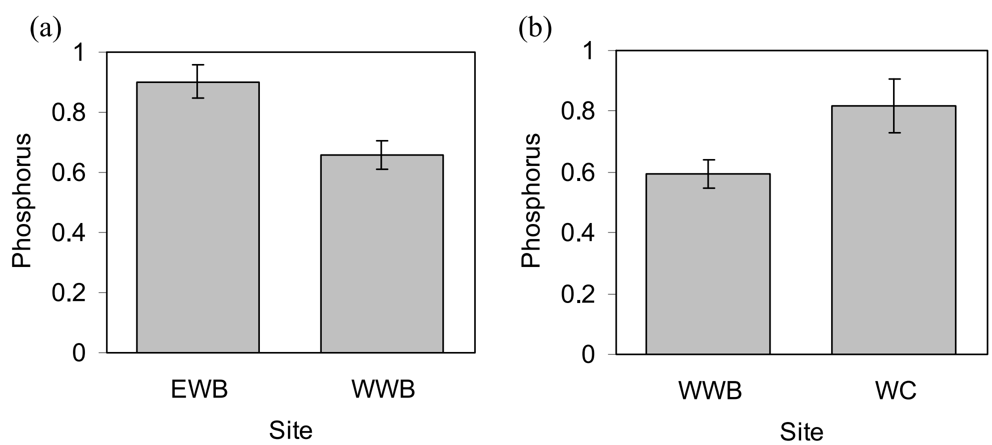

Figure A.9.8. Total average percent P body mass for BMI communities at select Walker River Basin sites sampled during 2007 and 2008: seasonal variation (a) total average percent P body mass for fall at sites EWB and WWB and (b) total average percent P body mass for summer at sites WWB and WC.

The functional feeding group of a BMI is an important classification, based on the food preference. Ecological stoichiometry utilizes consumer and prey elemental imbalance and therefore FFG should provide important clues in the quest to find species that are going to change the food web dynamics under environmental perturbation. Therefore, the role that spatial and temporal variations might play on BMI nutrient compositions within FFG was assessed. Overall, collector gatherers (approximately 0.79 percent) were significantly higher ($p < 0.05$, Tukey LSD Pair-wise Comparison) percent P compositions than predators (approximately 0.61 percent), which were higher than scraper collectors (about 0.55 percent; Figure A.9.9). Similarly, temporal and spatial variations revealed several significant ($p < 0.05$, Tukey LSD Pair-wise Comparison) body P content differences in several FFGs, and it was more pronounced in predators (Figure A.9.10). Two specific differences in predators are noted; at EWA (about 0.28 percent) and WWB (about 0.59 percent; Figure A.9.11a) and at WC (about 0.80 percent) and EWA (about 0.27 percent), specifically in fall (Figure A.9.11b). Similarly, for the FFG scraper collectors on site WWA, fall (Figure A.9.11a and 11b) P (approximately 0.68 percent) and N (approximately 12.00 percent) compositions were significantly higher ($p < 0.05$, Tukey LSD Pair-wise Comparison) than P (approximately 0.36 percent) and N (approximately 7.0 percent) concentrations in spring. The shredder FFG also had significantly varying ($p < 0.05$, Tukey LSD Pair-wise Comparison) mean percent P contents when analyzed by sites (Figure A.9.12).

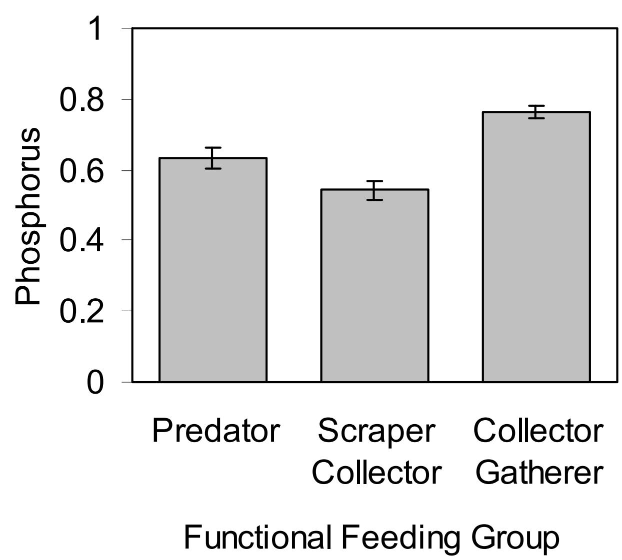

Figure A.9.9. Average percent P body mass for the FFG predator, scraper collector, and collector gatherer.

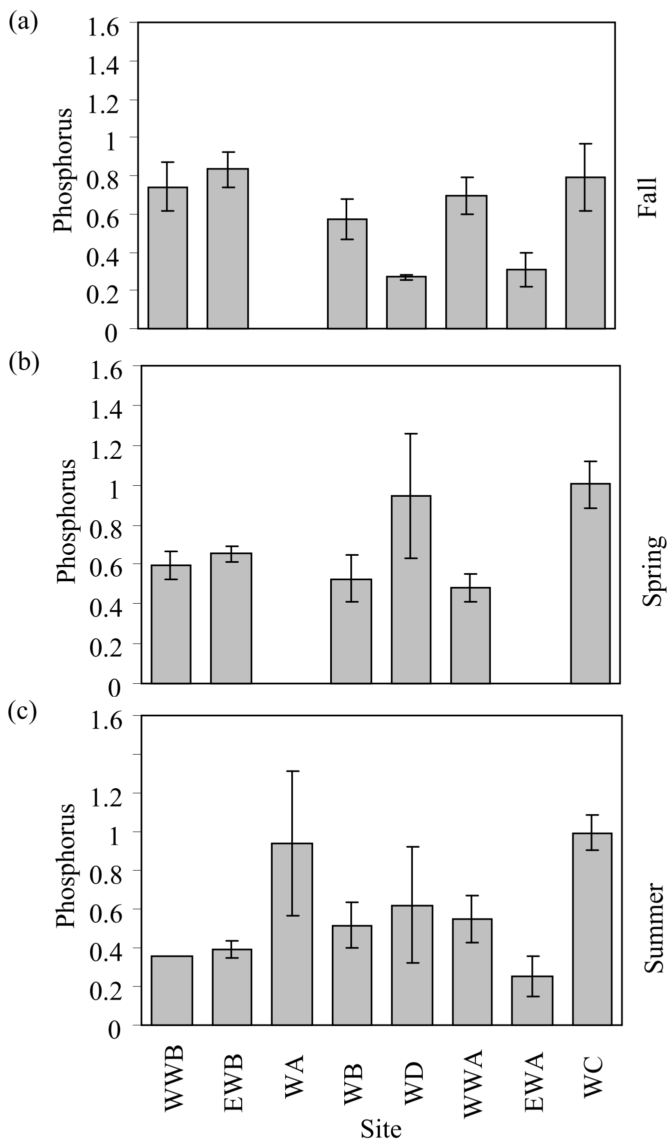

Figure A.9.10. Average percent P body mass for predators: seasonal variation (a) fall, (b) spring, and (c) summer at selected sites sampled during 2007 and 2008.

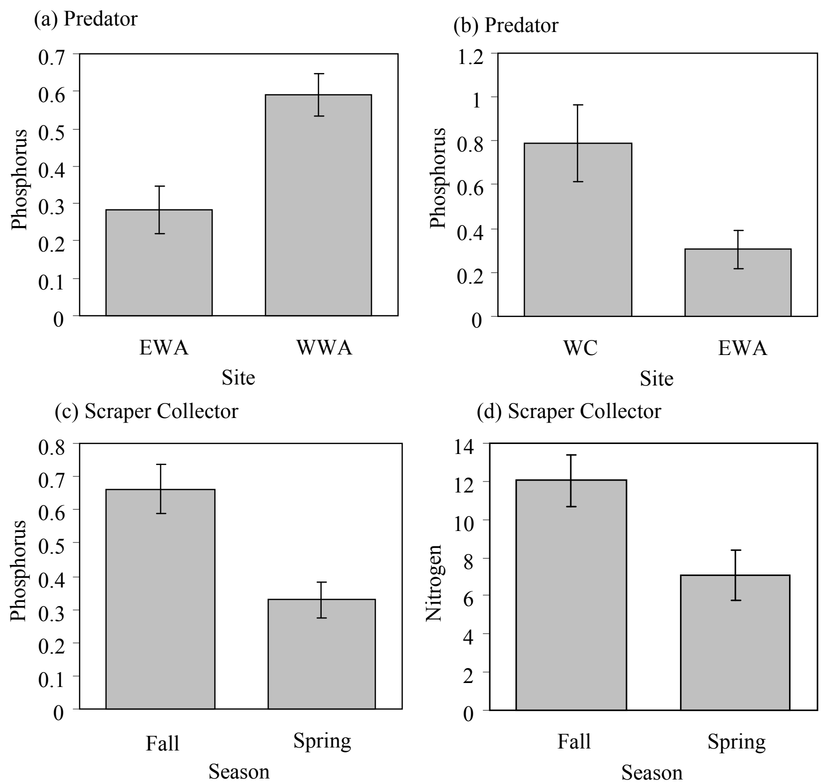

Figure A.9.11. Average percent nutrient body mass for selected FFG at sites sampled during 2007 and 2008: spatial and spatial variation (a) average percent P body mass for predators at sites EWA and WWA, (b) average percent P body mass for predators at sites EWA and WC in the fall, (c) average percent P body mass for scrapper collector at site WWA in the fall and spring, and (d) average percent N body mass for scrapper collector at site WWA in the fall and spring.

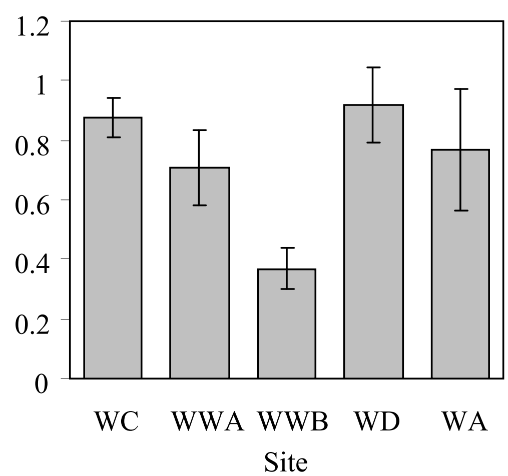

Figure A.9.12. Average percent P for FFG shredder at selected Walker River Basin sites sampled during 2007 and 2008: temporal variation.

DISCUSSION

From our data, the impacts of nutrients (anthropogenic activities) on the water quality and distribution of BMI are clear. However, it is not clear at this point if the nutrients are correlated to certain agricultural practices. Water quality correlates to the general characteristics of the Walker Basin. Site WWB upstream has significantly lower levels of TN, and TP, as this west fork of the upper Walker River is relatively pristine. The East fork (EWB), on the other hand, is just below Bridgeport Reservoir, which is known to undergo periodic algal blooms due to higher levels of nitrogen and phosphorus concentrations in the system (Nevada Division of Water Planning 2001). Total Nitrogen and TP levels generally increase along the gradient as the river moves downstream toward WC and WB. The most degraded part of the river is site WA Schurz. Water coming from the Sierra Nevada's into the WWB site has high flow and low nutrient concentrations. As the river flows downstream toward the remaining sites, it encounters agricultural areas where the water is being diverted out and the flow is decreasing. These areas are also adding nutrients to the system because of nonpoint source runoff, which is often high in fertilizers used to sustain livestock and agriculture in the area. Hence, by the time the river gets to WA, flow is very low and concentrations of nutrients (TN and TP) are quite high. This trend is shown in Figure A.9.2.

Species richness was generally observed to correlate with water quality data. Subsequently, WWB, a relatively pristine section of the river, was richest in species compared to other sites. Similarly, for site EWB in fall, high TN and TP correlated with low species richness (see the section by Sada *et al*. for more details about taxa and richness metrics of Walker River).

Since the water quality data correlate with the general understanding of the basin characteristics, they can be used to assess BMI seasonal and spatial stoichiometric variations. As discussed earlier, invertebrates are homeostatic, so if the homeostasis theory holds true, they should not vary in C, N, and P body composition regardless of environmental conditions. However, the degree of homeostasis differs between species and genus (Elser and Urabe 1999). Similarly, Acharya *et al*. (2004a) have shown that the same species of *Daphnia* fed low-quality P-limited food had a lower body P content compared to the *Daphnia* fed high-quality P-rich food. Therefore, it is not surprising that the existing data suggest that this theory does not explain a complex system like Walker Basin, so it is best to approach this at a much finer scale.

At the genus level, the data suggest that P composition for *Ephemerella* sp. and *Skwala* sp. are significantly different at sites WWB and EWB, correlating with the water quality data, i.e., site WWB has significantly higher TP concentration levels than site EWB. Also, genus *Heptagenia* sp. differed in body composition due to habitat differences. It is possible that genuses *Skwala*, *Heptagenia*, and *Ephemerella* may not regulate their bodies as efficiently as other invertebrates. So, species in these genera may be more susceptible to increased nutrients or lack thereof in the Walker Basin system. During detailed analysis, significant seasonal variations in many genuses were shown to reflect the seasonal nutrient dynamics. For example, *Brachycentrus* sp. (Figure A.9.7a) body P content significantly differed between summer and spring. As shown by water quality data (Figure A.9.3), generally higher levels of TP occurred in summer than spring on all sites. A similar trend was established in the genus *Skwala* sp., which had significantly higher levels of %P composition in the spring compared to fall. These differences may have arisen because of the inability of *Skwala* sp. and *Brachycentrus* sp. to regulate their bodies as efficiently as other genuses. Hence, it is likely that a change in water quality would impact these particular genuses more than others. However, recall that many zooplankton and invertebrate species are known to have bodily nutrient demand based on their growth. For example, Acharya *et al*. (2004b, 2006) found that faster-growing zooplankton at juvenile stages have higher P requirements and therefore higher concentrations in the body to meet increased growth and maintenance demands. It is possible that the seasonal differences in body nutrient contents in *Skawala* and *Barchycentrus* are also partly due to their life stages requiring higher P contents. This can only be verified by understanding the details of the life history characteristics of these invertebrates.

When the role of spatial and temporal analysis in specific FFG was assessed, it was found that; overall, collector gatherers were higher in body percent P contents than both scraper collectors and predators. Similarly, predators were higher in percent P than scraper collectors (Figure A.9.9). Previous studies have found higher percent N in predators relative to herbivores (Fagan *et al*. 2002, Cross *et al*. 2003). Fagan *et al*. (2002) suggested that herbivores have evolved a lower dependence on N because of the chronic existence of low dietary N. They argue that if this is correct, then herbivores should also have lower P contents than predators. This is supported by the data where scrapper collectors had lower body P content than predators, strengthening Fagan *et al.*'s hypothesis. This trend means a shift in community composition of FFGs can occur based on excess nutrient inputs or severe nutrient deficiencies. Therefore, the data suggest that collector gatherers may out-complete other FFGs if highly concentrated nutrients are discharged into the system.

A more genus-level fine-scale approach showed other alarming results when FFGs were analyzed based on season and spatial variations. Predators showed significant variations in percent P composition when analyzed by site and season (two-way ANOVA, effect of 'site x season') ($p<0.05$, Figure A.9.10). For example, elemental composition of predators at sites EWA versus both WWA and WC differed significantly. Similarly, for scraper collectors, a significant difference was found for percent P and percent N compositions at site WWA in fall versus spring. All four of these differences do not correlate with water quality, however, suggesting that there is more than just TN and TP playing a role in the system. Based on these studies, the periphyton and other food stoichiometry cannot conclusively link all the nutrient data with BMI body nutrient contents and stoichiometry. However, the existing lack of correlation between predators and water quality in this category may be due other factors not covered by our studies.

Overall, the data provide a basic understanding or snapshot, of what is going on between BMIs in changing environmental conditions, and much of it points towards a very complex system. The data do not provide conclusive and overarching trends or correlations, therefore, a more focused genus-based detailed data collection and analysis of the Walker Basin BMIs is required for thorough understanding of the environmental impacts on the BMIs and overall food web ecosystem. This study is the first to examine

Walker River BMI elemental composition and stoichiometry on a relatively large scale. The results indicated that some specific invertebrate taxa in streams are relatively invariable in their elemental composition, however, considerable differences were also found among taxa. Many of these variations were explained by regional and seasonal variation in water quality. More targeted biomonitoring involving BMI and primary productivity is suggested in the future to ascertain the stresses on particular organisms in the area. It is also suggested that a precautionary approach be taken when water rights acquisitions are allotted, especially in areas with higher pollution levels.

CONCLUSION

Excess nutrients alter the elemental composition of several food sources for macroinvertebrates including CPOM, FPOM, SPOM, periphyton, and epiphyton, increasing the storage of P or N. These results indicate that human modification of nutrient inputs into aquatic ecosystems can alter the stoichiometric relationships between consumer and food with consequent effects of food web structure and function. Theory of ecological stoichiometry (Sterner and Elser 2002) provides a mechanistic framework for how animal species vary in mediating nutrient cycling, a key ecosystem process. The assemblages and distribution of the BMIs' frequent changes in response to pollution stress allow for the development of biological criteria to evaluate anthropogenic influences. The BMIs responded by either reducing diversity or increasing dominance by a single or group opportunistic species, and a reduced individual site has larger implications to the food web. This is important because the dominant species with different levels of pollution tolerance will lead to an uneven population distribution and higher population at more polluted sites by pollution-tolerant species.

In conclusion, identification of BMI species and genus with their body elemental concentration at polluted and non-polluted parts of the same river could be used as potential bioindicators for river pollution. These macrobenthic species can be used to establish biological criteria for classifying the river ecosystem as healthy or polluted. This information is very important for informing regulators of the conditions and how the use of bioindicators can assist in environmental monitoring and management. The data collected in this study serve as a start towards establishing potential bioindicators for river pollution, however, additional studies are needed in this area.

ACKNOWLEDGEMENTS

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A.10: FISHES OF WALKER RIVER: PRESENT COMPOSITION AND BASIC ECOLOGY

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INTRODUCTION

Historically, Lahontan Cutthroat trout (*Oncorhynchus clarkii henshawi*; LCT) occurred and spawned in the Walker River Basin from Walker Lake to the Twin Lakes in California. However, with the introduction of invasive species and barriers on the river, native LCT have been extirpated from the system. Multiple irrigation diversions are located on the Walker River that impede fish passage year round and seasonally depending on the amount of water flow. Although multiple reservoirs have been built in the Walker Basin, three main reservoirs are have been built that provide water for irrigation, the upper reaches of the East Fork (Bridgeport Reservoir) and West Fork (Topaz Lake) and on the main stem of the Walker River (Weber Reservoir). These reservoirs also impede fish passage to potential spawning habitat. Samples were collected during three periods (August 2007, September 2007, April 2008) from eight locations similar to the benthic and water quality monitoring sampling (see previous chapters). The objective of this study was to document the current ecological condition of the Walker River fish community along a longitudinal gradient.

Electroshocking transects, at each of the eight locations, encompassed all river habitats (pool, run and riffle) when possible. Lower and upper boundaries were established at each sampling location and a one-pass sampling scheme was preformed using one electroshocker and three netters. Due to the width of the river at a majority of the sampling locations and a limited number of field personal, block-netting was not possible and, therefore, overall fish population densities were not able to be calculated. Of particular interest, was that no LCT was caught at any of the eight sampling locations or sampling dates. Overall, the fish community composition consisted of 10 fish species from the eight locations where electroshocking occurred (Tables 1 and 2). Weight, length, and body condition were taken for each fish (Table 1). Fifty percent of the species were native, with nonnative coldwater species (brown trout, rainbow trout, etc.) captured in the upper reaches and warmwater nonnative species (bass, catfish, and carp) caught in the middle to lower reaches. Lahontan redside shiner, a forage fish for top predators, was the only native fish captured across most reaches. Otherwise, larger, coldwater predators (nonnative and native) such as brown trout, rainbow trout, and mountain whitefish were found in upper, middle, and lower reaches, but not necessarily overlapping. Whitefish and rainbow trout were only caught in the upper reach of the East Walker River (WWLW). Brown trout were only caught in the upper site on the West Walker (MURP). Both locations have high benthic diversity, with rainbow trout having the largest diversity of prey items identified.

Table A.10.1. Walker River fish composition. Mean weights and lengths are pooled from all locations due to lower sample size across seasons.

Scientific Name	Common Name	Code	Weight (g)	Mean ± SD	Length (mm)	Mean K
Amereiurus nebulosus	Brown Bullhead Catfish	BB	54.5	10.0	134.8	2.6
Catostomus platyrhynchus	Mountain Sucker	MS	38.9	5.5	104.2	2.2
Cottus beldingii	Paiute Sculpin	PS	8.7	1.2	69.0	2.4
Cyprinus carpio	Common Carp	CC	411.0	111.9	222.6	2.5
Micropterus dolomieu	Smallmouth Bass	SB	75.3	4.5	139.8	2.6
Oncorhynchus mykiss	Rainbow Trout	RB	207.4	35.3	211.0	1.9
Prosopium williamsoni	Mountain Whitefish	WF	222.7	81.0	219.9	1.5
Rhinichthys osculus	Speckled Dace	SD	2.2	0.6	41.2	2.7
Richardson balteatus	Lahontan Redside shiner	RS	3.3	0.4	54.0	2.1
Salmo trutta	Brown Trout	BT	94.7	42.4	137.0	1.9

Table A.10.2. Fish composition by location.

Location	BB	BT	CC	MS	PS	RS	RB	SB	SD	WF
FLST				X		X			X	
MURP		X								
MVWR	X		X			X		X		
SHRZ				X		X				
STRB				X		X				
WABU			X			X		X		
WLSN				X		X			X	
WWLW					X		X			X

Nonnative rainbow trout seemed to feed across many different benthic invertebrate taxa but predominantly on trichoptera and dipterans (Figure A.10.1). Nonnative brown trout selected mostly emphemeropterans and dipterans, while native mountain whitefish overlapped with both rainbow trout and brown trout diet by feeding on dipterans and trichoptera. Diet selection by weight indicated dominant use of trichopterans for all game fish species (Figure A.10.2). Dipterans supported brown trout and whitefish energetics, with brown trout utilizing crayfish (decapods), ephemeropterans, and coleopterans.

Future research should focus on understanding the relationship of diets during more wet periods and model the growth of species in relation to food and flow. This will allow for better predictions related to changes in environmental conditions over time.

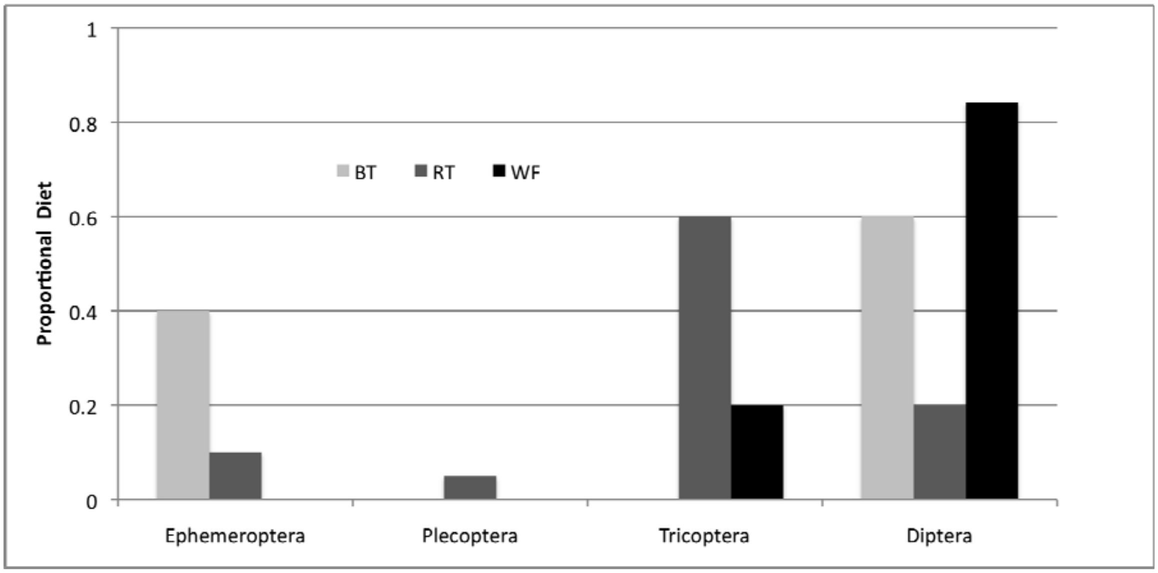

Figure A.10.1. Proportion of diet by occurrence (BT n = 11; RT n = 8; WF n = 6).

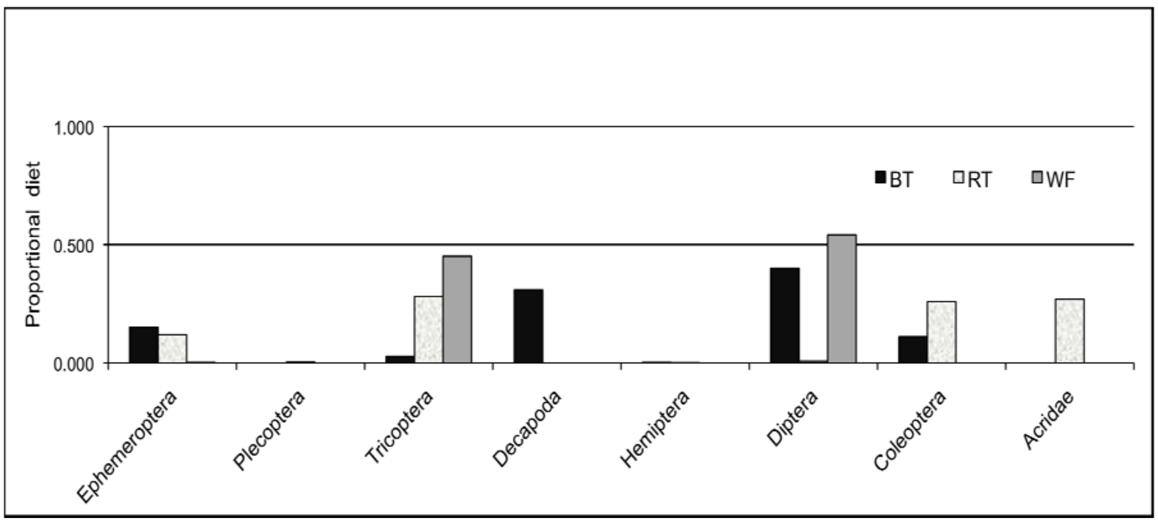

Figure A.10.2. Proportional diet of rainbow trout, brown trout, and whitefish by dry weight.

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PROJECT B: ALTERNATIVE AGRICULTURE AND VEGETATION MANAGEMENT

ALTERNATIVE AGRICULTURE AND VEGETATION MANAGEMENT IN THE WALKER BASIN

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

With increasing demands on available water resources in Nevada, research is needed to determine the practicality and profitability of growing low-water use crops. Currently, the majority of irrigated agricultural land in Nevada is used to grow alfalfa, a high-water use and relatively low-profit crop. In this study, we compared the performance of 14 varieties of 13 alternative crops, which included annual grain and biomass crops, under different watering regimes (4, 3, and 2 feet/acre) on several soil types in the Walker Basin, Lyon County, Nevada. The goal was to determine which species are the most productive in Nevada, as well as which species maintained the highest productivity under reduced water application. Teff and amaranth were the highest performing annual crops, with seed production comparable to production elsewhere. Additionally, both species produced seeds at the lowest watering levels. Warm season biomass crops were generally not as successful as cool season ones, though old world bluestem was an exception, establishing well and producing biomass comparable to cool season species. Additionally, bluestem was the top performing warm season grass in the lowest watering treatment. Cool season grasses established and grew well in both sites, and were very competitive with weeds. There was variability in performance of some species between sites, but tall wheatgrass was consistently a top performer, in both high and low water applications.

In some cases, farmers may choose to cease farming rather than continue to grow crops with large water requirements. When previously farmed land is reverted back to an unmanaged state, this can lead to soil loss and/or the creation of weedy acreage with low-quality forage. We compared the establishment of multiple restoration species (a mix of native grasses and shrubs), monitoring the relative success of planted species with either little (1 foot/acre) or no water addition. All native grasses established significantly better with water application, though there were differences in rank performance between sites. Indian ricegrass was the best performer at one site, with the highest biomass and weed suppression of the other grasses, while beardless wheatgrass was the top performer at the other restoration site. Sagebrush survived transplanting significantly better than other species, and greasewood, though it had low survival, had the fastest growth rate and responded the most to water addition. Watering will not continue in 2010, and additional monitoring will determine which species shows the best long-term potential for revegetation of former farmed sites in Nevada.

INTRODUCTION

Irrigation is the largest water use in the state of Nevada, with field crops accounting for 70% of total irrigated acreage (Nevada Agricultural Service). Ninety-three percent of the field-crop land in Nevada is utilized for hay production, primarily alfalfa (63% of hay acreage in 2007, Nevada Agricultural Service). Alfalfa is a water-intensive crop and may be poorly suited to an arid region where water is becoming increasingly scarce (Grimes et al. 1992). While alfalfa plants will survive with less water than is currently applied (four feet/acre), withholding water from alfalfa fields reduces yield and eventually permanently damages the plants (Ottman et al. 1996). Alfalfa is a relatively low-value crop (Breazeale and Curtis 2006), and little research has been conducted to gage the productivity of other low water-use alternatives. Thus, data are needed to provide Great Basin farmers with viable alternatives to alfalfa production. Other crops may be equally or more profitable to grow than alfalfa and with less water. While there is a strong interest within Nevada's agricultural community in growing specialty crops, no information is currently available on the suitability of alternative crops to Nevada's agricultural lands (USDA plants database http://plants.nrcs.usda.gov).

We tested the performance of three main types of plants under three different watering regimes: annual pseudograin crops, cool season biomass crops, and warm season biomass crops. Annual pseudograin crops can be used as either alternative food crops for humans or high-quality forages (Sedivec and Schatz 1991, Abule et al. 1995, Sleugh et al. 2001, Curtis et al. 2008). Because the growing season of annual crops is shorter than perennial ones, overall water use by these plants is normally lower than alfalfa. Biomass crops are currently under investigation for use as alternative cellulosic ethanol fuels (Milliken et al. 2007). Warm season grasses use C_4 photosynthesis, and have greater water use efficiency (WUE) than cool season grasses, which use C_3 photosynthesis. Alfalfa also uses C_3 photosynthesis and has WUE rates comparable to other C_3 species (Grimes et al. 1992). Warm season grass phenology dictates that growth occurs in the hottest part of the year, and long day lengths combined with increased temperature can lead to extremely high productivity in these species. In addition, warm season grasses are particularly recommended for biofuel production (Sanderson et al. 2006).

Nevada has a range of environmental variability that far exceeds the variability of the Northern Prairie, where most data on biofuel crops are collected. Warm season and cool season grasses have different responses to environmental variability that directly affect their suitability for biofuel production (Jefferson et al. 2004), and the warm season plant phenology requires that water be applied during the hottest part of the growing season, when water can sometimes be unavailable in Nevada. Additionally, competition with common weed species may be higher for warm season grasses, as soil resources may be preemptively uses by predominantly cool season weeds.

The first portion of this study evaluated the relative performance of annual vs. perennial species and C_3 vs. C_4 species when grown in conditions typical in the state, including soil characteristics, weed competitors, and limited water availability in some years. We present data on the productivity of perennial biomass crops at two sites under different watering regimes. Analysis on whether new crops have the potential to significantly increase the earning potential of farmers while decreasing water use is presented in Curtis et al. (this volume).

The amount of land used for agriculture in Nevada has been slowly declining. Irrigated land has dropped from 8,900,000 acres in 1983 to 6,300,000 acres in 2007-2008 (Nevada Agricultural Statistical Service 2008). While some of agricultural land has been converted to housing and suburban use, some farms have been abandoned following the sale and or transfer of water rights from the land. Abandoned farms generate an environmental legacy that includes air pollution from soil loss and acres of weedy wastelands with poor regeneration of native vegetation (Jackson and Comus 1999). In desert areas, land that has been previously used for agriculture does not automatically revert to native vegetation when farming ceases (Jackson and Comus 1999, Jackson and

Jackson 1999). If reseeding does not occur, weeds will proliferate and soil will be lost. Sowing perennial grasses and irrigating at a low level through the establishment phase may suppress weeds (Blumenthal et al. 2005, Bugg et al. 1991), increase water quality (Lodge 1994), and encourage establishment of native vegetation after a farm has been abandoned (Burke et al. 1995).

There is some evidence that seeded perennials may not persist on abandoned agricultural lands without management (Rein et al. 2007), but the effect of a minimal watering regime to assist establishment has not been tested in Nevada. Seeding perennial grasses may provide forage for large herbivores and habitat for birds and other small animals, both of which are superior to weed infested lands (Elstein 2004). The potential for and effectiveness of restoring agricultural lands using perennial grass seedings and shrub planting has not been researched in the Great Basin. Species commonly used in post-fire restoration in the Great Basin may also be effective in reclaiming abandoned agricultural land. In the second portion of this study, we tested the effectiveness of five different perennial grass species and four native shrubs, and included comparisons of commercially available varieties within two grass species. We expect that water would increase establishment and productivity of seeded grasses and shrubs, but also expected weeds to respond favorably to water application. Our hope is that over time, perennial species will come to dominate restored sites: as they become established, they may become more competitive for soil resources.

METHODS

Overview

These experiments were initially conducted at four locations in Mason Valley, Lyon County, NV (Figure 1) in 2007/2008. Establishment of all species was poor at two of these sites, and these were abandoned at the end of the 2007/2008 season, reducing the experiment to two remaining sites. Overall, 24 varieties of 22 species were planted, including warm and cool season biomass crops, alternative annual pseudograin crops, native grasses and shrubs. Annual crops were planted anew in the late spring in 2008 and 2009, while perennial grasses were established once, in either the fall of 2007 (cool season grasses) or the spring of 2008 (warm season grasses). Perennial shrub seedlings were transplanted into restoration sites at two locations in the fall of 2008.

The goal of the irrigation applications for the annual pseudograin crops, cool season biomass crops, and warm season biomass crops was to apply one of three watering levels: a full, 100% watering treatment designed to correspond to standard alfalfa farming practices (4 acre feet of water/year), a 75% treatment (3 acre feet/year), or a 50% treatment (2 acre feet per year). The goal of the irrigation applications for the restoration experiment was to apply either a 25% treatment (1 acre foot/year), or a no water treatment. Annual crops were harvested at the end of each growing season (2008, 2009). Establishment and density measurements of perennial grass species and weeds were recorded in 2008, as well as productivity for cool season grasses at one field and production data for a subset of annual crops. Biomass measurements of warm and cool season perennial grasses and weeds were obtained in 2009, as well as survival and growth measurements of transplanted shrubs in restoration fields, and production data was again obtained for a subset of successful annual crops.

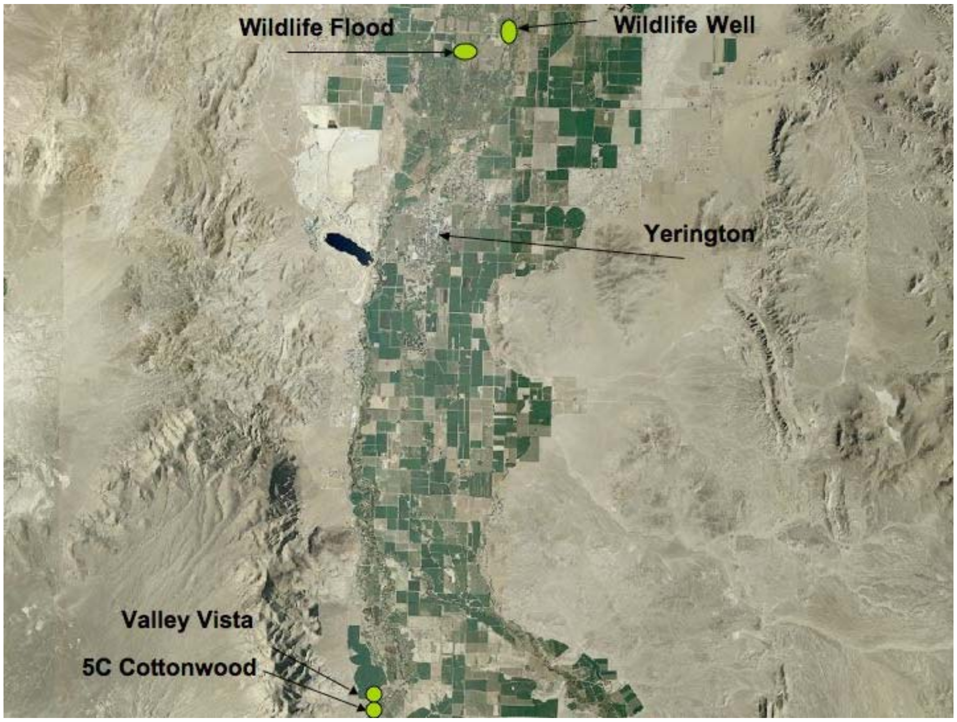

Figure 1. Location of all four field sites. Wildlife Flood and Wildlife Well were farmed in 2007/2008 only; Valley Vista and 5C Cottonwood were farmed for two growing seasons (2007/2008 and 2008/2009).

We anticipate maintaining the two successful fields for additional growing seasons. The current watering regime will be maintained on warm and cool season biomass crops, and productivity will be monitored for an additional 2-3 years. Restoration fields will be unwatered in 2010, and we will monitor the survival and productivity of restored species and weeds in these plots for an additional 2-3 years. If we receive additional funding, trials of the successful annual grain crops will be tested for the next 2-3 years, with alternative weed management methods incorporated into the planting design, in order to determine the best cultural practices for establishing these species.

Field Locations and Preparation

2007/2008

The Wildlife Flood (Figure 2a) and Wildlife Well (Figure 2b) sites were formerly utilized for forage cultivation at Mason Valley Wildlife Management Area, and are collectively referred to as the Wildlife sites (39°02' N, 119°06' W. The 5C Cottonwood site (5C) and Valley Vista sites occur on private ranch properties (Figure 2c), and are collectively referred to as the Ranch sites (38°51' N, 119°11' W). The 5C site is a historically cultivated field, which has been fallow for 20+ years, and the Valley Vista site was used for alfalfa cultivation up to the start of this experiment. Three fields (5C, Valley Vista, and Wildlife Well) were irrigated with sprinklers, and Wildlife Flood was irrigated with flood irrigation. These fields occur on different soil types with different salinities, as detailed by Miller et al. (this volume).

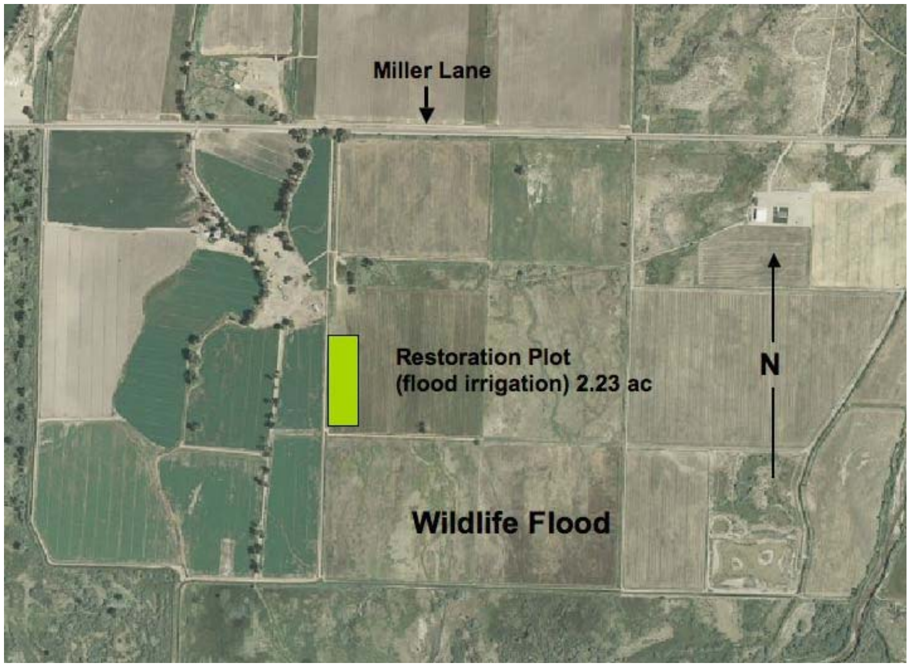

Figure 2a. Wildlife Flood site. Restoration site shown in rectangle; no crops were planted at this site.

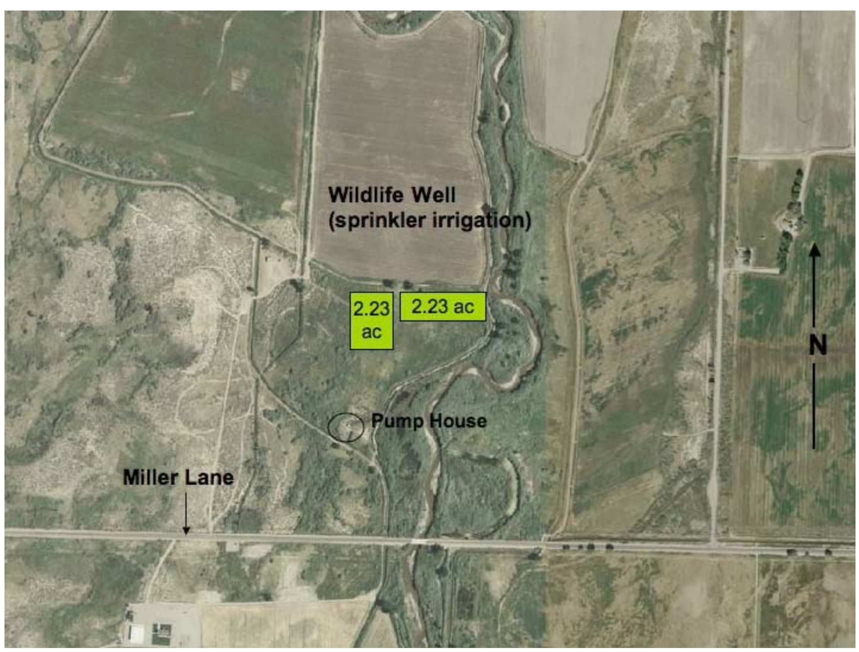

Figure 2b. Wildlife Well site. Restoration field is eastern-most rectangle, alternative crops are in western rectangle.

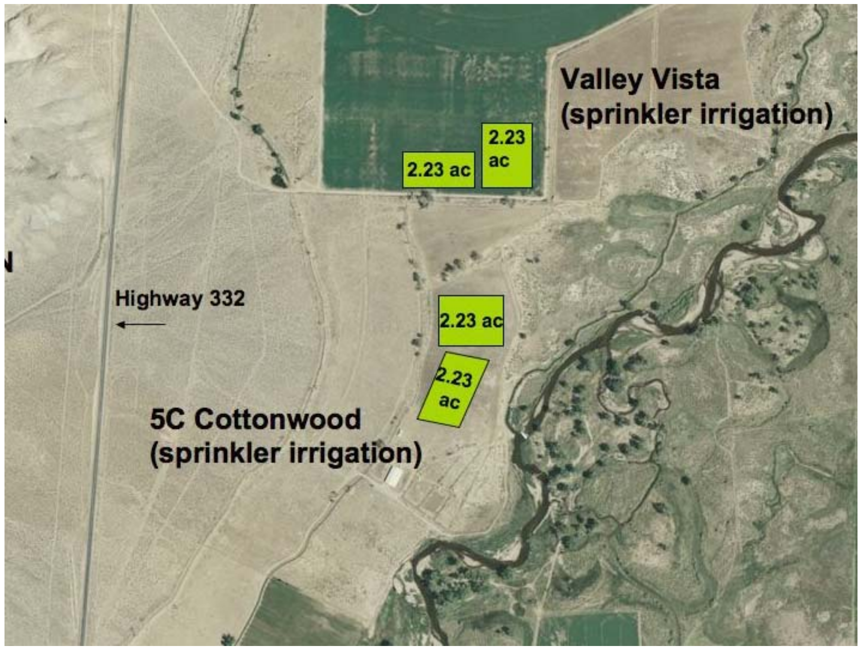

Figure 2c. 5C and Vista Valley sites. Restoration fields are west (Valley Vista) and south (5C) fields.

Both herbicide and mechanical treatments were used to prepare the fields for planting. An herbicide treatment (Glyphosate, 1.0 a.e lb/acre in 20 gallons water per acre,) was applied to the Valley Vista site on June 29, 2007 in an effort to kill the existing alfalfa. It was only marginally successful and the field was resprayed on August 20, 2007 with a tank mixture of Glyphosate (2 lbs a.e. per acre) and Dicamba (.5 lbs a.i. per acre) in 20 gallons of water per acre. In addition, the same herbicide mixture was applied to the Wildlife Well and flood sites on the same date. Herbicide was applied to the Well site in an effort to control creeping wild rye (*Leymus triticoides*) and willow (*Salix* sp.) resprouts. The application to the Wildlife Flood site was to control existing tall wheatgrass (*Thinopyrum ponticum).*

The three fields prepared for sprinkler irrigation (Wildlife Well, 5C and Valley Vista) were ripped, disced and floated in September of 2007. The Wildlife Well site was mowed prior to ripping, discing and floating to remove large amounts of standing willow (*Salix* sp.) biomass. The Wildlife Flood site was prepared for flood irrigation by mowing, ripping, and discing followed by laser-leveling and levee building to separate different watering treatments.

Establishment of Restoration Fields

2007/2008

Six sowing treatments (corresponding to seven varieties of five species, and one control, non-seeded treatment, Table 1a) and two watering regimes (no water and 25% water,) were combined in a factorial design, with three replicates of each species and water combination per field (Figure 3a). Watering regimes were applied in strips, with each strip alternately no- or 25% water, for a total of three treatment blocks. Two strips were non-randomly sown, while sowing treatments were random in the other four strips. Plots were 30 by 90 feet, and each strip contained a full complement of the six sowing treatments. Single varieties of beardless wheatgrass, inland saltgrass, and basin wild rye were sown, and two varieties of Indian ricegrass and of western wheatgrass were sown, at recommended seeding rates (Table 1a). When two varieties were sown, the plot was split and half the plot (30' by 45') was sown with one variety, and half with the other. Seeds were planted using a Truax seed drill, with seeds placed 0.5 inches deep, followed by press wheels. All plots except saltgrass plots were rolled with a cultipacker after seeding. The Well and Flood sites were sown Nov 19-20 2007. The 5C site was sown Dec 13, and Valley Vista was sown Dec 18. Saltgrass seeds were scarified by alternating temperatures (40° C and 20° C, each 12 hours) in the growth chamber from May 16 to July 14 prior to sowing into the 5C and Valley Vista fields on July 15 2008.

Table 1. Seeded plant abbreviations and seeding rates.

Common name	Scientific name	Variety	Lbs (pls)/acre	Code
	Restoration species			
a. Grasses				
Indian ricegrass	*Achnatherum hymenoides*	Nezpar, Rimrock	8	Ric
Basin wildrye	*Leymus cinereus*	Trailhead	10	Bas
Beardless wheatgrass	*Pseudoroegneria spicata*	Whitmar	8	Bea
Western wheatgrass	*Pascopyrum smithii*	Arriba, Rosana	12	WesA WesR
Saltgrass	*Distichlis spicata*	VNS	14	Inl
Control	Nothing sown	-	-	NS
b. Shrubs				
Shadscale saltbush	*Atriplex confertifolia*	-	-	
Fourwing saltbush	*Atriplex canescens*	-	-	
Greasewood	*Sarcobatus vermiculatus*	-	-	
Wyoming sagebrush	*Artemisia tridentata ssp. wyomingensis*	-	-	
c. Cool season grasses				
Tall wheatgrass	*Thinopyrum ponticum*	Alkar	15	Tal
Basin wildrye	*Leymus cinereus*	Trailhead	10	Bas
Mammoth wildrye	*Leymus racemosus*	Volga	12	Mam
Tall fescue	*Schedonorus phoenix*	Fawn	15	Fes
d. Warm season grasses				
Switchgrass	*Panicum virgatum*	Nebraska 28	7	Swi
Sand bluestem	*Andropogon hallii*	Woodward	12	San
Indiangrass	*Sorghastrum nutans*	Cheyenne	7	Ind
Prairie sandreed	*Calamovilfa longifolia*	Goshen	7	Pra
Bluestem	*Bothriochloa ischaemum*	WW Iron Master	8	Blu
e. Annuals & alfalfa				
Teff	*Eragrostis tef*	Brown	2	TefB
Teff	*Eragrostis tef*	Ivory	2	TefI
Buckwheat	*Fagopyrum esculentum*	Mancan	50	Buc
Amaranth	*Amaranth hybridus* x *hypochondriacus*	Plainsman	2	Ama
Pearl millet	*Pennisetum glaucum*	Tifgrain 102	3	Mil
Alfalfa	*Medicago sativa*	Mountaineer 2.0	20	Alf

a. Restoration plot layout

I		II		III	
25	**0**	**25**	**0**	**25**	**0**
RicN RicR	RicN RicR	WesA WesR	NS	Inl	WesA WesR
Inl	Inl	Inl	WesA WesR	Bea	RicR RicN
Bea	Bea	NS	Inl	Bas	Inl
NS	NS	Bea	Bas	NS	Bea
WesA WesR	WesA WesR	Bas	RicN RicR	RicR RicN	Bas
Bas	Bas	RicR RicN	Bea	WesR WesA	NS

b. Biomass and grain crop layout

I			II			III		
50	**75**	**100**	**100**	**75**	**50**	**50**	**75**	**100**
Ama	Ama	Ama	Bas	Blu	Blu	Ama	TefI	Alf
Bas	Alf	Swi	Mil	Fes	TefI	Fes	Ama	San
Buc	Buc	Buc	Pra	Pra	Mam	Alf	Fes	TefI
Alf	Ind	Ind	Blu	Ama	Alf	Tal	Buc	Fes
Ind	Tal	Mil	Ama	Mam	TefB	San	Alf	Mil
TefI	TefI	TefI	Swi	Mil	Fes	Ind	Blu	Mam
Blu	Blu	Blu	Alf	TefI	Pra	TefI	Mil	Blu
Pra	Pra	Pra	Ind	Bas	Tal	Buc	San	TefB
Tal	Fes	Fes	TefI	Alf	Buc	Mil	Ind	Ama
Mam	Mam	Bas	San	TefB	Mil	Blu	Bas	Buc
Fes	Bas	Mam	Buc	Ind	Bas	Swi	Mam	Swi
TefB	TefB	TefB	Mam	San	Ama	Pra	Tal	Ind
Swi	Swi	Alf	TefB	Tal	San	Mam	Swi	Tal
Mil	Mil	Tal	Fes	Swi	Swi	Bas	TefB	Bas
San	San	San	Tal	Buc	Ind	TefB	Pra	Pra

Figure 3. Examples of restoration (a) and biomass and grain crop (b) plot layout. Roman numerals correspond to blocks, watering treatments (0, 25, 50, 75, 100) correspond to strips, and individual boxes are 30’ by 90’ plots in (a), and 24’ by 30’ plots in (b).

2008/2009

Two-year old seedlings of four shrub species (Table 1b) were transplanted into the restoration plots at 5C and Valley Vista on December 2, 2008. A total of 77 shadscale, 118 four-wing saltbush, 93 black greasewood, and 132 Wyoming sagebrush individuals were planted across both sites. Seedlings were grown in an outdoor location in Reno, NV, in ½ gallon plastic pots, and were hand transplanted approximately 5 m apart. Seven shrubs were planted in each plot, with one of each species in each plot, and the remaining three spots assigned at random from the remaining plants available. Initial size measurements were recorded (height, width, and length) on 3/25/09, and final survival and size measurements were taken on 8/15/5009. A small number of shrubs were excluded from analysis, if their identification tags were removed or loss appeared to be from unexpected causes (e.g. deer pulled plants from the ground).

Establishment of Biomass and Alternative Annual Crop Fields

Cool season species (Table 1c), warm season grasses (Table 1d), and annual psuedograin crops (Table 1e) were sown in three of the four locations (5C, Valley Vista, and Wildlife Well). The fifteen different species were sown in strips receiving either 50%, 75% or 100% irrigation. Each strip contained a full complement of species, with plot measuring 24' by 30', and each species by watering treatment combination was replicated three times per field (Figure 3b). One set of irrigation treatments (a block) contained a non-random array of sown species, the other two blocks of irrigation treatments had species plots randomly assigned.

Cool season grasses were planted in November and December of 2007. The warm season grasses were planted in May 2008: Valley Vista was planted May 20, 5C on May 21, and Wildlife Well on May 22. All of these plots were sown using a Truax seed drill, with seeds planted 0.5 inches deep, followed by press wheels. A cultipacker was used after sowing on the cool season grasses. Annual pseudograins were planted 0.5 inches deep, except for teff, which was planted as near the surface as possible. In 2008 the annual grains were planted on May 20, 21, and 22, and on June 1 and 2, 2009.

Irrigation

In both years, the fields were irrigated using 3" hand lines with rainbird sprinkler heads set on a 30' by 30' pattern. The sprinkler heads used were ½" brass impact heads delivering approximately 2 gallons/minute/sprinkler. A totalizing flow meter was installed at all locations and used to determine irrigation application amounts. In both years a small amount of watering occurred starting at the beginning of April as a part of the irrigation installation and calibration process.

In 2008, the allowable water available for the 5C site was inadequate to complete the planned irrigation levels on all of the biomass and psuedograin experiments. The restoration plots at three sites received the planned treatment amount, as did the experimental plots at Valley Vista and Wildlife Flood sites. Irrigation at the Wildlife Well site was discontinued mid-season due to problems with the irrigation system, lack of plant establishment, and excessive weed competition.

The 5C, Valley Vista, and Wildlife Well fields were sprinkler irrigated beginning in May 2008. Wildlife Flood was first irrigated on May 5, 2008. On July 9, 2008 the sprinklers to the 50% watering treatment were turned off at 5C, when all treatments had received 2 ft/acre of water. The 75% and 100% irrigation treatments on the 5C site were not applied due to a lack of irrigation water. On July 18, 2008 the sprinklers to the 50% watering treatment were turned off at Valley Vista, followed by the 75% irrigation treatment on August 18, 2008. The final irrigation on Valley Vista occurred on September 8, 2008 when the 100% irrigation treatment levels had been reached.

Only the 5C and Valley Vista sites were irrigated in 2009, and available water was adequate to meet the experimental irrigation treatments on all experimental plots. The experiments were irrigated on a weekly basis beginning in late April (biomass crops and restoration plots), or early June (annual crops) using the equipment and techniques described above. The irrigation was discontinued in each treatment strip when the appropriate amounts of water had been applied. Irrigation was completed in the last week of August 2009 when the 100% level was obtained.

Weed Seed Bank Measurements

Soil cores were taken from all four restoration fields in December 2007 for weed seed bank analysis. Twenty-five haphazardly-placed cores (1” in diameter, 6” deep) were taken per strip. Cores were mixed within strips, and separated into two subsamples per strip. Each subsample was prepared for greenhouse germination (after Creech et al. 2008) by mixing 400ml of soil mixed with 200ml of sand, and placing it in a flat 25cm x 25cm pot which had a 1cm layer of perlite at the bottom, covered with landscaping cloth. Pots were placed on greenhouse tables covered with tarp under polyester quilt batting in order for moisture to wick up through the bottom of the pot. Pots were also watered from above as needed to keep both the soil and the quilt batting moist. Greenhouse temperatures were kept above 50°F and below 90°F, and pots experienced ambient day length. Pots were placed in the greenhouse Feb 5 2008, watering commenced, and germination was monitored. On 17 March 08, the soil within each pot was mixed, and watering and germination monitoring continued until April 17. At this point the pots were allowed to completely dry for one month. Soil was mixed within each pot on May 17, and pots were watered and germination was recorded through June 17 2008. Seedlings were identified to species, when possible, but data presented here is total density of all weed species.

Weed Control

The restoration and biomass/annual pseudograin crop fields were sprayed, mowed, and hand-weeded as needed in an attempt to control common tumble mustard (*Sisymbrium altissimum*), tansy mustard (*Descurainia pinnata*), filaree (*Erodium* sp.), lambsquarters (*Chenopodium album*), kochia (*Kochia scoparia*), annual bursage (*Amabrosia anthicarpa*), goatshead (*Tribulus terrestris*) cheatgrass (*Bromus tectorum*), barnyardgrass (*Echinochloa crus-galli*), and annual love grass (*Eragrostis spp.*).

Prior to planting in May of 2008, all plots in restoration, biomass and alternative crop fields were treated with 0.5 lbs a.e./acre 2,4-D ester in 20 gallons/acre of water. The 5C and Valley Vista sites were mown to a height of 2 inches in June 2008 as a post-emergence weed control treatment for annual grasses. Additionally, post-emergence weed control herbicide sprays were applied in to 5C and Valley Vista in June 2008, using a 4-wheeler with 15 foot boom applying 15 gallons/acre of water ± .025% NIS (nonionic surfactant). In these treatments the teff, pearl millet and warm season grasses were treated with 0.33 oz/acre escort. The cool season grass plots were treated with 0.5oz/acre escort ± 0.5 pound/acre a.e 2,4-D low volatile ester ± 2.5% by volume AMS (ammonium sulfamate). Buckwheat, amaranth, and alfalfa plots at these two fields were not sprayed, but were hand-weeded during June and July 2008. Alfalfa plots were mowed at Valley Vista on June 27 and at 5C on July 2, 2008. Warm season grass plots at 5C were mowed to a height of 2" on July 7, 2008. In late June, prior to planting, the saltgrass plots at 5C and Valley Vista were sprayed with roundup (0.76lb/acre glyphosate, 0.0475 lb/gal concentration, ± 0.025% NIS) to control summer annual weeds growing in the plots. Mowing of the warm season grass plots to a height of 6" continued throughout the growing season, at approximately every two weeks in an attempt to reduce competition from annual grasses.

The 2009 weed control efforts consisted of herbicide application mowing and hand weeding on the biomass/alternative crop experiments. No weed control efforts were undertaken on the restoration plots in 2009. The warm and cool season grass biomass plots on the 5-C and Valley Vista sites were sprayed on April 27 and 28, 2009 with 2,4-D amine at 1.5 pounds a.e. plus .25% NIS in 15 gallons of water per acre. The spray was applied using the equipment described previously. The plots were mowed in mid-May to a height of approximately 6" in an attempt to reduce competition from annual grasses. The Valley Vista plots were spot sprayed by hand using Weedmaster (Dimethylamine salt of dicamba 12.4%, Dimethylamine salt of 2,4-dichlorophenoxyacetic acid 35.7%) @ 1oz weedmaster/gallon of H_2O for broadleaf weed control.

The annual psudeograin plots on 5-C and Valley Vista were sprayed on April 27 and 28, 2009 with 2,4-D amine at 1.5 pounds a.e. plus .25% NIS in 15 gallons of water per acre. The spray was applied using the equipment described previously. The plots were then rototilled to a depth of 3 inches in mid-May to control annual weeds described previously. In late May and June, prior to and following planting, the plots were spot (hand) sprayed with Round-up Super Concentrate (glyphosate isoproylamine salt 50.2%) at 2.5 fluid oz/gallon H_2O to control all emerged annual plant species. All annual pseudograin plots were hand weeded at both sites. Hand weeding continued throughout the growing season on a weekly basis or as required.

On July 2, 2009 the east half of each buckwheat and amaranth plot on the Valley Vista site was hand sprayed with Poast (sethoxydim 18%) @ 1.9 fluid oz/gallon H_2O. This treatment was necessary as the annual grass populations were unable to be controlled using hand weeding and the competition was threatening the viability of the crop species on these plots. Only half of each plot was sprayed, as we were uncertain about the effects of the herbicide on the desired species. The treatment was successful and the production data was obtained from the treated side of the plots.

Fertilization

The plots were not fertilized in 2007-2008 as potential weed competition was deemed to be a major factor and soil test did not indicate the need for fertilizer applications. During 2009 all of the cool and warm season grass plots on the 5-C and Valley vista site were fertilized with 476 pounds per acre of ammonium sulfate (21-0-0). The pseudograin plots on each location were fertilized with the same material at 238 pounds per acre. The fertilizer was applied using hand broadcasters on May 18, 19 2009. No other fertilizers were applied during the course of the experiment.

Monitoring Germination and Establishment

Establishment of seeded species was recorded in 2008 by sampling plots with a rectangular 22 x 31cm frame. Cool season biomass plots were sampled in a stratified random manner with five samples taken per plot. Sampling dates were April 18 for Valley Vista, April 21-22, 2008 for 5C, May 5 for Wildlife Well, and May 6 for Wildlife Flood. Weed density and cover data were also collected at this time. Weed species were either morphotyped or positively identified, and the number of individual weed plants (all species/morphotypes) and the percent cover within the frame was assessed for each quadrat. Here we present data for all weed species combined for simplicity. Establishment of warm season biomass and annual crops was sampled on July 13-15, 2008, using the same methodology. Weed density and cover were not collected for warm season and annual species because weed control efforts at this point were plot and species specific, including mowing and herbicide use that differed (by necessity) by species.

Restoration plots (except saltgrass, which wasn't planted until July 2008) were sampled with the same methodology and over the same time frame. The only exception was in plots with two varieties, where three samples were taken in each half of the plot. Weed densities and cover were measured at all four restoration fields in late April through early May and again in late June through early July 2008. For weed sampling, five stratified-random samples were taken per plot using a rectangular 22 x 31cm frame. When two native seed varieties were sown in a plot, three samples were taken from each half of the plot. Restoration plots were sampled again, using the same protocol to determine mortality over a 5-7 week period: the 5C and Valley Vista sites were sampled on June 12, and Wildlife Well and Wildlife Flood sampled on June 13 2008. Initial shrub size was measured on March 25, 2009, by measuring the height of the tallest point, the length of the widest area, and the width of the shurb perpendicular to its length.

Establishment of seeded species was recorded in 2008 after sowing, by sampling plots with a rectangular 22 x 31cm frame. Cool season biomass plots were sampled in a stratified random manner with 5 samples taken per plot. Sampling dates were April 18 for Valley Vista, April 21-22 for 5C, and May 5 for Wildlife Well. Weed density and cover data were collected at this time. Restoration plots (except saltgrass) were sampled similarly and on the same dates, however plots with two varieties had 3 samples taken in each half of the plot. The Wildlife Flood site was sampled on May 6 2008. Restoration plots were sampled again, using the same protocol to determine mortality over a 5-7 week period: the 5C and Valley Vista sites were sampled on June 12, and Wildlife Well and Wildlife Flood sampled on June 13 2008. Warm season biomass and alternative crops were sampled post-emergence in a completely random manner, using the same frame size and sampling frequency as the other plots. Establishment of seeded plants was monitored on July 13-15 2008. Weed density and cover were not collected in these plots, because weed control efforts at this point were plot and species specific, including mowing and herbicide use that differed (by necessity) by species

Harvest and Productivity

Restoration Plots

Density and biomass of native grasses and weeds were recorded on August 11-12, 2009. The plots were monitored with five 25 cm2 quadrats randomly placed throughout the plot, with the exception that plots with two varieties were sampled with three quadrats per variety. After crop wet biomass was recorded, a subsample of the target restoration species from each plot was collected and weighed wet, oven dried at 40°C and reweighed to obtain a formula for wet/dry biomass conversion. Data is presented as dry biomass, in grams/m^2. Because of the large variability in weed identity from plot to plot, an average water content would not have been very helpful for determining dry weights across plots. Therefore, weed biomass was not dried, and is presented as wet weights, in grams/m^2. Shrub size survival and size was measured on August 15, 2009, again, measuring height, length, and width of plants.

Biomass Harvest

In 2008, biomass data was only collected from the cool season grass plots located on the Valley Vista site. The cool season biomass production was collected from a 20 square meter plot subplot using a Carter forage harvester. A grab sample was obtained, weighed, oven dried and reweighed to convert wet weights to dry. The results are presented as 100% dry matter and are displayed in tons/acre. In 2009, all grass biomass plots from both sites were evaluated for production of seeded species and weed species by clipping and weighing. Sampling took place September 3, September 8-11, and September 14-16 2009. Three randomly located 50 cm^2 quadrats were placed within each plot, except for one species at one site (Tall Fescue at 5C), which had poor establishment. For this species, 25cm^2 quadrats were placed subjectively within the plot in areas where establishment had occurred. Plants were cut to approximately 1 cm above the ground, and separate wet weights were taken for crop and weed biomass. A subsample of wet material of each crop was collected, dried, and weighed for wet/dry conversions.

Alfalfa Harvest

No alfalfa production data was obtained in 2008 as the seeded stands were not fully established. In 2009 the alfalfa plots were harvested 3 times (June 8, July 21, September 3) at the early bloom stage of growth. Each plot was harvested using a Carter forage harvester. Total biomass was weighed from a sub-plot approximately 6.8 square meters in size. A grab sample was obtained, weighed, dried, and reweighed for conversion to dry biomass. The results are presented as 100% dry matter and are displayed in tons/acre

Alternative Grain Harvest

The annual pseudograin crops were harvested during October of 2008 and 2009. In 2008 the teff varieties were evaluated using a Kincaid plot combine to cut a 53.5 square meter area within each plot. The resulting seed was hand cleaned using screen sieves and forced air to separate chaff and contaminates from the seed. In 2009, the teff crops were harvested within a 9 square meter area in each plot using a sickle bar mower. The seed heads were then clipped by hand, and the seeds were collected by rubbing the dry seed heads on a screen. The resulting seeds were then cleaned as previously described. In 2008 and 2009, the amaranth plots were hand harvested by clipping all the seed heads from 3 randomly located, 1 square meter sub-plots in each main amaranth plot. In 2008, measurements were only taken at the 5C, as the plots at the Valley Vista site were lost due to weed competition. The seeds were separated by rubbing the heads on a screen and then cleaned as described previously for teff. The buckwheat and pearl millet plants did not produce enough seeds for harvest in 2008 or 2009.

Data Analysis

All analyses were conducted with JMP (JMP 5.0, SAS Institute, Cary NC), and significance was measured at the $P = 0.05$ level. In all figures, different letters indicate significant differences as measured by Tukey's HSD tests, and bars are standard error. Unless otherwise indicated, transformations were not required to meet assumptions of ANOVA. Unless specified otherwise, ANOVA model effects were: field, block (nested within field), watering treatment, species, and all two and three way interactions between field, species, and water treatment. Due to extreme differences in variance between the Ranch sites (5C and Valley Vista both had high establishment) and the Wildlife sites (Wildlife Well and Wildlife Flood both had low and variable establishment), the Ranch and Wildlife locations were analyzed separately for the 2008 measurements.

Early establishment (April 2008) and end of year one (June 2008) survival of seeded restoration species and of weeds was analyzed using ANOVA. Response variables were the number of established seeded individuals per m^2 and the percent weed cover. Varieties of Indian ricegrass and western wheatgrass were analyzed separately with a similar model separately (with variety in place of species) to determine if the varieties should be kept apart in the full analysis. The two varieties of Indian ricegrass did not perform significantly differently in 2008 or 2009 and were combined for analysis. The Arriba and Rosana varieties of western wheatgrass performed differently ($P < 0.0001$), and so were kept separate in the full analysis. Seed bank data from restoration plots was analyzed with subsamples of strips within blocks averaged prior to analysis, and these averages were analyzed with ANOVA model with field and block nested within field as the model effects. Dependent variables were the total number of weeds, the number of forbs, and the number of grasses per m^2.

Second year measurements were analyzed with the same ANOVA model. Performance of restoration grasses (biomass and density) was analyzed in two ways: once with all species in the model, and separately for the two varieties of Indian ricegrass and western wheatgrass, to test for performance differences between the commercially available varieties. Survival of shrubs was analyzed with logistic regression, and final shrub size (length x height x width, log transformed) was analyzed with the standard ANOVA model, except that initial size of the shrub was included as a covariate, and site was not included, as not all species survived in all watering treatments in both sites. Additionally, growth rate was calculated as (final size-initial size)/initial size.

Early establishment (April 2008) of seeded biomass species and alternative grains was analyzed using ANOVA without watering treatment in the model (because they were not yet different), while second season productivity measurements were analyzed including watering treatment in the model. Number of seeded individuals per meter established, percent seeded species cover, and percent weed cover (cool season grass plots only) were the response variables analyzed from 2008, while productivity of planted species and weeds were analyzed in 2009. Alternative crop density was log transformed for analysis, while all other dependent variables fit model assumptions in their raw form. Annual pseudograin production was analyzed separately for each field site in 2008, because the watering treatments were not applied at the 5C site, while data from 2009 included both sites and watering treatments in one analysis. Second year productivity of alfalfa under differing watering treatments was analyzed in two ways. First, total productivity was summed over the entire three harvests to determine overall differences in yield (site, block, and watering treatment as model factors), and secondly, repeated measures ANOVA was used to determine how biomass changed over time in different watering treatments.

RESULTS

Restoration Plots

Year One: Establishment and Initial Weed Cover

There were significant differences in April establishment in Ranch sites (Table 2a, Figure 4), and species that established well in one site generally established well in both fields (no significant field * species interaction, Table 2a). The small amount of early watering that took place had no effect on establishment at the Ranch sites (Table 2a). In contrast, establishment varied between the two Wildlife sites, as there was a significant three-way interaction (species*field*water), with main effects also significant (Table 2b). Species performance was differently affected by the watering treatments in the two Wildlife sites (Figure 5), with poor establishment at Wildlife Well (generally less than 5 plants/m^2), regardless of the watering treatment. Additional water did increase establishment at Wildlife Flood ($P = 0.01$, Figure 5). Establishment was significantly different between the three blocks at the Ranch sites, and was nearly significant ($P = 0.0502$) at the Wildlife sites, indicating spatial variation in site suitability for these native species.

Weed cover in April was influenced by the early watering treatment at both the Ranch sites (Table 2a) and the Wildlife Well site (Table 2b). At the ranch sites, watered plots had fewer weeds than non-watered plots (no water, weed cover: 19.4 ± 0.87 percent; with water: 16.5 ± 0.88 percent), and the same was true at the Wildlife Well site (Figure 6). At the Wildlife Flood sites in April, there was no difference in weed cover in the designated water plots (2.1 ± 0.45) or the designated non-watered plots (1.9 ± 0.21).

Greater differences in seeded species establishment emerged between the two Ranch sites when plant densities were measured in June of 2008. In general, Valley Vista had greater establishment (125 ± 150 plants/m^2) than 5C (92 ± 113 plants/m^2, Table 2c). In addition, there were species-specific differences in performance between these two fields (field*species interaction, Table 2c, Figure 7). In particular, bearded wheatgrass established much better at Valley Vista than at 5C. The Arriba variety of western wheatgrass established very poorly at both sites. Watering treatment also affected establishment at the Ranch sites: plants in watered plots had significantly poorer establishment (4.7 ±35.5 plants/m^2) than plants in unwatered plots (5.0 ± 21.5 plants/m^2, Table 2c).

Table 2. Results of ANOVA testing the effects of water and field locations on establishment of restoration species at Ranch (a,c) and Wildlife sites (b,d) in April (a,b) and June (c, d).

	a. **Ranch sites: April establishment**				b. **Wildlife sites: April establishment**			
	Crop Density		***Weed Cover***		***Crop Density***		***Weed Cover***	
Variable	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*
Field	0.0_1	0.995	1.8_1	0.186	25_1	**<0.0001**	1.6_1	0.213
Block(field)	4.1_2	**0.0184**	1.7_2	0.154	3.0_2	0.0502	35_2	**<0.0001**
Water	0.64_1	0.424	5.5_1	**0.0199**	6.4_1	**0.0124**	11_1	**0.0012**
Species	25_4	**<0.0001**	2.1_4	0.0638	1.5_4	0.191	1.1_5	0.360
Water*field	1.2_1	0.268	1.2_1	0.265	13_1	**0.0004**	10_1	**0.0017**
Field*Species	2.0_4	0.0995	1.2_4	0.325	3.1_4	**0.0180**	2.0_5	0.0772
Species*water	0.62_4	0.649	0.49_4	0.783	2.8_4	**0.0287**	1.4_5	0.232
Species*water*field	1.5_4	0.207	0.89_4	0.487	4.7_4	**0.0011**	0.38_5	0.864
	c. **Ranch sites: June establishment**				d. **Wildlife sites: June establishment**			
	Crop Density		***Weed Cover***		***Crop Density***		***Weed Cover***	
Variable	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*
Field	7.2_1	**0.0079**	150_1	**<0.0001**	13_1	**0.0004**	25_1	**<0.0001**
Block(field)	9.5_2	**0.0001**	1.5_2	0.235	0.036_2	0.965	7.7_2	**0.0006**
Water	24_1	**< 0.0001**	45_1	**<0.0001**	1.9_1	0.174	15_1	**0.0002**
Species	14_4	**<0.0001**	0.6_5	0.690	2.1_4	0.0779	1.3_5	0.277
Water*field	0.68_1	0.411	12_1	**0.0007**	0.71_1	0.399	1.6_1	0.207
Field*Species	5.7_4	**0.0002**	0.81_5	0.542	1.8_4	0.125	1.3_5	0.283
Species*water	1.6_4	0.188	0.75_5	0.590	1.5_4	0.120	1.2_5	0.334
Species*water*field	0.64_4	0.633	1.4_5	0.231	1.2_4	0.325	2.4_5	**0.0350**

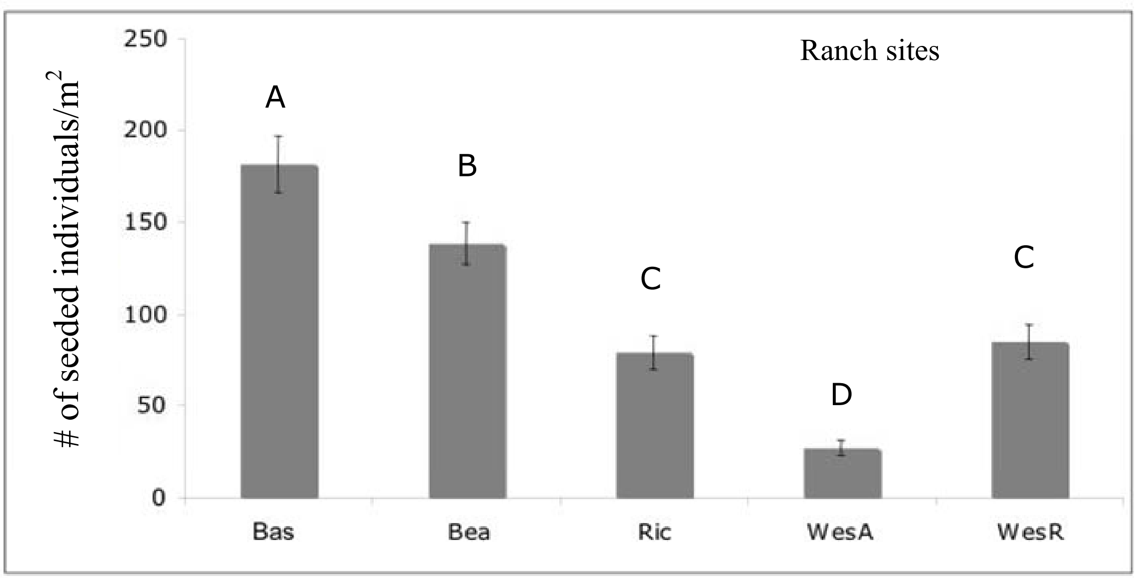

Figure 4. Establishment of native grass species in restoration plots at the two Ranch sites (combined) in April 2008.

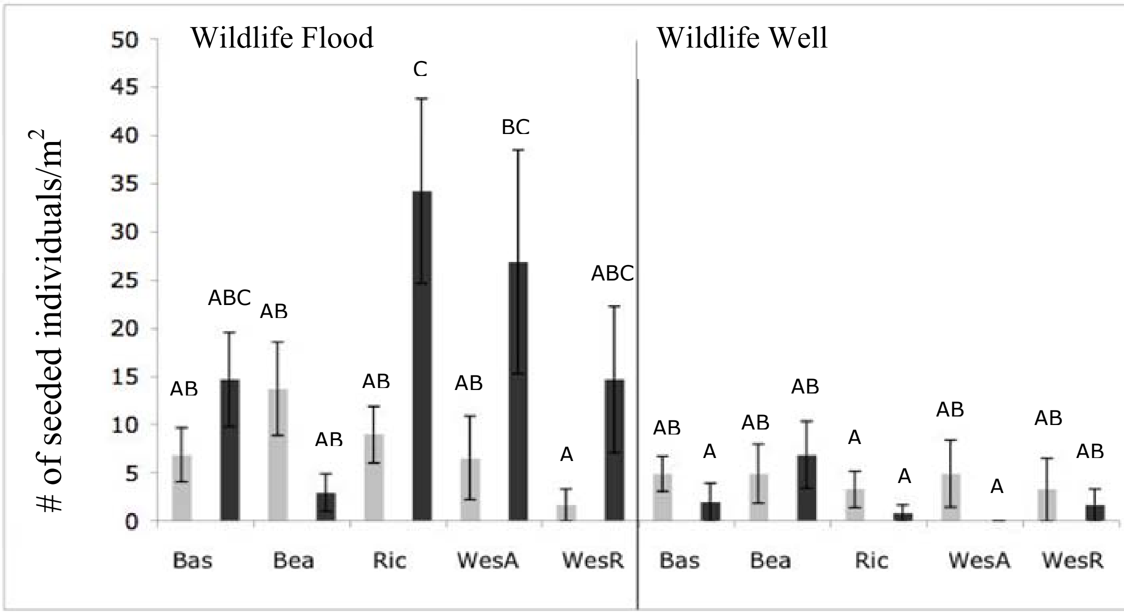

Figure 5. Establishment of native grasses in restoration plots at the two Wildlife sites in April 2008. Dark bars are watered (1 acre/foot) plots, light bars are unwatered plots.

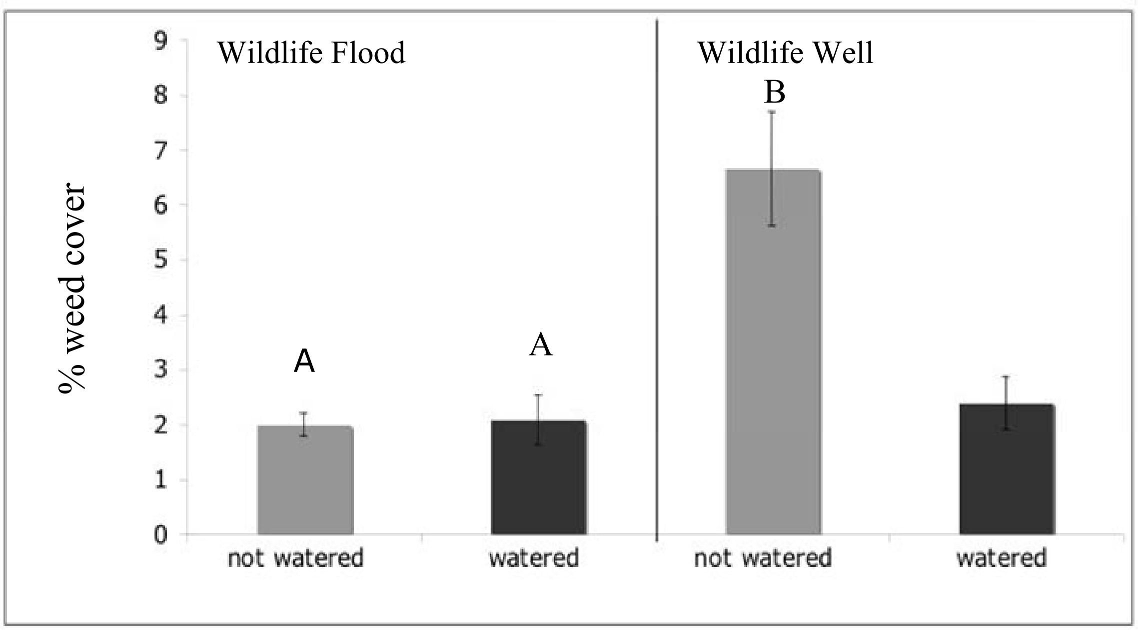

Figure 6. Percent cover of weeds at the two Wildlife sites in April 2008.

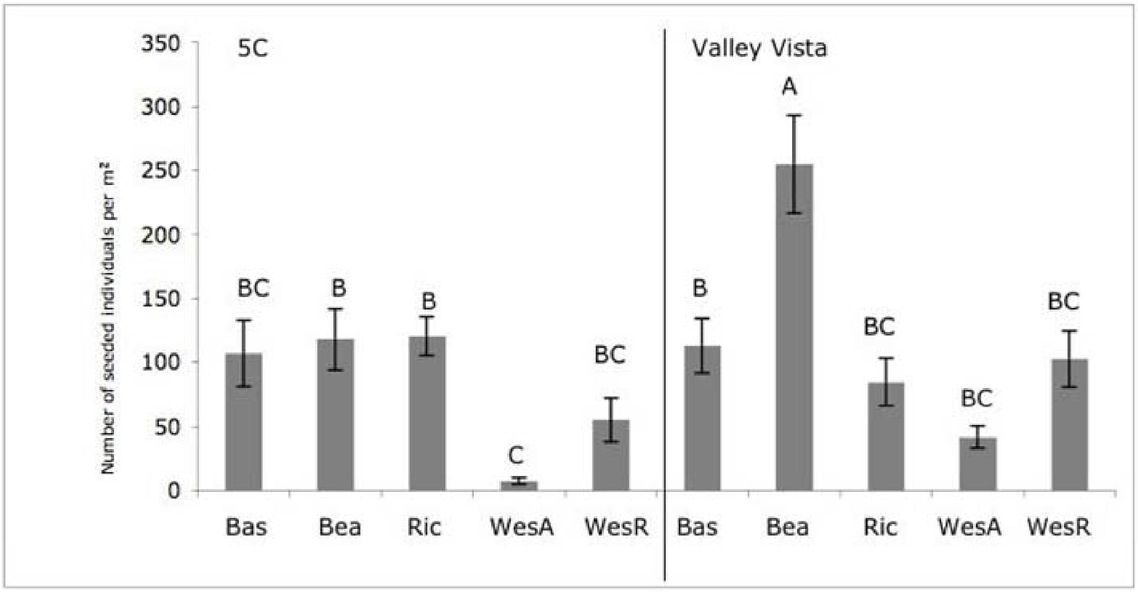

Figure 7. Establishment of native grass species in restoration plots at the two Ranch sites in June 2008.

Mortality at the Wildlife Well site resulted in markedly poorer measured establishment in June (0.4 ± 2.5 plants/m^2) compared to Flood (3.6 ± 8.0 plants/m^2, Table 2d), a reversal of the relationship measured in April. Watering treatment improved seeded species establishment at the Wildlife sites, with watered plots showing 2.4 plants/m^2 (± 26.5) and unwatered plots showing 1.4 plants/m^2 (±16.3, Table 2d).

In general, watering treatments increased June 2008 weed cover at all sites (Table 2c, Table 2d, Figures 8 and 9). At the ranch locations, sites responded differently to the watering treatment (significant field*water interaction, Table 2c). Watering at Valley Vista resulted in a greater increase in weed cover compared to 5C (Figure 8). There were three-way interactions between water addition, site, and species at the Wildlife sites (Table 2d, Figure 9. Water generally increased weed production, except for within basin wild rye plots and western wheatgrass var. Arriba plots at the Wildlife Well site and control plots at the Wildlife Flood site (Figure 9), where watering either reduced or had no effect on weed cover.

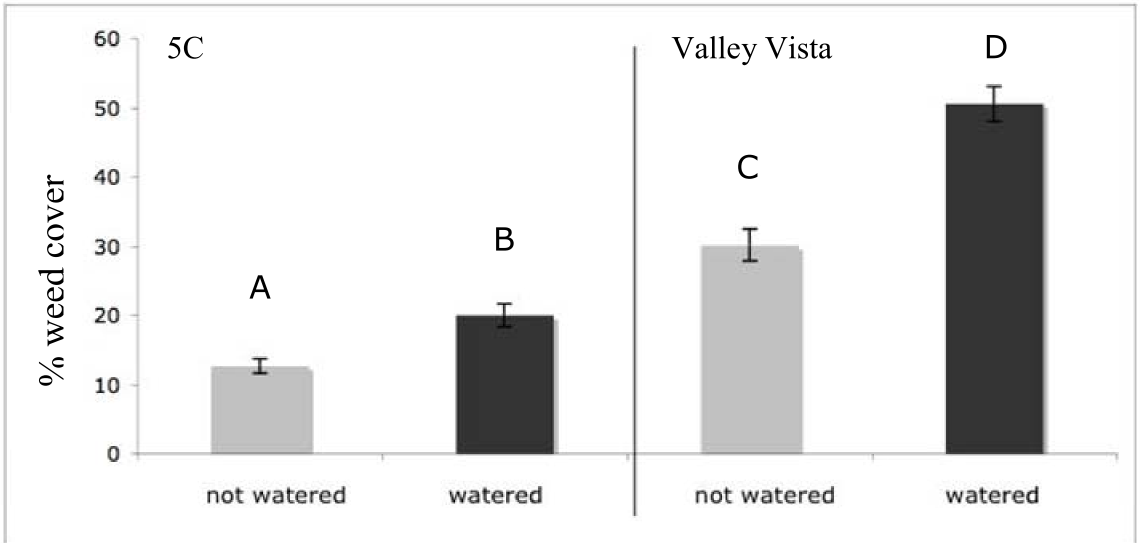

Figure 8. Percent cover of weeds in watered and unwatered plots at the two Ranch sites in June 2008.

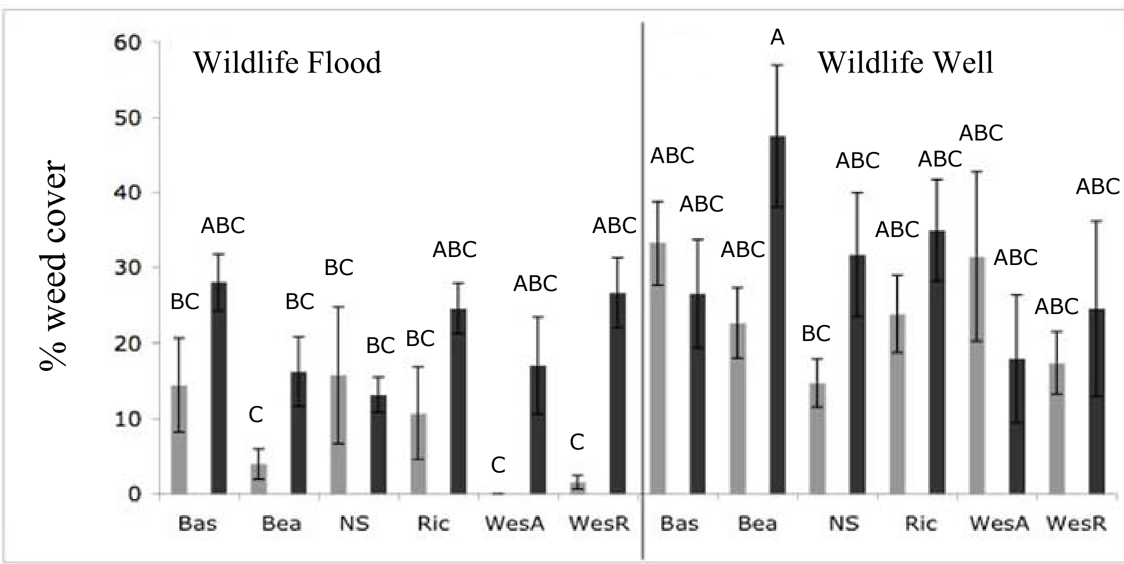

Figure 9. Percent cover of weeds at the two Wildlife sites in June 2008.

There was a difference between Wildlife and Ranch sites in measured seed bank density, with Wildlife sites containing a significantly greater number of seeds (Table 3, Figure 10). This is in contrast to the generally lower amount of weed cover observed growing in these fields (21.4%) compared to the Ranch fields (28.4% cover).

Table 3. Results of weed seed bank analysis from restoration plots.

Variable	F_{df}	*P*
Field	13.0_3	**0.0002**
Block(field)	1.8_4	0.1742
Overall	6.6_7	**0.0009**

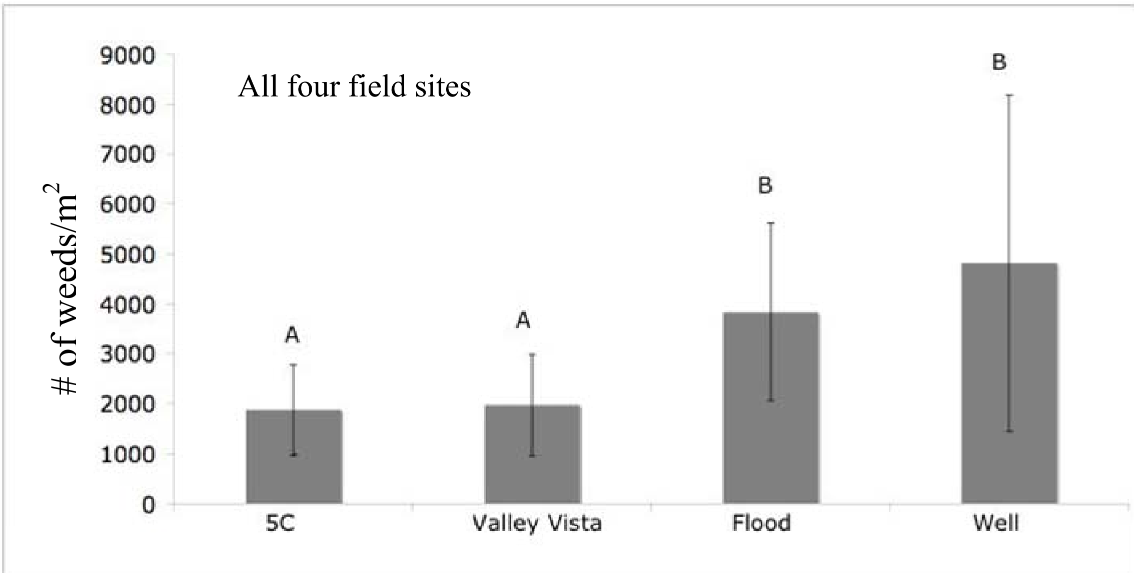

Figure 10. Comparison of weed seed bank densities from all four sites.

Year Two: Density and Biomass

After two years of growth, restoration species differed significantly in their density and responded differently to watering treatments (significant species*water interaction, Table 4a), though densities were similar between the two sites (Figure 11). Saltgrass did not establish at either site, regardless of watering treatment. Western wheatgrass established very well under the 25% watering treatment, but not at all without water. Beardless wheatgrass basin wildrye, and Indian ricegrass had similar densities at 25% water of around 30 plants per m^2, and low densities in the 0 water treatment (between 1 and 4 plants). Biomass differed by species, field, and watering treatment (significant species*water*field interaction, Table 4b). There was very low biomass of native grasses in the no water treatment at 5C (Figure 12a), and almost no plants established in the no water treatment at Valley Vista (Figure 12b). Species performance differed between sites: at 5C, Indian ricegrass had the highest biomass in the 25% watering treatment, while at Valley Vista, the most biomass was made by beardless wheatgrass, followed by western wheatgrass (Figure 12).

Table 4. Results of ANOVA testing the effects of water and field locations on plant density and biomass of restoration species at 5C and Valley Vista (a,b), 2009.

	Ranch sites: Restoration grasses				**Ranch sites: Weeds**			
	a. Crop Density		***b. Crop Dry Biomass***		***a. Weed Density***		***b. Weed Wet Biomass***	
Variable	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*
Field	0.0_1	0.8597	5.8_1	**0.0170**	5.6_1	**<0.0001**	5.7_1	**0.0179**
Block(field)	2.6_2	**0.0366**	1.0_2	0.3919	2.2_2	0.0502	1.4_2	0.2349
Water	204.6_1	**<0.0001**	316.1_1	**<0.0001**	117.1_1	**0.0124**	63.5_1	**<0.0001**
Species	29.9_4	**<0.0001**	21.8_4	**<0.0001**	10.1_5	0.191	9.4_5	**<0.0001**
Water*field	1.9_1	0.1651	9.5_1	**0.0023**	6.0_1	**0.0004**	6.8_1	**0.0097**
Field*Species	1.6_4	0.1641	11.0_4	**<0.0001**	2.9_5	**0.0180**	1.3_5	0.2534
Species*water	$0.31.6_4$	**<0.0001**	20.0_4	**<0.0001**	9.1_5	**0.0287**	8.3_5	**<0.0001**
Species*water*field	1.1_4	0.3357	9.5_4	**<0.0001**	3.1_5	**0.0011**	1.5_5	0.1999

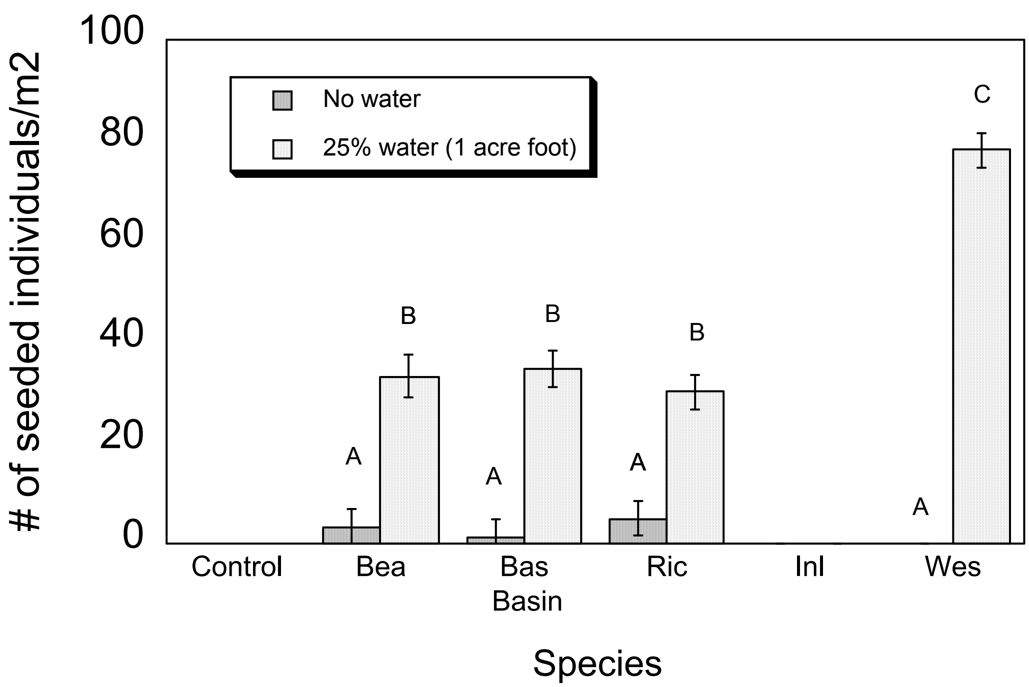

Figure 11. Density of native grass species in restoration plots at the two Ranch sites (combined) in August 2009.

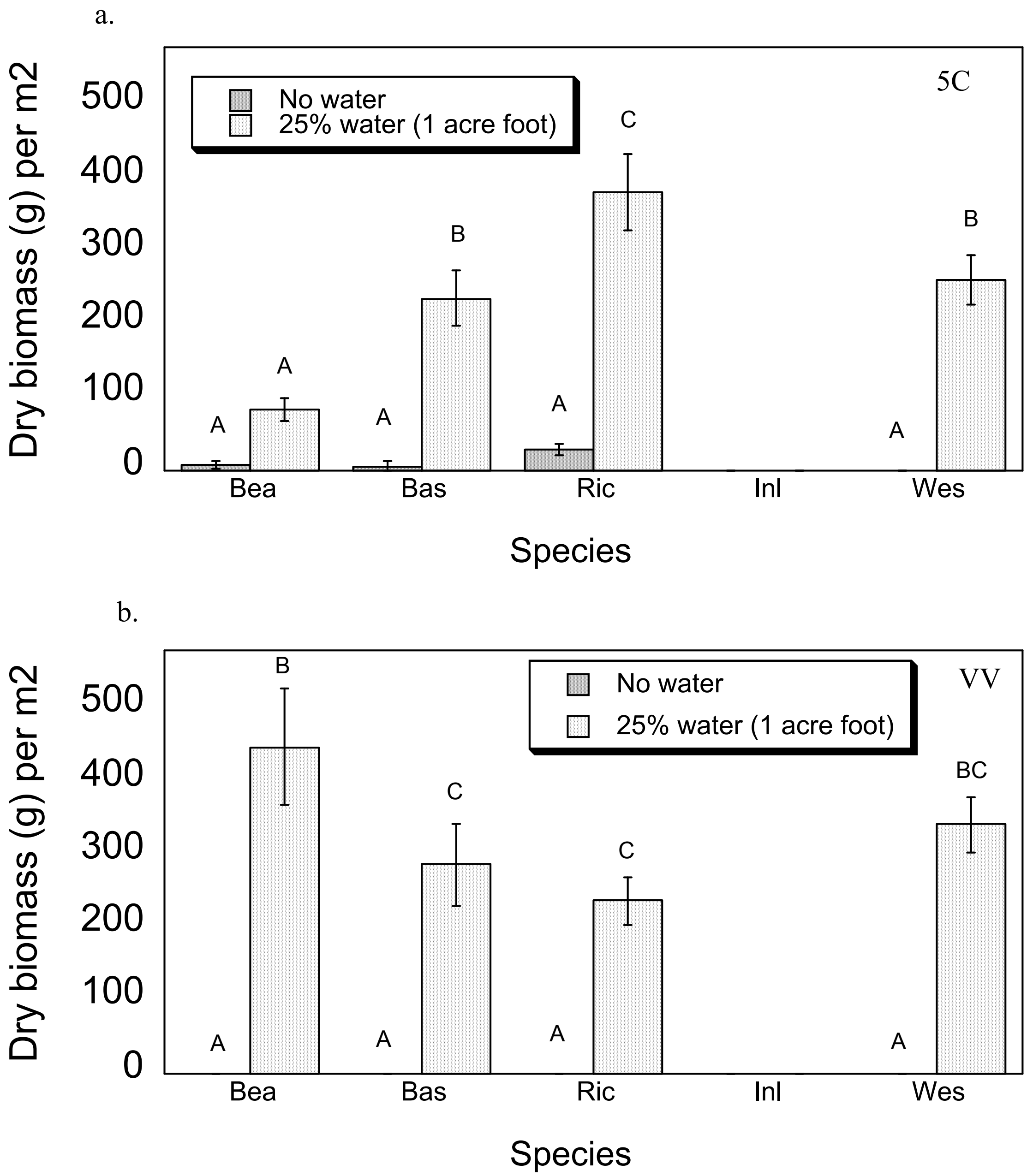

Figure 12. Biomass of restoration grass species at the two Ranch sites in 2009.

Weed densities differed significantly between species, field, and watering treatment (significant species*water*field interaction, Table 4c), while weed biomass was affected by watering treatment, species, and site (significant species*water and field*water interactions, Table 4d, Figure 13). Weed biomass was higher overall at the Valley View site, and at both sites, the most weeds grew in the 25% water application of the non-seeded control plots (NS) and the Saltgrass plots (Inl), which had no establishment. The four remaining native grasses all suppressed weed biomass in the 25% water treatment, though there were differences in performance between the two sites. For example, Indian ricegrass suppressed weed biomass the most at 5C (Figure 13a) but was not as competitive as other species at Valley Vista (Figure 13b).

a.

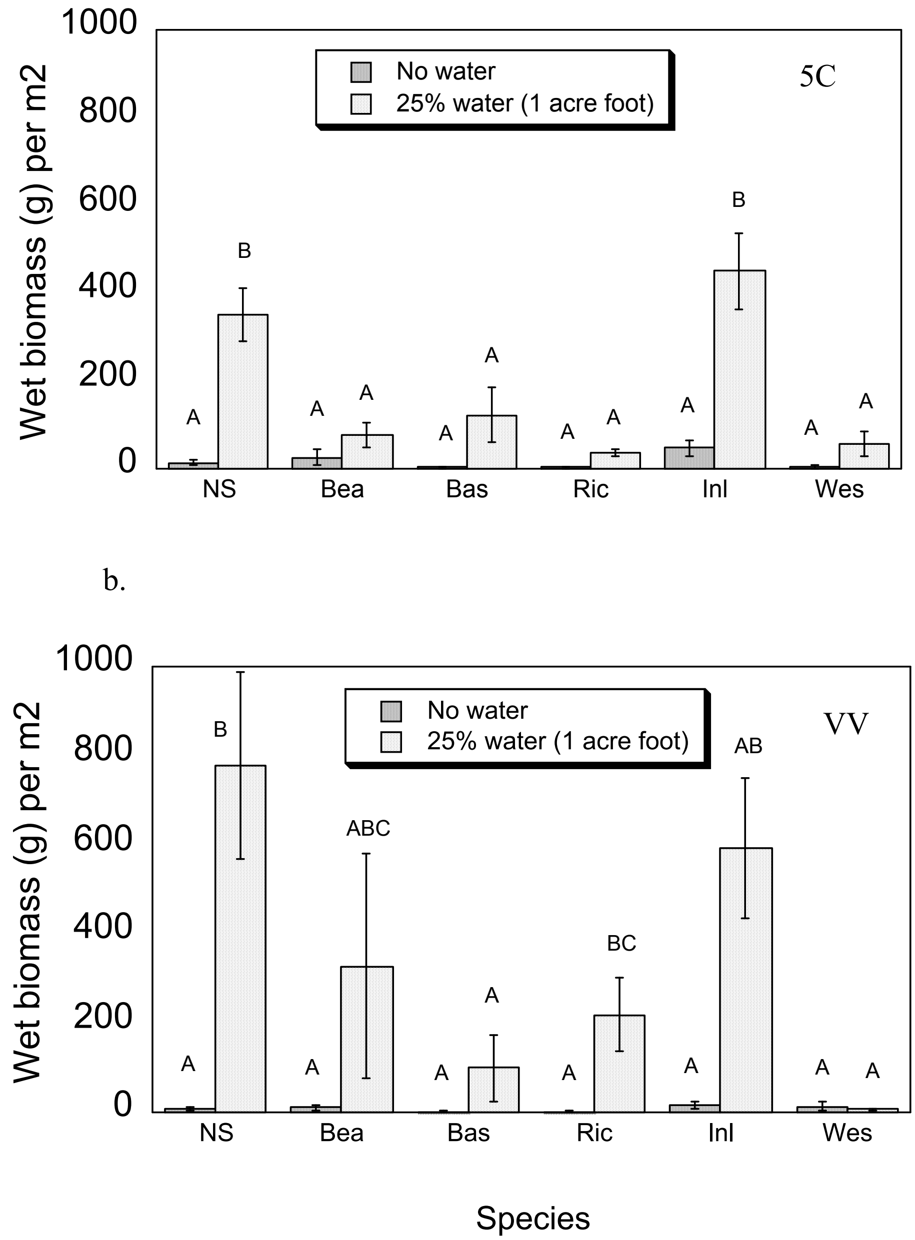

Figure 13. Weed biomass in restoration plots at the two Ranch sites, 2009.

The two varieties of Indian ricegrass established at similar densities in the two sites (F $=0.02_1$, $P = 0.9060$), but had different biomass under the 25% watering treatments (variety*water; $F = 5.2_1$, $P = 0.0266$). Nezpar outperformed Rimrock at both fields (5C: Nezpar 485.3 ± 86.6, Rimrock 280.5 ± 38.1; VV Nezpar 275.7 ± 54.9, Rimrock 197.8 ± 34.6; grams/m2, mean ± standard error). The two varieties of Western wheatgrass had similar densities in the two sites ($F = 1.3_1$, $P = 0.2700$), and biomass did not differ ($F = 2.2_1$, $P = 0.1410$).

Shrub Establishment

The watering treatment did not affect the survival of shrub transplants ($\chi^2 = 0.001$, $P = 0.9710$), and survival was similar between the two sites ($\chi^2 = 0.002$, $P = 0.9636$) but species differed considerably ($\chi^2 = 18.5$, $P = 0.0003$). The best survivor was sagebrush, with an overall survival rate of 55.6%, followed by four-wing saltbush at 27.4% (Table 5). No shadscale plants survived at all, and greasewood survival was very low (6.7%). The watering treatment significantly increased the size and growth rate of surviving shrubs (size: $F = 8.5_1$, $P = 0.0004$; growth rate: size: $F = 17.1_1$, $P < 0.0001$), and species differed in these measures (size: $F = 16.0_1$, $P < 0.0001$; growth rate: $F = 11.6_1$, $P < 0.0001$) and were differentially affected by the watering treatment (size: species *water, $F = 3.3_1$, $P = 0.0403$; growth rate: size: $F = 9.9_1$, $P = 0.0001$). Fourwing was the largest plant (average volume = 6477.8 cm^3 ± 980.4) but only increased in size by 32.0% with additional water. Sagebrush was the smallest plant (1607.6 cm^3 ± 599.1), and increased in size by 298.9% with additional water. Greasewood (average size of 3530.6 cm^3 ± 2118) had the highest growth rate and responded the most to additional water, increasing in size by 1084% in the 25% watering treatment.

Table 5. Survival of shrubs in restoration fields, 2009. Values are combined for the two Ranch sites.

Species	Water	Number planted	Number survived	% survival
4-wing saltbush	0	59	16	27.1%
Greasewood	0	47	4	8.5%
Sagebrush	0	65	32	49.2%
Shadscale	0	33	0	0%
OVERALL		**204**	**52**	**25.5%**
4-wing saltbush	25%	47	13	27.7%
Greasewood	25%	39	2	5.1%
Sagebrush	25%	61	38	62.3%
Shadscale	25%	42	0	0%
OVERALL		**189**	**53**	**28.0%**

Biomass and Alternative Grain Plots

Biomass crops: Establishment and Weed Cover

Overall, cool season grasses established better than warm season grasses. Cool season grasses established better at the Ranch sites compared to the Wildlife Well site (Figure 14). Species performance differed between sites (significant field*species interaction, Table 6a, Figure 14). All species had similar establishment at the 5C and Wildlife Well sites, but at Valley Vista, basin wildrye had the greatest establishment, which mammoth wildrye had the lowest establishment (Figure 14). Weed densities varied by field and by species (Table 6b, Figure 15). Within the cool season grass plots, the highest initial weed densities occurred at the Valley Vista site, followed by the 5C and

Wildlife Well sites. Overall, basin wildrye plots had the fewest weeds (43 ± 41 plants/m^2), and mammoth wildrye plots had the greatest number of weeds (55 ± 64 plants/m^2), due to differences in performance at the Valley Vista site. Weed densities were not different among cool season grass species plots at either the 5C or the Well fields (Figure 15).

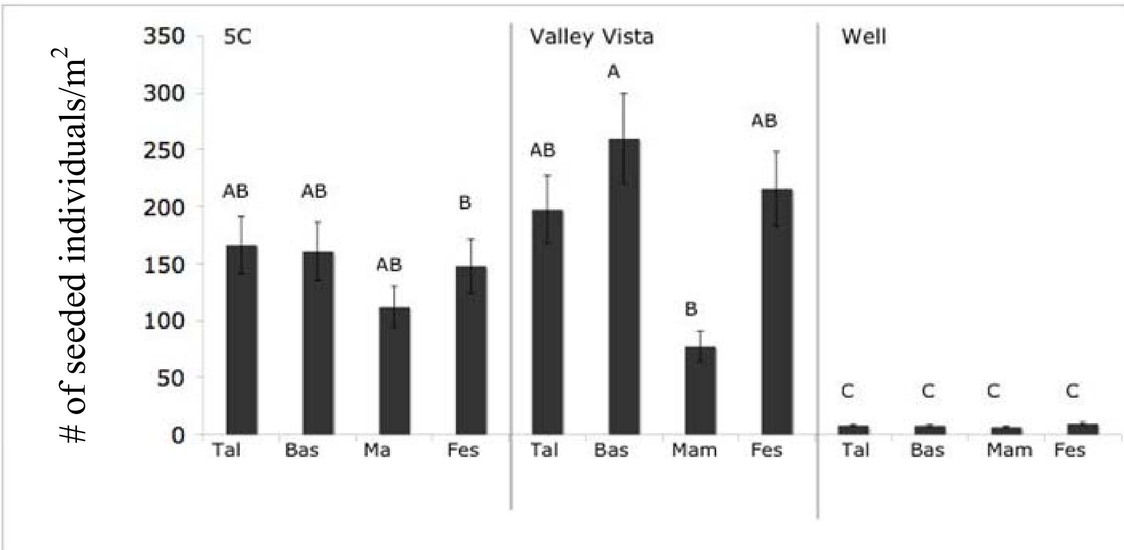

Figure 14. Cool season grasses establishment at three fields in April 2008 (cool season grasses were not planted at the Wildlife Flood site).

Table 6. Statistical summary of early establishment (April 2008) analysis.

	Cool season crops					
	a. Crop Density		***b. Weed Cover***		***c. Weed Density***	
Variable	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*
Field	380_2	**<0.0001**	77_2	**<0.0001**	76_2	**<0.0001**
Block(field)	2.3_6	**0.0333**	5.4_6	**<0.0001**	6.3_6	**<0.0001**
Species	4.4_3	**0.0046**	2.2_3	**0.086**	2.8_3	0.086
Field*Species	2.3_6	**0.0362**	3.3_6	**0.0035**	3.4_6	**0.0035**

	Warm season crops				Alternative crops			
	d. Crop Density		***e. Crop Cover***		***f. Log(Crop Density)***		***g. Weed Cover***	
Variable	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*	F_{df}	*P*
Field	33_2	**<0.0001**	40_2	**<0.0001**	75_2	**<0.0001**	200_2	**<0.0001**
Block(field)	3.2_6	**0.0044**	1.5_6	0.170	2.1_6	0.0534	6.1_6	**<0.0001**
Species	7.7_5	**<0.0001**	16_5	**<0.0001**	56_5	**<0.0001**	8.6_5	**<0.0001**
Field*Species	4.2_{10}	**<0.0001**	6.1_8	**<0.0001**	1.9_{10}	**0.0382**	7.3_{10}	**<0.0001**

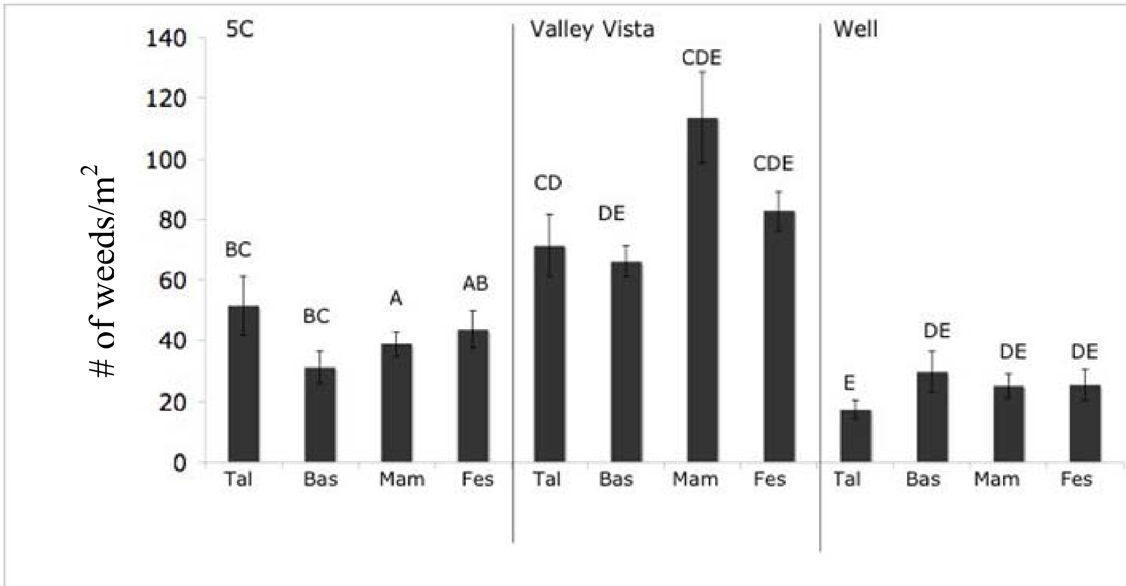

Figure 15. Weed densities in cool season grass plots in all three field sites 2008.

In 2008, cool season grasses at the Valley Vista site differed significantly in overall performance (F = 34.21; P < 0.0001), with mammoth wildrye and tall wheatgrass outperforming basin wildrye and tall fescue (Figure 16). In general, increased water led to increased production (F = 47.41, P < 0.0001), but species responded differently to the watering treatments (species*water treatment interaction, F = 6.21, P <0.0001, Figure 12c). Most species produced statistically equivalent biomass in the 75 and 100% watering treatments, except basin wildrye, which produced considerably more biomass in the 100% level treatment than it did at lower levels (Figure 16). Tall wheatgrass grew as much biomass in the 50% watering treatment as did tall fesuce and basin wildrye at 100%. At the two highest watering levels, tall wheatgrass and mammonth wildrye outperformed the other two species (Figure 16).

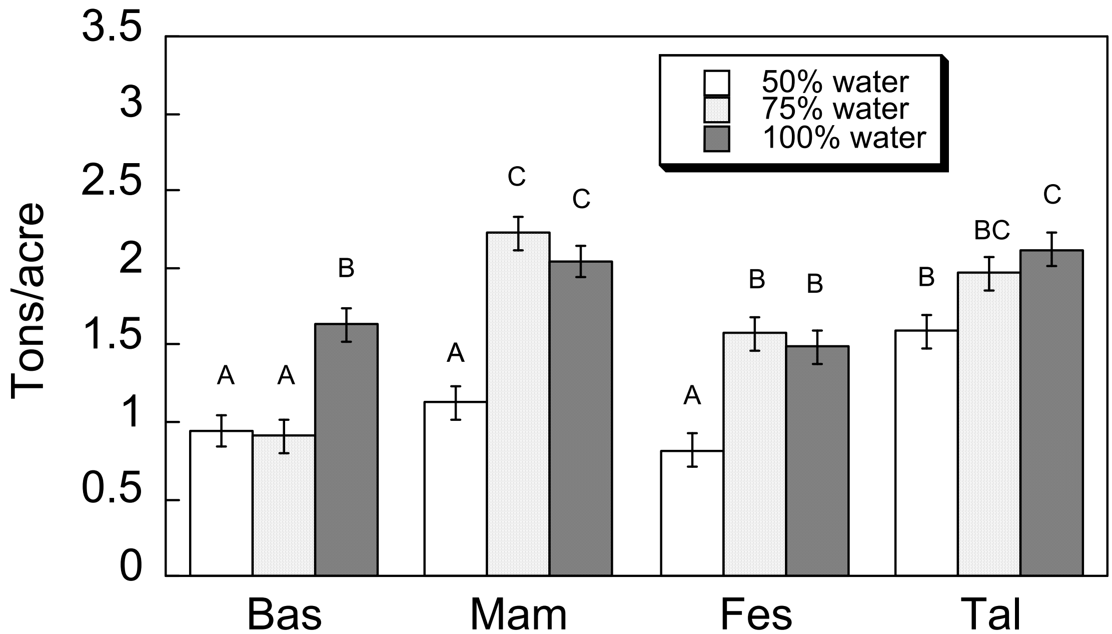

Figure 16. First year growth of cool season grasses at Valley Vista, harvested in 2008.

Warm season grass densities in April 2008 were different between sites and species (significant site*species interaction, Table 6d). The 5C site had the highest plant establishment of warm season grasses overall, followed by Valley Vista and Wildlife Well (Figure 17). Indiangrass established poorly at the Valley Vista site, but performed better at the other two locations (Figure 17). Old world bluestem and sand bluestem established at the highest densities overall. There were no significant differences in plant species performance at the Wildlife Well site, but old world bluestem outperformed switchgrass, prairie sandreed, and Indiangrass at the 5C and Valley Vista sites. Indian grass and prairie sandreed had the lowest establishment densities at the two ranch locations (Figure 17).

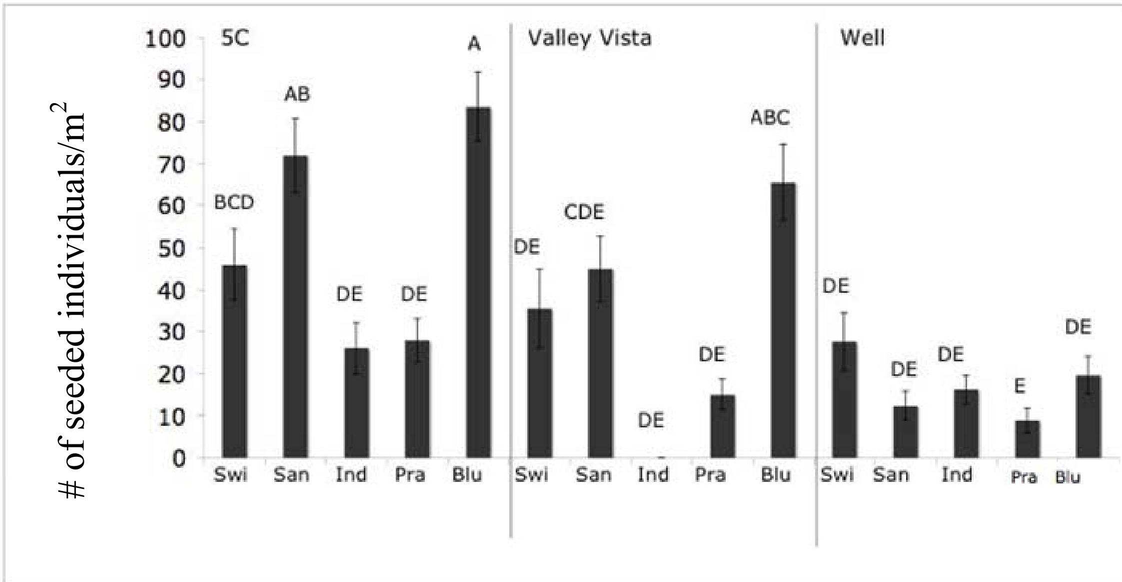

Figure 17. Seeded species establishment of warm season grasses in all three fields, 2008.

Year Two Productivity

Warm and cool season grasses differed significantly in their biomass (Table 7a, Figure 18), with cool season grasses outperforming warm season species at both locations. This difference was more pronounced at Valley Vista (significant field*season interaction, Table 7a). All species increased production with increased water, and overall, species differed in biomass (Table 7a, Figure 19). Ranking of productivity differed between the two sites, but overall, tall wheatgrass and old world bluestem were consistently top performers at both sites (Figure 19). All species responded similarly to increased water addition (no species*water interaction, Table 7a). Productivity of some species at the lowest watering treatment rivaled that of others at the full 100% treatment, e.g. tall wheatgrass biomass in the 50% treatment was higher than all but one of the warm season grasses at 100% water, at both sites (Figure 20).

Table 7. 2009 productivity of warm and cool season biomass crops at 5C and Valley Vista (a,b).

	Ranch sites: Biomass crops			
	a. Grass Dry Biomass		***b. Weed Wet Biomass***	
Variable	F_{df}	*P*	F_{df}	*P*
Field	4.4_1	**0.0363**	5.9_1	**0.0153**
Block(field)	2.8_4	**0.0231**	5.1_4	**0.0005**
Water	372.5_2	**<0.0001**	18.1_2	**<0.0001**
Season	393.8_1	**<0.0001**	310.6_1	**<0.0001**
Species(season)	689.8_7	**<0.0001**	34.1_7	**<0.0001**
Water*field	2.7_2	0.0689	8.1_2	**0.0003**
Field*Season	18.3_1	**<0.0001**	2.7_1	0.1028
Season*water	1.1_2	0.3228	7.7_4	**0.0005**
Species*water*field	1.7_2	0.1785	0.8_4	0.4520

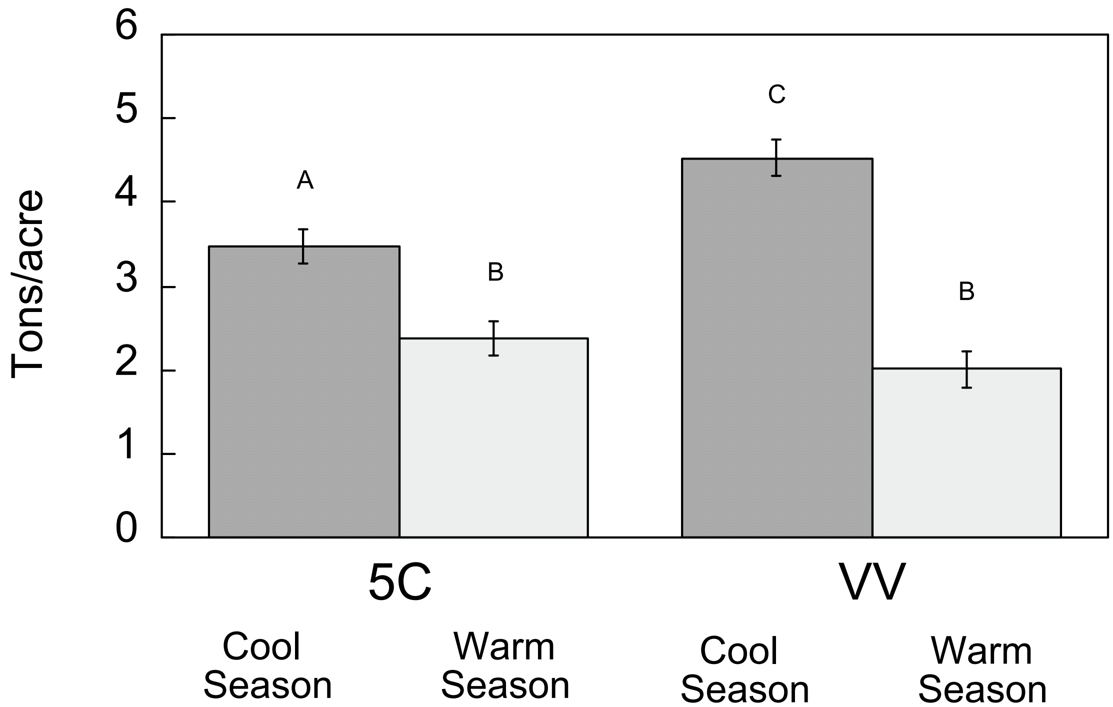

Figure 18. Productivity of warm and cool season grasses in 2009, averaged across watering treatments and sites.

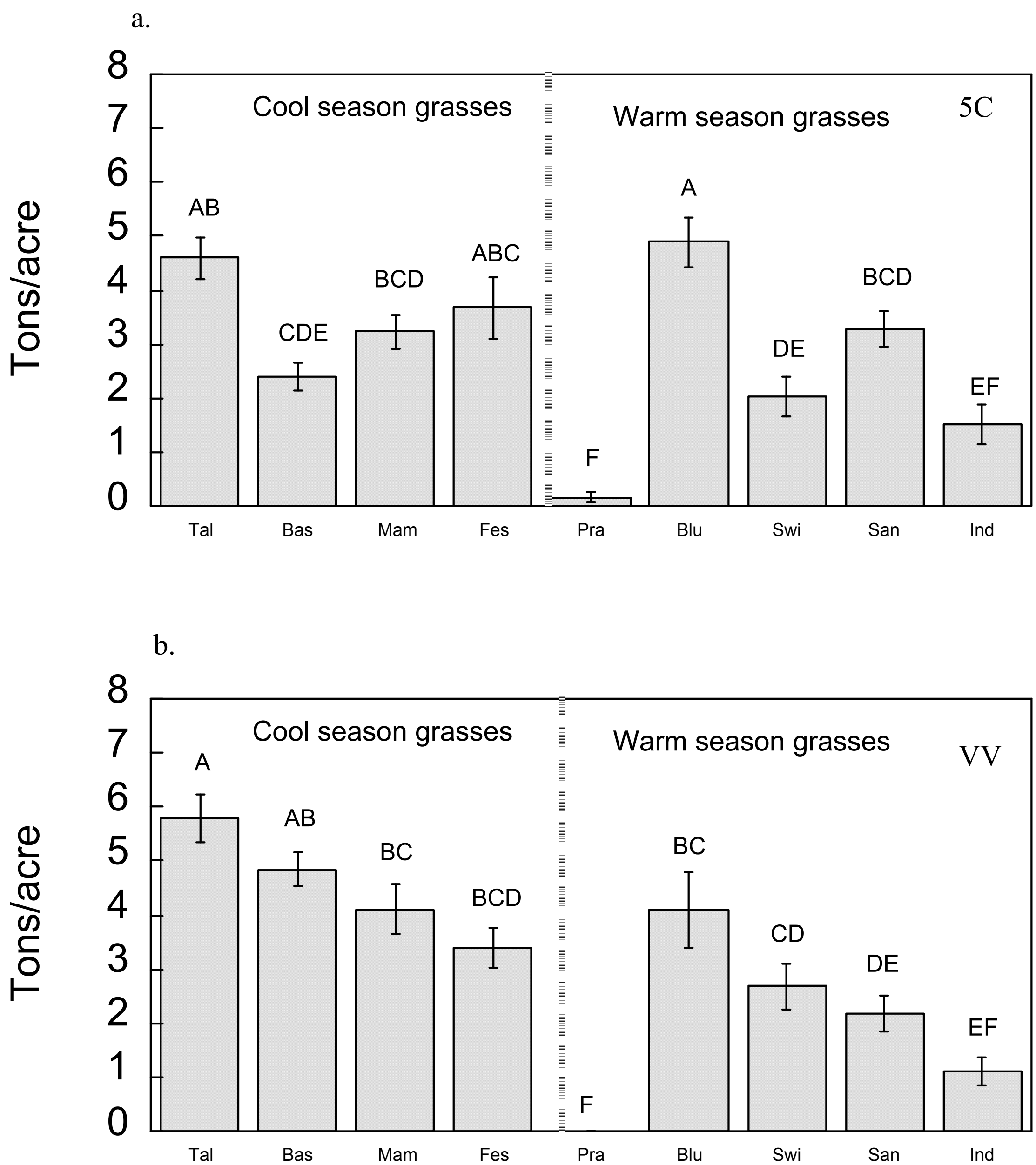

Figure 19. Biomass crop production at the 5C (a) and Valley Vista (b) sites in 2009.

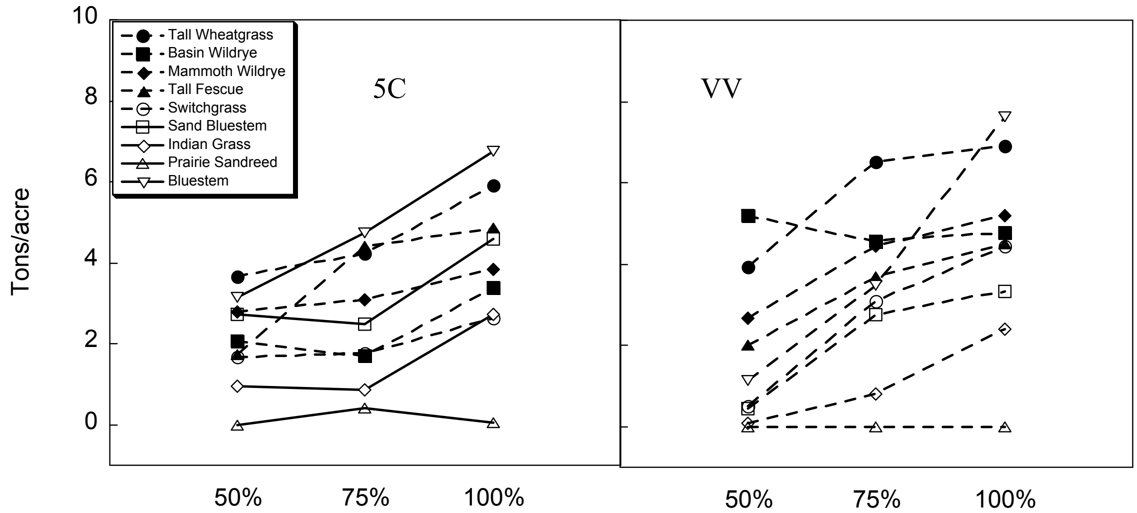

Figure 20. Individual species response to watering treatments at the 5C and VV sites, 2009.

Weed biomass was significantly affected by most model factors (Table 7b), including field, seasonality of the grass (warm vs. cold), species, and watering treatment, though seasonality had the largest affect on weed biomass. Overall, weed biomass (g/m^2) was much higher in warm season grass plots than in cool season plots (cool season, 239.0 ± 26.4, warm: 862.8 ± 23.6), higher at the 5C site (5C: 594.0 ± 25.0; Valley Vista: 507.8 ± 25.0) and increased with water application (50%: 460.8 ± 35.3; 75%: 559.2 ± 40.0; 100%: 58.0 ± 58.0). Additionally, species differed in their competitive ability with weeds, and there were site*water and season*water interactions (Table 7b), with water application increasing weed biomass more at the 5C site than at Valley Vista, and increased water improving weed performance more in warm season grasses than in cool season grasses (Figure 21).

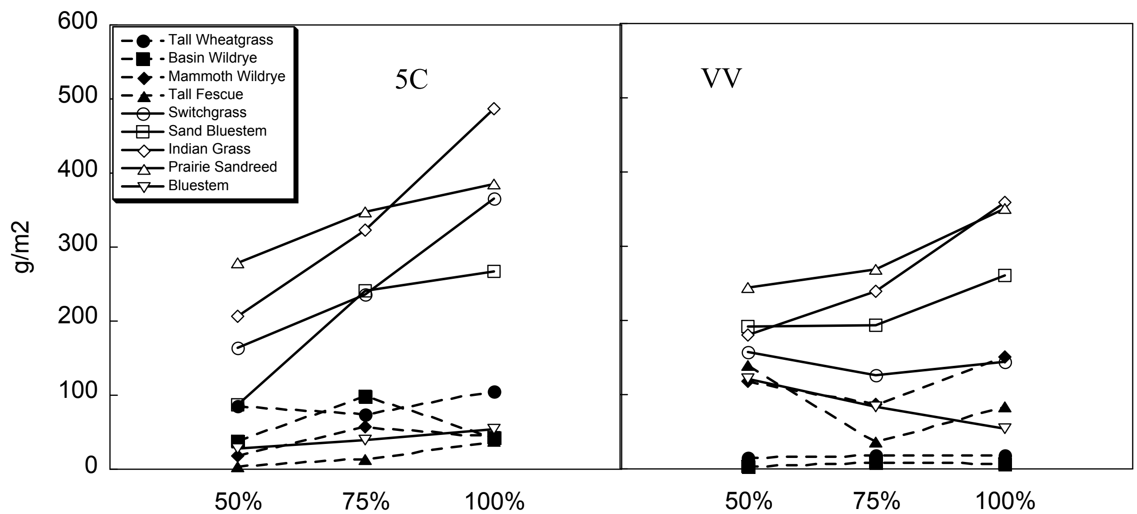

Figure 21. Weed biomass from biomass crop fields, 2009.

Annual Crops

Establishment

Species differed in establishment in different fields (significant species*field interaction, Table 6f). Alfalfa established very well at the Valley Vista and 5C sites (Figure 22). The high measurement of 377 ± 34 plants/m^2 at Valley Vista was probably influenced by the fact that alfalfa already existed at this site and attempts to eradicate established plants were not 100% successful prior to sowing. However, the establishment of alfalfa was not significantly different from either teff variety or from buckwheat at any site. Amaranth establishment, though low (15 ± 16 plants/m^2) at 5C, was not significantly different than alfalfa due to the high variability in crop densities for both species. Pearl millet and amaranth established at the lowest densities at the Valley Vista and Well sites (Figure 22).

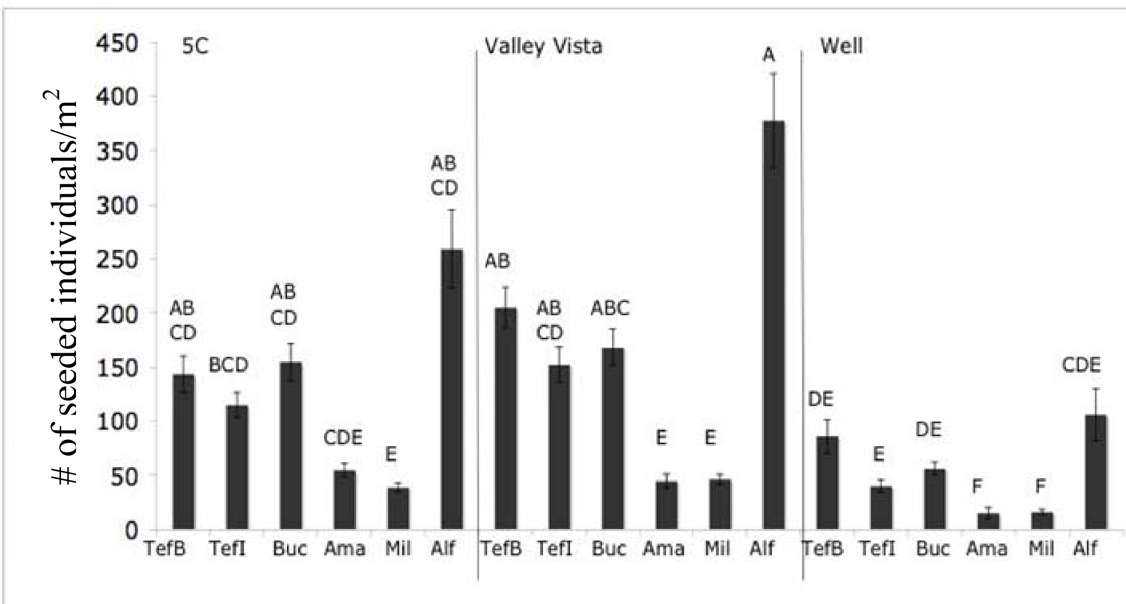

Figure 22. Establishment of alternative annual grain crops in July 2008 in all three fields.

Results for crop cover also differed by site and species (significant field*species interaction, Table 6g), but showed a different pattern than results for crop density (Figure 23). Alfalfa cover was relatively low at 5C, in contrast to its high establishment, while amaranth and teff had the highest cover at this site (Figure 23). Teff had high cover at the Valley Vista site as well, but amaranth cover was the lowest of all species at Valley Vista (Figure 23). There were no significant differences in species cover at the Wildlife Well site.

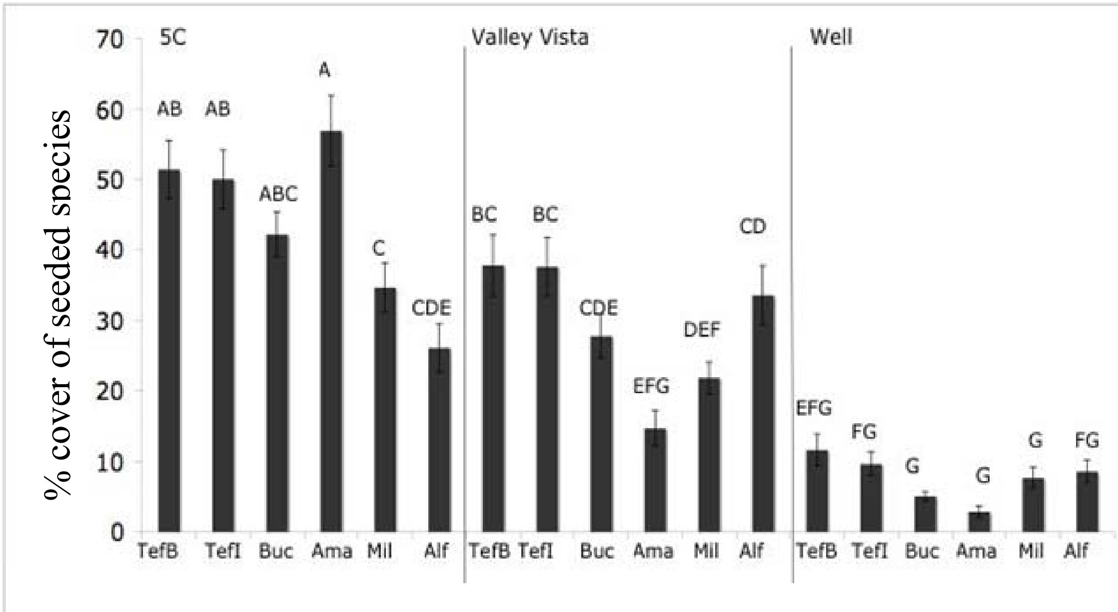

Figure 23. Percent cover of seeded species cover in alternative crop plots in July 2008, in all three field sites.

End of Season Density and Productivity

Amaranth and teff were the only species to produce enough biomass for analysis in 2008 and 2009, and amaranth was only harvested at the 5C site in 2008 because of low productivity at Valley Vista. At the 5C, there was no difference in production between white and brown teff ($F = 0.51$, $P = 0.4839$, Figure 24). Amaranth production was 637 lbs/acre (Figure 24). At the Valley Vista site, teff varieties performed equally ($F = 0.34$, $P = 0.5716$), and both varieties responded to difference in watering treatment ($F = 4.02$, $P = 0.0489$, Figure 24). While the interaction between teff varieties and the watering treatment was not statistically significant, we present the results separately to inform future studies. Brown teff had a more incremental response to increased water, while white teff performed equally at the 50% and 75% treatments, with a jump in production with 100% water (Figure 24).

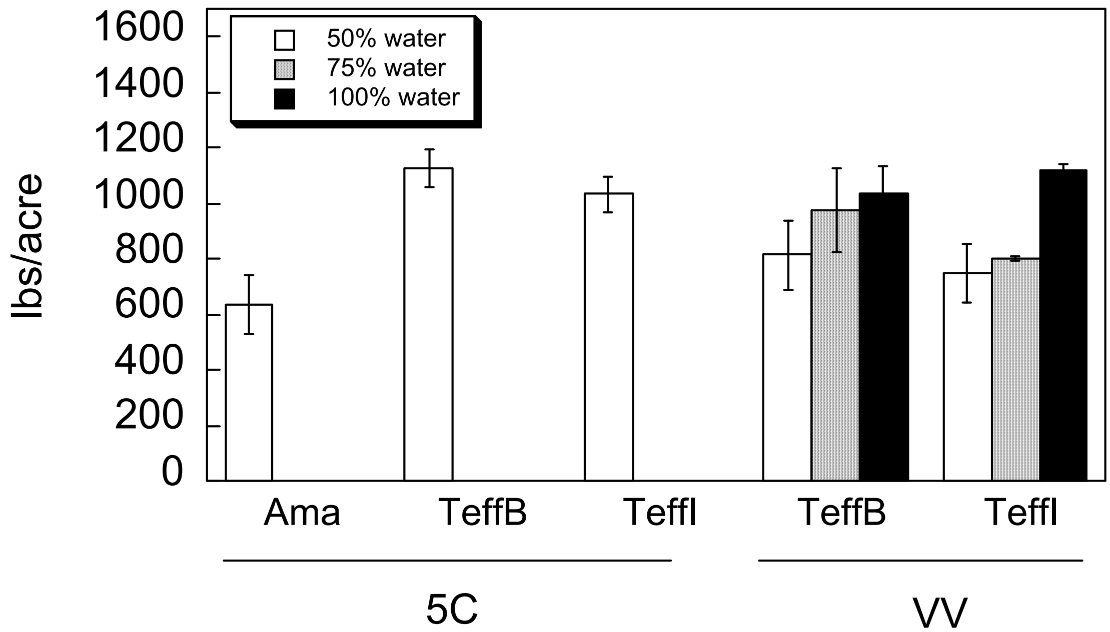

Figure 24. Pseudograin production in 2008. The 5C site only received 50% water total, so values are averaged across all plots.

In 2009, white teff did not produce seeds, and only brown teff was harvested.In 2009, both amaranth and teff increased production in response to increased water (amaranth: $F = 8.34$, $P = 0.0110$; teff: $F = 8.55$, $P = 0.0103$, Figure 25). Though results were not statistically different between the two sites, results are presented here. Average yields at the Valley Vista Site for 50, 75, and 100% watering treatments were 918, 930, and 1021 pounds per acre respectively. On the 5-C site, the differences between watering treatments were more pronounced but average yields were lower: plots irrigated at 50, 75 and 100% produced 476, 725, and 925 pounds per acre. Amaranth increased production with additional water, but production was statistically equivalent at the 75% and 100% treatments, while brown teff showed the same incremental increase in production observed in 2008. Amaranth production was not statistically different between the two sites, but values are presented here for information: production in the 50, 75, and 100% watering treatments at the 5-C sites were 554, 773, and 857 pounds/acre, respectively, while yields were 437, 655, and 638 pounds/acre respectively.

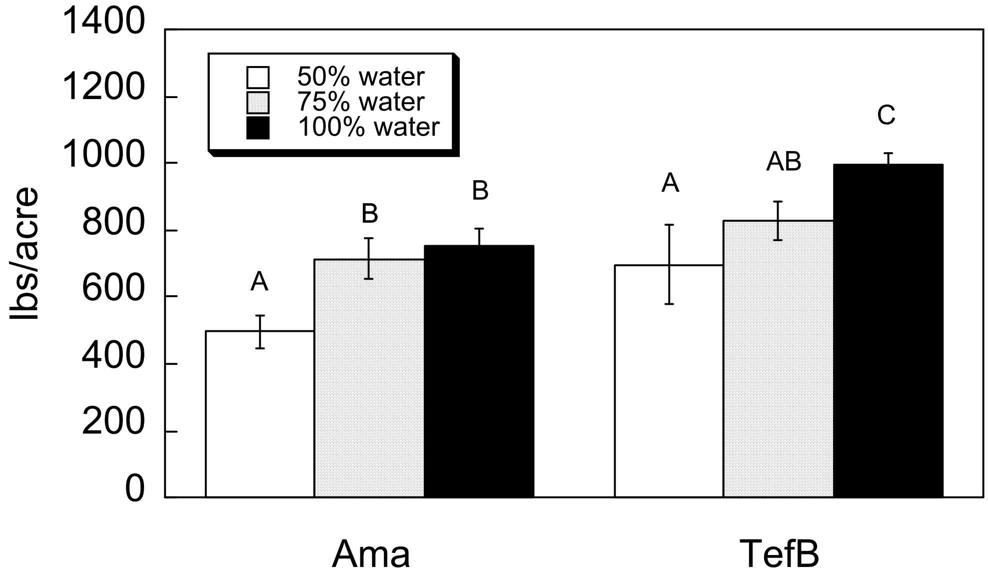

Figure 25. Pseudograin production in 2009, averaged across the two Ranch sites.

Alfalfa

Cumulative total harvest of alfalfa did not differ between sites, nor was it significantly affected by the watering treatments (Table 8). The watering treatments did, however, significantly affect harvest over time, with the 50% watering treatment in particular showing a marked decreased in productivity at the final cut (Figure 26). Productivity in the 75% and 100% water applications were almost identical, at both sites, and did not decrease over time (Figure 26).

Table 8. Overall productivity of alfalfa at 5C and Valley Vista (a) and repeated measures analysis of productivity over time (b).

	a. Overall productivity	
Variable	F_{df}	*P*
Field	1.6_1	0.2474
Block(field)	0.5_4	0.7680
Water	2.1_2	0.1970
Field*Water	0.2_2	0.8534
	b. Productivity over time	
Variable	F_{df}	*P*
Field	2.3_1	0.1550
Water	3.1_2	0.0878
Field*Water	0.3_2	0.7511
Time	19.5_2	**0.0004**
Time*Field	1.0_2	0.3916
Time*Water	6.7_4	**0.0014**
Time*Site*Water	0.8_4	0.5222

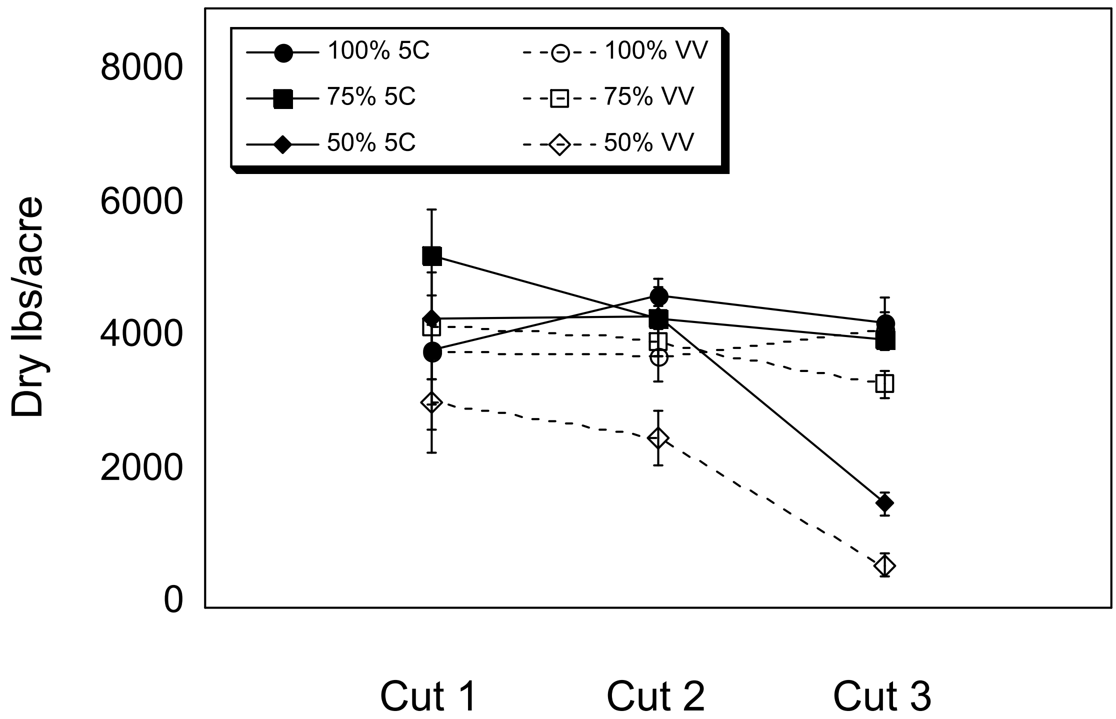

Figure 26. Alfalfa production in 2009, on both ranch sites. Cut 1 was taken on June 8, cut 2 on July 21, and cut 3 on September 3.

DISCUSSION

Permitted irrigation levels in Mason Valley and other parts of Nevada are dependent on water right priorities and the amount of irrigation water available from storage in upstream reservoirs. This amount is dependent on snowfall and other precipitation amounts received in the fall and winter of the previous year. Due to this uncertainty, water availability is unpredictable from year to year, and, as we experienced in 2008, in some years late season water is not available. This is likely to affect productivity of warm season grasses and annual grain crops more than cool season grasses or alfalfa, which makes these types of crops somewhat more risky.

Restoration Plots

Results in the restoration fields were very promising, and it is possible that effective restoration could be accomplished with even lower water applications, as 1 acre foot of water resulted in very high establishment of native grasses. Densities were very low in unwatered restorations (on average, 1.8 plants/m^2), which are lower than typical results in wildland restorations (Leger, unpublished data). In contrast, densities were very high in watered plots (on average, 36.5 plants/m^2), which is considerably higher than what is common in natural settings. Clearly, thinning will occur during the next (unwatered) seasons. The hope is that strong intraspecific competition will not weaken all plants, but that large individuals will quickly take up resources and survive, while smaller plants will die.

At the sandiest site (5C), Indian ricegrass was the top performer, establishing at high densities, producing the highest biomass, and suppressing weeds effectively. This species can establish very well in restoration settings (e.g. Thompson et al. 2006), and its affinity for sandy soils is well known. At the more fertile site, beardless wheatgrass and western wheatgrass produced the most biomass, and western wheatgrass was the best at suppressing weeds. Saltgrass (*Distichilis spicata*) did not establish at all in these fields, and seed germination is notoriously difficult for this species (Cluff et al. 1983), which typically reproduces clonally in the wild. Restoration with this species can be very desirable, as it is drought tolerant and capable of growing on saline soils (e.g. Bustan and Pasternak 2003), but it is more successful when rhizomes are used, rather than seeds (Shadow 2007). Shrub survival was typically low, but surviving individuals are important as a seed source for additional recruitment in favorable years. Surprisingly, sagebrush seedlings survived the best at this site, even though shadscale, fourwing, and greasewood are more common shrubs in the surrounding undeveloped vegetation. In the next growing season, these plots will not be watered, and we expect mortality to occur, as densities are considerably higher in watered plots than they are in desert systems. Western wheatgrass in particular, which established in the highest densities and is typically recommended for planting in slightly higher precipitation zones (10-12 inches, Ogle et al. 2000), may suffer during the next growing season. We will continue to monitor these plots, and determine which species are best able to survive with no additional water application.

Biomass Crops

Warm season grasses did not establish as well nor produce as much biomass as their cool season counterparts in this arid system, a result consistent with others (Robins et al. 2009, Robins in press). We believe that competition from weeds played a large role in this (discussed in detail below). A notable exception was the warm season grass old world bluestem, which established well in the first year, maintained relatively high productivity under low water application, and was competitive with weeds. Switchgrass, in particular, is of interest for use as a potential biofuel due to its rapid growth in other systems (e.g. Robins in press, Lee and Boe 2005, Liebig et al. 2005, Gilbert et al. 1979), but establishment of this species was low in our fields. It is possible that production could be high in Nevada, if weed control is sufficient, and we recommend additional trials with this species. Cool season grasses had much better establishment, overall productivity in year two, and suppressed weeds to a larger degree than did warm season species. Tall wheatgrass was the top performer at both sites, but all cool season grasses had similar biomass output in 2009. Productivity of perennial biomass crops is typically measured when these plants are 3-4 years old, and as our plots are only two years old, our yields are lower than other published reports, for warm season (e.g. Gilbert et al. 1979, Maun 1981, Duralia and Reader 1993, Hendrickson et al. 2000,Robins in press) and cool season grasses (Klebesadel 1985, Klebesadel 1993, Bartholomew and Williams 2008, Robins in press).

Pseudograins

All the pseudograins and alfalfa produced more than enough plants per square foot to establish successful stands during 2008 and 2009. In 2008, pearl millet and amaranth had the lowest number of plants per square foot of the seeded species while alfalfa had the highest initial establishment of all the species. However, by July 2008, all of the annual pseudograins had higher percent cover than alfalfa due to their rapid growth habit. In spite of the successful establishment displayed by all species in both years, only teff and amaranth produced adequate amounts of grain to be harvested in both years. Buckwheat and pearl millet flowered but failed to produce enough viable seed to be harvested.

Literature indicates that low levels of humidity, dry winds and high temperatures during flowering can severely reduce buckwheat yields due to flower and seed abortion (Berglund 2003, Oplinger et al. 1989). Although the plots were normally irrigated every seven days, the leaves on the buckwheat plants were usually wilted during the hottest portion of the day within three days of being irrigated. The buckwheat peak flowering times corresponded to the hottest temperatures of the growing season and hot afternoon winds were common throughout the summer months. Earlier planting dates were not possible due to the buckwheat plants sensitivity to frosts which occur commonly in late spring in western Nevada. Based on our results buckwheat cannot be recommended as a possible alternative crop at this time.

According to published work, pearl millet does not suffer from the same problems with high temperatures and drying winds as buckwheat (Lee et al 2004). However, in both years of this experiment the plants failed to set seed at either location. Plants appeared to growing normally, with emerged flowers and pollen evident. But, very few viable seeds were produced at either location. Irrigation was unlikely a factor, as seed set failed in all water treatments, at both sites, and in both years. Very little information is available concerning production of this plant under irrigation or growth in the climatic regions of western Nevada. It may be that the conditions considered "hot and dry" in the Southeastern United States, where all of the experimental results were developed, are less damaging to the flowers than "hot and dry" conditions in western Nevada. Further experimental work, including earlier planting dates, may be warranted for this plant, as it has potential as a high value food or forage crop.

Amaranth grain yields were comparable to other published studies, even though competition from weeds affected crops. At the 5C in 2008, where only 50% irrigation was applied due to water shortages, mean yields were still 637 pounds per acre. For comparison, reported average yields from Nebraska over a three year period were 700-880 pounds per acre (Baltensperger et al 1991), while the University of Minnesota expected yields ranging from 600 to 1500 pounds per acre (Putnum et al 1989). During 2009, when weed management was more successful and all plots were irrigated fully as planned, yields were higher. Production generally increased as the amount of irrigation water applied increased, with yields ranging from a low of 437 pounds per acre (Valley View, 50% water) to a high of 857 pounds per acre (5C, 100% water). Lower production values obtained on the Valley Vista site were the result of more intensive competition from weeds as the Valley Vista site consistently produced higher weed biomass throughout the experimental period.

Teff production during 2008 on the Valley Vista site mirrored that found with amaranth in that yields of both brown and white varieties increased as the amount of irrigation water applied increased. As with the previously mentioned crops, weed pressures were substantially higher on the Valley Vista location and resulted in lower production values for teff at that site. Weed management was again a major challenge during the 2009 season at both locations, and undoubtedly reduced yields. In contrast to 2008, white teff grain yields were non-existent during the 2009 growing season at both locations. The probable reason lies in the variety provided by the supplier in 2009. There are no named varieties of white teff available in the United States, which makes verifying seed source difficult. Though the same variety of white grain teff was requested in 2009 in 2008, the supplier may have inadvertently shipped a forage variety, as he also shipped a white forage variety to the author for testing in separate trial. The result was the white seeded variety produced large healthy plants but produced little to no grain in 2009. The brown teff variety produced normal plants and grain in 2009 at both locations. The brown teff yields produced during both years are similar to those produced commercially in other similar locations in Nevada. The average yields of brown teff during 2009 on approximately 1100 acres in 14 different locations was slightly above 1000 pounds per acre with full irrigation amounts, while average yields from approximately 800 acres on nine different locations in 2008 was approximately 1200 pounds per acre (Davison, unpublished data). No information on white teff grain yields has been developed as of the publication of this document.

The results indicate that teff and amaranth both show promise as potential alternative crops, and both species produced yields at low water (50%) applications, which makes them amenable to low-water farming. Further research is needed to test these species on larger areas and in additional locations. Commercial teff production is currently occurring in northwestern Nevada and is proving to be economically viable and is currently using approximately two thirds as much water to produce as alfalfa.

Weed Competition in Pseudograins and Biomass Crops

Competition from winter and summer annual weeds was the major impediment to the establishment and optimum production of all species evaluated in the alternative crop trials. This was especially true at the Wildlife well site, which was abandoned in late 2008 due to excessive weed pressure and lack of establishment of the seeded crops, and at the Valley Vista site which was an actively producing alfalfa stand prior to the establishment of the experimental plots in 2007. The 5-C site had been fallow for over 20 years and the weed pressures were generally lighter than those experienced on the Valley Vista site during the course of the experiments. A major challenge to management of these weeds is the lack of labeled herbicides for use on the seeded crop species, a problem that is especially apparent in the pseudograin crops. There are currently no herbicides labeled for teff, amaranth, or buckwheat, while 2,4-D or Peak (Prosulfuron: 1-(4-methoxy-6-methyltriazin-2-yl)-3-[2-(3,3,3-trifluoropropyl)-phenylsulfonyl]-urea are possibly labeled for use on pearl millet. However, even those uses are questionable if the millet is produced for grain and not forage (Berglund, 2003,Meyers, 2002, Meyers, 2002 Sakaliene 2008).

The winter annual weeds were managed primarily by pre-plant sprays of Glyphosate , 2,4-D and tillage. Following crop emergence the primary method of weed control was hand weeding and mowing. Broadleaf herbicides (2,4-D, Dicamba) were used postemergence on the grass species (teff, pearl millet) on an experimental basis and was generally successful in managing the broad leaf weeds. However, it could not be used on amaranth or buckwheat post emergence due to potential crop damage. Hand weeding of the winter annual broad leaved species proved to be achievable on the experimental plots, but would not be economically possible on a field scale due to the relative low value of the crops and large amount of manpower required. Cheatgrass was a not a major problem on the pseudograin plots in either year, likely due to late spring planting dates and the ability to remove it before the crop was planted. Generally, winter annual weeds were less of a threat to the establishment and production of the pseudograins than were the summer annual weed species.

The major competitors to the successful establishment and production of the pseudograins were the summer annual weeds; annual love grass (*Eragrostis spp.*), lambsquarters (*Chenopodium album*), and redroot pigweed (*Amaranthus retoflexus*). These species were managed using a combination of pre-plant herbicide sprays (glyphosate, 2,4-D) and tillage, resulting in a clean seedbed at planting. However, the soil seed bank was adequate at both experimental locations to produce enough weed seedlings to effectively compete with the planted species in both years of the experiment. Postemergence weed control was a combination of herbicide applications (2,4-D, Dicamba) on the grass crops and mechanical (hand weeding, mowing) on the broad-leaved crops. The mechanical methods were moderately successful on reducing populations of lambsquarters and redroot pigweed, but generally unsuccessful on reducing populations of annual love grass. The authors believe annual love grass populations were high enough to reduce yields of all the planted species at all locations. We base that statement on the observation of crop plants that grew adjacent to plot edges bordering sprinkler lines which were generally free of all plant growth. These plants were measurably larger in size, and produced larger seed heads than the same plants growing within the plots dominated by annual love grass. Annual love grass populations in 2009 were sprayed postemergence with Poast (sethoxydim 18%) on a portion of the amaranth and buckwheat plots located on the Valley Vista site. The Poast application was successful in that the annual love grass populations on the sprayed portions of the plots were reduced substantially without apparent damage to the crop species. However, Poast is not labeled for use by the public could not be used in a commercial endeavor.

The bio-mass crops were subject to severe competition from the same weed species as the pseudograin crops. A major difference was that all the bio-mass crops were perennial and once established the seeded species provided competition to the establishment of the annual weed species. The primary challenge to these crops was during the establishment phase and that was especially true for the warm season grass we tested. A second difference between pseudograin and the grass bio-mass crops is the number of labeled herbicides labeled for use with these species. Several broad leaf herbicides can be used on these grasses during the establishment and production phases. The list of herbicides labeled for grass weed control is much more limited and grasses are a major competitor during the establishment phase.

The herbicide treatments were generally successful in removing the majority of annual broadleaved weeds during both years of the experiment. The mowing treatments were generally ineffective at significantly reducing the populations of annual love grass or cheatgrass. Once established the cool season grasses generally competed very well with all the weeds found on the site. All species formed a dense, ground cover that precluded substantial establishment of the weedy species. This fact was more pronounced in 2009 when the cool season grasses generally produced less than one-half the weed biomass as that measured in the warm season grasses and the resulting bio-mass production was higher than that found on the warm season grass plots. In contrast, establishment and production of all the warm season grasses was negatively impacted by the competition from annual grasses. Indian grass and prairie sand reed were the least successful in establishing commercial stands at all locations. Old word bluestem, sand bluestem and switchgrass successfully established at all locations. However, total weed biomass production values generally equaled or exceeded the total biomass production values of the least successful warm season grass species in 2009.

The primary reason for the excessive annual grass weed populations found in the warm season grass plantings, but not the cool season grasses, is related to time of emergence and growth of crops and weeds. Both of the two primary competitors, cool season cheatgrass and warm season annual love grass, emerged and began a rapid growth period before the warm season species tested in this project. Cheatgrass germinates in the fall and is nearly mature before the warm season species grasses break dormancy and begin growth in the late spring. Annual love grass typically germinates at approximately the same time as the warm season grasses but its initial growth is much more rapid. Stands of both of these weeds rapidly colonized areas where the warm season species had failed to establish (especially true for Indian grass and sand bluestem), and severely reduced bio-mass production of the affected species. As warm season grasses often take up to three years to become fully established, the effect of competition from annual grasses may lessen in the future.

Cool season grasses have several competitive advantages over warm season grasses grown under the climatic conditions found in Northwest Nevada. When planted into a clean seed bed during the fall, cool season grass species are able to germinate and grow rapidly after the ideal time for germination of winter annual weeds and prior to the emergence of summer annual weeds. Therefore, the cool season grass seedlings are able to readily compete with both classifications of weeds. Moreover, the availability of broadleaf herbicides further reduces the competitive pressures experienced by the crop plants during the establishment year. Finally, cool season grass stands fully establish much more rapidly than warm season grasses. This results in the cool season species completely occupying a site in a shorter time frame reducing the opportunity for weedy species to become established and compete with the seeded species.

The results of this study demonstrate the critical nature of herbicides for weed control, especially on crops that are of relatively low value. While mechanical weed management techniques such as hand weeding and mowing can be cost effective in high value vegetable and fruit crops, the low values of field crops and the intensive nature of such methods precludes their use on a large scale. Much of the literature indicates the pseudograins evaluated will effectively compete with common weeds if planted in weed free seed beds and effective mechanical weed control is applied in the initial growth stages (Berglund 2003, Meyers 2002a, Meyers 2002b, Sakaliene et al. 2008). Our experience did not reflect that position. In fact, the crops evaluated had to be constantly hand weeded through the entire growing season. Likewise, mowing when applied on a regular basis failed to adequately control annual grass weeds in the perennial grass biomass crops.

While teff and amaranth show promise as pseudograin crops for Nevada, large scale adoption by producers will require additional research aimed at developing effective weed control strategies. This research should include crop safety experiments using various herbicides and investigating cultural practices necessary to reduce competition during the early stages of crop growth. In addition, government programs such as the Inter-regional Research Project 4 (IR-4) aimed at testing and obtaining pesticide labels for minor crops such those tested should be utilized to obtain registration of promising materials. Finally, both pseudograin species and some biomass crops are capable of producing reasonable yields at low water applications, and these species may be a valuable component of reduced-water agriculture in arid systems.

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PROJECT B: ALTERNATIVE AGRICULTURE AND VEGETATION MANAGEMENT

WATER USE EFFICIENCY AND PRODUCTIVITY OF ALTERNATIVE CROPS FOR AGRICULTURE IN NEVADA U.S.A. UNDER CONDITIONS OF LOW WATER AVAILABILITY

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ET evapotranspiration

NEE net ecosystem CO_2 exchange

VPD vapor pressure deficit

WUE water use efficiency

ABSTRACT

The productivity of crops in arid regions depends directly on the availability of irrigation water. However in years with low snowfall water is greatly limited. The objectives of our study were to: (1) quantify the evapotranspirative water losses of a selection of alternative agricultural crops under low water availability, and (2) explore ecological mechanisms by which plant WUE may be determined. Aboveground biomass yield was greatest for *Eragrostis tef* (299±24 g m^{-2} dry mass), followed by *Fagopyrum esculentum* (216±25 g m^{-2}), *Medicago sativa* (173±35 g m^{-2}, the species presently planted by farmers), *Festuca arundinacea* (102±19 g m^{-2}) and *Leymus cinereus* (74±13 g m^{-2}). Crop daytime evapotranspiration (ET) measured at the end of the irrigation period (451±94 mm) of an 84-day growing season was greatest for *Medicago* (11.7±1.4 mm day^{-1}), followed by the other species (8.2 to 6.3 mm day^{-1}). However, daytime ET of *Medicago* exceeded ET rates of the other species by factors of 1.4 to 8.0. Crop WUE, expressed as aboveground biomass yield per pre-harvest daytime ET, of *Fagopyrum* exceeded WUEs of *Leymus*, *Medicago* and *Festuca* by factors of 1.7 to 2.8. However, WUE expressed in biomass yield per irrigation water applied shows *Eragrostis* as the overall winner.

Key Words: Water use efficiency; crop water savings; dry land agriculture; arid land irrigation; evapotranspiration; net ecosystem CO_2 exchange

INTRODUCTION

Agriculture in arid climates supplies vast quantities of the world's food and forage needs (e.g., Smith 1995) and is equally important in supporting local economies and populations. However, agricultural production in these regions depends most on directing precipitation, runoff, and stream- and groundwater to croplands where plants are cultivated. Thus in arid ecosystems, plant production is directly dependent on the amount of irrigation water provided.

Over the last several decades federal and state land water management agencies in the western U.S., are confronted with increasing demands for water resources. For instance, how much groundwater can be extracted from existing aquifers before supplies to natural springs, riparian and low-basin phreatophytic ecosystems is harmed? How much water can be extracted from natural streams and rivers to irrigate commercial crops within large drainage basins and still have sufficient water supplies downstream to maintain the natural structure and function of riparian and lake ecosystems? How much agricultural irrigation water is needed in a region to maintain the economic viability of the local economy? To what extent can a shift in commercial agricultural plant species with lower water requirements for growth and yield alleviate the tension between competing water resource uses? The study presented in this paper seeks to provide empirical data that can be used to help address if changes in agricultural practices under conditions of low availability of irrigation water can help alleviate some of these demands.

The specific objectives of the study presented in this paper were: (1) to quantify the evapotranspirative water losses of a selection of alternative agricultural crops in the Walker River Basin of western Nevada, U.S.A. during a year in which irrigation water allotments originating from the Walker River were below average; (2) to calculate plant and ecosystem water use efficiencies of alternative crops; and (3) to explore ecological mechanisms by which plant water use efficiency may be determined. Our study focused on the production of aboveground biomass.

MATERIAL AND METHODS

Study Site

The study site was located at the 5C Cottonwood Ranch near Mason, Nevada (38°50'51.08" N 119°11'00.19" W) that was cultivated up to ca. 1988 and for the past 20 years the land has been used as a livestock feedlot. Five crop species (Table 1) were selected (out of a total of 15) for this study based on their potential to have a higher water use efficiency (WUE) than alfalfa (*Medicago sativa* L.), the crop most commonly grown in this region. We measured performance throughout the growing season of four of these species (forbs: *Medicago*, *Fagopyrum esculentum* Moench—buckwheat; graminoids: *Leymus cinereus* (Scribn. & Merr.) A. Löve—basin wildrye, and *Festuca arundinacea* Schreb.—tall fescue, renamed as *Schedonorus phoenix* (Scop.) Holub) and only measured final aboveground biomass yield of one other species (*Eragrostis tef* (Zuccagni) Trotter—tef grass, an east African cereal crop planted mainly in Ethiopia but also being considered for use as a high quality forage species—Abule et al. 1995). Each crop species was planted (Table 1) in individual 9.1 x 7.3 m plots with six replicates for each crop species. Some plots planted with *Festuca* failed to germinate, leaving only four valid plots available for study.

Fields were prepared for sowing and sprinkler irrigation in September 2007 by ripping, disking and floating the surface soil. Seeds of the cool season grass, *Leymus*, were sown on 17 December 2007 at depth of 12 mm at a density of 484 m^{-2} of Pure Live Seeds. The overlying soil was compacted using a cultipacker to ensure good soil-seed contact. The other four species were sown on 21 May 2008 using a Truax seed drill (New Hope, MN, U.S.A.), with seeds planted at 12 mm deep at the following densities: *Medicago*, 980 m^{-2}; *Fagopyrum*, 678 m^{-2}; *Festuca*, 1130 m^{-2}; and *Tef*, 614 m^{-2}, followed by press-wheel compaction. These species-specific densities were chosen based on previous field evaluations that determined optimal forage or grain yields for individual species which generally parallel each other (J. Davison, pers. comm.). We hand-weeded a 1.5 x 1.5 m area in each of the 22 experimental plots on 17 July 2008 within the area where ET and net ecosystem CO_2 exchange (NEE) were measured (see below) to prevent confounding effects of non-target species (weeds) on assessment of target species performance.

Fields were irrigated starting on 30 April 2007 using 7.6 cm diameter hand lines with the sprinkler heads set on a 9.1 x 9.1 m pattern. Brass impact sprinkler heads (12.5 mm) each delivered approximately 7.6 liters of water per minute. Fields were irrigated every 7-10 days up to 5 August 2008, for a total of 11 irrigations (Figure 1). This period of irrigation would be typical for a year with low water allotments. The approximate amount of water applied was calculated based on pump pressure, pipe diameter, sprinkler-head flow ratings, and duration of application. The calculated amount

Table 1. Alternative agricultural plant species and varieties evaluated at Valley Vista Ranch in the Walker River Basin, Nevada, for total water use (mm) and water use efficiency (biomass or seed yield per mm water ET, and net ecosystem CO_2 exchange per net ecosystem ET) along with their common names, families, seeding rates, sowing dates and ecology.

Species	Variety	Common name	Family	Ecology	Seeding rate		Sowing date
					(lbs. acre^{-1})	(kg ha^{-1})	
Eragrostis tef	Dessie	Tef	Poaceae	Annual C3 grass	2	2.2	21 May, 2008
Fagopyrum esculentum	Macan	Buckwheat	Polygonaceae	Annual forb	50	56.1	21 May, 2008
Medicago sativa		Alfalfa	Fabiaceae	Annual/perennial forb N_2 fixer	20	22.4	21 May, 2008
Leymus cinereus	Trailhead	Basin wildrye	Poaceae	Perennial cool season C3 grass	15	16.8	17 December, 2008
Festuca arundinacea	Fawn	Tall fescue	Poaceae	Perennial cool season C3 grass	20	22.4	17 December, 2008

of water applied at each 7-10 day irrigation across the two 0.30 ha experimental blocks used in this experiment was increased from 12 mm on 30 April to 115 mm on 5 August 2008 (Figure 1). The total calculated amount of irrigation water applied over the growing season (21 May to 7 August 2008) averaged 762 mm across the two blocks. The mean (± SE) actual amount of water applied over the latter part of the growing season (total of 451±94 mm from 12 June to 7 August 2008; n=7 tipping bucket rain gauges) was calculated from amounts measured using HOBO logging tipping bucket rain gauges (Onset Computer, Bourne, Massachusetts, U.S.A.) with one gauge installed on 12 June 2008 in seven of the 22 experimental plots. One tip of the tipping bucket was equivalent to 0.2 mm of water.

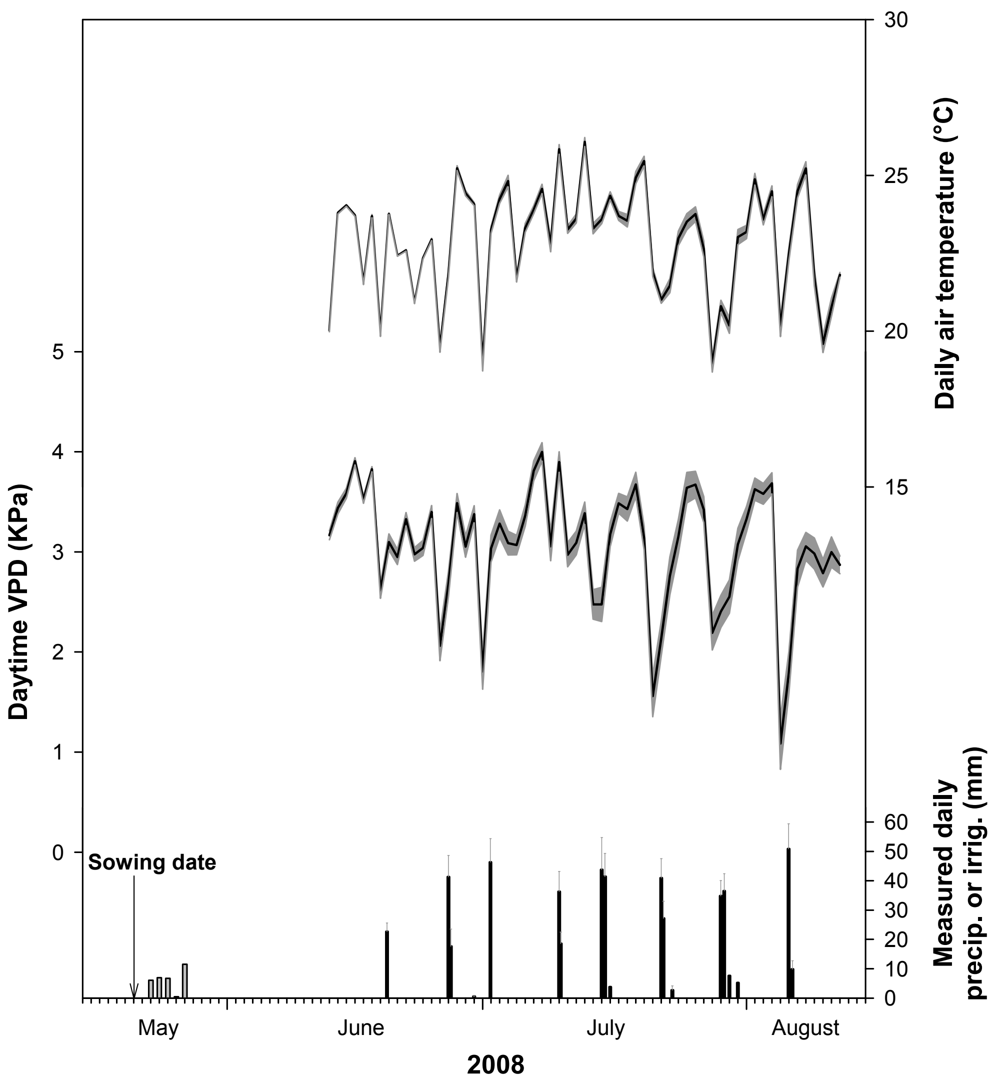

Figure 1. Time course of growing season (2008) mean (±SE, n=7 locations in experimental field) daily air temperature, daytime VPD, and daily sprinkler irrigation—filled bars (or, in May, natural rainfall—open bars) measured at the 5C Cottonwood Ranch site in Mason Valley, Nevada, USA.

Air temperature and relative humidity were recorded every 15 minutes using a shielded HOBOPro T/RH mini-logger at the same plots where the rain gauges were placed (Figure 1).

Static Chamber Measurement of Evapotranspiration (ET) and Net Ecosystem CO_2 Exchange (NEE)

ET and NEE were measured on all 22 1.0 m^2 plots using a 1-cubic meter static chamber (Arnone and Obrist 2003; Jasoni et al. 2005; Obrist et al. 2003) on three dates (21 July, 1 August, and 7 August 2008). On each sampling date when foliage was green, ET and NEE from each 1.0 m^2 plot were measured three to four times during an 8 h daytime period. Briefly, the static chamber method involves sealing the chamber over each 1.0 m^2 plot for 1 minute, measuring the rate of change in the water vapor and CO_2 densities inside the dome with a high frequency (10 Hz) open-path infra-red gas analyzer (LI-7500, LICOR Inc., Lincoln Nebraska, U.S.A.) with data logged every second using a laptop PC running the LI-7500 software, and adjusting this rate by accounting for the volume of the chamber, the area covered by the chamber, and changes in air temperature and air pressure during each 1-minute measurement. Only the initial linear portion of the change in water vapor and CO_2 densities inside the dome during each 1-minute sampling period was used to calculate ET and NEE, respectively; typically this was the first 20 to 40 seconds.

Plant Cover, Leaf Area, and Aboveground Biomass Measurements

Each 1.0 x 1.0 m subplot was photographed from a height of 2 m at each sampling date with a 8-megapixel Canon A630 color digital camera to estimate plant green cover. A greenness index was calculated by printing each digital photograph on 22 x 28 cm paper, overlaying a 2.4 x 2.4 cm transparent grid, counting the number of grid cells that were at least 50% green, and expressing this as a percentage of the total number of grid cells. On 12 August 2008, we clipped plant shoots in each of the 22 1.0 x 1.0 m subplots to a height of 5.1 cm above the surface of the soil. Leaves were separated from stems and dried separately at 70°C. We measured the area of a subsample of leaves from each subplot (LICOR LI-3000 leaf area meter) and dried these separately to calculate Specific Leaf Area (SLA, $cm^2\ g^{-1}$). To capture biomass growth below 5.1 cm, we clipped all shoot biomass to the ground in a 30 x 30 cm area inside each 1.0 x 1.0 m plot. Mass of harvested dry biomass was measured on a balance (Mettler Toledo PB-3002-S, Columbus, Ohio, U.S.A.).

For dates when no harvesting occurred, we estimated aboveground biomass, leaf area index (LAI) and leaf biomass using final harvest data and linear regressions of harvested biomass, or leaf biomass, on percent canopy green cover measured immediately before harvest. LAI was then calculated by multiplying leaf biomass by the SLA of a small subset of leaves harvested from the canopy of each of the 22 subplots on each sampling date.

Calculations and Statistical Analyses

We calculated water use efficiency by dividing final biomass yield by the mean pre-harvest daytime ET rate. Water consumption per unit leaf area at harvest was calculated by dividing mean daytime ET measured on each plot on 7 August 2008 by the leaf area of that plot on 12 August 2008. Leaf biomass allocation was calculated as the percentage of aboveground biomass accounted for by leaf biomass for each experimental plot. SLA was calculated as the ratio of leaf area to leaf biomass for a random subsample of leaves taken on each sampling date. Vapor pressure deficit (VPD) was calculated using the air temperature and RH data collected by the HoboPro T/RH loggers.

Time course data were analyzed using repeated measures analysis-of-variance (ANOVA) with "plant species" as the primary independent variable and "experimental plot" (i.e., 1.0 x 1.0 m) taken as the statistical unit (e.g., von Ende 1993, with n=4 to 6 plots). Plant performance data collected at the end of the study period were analyzed using a one-way ANOVA with "plant species" as the independent variable. In cases where the variance around mean values was non-homogeneous, data points were transformed using $\log_{10}$ (cf. Zar 1984) and then subject to ANOVA. Linear regression analysis of (a) mean aboveground biomass at harvest across all continuously monitored test species on mean WUE (g biomass at harvest liter^{-1} of daytime ET-H_2O) measured on 7 August, and (b) plot-level aboveground biomass at harvest on plot-level WUE were calculated using Stata® (Stata Corp., College Station, Texas, U.S.A.). Stata® was used for all ANOVAs, as well.

RESULTS

Air temperatures (mean daily values of 18 to 27°C) and natural rainfall (0 mm) measured at the site from mid-June to the end of the observation period (12 August 2008; Figure 1) were typical for this area of the Walker River Basin valley (WRCC 2009). Mean daytime VPD values measured at 0.5 m above ground surface ranged from 1 to 4 kPa during this period and indicated the potential for strong VPD-modulated reductions in leaf stomatal conductance within plant canopies (e.g., Bunce 1982; Körner 1994; Oren et al. 1999) for all five test species.

The plant canopy green cover data indicated that significant differences had already developed among test species (P<0.0001) by the first sampling date (23 July 2008; Figure 2a). Plant cover of the two species of forbs, *Fagopyrum* (80-83%) and *Medicago* (62-80%), exceeded that of the two grass species, *Leymus* (40-50%) and *Festuca* (28-37%), by almost 45% in mid-July and by nearly 35% in mid-August. Percent green cover increased during the last three weeks of the growing season for all species (P<0.01) other than *Fagopyrum*, which had already reached its peak by mid-July (ca. 82±4%). On average, percent cover of the two grass species did not differ from each other (P=0.2350). Cover of the two forb species also did not differ from each other viewed over the 3-week observation period (P=0.2925).

Similar temporal patterns and differences in mean aboveground biomass among species were observed over the 3-week period, although differences among the four test species, and among the species over the four observation dates, were not statistically significant (Figure 2b). However, biomass of *Fagopyrum* (185±20 g m^{-2}) measured in mid-July exceeded the mean biomass of the three other species (65±12 g m^{-2}) by 185% (Figure 2b, P<0.01). By harvest time, differences between *Fagopyrum* (216±25 g m^{-2}) and *Medicago* (173±35 g m^{-2}) had narrowed to a point where biomass yields of the two species were similar (P=0.3484; Figure 2b, Figure 3a). Thus, for the four test species

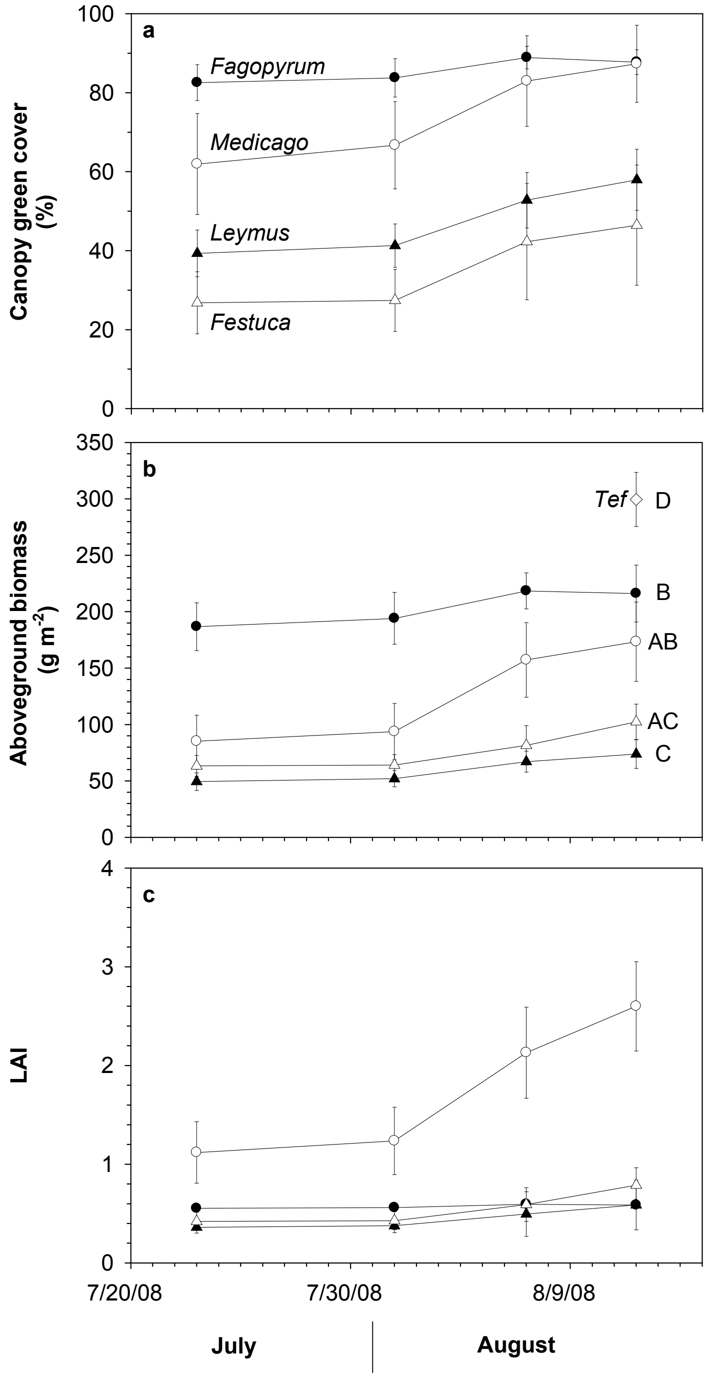

Figure 2. Time courses of growing season (**a**) crop canopy green cover, (**b**) aboveground crop biomass, and (**c**) leaf area index—LAI of the four continuously monitored test species (mean ± SE, n=4 to 6 experimental plots) measured in July and August 2008 at the 5C Cottonwood Ranch site in Mason Valley, Nevada, USA.

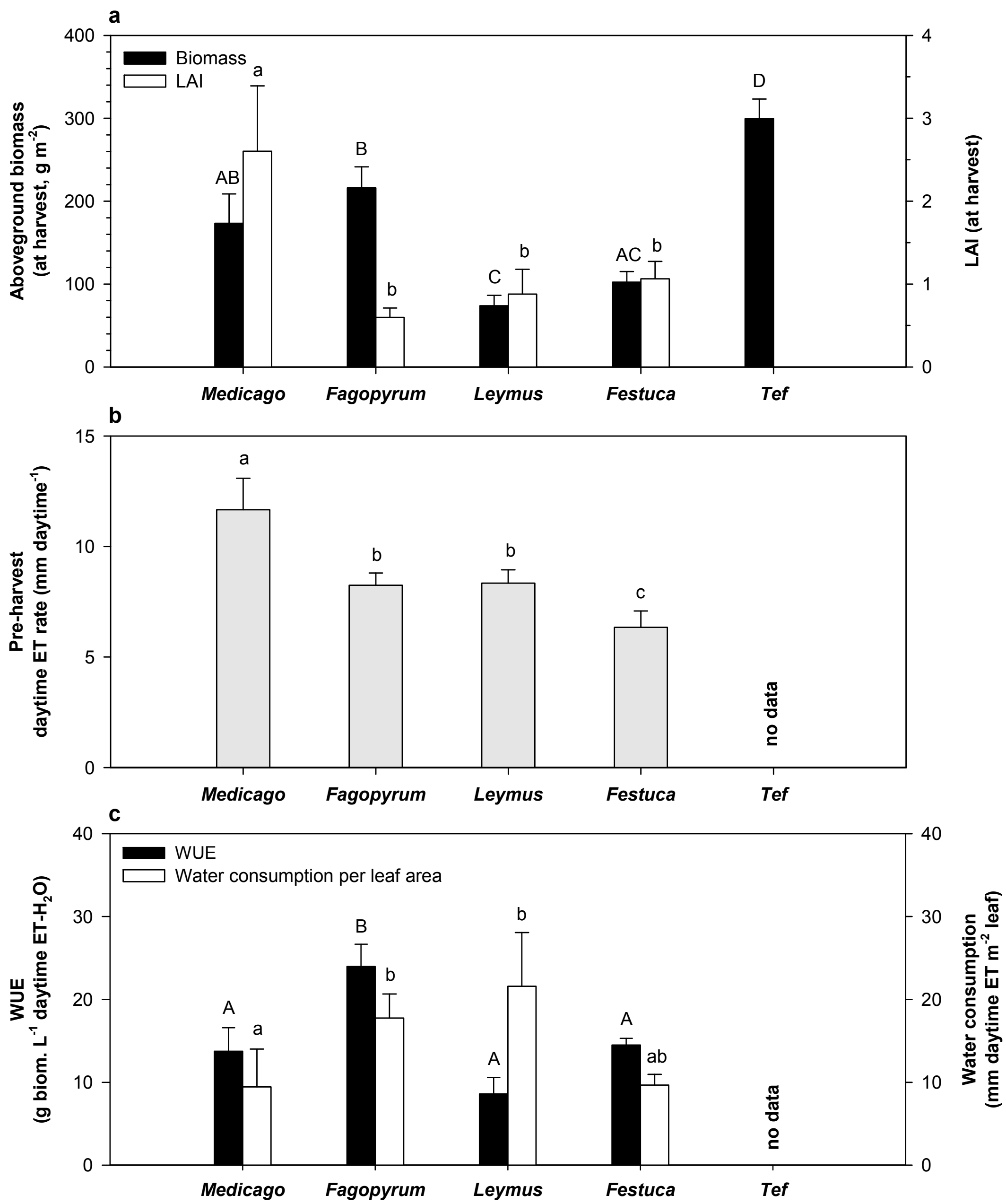

Figure 3. End of growing season (**a**) crop aboveground biomass yields and LAIs; (**b**) pre-harvest daytime ET rates; and (**c**) water use efficiency expressed as final biomass yield per unit of daytime ET measured in August 2008 one week before harvest (mean ± SE, n=4 to 6 experimental plots), and water consumption per unit leaf area, at the 5C Cottonwood Ranch site in Mason Valley, Nevada, USA.

evaluated over the entire 3-week period, mean biomass yields of *Fagopyrum* and *Medicago* at harvest were about 2.3 times greater than the mean biomass yields of *Leymus* and *Festuca* (although the biomass yields of *Leymus* and *Festuca* were statistically indiscernible; P=0.1590, $n_{Festuca}$=4, n_{Leymus}=6 plots) (Figure 3a). However, *Eragrostis* showed the highest biomass yield of all five of the species at 299±24 g m^{-2}—about 40% larger than the mean yield of *Fagopyrum*.

Allocation of aboveground biomass yield to leaves in each of the two species of forbs differed significantly, with a much higher allocation to leaves in *Medicago* (ca. 55±8%) than in *Fagopyrum* (30±5%; Figure 3a, $P_{species}$<0.0001). However, allocation to leaves remained constant within each of these species over the 3-week observation period (P_{date}=0.1799; $P_{spp\ x\ date}$=0.1827). Aboveground biomass of the two grass species consisted entirely of leaves. SLAs of the two forb species were over twice as high as those measured in the two grass species (P<0.0001) with SLAs of *Medicago* remaining constant at around 225 $cm^2\ g^{-1}$ and SLAs of *Fagopyrum* remaining at ca. 215 $cm^2\ g^{-1}$ through 1 August 2008 but then dropping to ca. 175 $cm^2\ g^{-1}$ by harvest (Figure 3b).

LAI of the two grass species, and that of *Fagopyrum*, appeared to have saturated under prevailing levels of irrigation and soil fertility before 23 July because no significant changes in LAI of any of these species were observed over the 3-week observation period (mean LAI of these three species: 0.45±0.31; Figure 3c). In contrast, LAI of *Medicago* was three to six times greater than the LAIs of the other species and increased from 1.12±0.31 in mid-July to 2.60±0.45 at harvest in mid-August 2008. At the time of harvest, LAIs of *Medicago* exceeded the LAIs of the other three continuously monitored test species by a factor of almost six (Figure 3c). LAI of *Eragrostis* was not measured at harvest.

ET measured two to four times during the daylight hours on each experimental plot on each of three separate dates showed no striking diurnal patterns (Figure 4a), although ET rates of some species peaked just before midday (e.g., *Medicago* and *Leymus* on 7 August 2008). Differences in ET between plots planted with different species only became apparent on 1 August 2008, with ET of plots containing *Medicago* significantly exceeding ET rates of plots containing *Leymus*, *Fagopyrum* and *Festuca*. On 1 August, mean daytime ET of *Medicago* exceeded ET of *Leymus* and *Fagopyrum* by a factor of 1.7, and ET of *Festuca* by a factor of 3.1 (Figure 4a). On 7 August, mean daytime ET of *Medicago* exceeded ET rates of *Leymus*, *Fagopyrum* and *Festuca* by factors of 1.4 to 8.0. The diurnal patterns in ecosystem ET for each of the three sampling dates translate into the patterns shown in Figure 6a.

The daytime ET rates of by experimental plots planted with *Medicago* measured five days before harvest (on 7 August) were the highest of the four species that were continuously monitored over the 3-week observation period (11.7±1.4 mm d^{-1}, $P_{species}$=0.0059; Figure 3b). This amounted to a 42% higher rate than measured in *Fagopyum* plots ($P_{species\text{-}2\ spp.\ comparison}$=0.0010), a 40% higher rate than that measured in *Leymus* plots ($P_{species\text{-}2\ spp.\ comparison}$=0.0012), and a 84% higher ET than that measured in *Festuca* plots ($P_{species\text{-}2\ spp.\ comparison}$=0.0010).

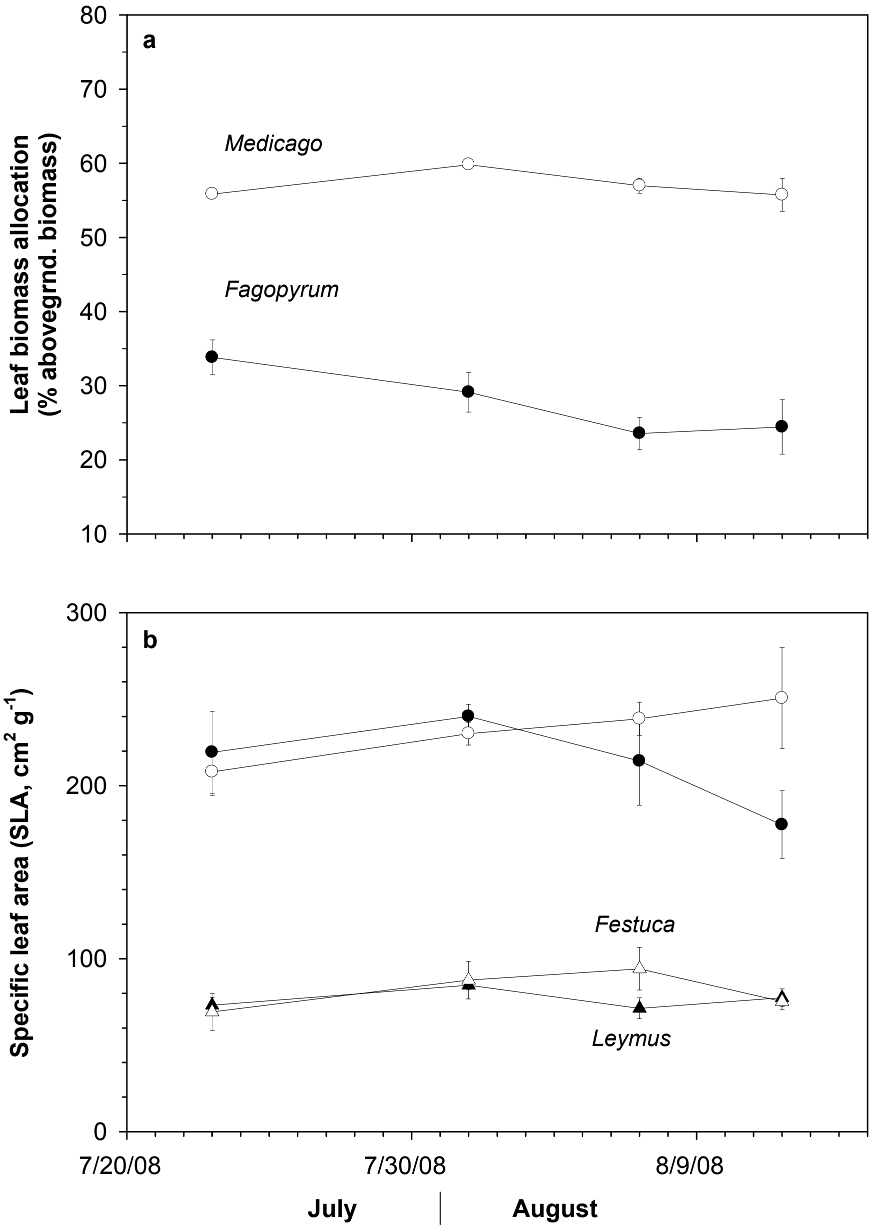

Figure 4. Time courses of growing season (**a**) leaf biomass allocation for the two continuously monitored forb species, *Medicago* and *Fagopyrum*; and (**b**) specific leaf area for all four continuously monitored test crop species (mean ± SE, n=4 to 6 experimental plots) measured in July and August 2008 at the 5C Cottonwood Ranch site in Mason Valley, Nevada, USA.

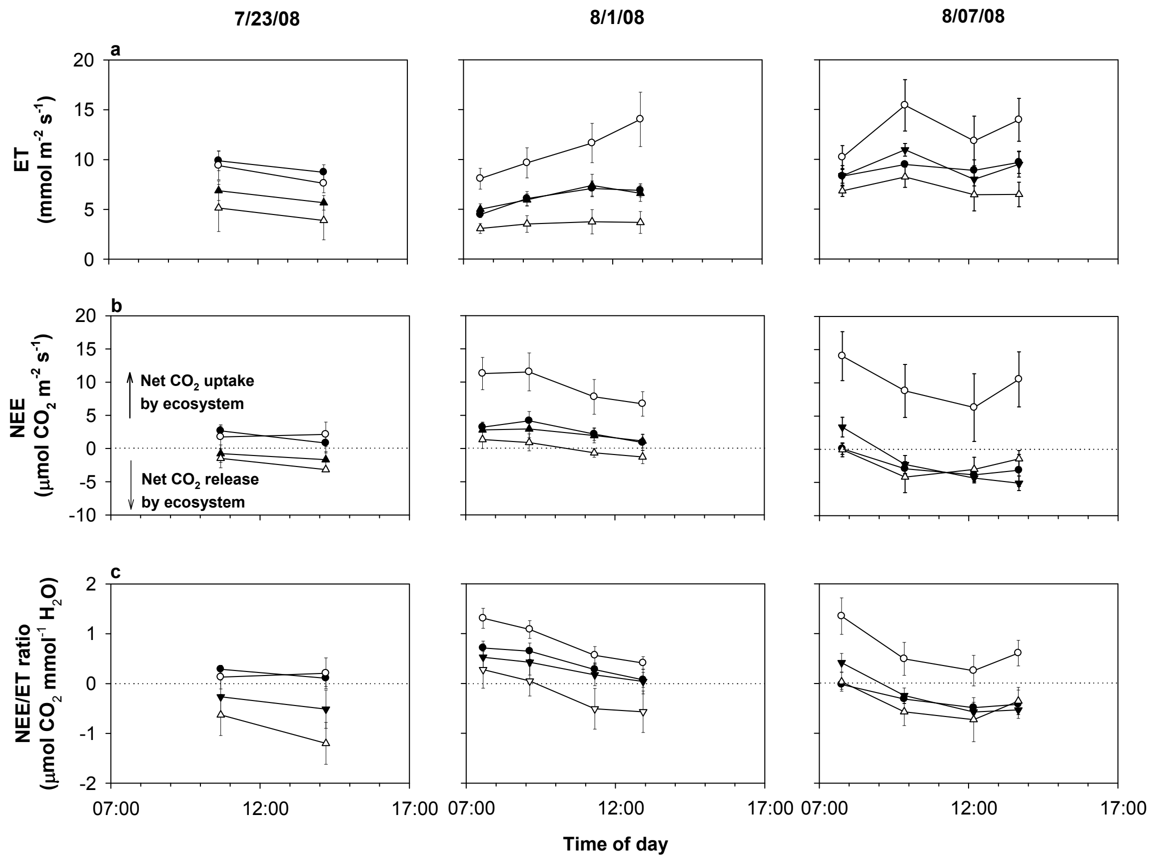

Figure 5. Diurnal time courses for each sampling date of (**a**) ecosystem ET; (**b**) net ecosystem CO_2 exchange—positive values indicate net CO_2 uptake by ecosystem/crop; and (**c**) ecosystem NEE:ET ratio (mean±SE, n=4 to 6 experimental plots) for the four continuously monitored test crop species measured in July and August 2008 at the 5C Cottonwood Ranch site in Mason Valley, Nevada, USA. Open circles, *Medicago*; closed circles, *Fagopyrum*,; open triangles, *Festuca*; close triangles, *Leymus*.

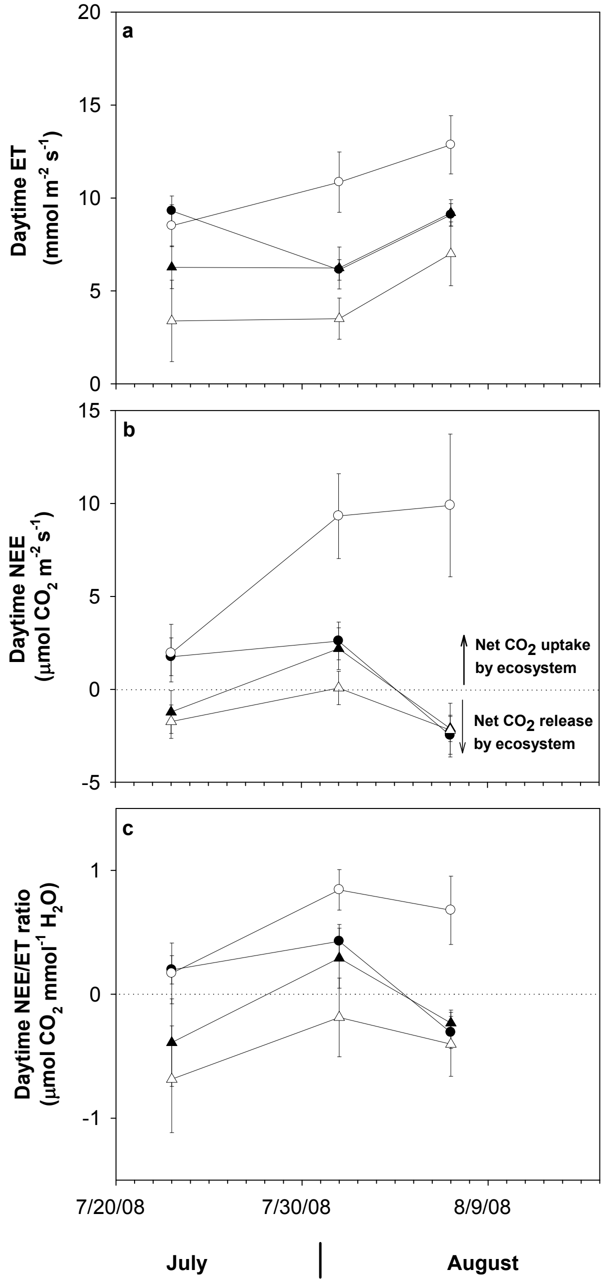

Figure 6. Time courses of growing season (**a**) daytime ecosystem/crop ET; (**b**) daytime NEE; and (**c**) daytime NEE:ET ratios for the four continuously monitored test crop species (mean ± SE, n=4 to 6 experimental plots) measured in July and August 2008 at the 5C Cottonwood Ranch site in Mason Valley, Nevada, USA. Open circles, *Medicago*; closed circles, *Fagopyrum*,; open triangles, *Festuca*; close triangles, *Leymus*.

Diurnal patterns in NEE, and differences observed among plots planted with the four continuously monitored species (Figure 4b), were generally the same as those observed for ET. However starting at the 1 August sampling, NEE of *Medicago* plots increase above NEEs measured in plots containing the other three species (Figure 4b). Daytime NEE in plots containing *Medicago* was strongly positive (ca. 10 μmol CO_2 m^{-2} s^{-1} on 7 August), whereas NEE of plots containing the other three species actually dropped below zero (ca. -2 μmol CO_2 m^{-2} s^{-1}) by the third sampling date (they were only slightly positive on 23 July and on 1 August). Thus plots containing the other three species were net emitters of CO_2 even during the daytime. NEE of plots with these three species were similar to each other (Figure 4b).

As a consequence of the patterns in ecosystem ET and NEE, patterns calculated for the daytime NEE/ET ratio (Figure 4c) tended to reflect the patterns observed in NEE (Figure 4b). No differences were observed in NEE/ET ratios between plots containing the four different species on 23 July. On 1 August, *Medicago* showed NEE/ET ratios that were significantly greater than NEE/ET ratios of only *Festuca*. On 7 August, NEE/ET ratios of *Medicago* exceeded those of all of the other three continuously monitored species.

When WUE was expressed as aboveground biomass yield at harvest per mean pre-harvest daytime ET measured with the chamber, *Fagopyrum* (24.0±2.7 g biomass $liter^{-1}$ daytime ET-H_2O) exceeded the three other continuously monitored species by factors of 1.7 to 2.8 (black bars, Figure 5). When water use was expressed as water consumption per unit LAI, *Medicago* showed lower consumption rates than *Fagopyrum* and *Leymus* but rates that were statistically indistinguishable from those of *Festuca* (white bars in Figure 5; no data available for *Eragrostis*). No differences in water consumption rates (per unit leaf area) were detected between *Fagopyrum*, *Leymus*, and *Festuca*. Regressions of total aboveground biomass yield on WUE (expressed as g biomass $liter^{-1}$ mean daytime ET-H_2O) calculated for 7 August across all continuously monitored species were highly significant and strong with species having higher WUE also exhibiting higher biomass yields and those with lower WUE showing lower biomass yields (Figure 7a, 7b).

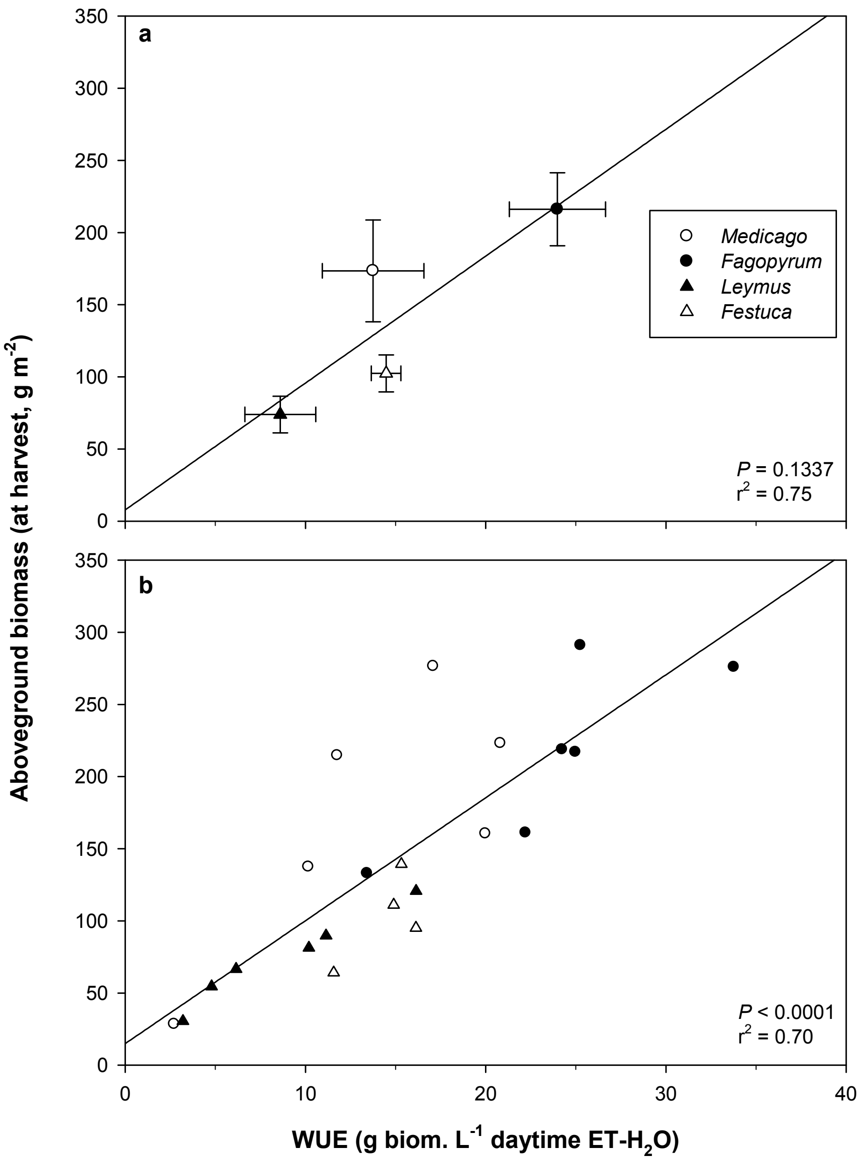

Figure 7. Linear regression relationships between (**a**) mean ± SE aboveground biomass yield at harvest and corresponding mean ± SE daytime water use efficiency calculated at the end of the growing season; and (**b**) plot-level aboveground biomass yield at harvest and corresponding plot-level daytime water use efficiency calculated at the end of the growing season for the four continuously monitored test crop species measured in August 2008 at the 5C Cottonwood Ranch site in Mason Valley, Nevada, USA.

DISCUSSION

Temporal patterns in canopy green cover, aboveground biomass or LAI of the four continuously monitored species indicate that most species had already reached their peaks by the time we began measurements, while especially *Medicago* was continuing toward its peak (Figure 2). Continued growth of *Medicago* between 23 July and 1 August 2008 suggests that this species was still exploiting available soil water (and nutrients) and aboveground (light) resources. However, *Fagopyrum* peaked much earlier and yielded as much biomass as *Medicago* by harvest time (Figure 2b). The absence of significant changes in *Leymus* and *Festuca* growth parameters over the observation period suggests either that soil resources may have limited their growth or that these species and varieties may not be well adapted to relatively dry spring and summer conditions.

The reasons for better growth performance of the two forb species, relative to that of the grass species, are unclear but may have to do with the greater ability of the forbs to produce leaves at multiple layers in the canopy, and thus to better exploit photosynthetically active radiation than the grasses could (e.g., Larcher 2003). Other potential explanations for the differences in crop growth between the forbs and grasses include: (1) lower VPDs, (Figure 1) created within canopy atmospheric micro-environments by the higher lateral density of leaves and stems present in plots containing forb species that allowed leaf stomata to remain open for longer periods—and thus assimilate more CO_2—than may have been possible in the relatively open, higher VPD canopies of the *Leymus*, *Festuca* and *Fagopyrum* plots where stomatal conductance and photosynthetic CO_2 assimilation may have been more limited (cf. Arnone et al. 2008; Bunce 1982; Körner 1994; Oren et al. 1999 particularly in graminoid dominated systems—Grace et al. 1998; Novick et al. 2004; Vourlitis et al. 1999; Wever et al. 2002—we did not directly measure leaf stomatal conductance in any species.); (2) in the case of *Medicago*, symbiotic nitrogen fixation in its root nodules enhancing plant nitrogen availability above levels than were possible for the other non-nitrogen fixing species (e.g., Arnone and Gordon 1990; Hebeisen et al. 1997; Newton et al. 1994; Soussana and Hartwig 1996; Zanetti et al. 1996); or (3) lower SLAs measured in grass species may have contributed to lower relative growth rates (Garnier 1992; Marañón and Grub 1993; Poorter and Remkes 1990;). However, higher leaf biomass allocation (leaf mass ratios—Lambers et al. 1998) of *Medicago*, relative to that measured in *Fagopyrum*, appear not to have contributed to higher relative growth rate in *Medicago* (Marañón and Grub 1993).

Higher plant WUE by *Fagopyrum* and *Medicago*, and lower water consumption per unit leaf area, may also help explain better biomass yield performance of forbs relative to the grasses *Leymus* and *Festuca* (Figure 3c). The apparent growth strategy (or inherent genetic plasticity) employed by *Fagopyrum* was a lower growth allocation to leaves (ca. 30%; Figure 4a), relative to that observed in *Medicago* (ca. 57%). Thus, two divergent growth strategies produced the same aboveground biomass yield, suggesting that aboveground biomass allocation may not be as functionally important in defining yield as we had originally hypothesized. However, lower leaf biomass allocation in the forb species *Fagopyrum* may confer ecological benefits to this species via improved WUE, expressed as aboveground biomass produced per unit of water lost through ET, when compared to higher leaf allocation and lower WUE measured in *Medicago* (Figure

4a, Figure 3c). Higher SLAs in forb species (ca. 210 cm^2 g^{-1}), compared to SLAs in grasses (ca. 90 cm^2 g^{-1}; Figure 3b), likely reflect commonly occurring inherent differences between plant functional types. It is unclear, however, how lower SLAs observed in *Fagopyrum* by harvest time, relative to those observed in *Medicago*, may confer higher WUE but also higher calculated water consumption per unit leaf area (Figure 3c). Regardless of the possible plant physiological mechanisms that may explain relative species performances, it is very clear that plant species with higher WUEs perform significantly better than those with lower WUEs (Figure 7).

Two to six-fold higher final aboveground biomass yields for plots with the grass *Eragrostis*, relative to plots of the other four species, indicate that WUE of this species may have also been highest among all five species tested (Figure 3a, Figure 7). If this were the case, then the pattern of higher forb species' performance, relative to grass species' performance, would be difficult to explain. At harvest, LAIs of *Eragrostis* appeared to be greater (we did not measure LAI in *Tef*) than LAIs of any of the other test species in our study—including *Medicago* and *Fagopyrum*, which also may have contributed to its superior performance.

Aboveground biomass (forage) yields measured in our study for *Medicago*, and *Festuca*, were generally much lower than yields reported in other studies. We were only able to find data on grain yields for *Fagopyrum* and no data on *Leymus*. Average *Medicago* forage yield in our study was 19 to 88% lower than yields reported in several other studies (Guitjens and Mahannah 1975; Hanson et al. 2007; McCormick and Myer 1958; Neyshabouri 1976; Tovey 1963; Tuteur 1976; Staubitz 1978; Wilcox 1978). When our single-harvest yields for *Medicago* are compared to first-harvest yields in other studies (e.g., Hanson et al. 2007), or to yields measured under deficit irrigation, differences were smaller (-19% to -44%; -68% to +19%). Not surprisingly the literature on yields of *Medicago* generally indicates that aboveground productivity increases with increasing water supply (irrigation or rain; e.g., Guitjens 1993; Hanson et al. 2007; Kimbell et al. 1990; Putnam et al. 2000; Robinson et al. 1994), suggesting that yields in our study were severely constrained by water availability. For example, yields of *Festuca* in our study (100±20 g m^{-2}) under 451±94 mm of irrigation water (based on rain gauge data) were 85% lower than yields reported for *Festuca* irrigated with 1067 mm (Davison 1993). Limited data available on yields of *Festuca* and *Leymus* indicate that high yields are possible in arid regions if these crops are provided adequate water and nitrogen (Davison 1993).

We were only able to find data on crop WUE expressed as g biomass yield $liter^{-1}$ H_2O lost through ET for *Medicago*. Values measured in our study were about five times greater than values calculated for *Medicago* growing in mesic climates (Grimes et al. 1992: 2.3 g biomass yield $liter^{-1}$ H_2O; Smeal et al. 1992: 1.8 g biomass yield $liter^{-1}$ H_2O; Wright 1988; 1.7 g biomass yield $liter^{-1}$ H_2O;) where greater precipitation and irrigation may have led to either a higher proportion of water losses occurring via evaporation or an actual depression of plant/crop WUE when water was more abundant.

Quantification of the relative potential of the ecosystems planted with the four continuously monitored crops to sequester C—assessed by measuring daytime NEE (Figure 6b)—suggests that a *Medicago* crop may surpass the other crops, but only if the aboveground biomass is allowed to remain on the site and contribute to the soil organic matter accumulation—which would not occur when the crop is removed from the site as it normally would be. Also, this estimate of potentially higher C-sequestration for *Medicago* does not include the likelihood of higher nighttime net ecosystem CO_2 losses to the atmosphere in these systems that contain more phytomass, and higher quality litter (cf. Arnone et al. 2008; Hirschel et al. 1997; Jasoni et al. 2005; Verburg et al. 2005), relative to the other test crops. Measurement of nighttime NEE over the entire growing season, and even during the fallow period, is required in order to quantitatively and accurately assess true ecosystem C sequestration potential by alternative crop species (e.g., Jasoni et al. 2005). It is unclear why plots containing *Medicago* indicated net CO_2 uptake during the day prior to harvest and the other three species did not.

Together, the results of our study indicate that (1) water losses through ET differ between alternative crop species indicating the potential for improved water savings and reduced irrigation requirements; (2) improvements in overall water use by some alternative crops correspond to enhanced water use efficiencies—expressed as aboveground biomass production per unit of water lost through ET or per unit of water applied—and higher ecosystem CO_2 uptake per unit of water lost through ET; and (3) alternative crop species demonstrating higher WUEs may achieve this by allocating less shoot growth to leaves, by producing leaves with lower C investment per unit area (i.e., higher SLAs), or by creating closed plant canopies, even at low water availability, that reduce atmospheric incursions into the canopy and allow VPDs to remain below levels that cause stomata to close and reduce leaf CO_2 assimilation. Thus, data from this study demonstrate the potential for large water savings by substituting high WUE forage/biomass species for traditional forage species such as alfalfa. Whether or not alternative crops will be used will however also depend on economic potential of these crops, which is also depends on the quality (e.g. nutrient content, grain chemistry) of the crop.

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PROJECT C: PLANT, SOIL, AND WATER INTERACTIONS

EFFECTS OF ALTERNATIVE AGRICULTURE IN WESTERN NEVADA ON PLANT, SOIL, AND WATER INTERACTIONS

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Once Upon A Time In The Arid West -- *there was a beautiful sub-alpine watershed whose pristine water was unparalleled throughout the land. From the sub-alpine tributaries to its lake terminus in the arid desert, the system was rich with plants, wildlife, and Native American heritage – and all was well.*

New visitors to the west also marveled at the abundance of water resource and envisioned many potential uses such as rangeland improvement, Municipal & Industrial, recreation, and agricultural based homesteads. But there was enough for everyone – and all was well.

It was soon apparent, however, that the once abundant resource was being rapidly depleted. It became necessary to consider water reallocation; both socially and environmentally. But who was to choose, and how? How is just compensation to the once indigenous users, or to those once encouraged to homestead and from whom the water must now be reallocated to be determined?

– and all is not well in the west.

INTRODUCTION

Alfalfa (*Medicago sativa* L.) has played a crucial role in the development of western agriculture and was once the most widely produced forage in the Great Basin area of the western US (Jensen et al. 1988). It is a perennial forage crop typically produced in regions characterized by hot dry summers and cold winters, and in arid regions such as northwestern Nevada optimum production can only be achieved through irrigation (Teare and Peet, 1983). Unfortunately, the varied demand for limited surface water often exceeds resource availability, thus forcing decisions for prioritized reallocations of water use. This, coupled with record high prices in 2007-2008 followed by record lows in 2008-2009 has highlighted the economic and environmental vulnerability of the alfalfa hay production model for sustainable agriculture (Putnam, 2009).

The state of Nevada experienced a 48 percent increase of irrigated lands at the start of the 20th century from 504,168 acres to a reported 746,653 acres in the 2002 agricultural census (Knight, 1918; USDA, 2004). By the early 1990s, more than 80 percent of water withdrawal in the state of Nevada was for agricultural use (NDWR, 1992). Between 1980 and 1990, however, Nevada also experienced a greater than 90 percent increase in the demand for public water consumption as a result of increased urban population (NDWR, 1992). At the same time environmental awareness identified new concerns pertinent to declining wetlands, endangered species and terminal lakes as a result of diminished water supply.

As a major water consumer, the search for salvageable water commonly focuses on irrigated agriculture. This scrutiny is based partly upon conveyance efficiencies, but to a large degree on a perceived crop water requirement (often used interchangeably with crop consumptive use) – i.e., the depth of water needed to meet the water loss through crop evapotranspiration (ET_{crop}) of a disease free crop, growing in large fields under non-restricting conditions including soil, water and fertility, and achieving full production potential under the given circumstances (Doorenbos and Kassam, 1979).

Over 50 years of research effort has been devoted towards delineating the crop water requirement for alfalfa production in northern Nevada. Much of this effort has become "blurred" or even lost over time, but the impending impact of water reallocation has stimulated renewed interest among the agricultural sector, not only in terms of alfalfa production but also with respect to alternative agriculture (e.g., biofuel crops and the production of low water use crops which currently are not being cultivated) and the restoration of abandoned agricultural lands. Of parallel concern is the response of existing ecosystems to future changes in water availability, allocation, and management. About 50,000 acres in Lyon County are currently devoted to irrigated alfalfa production (personal communication; Nevada Cooperative Extension, Yerington, NV. Conversion to alternative agriculture could have a significant effect on water resources, the local economies, and ecosystem stability.

The overall objective of this study is to determine likely responses by soils and vegetation to changes in water application and consumptive use, water table depth, and soil salinity in three key landscape circumstances: 1) currently irrigated and peripheral lands that may undergo lowering of water tables due to reduced irrigation; 2) the Walker River riparian zone that presumably would undergo an increase in water table levels and a change in the net direction of water movement with increased in-stream flows during the irrigation season; and 3) the Walker River delta which currently suffers from soil salinization and infestation from invasive species. This objective will be accomplished through the measurement of important soil characteristics and parameters, such as soil moisture depletion and evapotranspiration, susceptibility to wind erosion, salinization, nutrient fluxes, temperature, and organic matter content, as they relate to water treatment and vegetative cover.

Early Investigations of Water Requirements for Alfalfa Production in Northern Nevada

Central to the alternative agriculture issue is the actual amount of water needed to produce a given crop at a profitable yield level. Unfortunately, crops are often watered based on conveyance operation rather than actual watering needs (Neufeld and Davison, 1998). In the case of alfalfa, Houston (1950) initially applied an early version of the Blaney-Criddle (1952) model of ET estimation in northwestern Nevada and reported an estimated crop water requirement of about 22 inches (56 cm) over a 127-day growth period. Later, using both field measurement and tank lysimeter studies for water balance control, Houston (1955) reported a three-year seasonal average consumptive use of approximately 34 inches (86.4 cm) over the more traditional 180 to 190 day growing season with corresponding yields of 6-7 T/A (13.4-15.7 Mg ha^{-1}).

McCormick and Myers (1958) subsequently conducted field trials at the University of Nevada, Reno, Newlands Agricultural Field Station, to evaluate the water requirements for forage crop production in the Newlands Project. They reported that a water application of 38.7 inches (98.3 cm) resulted in the production of 9.5 T/A (21.3 Mg ha^{-1}) alfalfa (~12% moisture content) the first year following establishment; typically the highest harvest year. The amount of applied water was determined from Parshal flume measurements, but it was unclear as to whether the yields were derived from small or large scale harvests methods (Hill *et al.* 1983 has reported an estimated 20% lower yield may be expected under field harvest conditions). Tovey (1963) next studied weekly consumptive use and alfalfa yields on differing soil types, under different irrigation regimes, and with different levels of static water table over the period 1959 to 1961. Estimates of consumptive use ranged from 31.2 to 42.0 inches (79.2 to 106.7 cm) per season according to treatment. The corresponding yields ranged from 6.2 to 8.9 tons per acre (13.9 to 19.9 Mg ha^{-1}); higher production required more water. In a follow-up to his original publication (McCormick and Myers, 1958), McCormick (1966) subsequently proposed a series of management guidelines for deep-rooted alfalfa wherein he suggested that higher yields could be obtained by reducing the impacts of a fluctuating water table and promoting deeper rooting through less irrigation. By reducing the number of irrigations from 7 per season to only 4 (1 per cutting), McCormick (1966) reported he had obtained the highest yields in over 8 years of study at the Newlands location. Unfortunately, no actual data on per harvest or seasonal yield, crop consumptive use, or actual water application per irrigation was provided in the publication.

This information became paramount at a critical juncture in time. The Federal government in 1967 (US Dept. of Interior, 1967) developed an operating criteria and procedures (OCAP) for the Newlands Project in response to the impacts of irrigated agriculture water diversions on Pyramid Lake and other adjacent and downstream wetland ecosystems (numerous OCAP revisions were subsequently developed over the next 30 years). OCAP was developed to increase the use of water from the Carson River and minimize the use of water from the Truckee River while still satisfying Newlands Project water rights. Central to the 1988 revised OCAP was the stipulation of an applied water requirement for alfalfa production of 28.3 inches (71.9 cm). It is unclear as to how the Department of Interior arrived at this specific value, however, application of the early Blaney-Criddle model of estimation (Blaney and Criddle, 1952), the findings of Houston (1950, 1955) suggesting a consumptive use of 22.0 to 34.0 inches (ave. 28.0 inches) (56 to 86.4 cm), and the suggestion by McCormick (1966) that alfalfa yields could be maintained by reducing the applied water of 38.7 to 42.0 inches (98.3 to 106.7 cm) (McCormick and Meyer,1955; Tovey, 1963 and 1969, respectively) by approximately three-sevenths (i.e., 4 irrigations instead of 7), were clearly contributing factors.

Numerous quantitative studies over the next 30 years reported a much higher crop water requirement for alfalfa production in northwestern Nevada and the Newlands Project. Guitjens and Mahannah (1973, 1974, 1975) investigated water management by considering climatological data, changes in soil moisture, and applied water at the University of Nevada Newlands Agricultural Experiment Station, Fallon, NV. Using a neutron probe for soil moisture measurement, the average annual crop water use for alfalfa was estimated to be 42.8 inches (108.7 cm) in 1971 and 49.9 inches (126.7 cm) in 1972. Corresponding field yields were 5.36 and 5.38 T/A (12.0 and 12.1 Mg ha^{-1}), respectively. In August of 1972, three non-weighing lysimeters (A, B, and C) 10 ft (3 m) in diameter by 8 ft (2.4 m) deep were installed at the same location flush with the ground surface, backfilled with the excavated soil, and seeded to alfalfa. The purpose of the lysimeter tanks was to quantify essential elements of the water balance equation so that an exact solution for consumptive use could be determined. These lysimeters along with the surrounding fields served as a research tool for six consecutive studies over the next decade (Nevada Cooperative Extension, 1987) by Greil (1974), Tuteur (1976), Neyshabouri (1976), Wilcox (1978), Staubitz (1978) and Rashedi (1983). In each study, lysimeters were hand-harvested rather than windrowed and yields must therefore be considered approximately 20% higher than would normally be obtained from field harvests (Hill *et al.*, 1983).

Greil (1974) measured the overwinter consumptive use of alfalfa during the first year of establishment (late Sep 1972 through mid-May 1973). Consumptive use ranged from 9.5 to 14.0 inches (24.0 to 35.6 cm). The pertinence of this contribution was that it clearly demonstrated water use during winter months, contrary to the presumption that crop consumptive use occurred only during the traditionally defined growing season from May 20 to September 24. Tuteur (1976) used the three non-weighing lysimeters to measure annual consumptive use and reported a total of 38.9 inches (98.8 cm) in 1973 and 59.3 inches (150.6 cm) in 1974. Lysimeters A, B and C yielded 5.36, 6.56, and 5.98 T/A (12% moisture content) (12.0, 14.7, and 13.4 Mg ha^{-1}), respectively, in 1973 and 10.05, 7.67, and 9.44 T/A (23.5, 17.1, and 21.1 Mg ha^{-1}) in 1974.

Neyshabouri (1976) continued the study through 1975 and reported the annual crop water requirement to be 49.5, 45.4, and 48.0 inches (125.7, 115.3, and 121.9 cm) for lysimeters A, B, and C, respectively. Corresponding yields were 9.60, 9.80, and 10.30 T/A (21.5, 22.0, and 23.1 Mg ha^{-1}). Wilcox (1978) continued the overall study, but manipulated water applications for purposes of deficit irrigation. The reported annual water application for lysimeters A, B, and C was 24.50, 61.25, and 36.50 inches (62.2, 155.6, and 92.7 cm), respectively, with a corresponding measured consumptive use of 36.00, 42.13, and 41.85 inches (91.4, 107.0, and 106.3 cm) and yields of 5.33, 5.93, and 6.26 T/A (11.9, 13.3, and 14.0 Mg ha^{-1}). Staubitz (1978) took an alternative approach to deficit irrigation. Equal amounts of water were applied to each lysimeter up to a specified total. From then on lysimeters were irrigated differentially for purposes of drought simulation. Precipitation over the study period was 6.62 inches (16.8 cm). Total applied water for the 3 lysimeters was 24.0, 55.5, and 33.65 inches (61.0, 141.0, and 85.5 cm), respectively, with corresponding yields of 6.82, 9.9, and 8.66 T/A (15.3, 22.2, and 19.4 Mg ha^{-1}). Measured consumptive use was 30.38, 45.96, and 40.63 inches (77.2, 116.7, and 103.2 cm), respectively. Low, medium, and high irrigation applications corresponded to low, medium and high yields and consumptive use.

Using the same database, Rashedi (1983) sought to develop site-specific crop coefficients for estimating crop evapotranspiration using the Food and Agriculture Organization of the United Nations (FAO) modified Class A Evaporation Pan method and the subsequent scheduling of irrigation (Doorenbos and Pruitt, 1977) where

$$ET_{crop} = (((E_{pan} + P) * K_{pan}) * K_{crop}) * I_{eff} \qquad (1)$$

and E_{pan} is the pan evaporation, P is precipitation, K_{pan} is the pan factor or a coefficient describing local effects on pan evaporation (*i.e.* wind and humidity), K_{crop} is the plant factor or a coefficient describing the effect of plant growth stage on water usage, I_{eff} is the irrigation system efficiency, and ET_{crop} is the evapotranspiration of the crop or water lost through plant uptake that needs to be replaced. Data were taken from the highest yielding lysimeter during the 1974, 1975, 1977, 1978, 1981, and 1982 irrigation seasons. Crop coefficients ranged from 0.31-0.42 and 1.22-1.25, respectively, for the first and last five weeks of a twelve-week seasonal study period. The seasonal model, a second order polynomial, predicted an average crop coefficient of 1.16 over the entire irrigation season. From this study, Rashedi (1983) concluded that the main reason for lower annual yields was the lack of sufficient water for meeting consumptive use demands. Guitjens et al. (1983) also applied the long-term database to assess yield and water use efficiency, and determined that annual and per cutting yields were statistically proportional to crop evapotranspiration, whereas annual water use efficiency was not (Mahannah et al., 1987; Guitjens and Jensen, 1988).

There are a variety of additional models for the estimation of crop water requirements in *lieu* of actual measurement (Stewart and Hagan, 1969; Grimes *et al*., 1969; Hanks *et al*., 1969; Shipley and Regier, 1975; Stewart *et al*., 1975; Doorenbos and Pruitt, 1977; Doorenbos and Kassam,1979; Sammis, 1981; Guitjens, 1982; Wright, 1982; Martin *et al.*, 1984; Kagele, 1985). Pennington (1980) published a report on the evaluation of several empirical methods (Doorenbos and Kassam, 1977; Doorenbos and Pruitt, 1978) for selected sites in Nevada, including the

Newlands Project. Compared to reported measured crop evapotranspiration, the standard FAO methods over-estimated consumptive use by an average of 32%, whereas the modified FAO methods over-estimated by an average of only 13%. He concluded that with the inclusion of locally derived crop coefficients, the modified FAO methods could provide a more precise estimation of consumptive use for western Nevada (Pennington, 1980). Ten methods used for determining consumptive use were also compared throughout the western U.S. in cooperation with the Bureau of Reclamation (Hill et al., 1983): the USDA Modified Blaney-Criddle, FAO Modified Blaney-Criddle, Jensen-Haise, FAO Radiation, Hargreaves, Modified Penman, FAO Modified Penman, Class-A Evaporation Pan, and the FAO Evaporation Pan. Findings confirmed that no model of estimation was best for all sites, and that there was a great need for local calibration. From the various methods studied, seasonal estimates of consumptive use for alfalfa in the Newlands Project from the years 1973 to 1978 varied from a low of 31.56 inches (80.2 cm) to a high of 45.3 inches (115.1 cm) as determined by the various methods of estimation studied.

Nagging questions remained, however, particularly with respect to the contribution of shallow water table to the crop water requirement. Marston (1989) compared alfalfa yield and water table depths on data from designated bottomlands over the period 1982 through 1984. She performed an analysis of variance and a significant difference test among irrigation border means (three windrows east, middle, and west) and found shallow groundwater (approximately 3 to 5 ft (0.9 to 1.5 m) to water table) to have no significant influence on sustaining yield in the absence of irrigation. Marston (1989) thus reported a significant correlation between alfalfa yield and irrigation but no significant correlation between yield and water table depth. In other words, when stressed through deficit irrigation, alfalfa did not utilize enough shallow groundwater to meet the crop water requirement necessary to sustain yields.

A subsequent study reported similar findings (Auckly and Guitjens, 1995). This study consisted of three separate irrigation regimes during the growing season; irrigation over the first two growth cycles (i.e., harvests), the first three growth cycles, and irrigation over all four-growth cycles. The corresponding depth to water table was also measured for each irrigation regime. Yield was found dependent on the frequency of irrigation but not on the resulting water table depth, which ranged from 4.33 to 5.05 ft (1.3 to 1.5 m) over the season. Furthermore, non-irrigation of an adjacent area resulted in an 80% yield reduction.

In a collaborative project the effects of irrigation regime on alfalfa yield were studied on sprinkler-irrigated benchland wherein there were no confounding effects from a shallow or fluctuating water table (Jensen et al., 1988; Kimbell et al. 1990). Irrigation treatments were again based on the crop water (or consumptive use) requirement as estimated from the FAO modified Pan Evaporation model (Doorenbos and Pruitt, 1977). The study consisted of both small plot (6 cultivars) and field scale (single variety) components. Treatment variables consisted of 50%, 75%, 100%, and 125% (I-IV, respectively) of the estimated crop water requirement. Irrigation applied water was determined from:

$$IAW = \frac{(ET_{crop} - ppt)(TV)}{Application\_Efficiency} \tag{2}$$

and

$$TAW = IAW + ppt \tag{3}$$

where IAW is the irrigation applied water, ppt is the effective rainfall precipitation, application efficiency is 0.75 , TV is the treatment variable, ET_{crop} is the estimated crop water requirement, and TAW is the total applied water. The total amount of water applied for treatments I-IV the first year following establishment (1984) was 29.5, 46.9, 61.0, 73.1 inches (74.9, 119.1, 154.9, and 185.7 cm), respectively. Precipitation was 5 inches (12.7 cm). The highest measured yields were characteristically obtained when irrigating at 100% of the estimated crop water requirement (i.e., 61 inches of total applied water). The total application of 29.5 inches (74.9 cm), similar to the 28.3 inches (71.9 cm) stipulated in the 1988 revised OCAP (US Dept. of Interior, 1994), resulted in a yield only slightly greater than 3 T/A (6.7 Mg ha^{-1}). Conversely, the production function projected yields of 5.9 to 7.6 T/A (13.2 to 17.0 Mg ha^{-1}) for irrigation at the decreed water supply of 4.5 AF/A (1.4 ha-m ha^{-1}) (Nevada Cooperative Extension, 1987).

A related component of the study considered the effects of the same four irrigation treatments on dry matter yield, applied water use efficiency (AWUE), and forage quality as determined from crude protein, acid detergent fiber, and total digestible nutrient content. The highest yields over a 2 yr period (1984-85) were found when irrigating at 100% (treatment III), and the best AWUE was found when irrigating on the basis of 75% of the estimated crop water requirement (treatment II). The amount of irrigation applied water (i.e., exclusive of rainfall precipitation) for treatments II and III was 39 inches and 51 inches (99.1 and 129.5 cm), respectively, with yields ranging from 7.7 to 8.8 T/A (17.2 to 19.7 Mg ha^{-1}). Interestingly, the highest forage quality was obtained when applied water was based on 50% of the estimated crop water requirement (Jensen et al. 1988). Although the overall forage quality was higher, the total digestible nutrient content and yields were so low that this did not represent an efficient use relative to dry matter yield per unit of applied water (Jensen et al. 1988).

Kimbell et al. (1990) in a summary paper (1984-1986), demonstrated a significant yield difference between water treatments I and II, and II and III, but not between III and IV. Consistent with the findings of Hill et al. (1983), field yields were 15 to 20% lower than those from the small plot harvested cultivars. Polynomial applied water production functions were developed and data over the 3 yr study period projected that an average yield of 7.6 T/A (17.0 Mg ha^{-1}) dictated a corresponding consumptive use of 46.0 inches (116.8 cm) which, in turn, required an average of 57.6 inches (146.3 cm) of applied irrigation water. Lower water applications clearly reduced yields. Reported alfalfa production in northern Nevada currently ranges from 4.5 to 7 T/A for 3 or 4 cuts, respectively (Curtis et al., 2005[a]; Curtis et al., 2005[b]; Breazeale and Curtis, 2006).

Another component the study focused on estimation of individual harvest as well as seasonal water use production functions. Long-term yields were projected to increase with increasing irrigation treatments I through III, but decrease for treatment IV. For individual harvests, the production function indicated that it would take an additional 12.11 inches (30.8 cm) of applied water to produce an additional ton of alfalfa for the first harvest, 30.25 inches (76.8 cm) for the second, 21.99 inches (55.9 cm) for the third, and only 8.33 inches (21.2 cm) of applied water for the fourth harvest. The findings clearly showed that water use efficiency changes throughout the growing season and that irrigation models must consider the use of locally derived production relationships for appropriate water allocations in accordance with profit maximization (Myer et al., 1991; and Myer et al., 1993). In water short years, it may be necessary to terminate irrigation at some point during the growing season. Whether water is reduced throughout the irrigation season or deficit irrigation is used and water is applied at normal rates until it runs out, yields are typically reduced (Guitjens, 1993; Hanson et al., 2007). Since each successive cut produces reduced yields with reduced irrigation, deficit irrigation is the preferred method in that by fully watering the larger first and second harvests an alfalfa producer can better ensure the best possible yields (Nevada Cooperative Extension, 1987; Guitjens and Jensen, 1988) in water short years.

Although the sale of alfalfa and forage in general was at an all time high in 2008 (Putnam, 2009), it was extremely short lived. Furthermore, increasing costs of establishment, overhead, and energy costs coupled with diminished purchasing power may soon reduce profits making current agricultural production management much less lucrative than it is today (Curtis et al., 2005a,b; Breazeale and Curtis, 2006; Hellwinkel, 2008). This scenario along with increasing trends for water reallocation will ultimately dictate the need for alternative agriculture and, in response, cause changes in plant/soil/water interactions.

Promising Opportunities for Alternative Agriculture

Alternative Grains

There may be a unique opportunity to secure productivity in the future with alternative grains of growing popularity. These are crops that have been produced for centuries in the international community and are just now gaining interest and support in the United States. They are proven sources of excellent nutrition for both human and animal consumption, and typically grow well in water stressed environments. Potential new crops include Teff (*Erograstis tef* (Zuccagni) Trotter), Buckwheat (*Fagopyrum esculentum* Moench), Amaranth (*Amaranth cruentus* L.), and Pearl Millet (*Pennisetum glaucum* (L.) R.Br.).

Teff is a cereal crop of great popularity in Ethiopia. It is a summer crop that does very well with limited irrigation. In fact, excess water and fertilizer actually decreases grain quality and does not increase yield (Norberg et al., 2005). Best yields appear to be obtained at about 13 inches of received water. Teff is very nutritious, gluten free, and can be used for either human consumption or as cattle feed.

Buckwheat, originally from Asia, is a pseudo-cereal grown internationally, as well as within the United States, for human consumption. It is sensitive to drought conditions, but has many other redeeming qualities. It can be used as a second crop, improves soil tilth, and grows so vigorously that the necessity for weed control is minimal (Meyers, 2002a). Buckwheat can be produced on a wide range of soil textures and, although it is a heavy consumer of available phosphorous, can be grown on soils of moderate fertility. It can be productive in water limiting environments due to its short growing season, as it will generally reach maturity by the time irrigation supply has been depleted in water short years. Buckwheat also has the benefit of attracting and supporting large bee populations (Berglund, 2003; Meyers, 2002a).

Grain amaranth actually originated as an American Indian food source. It provides an excellent source of nutrition with high lysine and protein content and is slowly making a reintroduction as a food staple (Baltensperger et al., 1991, Putnam et al., 1989). Amaranth can be used for either human or cattle consumption. It is well adapted to drought conditions and therefore should do well in the high temperature, low water conditions of the arid west (Putnam et al., 1989; Sullivan, 2003; Weber, 1987). It also requires little to no fertilizer which makes it a good alternative for reducing overhead costs (Baltensperger et al., 1991). A major down side of Amaranth production today is the lack of approved herbicides for use, thereby requiring hand weeding until well established and the need for a killing frost in order for it to properly desiccate for harvest.

Pearl Millet is a cereal crop native to Africa and India that has been grown for forage in the United States for quite some time. It has recently been gaining recognition as a better nutritive source for feed animals due to its high lysine and protein contents. Pearl Millet can be used as feed for cattle, but is especially beneficial to poultry and possibly swine, and can also be marketed as wild bird seed (Andrews et al., 1996). It is tolerant of sandy, acidic, or infertile soils making it well suited for the Great Basin region (Andrews et al., 1996; Lee et al., 2004; Meyers, 2002b; Sedivec and Schatz, 1991).

Biomass Production

Climate change, increasing oil prices, and decreased oil supply all set the stage for the rising interest in biomass production as an alternative fuel source. Biofuels are a renewable, biodegradable alternative to gasoline. Substituting biofuels for one gallon of gasoline can save up to 20 lbs of carbon dioxide emissions into the atmosphere because the carbon dioxide released is recycled rather than mined in the form of fossil fuels (U.S. D.O.E., 2001). Biomass crops not only have the potential to be used as biofuel, but also as thermal energy and for bioderived plastics (Karp and Shield, 2008; Ragauskas, 2006). The use of "biocrops" rather than petroleum could ultimately reduce our dependence on foreign oil. In response, lawmakers have begun to set standards for future energy usage. For example, the Energy Independence Act of 2007 requires fuel producers to increase biofuel usage nearly five-fold by the year 2022. This act will help to guarantee the growth of biomass crops as an industry in the United States.

Current biofuel production in the United States is primarily limited to corn (*Zea mays* L.) ethanol. As of 2001, the ethanol industry employed 200,000 people and saved $2 billion a year in oil imports (U.S. D.O.E., 2001). While ethanol production can boost the economy and increase energy security, as it stands, there is great concern for its sustainability. Today's ethanol production relies primarily on corn which may not be finite, but is still a limited source. The United States currently uses 25% of corn produced domestically to produce enough ethanol to meet only 3% of liquid transportation fuel requirements (Orts et al., 2008). Further increases in corn for ethanol could result in a rivalry between fuel and food, as demand skyrockets past supply. There is also concern regarding the effects of increased corn production on the environment. As the public outcry for alternative fuel sources rages with soaring oil prices, acreages in corn production will rise also. There is evidence that increasing corn production would negatively affect water quality by increasing nitrogen and phosphorous loads (Simpson et al., 2008) from fertilization. Although ethanol production from the fermentation of corn is a start in the effort to resolve our current energy dependence, it may not be the ultimate solution.

Current ethanol production takes simple carbohydrates, such as sugar and starch, and through fermentation creates combustible fuel (Karp and Shield, 2008). However, about 70% of plant mass is in the form of complex carbohydrates such as cellulose and hemicellulose (Dale, 2008). The cost of transforming these complex carbohydrates into fuel is currently too high to be cost effective. The key to being able to process complex carbohydrates in an economically viable way is to develop a pretreatment technology that opens cell walls to enzymatic breakdown and to provide a variety of inexpensive enzymes (Dale, 2008; Ragauskas, 2006). This current limitation has created frenzy in the field of microbiology and new methods for inexpensively producing ethanol from cellulosic feedstock are hopefully on the near horizon. Given the potential for technological development, biofuels from cellulosic feedstocks is considered a viable alternative to current ethanol production processes.

The use of cellulosic feedstocks for biofuels would open the door to using a much wider variety of crops for fuel (Orts et al., 2008; Karp and Shield, 2008). The conversion of cellulose into energy allows for perennial grasses, which are high in complex carbohydrate content and have high yield potential, to be in production for biofuel applications. The production of perennial crops offers many benefits. For example, they have less of an impact on the environment than annual crops. Once a perennial grass stand is establish, there is no need to till soil until the stand needs to be replaced; erosion potential is reduced, they require much less fertilization than annuals, and because they have few natural pests there is a reduced need for pesticides (Karp and Shield, 2008; Lewandowski et al., 2003; U.S. D.O.E., 2001). Perennials also have the potential to produce much greater quantities of dry matter per unit land (Karp and Shield, 2008). Production of perennial crops offers a better return on energy input and also has a greater potential to reduce greenhouse gases per energy unit produced than annual crops such as corn (Orts et al., 2008, Karp and Shield, 2008; Lewandowski et al., 2003). Current ethanol usage reduces greenhouse gas emissions by about 18% percent as compared to gasoline, while cellulosic ethanol has the potential to reduce greenhouse gas emissions by approximately 88 percent (Farrell et al., 2006).

The new challenge for biomass production will be to increase yields of perennial crops to keep up with growing energy needs (Ragauskus et al., 2006). Much work has been performed to maximize yields for traditional feed crops such as corn, but perennial crops have been relative untouched. There also is a need to determine the difference in biomass quality of various crops which can only be accomplished by growing them at the same sites (Lewandoski et al., 2003). Different agricultural practices such as watering, fertilization, and time of harvest can have an enormous effect on the plant cellulose content as well as the quality of ash produced when burned. Furthermore, long-term productivity trials are required to assess crop sustainability and long-term effects on the environment (Lewandoski et al., 2003). Problems with sustainability are best addressed in advance of mass production. While a monoculture can sometimes be easier to manage, a mixture of grasses is sometimes preferred. Mixing grasses can reduce the risk of total crop failure due to disease or pest infestation, creates biodiversity, and will optimize biomass supply by offering harvested biomass at various times during the year thereby reducing storage needs (Lewandowski et al., 2003). Studies are needed to determine which combinations of grasses are best for production in the dry Nevada climate.

Switchgrass (*Panicum virgatum* L.) has taken the lead as the perennial grass with the most potential as a biomass crop. It is a warm-season, perennial sod-forming grass and, as a native grass, is less controversial (Karp and Shield, 2008; Lewandowski et al., 2003). It can be produced in every state in the union under a variety of soil and drainage conditions, including those conditions generally associated with marginally productive lands (Karp and Shield, 2008; Simpson et al., 2008; USDA, NRCS, 2008). Switchgrass is tolerant of moderately saline or acidic soils (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008), and can be farmed similar to traditional forage thus reducing the need for additional farm equipment (Lewandowski et al., 2003). It is somewhat drought resistant, but does best with 16 to 18 inches of water received (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008).

Other crops potentially suited for biomass production include sand bluestem (*Andropogon hallii* Hack.), Indiangrass (*Sorgastrum nutans* (L.) Nash), prairie sandreed

(*Calamovilfa longifolia* (Hook.) Scribn), bluestem (old world) (*Bothrichloa ischaemum* (L.) Keng), tall wheatgrass (*Elytrigia elongate* (Podp.) Z.-W. Liu & R.-C. Wang), Basin wildrye (*Leymus cinereus* (Scribn. & Merr.) A. Löve), Mammoth wildrye (*Leymus racemosus* (Lam.) Tzvelev), and tall fescue (*Festuca arundinacea* Schreb.).

Sand bluestem is a native, long-lived, perennial, warm-season bunch grass. It occurs primarily in the west with adaptations to sandy and sandy loam soils and drought conditions (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). Sand bluestem requires a minimum of 10 inches of received water. This species has weak seedling vigor and competition must be held in check during establishment (USDA, NRCS, 2008). A close seed source or a variety specifically suited for the planned production area would be an asset.

Indiangrass is a native, perennial, warm-season grass. It does well on deep, well-drained floodplain soils, but can be grown on poorly to excessively well-drained soils, in acid to alkaline conditions, and on any soil texture from sand to clay (USDA, NRCS, 2008). Indiangrass is moderately drought tolerant and requires a minimum of 12 inches of water annually. If well maintained, Indiangrass will produce a self-regenerating stand that does not need reseeding (USDA, NRCS, 2008).

Prairie sandreed is a native, sod-forming, warm-season grass. It does well on sandy soils in low precipitation zones (USDA, NRCS, 2008). Prairie sandreed is drought tolerant and adapted to an annual precipitation of 10 to 20 inches (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). It is not, however, very salt tolerant. Seedling vigor is moderate, but stands are slow to establish.

Old world bluestem is a non-native, warm-season clumpgrass. It is highly tolerant of over-grazing and drought, and can be produced on virtually any soil with the exception of those that are excessively sandy in character (Dalrymple, 2001; Ohlenbusch and Kilgore, 2008).

Tall wheatgrass is a non-native, cool-season bunchgrass. It is highly adapted to a wide range of soils and exhibits high tolerance to saline and sodic soils (Pawnee Buttes Seed Inc., 2004). It performs best with at least 16" of water yearly so is likely to require irrigation in Nevada (Smoliak et al., 1969). Washington State University is currently studying various cultivars of tall wheatgrass to determine which is best for biofuels production in their area (Stannard, 2008).

Basin wildrye is a native, cool-season, perennial bunchgrass (USDA, NRCS, 2008). Its seedlings are slow to develop, but once established are long-lived. Basin wildrye is adapted to a broad range of soil textures. It is somewhat tolerant of saline and sodic soils and very tolerant of drought (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). The Trailhead variety can be established in areas with as low as 5 inches of rainfall.

Mammoth wildrye is a cool-season, sod-forming grass. It does well on sandy soils, is highly tolerant of drought and can be moderately tolerant of saline and saline-sodic soils (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). It performs best with a precipitation range of 8 to 16 inches annually.

Tall fescue is a long-lived, cool-season bunchgrass. It can be invasive in some situations due to good seedling vigor, rapid germination, and tolerance of abuse and low fertility (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). Tall fescue is well adapted to most conditions. It is moderately adapted to drought conditions and can survive at 16 inches of water per annum although does much better in the 30 to 60 inch range (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008).

Considerations for Site Restoration: Water, Vegetation, Dust Control

As profits recede and water rights are transferred, fields previously irrigated and farmed become subject to abandonment. These areas then become susceptible to wind erosion and weed infestation due to dry out and the die off of previously irrigated vegetation (Perkins et al., 2008). Wind erosion from abandoned cropland can generate sources of fugitive dust which can cause a variety of respiratory health problems, reduce visibility on roadways, add nutrients and sediments to waterways, and damage property (NDEP, 2008). Factors that affect the level of wind erosion include climate, soil erodibility, field length, ridge roughness, and vegetation (Ferguson et al., 1999).

Two very pertinent historic examples exist. The classic example in the United States is the Dust Bowl in western Kansas, Oklahoma, and Texas, which is well documented in the literature. Well-established native grasslands had developed over the eons in response to limited summer precipitation. Since anthropogenic interests were more along the lines of production agriculture, native grasslands were destroyed in Kansas, Oklahoma and Texas in favor of what is now termed dry-land agriculture. In other words, a land use was adopted that was not suited to the climatic (hydrologic) conditions. Native vegetation was altered (biosphere), crop water requirements exceeded water availability (hydrosphere), continuous cropping and fallow degraded soil quality (lithosphere), with nothing to hold the soil there was a severe wind erosion hazard, and air borne particulate transport (atmosphere and air quality) caused devastating property damage and social consequences. A more recent example is that in the Owen's Valley and Owen's Lake of southern California, wherein surface and ground water were exported to serve the needs of a growing population elsewhere. Water exportation in Owen's Valley and from Owen's Lake has resulted in the lowering of water tables, changes in vegetation, the drying of Owen's Lake, declining soil quality, and major dust derived air pollution. The problem has become so severe, that putting water back onto the land has become a viable mitigation strategy.

Specific to Nevada, initial water right acquisitions by the USFWS within the Truckee Division of the Newlands Project in the area of Swingle Bench (near Fernley < 50 miles from the Walker Basin Project) have created additional sources of fugitive dust, in part, due to the predominantly coarse textured nature of soils common to the Swingle Bench area (e.g. Appian, Tipperary, Swingler Series)(US Department of Agriculture NRCS, 2001). At this location it appears to take between two to four years from the termination of irrigation for sites with perennial vegetation to degrade to a barren state that is highly susceptible to wind erosion. This effect is much more rapid for agricultural production areas. Preliminary studies have shown sites with undisturbed native vegetation to be only slightly erosive; however, previously irrigated sites exhibit the least stability following water removal and are more subject to desiccation, invasive and other weed species establishment, and wind erosion. It was reported that dry, non-vegetated abandoned lands could produce as much as 50 times greater dust volumes than adjacent agricultural lands and four times as much as the surrounding native desert on an annual basis (Capitol Reporters, 2004).

Between the 1997 and 2002 agricultural censuses, Lyon County experienced a 10% reduction in irrigated farmland (USDA, 2004). Without water, unless converted to other uses these fields will soon become vacant of sustainable vegetation. A management plan that requires re-establishment of native vegetation prior to the total transfer of existing water rights could potentially return many of these lands to their previous natural landscape; or some facsimile thereof. Native vegetative cover would help promote wildlife populations, reduce weed propagation and invasive species, as well as reduce the movement and ultimate loss of valuable soil resources. Potential vegetation for restoration activities include Indian ricegrass (*Achnatherum hymenoides* (Roem. & Schult) Barkworth), Basin wildrye (*Leymus cinereus* (Scribn. & Merr.) A. Löve), Beardless wheatgrass (*Pseudoroegneira spicata* (Pursh) A. Löve), Western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Löve), and Inland saltgrass (*Distichlis spicata* (L.) Greene).

Indian ricegrass is a native, cool-season bunchgrass that is widely distributed among the intermountain west. It prefers sandy coarse textured soils but can be found on a variety of soil textures (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). Indian ricegrass is a good revegetation species due to its palatable nature, its drought tolerance, salinity tolerance, and pleasurable appearance. It is, however, slow to establish and short-lived. Indian ricegrass can be produced in deserts with 6 to 16 inches of water per annum (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008).

Basin wildrye is a native, cool-season, perennial bunchgrass (USDA, NRCS, 2008). Its seedlings are slow to establish, but are long-lived. Basin wildrye is adapted to a broad range of soil textures, is somewhat tolerant of saline and sodic soils and very drought tolerant (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). The Trailhead variety can be established in areas with as low as 5 inches of rainfall per year.

Beardless wheatgrass is a native, perennial, cool-season bunchgrass. It is common to the western intermountain regions. Beardless wheatgrass is long-lived, drought tolerant, has good seedling vigor, and establishes quickly (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). It is also well adapted to slope stabilization, and performs well on medium to coarse textured soils. Beardless wheatgrass can reportedly survive the 8 to 12 inch zone of the Great Basin (Pawnee Buttes Seed Inc.).

Western wheatgrass is a perennial, cool-season grass. It does well in medium to fine textured soils. Western wheatgrass can withstand poor drainage, drought, and saline and sodic soils (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). It is slow to establish due to poor germination, but is low maintenance thereafter. Annual water requirements fall in the 10 to 20 inch range (Pawnee Buttes Seed Inc., 2004; USDA, NRCS, 2008). Western wheatgrass is also considered good feed for domestic animals and wildlife.

Inland saltgrass is a native, perennial, warm-season grass common to the dry west. It is recommended for revegetation in the arid west as it is a drought and salt tolerant plant (USDA, NRCS, 2008). It remains green when most other grasses have dried out from water stress and is resistant to over-grazing. It can be planted as seed, but it is more easily propagated by rhizomes and requires adequate irrigation during the establishment year (USDA, NRCS, 2008). Saltgrass can become invasive under some conditions.

Salinization of Arid Croplands

Irrigation of cropland can result in the addition of large amounts of soluble salts to the soil, especially in arid environments such as are found in Nevada. Water pumped from groundwater or from rivers is more likely to have been exposed to large amounts of easily weatherable minerals as well as having been exposed to dry air and high evaporation rates, both leading to a high concentration of soluble salts. As large amounts of water are applied to parched croplands, these salts are deposited within upper layers of the soil and may or may not be subject to further leaching. Over time these salts accumulate and eventually lead to salinity and/or sodicity problems within the soil profile.

Soil salinity/sodicity can be detrimental to plant health. High salt levels reduce the osmotic potential, thereby making it difficult for plants to remove water from the soil. This can reduce growth in established plants and make germination next to impossible. High levels of specific ions can also become toxic. Extremely high levels of sodium ions can reduce the uptake of other essential nutrients, and can result in a reduction in overall soil quality as soil colloids breakdown, further inhibiting the movement of air and water throughout the soil profile.

Use of Fiber Optic Temperature Sensing for Distributed Soil Moisture Monitoring

Measurement of soil moisture content is a critical component in the development of efficient irrigation strategies. Unfortunately, few methods exist to monitor, at the field scale, the moisture content of the rooting zone at high spatial and temporal frequencies. While many "point" sensors are commercially available to measure moisture content, these are generally costly and have measurements support volumes of only a few cubic centimeters of soil. Remote sensing of soil moisture, typically performed with active microwave (Radar) can only resolve soil moistures in the upper few millimeters of the soil profile and cannot penetrate into the active rooting zone. Recent developments in Raman Spectra temperature sensing (frequently called Distributed Temperature Sensing, or DTS) now allow for the nearly continuous in time and space, measurement of temperatures in both soil and water mediums (Selker et al., 2007; Moffet et al., 2008, Tyler et al., 2008). In soils, the thermal response of a soil to solar heating is strongly controlled by the soil moisture content and therefore the time evolution of temperature in a soil profile can be used to infer soil moisture content.

The sensing system consists of a laser source, and Raman Scatter detector at the head of the fiber optic cable. The optical laser pulse which propagates down the light pipe induces Raman Scattering, and this signal is propagated back to the detector. The position of the temperature reading is determined by measuring the arrival time of the returned scattered pulse, and the temperature at that location is determined by the intensity of the backscattered light. This system is somewhat analogous to radar and is commonly used in atmospheric applications as LIDAR. For soil moisture applications, a fiber optic cable can be buried beneath the soil at a specified depth and monitored. Assuming a one-dimensional transport of heat in the soil profile, the governing equation for soil heat transport can be written as (Jury and Horton, 2004):

$$\delta T \frac{\partial T}{\partial t} = K_T \frac{\partial^2 T}{\partial^2 z} \qquad (4)$$

where T represents the soil temperature, z represents the depth below the soil surface and K_T represents the apparent soil thermal diffusivity, which includes the effects of both thermal conduction and latent heat flux. For many conditions, the apparent soil thermal diffusivity can be related to the soil moisture content. By applying appropriate boundary conditions, equation 1 can be solved to describe the propagation of thermal energy through the soil profile. Through measuring the rate of propagation of temperature in the soil, and using estimates of soil bulk density and mineral soil thermal conductivity and specific heat, it is possible to predict the vertically averaged soil moisture.

Effects of Alternative Crops on Soil Nutrients

Soil organic matter (SOM), which includes a variety of C compounds originating from plants, microbes, and other organisms, helps to maintain soil fertility by supplying essential nutrients for plants and it helps to increase moisture retention in soils. As a result, SOM is an important indicator of soil quality (Komatsuzaki and Ohta, 2007; Lemenih et al., 2005). Cultivation of soils often results in declines in soil organic C (SOC) as a result of increased decomposition (Grace and Oades, 1994; Golchin et al., 1995) but C losses can be partly mitigated through manuring, adequate fertilization, and crop rotation for maintaining agronomic productivity (Duff et al., 1995; Mitchell et al., 1996; Reeves, 1997). Upon decomposition of SOM, CO_2 is released into the atmosphere and nutrients such as N and P are released into the soil. Both C and N mineralization are affected by many environmental and soil properties including temperature, moisture, organic matter quality, soil texture, and microbial community structure, among numerous other factors (Cookson et al., 2006; Fierer and Schimel, 2002; Ford et al., 2007; Franzluebbers, 1999; Giardina et al., 2001; Hassink, 1994; Pare and Gregorich, 1999; McLauchlan, 2006).

Soil temperature can greatly influence microbial activity, and thus C and N mineralization when moisture is not limiting (Cookson et al., 2006; Cookson et al., 2002; Zogg et al., 1997. However, in semi-arid areas, soil moisture is most likely to be more important than temperature in regulating C and N fluxes especially under non-irrigated conditions (e.g., Cookson et al., 2006; Murphy et al., 1998a, b). Soil moisture affects microbial activity via O_2 availability for microbial metabolism and substrate diffusion through the soil matrix (Ford et al., 2007). When soil moisture is low, microbial activity is limited by lack of water whereas high moisture content can cause blocking of soil pores limiting O_2 availability (Bouma and Bryla, 2000). In addition, many arid systems are characterized by repeated wetting and drying cycles (Ford et al., 2007; Fierer and Schimel, 2002; Lundquist et al., 1999). Drying-rewetting events could result in moderate short-term changes in respiration rates, substantial reductions in long-term respiration rates, an increase in nitrifier activity, and an increase in the size of the microbial biomass C pool (Fierer and Schimel, 2002). Carbon and N mineralization can also be affected by soil texture. SOM can be protected from microbial decomposition especially in clay-rich soils causing C and N mineralization to be slower compared to sandy soils (Hassink, 1994; Franzluebbers, 1999; Pare and Gregorich, 1999). This protection by clay-sized particles has been ascribed to adsorption of organics onto clay and sesquioxide surfaces, encapsulation between clay particles, or entrapment in small pores in aggregates inaccessible to microbes (Hassink, 1994).

Plants have an important influence on C and N cycling in soils. Changes in plant productivity, particularly root biomass, are likely to strongly influence the soil microbial community by altering root exudation patterns and the supply of root C to soil through root turnover (Bardgett et al., 1999). In addition, organic matter decomposition and nutrient cycling can be affected by plants species through differences in plant tissue composition (Hooper and Vitousek, 1997; Wardle et al., 1997; Grime, 1998). Previous studies have shown that structurally and functionally distinct microbial communities develop under different plant species (Degens and Harris, 1997; Bossio et al., 1998; Marilley and Aragno, 1999) and plant species can significantly alter soil microbial communities within three months which in turn affected N concentrations, pH, and N mineralization in the soil (Kourtev et al., 2003).

For this study we focused on the effects of moisture and plant species on C and N transformations in soils in the Walker Basin. The goal was to assess if changes in irrigation regime and alternative agricultural crops affect C losses from the soil and N availability for plants. We measured C and N mineralization under controlled conditions using a series of laboratory incubations focusing on effects of moisture and vegetation. We conducted incubation of soils prior to planting and following one cropping cycle. These laboratory studies were augmented with field measurements of C and N status as well as soil CO_2 efflux over one growing season. Soil CO_2 efflux, or soil respiration, integrates all components of soil CO_2 production, including respiration of soil organisms and plant roots. As a result, soil respiration represents an important efflux of C from terrestrial ecosystems.

Riparian Zone Affect on Nutrient Flux

Riparian zones have long been valued and studied for their capacity to buffer and regulate nitrate contamination from surface inputs to ground and surface water resources (Haycock and Burt, 1993). Riparian zone sediments often contain the favorable reducing conditions necessary for the removal of nitrate via microbial denitrification (Puckett, 2004). Study of floodplain lithology is necessary to determine the location of deeper layers in which buried organic matter may increase denitrification at depth and flood deposited coarse material may create conduits for groundwater flow that bypass the riparian zone (Hill et al., 2003).

Riparian zone hydrology must be determined as flowpath influences both the extent of contact between nitrate (the electron acceptor) and organic matter (the electron donor) and the residence time of the nitrate plume in the carbon rich zone (Rassam et al., 2005). Past studies of riparian nitrate removal have tended to focus on sites with similar hydrogeologic setting where flow paths are shallow, often restricted by impermeable clay layers and flow direction is from upland areas to surface water (Hill, 1996). Burt et al. (1999) observed that although a riparian zone showed large potential for denitrification, nitrate still passed through the zone via springs and gravel lenses beneath the floodplain soil. There remains some uncertainty as to the effect of depth on riparian denitrification. Hill et al. (2000) suggested that unless a deeper flow path induces interaction with localized supplies of organic matter denitrification will be limited. Jacinthe et al. (2000) noted increased denitrification rates when depth to the water table decreased from 50 cm to 10 cm. A study of three Rhode Island riparian sites found no significant difference in denitrification by depth (Kellog et al., 2005). Seasonal effects on flow path and nitrate retention were found in the NICOLAS study of 13 riparian sites in Europe where in summer a reversed hydraulic gradient prevented buffering of upland subsurface runoff (Burt et al., 2002). Nitrate concentration and water flux were the major variables in nitrate retention (Pinay, 2001; executive summary at http://www.aopv55.dsl.pipex.com/nicolas/nicolas.htm). Riparian zones with a relatively flat topography resulting in a low hydraulic gradient and increased residence times enhance anaerobic conditions necessary for denitrification (Vidon and Hill, 2004).

There remains some uncertainty about whether or not riparian subsurface denitrification decreases with depth or is limited when water tables drop below shallow, carbon-rich soil layers. Burt et al. (1999) found an exponential decrease in potential denitrification activity with depth, little denitrification below 40 cm, and no evidence of deep denitrification (> 1 m). Bernal et al.

also reported higher denitrification potential for shallow (<30 cm) soils than for deeper soils (2007). Jacinthe et al. (2000) noted increased denitrification rates when depth to the water table decreased from 50 cm to 10 cm. A study of three Rhode Island riparian sites found no significant difference in denitrification by depth (Kellog 2005). In contrast, Domagalski et al. reported that denitrification in the saturated zone tended to increase with depth as dissolved oxygen decreased with depth (2008). Hill et al. (2000) suggested that unless a deeper flow path induces interaction with localized supplies of organic matter, denitrification will be limited.

Previous studies of denitrification in riparian zones have often measured potential denitrification activity on soil cores in the lab (Hill, 1996). Microsites or "hotspots" of microbial denitrification result in denitrification being the most temporally and spatially variable of the N cycle processes (Mosier and Klemedtsson, 1994). *In-situ* methods are more capable of capturing microsite heterogeneity than soil core methods (Istok et al., 1997). Although *in-situ* methods are desirable for characterizing microbial metabolic activity, to date these methods have not been widely used and spatial relationships between microbial metabolic activities and in-situ water quality are lacking (Schroth et al., 1998).

Direct evidence of in-the-field denitrification below the saturated zone can be provided by conducting an *in-situ* "push-pull test" where groundwater amended with nitrate and a conservative tracer (bromide) is injected and subsequent changes in reactant and product concentrations are monitored during extraction (Trudell et al., 1986). Push-pull tests conducted in conjunction with the study of hydrogeologic setting can provide a more complete view of the nitrate removal capacity of riparian zones (Addy et al., 2001). Early studies employing the push-pull test method focused on the disappearance of nitrate (Istok et al., 1997; Trudell et al., 1986) or monitored the product formation of N_2O in the acetylene blocked partial denitrification reaction (Sánchez-Pérez et al., 2003; Schroth et al., 1998). Acetylene can be degraded both anaerobically and aerobically (Tiedje, 1982). Other limitations of the use of acetylene in the field include the inhibition of nitrification, incomplete diffusion of acetylene, and incomplete termination of the denitrification reaction at the N_2O step (Addy et al., 2001). The use of labeled $^{15}NO_3^-$ enables the researcher to allow the denitrification reaction to go to completion while also distinguishing the $^{15}N_2$ product from atmospheric nitrogen. Research has shown agreement between field push-pull methods and lab measurement methods of denitrification (Well et al., 2003).

Effects of Altered Water Use on Invasive Species in the Walker River Riparian Zone

Withdrawal of land from surface water irrigation in the Walker Basin may change the direction of groundwater flow and depth of the water table in the riparian zone particularly in the lower portion of the valleys where slopes are more gradual and water tables are higher. The change in water table depth may be the most critical factor in encouraging or discouraging the establishment and success of invasive plant species. Furthermore, the success or failure of invasive species with a high level of consumptive water use can have a dramatic effect on the ability of water to get into the Walker River and be delivered to the lake.

One invasive species that is of critical concern in the western United States and found in the Walker Basin is the invasive exotic crucifer *Lepidium latifolium* (Tall whitetop or Perennial pepperweed). *L. latifolium* is not only found in the Walker Basin, but it has also invaded thousands of acres of riparian lands in the Humboldt and Carson watersheds of Northern Nevada. The observations of the investigators in this study of the degree of infestation in the Truckee and

Caron River watersheds suggest that the Walker Basin is still in the early stages of invasion. This plant has had significant impacts on the ecology and economies of these areas, and it is expected to eventually spread throughout the entire state (Eiswerth et al., 2005).

Deep rooted invaders such as *Tamarix chinensis* (Saltcedar) use water from shallow water tables and gain a competitive advantage in disturbed riparian areas. These deep rooted invaders have also been reputed to have higher consumptive water use than native species and may negatively affect the availability of water in riparian ecosystems.

METHODS AND MATERIALS

Study Site Locations and Treatment Design

Walker Lake is a terminal lake within the Great Basin region. The bulk of the Walker River Basin is located in western Nevada with its headwaters in the Sierra Nevada along the eastern border of California. Elevations in the basin range from about 3,500 m in the upper reaches to about 1,200 m at the valley floor. Average annual precipitation ranges from approximately 32 inches at headwater locations within the upper watershed to as low as 4 to 6 inches at the lower elevations.

Study sites were located along the lower reaches of the Walker River in Mason Valley and included one riparian, one wildlife habitat, two sites under agricultural management, and one abandoned pasture (Figure 1). Two sites (wildlife habitat and flood irrigated pasture) were located within the Mason Valley Wildlife Management Area (WMA), and two were located at existing ranch sites (Valley Vista sprinkler irrigated alfalfa and 5C abandoned pasture). The basic study design consisted of planting alternative agriculture species for food, forage, and biofuels production, and a second component for land restoration. Differential water treatments were then super-imposed onto both components. Based on a total water allocation of 4 ft/year, four water treatments were planned for the alternative agriculture planted species: 0%, 50% (2 ft), 75% (3 ft), and 100% (4 ft). Planned water treatments for the restoration component were 0% and 25% (1 ft). The latter treatments were based on the common assumption that a 25% water allocation would be sufficient for the establishment of restoration vegetation. Different water treatments were reached by deficit irrigation. Plots within a water treatment were watered at full capacity until the water allotted to them for the season was used in full.

Vegetation treatments (Table 1) for the alternative agriculture included 14 crops of both annual and perennial varieties. Five alternative biofuel grain species were chosen as well as four cool season and five warm season grasses, for a total of nine potential biofuels. Five plant varieties were considered for the restoration component. Each vegetation and water treatment was replicated three times within each agricultural site. The alternative agriculture component was initially implemented at three of the four study locations (wildlife habitat, irrigated alfalfa, and abandoned pasture) and the method of water application was by sprinkler irrigation. The initial restoration component was implemented at all four study locations but the method of water application at the WMA irrigated pasture location remained under flood irrigation. Overall the general study design consisted of four locations, by two study components (alternative agriculture and restoration), 14 and 5 varieties respectively, 4 and 2 water treatments, and three replications. The two WMA sites were eliminated from consideration during the second year of study because of little or no germination during the establishment year. We believe this to have been due in part to alleopathy and fine soil texture at the wildlife habitat site, and high salinity/sodicity and fine soil texture at the flood irrigation site.

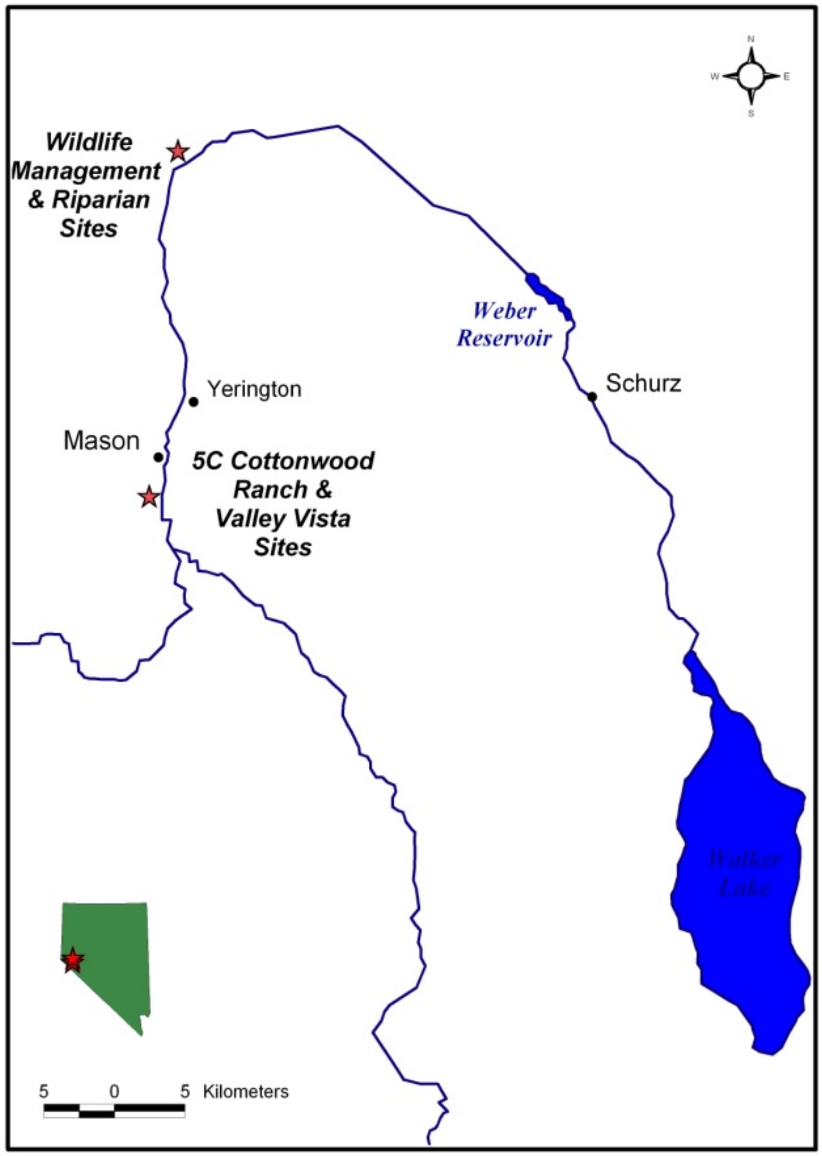

Figure 1. Map of agricultural and riparian site locations along the Walker River.

Table 1. Seeded plants for agricultural sites.

Common name	Scientific name	Variety
	Alternative crops	
Tef	*Eragrostis tef*	Brown
Tef	*Eragrostis tef*	Ivory
Buckwheat	*Fagopyrum esculentum*	Mancan
Amaranth	*Amaranth hybridus* x *hypochondriacus*	Plainsman
Pearl millet	*Pennisetum glaucum*	Tifgrain 102
Alfalfa	*Medicago sativa*	Mountaineer 2.0
	Warm season grasses	
Switchgrass	*Panicum virgatum*	Nebraska 28
Sand bluestem	*Andropogon hallii*	Woodward
Indian grass	*Sorghastrum nutans*	Cheyenne
Prairie sandreed	*Calamovilfa longifolia*	Goshen
Bluestem	*Bothrichloa ischaemum*	WW Iron Master
	Cool season grasses	
Tall wheatgrass	*Elytrigia elongata*	Alkar
Basin wild rye	*Leymus cinereus*	Trailhead
Mammoth wild rye	*Leymus racemosus*	Volga
Tall fescue	*Festuca arundinacea*	Fawn
	Revegetation species	
Indian ricegrass	*Achnatherum hymenoides*	Nezpar, Rimrock
Basin wild rye	*Leymus cinereus*	Trailhead
Beardless wheatgrass	*Pseudoregneria spicata*	Whitmar
Western wheatgrass	*Pascopyrum smithii*	Arriba, Rosana
Inland saltgrass	*Distichilis spicata*	VNS
Control	Nothing sown	

Study Site Descriptions

Valley Vista Ranch (VV)

The Valley View Ranch site location included both revegetation and alternative agriculture experiments (Figure 2B). This site was located on Malapais complex soils (60%), Tocan sandy loam 2 to 4% slopes (20%), and Tocan sandy loam 0 to 2% slopes (20%) (US Department of Agriculture, 1984). Since the site was still under alfalfa production, Round-up and Dicamba were sprayed to remove existing vegetation. The field was then ripped and disked prior to seeding. Cool season grasses were planted in December 2007, alternative food and forage crops and warm season grasses were planted in May 2008, and salt grass was planted in July 2007.

5C Cottonwood Ranch (5C)

The 5C Cottonwood Ranch site also included both alternative agriculture and revegetation treatments (Figure 2A). It was located on sandy textured Malapais complex 2 to 15% slopes soils (100%) (US Department of Agriculture, 1984). The site had not been in production for several years and was used primarily as grazing land for burros and llamas prior to project implementation. Soils were highly compacted and void of vegetation. Due to the lack of vegetation, the only preparation applied to this field was ripping and disking. Cool season grasses were then planted in December 2007, alternative agriculture crops and warm season grasses were planted in May 2008, and salt grass was planted in July 2007.

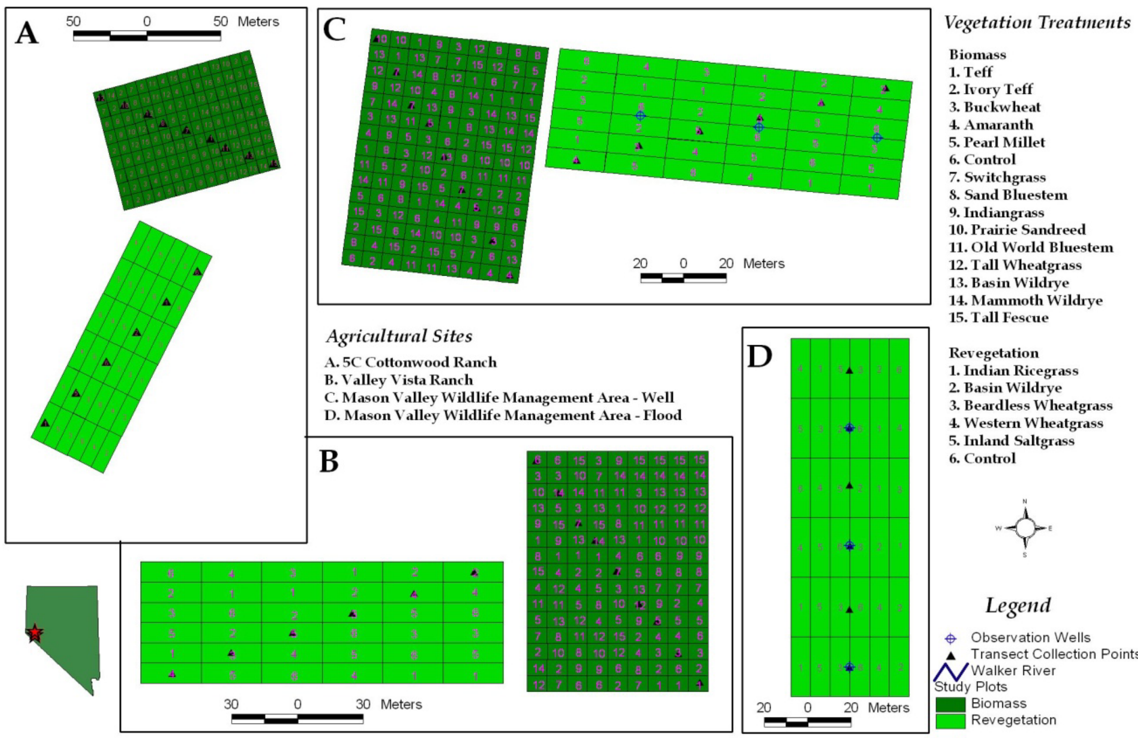

Figure 2. Site map of agricultural field sites with identification of transect locations and observation wells.

Mason Valley Wildlife Management Area Wildlife Habitat (WMW)

The wildlife habitat site at the Mason Valley Wildlife Management Area again included both alternative agriculture and revegetation experiments (Figure 2C). It was located on Dithod loam soils (75-80%) and Fallon fine sandy loam, saline alkali soils (15 to 20%) (US Department of Agriculture, 1984). The dominant existing vegetation at the wildlife habitat location was willows with intervening grasses. Willows were mechanically removed and Round-up and Dicamba were applied prior to planting. Cool season grasses were planted in November 2007, alternative agriculture crops and warm season grasses were planted in May 2008, and salt grass was planted in July 2007.

Mason Valley Wildlife Management Area Flood Irrigated Pasture (WMF)

The Mason Valley Wildlife Management Area flood site was used for only the revegetation portion of this study (Figure 2D). It was located on Dithod loam, saline-alkali soils (75%) and Eastfork clay loam, saline-alkali soils (25%) (US Department of Agriculture, 1984). Prior to clearing in the summer of 2007, existing vegetation consisted primarily of bunchgrasses.

This site was treated with Round-up and Dicamba, mowed, ripped, disked, and laser leveled. Cool season grasses were planted in November 2007, and saltgrass was planted in July 2008.

Walker River Riparian (WRR)

A riparian assessment site was also established along the Walker River within the Mason Valley Wildlife Management Area (Figure 3) for purposes of evaluating soil salinity and riparian zone nitrate buffering capacity. Land uses within the MVWMA include 1200 acres of farm land that is irrigated for grain and hay crops, in addition to native shrub and meadow lands. The soils at these two sites are classified as Fallon fine sandy loam, frequently flooded. Soil drainage class is listed as somewhat poorly drained and the area is arid receiving an annual mean precipitation of 10 – 18 cm (USGS, 2009). Elevation at the river is 1300.28 meters AMSL (Above Mean Sea Level) and the river flows north through the study site. The vegetation is composed of *Populus fremontii, Tamarix chinensis, Salix gooddingii, Distichlis spicata*, *L. latifolium,* and *Elymus trachycaulus.* Immediately north of these sites irrigation water is delivered to fields from surface water diversion ditches.

Figure 3. Aerial photograph of Walker River riparian site location.

Soil Properties

Baseline soil analyses included infiltration, bulk density, and textural classification. A transect was established across each field. Along each transect one point was delineated in each water treatment, or row, totaling nine points for each alternative agriculture and six points for each revegetation component (Figure 2). At each of these sampling points two tests were performed. A bulk density sample was taken using a standard bulk density sampler to extract a core of known volume. The core was dried and weighed to determine the mass of soil per unit volume. An infiltration test was next performed using a disc permeameter. Philip's equation was then applied to determine near saturation hydraulic conductivity at each location (Philip, 1957).

Soil texture was measured on the samples taken for chemical analysis using a Saturn Digisizer 5200 Laser Particle Size Analyzer.

Soil samples were collected within each water and vegetation sub-plot at each site. Baseline samples were collected June through September 2007 and post-harvest samples were taken in March/April of 2009 using a standard bucket auger (Figure 4). Control plots were sampled at six depths; 0 to 6", 6 to 12", 12 to 24", 24 to 36", 36 to 48", and 48 to 60". Non-control plots were sampled at two depths; 0 to 6" and 6 to 12". Samples were taken from the center point of each sub-plot totaling approximately 1,300 samples each year. Control samples from 2007 were analyzed for soil electrical conductivity (EC), hydrogen ion activity (pH), and water soluble and exchangeable ions to characterize nutrient status. Sub-samples from each plot and depth from 2009 were analyzed to determine changes in nutrient status associated with differing crop types and water treatments.

Figure 4. Dr. Paul Verburg using bucket auger to collect soil samples at WMW site in the fall 2007.

Soil samples were hand ground and passed through a 2 mm sieve to break aggregates and remove coarse rock fragments and plant debris. Deionized water was added to develop a saturated paste according to methods outlined by Bower and Wilcox (1965). Soil solution was extracted using a vacuum system and Whatman no. 5 filters. The water extract was again filtered with a 0.45 μm nylon membrane filter to remove fine particulates. Filtered extracts were analyzed for water soluble anions (PO_4-P, SO_4^-, NO_3^--N, NO_2-N, Cl^-) (Dionex Corporation, 2003) and cations (NH_4^+, Na^+, Ca^{2+}, Mg^{2+}, and K^+) (Dionex Corporation, 2001) using a Dionex ICS-3000 ion chromatography system. Extracts were once again utilized to measure pH with a Hannah Instruments portable pH meter and electrical conductivity with an Oakton CON6/TDS 6 Hand-held Conductivity/TDS Meter. In a corresponding study, sub-samples consisting of 5 grams soil were equilibrated with 10 mL deionized water. Soil pH was measured and salinity was characterized by electric conductivity measurements of the soil/water slurry. Conductivity values (µS/cm) were converted to a salt concentration (mg/kg) according to the procedures followed by the Soil Characterization Laboratory at the Desert Research Institute.

Wind Erosion

Twenty-four dust collectors (Fryrear, 1986), were installed at the 5C and Valley Vista Ranch sites (Figure 5) in nests of 4 traps each. The traps on each nest were set to collect at heights of 10 cm, 35cm, 60 cm, and 100 cm above the soil surface. A mat was installed on the ground at the base of each nest to prevent rapid weed growth from interfering with the movement of the bottom trap. The dust collectors were established to capture the difference in soil erosion from varying water treatments within revegetation fields in comparison to control sites in neighboring fields.

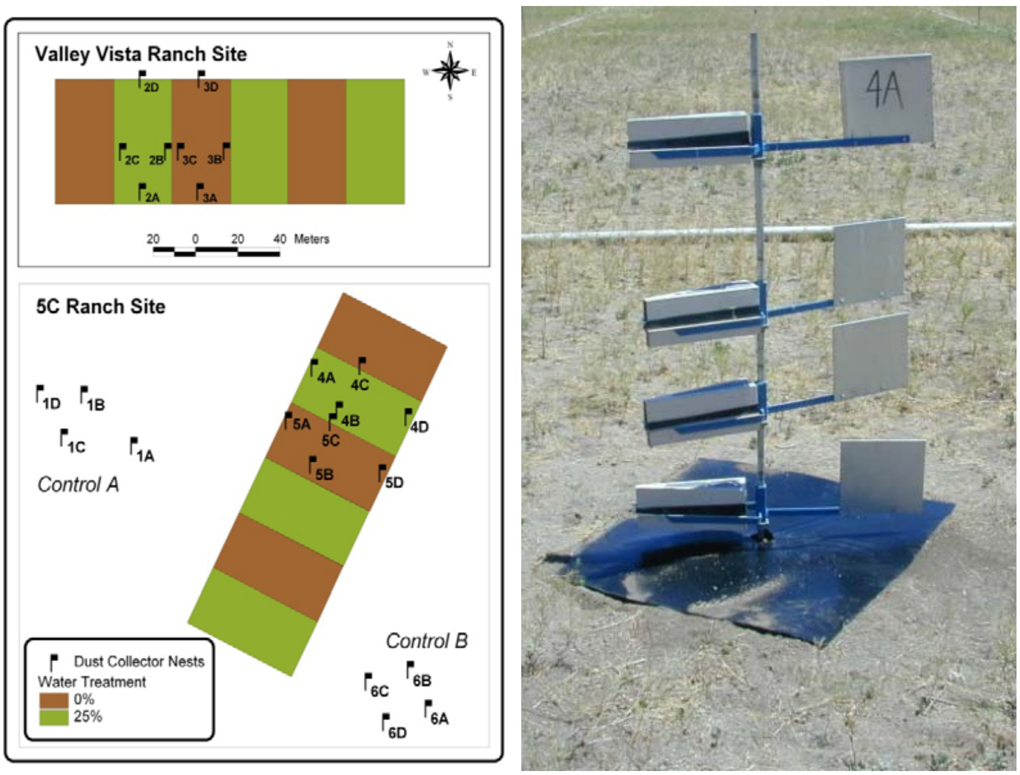

Figure 5. Dust collector locations as of spring 2009 and dust collector nest at 5C site (Fryrear, 1986).

After a number of preliminary measurements, a diamond shape layout was adopted and installed in the spring of 2009. This layout allowed us to best capture the dust entering and exiting each area from all boundaries and thereby determine what was being deposited and generated over the differing soil surfaces. Two control areas were selected to compare revegetated surfaces to those most representative of natural conditions in the area.

Control A, was located on similar soils west of the 5C revegetation plots. It has never been farmed, and was grazed at some point in its history but not within the previous 5 to 10 years. Comparatively it was not as compacted as was the Control B site.

Control B, located on similar soils just east of 5C revegetation plots. Like the revegetation plots, it had once been farmed and had been highly compacted by years of concentrated grazing until just before project planting. This area was not tilled for planting in 2007 and remained highly compacted.

Dust traps were emptied after each major wind event (sustained winds over 10 mph and gusts over 30 mph).

Agricultural Hydrology

A total of four rain gauges were installed at three of the four sites; one at WMW, one at WMR, and two on opposing corners of the site at 5C. Data collected from the rain gauges were added to irrigation values to determine the total water application to each site. Three observation wells were installed at each of the two Wildlife Management Area sites to monitor water table height (Figures 4 and 5). Wells were monitored before and after each irrigation, after rainfall events during the growing season, and monthly over the winter season. Soil moisture samples were taken weekly prior to irrigation and monthly during dormancy to isolate changes in the soil moisture profile. One point within each water treatment and replication along each transect were chosen for sampling at four depths; 0 to 6”, 6 to 12”, 12 to 24”, and 24 to 36”. Soil moisture data was also collected to correspond to soil temperature data. Corresponding soil moisture data was collected at 22 points along the cable path at the 6” depth pre- and post-irrigation (Figure 6).

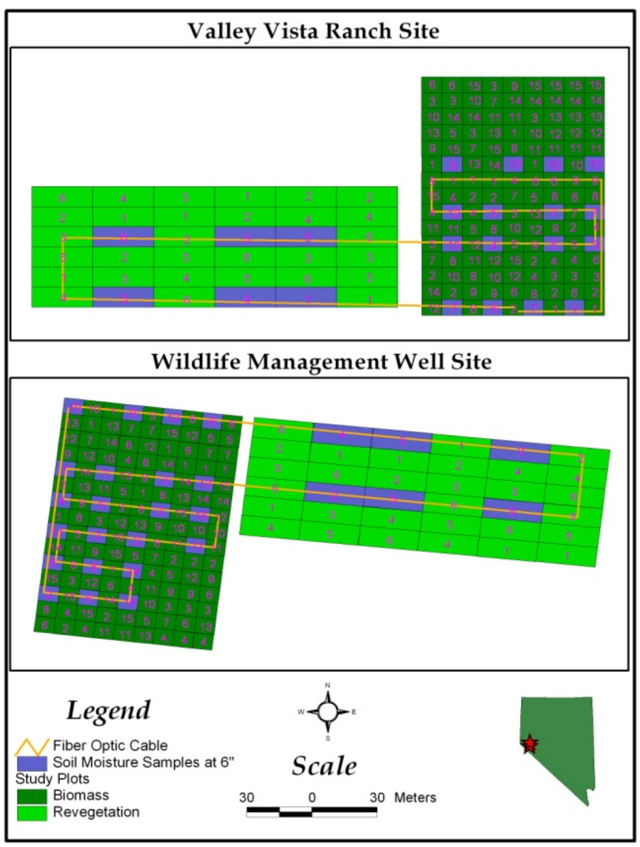

Figure 6. Location of fiber optic cable and soil moisture sampling points at VV and WMW sites.

Soil Temperature

A fiber optic cable was installed 15 cm beneath the soil surface using a plow system similar to that used to install subsurface drip irrigation tubing. Approximately 1,000 m of commercial fiber optic cable was buried at the WMW and VV sites (Figure 6). Figure 7 shows the installation of the fiber behind a small tractor. The fiber location was geo-referenced and mapped using GPS and was installed to generally cover the majority of alternative agriculture crops and all water treatments for the two sites. Temperatures were measured along the fiber optic cable using a Sensornet Sentinel and Sensornet Halo Raman spectra DTS system.

Figure 7. Installation of fiber optic cable at the Valley Vista ranch site in December 2007. Approximately 1,000 m of fiber was installed at both Alternative Agriculture sites.

In 2009, the WMW site was found to have poor quality control on the fiber burial depth. This was primarily a function of the heavy texture of the soil, as well as the moderate size of the installation plow system. A much heavier plow system, capable of burying up to 3 fibers has recently been constructed and tested, and will be used in subsequent studies. Furthermore, there was no germination of any plantings for any treatment at the WMW study site. Consequently, DTS temperature studies in 2009 focused on the VV site exclusively.

Soil Nutrient Availability

Laboratory Incubations

Two laboratory incubations under controlled conditions were conducted to assess potential C and N mineralization (Stanford and Smith, 1978). For the first laboratory incubation, soil samples from the Mason Valley Wildlife Management Area (WMW), the Valley Vista site (V V), and the Cottonwood Ranch (5C site were used. In this study four crops: Tef (*Erograstis tef)*, Amaranth (*Amaranth cruentus)*, Alfalfa (*Medicago sativa)* and Switchgrass (*Panicum virgatum)* were included. The samples for this incubation were taken in the fall of 2007 prior to planting between 0 and 15 cm depth. The alternative and revegetation fields from the Valley Vista and Cottonwood Ranch sites and the revegetation field from the wildlife habitat site were sampled. Five vegetation plots were randomly selected from each of the 5 fields for a total of 25 plots. Prior to incubation soils were air-dried and sieved over a 2 mm sieve. Each soil was incubated at three moisture levels 0.05, 0.15, and 0.30 g H_2O/g soil using three replicates for each sample resulting in a total of 75 samples. For each soil, 15 gram of air-dried soil was placed into a 250 mL glass jar equipped with a septum in the lid. Next, DI water was added to each soil according to its designated moisture level. After the water addition the lid was firmly screwed on to the jar and placed into a constant 25ºC temperature refrigerator for a period of 5 weeks. Periodically, air samples were taken from the headspace for CO_2 measurements using a 250 μL syringe through the septum in the lids of each jar. The CO_2 concentration in these samples was measured using a LI-COR 6251 CO_2 analyzer. The jars were opened periodically to allow for oxygen to enter the jars. Respiration was calculated as the increase in CO_2 concentration over time.

For the second (post-planting) incubation, only soil samples from the Valley Vista and Cottonwood alternative crop fields were used for reasons previously stated. Soils for this incubation were sampled at the end of August, 2008 following the first growing season. Within each field, soil samples were pooled by vegetation type and homogenized resulting in a total of eight samples (2 fields x 4 vegetation types) from which subsamples were taken. These samples were incubated at the same moisture level as used for the first incubation using three replicates for each field and moisture combination resulting in a total on 72 samples. The incubation procedures were the same as those used for the pre-planting incubation.

At the beginning and end of the incubation period, all soils were extracted using 2M KCl. Five grams of each soil were placed into a 50 mL plastic syringe equipped with a filter, 50mL of the KCl solution was added and allowed to soak into the soil for 30 minutes. After 30 minutes, the soils were extracted over a 30 minute time period with a SampleTek Vacuum Extractor. The extracts were frozen until analyzed. The extracts were analyzed for NH_4 and NO_3 using a Lachat autoanalyzer. Net mineralization was calculated as the change in total inorganic N concentrations between the end and beginning of the incubations. Subsamples of each soil were dried to obtain the moisture content at the end of the incubation and were used for total C and N analysis. Soil samples were analyzed for total C and N at the Soil Water and Forage Analytical Laboratory at Oklahoma State University using a Leco CHN analyzer. Bulk density cores were taken on October 23, 2008, using a 5.4 cm diameter, 3 cm tall ring. Particle size analysis of the all soils was conducted by sieving over a 2 mm mesh sieve followed by analysis of the <2 mm fraction using a Micrometrics Saturn DigiSizer 5200 Laser Particle Size Analyzer in the Soil Characterization Laboratory at the Desert Research Institute of Reno.

Field Measurements

Soil CO_2 efflux was measured during the first growing season in Valley Vista and Cottonwood alternative agriculture fields in four vegetation types. Initially, we selected plots to cover the three irrigation regimes. Due to a water year shortage only one irrigation regime was used. Respiration was measured at 7 times between June 6 and August 28, 2008 in 72 plots (4 vegetation types x 9 replicates x 2 fields) using a static chamber (0.48 L) equipped with a Vaisala GMT CO_2 analyzer. The static chamber was placed on a 15.24 cm diameter PVC ring, installed in each plot prior to the emergence of the crops. Soil respiration rates were calculated as the rate of increase in CO_2 concentrations inside the chamber. Each measurement lasted approximately one minute. All measurements were taken between 10:30 AM and 3:30 PM to limit changes in ambient temperature. Soil moisture was measured with a Delta-T HH1 Theta Meter for the first four trips and a Decagon ECH2O-5TE moisture and temperature probe for the last three sampling dates. Air temperature and relative humidity data were collected between June 6th and August 12th by a HOBO H8 Pro Temp/RH sensor (Onset Computer Corporation, Bourne MA) in the Valley Vista field. On the last three sampling dates, soil temperature was measured using the Decagon probe.

Vegetation samples were taken on August 20 and 21, 2008, to assess the total aboveground biomass in each plot at the end of the growing season. Aboveground vegetation was harvested inside a 1.36 m diameter circle surrounding the soil respiration collars. Biomass was separated into crops and weeds. All samples were dried at 70ºC until constant weight.

Statistical Methods

For the laboratory incubations effects of field, moisture and vegetation type and their interactions were tested using a 3-way Multiple Analysis of Variance (MANOVA). Student t-tests were used to determine differences between vegetation, field, and pre- and post planting incubations. The effects of moisture, texture, initial C/N, and initial percent organic N on C respiration rate constant, cumulative C production, net N mineralization were further examined using multiple linear regression analysis.

For the field measurements effects of vegetation type, field, and date and their interactions were tested using a MANOVA. Student t-tests were used to assess differences between vegetation types and fields. The effects of moisture, texture, vegetation biomass, percent N, percent C, fifteen minute air and soil temperature, and relative humidity on C respiration rate and net change in total inorganic N, NH_4 and NO_3 concentration were determined using linear multiple regression analysis. Multiple regression analyses run versus factors that were only measured at the end of the growing season (e.g. percent N and percent C in soil and biomass, and net change in inorganic-N) only included C respiration rates at the end of the growing season as well. Effects were considered significant if $p<0.05$. All statistical analyses were carried out using DataDesk version 6.1.

Riparian Zone Denitrifiction

A transect of 4 piezometers was installed and oriented perpendicular to the Walker River. Piezometers were constructed of 2 inch schedule 40 PVC pipe. Bore holes were constructed with 2 inch augers. During auguring, soil samples were collected at 1ft intervals and at any change in soil horizon characteristic. Lithology was determined based on visual inspection during augering. Piezometers were screened over the lower 2 ft. Maximum depth of piezometers (10 ft) was limited by the length of the auger extensions. Annular spaces were narrow and were backfilled with native sandy soil. The piezometers were vertically surveyed with an auto-leveling laser level with a factory specified precision of 2.4 mm at 30 m. Latitude/longitude was taken with GPS equipment. To supplement the piezometer transect, staff gages were installed in the river and in the drainage ditch. Staff gages were surveyed in the same way as the piezometers. A partial second transect with two additional piezometers was located 30 ft in the downstream direction (Figure 8).

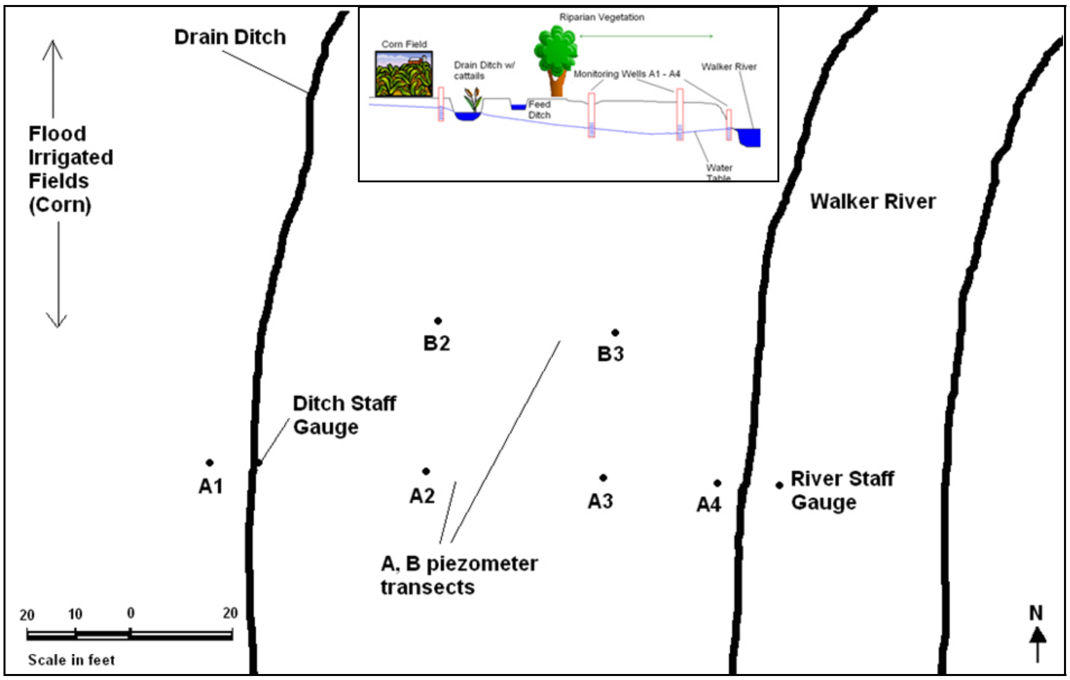

Figure 8. Piezometer transects at WRR site and site profile.

Depth to water measurements in the piezometers and stage levels in the river and ditch were taken monthly. Measurements in the piezometers were taken with a well sounder. Stage readings in the ditch and river were taken by sight reading off the previously installed staff gages. Slug tests were performed on 3 of the piezometers in order to characterize site hydrology and to target feasible sites to conduct the push-pull-tests. Water levels inside the well during the slug test were monitored with a pressure transducer/data logger. Slug testing followed the Bouwer and Rice method for partially penetrating wells as described by Kruseman and Ridder (1990).

Specific locations where "push-pull-tests" (PPTs) were conducted were chosen based on suitability of hydraulic conductivity, depth below water table, organic matter content, and distance along a transect perpendicular to the Walker River. Potential sites for PPTs were identified after conducting slug testing of piezometers, mapping the hydraulic gradient, and sampling soil horizons for combustible organic matter. Injection wells (Figure 9) for the PPTs were constructed of a retractable drive tip injection head attached to 3/16" ID tubing and two 5' extensions. The injection wells were driven into the soil with a post pounder until just below the desired injection depth and the pulled up slightly to expose the screened section of the retractable tip. This enables the user to drive through clayey soil horizons without clogging the screens.

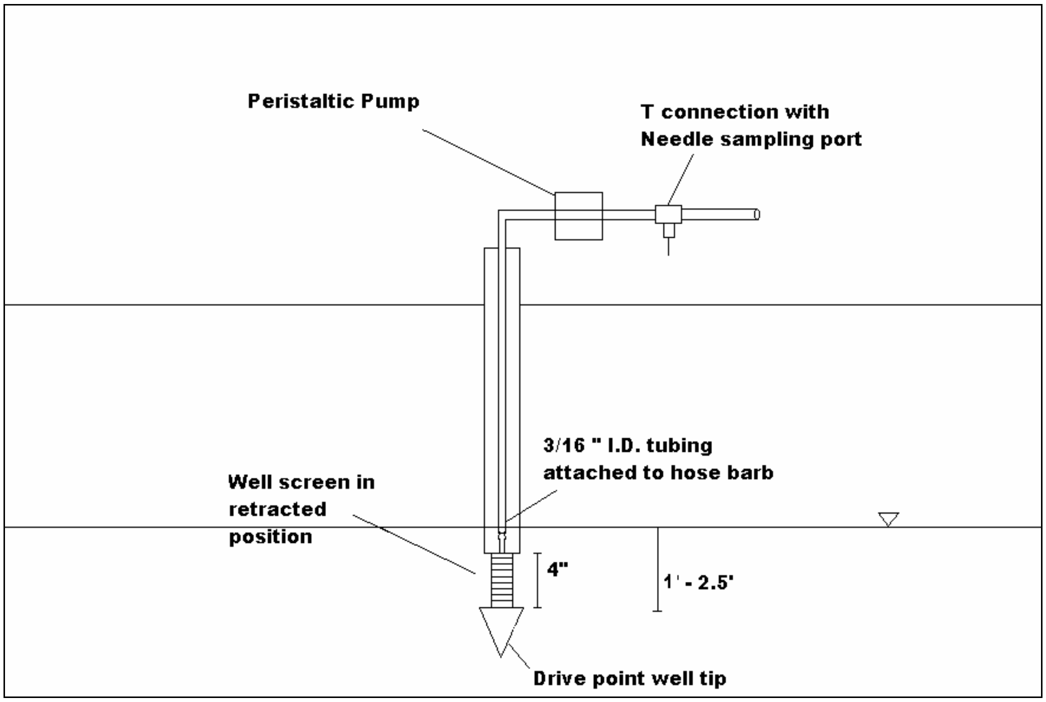

Figure 9. Injection well design as installed at WRR site.

Five “Push-Pull” tests (PPT) were performed in the Spring, Summer and Fall of 2008. Testing began on 5/04/08 with the first 24 hour PPT and was completed by 9/17/08 with the final PPT, also a 24 hour test. Only PPT 2 allowed for 48 hour incubation due to the lower hydraulic conductivity of soils at that site.

The use of a drive point style well prevents any annular space around the well. The use of narrow gauge tubing ensures that the minimum amount of injection solution will be left behind in the well. Both measures effectively ensure the maximum amount of injection solution will interact with in-situ soil microbes. Injection wells were developed by first extracting at least 5 L of groundwater. Groundwater samples were taken prior to injection and analyzed for bromide, nitrate, pH, temperature, dissolved oxygen (DO), and isotopic ratios of dissolved dinitrogen and nitrous oxide gas. DO, pH, and temperature were measured in the field using an Orion 5 star multiprobe (model # 1219000). Five L of ground water was then pumped and set aside in a carboy and amended with 10 mg/L 98% enriched KNO_3 and 100 mg/L KBr, a conservative tracer. The injection solution was then air sparged with high purity helium until DO reached background levels. Injection was accomplished with a peristaltic pump injecting at a slow rate (less than 500 ml/min) to minimize disturbance to the natural flow of groundwater. The injected solution was left to incubate for a period of 24 to 48 hours.

Following incubation, 1.5 times the injected volume was “pulled” from the injection well with a peristaltic pump. During the extraction phase dissolved oxygen was monitored with a polarographic DO probe (Orion, model # 083005MD). Water samples were taken at 1 L and 0.5

L intervals. Samples to be analyzed for dissolved nitrogen gas were taken via a "T" connection equipped with a non-coring needle directly into gas evacuated exetainers. Samples taken for solutes were collected via the HDPE tubing in 250 ml HDPE bottles and stored at 4 degrees C in a field cooler until being frozen for future analysis. Extraction rates were less than 500 ml/min.

Bromide concentrations were measured with a half cell bromide electrode (Orion, model #9435BN) and reference cell electrode (Accumet, model # 13-620-258) on an Accumet pH meter 900 in the mV setting. Millivolt readings were converted to mg/L by the equation derived from the linear relationship of the log of bromide to mV. A calibration curve of log bromide plotted against mV was developed with four data points ranging from 1 mg/L to 100 mg/L with a correlation coefficient of 0.998.

Nitrate concentrations were measured by flow injection analysis using a Lachat Quickchem 8000 autoanalzyer. Nitrate is quantitatively reduced to nitrite through a copperized cadmium column. A reaction with a sulfanilamide produces a reddish water soluble dye which is read at 513 nm. Calibration curves with 6 data points ranging from 0 to 1,600 micrograms/L nitrate produced correlation coefficients exceeding 0.999.

Gas samples were collected during the extraction phase of each push-pull test in order to analyze the concentrations of N gases produced in-situ. 98% labeled ^{15}N potassium nitrate was used for the injection solution so that gaseous products could be distinguished from natural background gases. Completely filled 12 mL exetainers were shipped to the UC Davis Stable Isotope Facility for analysis of dissolved N_2 and N_2O gas. Dissolved gas is sampled by head space equilibration where 6 ml of water is removed from the exetainer and replaced with helium under atmospheric conditions. Analytical equipment was a SerCon Cryoprep trace gas concentration system interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK). Data was reported as micromoles $^{15}N_{2,}$ - picomoles N_2O, total mass of N_2 and N_2O recovered, and percent enrichment.

Nitrate removal rates were calculated based on nitrate disappearance corrected for mechanical losses with bromide tracer data. Rates were assumed to be first-order. In a review paper by Heinen (2006), the majority of models evaluating denitrification were found to employ a first-order decay process. The $k_{\text{nitrate removal}}$ constants were calculated by determining the amount of nitrate remaining in the core of the injection plume after a known incubation period. Nitrate concentration values were corrected for mechanical losses by subtracting the ratio of nitrate in the sample divided by injected nitrate from the ratio of tracer in the sample divided by injected tracer. The first order equation was solved for $k_{\text{nitrate removal}}$ using the known initial concentration of nitrate and the tracer corrected nitrate concentration of a sample taken from the core of the plume during extraction.

$$k_{\text{denitrification}} = (\text{natural log } (\text{Nitrate}_{\text{at time t}} / \text{Nitrate}_{\text{initial}}))/\text{incubation time} \quad (5)$$

The plume was considered to be the first sample volume interval where tracer recovery was the highest, unless dead volume was suspected in the injection apparatus, whereupon the following sample volume interval was used. Time was defined as the interval between the injection start time and the extraction end time. Since samples were collected at one time point, the first order decay equation was fit to two data points, tracer corrected initial nitrate concentration and tracer corrected nitrate concentration at time t.

Soil samples collected during piezometer installation were analyzed for combustible carbon. Samples were placed in tins and dried for 2 hours at 110ºC. Samples were then placed in a desiccator until room temperature was reached and then weighed. Samples were then baked for 4 hours at 450 degrees, allowed to come to room temperature in a desiccator and then reweighed. The difference in baked weight to dry weight divided by dry weight was reported as percent organic matter. Evidence was found of deeper buried carbon deposits, a phenomenon not uncommon in alluvial formations. SOM ranged from 0.5 – 3.7 %. SOM content of over 2% was found in 5 deeper samples (2 m and over). The data suggests some significant buried carbon deposits in the 2 - 3 m depth interval along the riparian transect at the B2, B3, and A3 bore hole sites.

In addition a simplified, field-scale model of nitrate attenuation that included hydrology was developed for the Walker River riparian area in which field measured nitrate removal rates and groundwater flow were taken into account. This provided a means to extrapolate nitrate removal rates based on measured soil properties. This was accomplished by building a 2-D grid nitrate removal and flux model based on "push-pull test" (PPT) results where available and extrapolated based on soil organic matter (SOM) for other grid cell locations. A MODFLOW groundwater flow model with the MT3D reactive transport module was used to solve for nitrate flux across the riparian zone. Two riparian subsurface flow scenarios were considered: a high gradient scenario where subsurface flow loss from a full drainage ditch traveled toward the Walker River, and a low gradient scenario where the ditch had just emptied and the hydraulic gradient was less severe but still toward the river.

Effects of Altered Water Use on Invasive Species in the Walker River Riparian Zone

Deep rooted invasive plants may gain a competitive advantage in anthropogenically disturbed riparian areas. Because deep rooting invaders have also been known to use water from shallow water tables and have higher consumptive water use than native species, these species may affect the availability of water for native plants in riparian and downstream areas. This portion of the study tested the hypothesis that *Lepidium latifolium* (Tall whitetop) gains a competitive advantage through a deep root system that has a substantial root mass which penetrates shallow saturated zones in riparian areas.

This study consisted of two complementary experiments: (a) a field study measuring the whether *Lepidium latifolium* is able to utilize groundwater from a relatively deep depth (1-2 m) in the riparian zone of the Walker River by comparing the isotopic signature of water taken up by the plant during the growing season to that of the groundwater and (b) competition experiments using the exotic invasive *L. latifolium* and the native perennial grass *Elymus trachycaulus* where the species were grown together in barrels subjected to various soil water conditions.

<u>Isotopic Signature of Water Uptake</u>

To compare root uptake of water as a function of depth samples of *L. latifolium* and associated soils were collected three times throughout the growing season. Xylem water was extracted from the *L. latifolium* plants and soil water was extracted from associated soil samples. The waters were then analyzed for stable isotopic ratios of ^2H and ^1H. The resulting ratios of ^2H to ^1H from the vegetation were then compared to those from the soil samples. Samples were collected from three sites that had stands of *L. latifolium* and were located within the riparian area of the Walker River.

Competition With Native Grass Under Different Soil Moisture Regimes

Competition experiments were conducted using the exotic invasive perennial dicot *L. latifolium* and the native perennial grass *Elymus trachycaulus* (Slender wheatgrass) where the species were grown together in barrels subjected to various soil water conditions. Competition experiments were carried out in triplicate at matric water potentials of either -10 kPa and -600 kPa, or -600 kPa with a water table that was maintained 1.1 m below the soil surface. The stomatal conductance rates of *L. latifolium* and *E. trachycaulus* were recorded to indicate whether the plants were able to maintain water uptake throughout the season. After harvest the above and below ground biomass of both plant species under the three moisture regimes. Belowground biomass was divided into 3 zones as a function of depth to determine which plants were able to reach the 1.1 m deep water table (Figure 10).

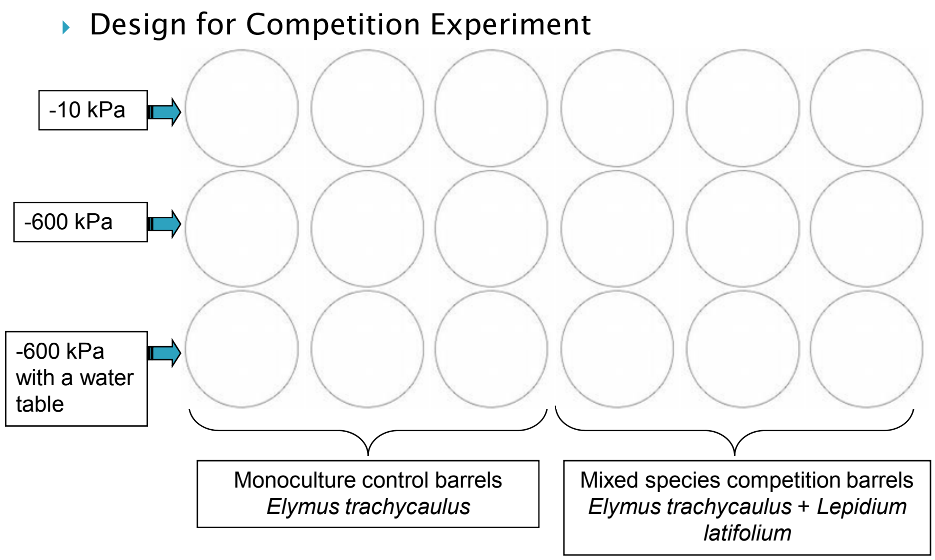

Figure 10. Experimental design for testing competition of *Lepidium. latifolium* and *Elymus trachycaulus*. Each circle represents a barrel in which either one or two species were grown. The designation of 3 moisture regimes is indicated by the labels on the left (e.g. -10 kPa) indicating the soil matric water potential at which the soil in the barrels was maintained.

RESULTS AND DISCUSSION

Infiltration, bulk density, sodicity and water soluble nutrient status for each study site are presented in the following tables and figures. Because this project component was focused on changes in soil solution chemistry, exchangeable and plant available nutrient extractions were not considered. Since the WMW and WMF sites were abandoned due to poor germination and establishment no post-project comparisons are presented for these locations.

Pre-Project Baseline Soil Characteristics

Valley Vista (VV) Ranch Site

Mean steady state infiltration rate, though notably higher at VV (7±2.4 in hr^{-1}; 2.7±1 cm hr^{-1}) study site, was generally similar to that at the 5C Cottonwood (4±1.9 in hr^{-1}; 1.6±0.7 cm hr^{-1}). This was attributed to the predominance of coarse textured surface soils at both sites and the long-term cultivation of alfalfa at the VV location (Table 2).

Soils at all depths were not found to be saline (Table 3). High variability in SAR at depths greater than 36 inches indicates that there may be hot spots of sodic soil (Table 4). The average pH at all depths fell within 8 to 8.5.

Higher concentrations of Ca and Mg near the surface and increasing Na with depth (Figures 11 and 12) suggest the application of agricultural gypsum sometime in the past. Consequently, the near surface Sodium Adsorption Ratio (SAR) is well within the normal range (Table 2). There also appears to be some historic evidence of NO_3 leaching. Water extractable solution concentrations of NH_4^+, Ca^{2+}, Mg^{2+}, and to some extent K^+ tended to decrease from east to west across the field site, whereas concentrations of Na^+, SO_4^-, NO_3^- /NO_2^- and PO_4^- tended to peak midway; albeit water extractable P was quite limited throughout the soil profile (Figure 12).

Table 2. Baseline infiltration and field bulk density for agricultural study sites.

Site	Steady State Infiltration Rate ($in*hr^{-1}$)	Bulk Density ($g*cm^{-3}$)
VV	7.0 ± 2.4	1.40 ± 0.12
5C	4.0 ± 1.9	1.34 ± 0.17
WMW	3.2 ± 1.5	1.07 ± 0.07
WMF	3.4 ± 1.4	1.18 ± 0.05

Table 3. Average Electrical Conductivity ($dS*m^{-1}$) for agricultural study sites. An electrical conductivity > 4 $dS*m^{-1}$ is indicative of a saline soil.

Depth	VV	5C	WMW	WMF
0-6”	1.1 ± 1.9	1.0 ± 0.9	2.5 ± 1.5	**25.5 ± 34.8**
6-12”	0.6 ± 0.5	1.7 ± 4.4	2.1 ± 1.6	**15.9 ± 4.5**
12-24”	0.6 ± 0.4	1.0 ± 1.0	1.9 ± 1.3	**12.8 ± 4.5**
24-36”	0.7 ± 0.8	1.3 ± 1.5	1.0 ± 0.6	3.8 ± 2.4
36-48”	0.6 ± 0.6	1.3 ± 1.7	0.5 ± 0.3	2.3 ± 1.4
48-60”	1.0 ± 1.0	2.2 ± 3.7	0.3 ± 0.2	

Table 4. Average Sodium Adsorption Ratio (SAR) for agricultural study sites. An anomaly within the 5C site is represented in parenthesis and not included in averages. An SAR > 13 is indicative of a sodic soil.

Depth	VV	5C	WMW	WMF
0-6"	1.8 ± 0.2	1.3 ± 0.5 (**43.6**)	6.6 ± 3.9	**40.4 ± 12.6**
6-12"	1.7 ± 0.2	1.8 ± 0.5 (**67.0**)	9.8 ± 10.7	**58.5 ± 10.1**
12-24"	2.1 ± 1.1	1.8 ± 0.2 (**97.8**)	14.5 ± 14.7	**49.9 ± 14.0**
24-36"	4.5 ± 7.2	1.9 ± 0.2 (**47.2**)	11.0 ± 9.8	**19.0 ± 13.0**
36-48"	5.9 ± 7.4	2.0 ± 0.7 (**76.3**)	5.0 ± 4.5	11.1 ± 3.7
48-60"	10.5 ± 13.8	2.7 ± 1.8 (**77.4**)	2.9 ± 1.2	

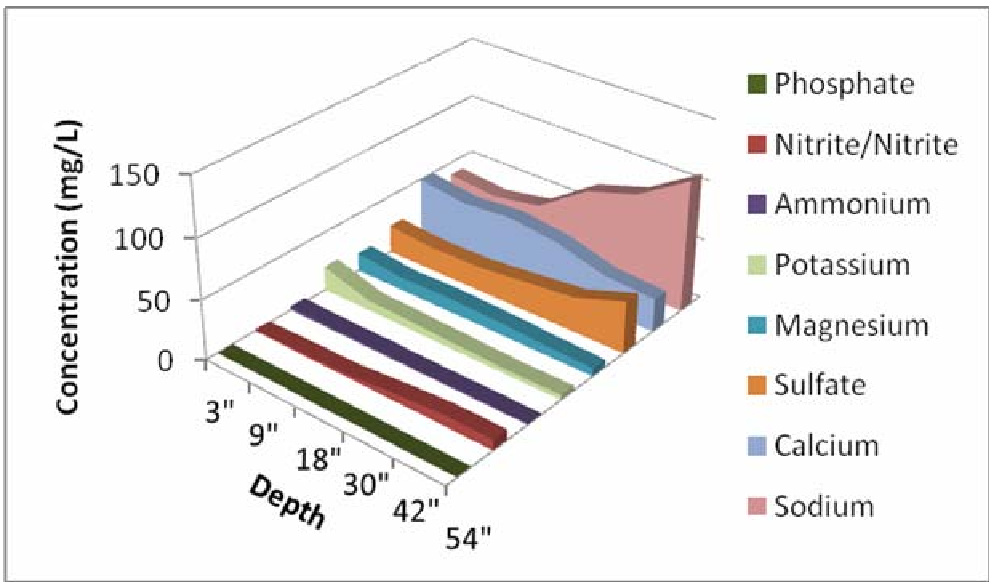

Figure 11. VV agricultural site soil nutrient profile in summer of 2007 – Average concentration of water extractable analytes by depth within the soil profile.

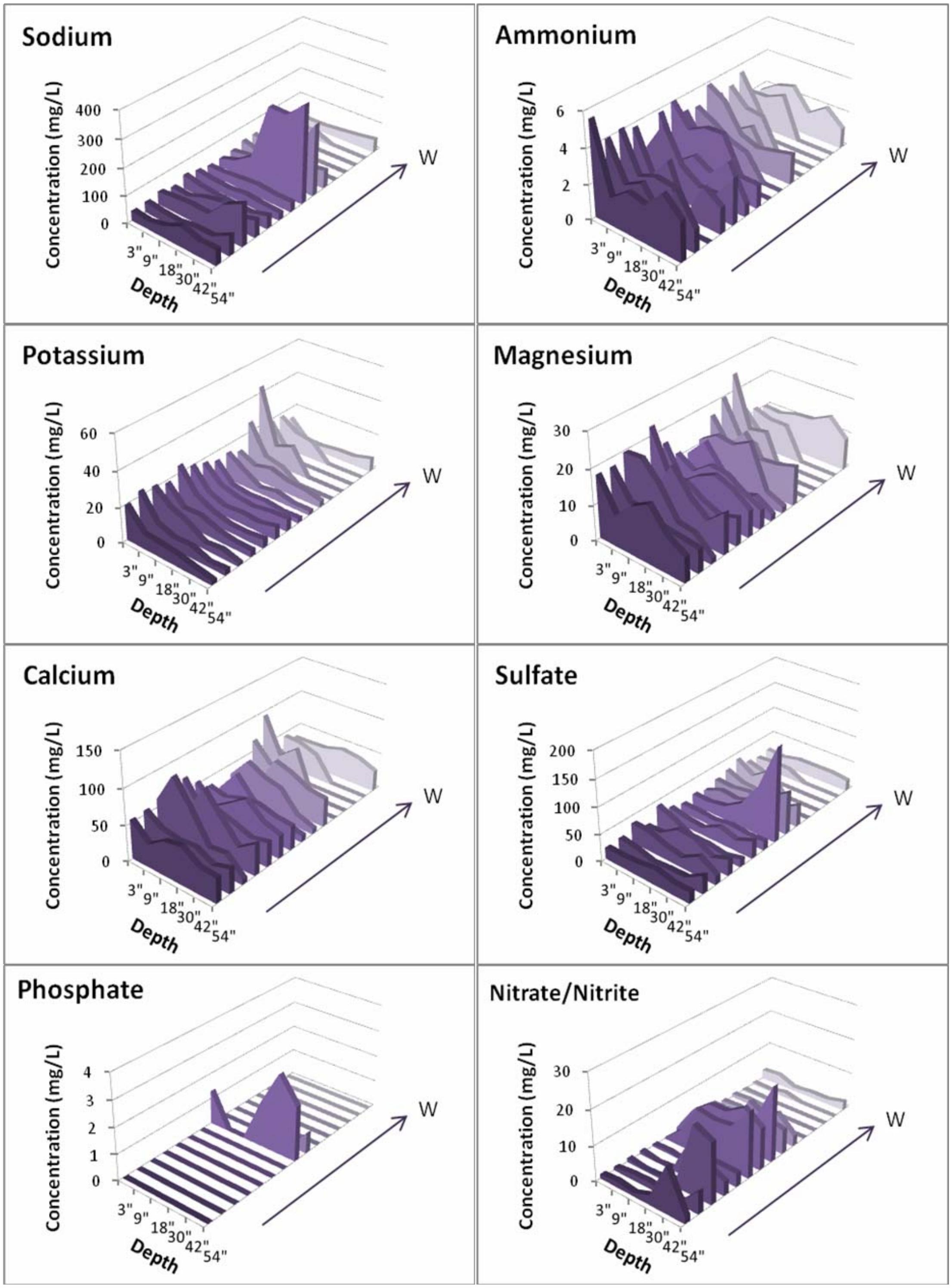

Figure 12. Individual analyte concentrations at VV agricultural site by depth within soil profile along the length of the field for summer 2007.

5C Cottonwood (5C) Ranch Site

Mean soil bulk density at the 5C was slightly lower than that of the VV study site (1.34±0.17 and 1.4±0.12 g cm^{-3}, respectively), but both were comparable to typical bulk densities found in coarse textured sandy loam soils (Table 2).

Variability in electrical conductivity in at depths greater than 48 inches indicates that soils at that depth could, on occasion, be saline (Table 3). Soils were not considered sodic with average SAR being less than 3 at all depths (Table 4). One sample location was considered an anomaly and not included in averages. Soil at this location was found to be sodic at all depths with extremely high average SAR of 40 to 100. The average pH at all depths fell within 8 to 8.5.

Water extractable concentrations of Ca^{2+} and Mg^{2+} at shallow depths did not suggest the historical application of agricultural gypsum (Figure 13) and although the SAR was more variable and somewhat higher than that found at VV, it remained within the normal range overall (Table 2). Concentrations of most nutrients were found to decrease from south to north and were typically higher near the surface decreasing with depth (Figures 13 and 14).

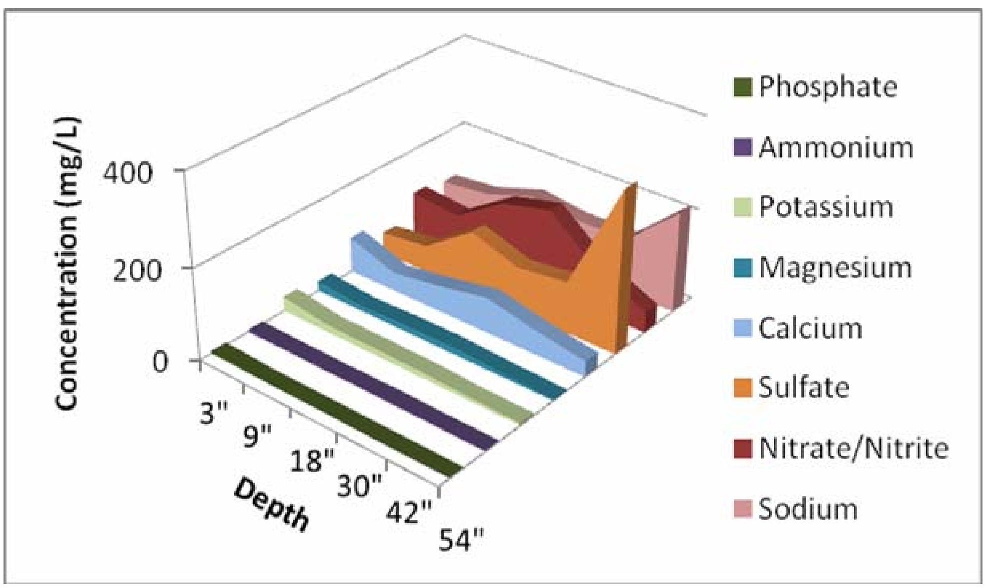

Figure 13. 5C agricultural site soil nutrient profile in summer of 2007 – Average concentration of water extractable analytes by depth within the soil profile.

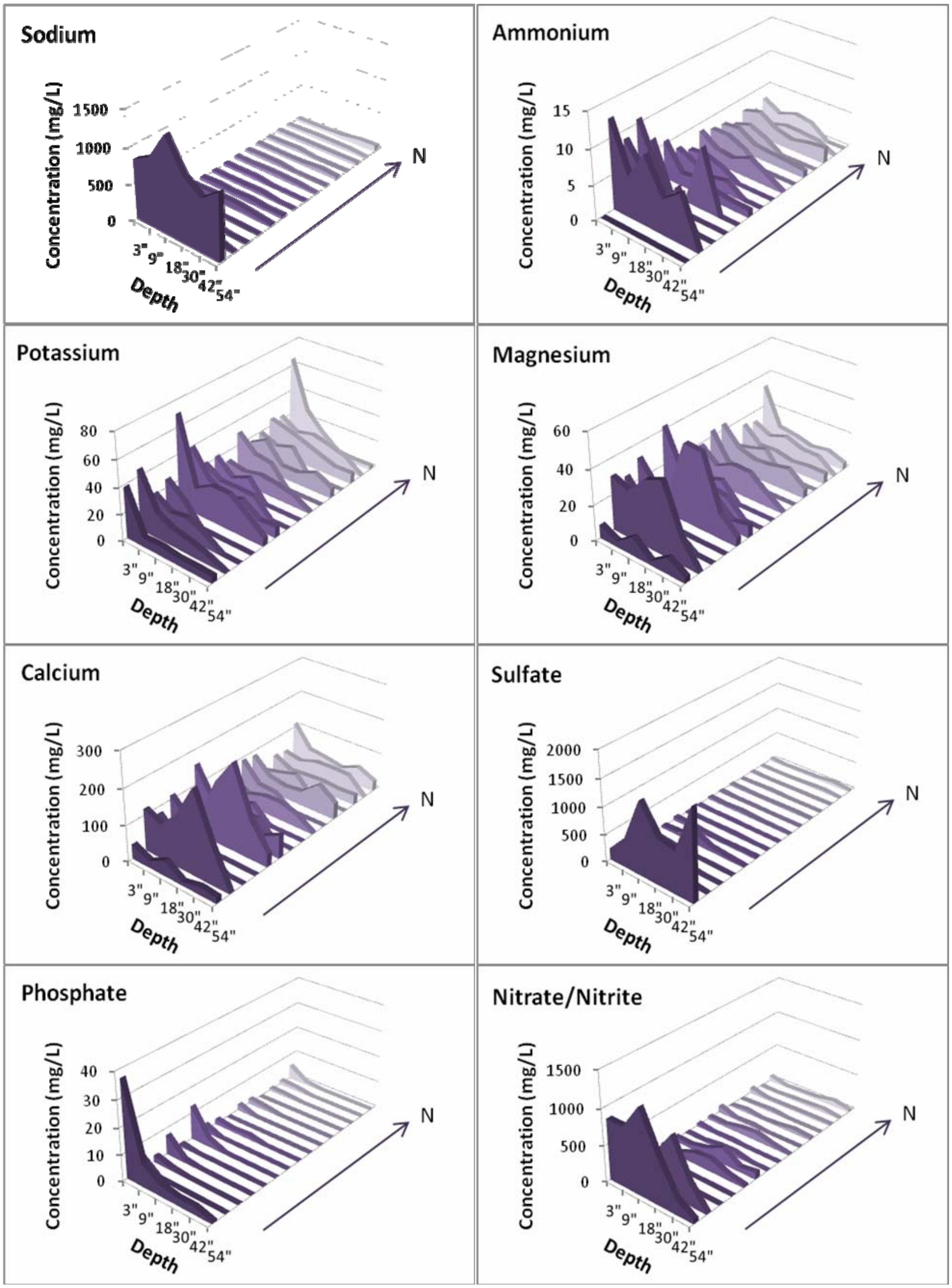

Figure 14. Individual water extractable analyte concentrations at 5C agricultural site by depth within soil profile along the length of the field for summer 2007.

Mason Valley Wildlife Management Area: Wildlife Habitat Site (WMW) and Wildlife Flood Irrigation Site (WMF)

Mean infiltration rates and mean soil bulk densities were similar at both wildlife management sites and were lower than those found at either the VV or the 5C study locations (Table 2).

Averages for electrical conductivity and SAR were found to be within normal ranges at all depth at the WMW site (Tables 3 and 4). A closer look at the variability within, however, reveals that there are most likely areas of saline soils at the surface above 6 inches and areas of sodic soils at depths greater than 36 inches. Soils at the WMF site were found to be saline-sodic at depths 0 to 24 inches. Soils at 24 to 48 inches, while on average were within normal ranges, had spots of salinity and sodicity. The average pH at both sites fell within 8 to 9, with higher pH being found in the surface soils.

Concentrations of water extractable phosphate were below detection at both sites indicating limited P solubility (Figures 15 and 16). Solution concentrations of sulfate and sodium were extremely high at the WMF site (Figure 16). Soils at the WMF location were clearly saline-sodic and higher concentrations of nutrient parameters (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, and SO_4^-) were typically found in the middle of the field (Figure 17) from south to north.

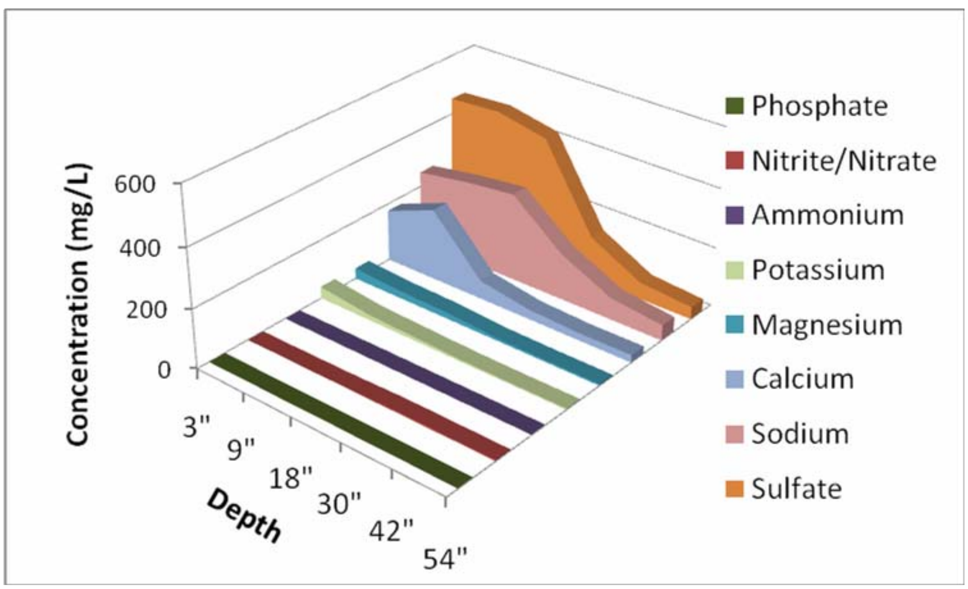

Figure 15. WMW agricultural site soil nutrient profile in fall of 2007 – Average concentration of water extractable analytes by depth within the soil profile.

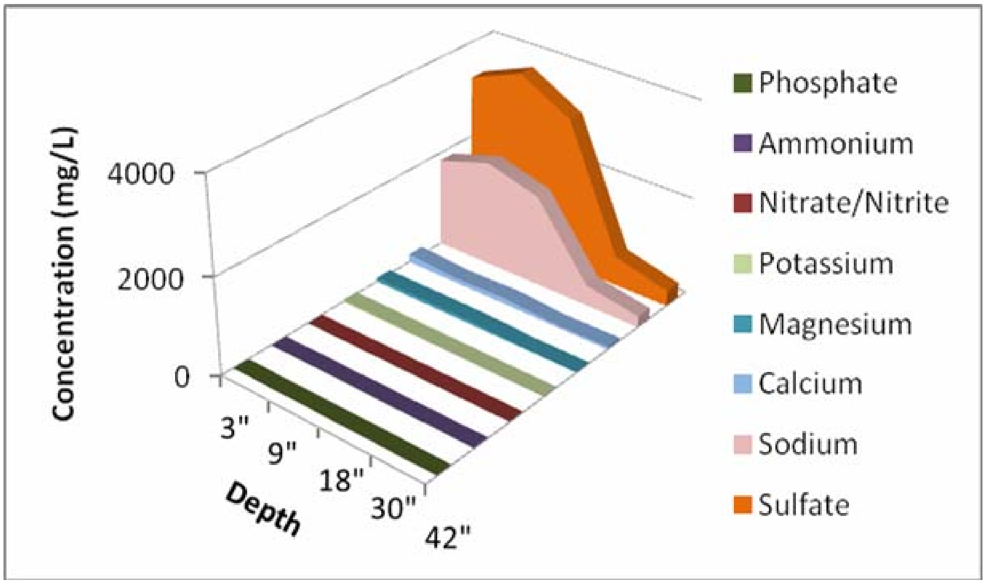

Figure 16. WMF agricultural site soil nutrient profile in summer of 2007 – Average concentration of water extractable analytes by depth within the soil profile.

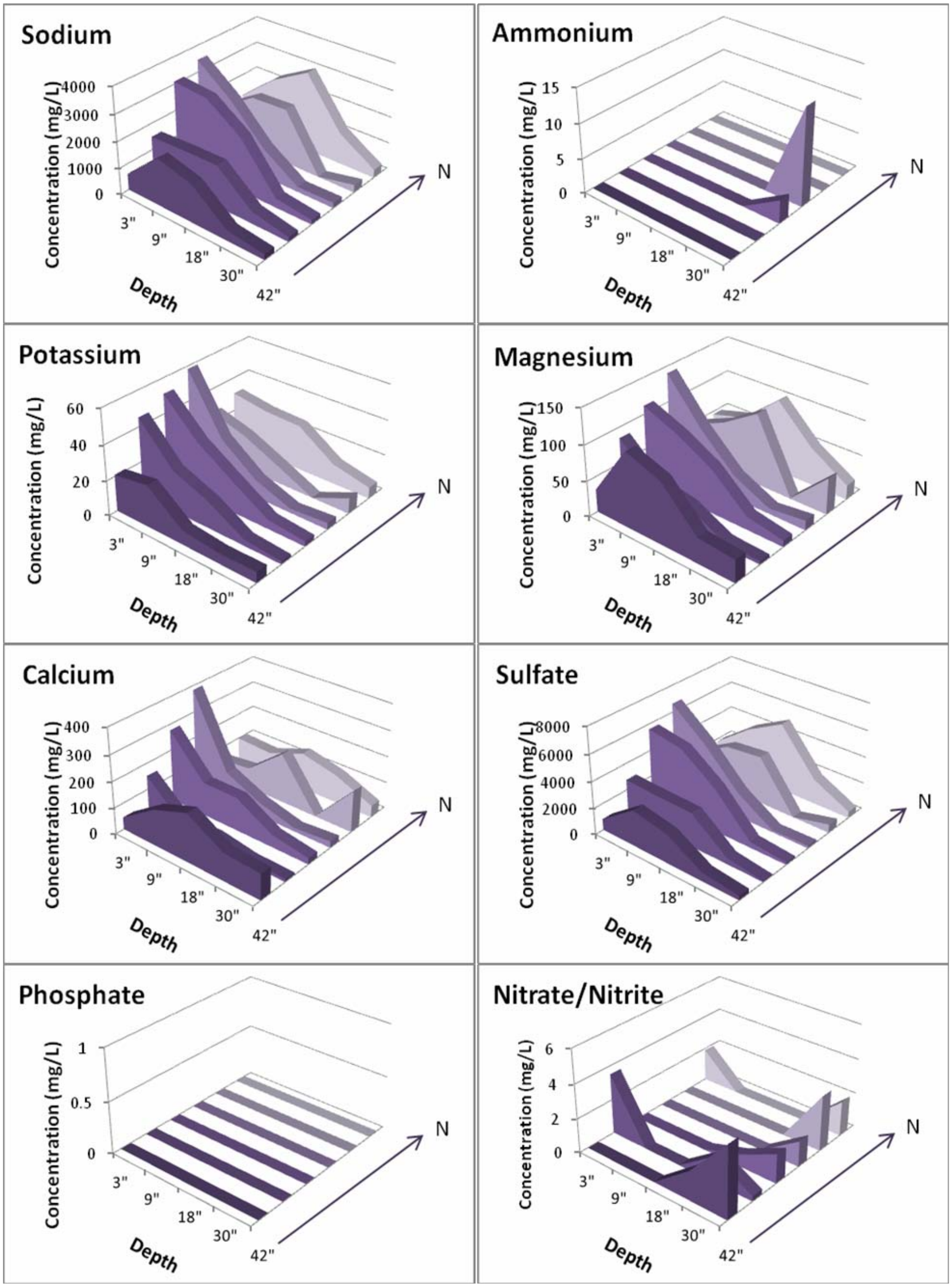

Figure 17. Individual water extractable analyte concentrations at WMF agricultural site by depth within soil profile along the length of the field for summer 2007.

Post-Harvest Nutrient Comparison

Valley Vista (VV) Ranch Site

Concentrations of water soluble calcium, magnesium and phosphate in control (non-treatment plots) were similar between pre- and post-project years (2007 and 2009, respectively) (Figure 18). Water extractable sodium and sulfate was greater in the 6 to 24" range post harvest suggesting some downward mobility consistent with the use of agricultural gypsum. Pre- and post-project potassium, ammonium, and nitrate/nitrite were significantly different throughout the soil profile. Solution concentrations of pre-project ammonium were higher whereas concentrations of nitrate/nitrite and potassium were higher post project. The difference in N species can largely be attributed to nitrification. Differences in soluble potassium between 2007 and 2009 may simply be the result of spatial variability.

Post-project soil nutrient analysis for individual water and vegetation treatments is currently in progress. Once available, data will allow further analysis of water treatment and vegetation type impacts on soil nutrient status at both the Valley Vista and 5C study sites.

Soil Moisture Profiles

The 2008 water year was extremely drought limited. Although enough water was available for all biomass and pseudograin treatments at the Valley Vista site (100%, 75%, and 50%), these study plots at the 5C Cottonwood site received a maximum of only 50% (2 AF/A) water allocation for the planned 75% and 100% treatments. The restoration plots at Valley Vista, 5C and Wildlife Flood sites received the planned water treatments of 0% and 25%, however rrigation at the Wildlife Well site was discontinued mid-season due to problems with the irrigation system, excessive weeds and the lack of plant variety establishment. Only the Valley Vista and 5C study sites were irrigated in 2009, and the available water supply was sufficient to meet the experimental treatments on all study plots (100%, 75%, and 25% for biomass and pseudograins; 0% and 25% for restoration).

Valley Vista (VV) Ranch Site 2008

An increase in soil moisture content relative to the control (0%) was observed to a depth of 2 to 3 ft following each irrigation, and a significant increase in soil moisture persisted for at least 24 hours after irrigation (Figure 19). Although the moisture profiles are similar for the 75% and 100% irrigation treatments (SMC 10-15%), soil moisture content was clearly diminished in the 25% restoration water treatment (SMC ~5%) and remained only slightly greater that the 0% treatment (SMC typically <5%).

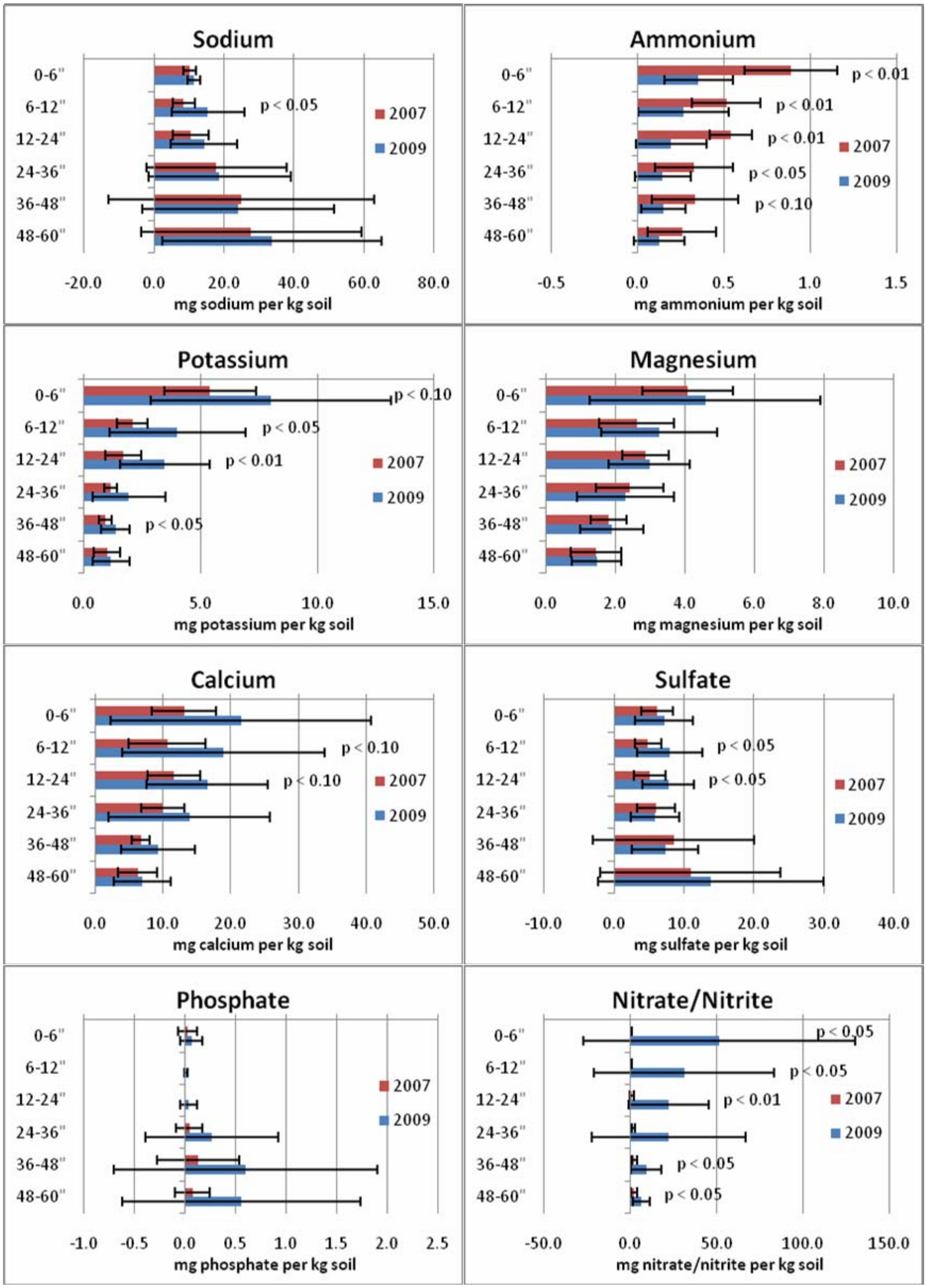

Figure 18. Comparison of summer 2007 water extractable nutrients to those of spring 2009 for VV agricultural site. Shown with standard deviation and significance of difference between years.

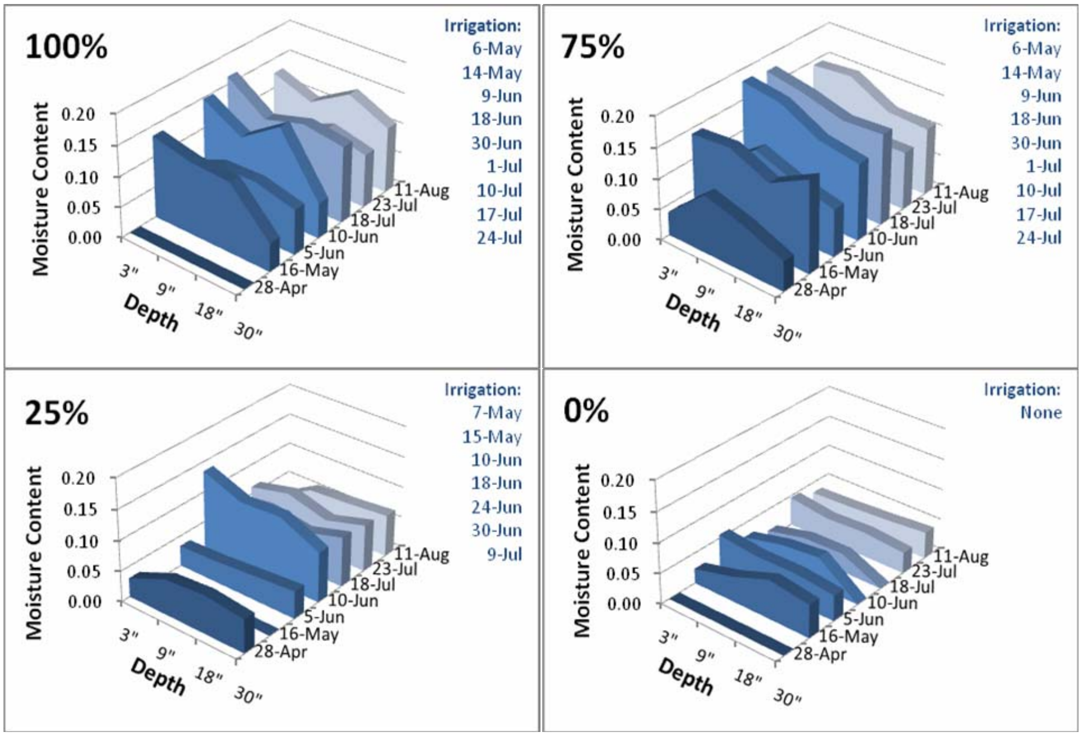

Figure 19. Soil moisture profile at VV agricultural site as mass water content for 100% and 75% water treatments on alternative agriculture field and 0% and 25% water treatments on restoration field for 2008 growing season.

Valley Vista (VV) Ranch Site 2009

The 50%, 75% and 100% water treatments all had similar impacts on the soil moisture distribution throughout the soil profile (Figure 20) early in the irrigation season. Although the surface moisture in the 50% water treatment diminished more rapidly in the weeks following the end of irrigation compared to the other treatments, moisture content in the lower profile seemed to be retained at levels similar to 75% and 100% treatments well into the end of August (SMC 10-15%). Future studies will consider whether or not crop species with greater rooting depths may have greater growth ability in 50% water treatments than those of lesser rooting depths and if that growth is comparable to that in 75% and 100% treatments.

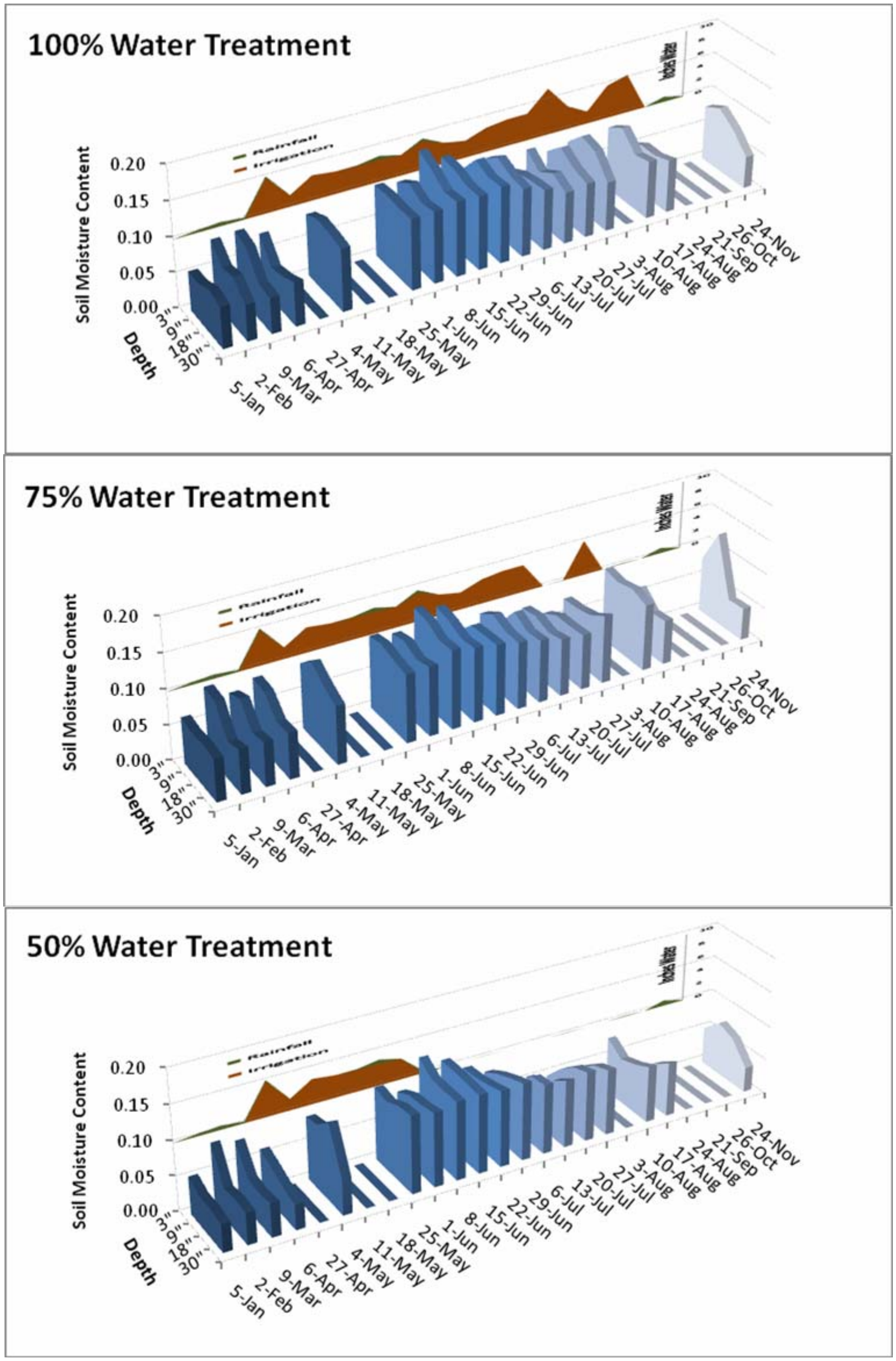

Figure 20. Soil moisture profile at VV agricultural site as mass water content for 100%, 75%, and 50% water treatments on alternative agriculture field for 2009. Precipitation and irrigation application are superimposed.

Soil moisture profiles in 0% and 25% revegetation treatments proved were similar (Figure 21) and as expected were lower than those found in the higher water treatments for alternative agriculture (SMC 5% and less compared to SMC 5-10%, respectively). Surface moisture content was slightly higher in 25% water treatment, but at depth there was not much difference. These results are as expected as surface soils are more easily dried out after irrigation while soils at depth have a greater ability to retain moisture in the absence of root extraction.

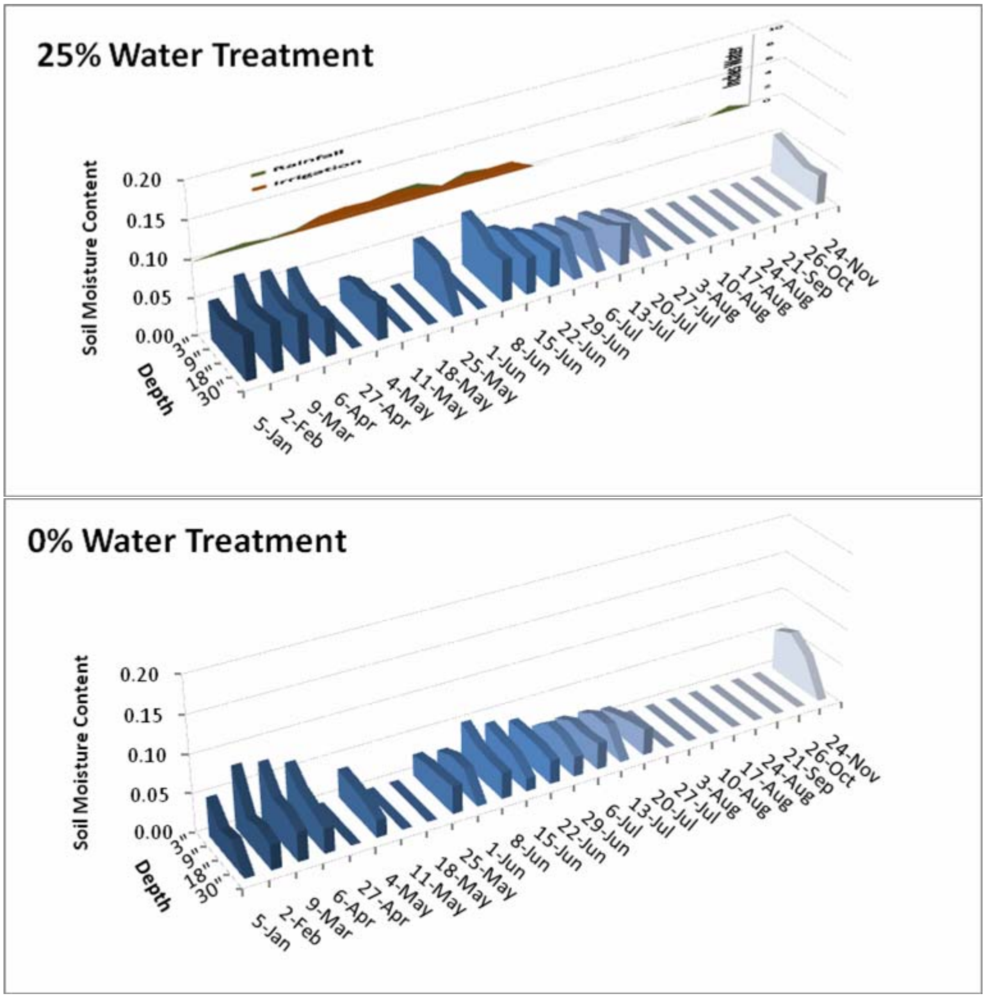

Figure 21. Soil moisture profile at VV agricultural site as mass water content for 0% and 25% water treatments on restoration field for 2009. Precipitation and irrigation application are superimposed.

5C Cottonwood (5C) Ranch Site 2008

This site is somewhat coarser in texture than that of the VV and does not appear to retain soil moisture for long periods following irrigation. The first few irrigations exhibit no significant difference in moisture content between the non-irrigated and irrigated plots within 24 hours following irrigation (All SMC ≤ 5%). This situation improved with continued irrigation over time, wherein a base of higher soil moisture content seemed to accumulate deeper within the soil profile and was not as rapidly depleted (Figure 22).

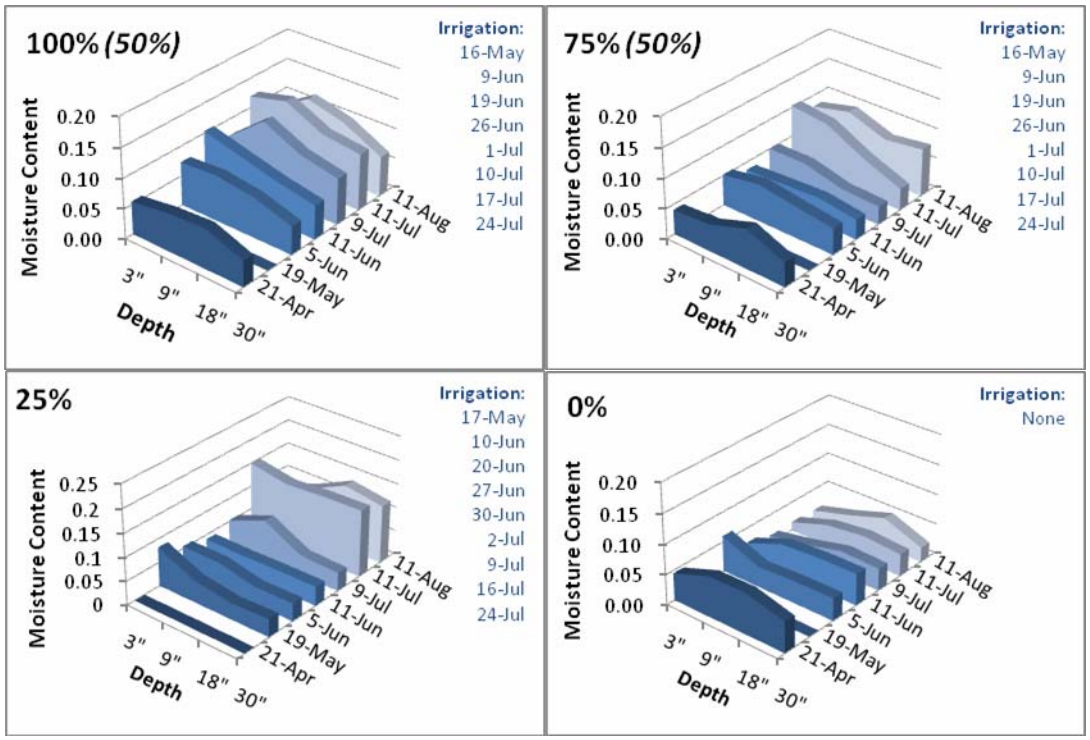

Figure 22. Soil moisture profile at 5C agricultural site as mass water content for 100% and 75% water treatments on alternative agriculture field and 0% and 25% water treatments on restoration field for 2008 growing season.

5C Cottonwood (5C) Ranch Site 2009

Once again, the difference between soil moisture profiles for the 75% and 100% water treatments was small for the alternative agriculture study (Figure 23). The disparity between SMC of the higher water treatments (SMC 5-10%) and the 50% water treatment post-irrigation (SMC < 5%) was much greater. Furthermore, moisture was not well retained with depth. This may be attributed in part lower water holding capacity associated with the sandier textured soils of the 5C study site.

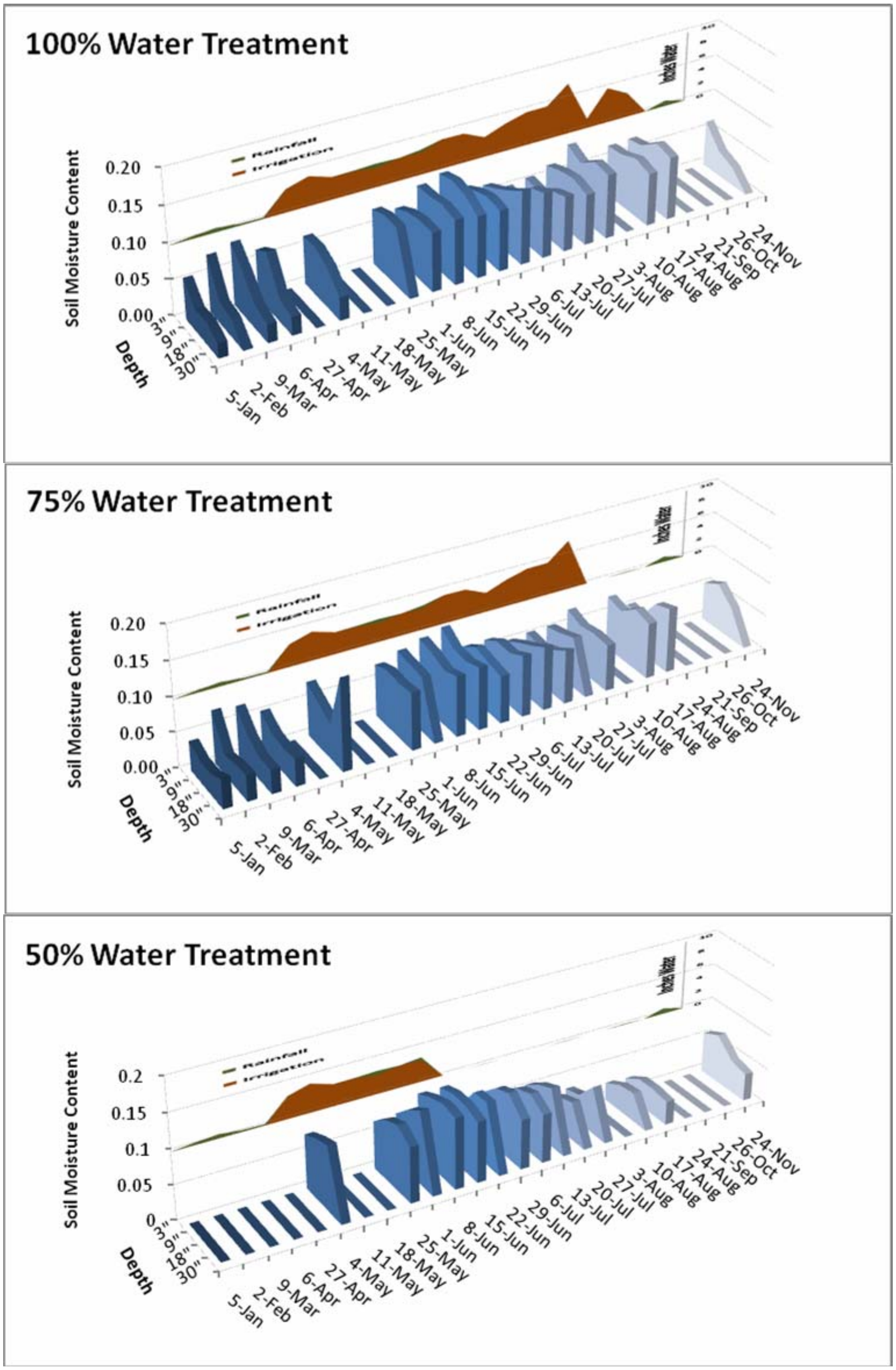

Figure 23. Soil moisture profile at 5C agricultural site as mass water content for 100%, 75%, and 50% water treatments on alternative agriculture for 2009. Precipitation and irrigation application are superimposed.

Differences between 25% and 0% water treatment soil moisture profiles were more apparent at the 5C site than at the VV site (Figure 24). This again, is likely due to the inability of coarser textured soils to retain soil moisture, even at greater depths.

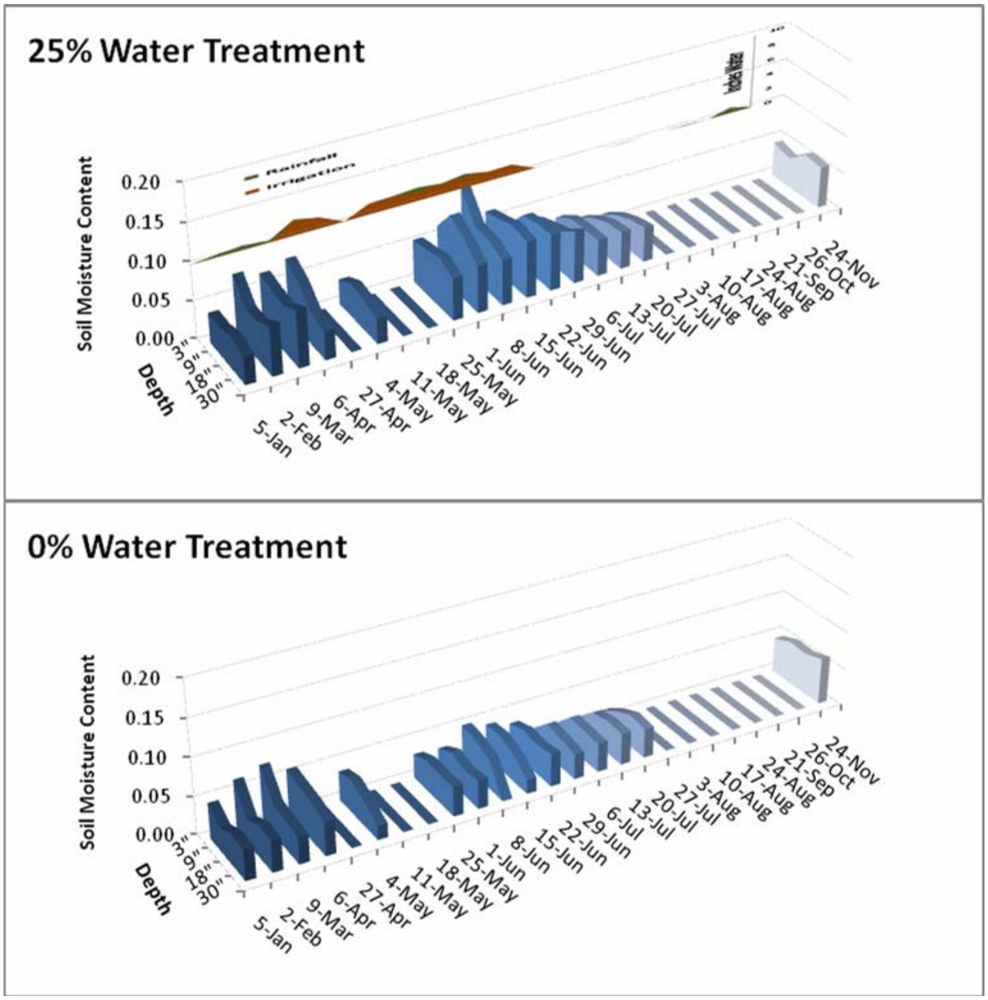

Figure 24. Soil moisture profile at 5C agricultural site as mass water content for 0% and 25% water treatments on restoration field for 2009. Precipitation and irrigation application are superimposed.

Mason Valley Wildlife Management Area: Wildlife Habitat Well (WMW) and Flood (WMF) Sites 2008

Soil at the WMW site was found to wet down 2 to 3 feet following irrigation, and a significant increase in soil moisture content was observed as long as 1 week later (Figure 25). Water holding capacity was greater than that found at either the VV or 5C study sites due to the finer soil texture. Soil moisture distribution with depth was similar for the 100% and 75% irrigation treatments that received <25% water allocation, but was notably less for the 25% restoration treatment and the control. At the WMF restoration site, the soil was found to wet only to about 6 inches immediately following irrigation; albeit a significant increase in soil moisture content remains up to 1 week later (Figure 26). The difference in profile wetting at the WMF site may be attributed in part to the method of irrigation (flood vs sprinkler), but is more likely due to the presence of highly sodic soils which would result in reduced penetration and more substantive water retention from poor subsurface drainage.

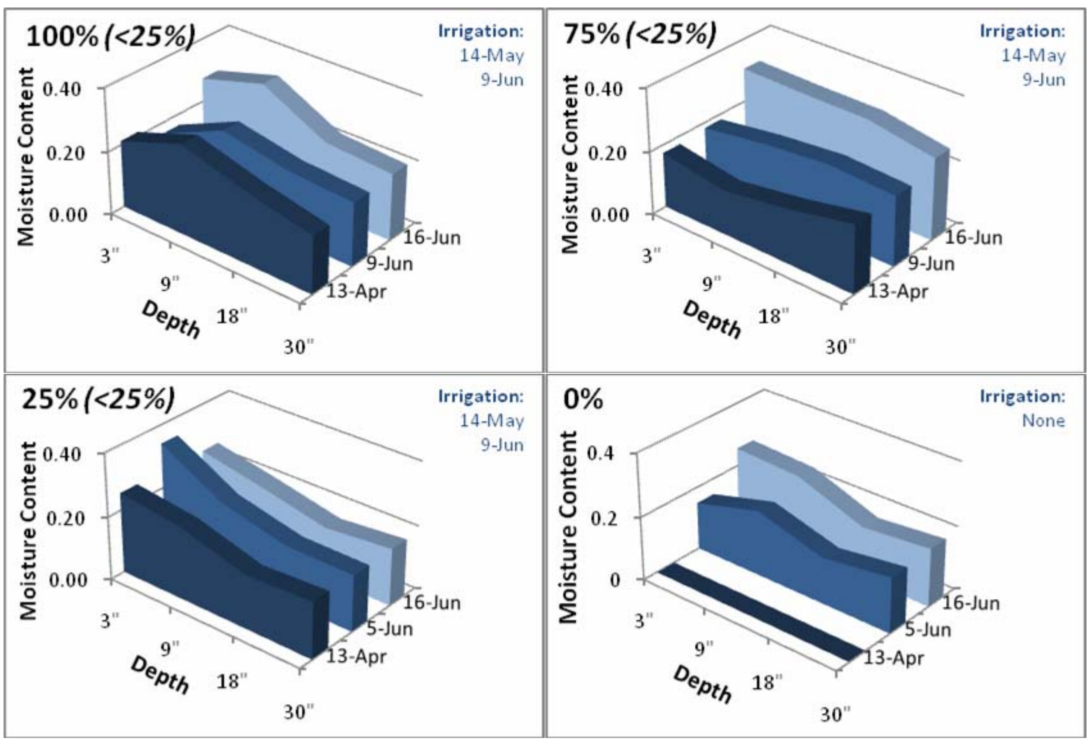

Figure 25. Soil moisture profile at WMW agricultural site as mass water content for 100% and 75% water treatments on alternative agriculture field and 0% and 25% water treatments on restoration field for 2008 growing season.

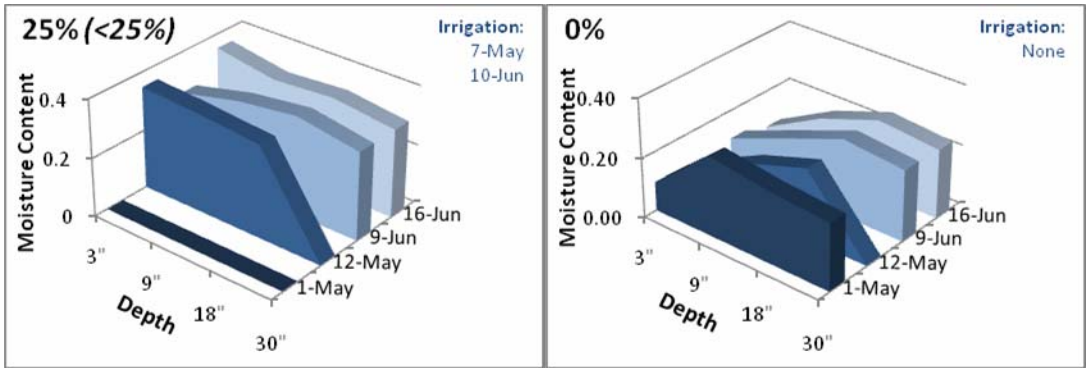

Figure 26. Soil moisture profile at WMF restoration site as mass water content for 0% and 25% water treatments on restoration field for 2008 growing season.

Dust Profiles

Since dust was collected at four elevations, it can be displayed as a profile of the air column up to 1 m. These profiles were subtracted from one another, according the prevailing wind direction, to determine the amount of dust generated (if the soil surface is eroding; represented as a positive amount) or deposited (if dust already in the profile is settling on the soil surface; represented as a negative amount). Wind direction was then applied to calculate the length of field over which the generation or deposition occurred. Wind events were selected to compare different event qualities such as duration, average wind speed, and maximum gust speed, and their effects on the various sites selected for study.

Effects of Event Duration

Two events of varying duration were compared, a long duration event consisting of 50 hrs and a short duration event of 17 hrs of average wind speed greater than 10 mph (Figure 27). Both events were characterized by the same general wind direction, average wind speed, and maximum gust speed throughout, leaving the duration as the primary variable between the two. Results from control plots were variable but exhibited no discernable difference between duration events. The 0% water treatment plots showed greater dust generation with increasing event duration whereas the 25% water treatment plots demonstrated greater deposition compared to the controls. These findings indicate that dust was continually deposited or generated over the course of the overall event.

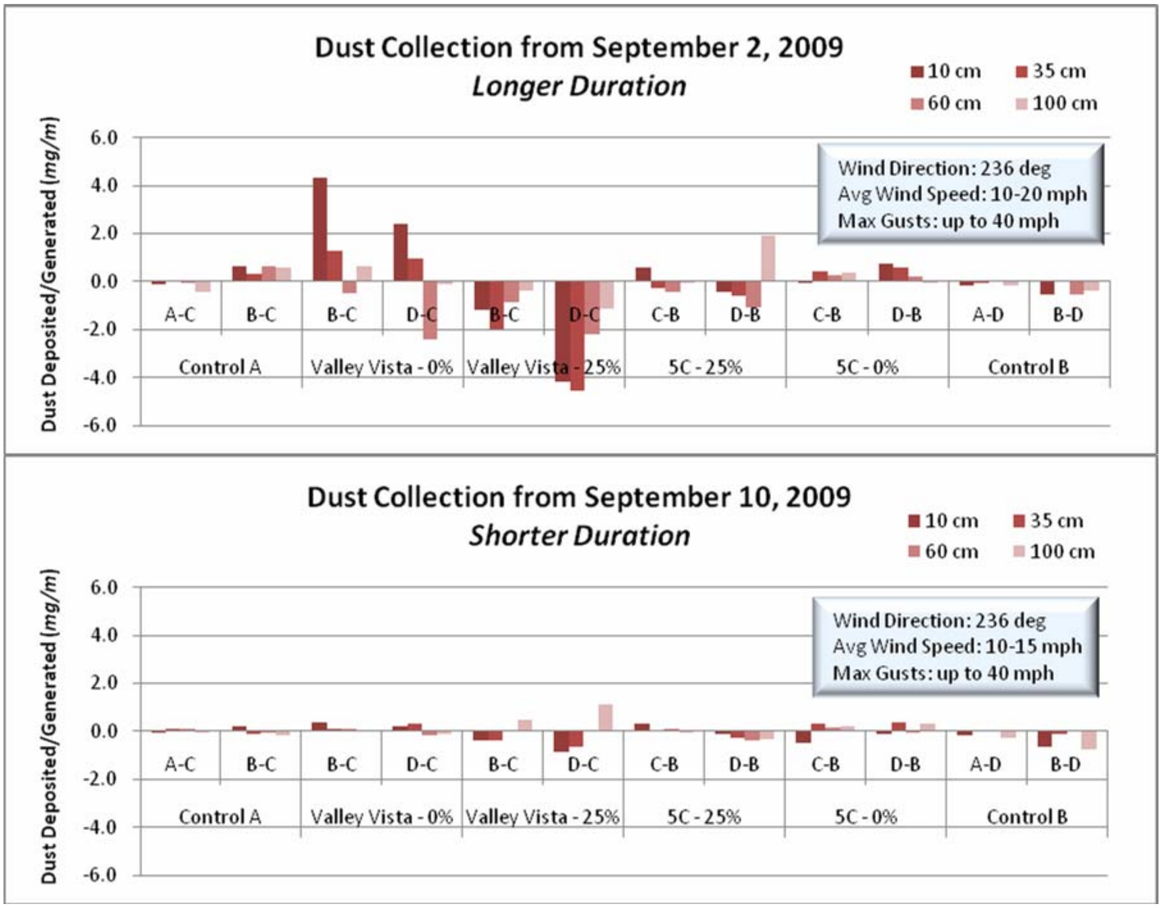

Figure 27. Dust deposited and generated collected from each group of nests on two separate dates. The conditions of the wind events (duration, direction, average wind speed, and maximum gusts) were all similar with the exception of event duration.

Effects of Wind Gusts

Two events of similar characteristics were compared wherein maximum wind gust was the primary variable. One event was characterized by gusts up to 40 mph and the other by gusts to 30 mph (Figure 28). Increased gust speed resulted in little to no difference in dust generation or deposition except for the VV site 25% water treatment plots and one aspect of the Control A site. Interestingly, both of these sites appear to have experienced a large increase in deposition with the increased gust speed which is contrary to expectations. The cause of this effect is unclear at this time.

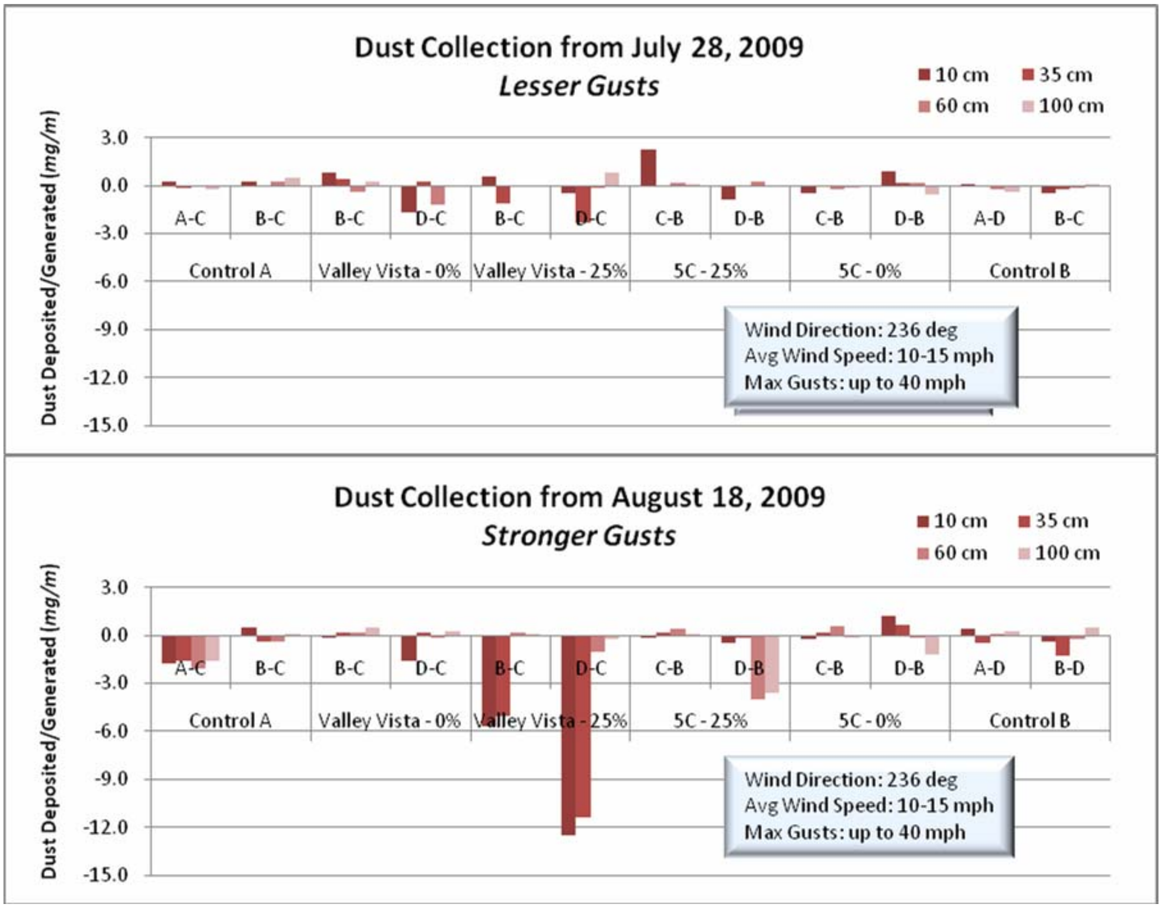

Figure 28. Dust deposited and generated collected from each group of nests on two separate dates. The conditions of the wind events (duration, direction, average wind speed, and maximum gusts) were all similar with the exception of maximum gust speed.

Effects of Sustained Winds

Two events of similar characteristics with differing average wind speed were next compared (Figure 29). The lesser of the two events maintained average wind speeds in the 10 to 15 mph range, whereas the greater of the two maintained average wind speeds in the 10 to 20 mph range. An increase in average wind speed demonstrated a corresponding increase in dust deposition at both 5C and VV sites for the 25% water treatment compared to the controls. For both VV and 5C sites the 0% water treatment plots exhibited a variable response with increased soil erosion in some instances and a greater reduction to the dust profile for collectors located in the shadow of the 25% water treatment vegetation.

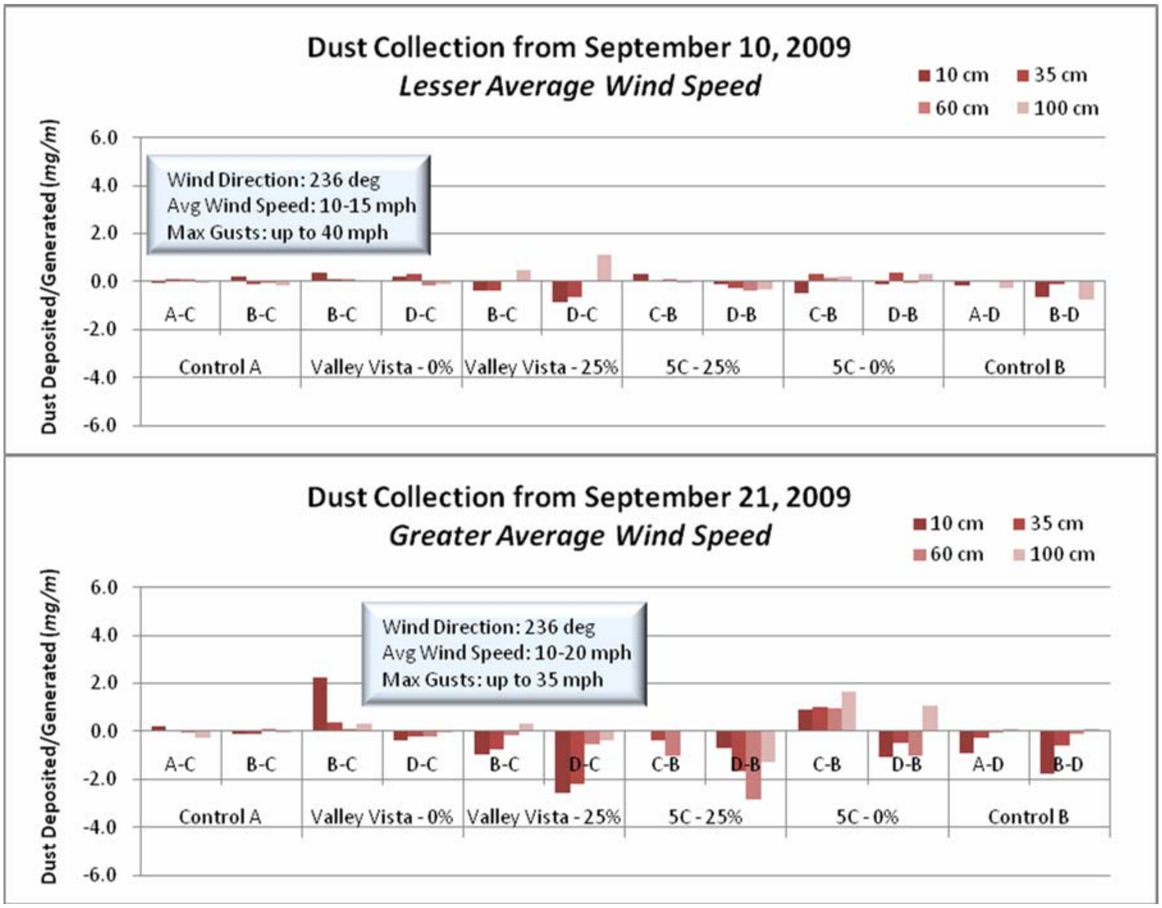

Figure 29. Dust deposited and generated collected from each group of nests on two separate dates. The conditions of the wind events (duration, direction, average wind speed, and maximum gusts) were all similar with the exception of sustained winds or average wind speed.

<u>Effects of Overall Storm Intensity</u>

Three events of varying intensity were compared to determine the combined effects of duration, average wind speed, and maximum gust speed on dust generation and deposition (Figure 30). Low intensity events exhibited variable and unpredictable deposition and generation of dust at all sites. Dust collection was limited and patterns in deposition or generation were riddled with anomalies. As the events increased in intensity, more definitive patterns began to emerge.

An increase in deposition at all heights except 10 cm was found for Control Site B. However, there was an apparent increase in dust generation 10 cm above the land surface. This was likely symptomatic of the grain size distribution present at the surface of control areas or the presence of surface crusting. Finer sized particles may have been depleted leaving largest sand grains at the surface. These particles, while erodible, do not lift as easily into the air column. Their presence then dominates the lowest portions of the dust profile. Without the presence of smaller soil particles to erode with these larger grains, the dust profile then becomes bottom heavy, producing the odd results observed at the Control B site.

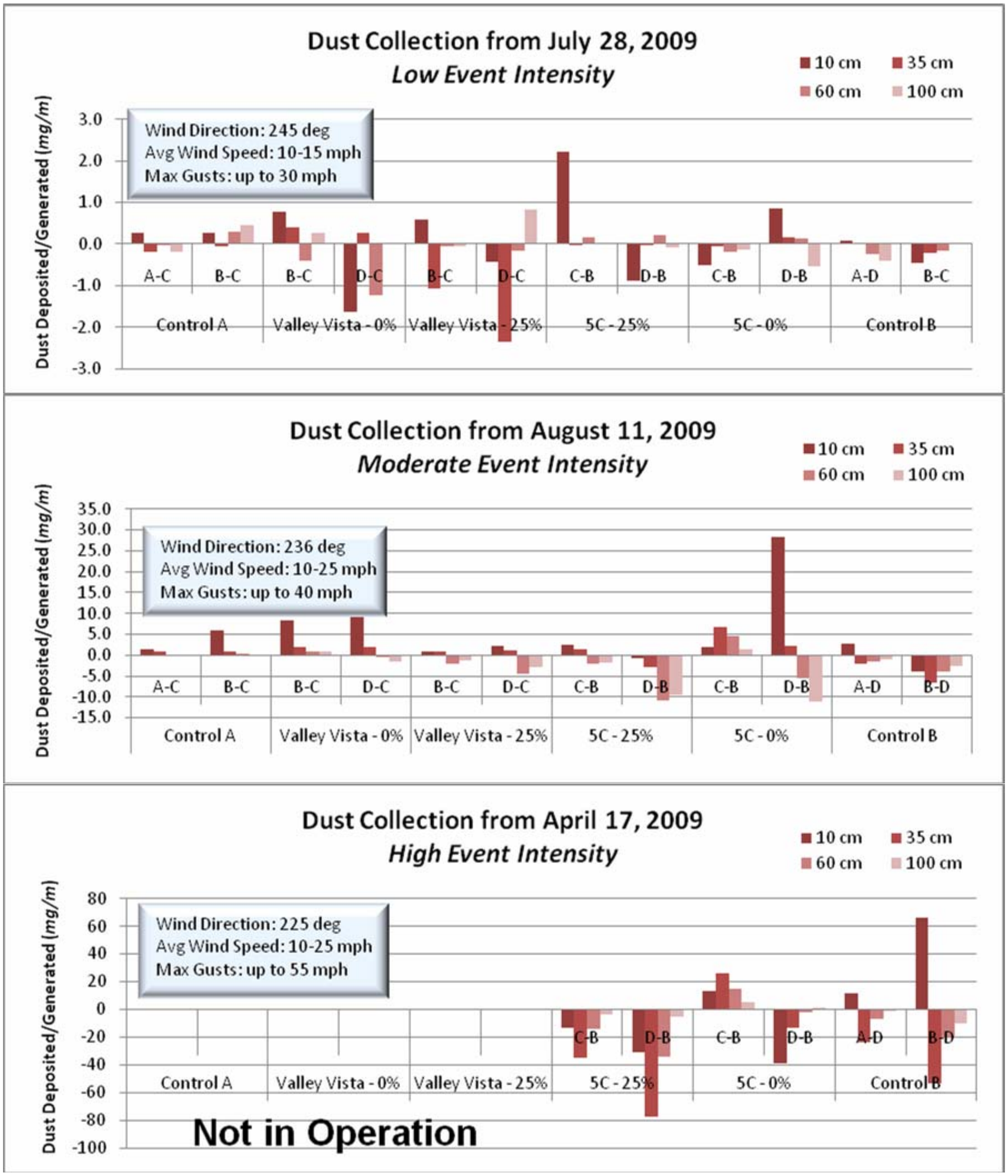

Figure 30. Dust deposited and generated collected from each group of nests on three separate dates. The conditions of the wind events (duration, direction, average wind speed, and maximum gusts) all varied in intensity adding up to three events covering low, moderate, and high event intensities. Please note that the scales for each event vary from the others.

A similar distribution was observed for the 25% water treatment plots during moderate intensity events, where there was a reduction in dust profile at the 60 and 100 cm heights but an increase at 10 and 35 cm. This display, however, may be the result of a different phenomenon. Vegetation produced by the higher water treatment may be effectively keeping the dust from moving higher in the profile. This distribution was also found on one side of the 0% water treatments. Closer examination revealed that where reductions in dust are seen collectors were located in the lee of the vegetation produced by the 25% water treatment, and where dust generation was observed collectors were located on the far side away from the shadow of the vegetation. Furthermore, the outgoing collector is more greatly influenced by the increased dust produced by the road (Figure 5).

Full profiles of accumulation were observed in the 25% water treatment plots during high intensity events, as well as in those collectors on the 0% treatment located to the lee of the 25% treatment vegetation. Erosion increased in 0% water treatment plots as event intensity increased.

Summary

Totals calculated for each event were summed for the 2009 growing season to illustrate the overall effect each specific site had on the dust profile (Figure 31). Overall, the 25% water treatments were far more effective at reducing dust generation and increasing dust deposition than the 0% water treatments and, in some instances more so than even the controls. The 0% water treatments were found to be far more erosive than natural conditions.

When the VV site was compared to the 5C site we generally observed greater dust deposition in the 25% water treatment of the former over the latter. This was likely due to a greater density of biomass present on the VV site. There was no discernable difference between the sites on the 0% water treatment plots.

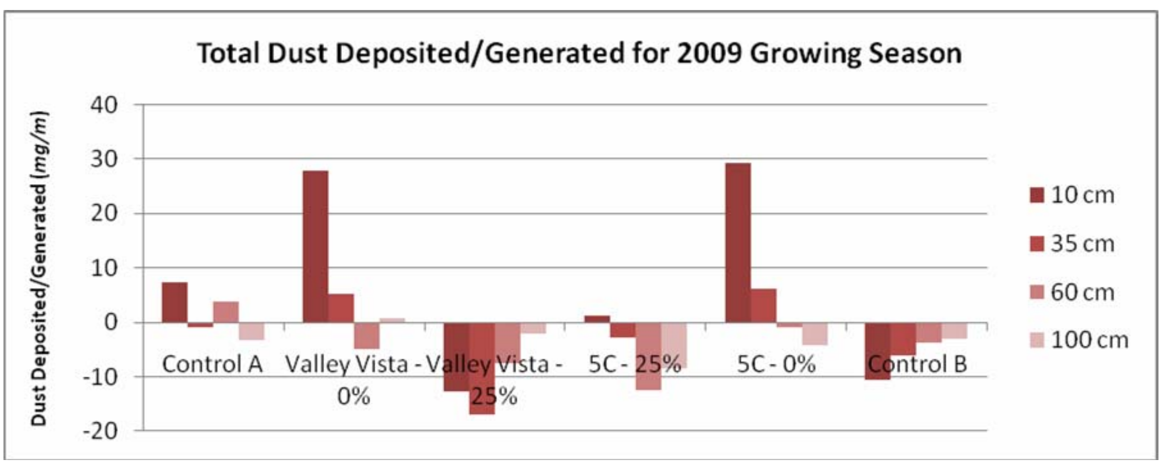

Figure 31. Total dust generated/deposited during the 2009 growing season (April through September) at all six collector sites.

Soil Temperature Sensing and Relationship to Soil Moisture Content

Several field campaigns were conducted at both the WMW and VV study sites during the summer of 2008. Preliminary data showed a clear delineation of differences in soil moisture and soil bulk density. Figure 32 shows the spatial distribution of differences in soil temperatures between night and day taken 15 cm below the soil surface. Those portions of the cable that exhibit larger day to night differences represent zones of moist soil, as heat transfer is facilitated by higher moisture content and the surface temperature pulse travels deeper and faster into the soil.

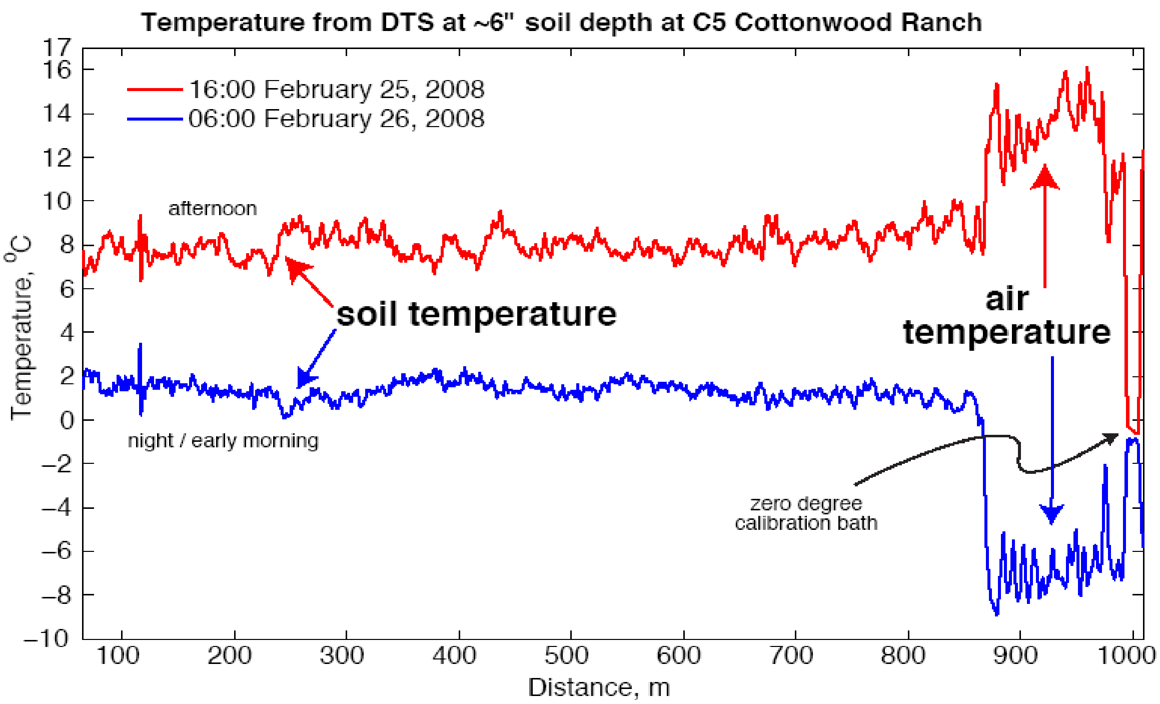

Figure 32. Soil temperatures at 15 cm below surface as measured using DTS. The X-axis represents distance along the fiber optic cable and the final 1~130 m of the fiber are located above the soil surface. Those portions of the fiber optic cable showing the largest differences between day and night temperatures are in areas of higher moisture content.

The effects of irrigation can also easily be seen in Figure 33, in which two temperature surveys were conducted during a given irrigation cycle. These traces represent “double ended measurements”, in which the two fibers in the cable were joined to produce a 2,000 meter long fiber. The data taken from 1,000 to 2,000 m in Figure 33 represents measurements in the same portion of the soil profile, but simply folded back on the original signal. Following irrigation (red trace), the soil temperatures were much cooler, in spite of the fact that the trace was taken in the middle of the day. In this case, the irrigation reduced the soil temperature everywhere, and was also likely aided by latent heat flux during evaporation.

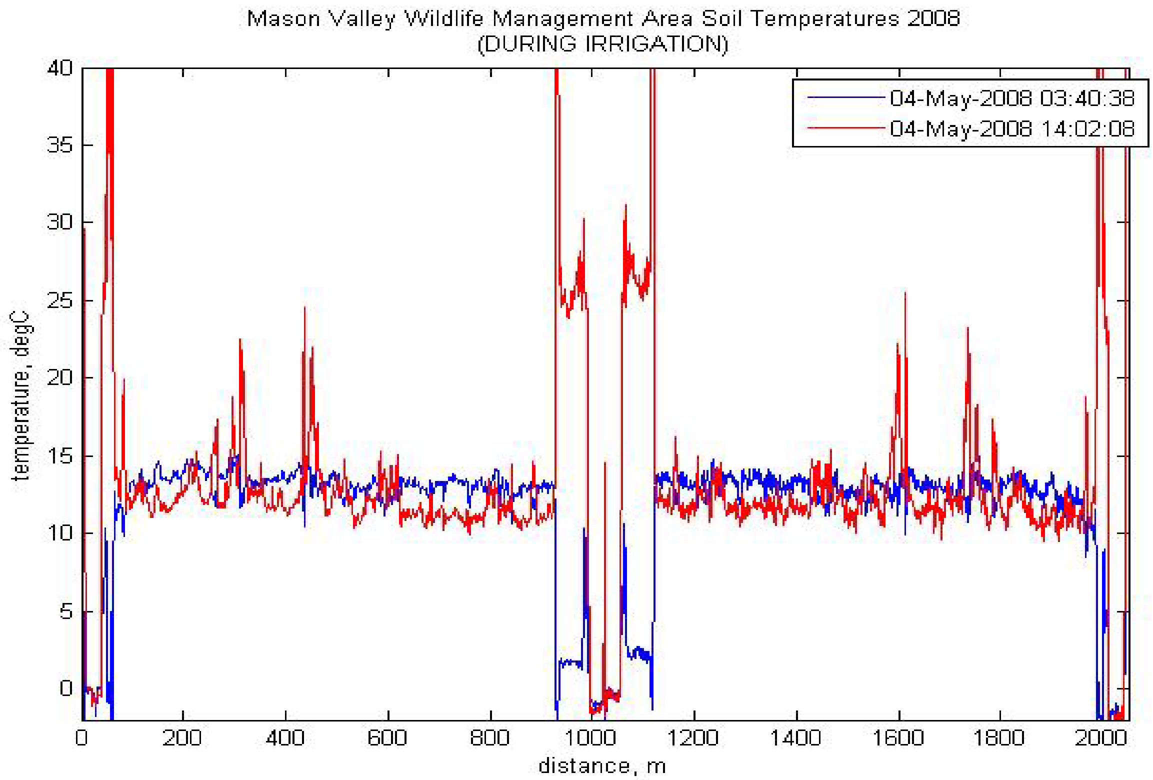

Figure 33. Soil temperatures at 15 cm below surface following an irrigation period. The soil temperatures decreased during the daytime period, in response to the infiltration of cool water. The measurements were conducted in "double-ended" mode, and data from the 1,000 to 2,000 m of the cable represents duplication of the first 100 m. The second 1,000 meter is much noisier than the first 1,000 m and is the result of connector losses at 1,000 m.

The bulk of the field data thus far from this study was collected in April 2009, and the entire data set comprises meteorological data, ground surface temperatures, subsurface temperatures, and soil water contents measured by both TDR and destructive sampling. The meteorological data, including air temperature, wind speed, and net radiation are shown in Figure 34. Shown in Figure 35 are the wind speed and the calculated evapotranspiration rate (expressed in mm day^{-1}) for each five-minute period as determined by the Penman-Monteith equation (Allen *et al.*, 1998).

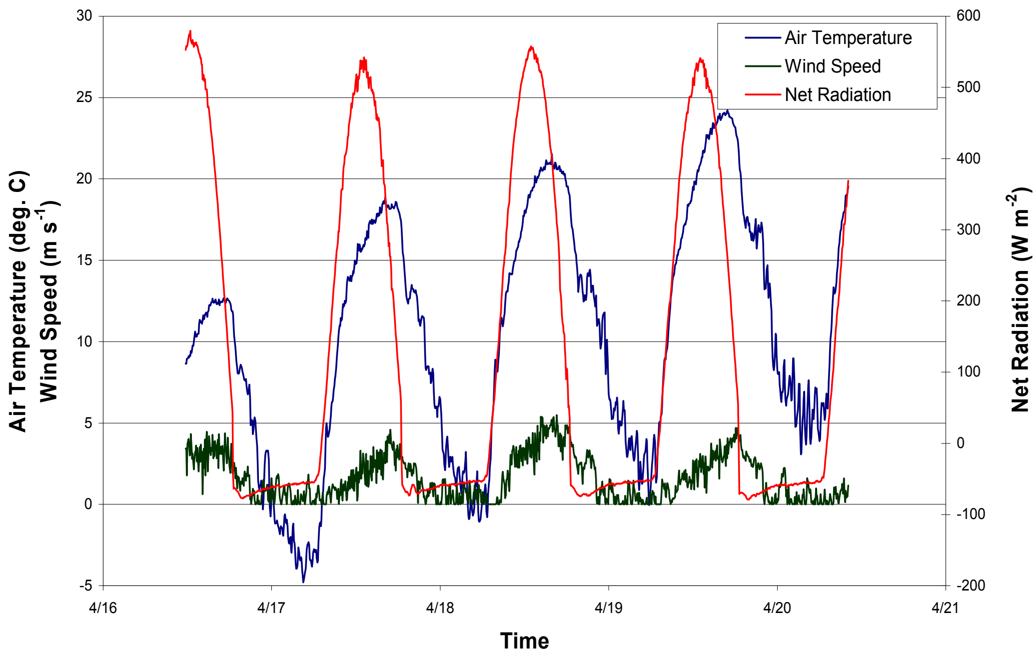

Figure 34. Meteorological data recorded at Valley Vista Ranch, April 2009

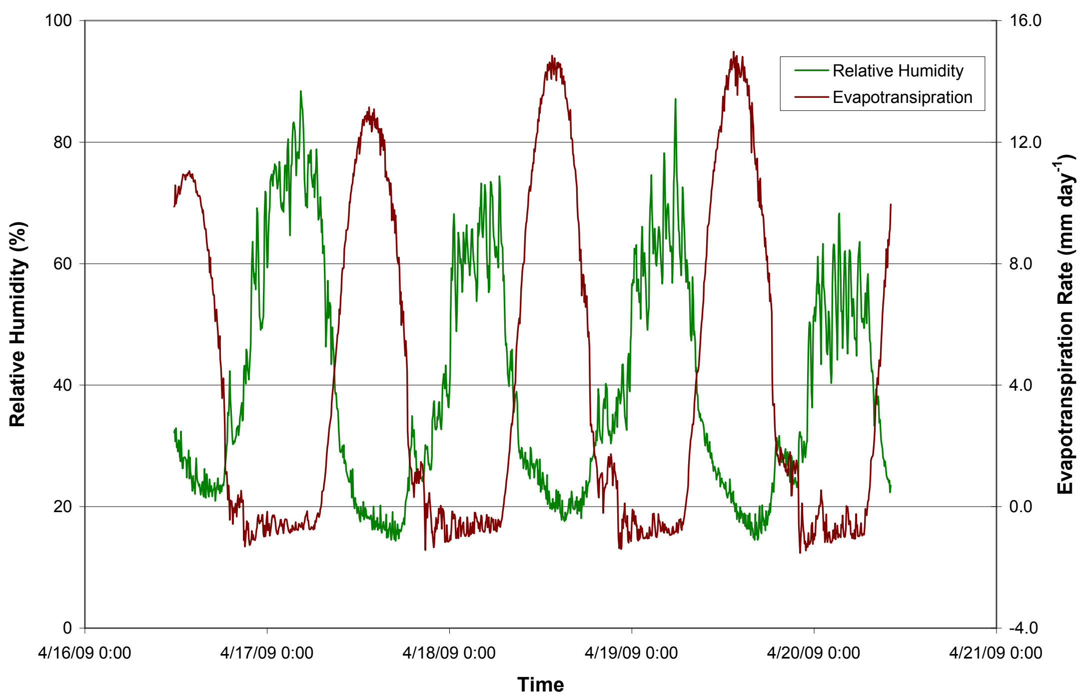

Figure 35. Relative humidity and Penman-Monteith evapotranspiration rate

The analysis in this study focuses on the west side of the VV site, where the revegetation study component was located. This area was divided into five plots, each approximately 30 meters wide, as depicted in Figure 36 below. Plots 1, 3, and 5 in this figure were not irrigated, whereas plots 2 and 4 were irrigated at 25% of a typical water year budget for crop production. Although the entire area had been seeded with native species, the only established vegetation was confined to plots 2 and 4 (irrigated). Plots 1, 3, and 5 had exposed bare soil at the surface and little or no vegetation within the plot area itself.

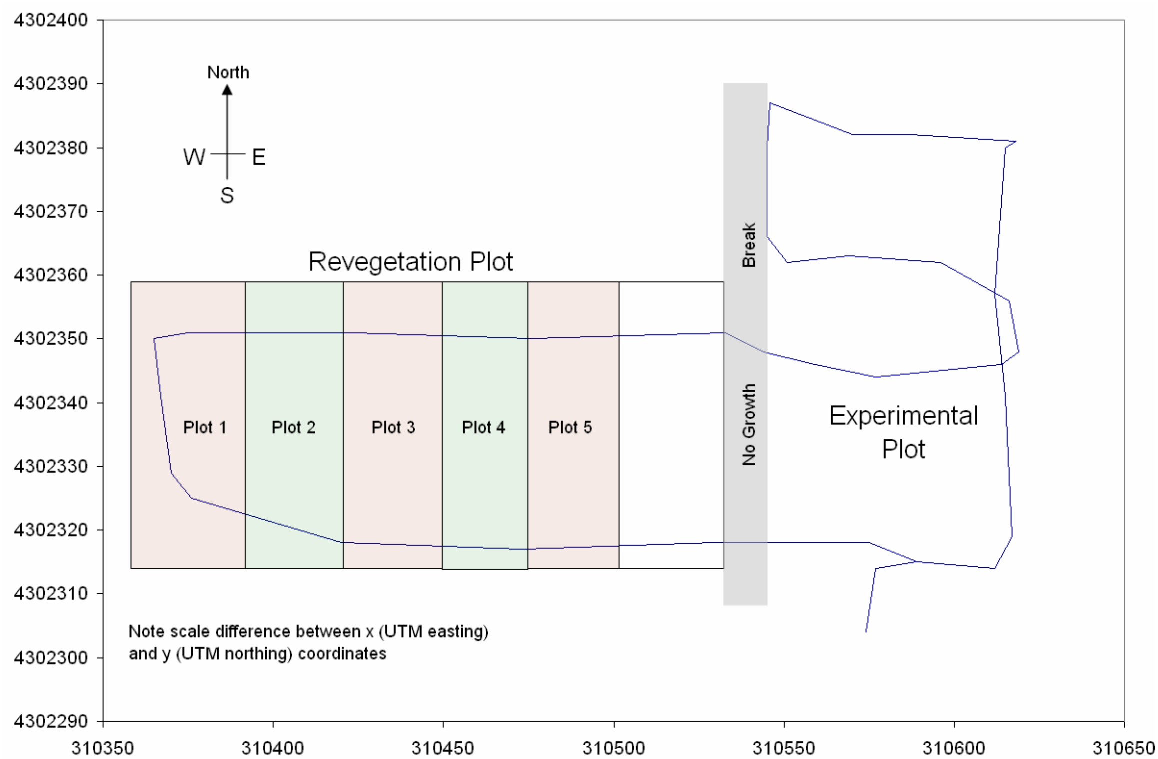

Figure 36. Alternating non-irrigated (#1, 3, 5) and 25% irrigated (2, 4) sections on the west side of the Valley Vista Ranch field site

The buried fiber-optic cable (shown in blue in Figure 36) passed through plots 2-5 two times (once on the south side and again on the north side of the section), and the cable made two 90° turns in plot 1 (as shown above). For each section, the points on the cable located within that section were identified and a composite temperature trace was calculated. The set of points within the section was trimmed, eliminating the first and last temperature reading (2 meters on either side of each plot) to minimize interference between vegetated and bare sections. The composite trace for each section was calculated by taking the mean temperature within the trimmed data set at each sampling time. The nine composite traces are shown in Figure 37.

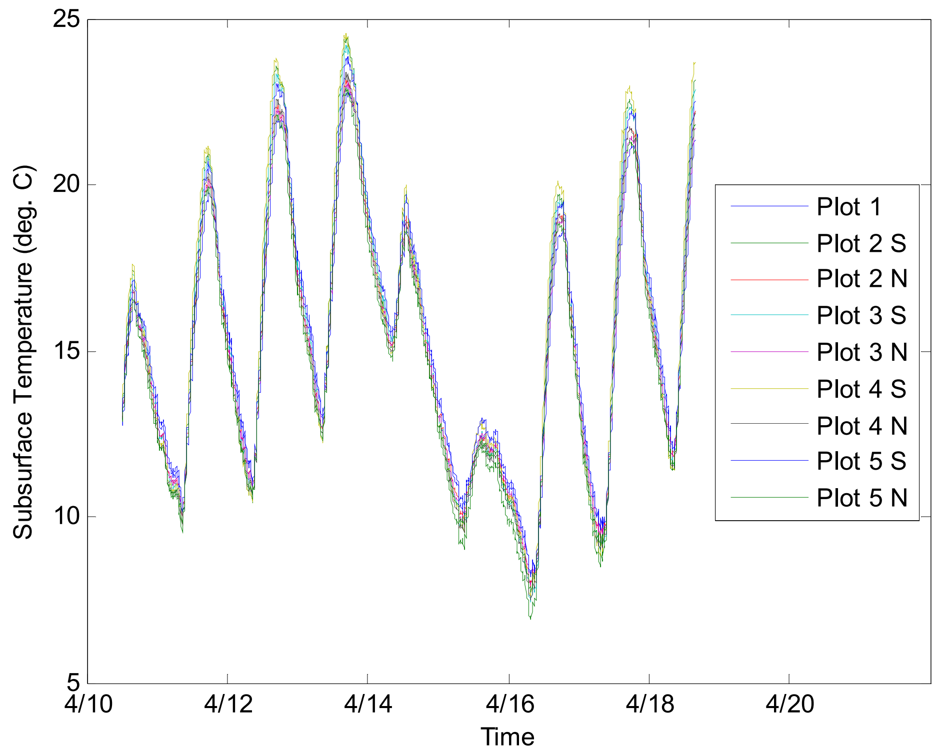

Figure 37. Composite temperature traces for the nine sections of cable comprising the western side of the VV study area.

Amplitude damping and phase shifts were calculated for each of the composite traces shown above. The ground surface temperature in each section was observed using a chromal-constantan thermocouple (Type E). Two different thermocouples were deployed: one in a barren area, and one in located beneath the canopy within a vegetated plot. The surface temperature traces evaluated here are shown below in Figure 38, along with the air temperature recorded by the meteorological monitoring station on site. Plots 1, 3, and 5 used the bare surface temperature as the basis for amplitude damping and phase shift calculations; plots 2 and 4 used the vegetated surface temperature trace for this purpose.

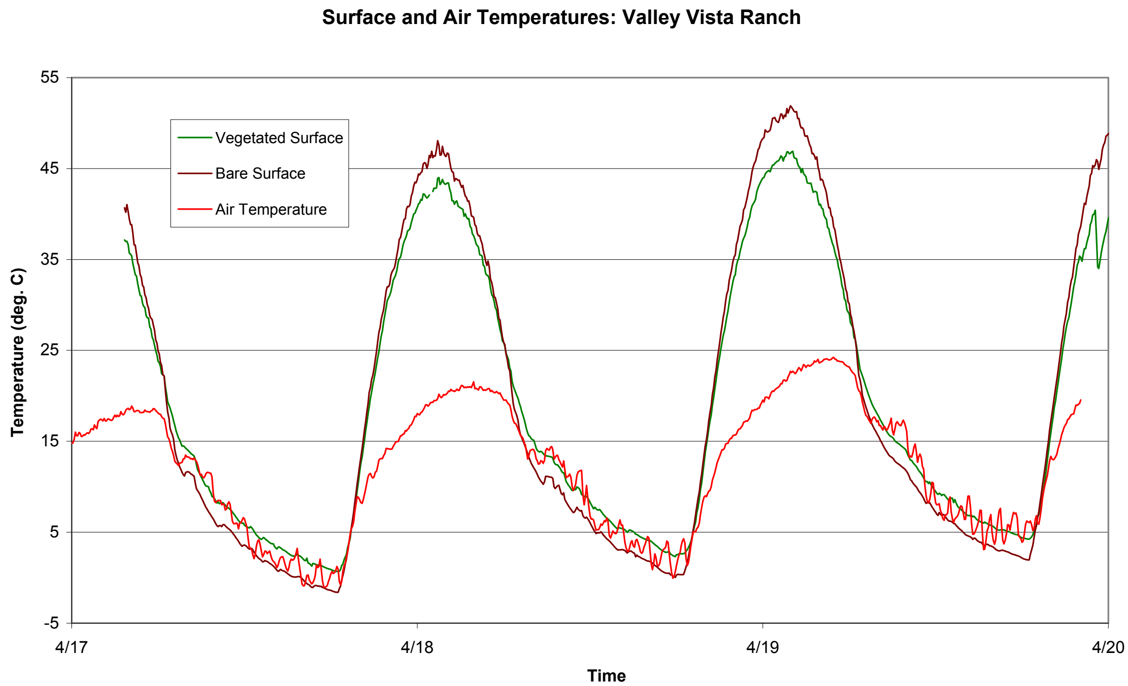

Figure 38. Representative temporal temperature evolution between air temperature and soil DTS temperatures measured beneath bare soil (brown) and vegetated soil (green). As expected, the bare soil peaks with higher temperatures due to increased soil heat flux.

Figure 39 shows the calculated thermal diffusivities from the measured phase lag and amplitude attenuation. Overall, the phase shift calculations are bias higher than the amplitude method, and are likely more robust as they do not rely on selecting a single point of maximum temperature, but rather make use of the entire temporal evolution of temperature.

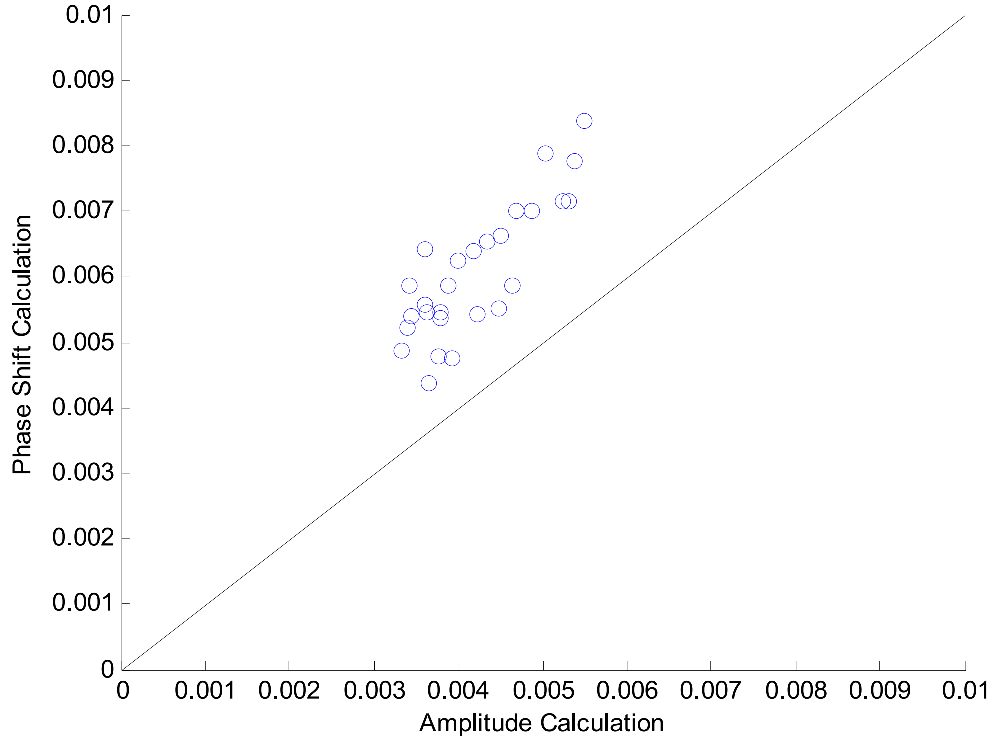

Figure 39. Calculated thermal diffusivities using both phase and amplitude shifts.

The calculated thermal diffusivities are somewhat lower than would be expected for the observed and calculated moisture contents, assuming commonly used models relating moisture content to thermal conductivity and heat capacity. However, during this period of study, the upper most portion of the soil profile was very dry, violating the assumption of uniform moisture content with depth over the top 15 cm. In addition, the undulating variability of cable installation depth lead to significant uncertainty in the calculated volumetric water contents.

To avoid these difficulties in the future, a multiple depth cable with finer vertical depth control will be implemented. Dunne-Steele et al (2009) have shown the advantages of multiple fibers at depth. These techniques reduce the impacts of cable burial uncertainty, and also remove the variability due to very dry surface soils, which will always bias the thermal diffusivities towards lower water contents.

Soil Nutrient availability

<u>Soil Texture</u>

The < 2mm soil fraction at the Wildlife Management Area revegetation field plots (WMF) had significantly higher percent clay (14.7 %) and silt content (54.7 %) and significantly lower percent sand content (30.6 %) than all other fields (Figure 40). There was no difference in texture between revegetation and alternative agriculture field plots at either the 5C Cottonwood and Valley Vista locations, although the Valley Vista plots had a significantly higher silt content (20.4 %) than the 5C Cottonwood plots (16.9 %) and a significantly lower sand content (75.7 %) than either of the Cottonwood fields (79.7 %).

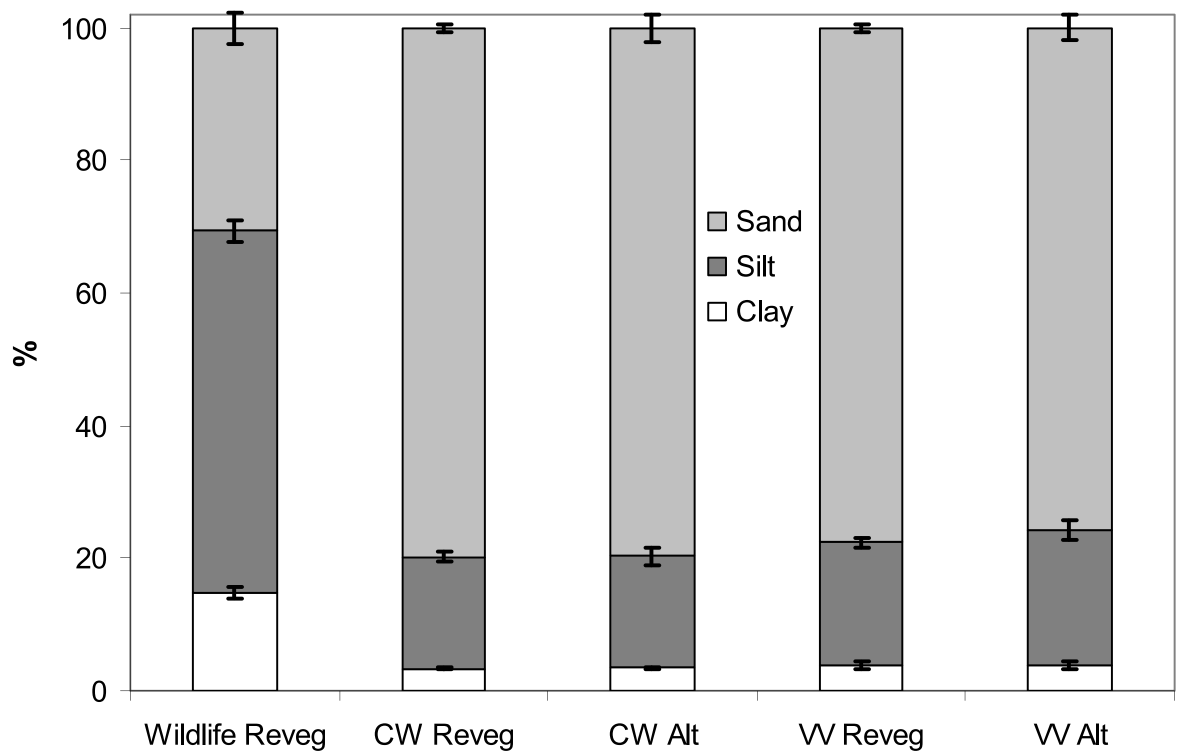

Figure 40. Particle size distribution for Wildlife Refuge, Cottonwood (CW), and Valley Vista (VV) revegetation (Reveg) and alternative agriculture (Alt) soils.

Soil C and N

Prior to planting, the WMF revegetation field had a significantly higher C (1.64 %) and N (0.13 %) concentration and C/N ratio (12.9) than all other fields (Figures 41 and 42). The Cottonwood revegetation plots had a significantly higher concentration of C (0.80 %) and N (0.07 %) and C/N ratio (10.8) than the Cottonwood alternative crops area (C=0.46%; N=0.05 %; C/N=9.2). Although soil C and N concentrations were measured in samples following planting, no significant changes were observed following one planting season.

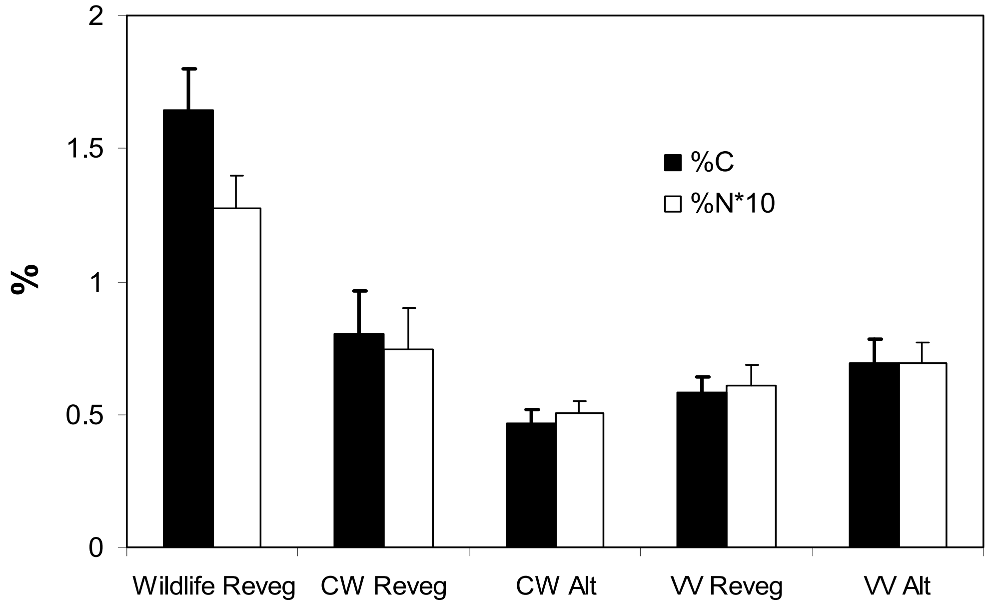

Figure 41. C and N concentrations for Wildlife Refuge, 5C Cottonwood (CW), and Valley Vista (VV) revegetation (Reveg) and alternative agriculture (Alt) soils used in the pre-planting incubation.

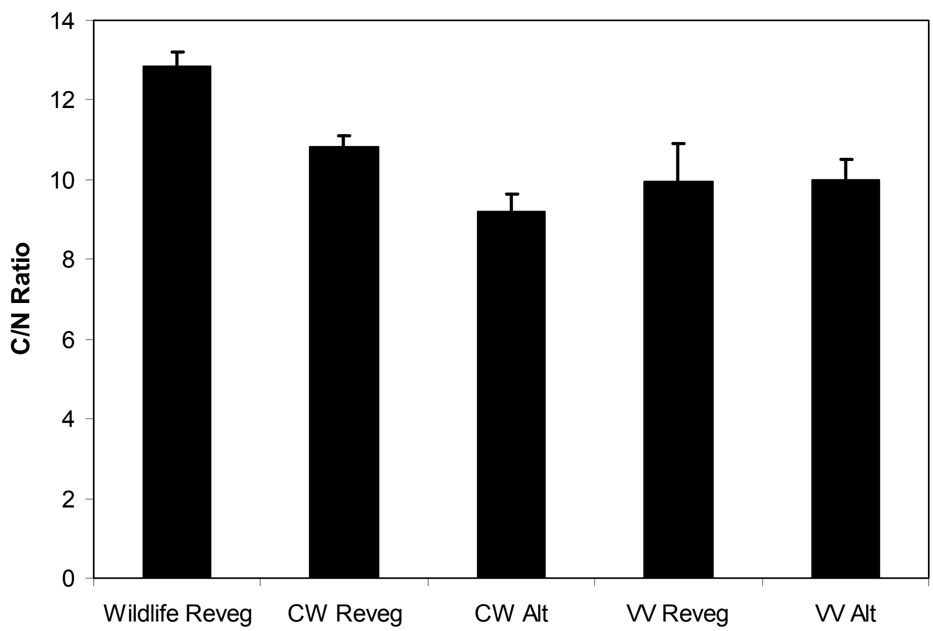

Figure 42. C/N ratios for Wildlife Refuge, 5C Cottonwood (CW), and Valley Vista (VV) revegetation (Reveg) and alternative agriculture (Alt) soils used in the pre-planting incubation.

Laboratory Study Results

Cumulative C mineralization - The MANOVA analysis showed that moisture and field significantly affected the cumulative C production per gram of soil in the pre-planting incubation (Table 4). Carbon mineralization was lowest for the 0.05 moisture treatment (1.42 ± 0.32 μgC g_s^{-1} d^{-1}) compared to the 0.15 (4.96 ± 0.74 μgC g_s^{-1} d^{-1}), and 0.30 (6.65 ± 0.71 μgC g_s^{-1} d^{-1}) moisture treatments (Figure 43). Carbon mineralization was highest in the Cottonwood revegetation (6.79 ± 1.37 μgC g_s^{-1} d^{-1}) followed by the Valley Vista revegetation (4.67 ± 0.89 μgC g_s^{-1} d^{-1}), Wildlife Area revegetation, (4.02 ± 0.90 μgC g_s^{-1} d^{-1}), Valley Vista alternative (3.88 ± 0.67 μgC g_s^{-1} d^{-1}), and Cottonwood alternative fields (3.41 ± 0.91 μgC g_s^{-1} d^{-1}).

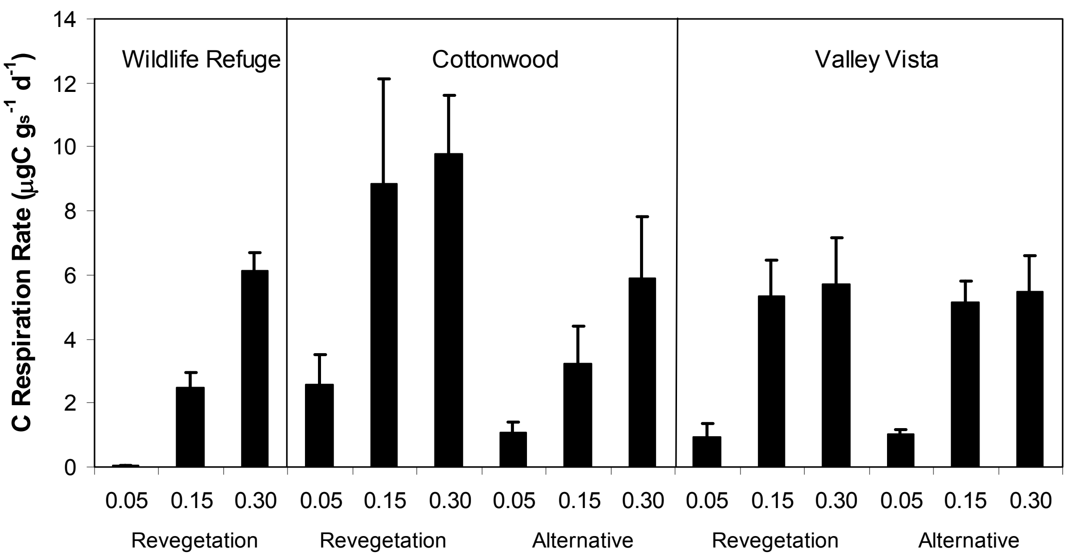

Figure 43. C respiration rate for the pre-planting incubation at the Wildlife Refuge, Cottonwood, and Valley Vista revegetation and alternative agriculture fields as a function of soil moisture content. Error bars represent standard error (n = 3).

For the post-planting incubation the MANOVA analysis showed that moisture and vegetation significantly affected the C mineralization (Table 4). Carbon mineralization rates were lowest for the 0.05 moisture treatment (5.08 ± 0.47 μgC g_s^{-1} d^{-1}) compared to the 0.15 (10.32 ± 1.02 μgC g_s^{-1} d^{-1}), and 0.30 moisture treatments (9.81 ± 1.01 μgC g_s^{-1} d^{-1}; Figures 44 and 45). Respiration rates were highest for Tef (11.64 ± 1.29 μgC g_s^{-1} d^{-1}), followed by Switchgrass (7.29 ± 0.86 μgC g_s^{-1} d^{-1}), Alfalfa (7.61 ± 1.02 μgC g_s^{-1} d^{-1}), and Amaranth (7.08 ± 1.07 μgC g_s^{-1} d^{-1}).

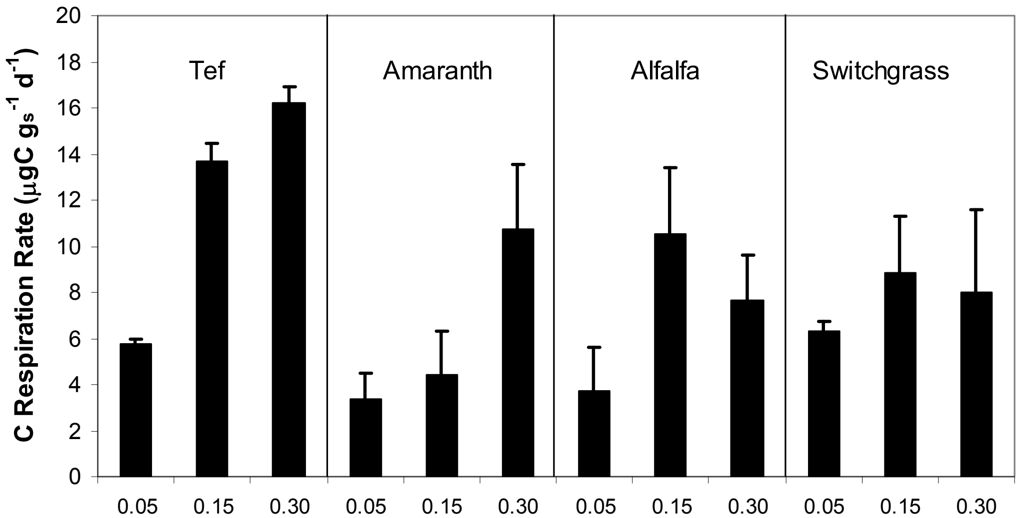

Figure 44. C respiration rates for the post-planting incubation in the Valley Vista field as a function of soil moisture content and vegetation type. Error bars represent standard error (n = 3).

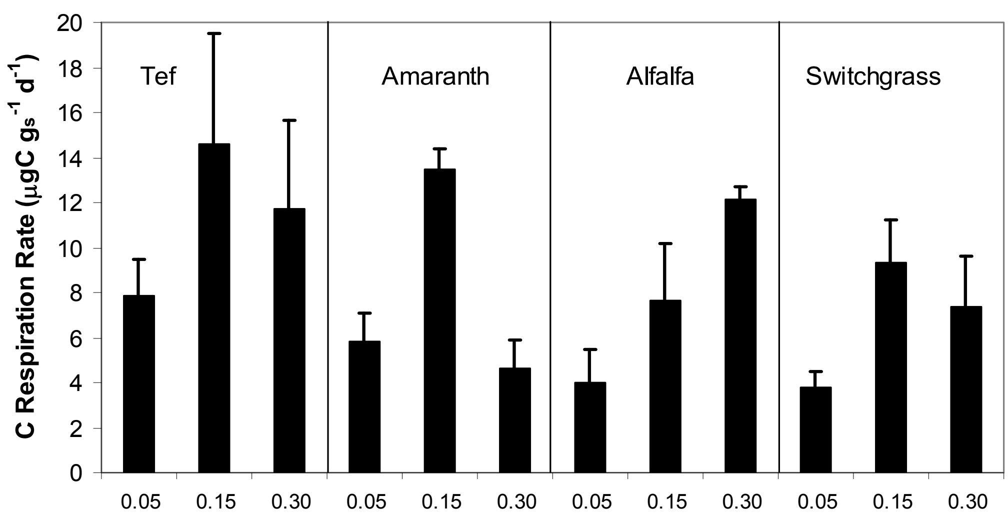

Figure 45. C respiration rate for the post-planting incubation in the Cottonwood field as a function of soil moisture content and vegetation type. Error bars represent standard error (n = 3).

Cumulative respiration rates also showed a significant moisture*field*vegetation interaction (Table 4) indicating that effects of moisture and vegetation were not consistent among fields. Respiration rates were similar in all Valley Vista and Cottonwood soils in the 0.05 moisture treatment. For the Valley Vista site, respiration rates were significantly higher in the Tef soils than in the Amaranth soils in the 0.15 moisture treatment. In contrast, at this moisture level respiration rates were the same for all the vegetation types in the Cottonwood field. For the Valley Vista field, respiration was higher in Tef than in Alfalfa soils in the 0.30 moisture treatment while for this moisture treatment, Amaranth soils had higher respiration rates than Alfalfa soils in the Cottonwood field. The overall C mineralization rate combining both fields and all moisture treatments in the post-planting incubation was 8.40 ± 0.57 μgC g_s^{-1} d^{-1}, which was significantly higher than the pre-planting incubation.

Net N mineralization - Moisture and field significantly affected the net N mineralization in the pre-planting incubation (Table 5). Net N mineralization was dominated by NO_3 production, or nitrification. The net N mineralization was lowest for the 0.05 moisture treatment (9.33 ± 1.95 mg N kg^{-1}), followed by the 0.15 (44.78 ± 6.56 mg N kg^{-1}), and 0.30 moisture treatments (74.85 ± 7.64 mg N kg^{-1}; Figure 34). The net N mineralization was highest in the Cottonwood revegetation (75.24 ± 14.81 mg N kg^{-1}) followed by the Valley Vista alternative fields (44.80 ± 8.41 mg N kg^{-1}), Cottonwood alternative (43.45 ± 8.11 mg N kg^{-1}), Valley Vista revegetation, (33.92 ± 7.39 mg N kg^{-1}), and Wildlife Area revegetation field (17.52 ± 4.44 mg N kg^{-1}). The overall net N mineralization for the pre-planting soils was 42.99 ± 4.59 mg N kg^{-1}.

Table 5. MANOVA results for the pre-planting incubation.

Factor	Moisture	Field	Mst*Fld
C mineralization	***	**	ns
Net N mineralization	***	***	ns

* = p<0.05; ** = p<0.01; *** = p<0.001; ns = not significant

In the post-planting incubation moisture, field, the moisture*field interaction, vegetation, and the field*vegetation interaction significantly affected the net N mineralization (Table 6). In contrast to the pre-planting incubation, net N mineralization did not increase with moisture. Instead, net N mineralization was highest in the 0.15 moisture treatment (34.33 ± 1.12 mg N kg^{-1}) compared to the 0.05 (8.68 ± 0.52 mg N kg^{-1}), and 0.30 moisture treatments (8.52 ± 2.69 mg N kg^{-1}; Figures 46 and 47). Net N mineralization was significantly lower for the Valley Vista (14.68 ± 2.31 mg N kg^{-1}) than for the Cottonwood fields (19.67 ± 2.56 mg N kg^{-1}). For the 0.15 moisture treatment, N mineralization was significantly lower in the Valley Vista field (31.70 ± 0.92 mg N kg^{-1}) compared to the Cottonwood field (36.97 ± 1.78 mg N kg^{-1}). For the 0.30 moisture treatment, N mineralization rates were lower in Valley Vista (3.26 ± 2.95 mg N kg^{-1}) than in Cottonwood (13.78 ± 4.07 mg N kg^{-1}).

Table 6. MANOVA results for the post-planting incubation.

Factor	Moisture	Field	Mst*Fld	Veg Type	Mst*VT	Fld*VT	Mst*Fld*VT
Cumulative C g_s^{-1}	***	ns	ns	**	ns	ns	*
Net N mineralization	***	**	*	**	ns	*	ns

* = p<0.05; ** = p<0.01; *** = p<0.001; ns = not significant

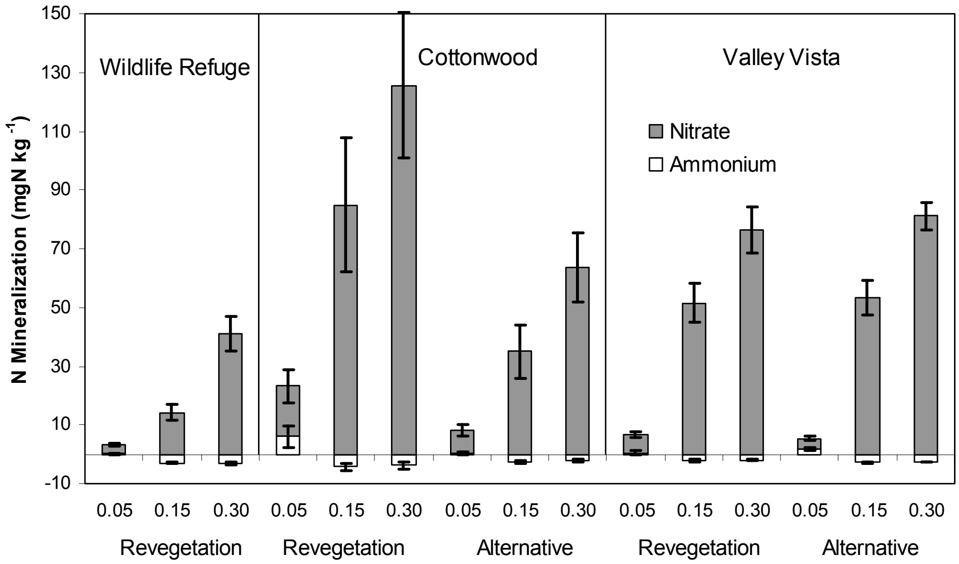

Figure 46. Average net N mineralization at the Wildlife Refuge, Cottonwood, and Valley Vista revegetation and alternative agriculture fields in the pre-planting incubation as a function of soil moisture content. Error bars represent standard error (n = 3).

Across all fields (Figure 48), net N mineralization was highest for Amaranth (22.49 ± 3.62 mg N kg^{-1}) followed by Alfalfa (16.12 ± 3.48 mg N kg^{-1}), Switchgrass (16.08 ± 3.24 mg N kg^{-1}) and Tef (14.02 ± 3.52 mg N kg^{-1}). The overall net N mineralization was significantly lower for the post-planting incubation (17.18 ± 1.74 mg N kg^{-1}) compared to the pre-planting incubation (42.99 ± 4.59 mg N kg^{-1}).

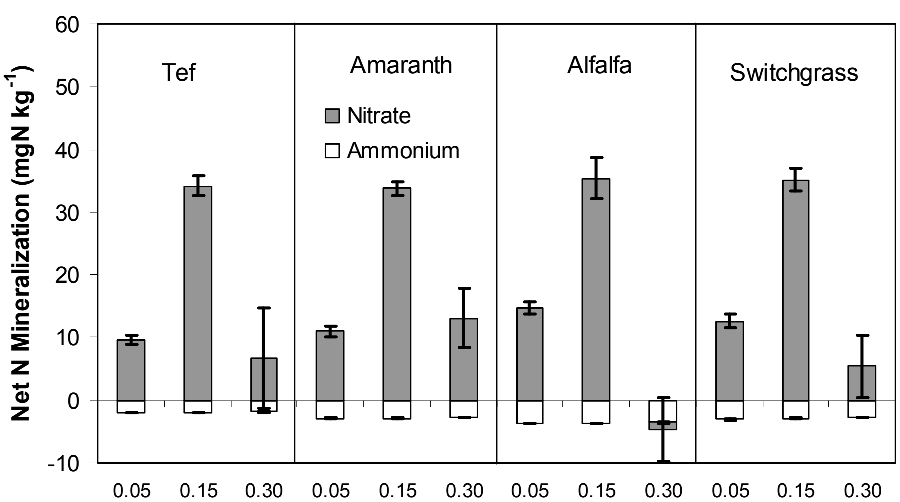

Figure 47. Net N mineralization in the Valley Vista field during the post-planting incubation as a function of vegetation type and soil moisture content. Error bars represent standard error (n = 3).

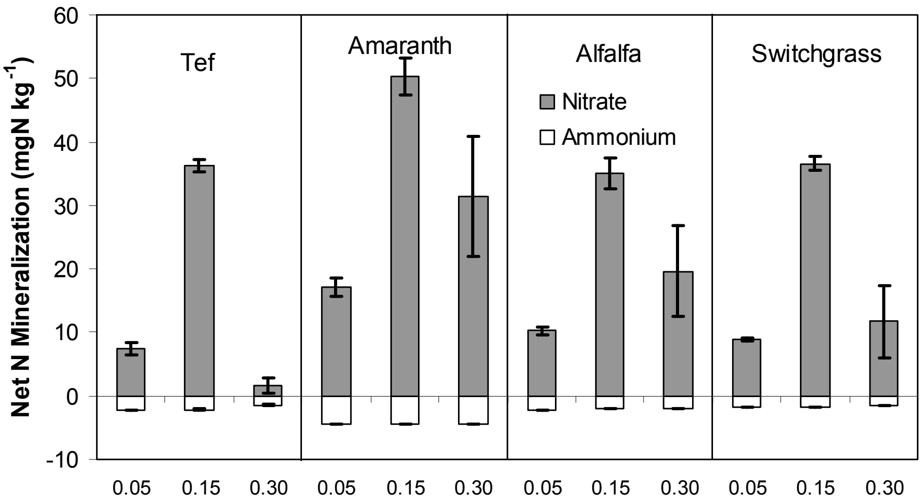

Figure 48. Net N mineralization in the Cottonwood field during the post-planting incubation as a function of vegetation type and soil moisture content. Error bars represent standard error (n = 3).

Multiple Regression Analysis - The multiple regression analysis showed that the cumulative C production over the incubation period was affected by moisture, percent clay, percent silt, and initial percent organic N in the pre-planting incubation (R^2 = 56.4%; Table 5), where only percent silt affected the cumulative C production negatively. Moisture, percent clay, initial percent C, and initial C/N were significant factors in the post-planting incubation (R^2 = 27.7%), where percent clay and initial percent C affected the cumulative C production (Table 5). Moisture, percent clay, initial C/N ratio, and initial percent organic N were significant factors affecting the net N mineralization in the pre-planting incubation (R^2 = 66.3%; Table 7). There were no significant factors for the net total N mineralization in the post-planting incubation (R^2 = 11.6%; Table 8). Performing the regression analysis with only moisture, percent clay, percent silt, initial C/N, and initial percent organic N as factors resulted in a R^2 of only 48.2% and the only factors affecting the N mineralization significantly were percent clay (p = 0.0019), percent silt (p = 0.0005), and initial percent organic N (p = 0.0004).

Table 7. Linear multiple regression results for the pre-planting incubation.

Factor	C Mineralization	Net N mineralization
Moisture	****	****
%Clay	*	****(-)
%Silt	*(-)	ns
%Sand	ns	ns
Initial %N	ns	ns
Initial %C	ns	ns
Initial C/N	ns	*
Initial %Org-N	****	***
Initial %Inorg-N	ns	ns

* = p<0.05; ** = p<0.01; *** = p< 0.001; ns = not significant; (-) indicates negative correlation

Table 8. Linear multiple regression results for the post-planting incubation.

Factor	C mineralization	N mineralization
Moisture	**	ns
%Clay	*(-)	ns
%Silt	ns	ns
%Sand	ns	ns
Initial %N	ns	ns
Initial %C	*(-)	ns
Initial C/N	*	ns
Initial %Org-N	ns	ns
Initial %Inorg-N	ns	ns

* = p<0.05; ** = p<0.01; *** = p<0.001; ns = not significant; (-) indicates negative correlation.

Field Study Results

Moisture - Soil moisture showed significant temporal variability with moisture being highest on June 11th in both fields (Figure 49). At most dates, soil moisture was highest at the Valley Vista site and season-average soil moisture was significantly higher in the Valley Vista soils (0.112 ± 0.005 m^3 m^{-3}) than the Cottonwood soils (0.078 ± 0.002 m^3 m^{-3}; Figure 49). The Valley Vista site received almost 70% more irrigation than the Cottonwood site (Figure 50). When averaged over the growing season soil moisture was significantly higher in the Valley Vista Switchgrass than the Valley Vista Tef plots (Figure 51). Soil moisture was the same in all vegetation types at the Cottonwood site.

Temperature and Relative Humidity - The average fifteen minute air temperature measured using the HOBO sensor at the Valley Vista site was 22.4ºC from June 6th, 2008 to August 12th, 2008. The maximum temperature during this time period was 38.0ºC and the minimum was -0.6ºC. The average fifteen minute soil temperature, measured at a depth of 10cm, at the Valley Vista site from the same time period was 30.3ºC with a maximum soil temperature of 40.4ºC and minimum of 16.1ºC. The average soil temperature measured between 10:30 AM and 3:30 PM at a depth of 5cm on August 13th, August 21st, and August 28th, 2008, was 36.6ºC in the Valley Vista field and 40.1ºC in the Cottonwood field (Figure 52). The maximum soil temperature was 46.0ºC in the Valley Vista field and 49.4ºC in the Cottonwood field. The minimum soil temperature was 24.8ºC in the Valley Vista field and 26.8ºC in the Cottonwood field. The average relative humidity during this time period was 31.0% with a maximum of 87.7% and a minimum of 4.5%.

Soil CO_2 efflux - Soil CO_2 efflux rates showed clear seasonal patterns with rates during the second through the fifth measurements being significantly higher than during the other three measurements (Figure 53). Overall, soil rates were significantly higher in the Valley Vista field (2.23 ± 0.08) than in the Cottonwood fields (1.36 ± 0.07 µmol CO_2 m^{-2} s^{-1}; Figures 53 and 54, Table 7). Vegetation significantly affected soil CO_2 efflux with Alfalfa having the highest rate (2.05 ± 0.15) and Switchgrass the lowest (1.52 ± 0.08 µmol CO_2 m^{-2} s^{-1}; Figure 54). Soil CO_2 efflux rates in Tef and Amaranth were similar (1.82 ± 0.10 and 1.80 ± 0.10). The MANOVA results showed that the vegetation*field*date interaction was significant indicating that effects of vegetation on soil CO_2 efflux varied by field and measurement date.

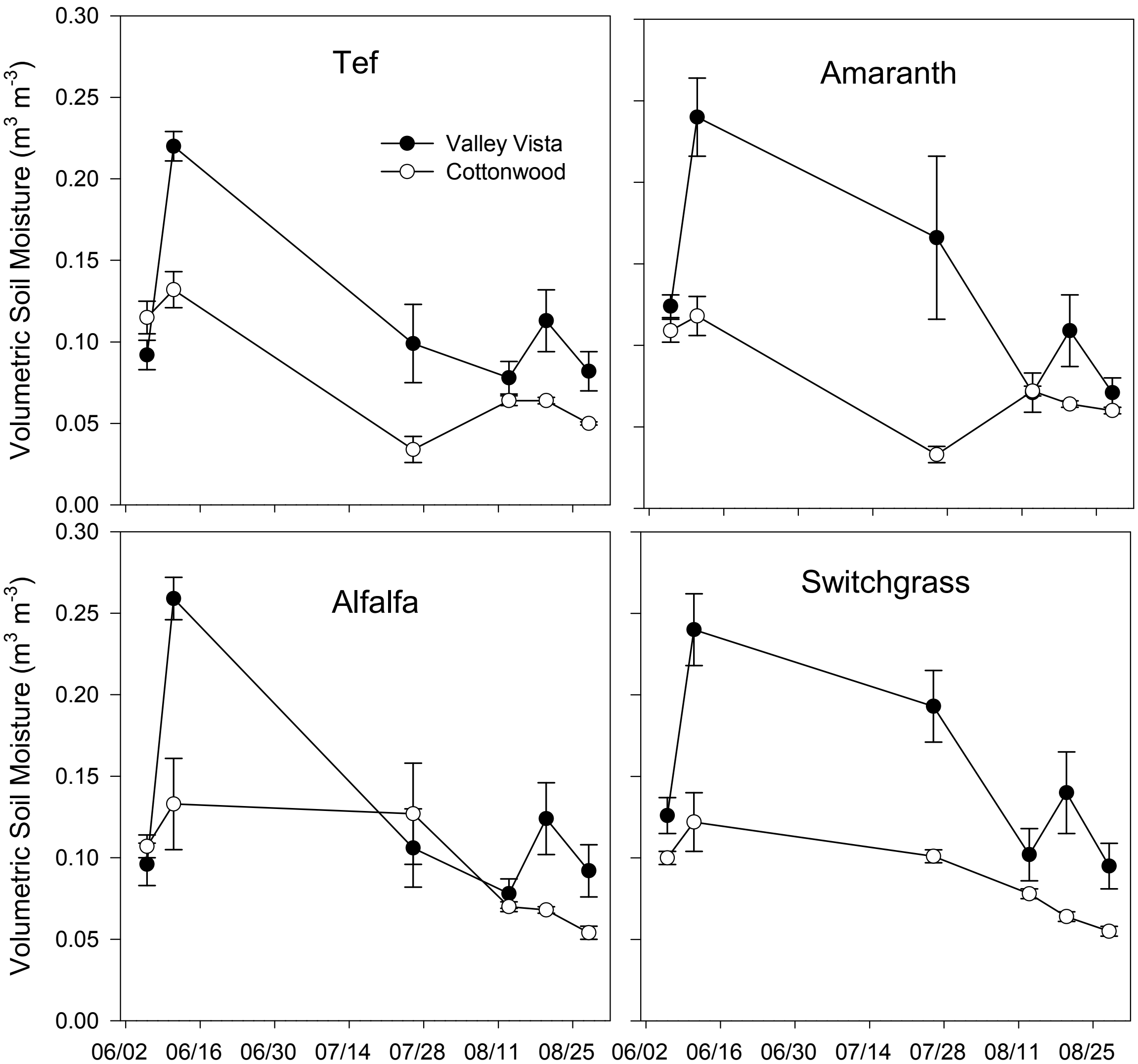

Figure 49. Average soil moisture contents over the 2008 growing season at the Valley Vista and Cottonwood sites for the four vegetation types.

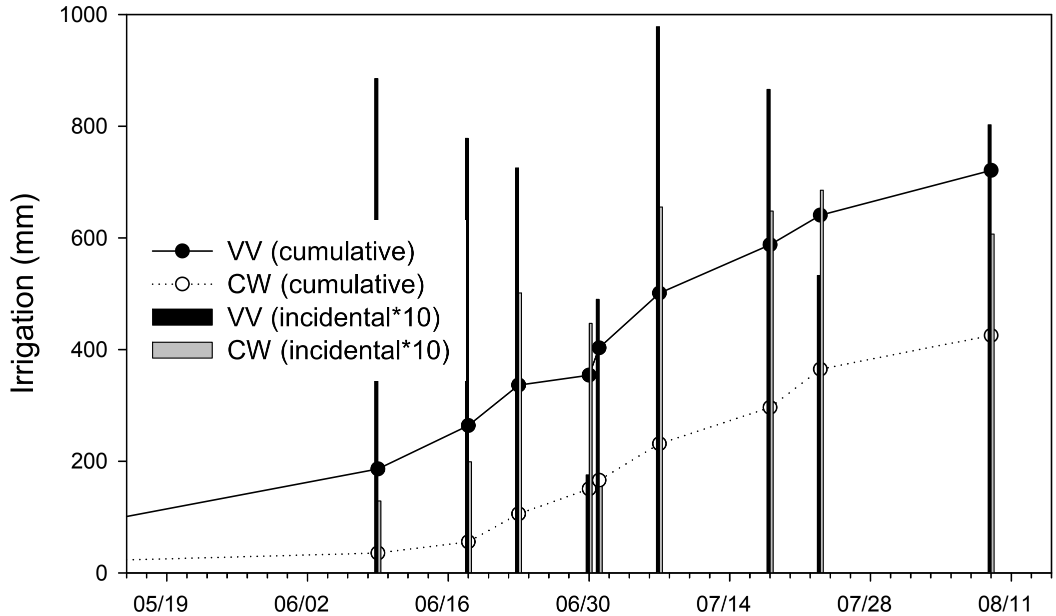

Figure 50. Timing and amounts of irrigation during the measurement period at the Valley Vista (VV) and Cottonwood (CW) sites.

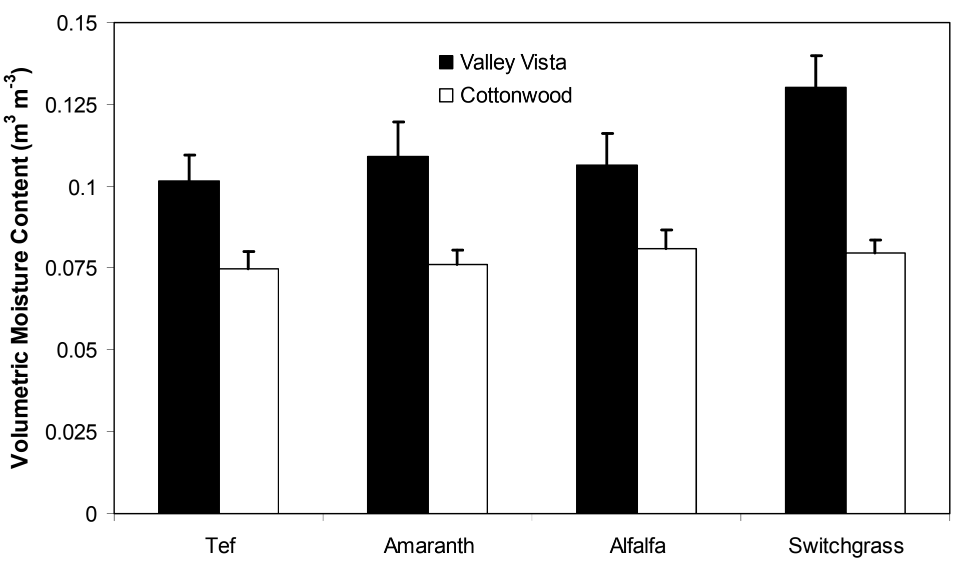

Figure 51. Season-average soil moisture contents over the 2008 growing season at the Valley Vista and Cottonwood sites for the four vegetation types.

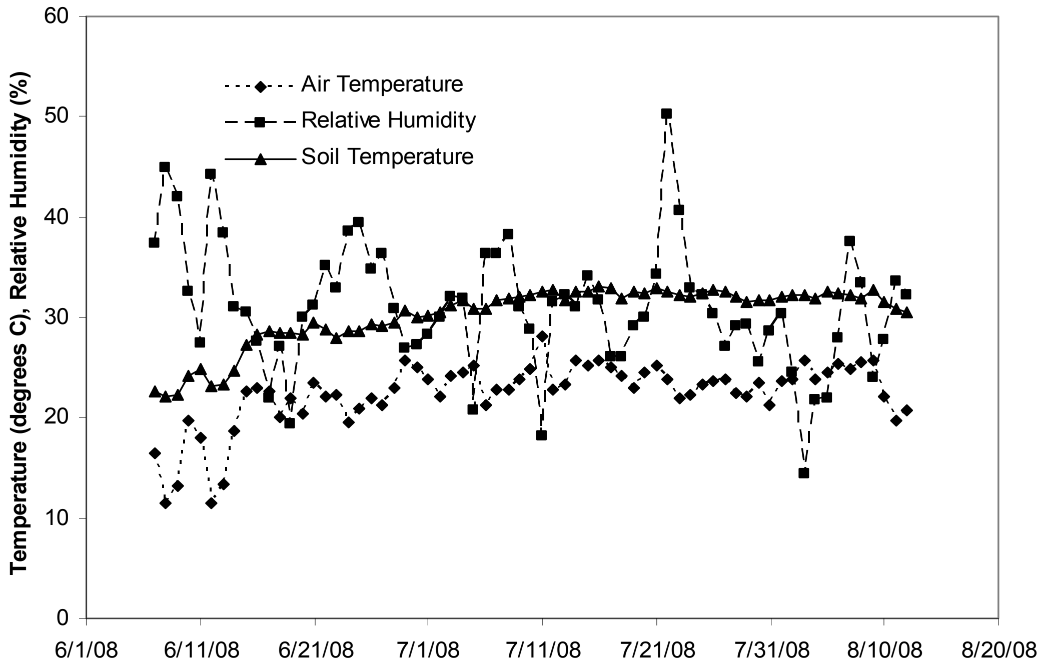

Figure 52. Average daily soil and air temperature (ºC) and relative humidity (%) values measured throughout the growing season.

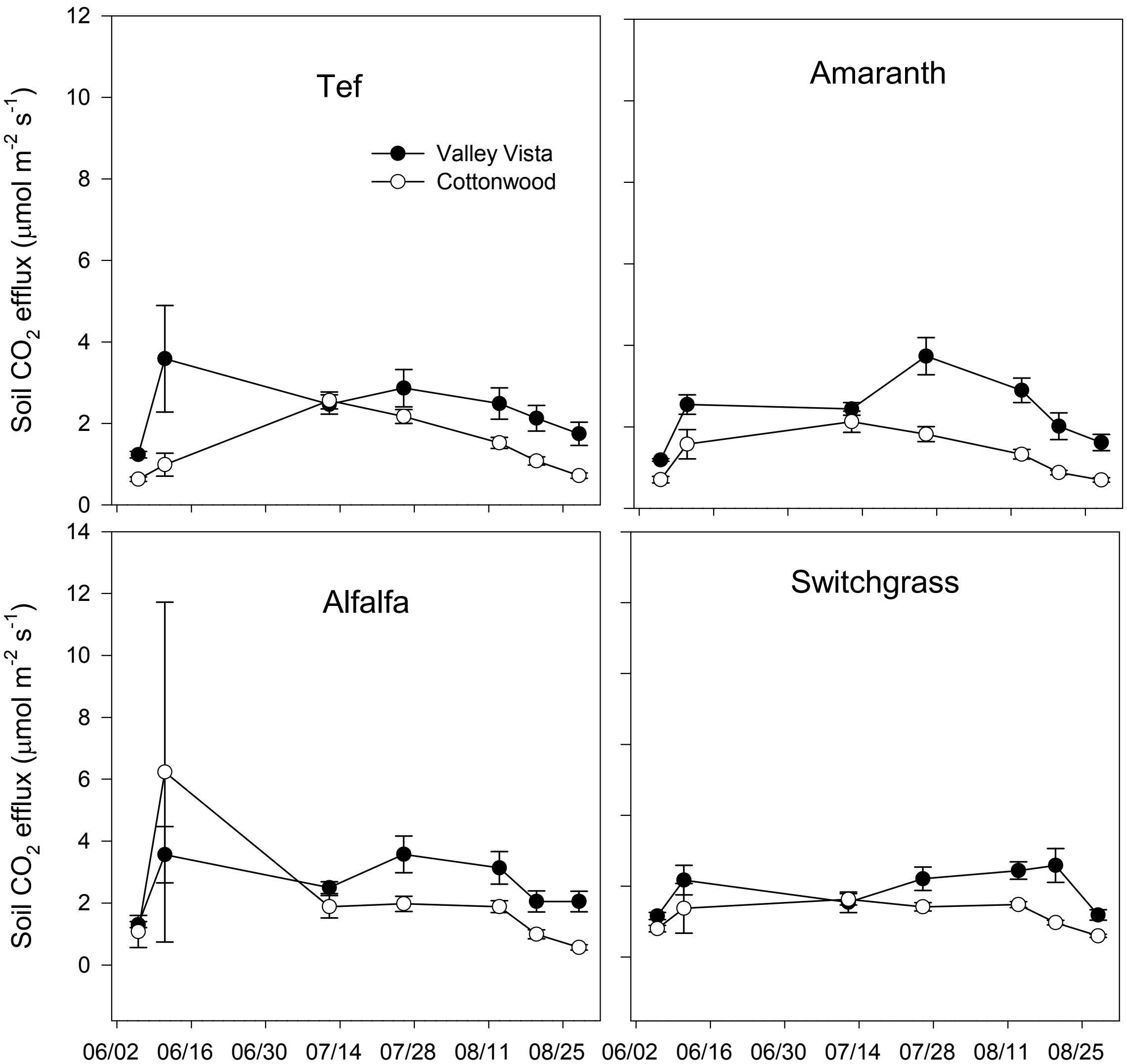

Figure 53. Average soil CO_2 efflux rates for the four vegetation types at the Valley Vista and Cottonwood fields. Error bars represent standard errors (n=9).

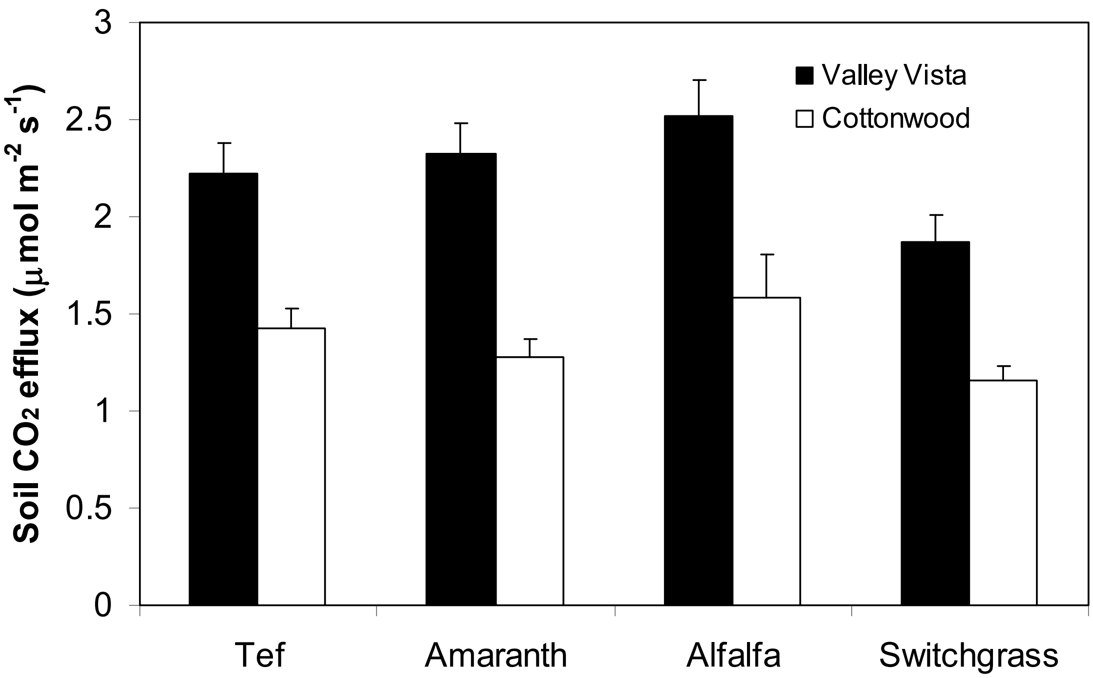

Figure 54. Season-averaged soil CO_2 efflux in the Valley Vista and Cottonwood fields as a function of vegetation type. Error bars represent standard errors (n=9).

Change in inorganic N - The MANOVA results show that only field and the vegetation*field interaction significantly affected the net change in inorganic N (Table 9). At the Valley Vista site, the soils showed an average increase in inorganic N of 4.16 ± 1.09 mg N kg^{-1} while in the Cottonwood field, the soils showed an average decrease of -4.44 ± 0.85 mg N kg^{-1} (Figure 55). At the Valley Vista site, the increase in inorganic N was significantly higher in Alfalfa (7.12 mg N kg^{-1}) than Amaranth (0.92 mg N kg^{-1}). In the Cottonwood soils, the change in inorganic N was the same for all vegetation types.

Table 9. MANOVA results for C and N fluxes

Factor	Soil CO_2 efflux	ΔInorganic N	ΔNO_3	ΔNH_4
Vegetation (VT)	***	ns	ns	ns
Field (Fld)	***	***	***	ns
Date	***	-	-	-
VT*Fld	ns	*	ns	ns
VT*Date	***	-	-	-
Fld*Date	***	-	-	-
VT*Fld*Date	*	-	-	-

* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$; ns = not significant; - = not included in analysis.

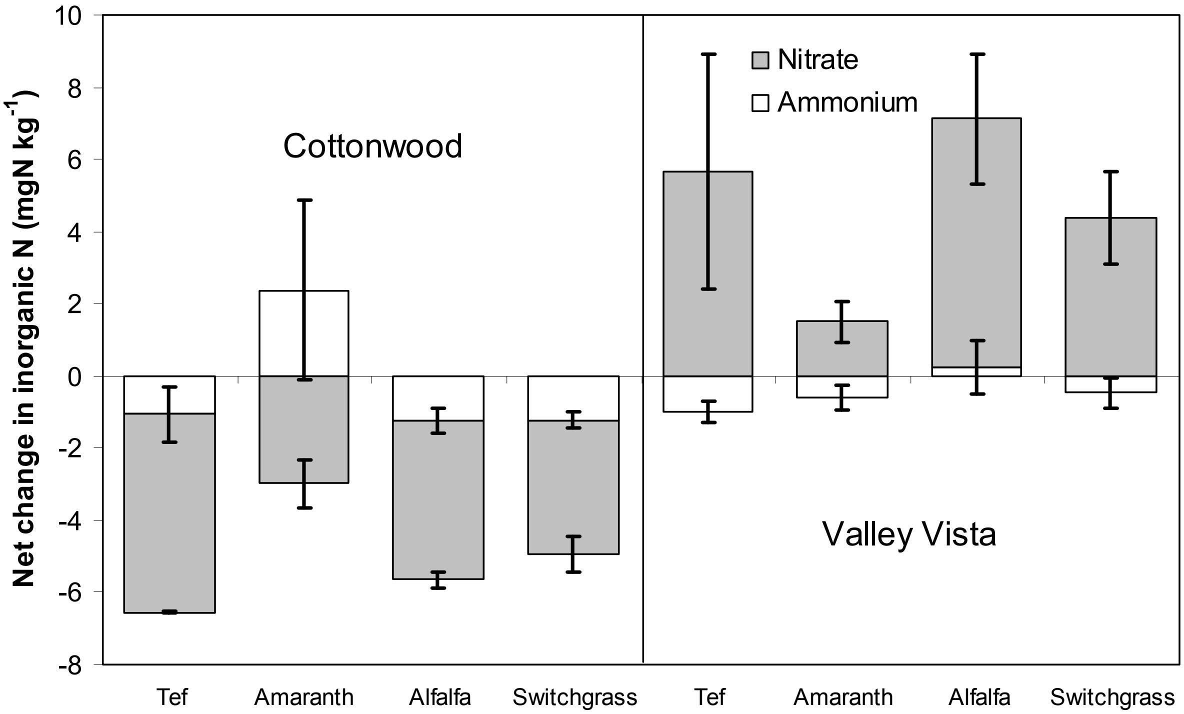

Figure 55. Net change in inorganic N during the growing season at the Cottonwood and Valley Vista sites as a function of vegetation type. Error bars represent standard errors (n=9).

Net nitrate and ammonium - The MANOVA analysis revealed that the net change in NO_3 was only affected by field (Table 7). The Valley Vista soils showed an average increase in NO_3 content of 4.61 ± 1.01 mg N kg^{-1} while all Cottonwood soils showed an average decrease of -4.15 ± 0.26 mg N kg^{-1} (Figure 55). Changes in NH_4 were the same for both fields with NH_4 decreasing by -0.45 ± 0.24 mg N kg^{-1} at the Valley Vista site and by -0.29 ± 0.68 mg N kg^{-1} at the Cottonwood site (Figure 55).

Vegetation biomass - At the Valley Vista site Tef had a significantly higher biomass than Amaranth, Alfalfa, and Switchgrass (Figure 56). The same was true at the Cottonwood site but Amaranth biomass was also higher than Alfalfa and Switchgrass. The Cottonwood Tef had the largest average biomass (307.3 ± 28.8 g) while the Cottonwood Switchgrass had the lowest average biomass (37.3 ± 5.6 g) across all fields. Both Tef and Amaranth biomass were significantly higher at the Cottonwood site than at the Valley Vista site while Switchgrass biomass was lower. Alfalfa biomass was similar in both fields.

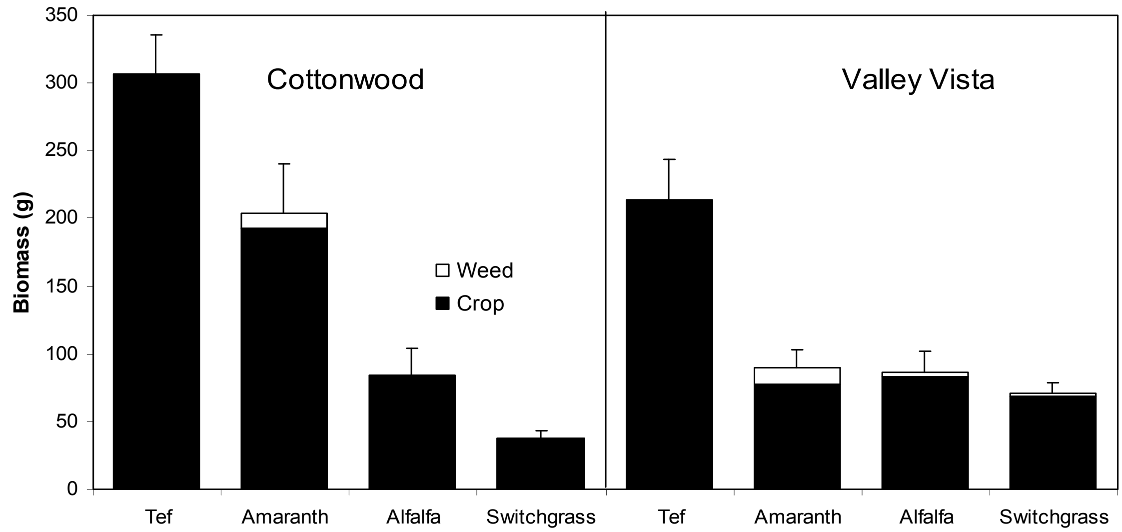

Figure 56. Average aboveground vegetation biomass at the Cottonwood and Valley Vista sites. Error bars represent standard errors (n=9).

Multiple Regression Analysis - Multiple regression analysis showed that the C respiration rate for these soils was positively affected by soil moisture (p=0.0177) and negatively affected by percent relative humidity (p=0.0329) when moisture, texture, air temperature, and relative humidity were included (Table 10). However, these two variables however explained only 20.8% of the observed variability in soil respiration. A regression of natural log transformed respiration rate data resulted in a slightly higher R^2 of 26.4%. When conducting a regression using data obtained at the end of the growing season, moisture (p<0.0001), vegetation biomass (p=0.0328), and soil temperature (p=0.0001) significantly affected the C respiration rate (R^2 = 64.2%) with soil temperature affecting the rate negatively when moisture, texture, biomass (vegetation and weed), percent N, percent C, and soil temperature were included. Regression of natural log transformed respiration rate data resulted in a slightly lower R^2 of 63.2%.

Two separate analyses were run for the soil CO_2 efflux. The first analysis (A) included parameters measured throughout the growing season and while the second analysis (B) included parameters that were only measured at the end of the growing season. Step-wise regression analyses were conducted on the N fluxes. Only the results from the regressions with the two highest R^2 values (C and D) are shown.

Multiple regression analysis revealed that there were no significant factors affecting the net change in total inorganic N (R^2 =41.2%) when moisture, texture, biomass (vegetation and weed), percent N, percent C, and soil temperature were included as main factors (Table 8). Moisture (p=0.0105), percent clay (p=0.0044), weed biomass (p=0.0262), and percent C (p=0.0028) significantly affected the net change in total inorganic N when all other factors were excluded (R^2 =36.9%) (Note: only these first two regression results are shown in the table). When percent clay, weed biomass, and percent N were included all three were significant factors (p=0.004, 0.0314, and 0.0127 respectively) but these variable only explained 27.5% of the observed variability.

Table 10. Linear multiple regression results of C and N fluxes against main factors.

Factor	Soil CO_2 efflux		ΔInorganic N		ΔNO_3		ΔNH_4	
	A	B	C	D	C	D	C	D
Moisture	*	***	ns	*	*	*	ns	ns
%Clay	ns	ns	ns	**	ns	-	ns	ns
%Silt	ns	ns	ns	-	ns	-	ns	-
%Sand	ns	ns	ns	-	ns	-	ns	-
Air Temp	ns	-	-	-	-	-	-	-
%RH	*	-	-	-	-	-	-	-
Crop biomass	-	*	ns	-	ns	*	ns	ns
Weed biomass	-	ns	ns	*	ns	-	***	***
%N	-	ns	ns	-	ns	-	ns	-
%C	-	ns	ns	**	ns	*	ns	ns
Soil Temp	-	***	ns	-	*	***	ns	*

* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$; ns = not significant; - = not included.

In this study, moisture was the most commonly important factor affecting the C and N fluxes in this study for both laboratory and field studies. Carbon and N fluxes showed differential response to moisture following one growing season most likely as a result of differences in the quality of C inputs following planting. In addition, microbial community structure may have changed in response to planting. The laboratory incubations showed that generally higher C fluxes were found in the Tef plots compared to the other vegetation types which may have been caused by differences in organic matter quality. Although aboveground Tef biomass yields were largest compared to other crops, no differences in soil C content were found. In addition, the higher yields for Tef did not translate into increased soil CO_2 efflux rates. Effects of vegetation on N fluxes were not consistent. Perhaps most surprisingly N fluxes in Alfalfa soils were not much different from Switchgrass and Amaranth, despite Alfalfa being an N fixing species. In addition, differences in initial C, N and inorganic N concentrations between Valley Vista and Cottonwood sites were not significant even though previous land use was dramatically different (vacant/grazing for Cottonwood and Alfalfa for Valley Vista). Post-planting differences in inorganic N between the two sites were obvious with the higher accumulation of inorganic N at the Valley Vista site. This difference may have been caused by the higher amount of irrigation received by the Valley Vista site, thereby stimulating N mineralization. Still, several factors were not studied that could explain differences found between fields. Future studies should include (1) root biomass measurements to allow for calculation of N uptake by vegetation, (2) organic matter fractionation to assess differences in organic matter quality as affected by inputs from different plant species, and (3) microbial assays to determine how microbial communities respond to differences in irrigation and vegetation type. Finally, the short duration of this study only allows for preliminary assessment of the effects of alternative crops on soils. Continuous planting for multiple years will most likely amplify effects of species in soils due to longer-term inputs of organic C from plants. This may have cascading response to microbial processes which, in turn will affect nutrient cycling in these systems.

Nitrate Removal in the Riparian Zone of the Walker River.

Groundwater surveys (Wilson, 2008) along denitrification transects indicated that groundwater flow was in the direction toward the Walker River and away from the direction of the nearby irrigation ditches (Figure 57). At the points where nitrate removal was measured, the groundwater surface was 1.2 to 1.8 m below the soil surface. When groundwater amended with labeled nitrate and a conservative tracer was injected into shallow wells and later extracted, there was substantial loss of nitrate compared to tracer levels (Table 11). These rates of nitrate loss were on the order of 10% per day. The nitrate removal rates in this study were on the same order, or higher, than in other riparian studies in which denitrification was measured. Nitrate removal rates were correlated to soil organic matter. Buried soil organic matter deposits provided the energy for nitrate removal, likely through denitrification, at depths up to 3 m below soil surface. N^{15}enrichment ratios in the nitrogen gas dissolved in the water suggested the presence of denitrification but low recovery of product gases prevented quantitative measurement of denitrification rate (Table 12). Nitrate removal rates in the Walker River riparian zone appear to be sufficient, even at some depth, to mitigate nitrate leaching.

The removal of nitrate flowing through the riparian zone of the Walker River depends not just on the rate of nitrate removal, but also on the residence time of groundwater flowing toward the river. Modeling of groundwater using MODFLOW showed that the residence time of water and nitrate removal rates are sufficient to remove nearly all nitrate from hypothetical ‘slugs” of water originating from the agricultural ditches and flowing through the riparian groundwater zone before entering the river. An example of the reduction in nitrate concentration in groundwater flow under a relatively high rate of flow is shown in Figure 58.

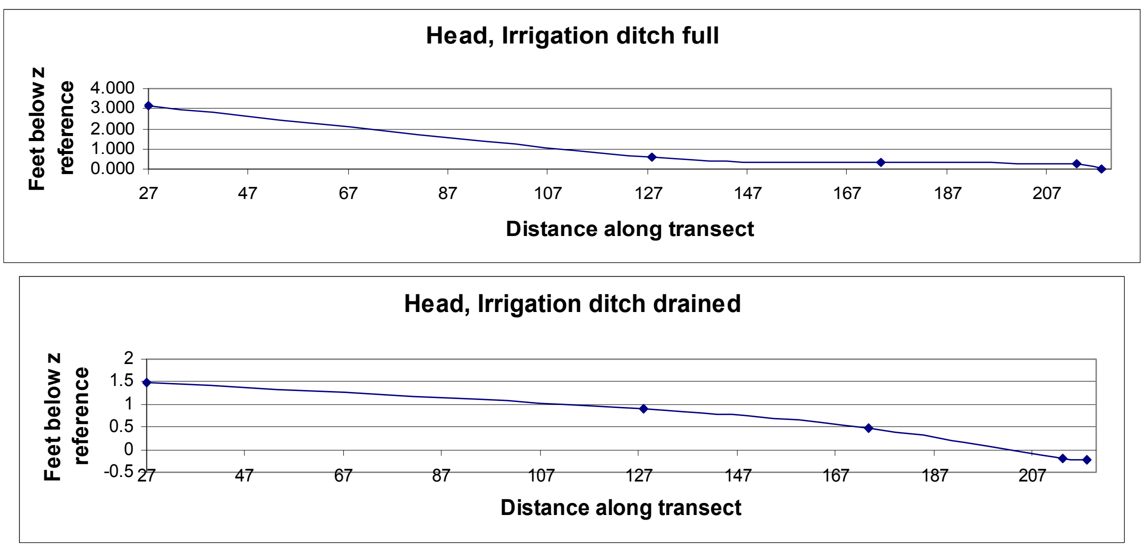

Figure 57. Observed heads in piezometers. Measured as feet below surveyed reference z. Ditch is left most point on x- axis, points in between are piezometers A2, A3, and A4, and the Walker River is the final data point on the right side.

Table 11. First order nitrate removal rates from in-situ push pull tests done in this study. PPT 5 denitrification rate was not calculated because injection recovery was too low. Values for first order denitrification rates result from fitting two points (initial nitrate concentration, and tracer corrected nitrate concentration at time t) on the nitrate vs. tracer recovery curves to the first order decay equation.

Push-Pull Test #	Distance from river (ft.)	Soil Texture	Injection depth (ft. below soil surf.)	Injection depth (ft. below water)	1st order nitate removal rate (d^-1)
1	43	sandy loam	8.1	1.9	-0.163
2	65	sand-clay	6.5	2.5	-0.072
3	8	sand	4.5	1.2	-0.136
4	190 (drain ditch)	sand	6.5	1.5	-0.085
5	101	course sand	11.2	5.2	*

Table 12. Maximum amounts of $^{15}N - N_2$ and $^{15}N - N_2O$ recovered and maximum enrichment ratios.

Push-Pull Test #	Maximum $^{15}N-N_2$ recovered (umol)	Maximum $^{15}N-N_2O$ recovered (umol)	Maximum ^{15}N enrichment ratio N_2	Maximum ^{15}N enrichment ratio N_2O
2	0.044	0.012	0.48	95.05
3	0.067	0.001	0.38	97.78
4	0.068	0.001	0.38	96.76
5	0.067	0.00001	0.37	61.56

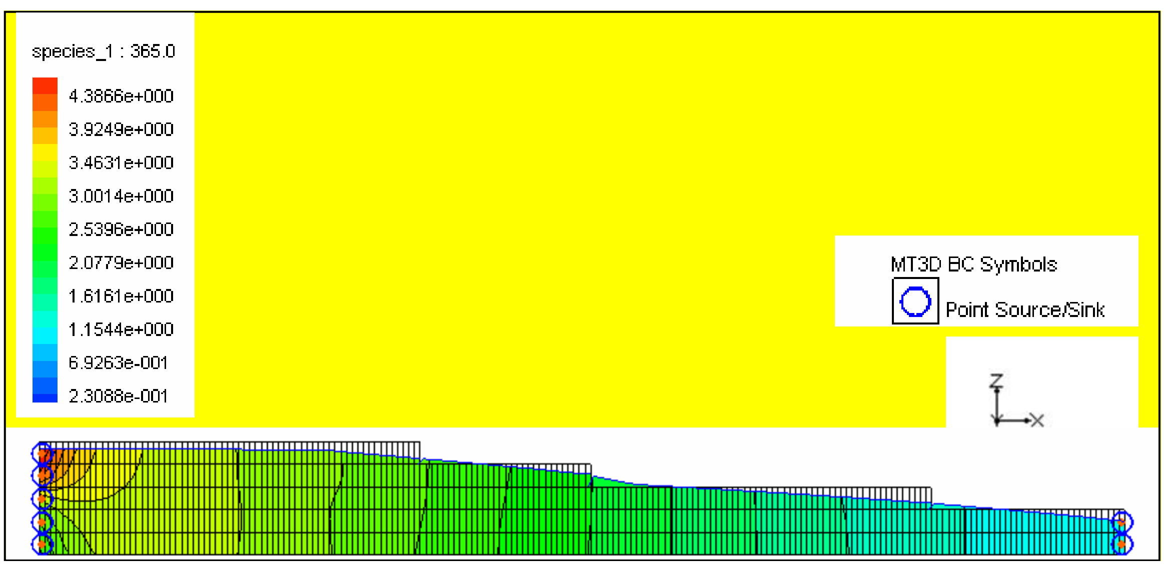

Figure 58. Modeled nitrate plume after 1 year under high gradient scenario with flow of nitrate. Units are in mg/L. Nitrate input at upper left cells corresponding to the drain ditch was set at 10 mg/L.

Effects of Altered Water Use on Invasive Species in the Walker River Riparian Zone

Based on the existing gradient of isotopic ratios found in the water from the soil profile, the ratio of ^{2}H to ^{1}H (δD) from water within the *L. latifolium* plants reflected the depth from which the water was taken up (Figure 59) (Dean, 2009). Water in the upper portion of the soil profile was more highly evaporated. At all three field sites *L. latifolium* used shallow water sources early in the growing season and deeper water sources later in the growing season. Use of water from deeper sources correlated with a decrease in moisture of shallow soils (Figure 60). Early in the growing season isotopic signatures of *L. latifolium* reflected the isotopic signatures of shallow soils (≤10 cm) whereas later in the growing season the isotopic signature of *L. latifolium* reflected the isotopic signatures of deeper soils (≥ 100 cm) and groundwater. In the field surveys done in this study it was found that *L. latifolium* has a deep root system that extracts water throughout the soil profile. Consequently, even late in the season, this invasive plant *L. latifolium* was consuming groundwater which may otherwise have contributed to late season flow in the river channel.

In competition experiments were carried out in barrels, soil matric water potentials were maintained at either -10 kPa, -600 kPa, or -600 kPa with a water table that was 1.1 m below the soil surface. *L. latifolium* was able to distribute its roots and utilize the artificially maintained water table to maintain high stomatal conductance rates throughout the growing season under drought conditions. In fact stomatal conductance rates of *L. latifolium* were very high (not shown), suggesting that it would be consuming water at high rates in the field even late in the season. However, the native grass that is the main native herbaceous species in the areas surveyed, *E. trachycaulus*, maintained most of its roots within the first 43 cm of the soil profile, had a low stomatal conductance rate under drought conditions and had limited access to the artificial water table. Despite these differences in response to water regime, there was no significant inhibitory competitive effect of *L. latifolium* on *E. trachycaulus* (Figures 61, 62, and 63). The presence of *L. latifolium* growing with *E. trachycaulus* in the mixed species treatment did not cause a statistically significant reduction in the biomass of *E. trachycaulus.* This lack of a negative competitive effect in the presence of *L. latifolium* may indicate its ability to persist in areas invaded by *L. latifolium* and that it may be useful in restoration of native riparian vegetation.

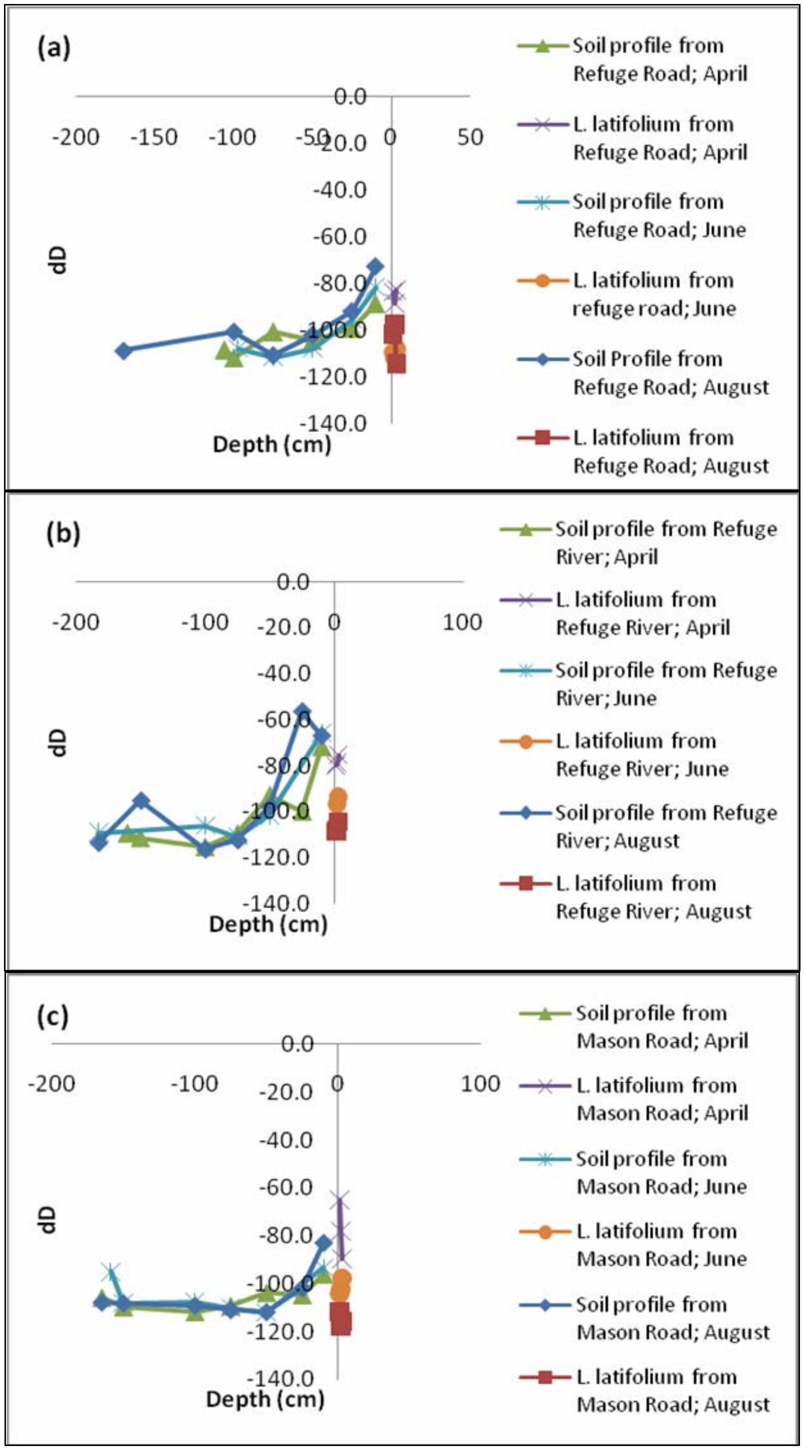

Figure 59. Isotopic signatures of water in *L. latifolium* and the corresponding soil profiles at various times throughout the growing season at a) Refuge Road Site b) Refuge River Site and c) Mason Road Site. The isotopic signature of water extracted from the roots is shown on the vertical axis and the signature of soil and groundwater is indicated as a function of depth. The correspondence between the isotopic signatures of the plant water and soil water indicates the depth at which it was taken up.

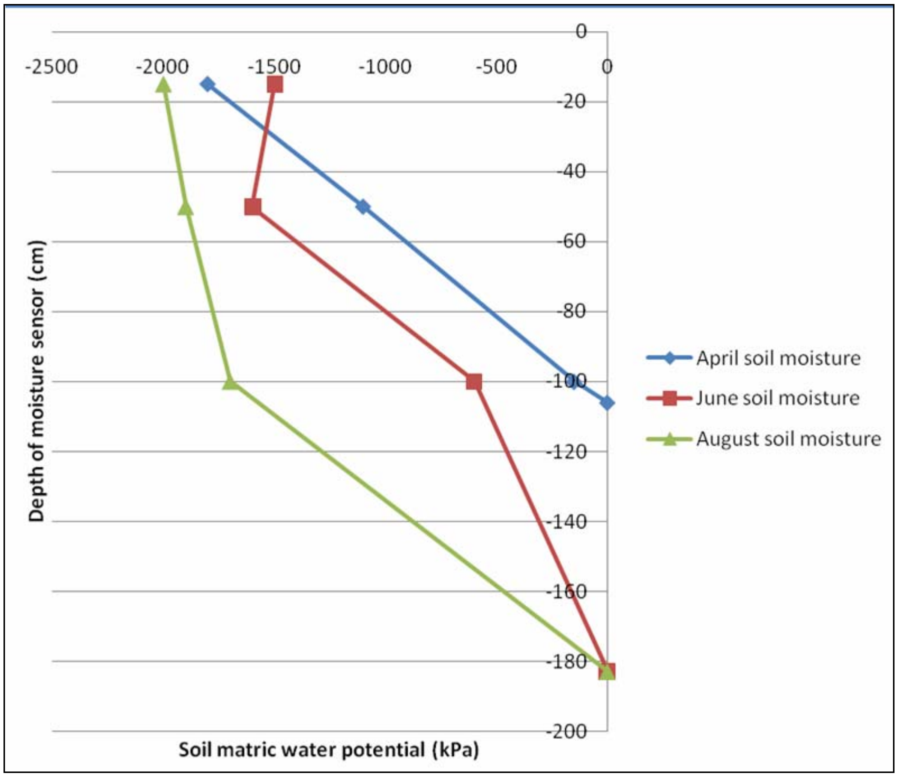

Figure 60. Field soil moisture (soil matric water potential) readings in kPa at different depths down to ground water at various times throughout the growing season in the plots in which *L. latifolium* was monitored. Points at 0 kPa represent the depth of groundwater (0 kPa by definition) at each period.

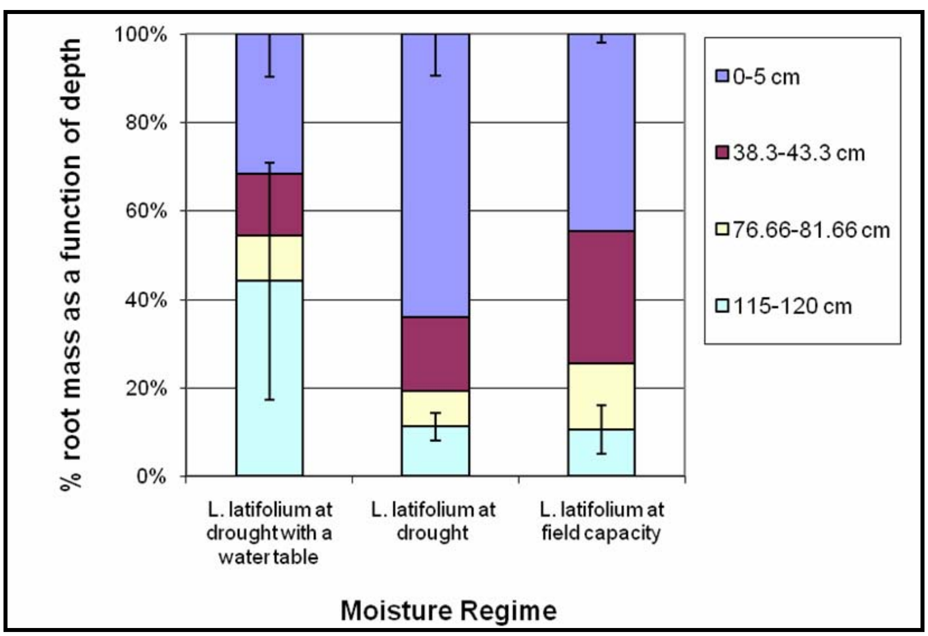

Figure 61. Distribution of below ground root biomass of *L. latifolium* in mixed species competition barrels at different moisture regimes expressed as a % of total of all depth increments.

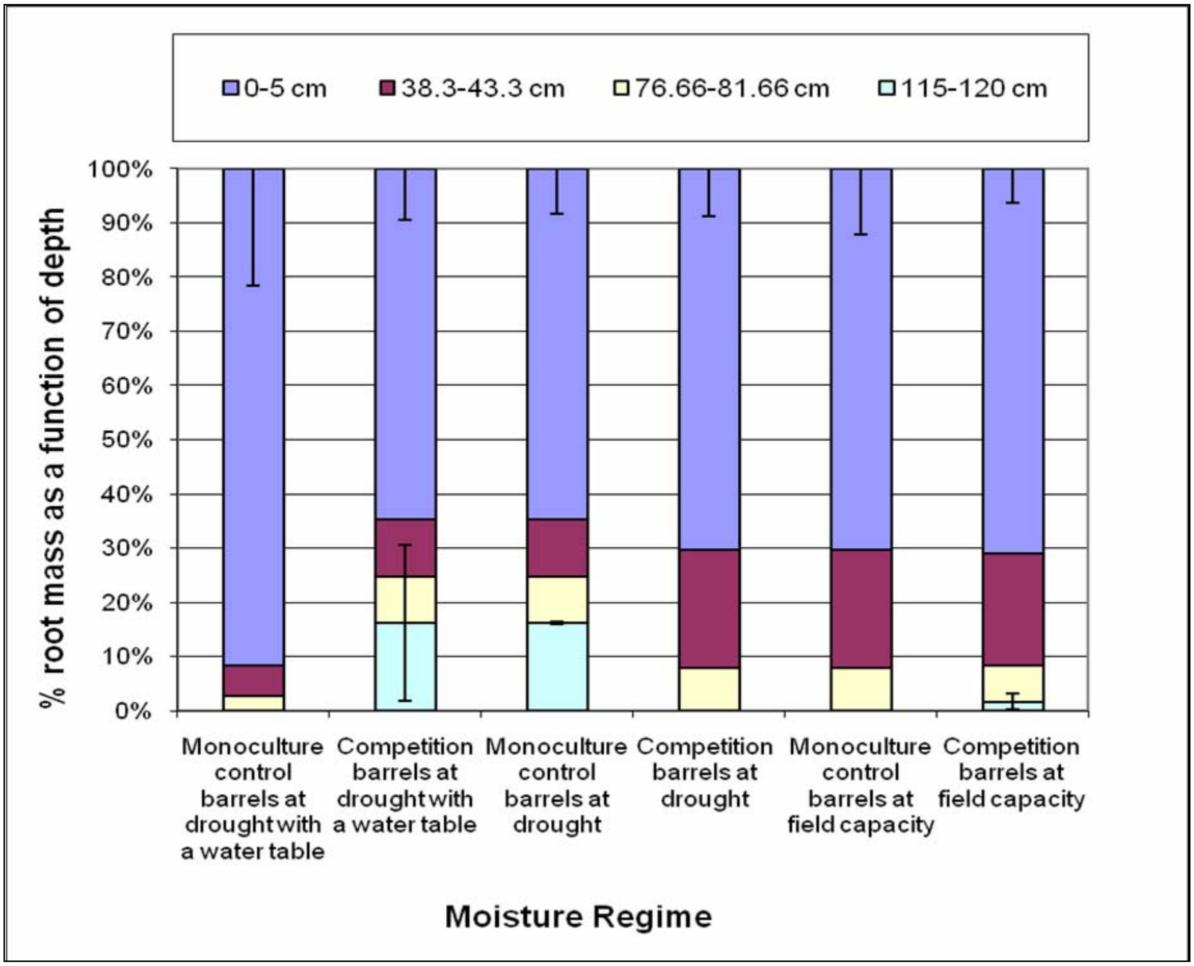

Figure 62. Distribution of below ground root biomass of *Elymus trachycaulus* (Slender wheatgrass) in monoculture control and mixed species competition barrels under different moisture regimes expressed as a % of total of all depth increments.

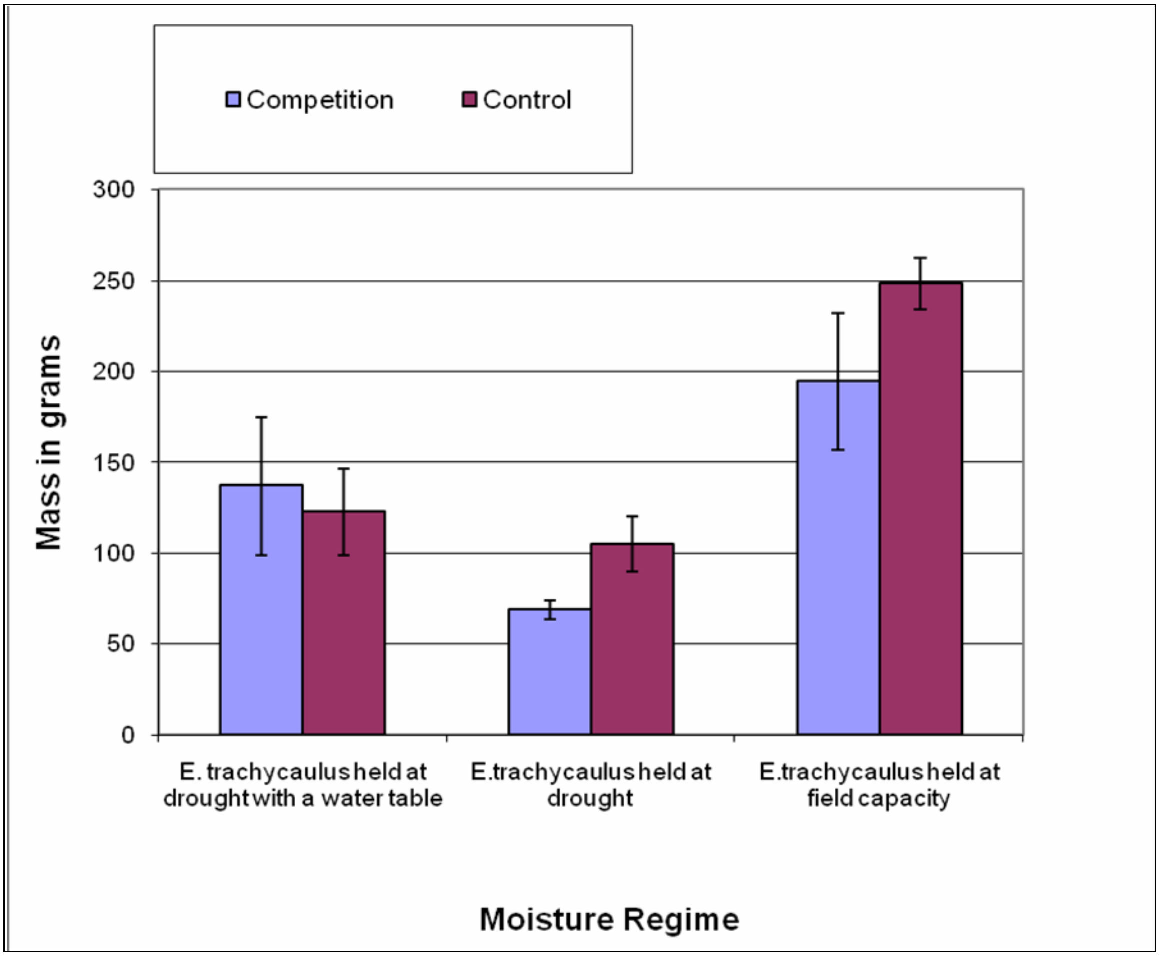

Figure 63. Above ground biomass of *E. trachycaulus* in monoculture control and mixed species (grown with *L. latifolium*) competition barrels at different moisture regimes.

This experiment confirmed that *L. latifolium*, because of its very deep root distribution, is capable of seeking-out and consuming groundwater throughout the growing season, even when surface soils are too dry to maintain water consumption by native grasses. In this way, this invasive herbaceous species resembles *Tamarix* species that have been implicated in undesirable consumption of riparian groundwater. Alteration of groundwater levels by decreases in irrigation in the Walker Basin is likely to have important influences in the spread of *L. latifolium*, throughout the riparian and ditch areas of the Walker Basin. Likewise, its spread could have a significant impact on in stream flow. However, the actual estimation of water consumption by *L. latifolium* in the segments of the Walker Basin would require scaling-up, using leaf area, plant density and evapotranspiration models.

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PROJECT C: PLANT, SOIL, AND WATER INTERACTIONS

LAND COVER CHANGE AND PLANT WATER USE IN AN AGRICULTURAL RIPARIAN LANDSCAPE

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Over the past 150 years, the Walker River riparian zone has experienced massive land cover conversion from native riparian vegetation to extensive agricultural landscapes characterized by irrigated pastures and alfalfa fields. Water withdrawals and diversions for agriculture have greatly reduced flows of water to the terminal lake, influencing aquatic ecosystem integrity. River regulation and reduced in-stream flows have altered riparian vegetation even in locations not devoted to agricultural use. In response to recent environmental concerns, purchase of water rights from agricultural producers is being considered. However, past abandonment of irrigated fields in the region has resulted in ecologically and economically undesirable effects, including surface soil erosion, salinization, and spread of invasive plant species. Careful orchestration is required for land use conversion to result in benefits for ecosystems and society.

Our research supports the potential for well-planned land use conversion by: (1) utilizing historical data to quantify historical land use/land cover change from the late 1800s to the present; (2) quantifying contemporary species-environment relationships for vegetation to characterize reference conditions for ecological restoration of irrigated agricultural fields; and (3) predictive modeling of the implications of historical and future land cover change for plant water use. These three tasks are supported by direct historical reconstruction of land use/land cover change, extensive mapping and mensurative vegetation sampling throughout the Basin, integration of detailed results from irrigation experiments, and development of spatial models that allow assessment of water use by vegetation given alternative land cover scenarios.

INTRODUCTION

Many riparian landscapes throughout the arid and semi-arid western United States have been dramatically transformed by irrigated agriculture. In our Walker Basin study area, the onset of irrigated agriculture occurred as early as 1861 when several of the early irrigation ditches were constructed in Mason Valley (Matheus 1995), and production of livestock feed is still the dominant land use throughout much of the riparian corridor at lower elevations with alfalfa hay accounting for 64% of the total crop area in Mason and Smith Valleys.

Although irrigated agriculture has proved essential for socioeconomic development and maintenance of a viable livestock industry in this semi-arid region, this land use practice has not been without environmental costs. Surface water diversions augmented by groundwater pumping have resulted in lowered water tables, reduced in-stream flows in the lower portions of the drainage, and lowered surface elevations in the terminal lake. Such changes have likely exerted substantial negative impacts on water quality, aquatic ecosystems, native vegetation communities, and ultimately on the sustainability of the agricultural industry itself as costs increase with reduced river flows and decreased groundwater levels.

Additional environmental costs are associated with invasion by exotic plant species, which is often facilitated by altered hydrologic regimes associated with agricultural land uses in riparian areas. In riparian ecosystems, exotic plant invasions have been linked to altered fluvial dynamics associated with dams and water diversions

(Nilsson and Berggren 2000; Richardson et al. 2007). Reductions in the magnitude of peak flows, and shifts in the timing of flooding, reduce availability of suitable microsites for establishment of native woody species and may benefit exotic species that are adapted to the modified flow regime, such as *Tamarix* species (Stromberg et al. 2007).

In the Walker River Basin, riparian areas have been heavily invaded by several weed species including *Tamarix ramosissima* Ledeb., *Elaeagnus angustifolia* L., *Lepidium latifolium* L., *Cirsium arvense* (L.) Scop., *Onopordum acanthium* L., *Acroptilon repens* (L.) DC., *Tribulus terrestris* L., *Cardaria draba* (L.) Desv., *Sonchus arvensis* L., *Cynoglossum officinale* L., *Cicuta maculata* L., and *Hydrilla verticillata* (L. f.) Royle. Efforts to restore Walker Basin riparian ecosystems through changing land use practices must consider the influence of exotic plant species. Furthermore, efforts to increase water flows to the terminal lake through changing agricultural practices should take into account the water use by exotic plant species, many of which are phreatophytes with high evapotranspiration rates (Glenn and Nagler 2005).

In response to recent environmental concerns, purchase of water rights from agricultural producers is being considered. However, past abandonment of irrigated fields in the region has resulted in ecologically and economically undesirable effects, including surface soil erosion, salinization, and spread of invasive plant species. Careful orchestration is required for land use conversion to result in benefits for ecosystems and society. In many situations, it will be viable to replace crop types requiring intensive irrigation with other, more water-efficient crop types. However, where planned land use changes involve the complete abandonment of agricultural practices, it is likely that active restoration and management will be required to produce the desired effects of water recovery to the terminal lake, improvement of water quality, and suitable habitat for fish and wildlife species.

An important component of ecological restoration is characterization of appropriate reference conditions (Richter and Richter 2000, Bainbridge 2007). In highly agricultural landscapes the need for historic reconstruction is especially important because the lack of contemporary reference areas that can be used for restoration. Reference conditions can be derived directly from reconstruction of historical conditions that predate intensive agriculture or other anthropogenic land uses, or can be interpreted from current species-environment relationships evident in natural areas. Our study used both a direct approach and predictive modeling approach to quantify ecologically based reference conditions for restoration of irrigated fields and riparian sites dominated by invasive plant species such as *Tamarix ramosissima*, *Elaeagnus angustifolia*, and *Lepidium latifolium*. The direct approach incorporated historical data, including General Land Office (GLO) surveys, archival maps and historical aerial photography, to reconstruct the vegetation present at a site before land-use conversion. In particular, the GLO surveys allowed us to identify precise boundaries of major vegetation community transitions and provided us with georeferenced data on the distribution of vegetation prior to and during the establishment of large-scale irrigated agriculture. GLO surveys contain both section line descriptions that can be analyzed as transect data for quantification of long-term land cover change (Andersen and Baker 2006), and witness tree data that can be analyzed as variable-radius plot sampling for quantifying changes in tree distribution, density, size class, and species composition over time (Bourdo 1956, He et al. 2000).

The predictive modeling approach used statistical models to identify major abiotic gradients that influence the current distribution of plant species and vegetation types, and to produce maps that predict potential vegetation distribution. Potential vegetation distribution was compared with current vegetation distribution, which was defined using a map photo-interpreted from 1-m true color NAIP orthophotography, combined with quantitative vegetation surveys stratified by map classes. Both map and field data were developed in collaboration with the U.S. Fish and Wildlife Service.

A primary goal of the overall Walker Basin project is to "explore the best means by which to get additional water to the lake while maintaining the Basin's economy and ecosystem" (http://www.nevada.edu/walker/about/index.html). In collaboration with Dr. Greg Pohll and his research group at DRI (TASK F) we have applied the newly developed Rip-ET modeling approach to compare with current groundwater modeling approaches, and improve estimates of basin-wide plant water use such that effects of riparian vegetation are more realistically incorporated.

Thus, our research approach spans historical, contemporary, and planned future time periods, and extrapolates known data and ecological relationships regarding vegetation, agricultural land use, and plant water use to the extent of the riparian area within the Walker Basin (Figure 1). We reconstructed historical land use/land cover change, developed statistical models of plant species distribution according to environmental gradients that can be used to define reference conditions, and used simulation modeling approaches to develop improved estimates of plant water use over basin-wide scales.

METHODS

Although the entire Walker River Basin was of interest to this project, certain tasks required different study areas with extents dictated by research questions and data needs. Modeling of species-environment relationships (i.e. vegetation modeling) was limited to the riparian areas of the Walker River Basin for which high-resolution LiDAR data were available. This encompassed most of the East and West Forks of the Walker River as well as the main stem and forms a swath up to 16 km in width. The reconstruction of historic vegetation task was concentrated in the agricultural and riparian areas of the Walker River Basin. Townships containing significant agricultural areas or that intersect the Walker River were included in this study. The ecological simulation models of plant water use were applied only to Mason and Smith Valleys because of the availability of monitoring wells of sufficient density for modeling.

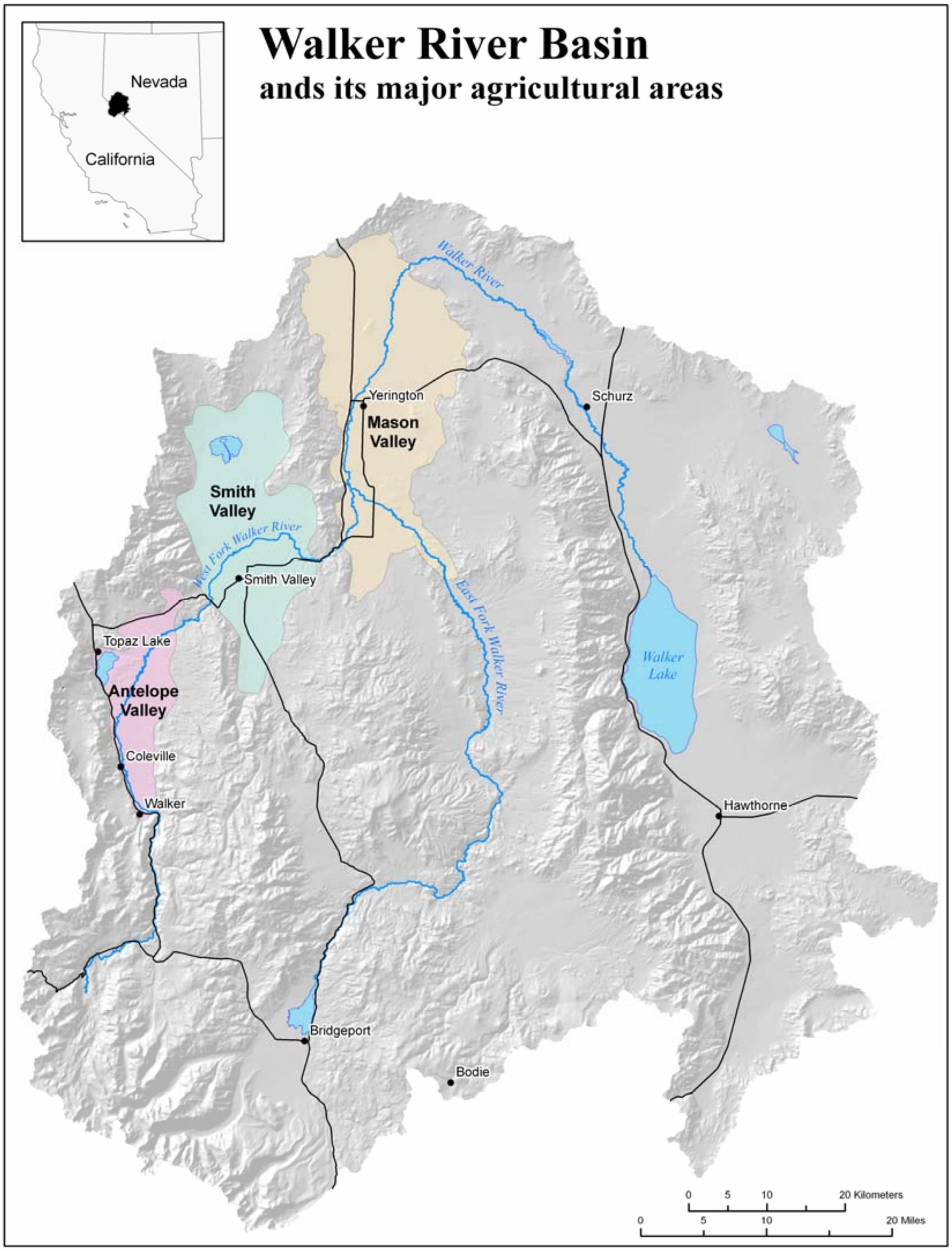

Figure 1. The Walker River Basin, showing its major agricultural and riparian areas.

Characterization of Reference Conditions and Historical Change

Our historical approach used numerous archival documents, including General Land Office survey notes, Bureau of Reclamation Service maps, and aerial photographs to characterize vegetation composition prior to and following the establishment of large-scale intensive agriculture in the Basin.

General Land Office surveys

General Land Office (GLO) survey notes were acquired from the Bureau of Land Management Nevada and California state offices. The earliest notes recorded were in 1857 while the latest notes were recorded in 1989. The majority of survey notes were recorded between 1859 and 1900 (Figure 2). Most surveys were implemented prior to the establishment of large-scale irrigated agriculture; however, small farms are evident in many of the notes.

The original survey methods were standardized with the 1855 publication of the first General Land Office Manual of Instructions, and were refined in subsequent manuals. Surveyors walked along section lines and recorded locational information about cultural features such as roads, fences, and buildings as well as natural features such as stream crossings, ravines, and transitions from one vegetation type to another. The survey notes also included the distance and bearing to witness trees at the beginning and end of each section line if trees were available to blaze. General descriptions were written about the vegetation of each survey line walked. Survey notes were then used to compile a plat map of the township.

The survey notes, originally provided on microfiche, were scanned, digitized and saved electronically in a geographic information system. Notes were interpreted from their original handwritten form and pertinent section line and witness tree data were entered manually into spreadsheet format. Survey notes from forty-six townships were included in the analysis with 15,767 segments totaling 6,396 kilometers. Vegetation descriptions varied from surveyor to surveyor; however, we classified all descriptions into one of nineteen categories, corresponding with categories used in the 2007 Walker River Vegetation Map. After classification the data were converted into ESRI shapefiles using the GLO Analyst extension for ArcView 3.3 (Andersen and Baker 2006).

Witness tree data were generated from the same survey notes as the section line data, and were entered into the GIS using the coordinates at the section line end point or midpoint. Coordinates were taken from the Bureau of Land Management's Geographic Coordinate Data Base. Witness tree attributes included distance from the section end or midpoint, the bearing from the end/midpoint to the tree, and the diameter of the tree. An overview of the GLO data for a small area is shown in Figure 3.

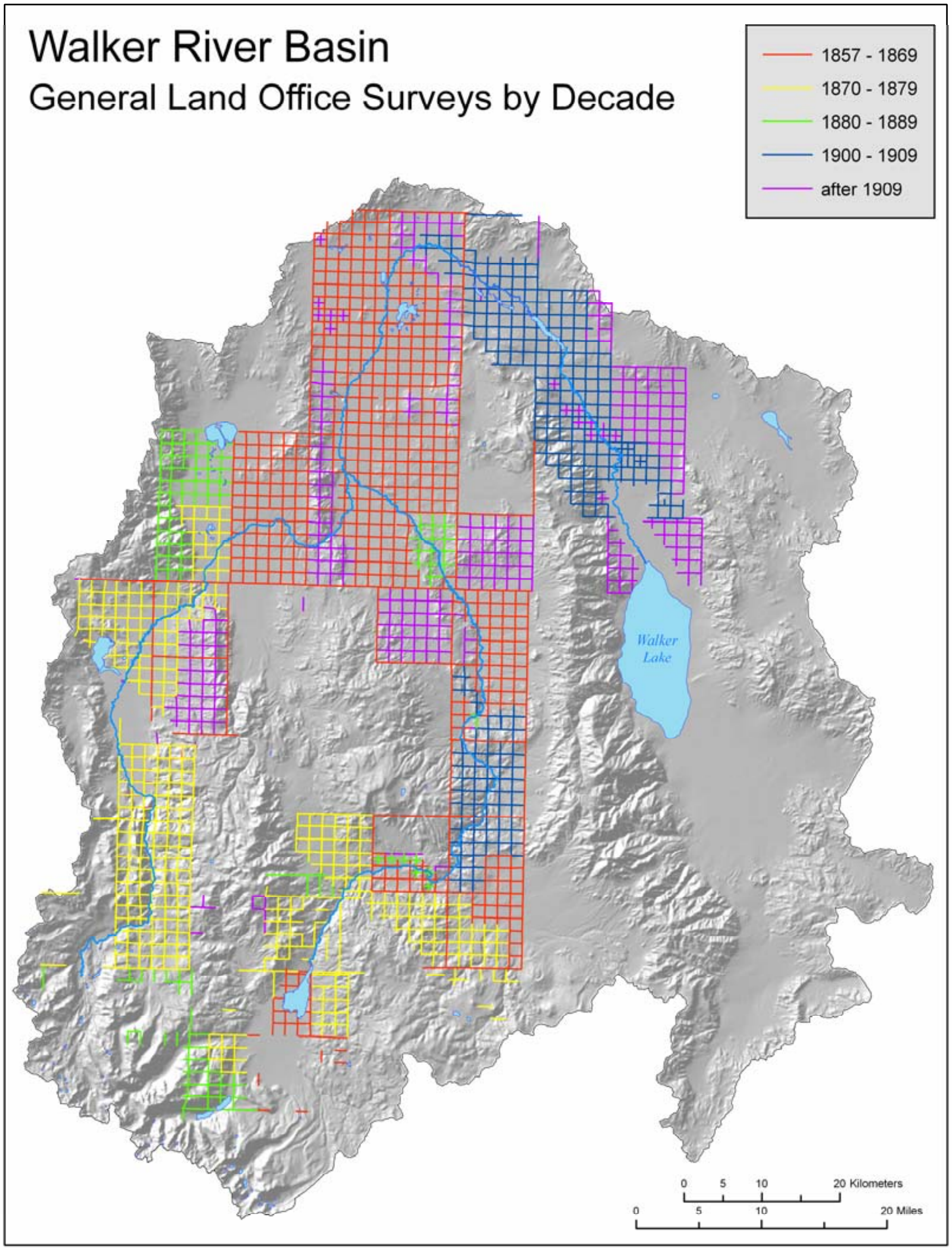

Figure 2. Earliest known General Land Office survey by decade for the Walker River Riparian/Agricultural areas.

Figure 3. Overview of data sources for a small area near Schurz. (a) GLO section line with two witness trees, overlaid on the 2007 vegetation map developed in collaboration with U.S. Fish and Wildlife Service. In 1904, agriculture existed where there is now an alkali shrubland (left) and there are now fields where there was once a cottonwood forest (right). The middle portion of the map shows cottonwood forest both today and formerly. (b)The corresponding portion of the 1-m, true-color NAIP orthophotograpy from which the vegetation map was derived. (c) The GLO survey plat map from 1904.

Particular research questions motivating our analysis of historical LULC change in the Walker Basin included:

1. What was the extent of riparian gallery forest along the Walker River prior to intensive agriculture use? Have cottonwood forests declined along the main stem as a result of changing hydrologic regimes, groundwater withdrawals, and land use conversion, as has been observed for other areas of the western U.S. (Fenner et al. 1985; Rood and Mahoney 1990)?
2. Has the relative dominance of woody vs. herbaceous vegetation types changed throughout the Walker Basin riparian corridor, in areas not directly converted to agricultural use? Are there indirect effects of irrigated agriculture on adjacent plant communities, perhaps due to water subsidies and reduced depth to groundwater?
3. Which types of natural communities have been preferentially converted to agricultural use? Following historical abandonment of agricultural land use, have plant communities reverted to their pre-agricultural vegetation type?
4. How does the probability of invasion by exotic phreatophytes such as *Tamarix ramosissima* and *Elaeagnus angustifolia* vary with plant community type or historical land use?

<u>Walker River service maps</u>

In 1905, the US Reclamation Service undertook a survey of the irrigable lands within the Walker River Basin. They produced detailed maps showing the extent of agriculture as well as the crop types, diversions, homesteads, and other features of interest. These maps have been digitized in order to assess changes that occurred immediately after the establishment of large scale irrigated agriculture in the basin.

Historical air photos

In order to assess vegetation change during the middle of the 20th century, aerial photographs were acquired from the US Geological Survey for the years of 1938 and 1952. The photos were georeferenced using ArcMap maintaining a root mean square error of less than 4 meters. Control points were selected as close as possible to the Walker River and a second order transformation was applied to the image. Images were then mosaicked together into tiles.

Analysis of historical conditions

Distribution of cottonwood forest

Historical and current cottonwood distributions were analyzed using both the GLO section corner witness tree data and the GLO section line data. GLO section corners were extracted for all townships in the Walker River Basin that intersected the Walker River. Section corners that were recorded after 1910 were not included in the analysis because most areas of the river had been settled by that point in time. To compare the presence and absence of cottonwood at the time of settlement with the current distribution of cottonwood we used a GIS to buffer each section corner by 100 and 200 meter buffers, and we manually examined aerial photographs to determine whether cottonwood were present or not. The maximum distance from a section corner to a witness tree that was recorded in the survey notes was approximately 200 meters. To generate a more conservative estimate we also used the 100 meter buffer. Images from the National Aerial Imagery Program (1 meter resolution) and an aerial photograph from Digital Globe (0.3048 meter resolution) were used in the analysis.

GLO section lines and the Walker River vegetation map were used to compare changes in the density and distribution of cottonwood patches between the time of early settlement (late 1800s) and 2007. A GIS was used to extract modern cottonwood patches using the Walker River vegetation map so that three states of cottonwood could be identified: 1) cottonwood patches that were present at the time of settlement and are present now, 2) areas of cottonwood that were present at settlement and are no longer cottonwood, and 3) areas of cottonwood that are present today but were not present at the time of settlement.

Conversion of natural communities to agriculture

We created a dataset that showed the distribution of agriculture for the entire Walker River Basin at three time periods: 1857 to 1899, 1905, and 2007. Polygons were digitized from the GLO survey maps to provide a dataset of settlement-era agriculture. The Bureau of Reclamation Walker River Service Maps were used as the data source for the 1905 map. The modern dataset was provided to us by Tim Minor at Desert Research Institute and covered Smith and Mason Valleys as well as areas along the East Fork of the Walker River. To provide a consistent map covering all areas of the basin we digitized additional polygons in Antelope Valley and in the Walker River Paiute Reservation. The GLO section line GIS layer was intersected with the polygons to generate a transition matrix showing the vegetation types that were converted to agriculture.

Changes in the distribution of non-agricultural plant communities

We compared changes in dominance and distribution of non-agricultural vegetation types using GLO section lines and the Walker River vegetation map. The GLO section line GIS layer was overlaid on the Walker River vegetation map and section lines were attributed with both historic and modern vegetation types. The Walker River vegetation map identified 19 major vegetation classes while the GLO data could only discern nine vegetation classes; therefore modern vegetation classes were cross-walked to match the coarser thematic resolution of the GLO data. Changes in vegetation type were assessed using a transition matrix, and areas where major changes occurred were distinguished and used for subsequent analyses of the spatial distribution of vegetation change in the Basin.

Predictive Modeling of Vegetation-Environment Relationships

The predictive modeling approach used detailed field inventory data to model the relationship between species composition and abiotic gradients. A combination of ordination techniques, generalized regression models, and other analyses (reviewed in Guisan and Zimmermann 2000) was used to predict the distribution of plant species according to environmental variables for which we have extensive spatial databases.

<u>Geodatabase development</u>

We identified a set of environmental gradients that are expected to affect spatial distribution of Walker Basin riparian vegetation at a landscape scale and developed a geodatabase to assemble these environmental gradients in GIS formats (summarized in Table 1). Because of the linear nature of riparian corridors, these variables can be classified as either transverse (i.e., lateral) or longitudinal types according to the direction of the pathway along which the corresponding environmental processes affect vegetation distribution (Bendix 1994, Wiens 2002). For example, depth to the groundwater and inundation frequency are transverse variables that vary considerably within a given cross section perpendicular to the river channel, while temperature and precipitation are longitudinal variables that are generally invariant within a cross section but vary along the entire course of a river. In general, variations of transverse variables are measured at fine scales (e.g. meters) whereas variations of longitudinal variables are measured at broad scales (e.g. kilometers). Soil variables were derived from the Natural Resource Conservation Services' SSURGO database. Annual, maximum, and minimum precipitation and temperature datasets were downloaded from the PRISM group website. LiDAR data was flown in late September of 2006 by Fugro Horizons, Inc. and was provided to us as a digital elevation model. To derive variables that could be used as proxies for groundwater and flooding we created custom models in ArcGIS Model Builder to generate proxies for height above river (HAR) and flood height (FH). These models have been made publicly available for download at url: http://www.cabnr.unr.edu/weisberg/downloads/ and at the ESRI ArcScripts site. Height above river was calculated as the difference between the elevation at a particular location (raster cell) and the weighted average of the elevation of cells designated as river segments. The height above river variable is analogous to the elevation of a particular cell minus river base flow. Flood height was calculated by discretizing the height above river data into centimeter increments and using a *costdistance* function to identify all cells below each centimeter height above river that are physically-connected to the river channel.

Vegetation mapping

Current vegetation distribution and structure were quantified in three different ways: (1) vegetation mapping (from aerial photography), conducted primarily by the U.S. Fish and Wildlife Service (USFWS), with accuracy assessment conducted as a collaborative effort between USFWS and our research group at UNR; (2) sampling of understory plant community composition (herbaceous and shrub layers), implemented collaboratively between USFWS and UNR; and (3) sampling of overstory tree canopy structure, implemented collaboratively between our research group at UNR and Dr. Will Richardson, working with Dr. Dennis Murphy at UNR.

Table 1. List of environmental gradients assembled in the geodatabase

Scale of the variable	Abbreviation	Variable
Longitudinal		
	TMIN	Average annual minimum temperature (°C)
	TMAX	Average annual maximum temperature (°C)
	PRECIP	Annual precipitation (cm)
	PPT01	Average January precipitation (cm)
	PPT07	Average July precipitation (cm)
	TMIN01	Minimum January temperature (°C)
	TMAX07	Maximum July temperature (°C)
	PRICIRSD	Residual of precipitation against elevation (cm): an indicator of rain shadow effect
	ELEV	Elevation: 10 m resolution (m)
Transverse		
	D2RV	Distance to the Walker River (m)
	HAR	Height above river channel (m)
	FH	Flood height (m)
	SLOPE	Slope (°)
	SWNESS	Cosine(aspect – 225°) (Franklin et al. 2000)
	AWS	Available water storage for the soil to a depth of 1m (cm)
	PH	Soil pH
	CEC	Soil cation exchange capacity
	DRAINAGE	Natural drainage conditions of the soil: ordinal variable ranges from 1 to 5 with higher values indicating more well drained
	TPI	Topographic position index
	TCI	Topographic convergence index: a type of soil wetness index (Wolock and McCabe 1995)

The vegetation mapping effort was implemented during the summer and autumn of 2007. Mapping was implemented through photo-interpretation, by manually digitizing polygons from the National Agriculture Inventory Program imagery at 1:2,000 scale. A total of 19 vegetation classes was mapped, including 8 classes that are not generally considered riparian but were included in the map because of their proximity to the Walker River (Table 2).

Table 2. Area of each mapped vegetation class, developed in collaboration with the U.S. Fish and Wildlife Service. Vegetation classes marked by an asterisk are not true riparian vegetation types. Note that this is a preliminary vegetation type classification, subject to further modification.

Vegetation Type	Hectares	Percent of Total Area Mapped
Early Successional Riparian	287	0.65
High Density Riparian Shrub	2,307	5.19
Low Density Riparian Shrub	324	0.73
Mature Cottonwood w/ Xeric Understory	487	1.09
Mature Cottonwood w/ Riparian Shrub	445	1.00
Wet Meadow	647	1.46
Emergent Marsh/Wetland	526	1.18
Alkali Meadow	728	1.64
Alkali Shrub	2,833	6.37
Big Sagebrush*	7,284	16.38
Big Sagebrush w/ high Bitterbrush*	368	0.83
Big Sagebrush w/ high Rabbitbrush*	61	0.14
Silver Sagebrush	16	0.04
Pinyon-Juniper Woodland*	2,752	6.19
Jeffery Pine Forest*	1,093	2.46
Xeric Shrub*	10,117	22.76
Playa*	142	0.32
Tamarisk	1,093	2.46
Agricultural and Developed Land*	12,950	29.13
TOTAL ACREAGE MAPPED	44,459	

<u>Accuracy assessment of vegetation map</u>

Stratified random sampling was used in a GIS environment to generate 449 random points within each of the nineteen classes. Visual analysis of the distribution of sample points indicated that the points tended to be well distributed throughout the range of their respective classes in terms of abiotic predictor variables.

Map accuracy was assessed through a combination of field visits and comparison with other, high-precision maps. Validation points were overlaid with a digitized irrigated crop map produced by the Desert Research Institute. Points that did not fall in irrigated fields were visited in the field. The Walker River Basin contains land under a variety of different ownership categories. Within the riparian corridor of the Walker River public lands account for 41.1% of total the total area while private lands account for 39.0%, and tribal lands for 19.9%. Typically, access to private lands was very limited and, in many instances, not feasible within the time frame of this project. Therefore, due to primarily to access limitations, sampling was only conducted on 291 out of 449 potential sites.

Field visitation was implemented by navigating to the correct point location using a Garmin GPS. Once at the location the map accuracy was assessed within a 17.84 meter radius of the point (equivalent to 0.1 hectares). The following information was recorded at each site: whether the point was accurately mapped, what the correct vegetation class should have been, ocular estimates of cover by genus or functional types, general notes about the site, and photographs of the site.

The resulting data were entered into an error matrix from which agreement and kappa statistics were calculated. The kappa statistic has the advantage of accounting for unevenness in the number of samples in different classes, because it compares actual agreement with chance agreement (Congalton and Green 1999).

LiDAR analysis of vegetation structure

The Walker River was flown in November of 2006 and light detection and ranging (LiDAR) data were collected along the river corridor above Wabuska. LiDAR data were assessed for quality and processed to remove anomalous data by Wes Newton of the US Geological Survey and were provided in the form of digital elevation models. Work is ongoing to create canopy surface models and to derive estimates of canopy cover, canopy height, and biomass estimates in a spatially-explicit manner. Digital elevation models derived from the LiDAR data were the primary data source for the species-environment relationship modeling because they provide very high resolution information on surface topography and morphology. Canopy cover data derived from LiDAR will be merged with the Walker River Vegetation Map to provide accurate cover estimates for each plant structural class within polygons. LiDAR is also being used for single tree delineation of cottonwood trees and is being compared to the witness tree data to estimate how the extent of gallery cottonwood forests has changed since the late 19^{th} century.

Plant community sampling

A total of 168 sample sites was located using a random stratified sampling of vegetation types, classified according to soil type, landscape position relative to the river and species composition. Field sampling followed the point intercept procedures of Forbis *et al.* (2007). All vascular plants encountered during the field survey were identified to the lowest taxonomic level possible. Wetland plant species were subsequently classified within one of five national wetland indicator categories, each of which represents a probability of occurrence in wetlands (Reed 1988).

Plant community classification and species-environment modeling

Classification of species into major community types in the 168 plots was performed with the TWINSPAN (two-way indicator species analysis) procedure (Hill 1979) using the program PC-ORD. This procedure was used with the cut-off levels of 0, 2, 5, 10, 15, 20, 30, and 40% to translate species abundance into presence/absence of pseudo-species. After major community types were constructed, Indicator Species Analysis (ISA) was then used to assign species to the community type for which they had the highest indicator value (Dufrene and Legendre 1997). The indicator value is the product of species relative abundance and species relative frequency. Relative abundance, a measure of specificity, was calculated as the total coverage of a species in a given community type divided by total coverage over all types. Relative frequency, a measure of fidelity, is the percentage of sites in which a species was present for a given community type. The indicator value is maximized when all individuals of a species are found in a single group of sites and when the species is observed in all sites of that group.

We used Detrended Correspondence Analysis (DCA, Hill and Gauch 1980) to examine the major vegetation gradients in the specie-level sampling data. Graphic examination, correlation statistics, and regression analysis were then used to assess the importance of environmental variables in determining the major DCA axes. In the resulting ordination diagram, selected important environmental variables were depicted as vectors.

Dynamic Simulation Modeling of Groundwater and Plant Water Use

Although the project has ended we are continuing to develop linked models of land use/land cover (LULC) change with models of evapotranspiration and groundwater dynamics (Figure 4), to quantify the effects of changing agricultural practices on plant water use at the watershed scale. During the timeframe of the project, we have applied the RIP-ET package to improve plant water use estimation, and have developed a modeling system for dynamic linkage of vegetation and water use models. In future efforts, we will use MODFLOW to model groundwater flow alteration due to LULC change. The cascading effect of groundwater change on vegetation distribution will be examined by a vegetation/groundwater model. We will then use RIP-ET to examine the reciprocal interaction between vegetation change and groundwater depth through ET. We are collaborating with Greg Pohll on this effort, and making use of groundwater models for Mason and Smith Valleys that his group has already developed. Results will allow us to place water savings from changing agricultural and LULC practices in the context of a basin-level water budget, as well as to gauge the overall effects of irrigated agriculture on vegetation water use relative to pre-settlement conditions.

Groundwater model

Groundwater flow was simulated using MODFLOW-2000 (Harbaugh et al. 2000). MODFLOW is a well-documented and widely applied FORTRAN code (Anderson and Woessner 1992) that uses difference equation methods to numerically solve a set of differential equations governing the flow of groundwater. For our simulation of groundwater in the Mason Valley, the model domain was one unconfined layer in thickness. It contained 90,790 blocks or nodes. Block spacing were 100 m, with each node representing 1 ha area. Simulations were run with the Layer-Property Flow (LPF) package, Recharge (RCH) package, Well (WEL) package, Drain (DRN) package, and a newly developed Riparian Evapotranspiration (RIP-ET) package, described in the next section.

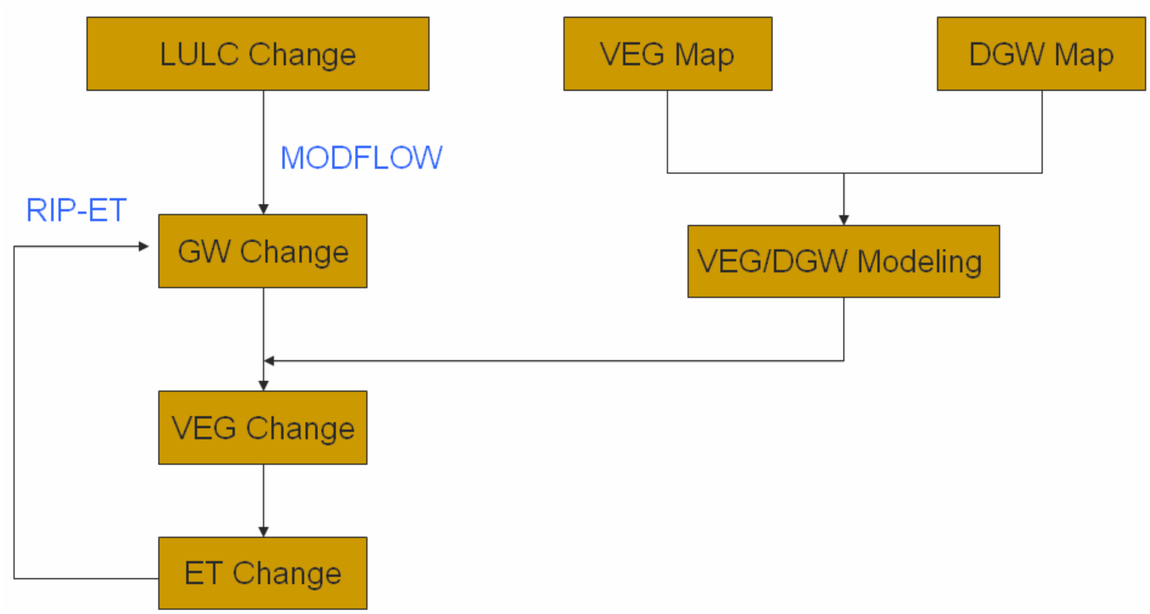

Figure 4. Modeling of the interaction between land use land cover change, groundwater, vegetation and evapotranspiration.

Simulating riparian evapotranspiration

We used the RIP-ET package (Baird et al. 2005) to link dynamics of riparian vegetation and groundwater. RIP-ET improves on the traditional groundwater models such as MODFLOW by providing a more realistic representation of evapotranspiration from riparian systems. Traditional approaches for modeling ET are based on a single, quasi-linear relationship between ET flux rate and hydraulic head (groundwater depth), which lacks consideration of ET differences among different riparian plant species. RIP-ET uses multiple, non-linear flux curves that reflect species-specific ecophysiological characteristics. Our simulation included six plant functional subgroups (PFSG) based on rooting depth and plant size. These are obligate wetland plants, shallow-rooted riparian, large-size deep-rooted riparian, medium-size deep-rooted riparian, small-sized transitional (upland) plants, and bare soil/water. The ET flux curve of each PFSG is derived from Baird and Maddock (2005). Because MODFLOW cells are generally large (1 ha in our study), some cells are likely to comprise a mixture of plant functional subgroups. In order to handle this problem, RIP-ET allows for fractional coverage of multiple PFSGs within a cell. For our simulation, the fractional coverage was computed from USFWS Walker River Corridor vegetation map and vegetation height and canopy coverage data derived from LiDAR.

Vegetation modeling at the community level

We have developed a steady-state (statistical) vegetation model to examine the potential effects of changing water tables on the composition and distribution of Walker River riparian vegetation. We used field vegetation data and spatial covariates to develop an empirical relationship between riparian plants community and environmental gradients associated with groundwater availability, flooding potential, and climate. We developed four random forest models for modeling 1) plant communities at a fine level of classification, 2) plant communities at a coarse level of classification, 3) riparian plant communities only, and 4) adjacent upland communities only.

PRELIMINARY RESULTS AND DISCUSSION

Validation of Modern-day Vegetation Map

Access limitations had the effect of limiting sampling on certain portions of the river, as well as within certain vegetation classes. In general, areas of the river corridor with a larger proportion of public or tribal lands had greater sampling intensity compared to those with more private lands. Table 3 shows the number of sites validated according to land ownership category. Access limitations also had the effect of limiting sampling on certain portions of the river, as well as within certain vegetation classes. In general, areas of the river corridor with a larger proportion of public or tribal lands had greater sampling intensity compared to those with more private lands. Table 4 shows the number of sites validated within six general sections of the Walker River.

Table 3. Number of sites validated by land owner type.

Land owner	Sites validated	Total sites	Percent validated
Public	190	216	88.0
Tribal	74	121	61.1
Private	27	112	24.1

Table 4. Number of sites validated by river section.

River section	Sites validated	Total sites	Percent validated
Lower river (below Wabuska)	86	143	60.1
Mason Valley	50	88	56.8
Smith Valley	3	20	15
Antelope Valley	14	28	50
West Walker River	72	78	92.3
East Walker River	70	91	76.9

Access limitations also led to uneven sampling among different vegetation types. Vegetation types that had the highest representation included Jeffrey pine, emergent wetland/marsh, and big sagebrush with bitterbrush. Mature cottonwood classes and tamarisk were least represented by the sampling effort. The number of samples from each class ranged from six (mature cottonwood with a riparian shrub understory) to 24 (Jeffrey pine).

Overall map accuracy was 79% with 230 out of 291 samples correctly classified. However, both producer's accuracy (1 – error of omission) and consumer's accuracy (1 – error of commission) differed among the vegetation types (Figure 5). Only tamarisk had 100% producer's and consumer's accuracy. Producer's accuracy ranged from a low of 41% (high density riparian shrub) to 100% (emergent riparian, playa, tamarisk, sagebrush/rabbitbrush, and sagebrush/bitterbrush). Consumer's accuracy ranged from 47% (sagebrush/rabbitbrush) to 100% (tamarisk, pinyon juniper woodlands, cottonwood with a riaparian shrub understory, and emergent marsh/wetland). Average producer's accuracy was 83.48% while average consumer's accuracy was 79% when all classes are weighted equally. The overall kappa value was 78%.

Overall accuracy of the map was good, but not remarkable. At 79% the value is slightly below the 85% threshold that is frequently used to as a cutoff between acceptable and unacceptable results (Congalton and Green 1999). However, the distribution of error among vegetation classes is not uniform, and some classes were classified correctly at high rates of accuracy. Certainly, many classes have distinctive spectral and/or textural properties that would have made them easier to identify from imagery. One example of a class that was mapped with a high degree of accuracy was tamarisk. Along the lower stretch of the Walker River it has invaded and out-competed native shrubs such as willow to form dense thickets. The surrounding vegetation is primarily xeric shrub and there isvery little overstory to obscure tamarisk. Therefore, spectrally and texturally tamarisk is very different than its neighbors, and it tends to be relatively easy to delineate patches. Issues with misclassification may arise due to inability to distinguish between classes with similar spectral properties (agriculture versus wet meadow), dense canopy cover that obscures the understory (cottonwood with riparian shrub understory versus xeric shrub understory), or successional state (abandoned agriculture versus big sagebrush/high rabbitbrush).

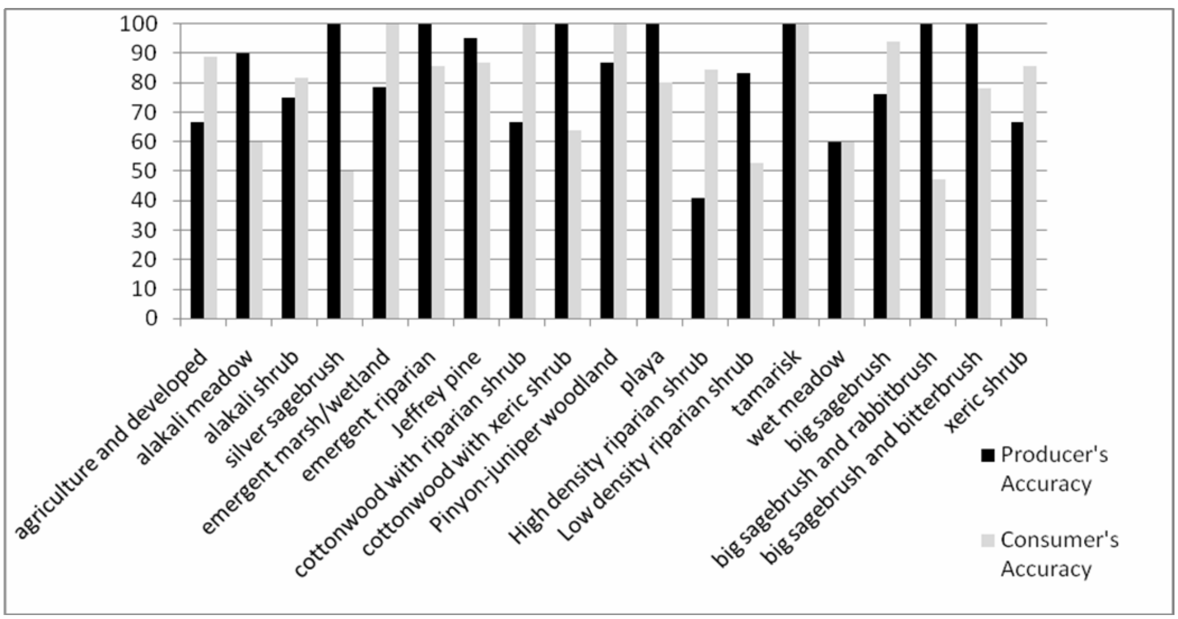

Figure 5. Producer's and consumer's accuracy for each vegetation class.

Characterization of Reference Conditions and Historical Change

Historical conditions: Cottonwood distribution

Analyses of the witness tree data from 1857 to 1910 showed a noticeable lack of gallery riparian forest across most of the Walker Basin (Figs. 6 & 7). Of 431 section corners only 16 had cottonwood trees present, and seven of these section corners were restricted to the lower river near present-day Schurz. Four corners contained cottonwood in Mason Valley. Along the West Fork there were four corners where cottonwood was present, while the East Fork only had one corner with cottonwood. Cottonwood presence at the time of settlement was limited to only 0.46% of section corners included in this study. The modern distribution of cottonwood, on the other hand, was widespread throughout most of the riparian areas of the basin and was present at 12% of section corners using the 200 meter buffer. Using the more conservative 100 meter buffer cottonwood trees were present at 9% of section corners. These estimates indicate that cottonwood trees today are likely 19 to 26 times more widespread than at the time of settlement.

The GLO section line data show a similar trend in increased cottonwood abundance throughout the basin. Of 34,071 meters of section line 23,938 (70.3%) had gained cottonwood while only 6,221 meters (18.3%) had lost cottonwood. Line segments with no change in cottonwood totaled 3,911 meters or 11.5% of the total. In contrast, areas where cottonwood had existed at the time of settlement showed decline in the total amount of cottonwood. The area below present-day Weber Reservoir where cottonwood existed prior to Euro-American settlement showed a loss of 3,514 meters or 56.1% of the historic length. Furthermore, the number of individual line segments increased from 29 at the time of settlement to 46 while the average length of the line segments decreased from 216 meters to 60 meters. The transition matrix of vegetation change from early settlement to the present-day along GLO section lines (Table 5) show that roughly equal proportions of settlement-era cottonwood segments had converted to upland shrub and agriculture (21.6% and 20.1%, respectively) with the remaining changes accounting for 20.7% of the total.

Across the western United States, gallery cottonwood forests along river systems have been in steep decline due to a lack of recruitment caused by river regulation (Rood and Mahoney 1990; Rood et al. 2005; Braatne et al. 2007). The relative lack of cottonwood along the Walker River at the time of settlement is surprising given the historical presence of large cottonwood groves on the nearby Carson and Truckee Rivers by John C. Fremont in his journals about his expedition in 1844. Analyses of aerial photographs taken in the 1930s and the 1970s showed large declines in cottonwood extent and canopy closure on the Truckee River due to a lack of recruitment from low flows (Lang et al. 1990; Rood et al. 2003). The Walker River, which is similar to the Truckee River climatologically and geographically, has been characterized by many of the same types of disturbances, such as diversions for agriculture, dam construction, channel straightening, and wetland drainage. Given its close proximity to the Carson and Truckee Rivers, similar geographic characteristics, and similar pattern of river regulation one might expect pre-settlement vegetation patterns on the Walker River to be similar to neighboring rivers. The lack of trees in Mason Valley was noted by author Samuel Post Davis in his 1913 book the History of Nevada in which he stated “There were no trees except a few in the southern part of the valley.”

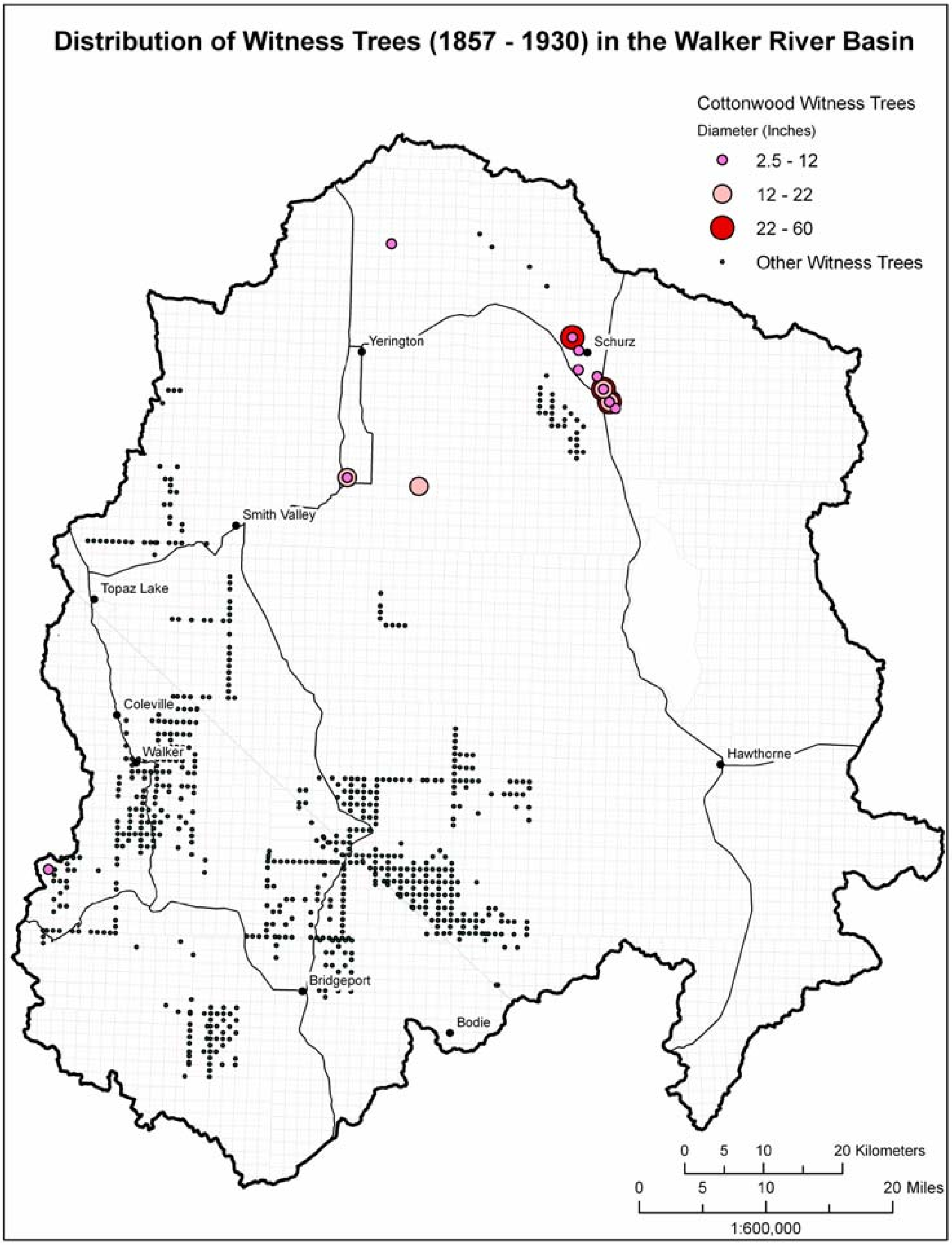

Figure 6. Distribution of witness trees from GLO surveys (1857 – 1930) in the Walker River Basin. Cottonwood trees are shown in color, with increasing symbol size reflecting increasing tree diameter.

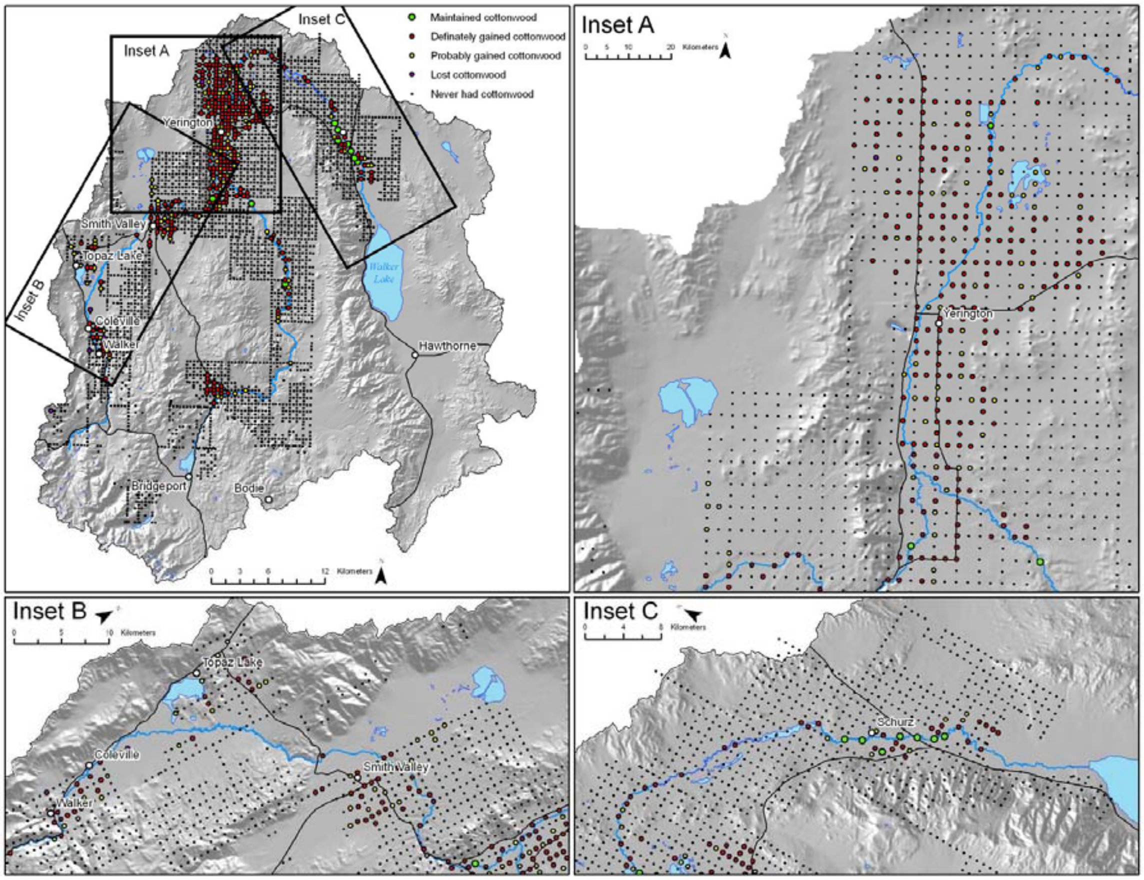

Figure 7. Presence-absence of cottonwood at 3,454 witness tree observation in the Walker River Basin, identifying sites that have changed with respect to occurrence of cottonwood over the period of study.

After Euro-American settlement, cottonwood expansion in the Walker River Basin was probably rapid. Valued for shade, they were planted near homes and along roadways. The construction of a ditch network in Mason Valley during the 1860s brought water and suitable regeneration surfaces to new areas. Early ditches required long hours of manual labor to keep them clear of debris (Young and Sparks 2002) which may have resulted in continuous deposition of sediments suitable for cottonwood germination. Large spring floods favored for germination are likely to have been common prior to construction of the first dam in 1922. The combination of a more geographically-dispersed seed source due to planting, new habitat, suitable germination surfaces, favorable floods and changes in grazing practices may have accounted for subsequent cottonwood proliferation after settlement.

Loss of cottonwood from its historical range along the river as evidenced by the GLO section line data appears to be equally due to conversion to agriculture and conversion to more xeric vegetation types. The net result is that the cottonwood patches along this section of river exhibit a more fragmented pattern compared to the more closed canopy forest that probably existed prior to white settlement. Conversion to more xeric vegetation types is consistent with river regulation having reduced the frequency of flows suitable for cottonwood recruitment. Cottonwoods require specific flow regimes that scour and expose moist sites, followed by a decline in the water table that is gradual enough for roots to maintain contact with the water (Mahoney and Rood 1998). The lowest reaches of the Walker River have been subject a two-thirds reduction in flow from 1882 to 1994, and correspondingly the lake level has experienced a 45 meter drop in surface elevation (Meyers 1997) resulting in severe incision along the lower river.

Historical conditions: Conversion of natural communities to agriculture

Conversion of natural communities to agriculture was the most frequent transition in the study area accounting for 59.4% of total change. Agricultural lands came from all previous land cover types including water and playa. However, the majority of agricultural lands came from upland shrub (58.5%) followed by meadow/wetland (23.1%) and riparian shrub (5.0%) (Table 5). Agriculture gained 111,958 meters along section lines while the next highest community, riparian shrub, only gained 18,044 meters. Tamarisk and cottonwood both showed net gains while meadow/wetland and upland shrub showed large losses.

Vegetation communities varied in the amount and proportion that they were converted to agriculture (Table 5). Meadow/wetland showed the largest percentage loss at 94.7%, of which conversion to agriculture accounted for 41.4% of the historic total. Riparian shrub had the largest proportion converted to agriculture (48.8%) and was second highest in the percentage of overall change (82.9%). Cottonwood experienced over half its total line length converting to other classes (62.3%) with 20.1% being due to agricultural conversion. Upland shrub experienced 42.2% change to other communities with agriculture accounting for 31.1% of that change. The percentage of the modern total that was retained from the original was smallest for riparian shrub (7.5%) followed by cottonwood (19.2%), meadow/wetland (32.2%), and playa (35.2%). Tamarisk was not present in the Basin at the time of survey.

Agricultural expansion was more common than agricultural abandonment. Most agricultural lands were established after 1905 rather than before 1905 (20,554 ha versus 7,831ha). Although agricultural abandonment was relatively rare, at total of 3,965 ha of agricultural land were abandoned or converted to other land uses. Abandonment was most common in the present-day Mason Valley Wildlife Management Area in the northern part of Mason Valley and off of the East Fork downriver from Bridgeport.

In the Walker River Basin 94.7% of meadow and wetland has converted to agriculture or upland vegetation types with much of the remaining meadow/wetland being located at high elevations close to the river's source. According to Samuel Davis in the History of Nevada, "Before the white man turned his face westward, Mason Valley was inhabited by the Piute tribe of Indians. It was a fertile country with meadows of wild grass along the river, which was filled with trout." Maps created by the General Land Office surveyors seem to corroborate this description showing large areas along the rivers as meadow. The first agriculture in Mason Valley was largely focused around grazing cattle and harvesting wild hay, while subsequent efforts involved converting native hay meadows to alfalfa fields. James Young (2006) describes the native hay meadows. "These fields featured a mixture of native and introduced grasses, sedges, rushes, tules, and willows, all of which were cut for low-quality hay."

Table 5. Transition matrix showing change in land cover type from the period of settlement (1857 – 1910) to present-day.

	Cottonwood	Riparian Shrub	Mead./Wet.	Upland Shrub	Woodland	Jeffery Pine	Playa	Ag.	Tamarisk	Water	Historic Total
Cottonwood	2,514	600	434	1,440				1,338		348	6,674
Riparian Shrub	1,268	2,417	270	2,810				6,878		458	14,101
Meadow/Wetland	2,874	9,934	4,086	25,601	848			31,937		1,807	77,088
Upland Shrub	3,483	10,130	7,444	150,031	1,818	352	1,147	80,881	118	4,301	259,703
PJ Woodland	25	852	1	1,438	23,159			660		278	26,413
Jeffrey Pine		1,476	90	7,815		12,026		54		511	21,972
Playa				697			623	312			1,632
Agriculture	2,097	5,404	27	3,748				14,255		769	26,300
Water	859	1,331	326	10,085	31	87		1,942	10,850	638	26,150
Modern Total	13,120	32,144	12,678	203,665	25,855	12,465	1,770	138,258	10,968	9,111	460,023

The advent of irrigation allowed large areas of upland shrub communities within Mason and Smith Valleys to be converted to agriculture. Some of the most productive alfalfa lands in Nevada were former sagebrush lands with well-drained loamy soils. Drainage and leveling of fields were essential for alfalfa production, and the expansion of agriculture led to the disappearance of the native hay meadows and the cultivation of former upland shrub areas.

Historical conditions: Changes in the distribution of non-agricultural plant communities

Transitions from one natural community type to another were frequent throughout the basin, although taken together they were less frequent than transitions to agriculture. The most common natural community transition was meadow/wetland conversion to upland shrub which accounted for 11.0% of overall change. This conversion generally occurred on the downstream end of most large valleys (Mason, Smith, and Antelope). Conversions from upland shrub to riparian shrub and meadow/wetland to riparian shrub accounted for 4.35% and 4.27% of the change respectively. Areas where conversion from upland shrub to riparian shrub was common included areas of the lower portion of the Walker River upstream from Weber Reservoir, parts of Mason Valley, and sections of the river between Antelope and Smith Valleys. Conversion from meadow/wetland to riparian shrub occurred in most parts of the upper portion of the watershed including the large valleys (Mason, Smith, and Antelope) and the East and West Forks. The creation of tamarisk habitat was the fourth largest transition accounting for 4.66% of the total change. The majority of mapped tamarisk patches (98.9%) occur in areas that were formerly part of Walker Lake itself.

Natural plant communities in the vicinity of agricultural areas are subject to physical and hydrological effects that result from agricultural practices. For example, agricultural practices can result in raising or lowering the water table through irrigation or groundwater pumping. This has been shown to lead to changes in vegetation communities that can occur rapidly once the water table drops below the rooting zone (Elmore et al. 2006). The conversion from meadow/wetland to upland shrub may serve as an indicator of changing groundwater conditions due to pumping or river channelization. In Walker Basin, extensive areas of historical conversion from meadow/wetland to upland shrub communities are generally located near the downriver portions of large valleys.

Conversion from upland shrub to riparian shrub was most common above Weber Reservoir on the lower Walker River. This conversion may be the result of higher water tables resulting from the creation of the reservoir. Conversion from meadow/wetland to riparian shrub was common throughout much of the river system. One especially notable area is the portion of the river that is downstream of the diversion to Topaz Lake, but upstream of where the outflow of the lake returns to the river. Changes in flow regime have resulted in a narrowing of the river channel in areas where water was diverted from as well as a loss of sinuosity. These changes may have favored the expansion of woody shrubs, such as willow.

Current conditions – Description of current vegetation

Agricultural and other developed land occupies nearly 30% of the area mapped. Xeric shrub and big sagebrush communities form the next most dominant vegetation communities (23% and 16%, respectively; Table 2). Cottonwood forests and invasive *Tamarix* stands each occupy approximately 2-3% of the area mapped, although much of the *Tamarix* is concentrated on the lower portion of the main stem of the Walker River, and on the delta where the river flows into the lake.

Species composition and community structure

We encountered 314 species over the 168 plots sampled during field surveys. Dominant woody species and herbaceous species are provided in Table 6, along with their frequencies of occurrence and wetland indicator scores. A total of 112 rare species (absolute frequency of occurrence < 3 plots) were excluded from further analysis.

Table 6. Ten most frequent woody species and ten most frequent herbaceous species observed on 168 plots, reported with their wetland indicator scores (Reed 1988).

Symbol	Scientific name	Common name	Wetland score	Frequency (%)
Woody species				
CHNA	*Chrysothamnus nauseosus*	rabbitbrush	5	47.0
SAEX	*Salix gooddingii*	narrowleaf willow	1	41.1
ARTR2	*Artemisia tridentata*	big sagebrush	5	40.4
SAVE4	*Sacrobatus vermiculatus*	greasewood	4	29.7
ROWO	*Rosa woodsii*	Woods' rose	2	23.8
SHAR	*Shepherdia argentea*	silver buffaloberry	1-2	20.8
TACH2	*Tamarix chinensis*	five-stamen tamarisk	2	18.5
POFR2	*Populus fremontti*	Fremont cottonwood	2	16.7
ATTO	*Atriplex torreyi*	Torrey's saltbush	3	16.0
ATCO	*Atriplex confertifolia*	shadscale saltbush	5	13.7
Herbaceous species				
LETR5	*Leymus triticoides*	beardless wildrye	2-3	47.0
JUBA	*Juncus balticus*	baltic rush	2	39.3
DISP	*Disichlis spicata*	inland saltgrass	3	38.1
ORHY	*Oryzopsis hymenoides*	ricegrass	5	26.2
IVAX	*Iva axillaris*	povertyweed	2	25.0
BRTE	*Bromus tectorum*	cheatgrass	NA	23.8
ACMI2	*Achillea millefolium*	common yarrow	4	23.2
EQHY	*Equisetum hyemale*	scouringrush horsetail	2	19.6
CAREX	*Carex*	sedge	1	16.7
IRMI	*Iris missouriensis*	Rocky Mountain iris	1	16.1

We identified 10 community types based on the TWINSPAN results. These 10 communities were shown as terminal nodes that varied at levels in the TWINSPAN dendrogram (Figure 8). The division at the first level separated the riparian sites (n = 107) from upland sites (n = 61). At the second level, a xeric desert scrub (XS) community that is associated with *Atriplex confertifolia* and *Sarcobatus baileyi* was identified (n = 19) from the other upland sites. At the third level, an emergent wetland (EM WET) community (n = 2) associated with *Cirsium vulgare* and *Scirpus microcarpus* and a wet meadow (WET MED) community (n = 21) were identified for the riparian sites allied with obligate wetland species *Carex* L. and *Juncus balticus*. A riparian shrub (RIP SHR) community (n = 38) associated with *Rosa woodsii* and *Salix goodingii* was singled out from other riparian sites at this level as well. The other two upland communities were also classified at the third level. They are the upland sagebrush community (n=36) and pinyon-juniper woodland (PJW) community (n = 6). Four additional riparian communities were classified at finer levels. They are the cottonwood community (n = 11) characterized by *Populus fremontti*, an alkali meadow (Alk MED) community (n = 6) associated with high coverage of *Leymus triticoides* and low coverage of *Juncus balticus*, an alkali shrub (ALK SHR) community (n = 21) associated with *Sacrobatus vermiculatus* and *Disichlis spicata*, and a tamarisk-dominated community (n = 7).

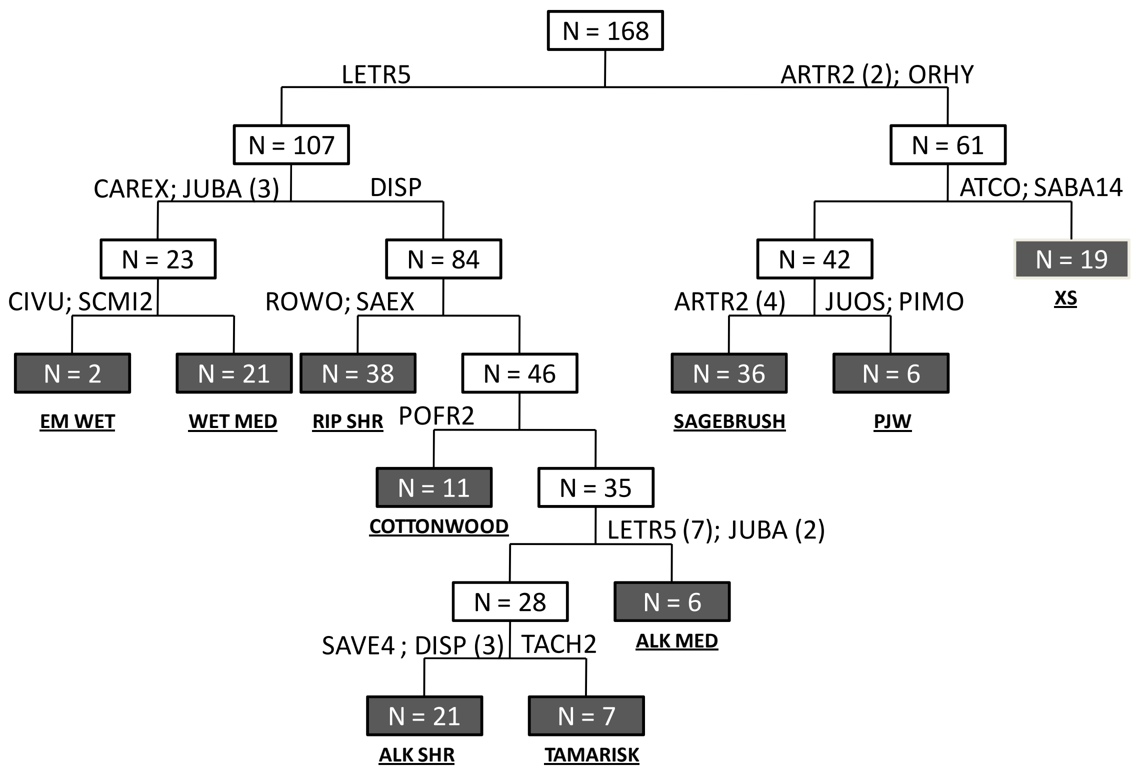

Figure 8. Dendrogram from TWINSPAN results. The 10 terminal nodes, filled with gray color, are paired with their corresponding community names. The number shown in each box is total number of sites belonging to this node.

The indicator species identified by the TWINSPAN and the ones identified by the ISA were combined, and their highest and second highest indicator values and corresponding communities are presented in Table 7. Communities EM WET, WET MED, PJW, and XS are strongly distinctive from others in terms of floristic characteristics as their indicator species are exclusively confined. Other communities are less so, particularly ALK MED and ALK SHR. The indicator species of ALK MED are observed in relatively large abundance or frequency for WET MED and RIP SHR; and each of the three indicator species for ALK SHR has a high indicator value for TAMARISK, COTTONWOOD, and XS communities correspondingly.

Table 7. Indicator species for each of the ten plant communities.

Indicator Species	Community with the highest IV	The highest indicator value	Community with the second highest IV	The second highest IV
ELPA3	EM WET	100	NA	0
SCAM2		100	NA	0
SCMI2		100	NA	0
CIVU		99	NA	0
CAREX	WET MED	68	ALK MED	1
IRMI		65	ALK MED	2
MURI		45	NA	0
LETR5	ALK MED	49	WET MED	12
JUBA*		32	WET MED	31
MEAL2*		17	RIP SHR	16
DISP	ALK SHR	54	TAMARISK	23
ATTO		36	COTTONWOOD	4
SAVE4		35	XS	27
TACH2	TAMARISK	63	COTTONWOOD	16
CHNA		44	SAGEBRUSH	10
SAEX	RIP SHR	59	COTTONWOOD	3
SHAR		48	COTTONWOOD	1
ROWO		41	SAGEBRUSH	5
POFR2	COTTONWOOD	48	RIP SHR	5
XAST		11	TAMARISK	7
ARTR2	SAGEBRUSH	62	PJW	20
SIHY		40	PJW	14
PUTR2		34	PJW	16
JUOS	PJW	82	NA	0
POSE		67	NA	0
PIMO		65	NA	0
TEGL	XS	60	PJW	1
ATCO		53	ALK SHR	8
SABA14		53	NA	0

* The highest and the second highest indicator value are too close for these species to be indicators in a strict sense.

Predictive Modeling of Vegetation-Environment Relationships

The relative distribution of species along axis 1 of the DCA ordination space was generally in line with species' wetland indicator status (Figure 9). For example, obligate wetland species ELPA3, SCAM3, SCMI2, and CIVU had the lowest DCA axis 1 score, immediately followed by facultative wetland species such as SHAR, SAEX, JUBA, POFR2, and TACH2. Facultative species DISP, ATTO and XAST were distributed towards the center of DCA axis 1. Facultative upland species (e.g., SAVE4, MURI) and upland species (e.g., SABA14, ARTR2) were distributed on the right side. The first axis was strongly correlated with the transverse-scale variables, HAR, FH, AWS, and SLOPE. Elevation was also highly correlated with the first axis, but was much more so with the second axis. The top three environmental gradients correlated with axis 2 were the longitudinal-scale variables, elevation, temperature, and precipitation. The relationship between the variables and ordination scores of species assemblages is represented in the joint plot (Figure 10), where the angle and length of the radiating lines indicate the direction and strength of relationships of the variables with the ordination scores. The joint plot shows that the overall influence of longitudinal variables (ELEV, TMIN, TMAX, and PRECIP) was stronger than that of transverse variables (HAR, FH, SLOPE, and AWS). The joint plot also showed that most sites were clustered according to their communities in the ordination space, although a few outliers overlapped with other communities.

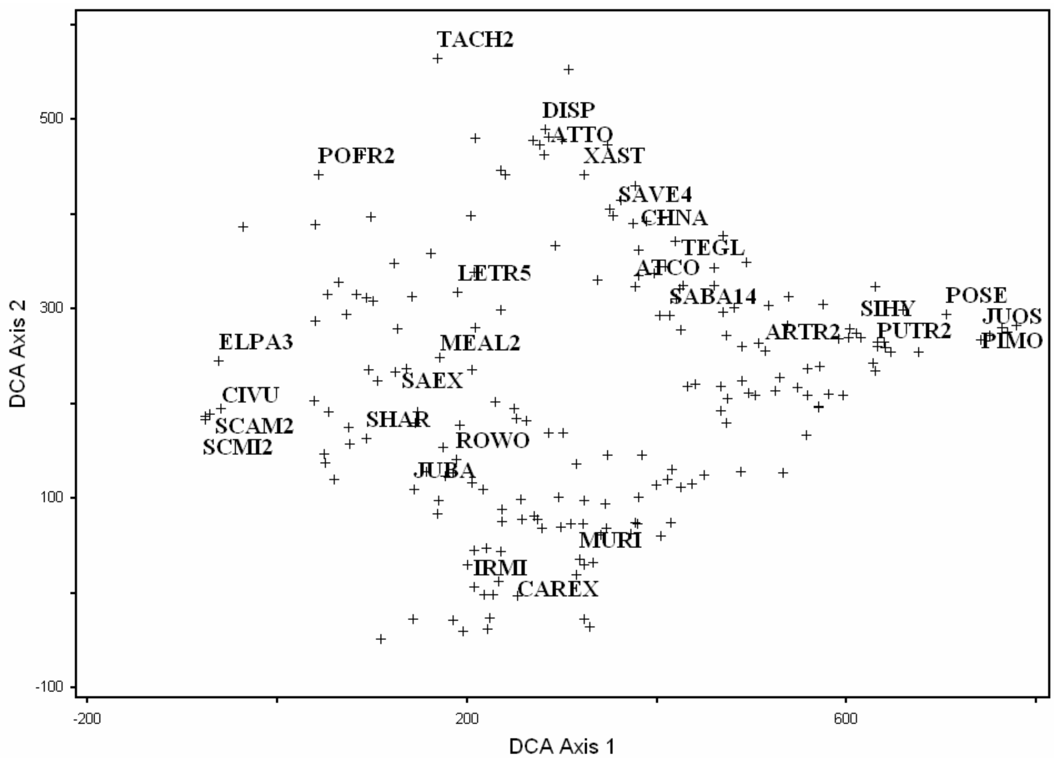

Figure 9. Distribution of Walker River woody and herbaceous species (n = 202) in DCA ordination space. The names of 29 indicator species listed in Table 3 are shown in this figure.

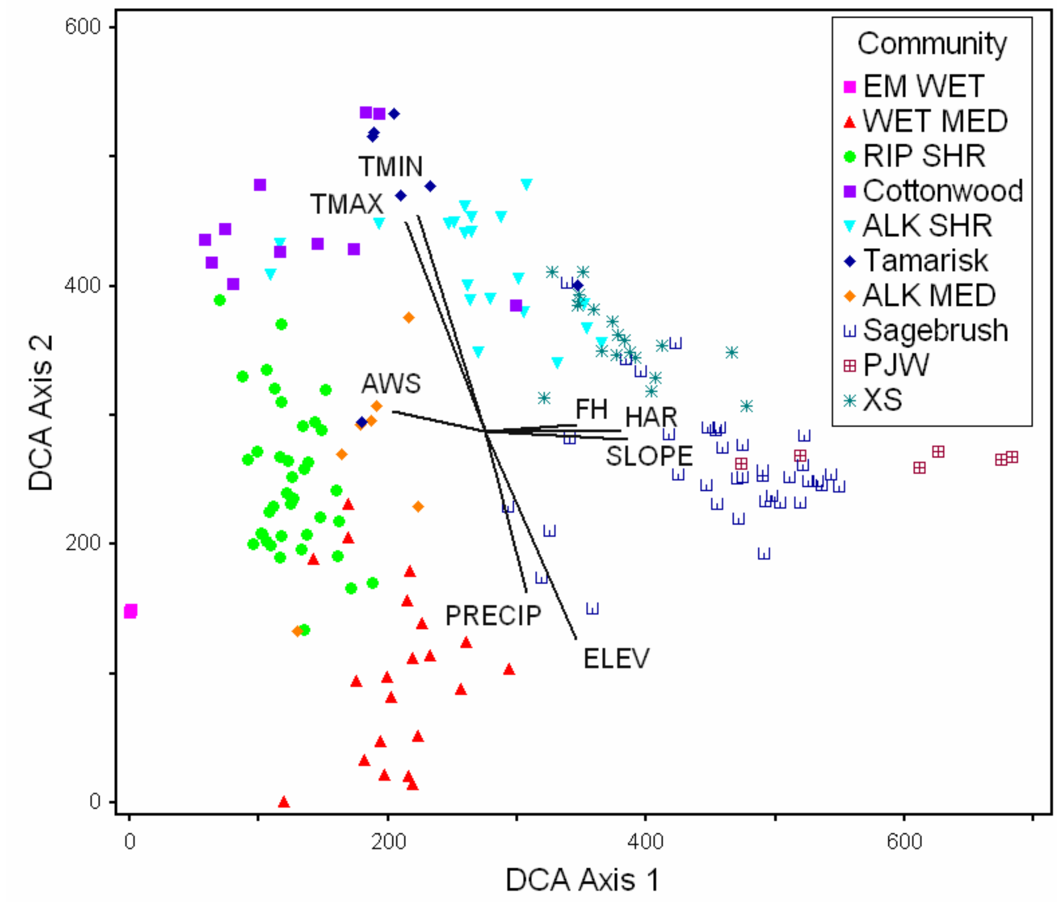

Figure 10. DCA ordination scores of 168 sites and the correlations with the major environment gradients.

The ability of a random forest classification model to discriminate plant communities varied with the level of classification and scope of plants included in the study. When modeling Walker River Basin riparian corridor species assemblages at a fine level with 7 riparian and 3 adjacent upland plant communities, the overall Cohen's Kappa was 0.56, reflecting a moderate level of agreement. This agreement was substantially improved when modeling species assemblages at a coarse level with two aggregated types only (Model 2, Table 8). The Kappa value was high (0.84) when modeling only upland species assemblages, but became lower (0.46) when modeling only riparian types.

However, the classification model including only riparian types improved prediction power for WET MED, RIP SHR, COTTONWOOD, and ALK MED (Model 3 vs. Model 1, Table 8).

Table 8. Modeling performances measured by Cohen's KAPPA, overall classification error, and error rate of each community type for four random forest models: 1) modeling plant communities at a detailed level of 10 types 2) modeling plant communities at a coarse level of two aggregated types 3) modeling seven riparian communities only and 4) modeling three adjacent upland communities.

	Model 1	Model 2	Model 3	Model 4
KAPPA	0.56	0.77	0.46	0.84
Overall classification error	0.38	0.11	0.44	0.09
Error rate by Community type				
Riparian Type		0.08		
EM WET	0.16		0.20	
WET MED	0.29		0.22	
RIP SHR	0.58		0.39	
COTTONWOODS	0.62		0.58	
AL SHR	0.82		0.86	
TAMARISK	0.15		0.15	
AL MED	0.72		0.69	
Adjacent Upland Type		0.16		
SAGEBRUSH	0.22			0.06
PJ W	0.17			0.21
XS	0.19			0.08

The relative importance of predictor variables identified by the random forest models also varied with the level of classification. When modeling the full set of ten communities, the two most important predictor variables were HAR and FH, indicating groundwater availability and flood potential. For this model, the five most important variables were all at the transverse scale. Among all the longitudinal gradients, PPT01 was the most important; but its importance was ranked only sixth among all the variables (Figure 11a). The longitudinal scale variables such as ELEV, PPT01 and TMAX07 increased their importance for modeling plant communities at the coarse level of classification distinguishing only riparian from upland vegetation types (Figure 11b). When the modeling scope was limited to riparian communities, distance to the river (D2RV) replaced HAR as the most important predictor variable, followed by the longitudinal variables such as PPT01, TMAX07 and ELEV (Figure 11c). Variables that represented temperature and precipitation, which are of longitudinal scale, were identified as the most important predictors for models that only included upland communities (Figure 11d).

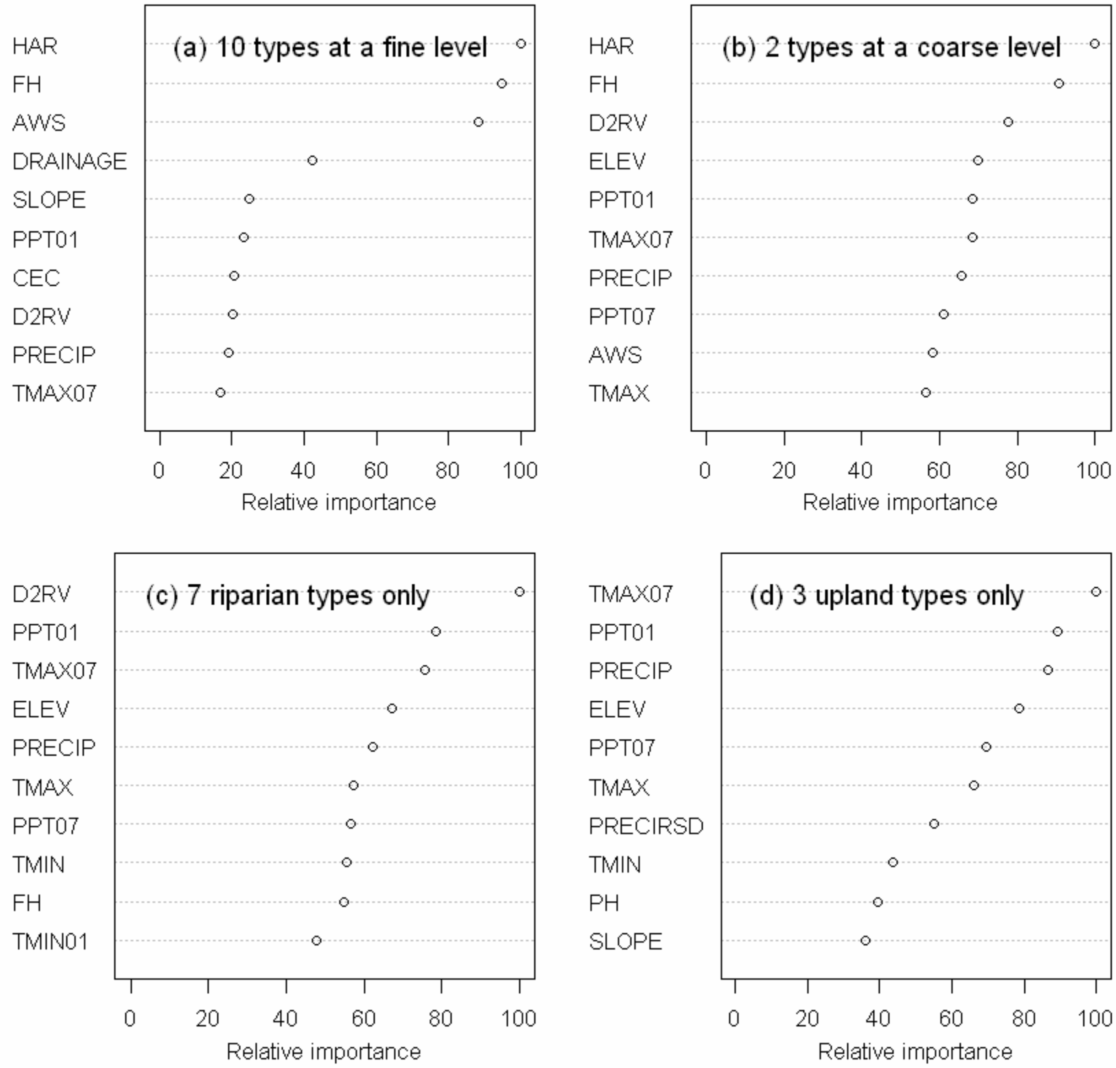

Figure 11. Relative variable importance when modeling (a) the 10 riparian and adjacent upland community types all together, (b) the 2 aggregated types riparian vs. upland, (c) the seven riparian types only, and (d) the 3 adjacent upland types only. Only the top 10 important variables are shown here.

Refinement of riparian plant water use estimates

The annual fluctuation of simulated ET rates within the riparian areas of Mason valley is correlated with climatic fluctuations. For example, ET rates peaked in the wet years of 1998 and 2006 and reached low values in the dry years of 2003 and 2004 (Figure 12). We found a significant (> 30,000 m^3/day on average) reduction of ET estimations when using the RIPET package (Figure 12) comparing to the ones simulated using the original EVT package of MODFLOW. Because lower ET losses were simulated using the RIPET package, the simulated water table elevations were higher (~ 0.2 m) than those simulated using the EVT package (Figure 13).

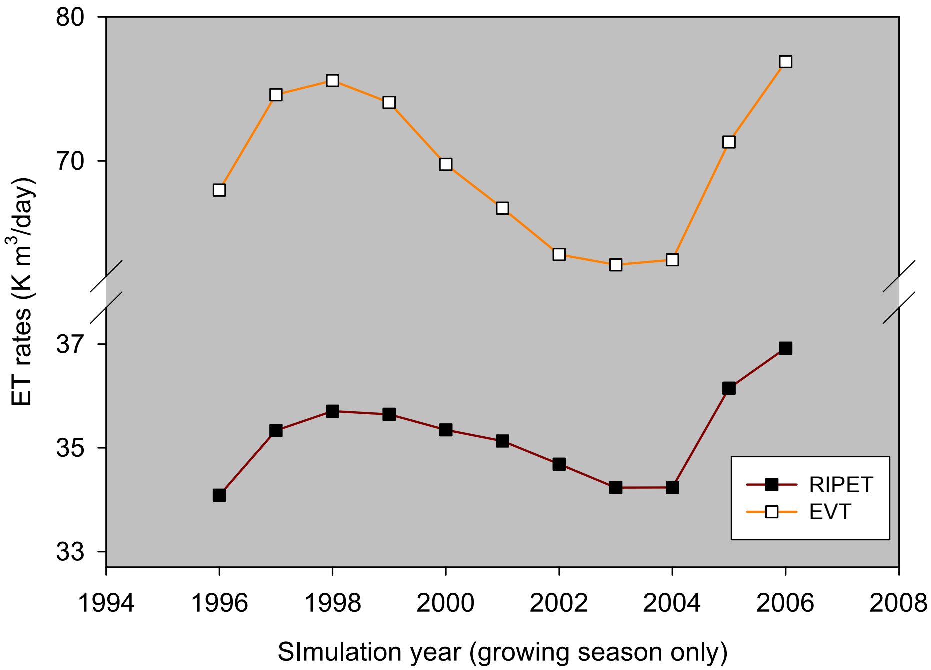

Figure 12. Simulated ET rates for riparian areas of Mason Valley using the original EVT package and the newly developed RIPET package.

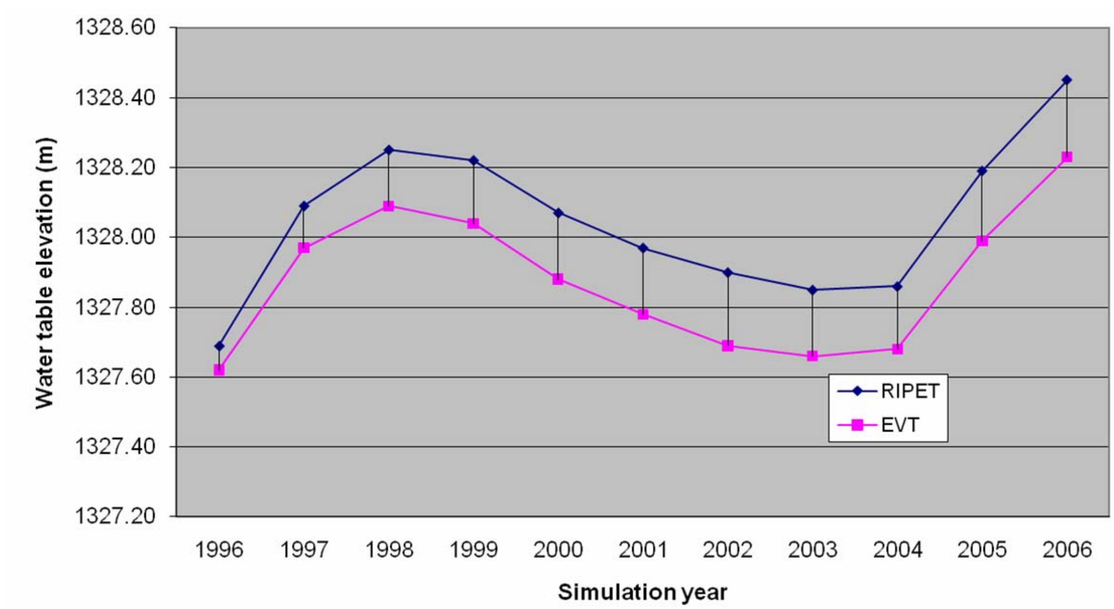

Figure 13. Simulated water table elevations for riparian areas of Mason Valley using the original EVT package and the newly developed RIPET package.

Simulated mean water table elevations were then subtracted from land surface elevation to derive depth to groundwater. The box plots of simulated mean depth to groundwater across different vegetation types show the upland vegetation (WSS/BSS and XS) occupying sites with higher depth to groundwater than phreatophytes (ALK SHR) or obligate wetland vegetation (Figure 14). The general ranking of mean depth to groundwater across these vegetation types is similar to the order exhibited in the ordination scores along axis 1 (Figure 14 vs. Figure 10), suggesting that the groundwater model using the newly developed RIPET package has produced reasonable outputs for modeling groundwater effects on riparian vegetation distribution.

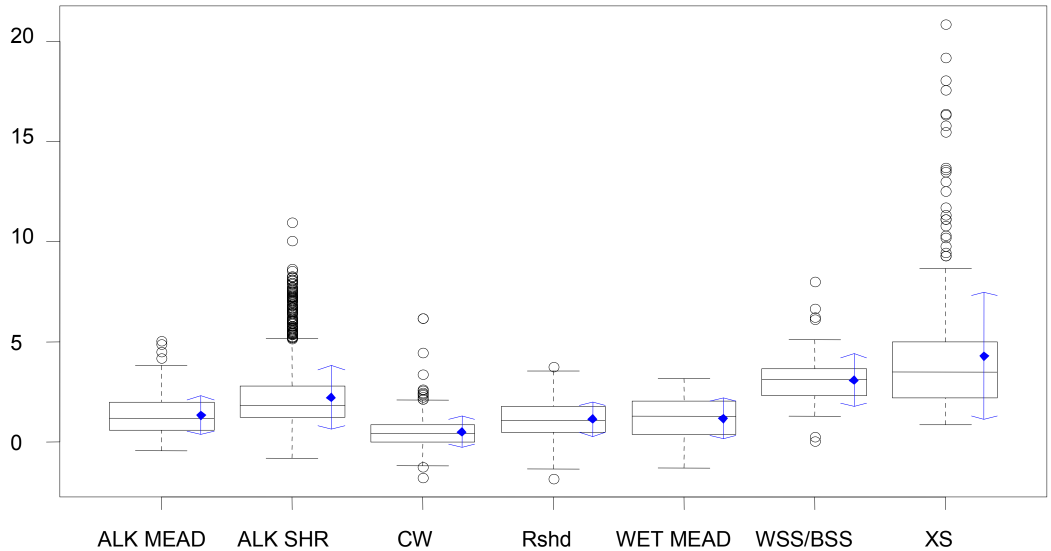

Figure 14. Box plots of simulated mean depth to groundwater (m) during growing seasons across vegetation types. Blue dots and arrows indicate mean values and standard deviations.

CONCLUSIONS

This study provides critical information regarding the baseline conditions that existed prior to intensive agriculture in the Basin. Our analyses of historical changes show a general tendency for transitions to more xeric communities for those vegetation patches that have not directly been converted to agriculture. Much of the historical riparian area in the lower river was dominated by wet meadow and emergent wetland habitats, of which the great majority that was not directly converted to agriculture has transitioned to riparian shrub, or desert shrub communities. The dominant direction of change observed in the historical analysis indicates a riparian environment that has become narrower, more channelized, and with reduced groundwater availability. Just as changes associated with river regulation and water withdrawal have altered the Walker Lake ecosystem, riparian environments in the floodplain have also experienced extensive alteration that likely result from the indirect effects of the hydrologic modifications needed to sustain an agricultural economy at the watershed scale. Changes to natural plant communities that do not result from agricultural conversion have been of a similar areal extent as transitions resulting from direct conversion to intensively managed agricultural land.

One of the more striking historical changes has been the redistribution of Fremont cottonwood trees from a few areas of floodplain forest, with the most extensive of these occurring at the former delta of the Walker River when lake levels were higher, to numerous small patches and individual trees scattered throughout the riparian and agricultural portions of the Basin. The cottonwood habitat type is at the same time more extensive and more fragmented than during the early Euro-American settlement period. Riparian grassland and wet meadow communities, however, have experienced great areal reductions through both direct and indirect influences of irrigated agriculture; climate change may also play a role. Ecological restoration efforts in the Walker Basin aimed at historical reference conditions might consider fostering the development and long-term maintenance of meadows. Such native "hay meadows" could also be compatible with sustainable livestock grazing practices, as they likely were prior to the introduction of alfalfa to the Basin.

Ongoing ecological modeling research will address the likely response of vegetation to current and future land and water use scenarios. Historical effects of flow alteration, river incision and groundwater withdrawal have apparently altered riparian plant communities in ways that are predictable and mappable, lending validity to our ecological modeling efforts. Current vegetation distribution is closely associated with measurable longitudinal and transverse predictor variables, including proxies for changing groundwater availability. Models of vegetation response to groundwater availability and climatic variables can be used to extrapolate future responses of plants to alternative agriculture scenarios and ecological restoration activities. Knowledge gained will be valuable for directing future changes in land management and water allocation, for restoration of former agricultural lands or lands currently dominated by invasive plants, and for management of associated plant and wildlife resources.

RESEARCH PRODUCTS

Papers

Dilts, T.E., Yang, J., Weisberg, P.J., Olson, T.J., Turner, P.L., and Condon, L.A. (in revision) Direct and indirect effects of irrigated agriculture on vegetation change in an arid lands watershed.

Yang, J., Dilts, T.E., Turner, P.L., Condon, L.A, and Weisberg, P.J. (in review) Modeling longitudinal- and transverse-scale environmental influences on riparian vegetation.

Dilts, T.E., Yang, J., Weisberg, P.J. (2010) Mapping riparian vegetation with LiDAR data: Predicting plant community distribution using height above river and flood height. ArcUser Magazine, Winter 2010 Issue.

Presentations

February 3, 2010: Historical ecology and GIS: an example from the Walker River Basin. An invited talk for the University of Nevada Reno, Department of Geography Colloquium. Reno, Nevada.

October 27, 2009: Reconstructing the vegetation of the Walker River Basin at the time of Euro-American settlement using General Land Office survey notes. International Symposium on Terminus Lakes. Reno, Nevada.

October 26, 2009: An Ecohydrologic Approach to Simulating the Interactions between Groundwater Flow and Riparian Vegetation at the Landscape Level. International Symposium on Terminus Lakes. Reno, Nevada.

May 18, 2009: Integrating R with ArcGIS for Mapping Riparian Vegetation Distribution along the Walker River. The 19th Nevada GIS Conference, Reno, NV.

April 14, 2009: Land use change in an arid agricultural landscape: reconstructing the historical vegetation at the time of settlement. United States Regional Association of the International Association of Landscape Ecology Symposia, Snowbird, Utah.April 14, 2009: Environment Influences on Riparian Vegetation Distribution: Scale and Level of Ecological Organization. United States Regional Association of the International Association of Landscape Ecology Symposia, Snowbird, Utah.

Posters

Dilts, T.E., Yang, J., Weisberg, P.J., Turner, P.L., and Condon, L.A. Multiple approaches to modeling vegetation communities in the Walker River Basin. Presented at the Report to the Basin public meeting. Yerington, Nevada. June 24, 2009.

Yang, J., Dilts, T.E., Wesiberg, P.J. Landscape-scale Modeling of Riparian Vegetation Distribution. Society of American Foresters 2008 National Convention. November 5, 2008.

Software/Scripts/Models

Riparian Topography Tools for ArcGIS - Tools for deriving topographic variables from a high-resolution DEM - http://www.cabnr.unr.edu/weisberg/downloads/ and http://arcscripts.esri.com

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PROJECT D: SCIENCE, POLITICS, AND WATER POLICY: RESOLVING CONFLICT IN THE WALKER RIVER BASIN

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CONTENTS

CHAPTER ONE: CHANGING CONTEXTS IN WESTERN WATER POLICY

INTRODUCTION

> *History is primarily a record of the tug-of-war between people and their environment. Half of their environment—the social milieu—humans construct themselves. The other half they come to accept after settling in a particular locale…. The elemental components of the Nevada heritage are land, water, and the habitat that nature has provided. Since the days when Jedediah Smith and Peter Skene Ogden first probed the edges of this region in 1826, our predecessors cursed the desert and mountain terrain; they feared the blistering heat of summer and the blizzards of winter. But also, by steps as slow as those of the earliest pioneers, Nevadans have come to realize that the geology, the ecology, and the atmosphere of Nevada and the surrounding area are, in combination, greater treasures than all the precious metal of the Comstock Lode or the wealth of the gambling casinos (Hulse, 2004: 1).*

There is a saying in the western part of the United States: Whiskey is for drinkin' and water is for fightin.[1] Those living west of the 100th meridian know the truth behind this saying all too well. From the beginning of settlement of the American West, "wars" have been waged over this scarce and precious resource. The Great Basin, in which most of the state of Nevada is located, is a vast expanse of land that includes most of northern Nevada, half of Utah, and parts of California, Oregon, Idaho, and Wyoming. The Great Basin is the "land of interior drainage" because the rivers run inland toward lakes or sinks—none of its mostly snow-fed surface waters ever make it to the ocean or the sea (Hulse, 2004: 3).[2] The Sierra Nevada mountain range, with peaks reaching 10,000-12,000 feet, blocks storms from the Pacific Coast. Horton calls this damper on precipitation a "rain shadow" over the Great Basin (1996: i-iii).

Most western states receive less than 20 inches of precipitation each year. The state of Nevada receives less than 10 inches of precipitation, making it the driest state in the union. In west central Nevada, which is the location of the Walker River, average annual precipitation is less than five inches (Horton, 1996a:i-iii).

A key feature of three of Nevada's major river systems—Truckee, Carson, and Walker—is that each originates in California. The Truckee River rises from Lake Tahoe—its major water source—and flows about 120 miles, through the Truckee Meadows (Houghton, 1996a:61). The Truckee historically terminated in Pyramid Lake, but since completion of Derby Dam in 1905 to 1968, an average of 250,000 acre-feet-year (a-f-y) was diverted from the Truckee River to Churchill County, where it has been

[1] This saying purportedly originated in the state of Texas.
[2] Geologists describe the region of which the Great Basin is a part, as the "Basin and Range province"; this province also includes part of Southern Nevada, Arizona, New Mexico, western Texas, and Mexico (Hulse, 2004: 3).

used, along with Carson River water, to support irrigated agriculture in the area (Horton, 1996:1-7).[3]

The Carson River rises in the high Sierra Nevada in Alpine County, California. Its east fork originates on the slopes of Sonora Peak, at 11,000 feet; the west fork originates near Carson Pass. The two forks flow north to cross the Nevada border and merge in the Carson Valley, where it has been used to irrigate farmlands in Churchill and Douglas Counties (Hulse, 2000: 12). The Carson River naturally flowed 180 miles into the Carson Sink. However, starting in 1915, the waters of the Carson River have been captured and stored in Lahontan Reservoir, which is part of the Newlands Project,[4] for distribution to project farmers (Houghton, 1994: 85).

The Walker River originates on the Sierra Crest's western boundary of Yosemite National Park. Through its two forks, the East and the West, it winds through mountain valleys and canyons along the California [Mono County]-Nevada border to Smith and Mason valleys, where a significant portion of the surface waters are used to support irrigated agriculture. The two forks merge five miles south of Yerington, becoming the mainstem Walker River. By the time the two forks merge, the volume of each has been greatly diminished, having been used to support extensive irrigated agriculture in Mason and Smith Valleys, in Lyon County, Nevada. The river then passes by ranches and farms surrounding Yerington, through a state of Nevada wildlife refuge and Lahontan cutthroat trout hatchery, across the boundary of the Walker River Paiute Reservation, and eventually into Walker Lake (Horton, 1996b).[5] The reservation and the lake are located in Mineral—not Lyon—County. Besides sharing these three rivers, California and Nevada also share Lake Tahoe. One-third of the lake lies on the Nevada side of the border; the other two-thirds are in California.

These circumstances ignited competition for water in the mid-20th century, not only between the two states, but between users within each state. For over a century, attempts have been made to resolve conflicts over these shared water resources (Jackson and Pisani, 1972, 1973, 1974).

Managing Western Water: The Early Years

The management of underground and surface water resource systems in the United States is achieved through a complex arrangement of case law, judicial decrees, doctrines, statutes, regulations, and permit systems—and is carried out by a diverse set of organizations at all three governmental levels (federal, state, local). The federal government has long been "the most important single player" (Reisner and Bates,

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[3] This translates to about half the flow of the Truckee River, on average. According to Joe Gremban, President of the Sierra Pacific Power Company in the late 1980s, the diversion took, at time, ALL of the water in the Truckee at Derby Dam, leaving nothing to flow to Pyramid Lake.

[4] The Newlands Project was the first reclamation project constructed by the Bureau of Reclamation. Located in Churchill County, this project has been the focus of more than 150 years of conflict and litigation. For more information on this project, see Wilds, et al., 1994; Wilds and Acton, 1997; and Wilds and Acton, 2005.

[5] The Humboldt River, contained wholly within the state of Nevada, flows out of the Ruby, Jarbidge, Independence, and East Humboldt mountains. It empties, 265 miles later, into the Humboldt Sink (Horton, 1996b: iii). Because California and Nevada do not share this resource, it is not discussed here. The Colorado River, the major source of water in southern Nevada, is also outside our scope.

1990:8) in water policy in the West, largely through the policies and activities of the US Army Corps of Engineers (COE) and the Bureau of Reclamation (Reclamation). Mechanisms for control also exist in all three branches of the federal government. States have developed their own mechanisms for regulation and control, which tend to reflect wide variation in supply, demand, public attitudes, and historical precedent. At the local level, water management officials must adapt to changes in state and federal policies. At the bottom of this tier are the actual water users. It is not surprising, then, that conflict among managers and users at all levels is as old as the history of western settlement.

The first major Anglo use of water in the West was for mining, followed by agriculture.[6] Both uses require the removal of water from the streambed, applying the water, and then returning to the river the small portion that remains. The reality of water uses in the early West gave rise to the three major principles of the "prior appropriation doctrine": the priority rule, the diversionary requirement, and the beneficial use requirement[7] (Welden, 2003).

The priority rule states that the first person to divert water on a stream has the prior right to use the water: "first in time, first in right." Thus, users of appropriated water are assigned priority according to the verifiable dates on which each began to use the water. The amount of the first priority must be satisfied, or "made whole," before the next claimant can use any water. In times of shortage, the junior users may be required to reduce operations—or to cease them altogether. Water must be diverted from rivers and streams; the date the water was diverted often serves as the priority date for use of that water. Appropriated water must also be put to a "beneficial" use within a given amount of time. Failure to do so may result in a challenge to or loss of the right to use the water. Beneficial uses were based in common law, and initial western uses, such as mining and irrigation, were eventually incorporated into statutory law as beneficial uses.

The ultimate result of these principles has been the development of a "consumptive" ideology, which historically perpetuated the notions that (1) water not used is wasted or lost; (2) only economic, diversionary uses are beneficial; and (3) individuals have the right, if all other requirements are met, to use the allotted amount of water no matter what conditions prevail—even to the detriment of other, subordinate users or the surrounding environment. Moreover, if a water-rights-holder does not continuously use the water for defined beneficial purposes, those rights may, under certain specified conditions, be considered abandoned or forfeited (Houghton, 1994:66). The prior appropriation doctrine being the dominant water allocation and use principle in the West has contributed greatly to the conflicts that have arisen over water.

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[6] To be sure, Native peoples relied on the same waters in situ for much of their sustenance. Those waters were also a source of cultural identify for the tribes. This is discussed in more detail in a later chapter.

[7] All 17 western states adopted the appropriation doctrine. Nine western states also apply the riparian doctrine to lands adjacent to surface waters. This doctrine was developed in England and adopted by eastern states, where water was relatively abundant. Under this doctrine, those who own land abutting a body of water have the right to reasonable use of that water. The rights are not fixed and exist in perpetuity. No administrative mechanisms, therefore, were needed to administer these rights (Welden, 2003).

Emerging Conflicts and the Search for Solutions

The first major series of water disputes between the states of California and Nevada arose in the mid-19th century, when Nevada questioned the right of private interests to draw off the waters of Lake Tahoe to encourage and support growth in northern California. Although each state controlled individual water rights within its borders, who had the right to determine allocation of the three river systems (the Carson, Truckee and Walker) shared between the two states? What role would or should the federal government play in making these determinations? The courts eventually became involved in attempting to answer these questions, resulting in a number of agreements and decrees to govern the use of the waters of Lake Tahoe and the Truckee, Carson, and Walker River systems.[8] None of these provided any definitive, long-term solutions to water allocation and use issues in either state, however.

By the early 1950s, both California and Nevada were worried that the other would start taking more than its fair share of the waters of the three rivers they shared. California politicians wanted assurance that some of the flow of all three rivers would be available to support future state growth. Nevada's leaders were fearful that California would eventually lay claim to the waters that, although originating in California, flowed naturally into Nevada. Both sides came to realize that an interstate water compact was the only way to get a comprehensive water agreement between them (Wilds et al., 1994:180).

Compact commissions were formed by both California and Nevada early in 1955, and when President Eisenhower signed enabling legislation on August 4, 1955, the framework was in place to begin negotiations in earnest. There was much optimism:

> *At the first joint meeting of the two state commissions held on January 17, 1956, Shamberger [Nevada State Engineer] sounded an optimistic key-note: "The job that is ahead of us is a large one. We are facing a rather unique situation. I don't know of any similar situation in the country where we are attempting to negotiate a compact on three separate stream systems and one interstate lake…. But I am sure that we have a group here that within a few months, a year or so, will be able to come to agreement" (Jackson and Pisani, 1974:255).*

Yet it took more than 14 years to finally reach an agreement. The California-Nevada Interstate Compact Concerning the Waters of Lake Tahoe, Truckee River, Carson River, and Walker River Basins was finalized on June 25, 1968 and ratified by California in 1970 and Nevada in 1971 (Wilds et al., 1994) (see Appendix A).

Both states lobbied for and expected Congressional approval, yet this was withheld. From 1971 to 1979, Nevada and California congressional delegations proposed six different bills seeking ratification; none even received a hearing. One final major effort was made by Nevada Senator Paul Laxalt in 1985. Although a hearing was held on the bill he introduced, the bill never became law (US Senate, 1990:9). As discussed below, there were just too many issues left unresolved by the compact for it to be ratified.

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[8] These include the Truckee River General Electric Decree (1915), the Truckee River Agreement (1935), the Orr Ditch Decree (1944), the Alpine Decree (1980), and Decree C-125 (1939).

Since that time, in a show of mutual trust and support, both California and Nevada retained the provisions of the compact in their respective laws, and agreed to abide by those terms at the state level, as a "gentlemen's agreement" (Haller, 1989).

Reasons for Failure

The failure of various parties to obtain ratification of the compact for more than 15 years was largely because the versions of the compact submitted to Congress emphasized the protection of the water rights of those involved in negotiating it, to the exclusion of other interests (Haller, 1989). In particular, Article I (Purposes) states the following:

> *Consistent with the provisions of the authorization Acts of the State of California and the State of Nevada and the United States, the major purposes of this compact are to provide for the equitable apportionment of water between the two states; to protect and enhance existing economies; to remove causes of present and future controversies; to permit the orderly integrated and comprehensive development, use, conservation and control of the water within the Lake Tahoe, Truckee River, Carson River, and Walker River Basins (emphasis added) (1968).*

The prior appropriation doctrine has that bias built into it: to maintain the status quo, which translated to continued use of these water supplies to largely to support irrigated agriculture.

Nonetheless, significant efforts have been made to adapt state water law to accommodate changed and changing circumstances. Getches suggests that a virtual "revolution" in western policy has been underway since the 1980s. For example, there is an increased emphasis on conservation and efficiency, water marketing, water leasing, environmental protection, sustainability, and improved water management strategies (1997: 4). These trends have been, in turn, driven by changing western demographics.

The west is the fastest growing[9] region in the United States, as well as home to more than half of the country's population. It is also increasingly urbanized. As more and more people move into the cities, rural American is "emptied out" (Getches, 1997: 3). Politicians and policy makers have been forced to recognize these changes, and alter public policy to fit changing circumstances.

States are now asking difficult questions about the use of water for irrigated agriculture: Is this use truly beneficial? Are the methods of diversion and distribution really efficient? Is the amount of water diverted for irrigated agriculture reasonable in the current climate? As a consequence, greater value is being placed on the western environment in general and on water-dependent environmental resources in particular. These compete with traditional, consumptive uses of water, especially water used in irrigated agriculture, which had consumed the lion's share of water in the West for decades. Congressional refusal to ratify the 1968 compact can be seen as tacit recognition of these policy changes.

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[9] Nevada is the fasting growing state in the nation.

Failure to achieve ratification after the 1970s is attributable to other factors as well, such as the nature of interstate compacts. Although the Constitution does require congressional ratification of interstate compacts, Congress routinely ratifies most of these, deferring to agreements that were negotiated primarily by two or more states. The precedent on interstate compacts that involved tribal water rights was to include a statement to the effect that "nothing in this compact would affect the rights of the United States or its Indian wards" (Pelcyger, 1995). The California-Nevada compact included an opposite provision, which stated that the compact would not be effective unless "Congress provides in its consent legislation…that the…provisions of the compact shall be binding on the agencies, wards, and instrumentalities of the United States of America" (Article XXII, Section 3). One of the last things then-Secretary of the Interior(Interior) Stewart Udall did before leaving office was to write a letter to the Office of Management and Budget (OMB) expressing Interior's opposition to the compact, citing both that unusual provision and the impact it would have on Pyramid Lake if ratified in its present form. Pyramid Lake had by that time been receiving recognition as a national treasure that should be protected. It was also home to two endangered species (the Lahontan cutthroat trout and the cui-ui). The Justice Department was vehemently opposed as well, as it was contrary to the interests of the federal government to bind itself to the terms of a state agreement (Wilds, 2008).

Changes in western water policy[10] are partly attributable to the rise and evolution of the environmental movement as well, which raised public consciousness of the values associated with recreation, fish, and wildlife and enhanced awareness of the impact of water development projects on these values. Wilds, et al., note that in the West this has translated into recognition that irrigated agriculture has been a significant "environmental offender" in its own right. For example, agriculture is a principal source of non-point pollution. The long-term effects of pesticides, fertilizer and trace elements in drainage and return flows were beginning to be recognized. Environmental groups, armed with environmental laws and court precedents, became much more effective at forcing something to be done about those impacts (1994: 177).

Throughout the 1960s and 1970s, Congress passed a host of laws designed to put into place national environmental protections—to clean up the damage that had already been done and to prevent further degradation. All of these laws were passed with little political fanfare.[11] Although the election of Ronald Reagan in 1980 may have signaled the end of the environmentalism of the 1970s, the laws and the bureaucratic machinery to carry them out have for the most part remained. Although many of these acts were

[10] Since the early 1970s, western states have been making creative adjustments in their water rights systems to accommodate conditions on transfers and exchanges of water rights, permits for a designated period of time, the acquisition and reallocation of existing water rights through purchase. In addition, non-traditional uses of water have become recognized as beneficial in state water laws, including instream flows, water quality, recreation, and aesthetics (Wilds, 2008:11).

[11] For a complete listing of these laws, see Norman J. Vig and Michael E. Kraft (eds.), Environmental Policy: New Directions for the Twenty-First Century (Washington, D.C.: CQ Press, 2006).

amended in various ways in the late 20th and early 21st centuries, environmentalism, both as a movement and a part of American culture, is here to stay.[12]

The environmental impact of irrigated agriculture on two of Nevada's lakes—Pyramid and Walker—has not gone unnoticed. Eighty percent of the surface waters of the Truckee, Carson and Walker rivers have historically been used to support irrigated agriculture.[13] Pyramid and Walker are two of the six larger desert terminal lakes in Western North America. They also are two of the three desert terminal lakes in this area that contain a freshwater fishery.[14]

By 1966, the level of Pyramid Lake had dropped by 80 feet, exposing sandbars at the mouth of the Truckee River; fewer and fewer fish were able to spawn. After passage of the Endangered Species Preservation Act of 1966 (P.L. 89-669), the Lahontan cutthroat trout (*Oncorhynchus clarki heshawi*) and the cui-ui[15] (*Chasmistes cujus*), both found at Pyramid Lake, were listed as threatened and endangered, respectively.[16] This enabled the Pyramid Lake Paiute Tribe to argue strongly for obtaining more water for the lake (Wilds and Acton, 2005).

By 1966, as well, the level of Walker Lake had dropped by 108 feet.[17] This, coupled with greatly increased levels of total dissolved solids (TDS), threatened the lake's viability as a fishery. Moreover, Nevada was experiencing rapid growth, and demands were being made by the local water purveyor, Westpac Utilities (now the Truckee Meadows Water Authority), for increased storage capacity for use in times of drought. Demands were also being made by environmentalists for the preservation, enhancement, and maintenance of the Lahontan Valley Wetlands, which, by 1987, had been reduced by 85% (from 113,000 acres to about 15,000). These wetlands (which include the Stillwater Wildlife Management Area) comprise "the largest primary wetlands within the Lahontan Valley. Over 410,000 ducks, 28,000 geese and 14,000 swans have been observed using the area…. Over 4,500 breeding pairs of ducks…have been recorded in the area, producing up to 25,000 waterfowl annually" (U.S. Senate, 1990:16). It is home to the largest breeding colony of white-faced ibis in North America. Bald eagles winter there. American white pelicans fly to their nesting colony there to feed (Wilds, et al., 1994:173-199). These wetlands require significantly increased firm supplies of clean water in order to survive.

By the time the compact was submitted to Congress, then, the circumstances surrounding all three river systems had changed dramatically. Realizing this, Congress refused to ratify the compact.

However, beginning in 1986, the newly-elected Nevada senator, Harry Reid, revived the idea of an interstate compact. He brought the parties together to negotiate a

[12] For a complete history of the origin, evolution, and impact of the environmental movement, see: Riley E. Dunlap and Angela G. Mertig (eds.), American Environmentalism: The U.S. Environmental Movement: 1970-1990 (Philadelphia, PA: Taylor and Frances, 1992).
[13] In the case of Walker Lake, that figure is 90%.
[14] The other is Summit Lake, also located in Nevada.
[15] The cui-ui are found nowhere else in the world—they exist only in Pyramid Lake.
[16] The Lahontan cutthroat trout were initially classified as endangered but soon reclassified as threatened to allow fishing according to state regulations, since this species occurs in other Nevada locations.
[17] As of 2008, the lake level had dropped 145 feet.

compact that recognized the changed circumstances such that it would pass congressional scrutiny. The stakeholders included the states of California and Nevada, the United States government, the Truckee Meadows Water Authority (formerly Westpac Utilities of Sierra Pacific Power Company), the Newlands Project irrigators,[18] the Pyramid Lake Paiute Tribe, and the Fallon Paiute Shoshone Indian tribes. The end result was passage of an interstate compact, Public Law 101-618, in November 1990 (see Appendix B).

Title I of that act, the Fallon Paiute Shoshone Indian Tribes Water Rights Settlement Act, dealt with the failure of the federal government to ensure that the tribe's water and other rights were preserved. Title II of the settlement act, the Truckee-Carson-Pyramid Lake Water Rights Settlement, settled water rights allocation issues between California and Nevada, allocating 90% of the Truckee and 80% of the Carson rivers to the state of Nevada, leaving the rest to California to support future growth on its eastern slope. It resolved most of the water allocation and use issues among users within Nevada by developing a new water management regime, the Truckee River Operating Agreement (TROA). This agreement will ultimately maximize water distribution to the major stakeholders, including Pyramid Lake, TMWA, Newlands Project farmers, Churchill county wetlands, and fishing and recreational enthusiasts (Wilds, 2008).[19] It also ended decades of litigation among most of the parties.

At the time of its passage, P. L. 101-618 was hailed as revolutionary. Perhaps, some observers noted at the time, this was the beginning of the end of irrigated agriculture in the West. The law also was touted as a model, both in its process and outcome, which other states might adopt to resolve their own water resource issues (Stalnaker, 1990; Wilds et al., 1994). However, it did not include the Walker River, even though it had been included in the earlier compact. Senator Reid, who ultimately made this decision, did so for several reasons.

He believed that the water allocation and use issues on the Truckee and Carson Rivers were intertwined with each other—but not with the Walker River. The waters of both the Carson and Truckee rivers have historically been used to support irrigated agriculture in the Newlands Project area. Any decision affecting the one would impact the other. The federal government was plaintiff or defendant in much of the litigation that had emerged over the past several decades. The government was also being pressured to address the environmental damage that had been caused by the project. In addition, in 1986, when Senator Reid was gearing up for the negotiations, the various stakeholders on the Carson/Truckee system had decided to engage in such negotiations. Two Indian tribes had been significantly impacted by the Newlands Project. Senator Reid believed that the time was ripe to address those issues (Reid, 2008).[20]

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[18] The Truckee Carson Irrigation District (TCID), which represented the Newlands Project farmers, withdrew from the process in June, 1988. They saw no purpose in negotiating for less water.
[19] Although P.L. 101-618 mandated the negotiation of TROA, it took the parties 17 years to reach an agreement. TROA was finalized and signed by the parties in August 2008.
[20]For a complete history of those negotiations and the outcomes they produced, see Wilds, 2008, *Calming Troubled Waters: The Newlands Project Revisited* (unpublished manuscript submitted to the University of Nevada Press in Summer, 2008).

The water stakeholders in Walker Basin were not as ready to negotiate as were those in the Carson and Truckee River Basins. Additionally, the federal government had not been involved in the development and operation of the irrigation systems in Walker Basin; these were privately owned and operated. Reid believed that the situation in the Walker River Basin was different enough that it should be tackled at another time, using a different process (Reid, 2008).

On to the Walker River

The approach taken in the Walker River Basin is both creative and unique. It is not the result of negotiations. It is not a water-importation project. It is not an inter-basin transfer. It is not directed at changing water use from agriculture to municipal or industrial use. It is not a large-scale public works project aimed at improving storage and conveyance infrastructure. It is a federally-funded, science-driven attempt to purchase enough water from agricultural users in the Walker Basin to preserve Walker Lake, while minimizing or mitigating economic and ecological impacts to the region.[21]

This, then, is the story of that effort—come to be called the Walker Basin Project—as it has evolved.

Chapter Two examines major influences that shaped the creation and development of the state of Nevada. These include mining, which led to the adoption of prior appropriation as the major (and eventually, only) water rights doctrine in the state. Chapter Two also includes an overview of the role the Church of Jesus Christ of the Latter-Day Saints (Mormons) played in shaping Nevada culture and politics. Chapter Three turns attention to two other major influences on Nevada culture and politics: cattle-ranching and agriculture. It includes a discussion of the impact these forces have had on Native Americans in general, and the Northern Paiutes in particular. This chapter ends with a discussion of the contemporary situation, which led to passage of P. L. 109-103.

Chapter Four examines the legislative and political history of P.L. 109-103, as well as the specifics of the Walker Basin Project that emerged from that legislation. It includes a discussion of the process used to attempt to save Walker Lake—and to begin to address water-resource, environmental, and economic problems in the Walker River Basin as a whole. Chapter Five discusses the findings of the research projects, and the ways in which those findings have been used in accomplishing the project's goals. It ends with by offering observations and insights about the progress of that project to date.

[21] It remains to be seen whether and to what extent that research will result in a "science driven" acquisition program or whether the program be informed by the results of that research over time, as well as shaped by politics and other factors as the program evolves.

CHAPTER TWO: THE PAST AS PROLOGUE—THE WALKER RIVER BASIN

> *Visibly our new home was a desert, walled in by barren, snow-clad mountains. There was not a tree in sight. There was no vegetation but the endless sage-brush and greasewood. All nature was gray with it. We were plowing through great deeps of powdery alkali dust that rose in thick clouds and floated across the plain like smoke from a burning house. . . Long trains of freight-wagons in the distance . . . suggested pictures of prairies on fire. These teams and their masters were the only life we saw. Otherwise we moved in the midst of solitude, silence and desolation (Mark Twain, approaching Carson City, 1871, Roughing It).*

THE PULL OF THE WEST

Prior to the mid-19th century, there was minimal settlement of the land west of the 100th meridian. The vast territory on the other side of the Mississippi River was regarded as a formidable, inhospitable wasteland, partly due to stories about the explorers, mountain men, and trappers of the early 1800s. It became both the repository of America's best hopes—land, prosperity, liberty, and democracy—and the epitome of its worst fears—tornadoes, wildfires, "savage" Indians, ferocious wild animals, impassable mountains, and endless deserts. All of this reflected, in the American mindset, a natural and cultural lawlessness that generated both awe and terror (Nash, 1982).

Such reluctance to migrate began to diminish in the mid-1840s, however, when the federal government began to actively promote western settlement. One reason was to ease the population pressure on the east coast, which increased with the waves of new immigrants.

Another reason was the "burgeoning pride that characterized American nationalism in the mid-19th century" and an "idealistic vision of social perfection… [resting] on the idea that America was destined—by God and by history—to expand its boundaries" from one coast to the other (Brinkley, 2000:365). The idea of manifest destiny was loudly proclaimed by national politicians and by the new "penny press" that made newspapers more available and affordable. The mantra of the time, it seems, was "Go West, young man!" Millions of Americans ultimately heeded that call.

A third reason for encouraging settlement of the West was to connect its economy with that of the East. As the settlers pushed the frontier westward, they established communities along the way, creating a demand for eastern goods. Once the West was settled and began to develop on its own, the goods would flow in both directions. Economic connections between East and West were eventually facilitated by the completion of a transnational railroad in 1869. In the mid-to-late 1800s, Western European immigrants began to head westward by the tens of thousands; after the Civil War, they numbered in the millions.

The discovery of gold at Coloma, California[22] that precipitated the Gold Rush of 1848-1850 was also a powerful incentive for moving West. According to Rohrbough:

[22] This was near present-day Auburn. The actual location was Sutters Mill in Coloma.

> The California Gold Rush thrust mining into the center of the expansion of the American nation and began a series of new chapters in the development of the American West. On January 24, 1848, at about ten o'clock in the morning, James W. Marshall, employed by the entrepreneur John Sutter to construct a saw mill on the American River, picked some flakes of mineral out of the tail race. By this act, Marshall set on foot a series of events that would change the history of California, [the history of Nevada], the history of mining, and the lives of hundreds of thousands of 49ers and their families (2004: 114).

Word spread quickly about the find, from newspaper to newspaper and mouth to mouth. Two truths emerged that caused more than 80,000 people to relocate to California in 1849 alone and 300,000 by 1855. First, the gold was abundant. Between 1849 and 1855, more than $300 million was harvested in gold from California. Second, it was a pretty level playing field. It was a game anyone with a pick, pan, and shovel could play (Rorhrbough, 2004). Families began to migrate on the heels of the 49ers, primarily from the Midwest. Some went not for gold but to escape the crowded eastern seaboard, to seek land of their own, or to find adventure. Very few of these families were wealthy, but many were relatively well off. Those who could not afford to make the trip on their own joined other groups and earned their keep along the way.

Two additional incentives drew settlers in a westward direction: an assurance that "rain would follow the plow" and the Homestead Act of 1862 (U.S. Statutes at Large, Vol. XII, p. 392 ff). The former was the belief that regional precipitation increased as the ground was tilled, labeled by Reisner and Bates as the "meteorological fraud of the century" (1990:12). The Homestead Act, which provided up to 160 acres of land to those who would settle it, was fraudulent in a different sense: 160 acres was insufficient to sustain a farming family in the arid and semi-arid West.[23] Recognizing this deficiency, Congress passed the Desert Land Act of 1877 (U.S. Stat. at Large, XIX 377), which offered potential settlers 640-acre parcels of land, if they agreed to irrigate it. This act not only did not achieve its goal, but resulted in widespread land speculation. Another attempt to encourage western settlement was the Carey Act of 1894 (U.S. Stat. at Large, XXVIII, 422), which authorized the federal government to grant tracts of land to states to sell to settlers for irrigated farming. During the following 16 years, only 288,000 acres were irrigated under the auspices of this act. By 1893, only 400,000 farming families, of more than a million who had made the attempt, remained on their farms (Reisner and Bates, 1990:12).

Of those who stayed, the families that located their farms near surface irrigation sources (streams and rivers) enjoyed greater success than the others. Seeing a potential for profit, numerous private irrigation companies, backed by eastern capital, were created to build irrigation projects to serve farming communities. Landowners also formed cooperatives to build irrigation projects of their own. By the early 1890s, western farmers

[23] To become eligible for the land, one had to be the head of a family, at least 21 years old, and a citizen of the United States (or expect to become a citizen in the future). If one had taken up arms against the Union during the Civil War, that person was ineligible. To take title to the land, one had to reside on or cultivate the land for five years. To receive patent to the land, a ten-dollar fee had to be paid.

were irrigating nearly 3.5 million acres of land (Reisner and Bates, 1990:13). The Mormons in Utah, Nevada, and Arizona were responsible for at least half of this achievement.[24] The Mormons were among the first western settlers to master the art of irrigated agriculture in an arid environment, as early as 1847 in Utah. Although they did not know much about irrigated agriculture when they headed toward Utah,[25] they were aware that water was scarce and that irrigation would be necessary to grow crops in order for the community to survive. Their earliest efforts were improvised and modest; large-scale projects were not undertaken until the 1870s. Their success can in part be attributed to the Mormon ethic of community action. They developed a "whole set of cooperative management techniques for building and maintaining dams and canal systems, distributing water to individual farmers, and applying it to the fields," which "evolved into a model for later settlers in the West" (May, 2008:2; Arrington and May, 1975).

In the years that followed, millions of acres were irrigated, not only in Utah but in surrounding states. From the 1860s through the 1880s, hundreds of private companies were created to tackle large-scale irrigation projects; almost none of these early private attempts lasted more than 10 years. Thus, in spite of the money and effort put into individual and corporate irrigation projects, the West remained largely unsuitable for settlement. Farms failed by the thousands, and communities dwindled. By 1898, so many irrigation efforts had failed that the western landscape was likened to a "graveyard." Senator Francis Newlands declared Nevada, the state that he represented, to be "dying" because of the degree to which agriculture had failed there.[26] The population decline in Nevada at the time (32%)[27] is still regarded as the most severe in American history (Reisner and Bates, 1990:13-14). Large-scale dams and reservoir systems needed to be constructed for the capture, storage, and distribution of water in order to reverse the flow of settlers out of Nevada. The federal government was pressured to undertake this task on behalf of western settlers who without adequate water were unable to provide even a subsistence living for their families. The government eventually passed the Reclamation Act of 1902 (32 Stat. 388, 43 U.S.C. 371). Under this act, the Reclamation Service (later the Bureau of Reclamation) constructed over 1,000 such projects, which are scattered throughout the West.

Not all western settlers welcomed—or, as it turned out—needed the help of the federal government to survive or even prosper. That was the case in the Walker River Basin, where irrigated agriculture struggled to take hold even though a thriving civilization had existed many millennia earlier.

Northern Nevada: The Earliest Arrivals

It is widely accepted that the first immigrants from Asia reached the valleys of the Basin and Range province at least 12,000 years ago. These early arrivals typically lived in caves or under rock shelters; most of what is currently known about them came from

[24] Much of the rest occurred in southern California along rivers whose waters were easily diverted and stored in natural off-stream basins for use in the summer.
[25] The Mormons had relocated several other times in their early history because non-Mormons were suspicious of and hostile to them. Their leader at this time, Brigham Young, believed that Utah would prove to be a new promised land for them.
[26] There was a sharp decline in mining as well.
[27] Townley (1988) put this figure at 50%.

studies of these sites by archeologists and anthropologists. Human artifacts from these sites were remarkably well preserved. Much of the land was covered with "ancient lakes and expansive and lush grasslands formed during the last ice age" (Horton, 1996b: ii-iii). Lake Lahontan, in northwestern Nevada, and Lake Bonneville, in northwestern Utah and northeastern Nevada, were the largest of these prehistoric lakes. Lake Lahontan was fed by the "flows of the Truckee, Carson, Walker, Humboldt, Susan and Quinn rivers, attained a maximum surface elevation of approximately 4,380 feet above mean sea level (MSL), and reached a maximum depth of at least 886 feet where Pyramid Lake…now remains" (Horton, 1996b: II-1). Pyramid and Walker Lakes are the only remaining evidence of the once-vast Lahontan Lake.

The first emigrants to this area lived near these enormous lakes. As the lakes receded over the millennia, the area became more and more arid, particularly the part that would become Nevada. The hot, dry climate helped preserve remains from this prehistoric people, which have been found in Nevada near Winnemucca Lake, at the Humboldt Sink, at Etna Cave near Caliente, at Lehman Caves in White Pine County, at Jarbidge Cave in Elko County, and at Hidden Cave in Churchill County (Hulse, 2004: 19). Because of this, we know that the people who lived in the Lovelock Cave near Lake Lahontan 3,000 years ago used darts to kill game, were talented basket makers, created nets for catching rabbits, and wove bowls to contain their food. They knew nothing about agriculture and were basically nomadic hunter-gatherers. No one knows whether these original people died out completely or they managed to adapt to become ancestors of the Shoshones and Paiutes (Hulse, 2004).

Whatever the case, Native Americans in Nevada struggled to survive at the beginning of the historic period. They ranged over an area of more than 75,000 square miles in eastern California, western Nevada, southeast Oregon, and southern Idaho, the area presently known as the Great Basin. The Northern Paiutes—or Numa (the People) as they called themselves[28]—roamed the lands in north central Nevada.[29] When the first explorers arrived in the early 1800s, there were at least 20 distinct bands of Northern Paiutes, each consisting of 100-200 people. Each band resided in a specific territory typically located near a lake, wetland, or river system and often took the name of the main local food source. For example, there were the *Koop Ticutta* (Ground Squirrel Eaters) located in present-day Lovelock, the *Kamu Ticutta* (Rabbit Eaters) and the *Tobusi Ticutta* (Bulb Eaters) located in present-day Mason and Smith Valleys, the *Cu Yui Ticutta* (Cu Yui Eaters) located in present-day Pyramid Lake, *Toi Ticutta* (Tule Eaters) and *Koosi Pah Ticutta* (Muddy Water Eaters) located in present-day Stillwater and Fallon, the *Agai Panina Ticutta* (Trout Lake Eaters) and *Moa Ticutta* (Wild Onion Eaters) located in present-day Summit Lake, and the *Agai Ticutta* (Trout Eaters) and *Pugwi Ticutta* (Fish

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[28] The origin of the word Paiute is unclear. Some anthropologists have interpreted it to mean "Water Ute" or "True Ute." Sarah Winnemucca suggested that the name was associated with their pine-nut diet. It appears that this name was first applied to the Numa about the time that Joseph Walker was exploring Nevada, in 1833. In a report issued in 1976 by the Inter-Tribal Council of Nevada, they still referred to themselves as Numa. When the Walker River Reservation was established in 1859, it was under the name Paiute. The tribe in the Walker River Basin call themselves the Walker River Paiute Tribe.
[29] Other Nevada tribes include the Washo in west central Nevada, the Owens Valley Paiutes, Western Shoshone, and Southern Paiutes (Hulse, 2004:31).

Eaters) located near present-day Walker River [Inter-Tribal Council of Nevada (ITCN), 1976].

The Great Basin is an unforgiving desert environment, but the Native Americans who lived there were well-adapted to the extreme temperatures and harsh living conditions. In the summer, the people either were naked or wore garments they fashioned out of sagebrush fibers; in winter, they made robes of rabbit skins. The Paiutes harvested seeds and nuts and the roots of wild plants. They hunted many types of game, including squirrel, rodents, and rabbits. Their weapons were "obsidian-tipped spears" and the hand-flung darts known as "atlatl" (Laxalt, 1989: 32). Until the bow and arrow was invented, they were unable to bring down large game, such as deer and antelope.

Fish was a major food source as well. Each spring, fish journeyed upstream to spawn; trout virtually flooded the Truckee, Carson, Walker, and Humboldt Rivers, as well as Walker and Pyramid Lakes. Although several methods were used to fish, including nets and spears, the Paiutes fishing on the Walker River built rather sophisticated dams that essentially guaranteed them a bountiful catch. These dams:

> …consisted of overlapping three by six feet cottonwood frames within each of which horizontal willow strips were interwoven with vertical cottonwood sticks. These panels were supported by spaced cottonwood posts and stretched across the river at a chosen point. The frames were tied loosely to the supporting posts, although the downstream rush of the water also forced the panels against the face of the supports. The trout were thus prevented from travelling beyond the dam. (Speth, 1969: 229)

The fish were plentiful enough both to feed the people in the spring and to dry and store for winter. While the men harvested the fish, the women gathered cattails, peeling the leaves and collecting the white spears inside; the leaves were used to weave baskets to collect and store food (Wheat, 1967).

The bands had no identifiable tribal organizations, at least until white settlers arrived. The settlers, in their negotiations with these bands, needed to identify tribal "leaders" who could speak with authority on behalf of their groups. Being nomadic, they had no permanent homes during the spring, summer, and fall, fashioning temporary shelters from whatever materials they could find. In the winter, they built "wickiups,"[30] which had a fire pit in the center for warmth and a hole in the top for the smoke to escape. They also were a peaceful people and had no warrior traditions, although when threatened they did band together to fight in self-defense (Hulse, 204: 25-26). The cycle of seasons and life continued for millennia, without any outside influence. Only the weather of the Great Basin affected them—but they had learned to adapt to unpredictable droughts, scorching summer heat, and bitter winter cold.[31] When the first white men came to Nevada, the Paiutes greeted them with curiosity and friendliness.

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[30] A wickiup is a simple type of teepee or wigwam. It is a domed-shaped one-room structure made of reeds (or whatever was available in the area), thatched over with grass or leaves.

[31] Although we do not know how many Native Americans lived in Nevada 200 years ago, before white encroachment, some scientists suggest there were over 40,000. By the early 1870s, the number was 21,500,

The Arrival of Anglos

Anglo-American settlers did not explore the area that later became the state of Nevada until at least 200 years after they had arrived in North America. The Far West was explored first by Meriwether Lewis and William Clark from 1803 to 1806. Backed by President Thomas Jefferson, they crossed the northern plains and over the Rocky Mountains into the Columbia River Basin. They never made it to Nevada, but sent back reports of "rich lands and large rivers with plenty of fur-bearing animals" (Hulse, 2004:36). In the ensuing years, hundreds of trappers and fur traders followed, as there was a great demand in Europe for fur coats and hats.

Twenty years later, in the fall of 1826, another major expedition was led by 27-year old Jedediah Strong Smith, mountain man, fur trapper, and one of three co-owners of the Rocky Mountain Fur Company. His party entered the eastern and southwestern parts of the Great Basin. Heading southwest from the Great Salt Lake, they entered present-day Nevada on the Virgin River. The group then moved along the edge of the Colorado River toward Needles, California. The Native Americans[32] that they encountered there guided them through the barren, sweltering southern California desert, arriving at the San Gabriel Mission near present-day Los Angeles. Smith had inadvertently reached lands occupied by the Mexicans.[33] Suspecting that Smith and his men were invaders, the Mexican governor, "anxious about new colonial threats so soon after they had gained independence from Spain," had them arrested (Bowers, 1996: 2). When they were released, Smith and his men were ordered by the governor to backtrack along the route they had used to get there. Instead, Smith headed north and reached in early 1827 what is now the San Joaquin Valley. Not wanting to endanger his men by proceeding into and over the snow-covered Sierra Nevada in the winter, Smith left 13 of them in California. Taking two of his men, he successfully crossed not only the Sierra Nevada but central Nevada as well, eventually reaching the Great Salt Lake. No one knew which route Smith had taken until the 1960s, when a copy of his journal was discovered. It is now certain that he crossed the Sierra Nevada along what is now Highway 89, found the West Walker River, and followed it to Walker Lake. Smith encountered a group of Paiutes there but had little interaction with them. He noted in his journal that when "we found water in some of the rocky hills, we most generally found some Indians who appeared the most miserable of the human race, having nothing to subsist on (nor any clothing) except grass and grasshoppers" (Morgan, 1953: 210). The three men then:

> …proceeded eastward across the arid, life-threatening center of the Great Basin. When they could not find game, they killed and ate their mules. In some places they struggled across high mountain passes, in others they

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and by the 1930s, there were only 12,000. Currently, there are approximately 35,000 Native Americans residing in Nevada (U.S. Bureau of the Census).

[32] Different tribes of the Paiute, Shoshone, and Washo lived near the Walker, Carson, and Truckee Rivers. The present-day Walker River Paiute tribe are descendents of the Northern Paiute—or Numa (the People), as they called themselves. Because the early explorers and trappers tended to confuse the Paiute, Shoshone, and Washo tribes, they often used the generic "Indians" to refer to them.

[33] Mexico and Spain signed the Treaty of Córdoba, which granted Mexican independence from Spain, on August 24, 1821.

> encountered deep sand. Often they had to ration their water carefully, and once they [even] dug themselves into the ground to get relief from the blistering heat…. Through a combination of bravery and desperation, they finally reached the Great Salt Lake and reestablished contact with his company. They had crossed the Sierra, the middle of Nevada, and half of Utah in six weeks, one of the most remarkable feats in the history of western exploration (Hulse, 2004: 38).

In 1827, Smith returned to California to meet up with the men he had left behind. This time, he avoided the treacherous route he had taken before and went through Oregon. After returning to his base camp in the Great Salt Lake, Smith never returned to Nevada.

A little-known pioneer in exploring Nevada was Peter Skene Ogden, a Canadian and a lead trapper for Hudson's Bay Company. Ogden led six expeditions into Snake River country between 1825 and 1831, venturing into the Walker River Basin on three of them. The company's records indicate that Ogden explored the entire Humboldt River Basin in 1828; trapped beavers in what is present-day Winnemucca;[34] and explored areas around the lower Carson River, Walker Lake, and the Colorado River.[35] Ogden's group had several interactions with the Paiutes in Nevada that could have turned violent. According to a journal entry made while he was camping along an "unknown"[36] river near present-day Lovelock on May 28, 1829,

> [Three] of the trappers came in with word of more traps stolen. He pursued the thieves and punished them but could not recover the traps. A man who had gone to explore the lake at this moment dashed in and gave the alarm of the enemy. He had a most narrow escape, only the fleetness of his horse saved his life. When rounding a point within sight of the lake, 20 men on horseback gave the war cry. He fled. An Indian would have overtaken him, but he discharged his gun. He says the hills are covered with Indians. I gave orders to secure the horses, 10 men then started in advance to ascertain what the Indians were doing but not to risk a battle as we were too weak. They reported upwards of 200 Indians marching on our camp. They came on. Having [signaled] a spot for them about 500 yards from our camp, I desired them to be seated. This order was obeyed. From their dress and drums and the fact only one elderly man was with them, I concluded it was a war party. If they had not been discovered, they had intended to attack us, weak as we were in gun—only 12—they would have been successful. It was a narrow escape (Townley, 1983: 24).

[34] Odgen was under orders from Hudson's Bay Company to deplete the beaver population in an effort to end the competition between the American and British for dominance over the territory (Ogden, 1828; Johnson, 1975).

[35] According to Hulse, Ogden and his men made "a trek that matches the most remarkable exploits of the great British explorers in the depth of Africa and the sands of Arabia" (2004: 39).

[36] The unknown river was later named the Humboldt River by Captain John C. Frémont. This river became the most important "transportation corridor" for early emigrants passing through the Great Basin en route to California through either the Carson or Luther passes in the Carson River Basin or Ebbett's Pass in the Walker River Basin (Horton, 1996b: II-3).

Ogden left the area by June 5, 1829 because no more beaver could be found; Ogden and his men had virtually wiped them out. Ogden also wanted to avoid further contact with the locals.

Four years later, the Northern Paiutes had another major, and this time, disastrous, encounter with whites. A group led by Captain Benjamin Louis Eulale de Bonneville and his chief lieutenant, Joseph Walker, both employed by Hudson's Bay Company, followed the trail detailed in Ogden's journals. Walker was chosen to accompany de Bonneville because he had experience with the Nez Perce and was an excellent trapper. Upon arrival at Ogden's unknown river (the Humboldt), they began setting traps for beaver. As the days passed, Walker and his men noticed not only more Indians but that traps began to disappear. The Paiutes, being non-aggressive and peaceful, bore no ill will towards the trappers. Rather, they did not share the Anglo perception of private property and often took what they wanted, puzzled at the white man's unwillingness to share. The Paiutes extended several invitations to meet with the white men, and Walker accepted. When the meeting took place with a group of 30-40 Paiutes, Walker and his men attacked without provocation or warning, killing 14 Indians and setting the stage for three decades of "intermittent warfare and recrimination" (Laxalt, 1989: 33). Zenas Leonard, a member of Walker's party, later recounted in his journal that this practice was a routine one, designed to "test" the skills Walker's men had at killing Indians. Between 1833 and 1834, they killed over 100 Paiutes (ITCN, 1976).[37]

Besides the trappers, mountain men, and explorers, another intruder on the Paiutes was the tamarisk. It was introduced in the southwest as an ornamental tree in the mid-1830s and became well-established by the time this area began to be settled by whites. Tamarisk flourished along the river banks and streambeds, crowding out the cottonwoods and willows that were necessary to the survival of the natives. Tamarisk has deep roots, consumes much water, and is worthless as wildlife habitat or forage (Kartesz, 1987). It continues to be difficult to eradicate from the Walker River Basin and elsewhere in the Great Basin.

Another major western explorer was Captain John C. Frémont,[38] renowned surveyor and map maker. In 1842, the U.S. Bureau of Topographical Engineers commissioned Frémont to survey the Great Basin. His first visit to this area was in 1842-1843; he headed south from the Columbia River Basin and eventually discovered Pyramid Lake, which he so named because of the pyramid-like rock formation that sits at the eastern end of the lake. He also explored what is now the Truckee River, which supplies fresh water to the lake.[39] After a month of mapping the area, he left the Great Basin to find the "lake in the mountains" that had been described to him by the Paiutes. After reaching present-day Lake Tahoe, he proceeded down the mountain toward the American River.

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[37] The story of these expeditions was published in 1837 as Washington Irving's *Adventures of Captain Bonneville in the Rocky Mountains and Far West.*

[38] He was also renowned for the role that he played in the conquest of the southwest for the United States and for eventually being elected to the U.S. Senate, representing California.

[39] Salmon Trout River, the name given to the Truckee River by Frémont, was not adopted.

The second time he explored Nevada, in 1845, he was accompanied by Joseph Walker, about whom we have already heard, and Kit Carson, whose exploits would become legendary. Their party crossed the Great Basin in two groups, "redefining" the limits of the Humboldt, Carson, Walker, and Truckee River basins. Because Frémont kept a far more thorough record of his explorations than his predecessors, the names that he gave to prominent natural landmarks were officially adopted. In addition to Pyramid Lake, he named the Walker and Carson rivers after his co-explorers; he named Ogden's "unknown" river after Baron Alexander von Humboldt, a German scientist; and he even gave the Great Basin its name (Hulse, 2004: 42).

Between 1800 and 1840, a steady stream of emigrants headed "westward through the forests, from the Appalachia Mountains to the middle of the continent, and then west of the Mississippi River. For a few years they stopped at that point, like water behind a dam, because the arid prairies and the 'Indian Barrier' presented many hazards" (Hulse, 2004:43). By 1840, however, reports of abundant, essentially "free" land began to attract American families east of the Mississippi.[40] Unlike their predecessors, these people were interested in establishing a new life in the Far West.

The first expedition to successfully cross the Great Basin was organized by 29-year-old school teacher John Bidwell, head of the newly-formed Western Emigration Society, and led by him and John Bartelson in 1841. Yet, their ignorance about the western frontier, the land they would cross, and the obstacles they would face did not portend well for the group (Bowers, 1996). The extent of their knowledge was that California lay west. At the beginning of their trip, they were fortunate to meet a group of Jesuits who were headed to Oregon and whose guide, Thomas "Broken Hand" Fitzpatrick, was an experienced fur trapper who knew the land well. The two parties traveled together more than 1,000 miles to the Bear River, near Salt Lake. Fitzpatrick and the missionaries then headed north toward Oregon, accompanied by about half of the original Bidwell-Bartelson party.

The other half, still led by Bidwell and Bartelson, headed independently toward the deserts of the Great Basin,[41] where they experienced wagons getting stuck in the sand and underbrush, the animals becoming exhausted, and food and water becoming scarce. Eventually, the group was forced to abandon much of its belongings in order to lighten the load for the struggling oxen.[42] They crossed the Ruby Mountains and entered the Humboldt River Basin on foot, because there were few horses left to carry them. Impatient at the slow progress, Bartelson and seven other men, all of whom had horses, peeled off from the main group and went ahead. Bidwell was left to lead the rest of the party through Forty Mile Desert into the Carson River Basin, where they headed south toward the Walker River. In the meantime, Bartelson and his men became lost. Disoriented and starving, they were discovered by a band of Paiutes, who gave them fish and pine nuts and guided them out of the desert. The Bidwell and Bartelson parties

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[40] In 1831, Congress passed the Preemption Act, which recognized the right of "squatters" to acquire title to land in the West simply by using it.

[41] Two of these were Nancy Kelsey and her daughter, who became the first white woman and child to cross the Great Basin.

[42] This was to happen repeatedly to emigrants, who often attempted to bring most of their transportable worldly goods.

unexpectedly reunited in the Walker Basin, where they headed across the snowy mountains. Along the way, they ran out of food and were forced to slaughter their oxen and horses. Finally, on October 31, 1841, they arrived at their destination, the San Joaquin Valley. Remarkably, they had completed the trip with neither maps nor guides, though it had taken six months. No one had died or been killed along the way, and their encounters with Indians were few and friendly (Hulse, 2004: 47).

Later that same year, the Rowland-Workman party traveled from Santa Fe to Los Angeles along Jedediah Smith's route. They managed to bring a flock of sheep and, upon arrival in the Los Angeles area, obtained land grants from the Mexican government. They settled in the area, becoming prominent ranchers near San Gabriel, California. This time the trip had been completed in two rather than six months (Hulse, 2004: 47). Despite the success of these two groups of settlers, the following decade saw only a steady trickle of western emigration.

Several other parties traversed the Humboldt Trail in the 1840s. The one led by Elisha Stevens, Martin Murphy, and John Townsend in 1844 (Bowers, 1996) opted not to follow the well-established route from the Humboldt Sink south to either the Carson or Walker Rivers. Instead, they took an unknown path across Forty Miles Desert to a river that they called the Truckee. Parts of the Truckee River canyon were so steep and narrow that the travelers had to walk in the river, their feet bleeding from the river rocks. The present-day Donner Pass proved even worse. They had to take their wagons apart and pull them over the steep canyon walls using pulleys. In only two months, they reached the Central Valley of California with no loss of life and most of their belongings intact (Hulse, 2004: 47).

Donner Pass through the Sierra Nevada received its name because of the fate of the Donner Party, which attempted unsuccessfully to cross it.

The original party of 32 organized in Springfield, Illinois under the leadership of George Donner. By the time the party arrived in Independence, Missouri, it had grown to about 100 people, a disproportionate number of whom were elderly, women, and children. They left Independence on May 3, 1846. The first 78 days were uneventful because they traveled a well-known route, which many emigrant groups had successfully traversed (Beck and Haase, 1974). However, on July 20, at Little Sandy, the first critical decision was made. A messenger from Lansford Hastings told them of a cutoff that Hastings had discovered that would shorten the trip by 350-400 miles. Part of the group stayed on the well-marked California Trail, while the other 87 took the shortcut. Before reaching Fort Bridger, they encountered Joseph Walker, who urged them to return and take the marked trail. They rejected his advice, and set off into the trail-less Utah wilderness without a guide. It took them a month to reach the southern part of the Great Salt Lake, beyond which lay the dreaded Forty-Mile Desert.[43] As their oxen died from heat and exhaustion, they abandoned many of their wagons. On September 20, they reached the Humboldt River and returned to the California Trail, reaching it 45 days after the fragment of their original party. The group reached the base of the Sierra on October 30, "its morale shattered by murder, desertion, and death" (Beck and Hasse, 1974: 45). Had they kept going, they may have been able to beat the snow through the pass. Instead,

[43] It took them 21 days to travel just 36 miles.

they rested five days, and were completely snowed in by November 4. They did little to prepare themselves for surviving the winter. They cut no firewood, constructed no shelters, and slaughtered no livestock for food. The animals just wandered off in the snow and died.[44]

Part of the group camped in cabins on Truckee Lake; the other part camped in tents and huts near Alder Creek. On December 15, a group of 15 attempted to cross the pass, on crudely-constructed show-shoes, with barely enough rations to last six days. Their journey lasted 32 days, and only seven of the men survived it. As members of the groups died, their flesh was eaten by the others. The group left behind at the camps at the base of the summit also resorted to eating the flesh of those who died. When word reached Fort Sutter, four relief expeditions were sent to rescue what remained of the group. Only 47 survived the ordeal, most of whom were women and children (Beck and Haase, 1974). News of the disaster spread quickly and widely, dampening enthusiasm for making the trek for several years.

The Church of Jesus Christ of the Latter-Day Saints

The history of the Church of Jesus Christ of the Latter-Day Saints is intertwined with that of Nevada. Joseph Smith laid the foundation for Mormonism in New York in the 1820s. The new religious movement elicited controversy from the outset. It was a communal, egalitarian movement that put the good of the whole over that of the individual. Its members were well-organized, which when combined with their strong work ethic and ability to attract converts, made them economically prosperous—and the object of jealousy. Joseph Smith's New York flock numbered only 70, but by 1860, there were more than 65,000 Mormons in Utah alone. They also were aloof from their non-Mormon neighbors, even refusing to do business with them. And they practiced polygamy, which was abhorrent to other religious denominations (Baer, 1988).

In reaction to the escalating conflict between Mormons and non-Mormons, Smith moved his flock first to Ohio and then to Missouri, but still they were met with suspicion, hostility, and violence. They moved again in the winter of 1839, this time to Nauvoo, Illinois, where Smith began to build a religious and political power base. By 1844, Nauvoo had a Mormon population of over 12,000, making it the second largest city in Illinois. The Illinois legislature granted Nauvoo a charter that essentially enabled it to rule itself, as long as the laws it passed did not conflict with state or national laws. It even had its own militia, with Smith as its Lieutenant General. The assassination of Smith on June 27, 1844 at the jailhouse in Carthage, Illinois led his successor, Brigham Young, to move his people again. In 1846-1847, he led 15,000 Mormons to present-day Utah and laid claim to a vast tract of land for his people. In 1849, he proclaimed that region the State of Deseret (Bauer, 1988:9).[45]

Meanwhile, the United States was at war with Mexico for control of California and what is now the southwest. The war ended in 1848 with the Treaty of Guadalupe Hildago, which gave the United States control over California, Utah, Nevada, and

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[44] For a complete history of the Donner Party's experiences, see *The Perilous Journey of the Donner Party* (1999) and *Ordeal by Hunger: The Story of the Donner Party* (1963).

[45] This region included present-day Utah, Nevada, and Southern California and parts of Arizona, New Mexico, Idaho, and Colorado (Bowers, 1996: 5).

portions of Arizona, New Mexico, Wyoming and Colorado. The Great Basin was now "firmly ensconced in the hands of the United States" (Bowers, 1996: 5).

In 1850, Young petitioned Congress to admit the State of Deseret to the union as a state. Rejecting that petition, Congress passed the Compromise of 1850 instead. That act established California as a slave-free state[46] and created the New Mexico and Utah Territories, leaving each to decide whether to permit slavery. The Utah Territory, which included most of what is now Utah, parts of Colorado and Wyoming, and most of present-day Nevada (Bowers, 1996; Horton, 1996b), [47] was only half the size that Young had claimed for the State of Deseret. Brigham Young was appointed governor of the new territory on February 9, 1851.[48]

Not surprisingly, the first people to become established in the western edge of the Utah Territory, in present-day Nevada, were Mormon. Joseph Demont and Hampton S. Beatie established a trading post, Mormon Station, in Carson Valley in 1850. They sold or bartered goods to emigrants passing through. Although they ceased operations when winter arrived, they had demonstrated that trading stations could be profitable. Mormon Station was settled again in the following year, by a party led by John Reese, who came to the area to farm, and became the first permanent settlement in Nevada. Its name was changed to Genoa in 1856. Other pioneering entrepreneurs established stations in Carson, Eagle, and Jack's valleys as well as in the Truckee Meadows (Bowers, 1996).

The non-Mormon population in Carson Valley surged in 1850 after gold was discovered in Gold Canyon near Virginia City in 1850.[49] Prospectors often spent the warm months mining in the canyon, returning to California in cold weather and taking their usually small bounties. Although they built no permanent structures because they did not intend to stay, they did create a "culture'' of sorts, of their own (Hulse, 2004: 66). Other non-Mormons settled there as well. The relationship between Mormons and Gentiles was never comfortable. The Mormons viewed the newcomers as a threat, whereas the latter resented—and resisted—being governed by Mormons in Salt Lake City. The non-Mormon settlers held three meetings in Mormon Station in 1851, where they created a "squatter" government to pass laws and regulations. They also petitioned Congress for a "distinct Territorial Government" for the western part of the Utah Territory (Bowers, 1996: 8). The petition was denied. Then, in 1853, the non-Mormons petitioned California to annex their valley. Young responded by having the Utah legislature create Carson County in 1853, a huge new county that included present-day Carson City, Washoe, Douglas, Storey, Lyon, and Mineral Counties as well as parts of Churchill, Esmeralda, and Humboldt counties. Moreover, Young largely ignored the western part of the territory, leaving it with no local government and no protection from lawless forces. Finally, in January 1855, Young moved to exercise control over the region. The Utah legislature proclaimed Carson County as Utah's third U.S. judicial

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[46] California had never been a territory.

[47] Establishing the Utah Territory was also a result of the Compromise of 1850, the goal of which was to bring more slave-free territories into the union to balance the power between slave and free states.

[48] He was also appointed ex-officio superintendent of Indian Affairs, a responsibility that he took very seriously (Dale, 1949: 66).

[49] Several people claimed to have been the first to find gold in Gold Canyon. Because of conflicting records, this question may never be resolved.

district, and Young appointed Orson Hyde, a member of the Mormon governing board, as probate and country judge to organize the county. Carson County was also given one vote in the Utah legislature (Bowers, 1996).

Hyde came with 38 other Mormons to Carson valley in June 1855, determined to establish a functioning government there. Hyde called for county elections on September 20, and all but one of the winners in that election were Mormon. The non-Mormons again petitioned to be annexed to California. Young responded by sending 60 more Mormon families to Carson Valley, making them 500 strong. Mormon Station was renamed Genoa and made the county seat. For two years, Hyde and his fellow Mormons tried to build a society in Carson Valley that was based on Mormon principles, despite continuous resistance by the non-Mormon population (Bowers, 1996; Hulse, 2004). Hyde returned to Salt Lake City, although it is uncertain whether this was at Young's request. In any case, the fledgling government Hyde had established began to unravel. Other Mormons decided to return to Salt Lake City as well. Finally, in September 1857, Brigham Young summoned the Mormons in all the outlying settlements to return to Salt Lake City to defend it from a possible attack by the federal government. That battle never occurred, but many Mormons abandoned their farms in Carson Valley, which were quickly taken up by Non-Mormons (Hulse, 2004).

Paiute-Anglo Conflicts

As the number of emigrants increased during the 1850s, violence between the Native Americans and whites escalated. Many settlers were inclined to shoot the Indians they encountered at the "slightest provocation," which the Indians often unwittingly gave them. Not sharing Anglo ideas about private property, they "took" from the settlers things they wanted or needed. As additional settlers crowded the Paiutes out of areas they had freely roamed, they stole out of desperation. Nonetheless, the Native Americans in the Great Basin, as had been the case with Indians all over the United States, were clearly the victims of the "racist attitudes of a conquering nation whose army leaders and emigrants had little regard" for the Indians they encountered (Hulse, 2004: 61), often viewing them as less than human.

The federal government began to establish reservations onto which they eventually moved entire Indian tribes. Much of what we know about the Washo and Paiute tribes that lived in northwestern Nevada at this time came from Frederick Dodge, who was in the area from 1858 to 1860 as an Indian Agent for the Utah Office of Indian Affairs. His instructions were to find suitable lands for the tribes, where they could be relocated and trained to farm and raise livestock. The land that was typically selected for Indian reservations was so arid that farming was impossible. Most people seemed to believe that the Indians "preferred to live in the most unfruitful and desolate" regions of the country even though most Native American tribes circumscribed areas that included streams, rivers, and valleys (Dale, 1949). The real goals appeared to be to prevent Native Americans from impinging on settlers, to reduce the violence between the two cultures, and to indoctrinate Native Americans in the Anglo tradition.

Dodge first selected Truckee Meadows as a suitable reservation site, but by the time he sent his recommendation to Washington in 1859, the Comstock Lode was discovered in and around present-day Virginia City. Settlers began to pour into the adjacent valleys before the government had withdrawn the land. Dodge then selected land in Truckee and Walker River Basins and recommended that the two lakes the rivers emptied into be part of the two resulting reservations. On November 29, 1859, Walker Lake and 318,809 acres of land around it were withdrawn from the public domain to establish the Walker River Paiute Reservation, but no further action was taken to officially create the reservations (Horton, 1996b: II-8; Hulse, 2004).

The spring of 1860 brought the first major violence to Washoe country, between the frontier mining society and the Northern Paiutes in north central Nevada. James Wilson had established a trading station on the Carson River about 30 miles from Virginia City. In his absence, two of his men kidnapped two young Indian women and took them to the station, provoking an attack in which three white men were killed, likely by the Bannock Indians who were temporarily in the area. When Williams returned to find his friends dead and his station burned to the ground, he concluded that the Paiutes were on the warpath (Hulse, 2004: 69).

News of the killings spread in two directions: to the whites in Carson and Virginia City and to an Indian war council that was being held at Pyramid Lake among the Paiute, Shoshone, and Bannock. The news arrived at the lake just as a young Paiute chief, Numanga, was pleading for peace:

> You would make war upon the whites. I ask you to pause and reflect. The white men are like the stars over your head. You have wrongs, great wrongs, that rise up like those mountains before you. But can you, from the mountaintops, reach out and blot out those stars? Your enemies are like the sands in the beds of your own rivers. When taken away they only give place for more to come and settle there. Could you defeat the whites of Nevada, from over the mountains in California would come to help them an army of white men that would cover your country like a blanket…. I love my people; let them live; and when their spirits shall be called to the Great Camp in the southern sky, let their bones rest where their fathers were buried (Laxalt, 1989: 33).

When he heard about the white killings, he realized it was too late. They prepared for the inevitable attack.

When the news reached Carson, no one checked the validity of Williams' claim. His story spread in exaggerated form: hundreds of Paiutes were on the warpath. In response, a volunteer army of 105 men, under the leadership of Major William Ormsby, was assembled. It was a rowdy, undisciplined group unprepared for the kind of warfare they were instigating. On May 12, it proceeded down the lower Truckee Canyon towards Pyramid Lake. When they began to approach the lake, the Paiutes lured them into an ambush and "poured a shower of arrows and bullets into their disorganized ranks" (Laxalt, 1989: 34). The Paiutes killed 76 men, including Ormsby. The rest fled back to Carson to tell of the "horror" that had occurred.

When the news reached California, four companies of the U.S. Cavalry joined forces with 500 volunteers from Carson Valley. They attacked the Paiutes, killing 160 of them in a single battle near Pyramid Lake. Numanga sued for peace. A network of military posts was established to protect white settlers. Although the whites and Paiutes never made war against each other again, the truce was an uneasy one until around 1878. By then, treaties were signed between the Paiutes and the federal government, formally establishing reservations for them. They were forced to give up their nomadic way of life, to become farmers or menial workers in the white settlements. Some wound up beggars, hanging on the fringes of white settlements.

Gold and Silver In Nevada

The Comstock Lode was the first major silver deposit discovered in the United States, on the eastern slope of Mount Davidson beneath present-day Virginia City. The men who discovered the Comstock Lode, "Old Virginny" Fenimore, Henry P. Comstock, Patrick McLaughlin, and Peter O'Riley, were unaware of its worth. Between the year it was discovered, 1859, and when the mine was exhausted some 20 years later, it generated more than $300 million in silver and gold (Hulse, 2004:67). From 1865 to 1879, Nevada was regarded as "the most important center for the production of precious metals in America" (Hulse, 2004: 102). In addition to the Comstock Lode, new mining communities sprang up and thrived in the eastern counties, as pockets of gold and silver were discovered and exploited. The biggest boost to Nevada's mining industry came with the discovery of the "Big Bonanza."

John Mackay, an Irish immigrant, began his mining career as a hard-rock miner in Gold Hill. He and James Fair, also an Irish immigrant, gradually obtained an interest in Hale and Norcross, a mining enterprise located at the center of the Comstock Lode. They took the profits and acquired control of other mining claims in the Comstock, which became the Consolidated Virginia and California. At the center of the Comstock, 1,300 feet below the surface of Virginia City, their crews discovered the Big Bonanza.[50] It was a block of rich gold and silver ore extending 300 feet, the richest large body of high-grade ore found in America. Over the next nine years, it yielded over $100 million and paid more than $74 million to its stockholders.[51] James Mackay became known not only for his role in the Bonanza firm, but for his honesty in business and generosity to fellow miners who were down on their luck (Hulse, 2004: 106). A statue in his honor stands on the campus at the University of Nevada, Reno, and Mackay Stadium and the Mackay School of Mines are named after him.

Mining and everything associated with it influenced the social and political structure of Nevada for the next 100 years. Mining also became part of the Nevada psyche, as did gambling of all sorts. Mining towns experienced cycles of bust and boom, creating social instability. Nevada Senator William Morris Stewart, an ally of the mining interests, was responsible for the country's first mining law, the National Mining Law of 1868. This gave legal authority to mining regulations that were already in place. It also provided that miners could preempt part of public lands and its waters simply by laying claim to and making use of them (Hulse, 2004: 106), paving the way for western adoption of the appropriation doctrine. The provisions of this law remain in effect.

A new American phenomenon rose up around the major mining enterprises: mining cities. These were aptly portrayed in the popular press as extravagant, wild places

[50] Bonanza is a Spanish word meaning prosperity or a rich vein of ore.
[51] In that same year, the entire budget of the state was less than $600,000.

whose fortunes were determined by those of its mining magnates. During its heyday, Virginia City boasted some of the best establishments—mansions, opera houses, cultural centers, churches, and schools—in the West. It also had the most elaborate saloons. The city's wealthy wives furnished their homes and decorated themselves with the finest luxuries. Hulse captures the spirit of those times:

> Its wealthy magnates lived high on the mountainside, near or above C Street, which was the main business thoroughfare. Below, in alphabetical order, were streets where one could find the brothels, the bustling railroad station, the large hoisting works, the Chinese and the Indian communities. Most residents lived close enough together on the rocky slopes to be constantly within earshot of the business bustle on C Street, the riotous life of the saloons, the roar of the mine hoists and stamp mills, and the constant to-and-fro surging of humanity (2004: 107).

Its total population never exceeded about 20,000, yet it attracted celebrities from all over the United States. Scores of writers visited and wrote about its wonders. Mark Twain honed his craft there, first as a journalist and later as a satirist. He became one of the most famous western writers in America. For most of its boom period, Virginia City's men greatly outnumbered the women, sometimes by 16 to 1. Although a small minority, women provided a much-needed civilizing and stabilizing influence, involving themselves in the establishment of schools, churches, and civic centers. Some who came to the Comstock seeking their fortunes worked in the theaters, dance halls, saloons, or brothels (Hulse, 2004).

On October 25, 1875, a fire broke out in Virginia City, stoked by the winds and fed by the timber of thousands of trees that had been used to build the city. In several hours, it consumed most of the business center and public buildings. Mackay managed to save the mine shaft to the Big Bonanza. Comstock money rebuilt the city to be even more extravagant than before. The main buildings that are famous tourist attractions now were constructed after 1875 (Hulse, 2004: 108). Comstock's prosperity ended when most of the mines had been exhausted, compounded by the U.S. ceasing to mint silver dollars in 1873 and the increased production of silver in other areas of the state.

Nevada Statehood

The years from 1860 to 1864 were important ones in the creation of what was to become the state of Nevada, both physically and culturally. Even though the slogan "Battle Born" is emblazoned on Nevada's flag, no Civil War battles were fought there. Nor did Nevada's substantial silver wealth finance the Civil War, though this was widely believed. However, the Civil War catalyzed Nevada's transition to statehood. Southern states would have never approved the creation of more slave-free territories, especially those that were sparsely populated. But when the South seceded, there were no southern representatives in Congress to raise such objections. Sensing the inevitability of civil war, President James Buchanan signed legislation granting territorial status to Nevada during his last days as president, on March, 1861.[52] Shortly after Abraham Lincoln was inaugurated three weeks later, he appointed political supporter James W. Nye of New

[52] The Dakota and Colorado territories were established in 1861 as well.

York to serve as its governor. It took Nye eight months to establish a functioning government there (Hulse, 2004: 80). When the new legislature met for the first time, it designated Carson City as the capitol and provided for the creation of eight county seats and nine counties.[53]

When the territorial government met again, in late 1862, the legislature called a special election for September of the following year, to hold a referendum on becoming a state. The vote was overwhelmingly for statehood (6,600 v. 1,500). Even though Congress had not passed enabling legislation to authorize the territory to hold a constitutional convention, one was held anyway and elected 39 delegates to draft a constitution. The first constitution was rejected by the voters on January 19, 1864, largely because it was considered to be a taxation threat to the mining industry.

A second attempt at the process was spurred by the intervention of Lincoln and the Republican Party, who feared that they would not be able to carry enough states to win the presidency in the 1864 election. In spring of 1864, Lincoln signed legislation authorizing three new territories, Nebraska, Colorado, and Nevada, to convene constitutional conventions and to form state governments. Nevada was the only one to complete this process; the voters approved its constitution in September after the delegates removed the controversial mining clause.[54] President Lincoln proclaimed Nevada the 36th state in the union on October 31, 1864, "just in time to participate in the presidential election and to vote for the Thirteenth Amendment, which abolished slavery (Hulse, 2004: 84).

The formation and development of Nevada was greatly influenced not only by mining but cattle ranching and agriculture. The fates of the Walker Lake Paiute Tribe and Walker Lake have been shaped by these forces as well. This is covered in the next chapter.

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[53] These were Esmeralda, Douglas, Ormsby, Washoe, Storey, Churchill, Humboldt, and Lyon. The last county was to have been Lake County. No government was established there, however, and it was eventually annexed to Washoe County.

[54] Instead of taxing mines the same way that other property was taxed, as had been the case in the first constitution, only the proceeds of an active mine would be taxed.

CHAPTER FOUR: P. L. 109-103 AND THE WALKER BASIN PROJECT

BACKGROUND

The two forks of the Walker River rise in the high Sierra Nevada, north of Mono Lake in California. Each fork winds its way down the mountain. The West fork crosses the Nevada-California state line in Antelope Valley near Topaz Lake. The East Fork crosses into Nevada near Bridgeport, California, east of the Bridgeport Reservoir, and passes through the Sweetwater Mountains. The two forks merge five miles south of Yerington, becoming the mainstem Walker River. The river flows past ranches and farms around Yerington, through the Mason Valley Wildlife Management Area. It then travels 45 miles across the Walker River Paiute Reservation,[55] terminating in Walker Lake, near Hawthorne[56] (Horton, 1996b; Sharpe et al., 2007). Because most of the surface water of the East and West forks of the Walker River are used to support irrigated agriculture in Smith and Mason Valley, by the time the river reaches the reservation, its flows have been greatly diminished.

Mason and Smith Valleys are part of Lyon County, one of the fastest growing counties in the nation.[57] From 2000 to 2007, the population of Lyon County grew from 34,501 to 49,824 (U.S. Census, 2008). Such growth and development has increased the competition for water resources in the Walker River Basin. Additional pressure comes from the Walker River Paiute Tribe,[58] which is allied with the federal government in litigation to obtain more water rights for the reservation. Environmental, fishing, and recreational interests are interested in the preservation of Walker Lake.

Walker Lake is one of the six largest natural terminus lakes in western North America. It is also one of three desert terminal lakes in this area that support a freshwater fishery.[59] The river and the lake are facing serious issues. The river is over-allocated, meaning that not all the demands on the river can be met, even in "normal" water years. Because irrigated agriculture in Mason and Smith Valleys consumes a significant part of the river upstream from the lake, the lake has been steadily declining. The lake level dropped from an historic (1882) high elevation of 4,083 feet above mean sea level (msl) to 3, 934 (msl) (2007), which translates into a 149 foot drop in lake depth, and a decrease in total lake volume from approximately 9.0 to 1.7 million acre-feet. Upstream barriers (including major storage reservoirs diversion dams, lack of passage and screening facilities) have contributed to the demise of the Walker Lake ecosystem and its fishery as well. Consequent changes in water quality have impaired the entire lake ecosystem.

The original genetic strain of Lahontan cutthroat trout (LCT) in the lake is extinct, and the lake has been stocked with a different strain of LCT. The major food source for

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[55] The reservation, established November 29, 1859, is located 42 miles south of Fallon and 23 miles east of Yerington.

[56] Although Walker Lake and the Indian reservation are located in adjacent Mineral County, the center of agricultural production is in Mason and Smith Valleys in Lyon County.

[57] In part, this growth stems from the location of national distribution centers for corporate giants such as Wal-Mart, Amazon, and Sherwin-Williams.

[58] The tribe and the federal government are seeking legal recognition of storage rights in Weber Reservoir on the reservation, as well as water rights for lands that were returned to the reservation in 1936.

[59] The other two are Pyramid Lake and Summit Lake, also located in Nevada.

the existing LCT is the tui chub, which the lake ecosystem is increasingly unable to support. (Sharpe, et al., 2007:2-3).[60] The lake naturally experiences a build-up of total dissolved solids (TDS), particularly salts. TDS concentrations are more than 17,000 milligrams per liter (mg/l), up from 1882 recordings of 2,560 mg/l. Studies show that "concentrations approaching 16,000 mg/l would result in a 100% mortality rate for the lake's Lahontan cutthroat trout" (Horton, 1996b:I-12).[61] If the salinity issue is not dealt with in the near future, the lake will cease being a sustainable habitat for Lahontan cutthroat trout and migratory waterfowl. In 2004, water quantity and quality issues caused all of the Lahontan cutthroat trout in the lake to die. The Bureau of Reclamation asserts that the lake is currently at risk of "environmental collapse" (U.S. Bureau of Reclamation, 2008).

The federal government's physical presence in the Walker Basin is threefold. The U.S. Geological Survey (USGA) has several gaging stations by which it measures instream flows in the Walker River. There is an Army Depot in Hawthorne. And the Bureau of Land Management (BLM) owns the land surrounding much of Walker Lake. It has a legal presence as well, because of its trust obligations to the Walker Lake Paiute Tribe, on whose behalf the federal government advocates.

The irrigation system in Walker Basin is privately developed, owned, and operated. Its diversion works and irrigation canal systems were constructed by individual landowners and are managed by several ditch companies and the Walker River Irrigation District (WRID). Currently, there are ~110,850 acres of land in production in the basin (Sharpe, et al., 2007:6).[62] In Smith and Mason Valleys, WRID provides surface and storage water rights for ~80,000 acres of land.

Increased conflict on the Walker River system led to a 2003 Federal District Court-supervised and -sponsored mediation between stakeholders representing the Walker Lake Paiute Tribe; the Walker River Irrigation District; Lyon County, Nevada; Mineral County, Nevada; Mono County, California; the Walker River Working Group; the states of California and Nevada; and the federal government. Recognizing that more than three years of mediation efforts had produced no agreement on any of the basic issues, the Walker River Paiute Tribe withdrew from mediation, followed several months later by Mineral County and the Walker River Working Group (Riley, 2006:4A). The stay that had been placed on lawsuits challenging the provisions of Decree C-125 was lifted by the court, thereby permitting the parties to resume litigation.[63]

As early as 1993, Senator Reid sought help from conservation biologists at the University of Nevada, Reno in establishing baseline conditions for flora, fauna, and water quality of the Walker River Basin, on which federal actions could be taken. That research was completed by summer of 2004 and helped inform future policy developments

[60] Although the tui chub did spawn in 2005, there were no discernable, viable eggs or larvae (Sharpe, et al., 2007).
[61] The lake contains microenvironments that are spring-fed, which is buying time for both the lake and the fishery it supports.
[62] This figure represents the basin-wide total for lands with surface water rights (decree plus storage), not lands in production.
[63] C-125, issued June 1939, allocated the waters of the Walker River based on priority of uses (Horton, 1996b, p. III-7).

regarding Walker Lake. Eventually, Senator Reid sought—and received—authorization for a federally funded water rights acquisitions program to purchase water from "willing sellers" to deliver to the lake. That authorization came from P. L. 109-103, the Energy and Water Development Appropriations Act, which Congress passed on November 19, 2005.

PRECURSORS TO 109-103

The road to passage of P. L. 109-103 is an interesting one. On May 13, 2002, Congress passed P. L. 107-171, the Farm Security and Rural Investment Act of 2002 (the Farm Bill), a five-year authorization for all of the programs in the Department of Agriculture.[64] Section 2507 the Farm Bill authorized the Secretary of Agriculture to transfer $200 million to the Bureau of Reclamation Water and Related Resources account, to be used to study and assist at-risk natural desert terminal lakes. It stipulated that the funds "remain available until expended" [Sec. 2507(a) (2)]. To gain consensus on the $200 million, Section 2507 stipulated that none of these funds could be used to either purchase or lease water rights.

The following year, Congress enacted P. L. 108-7, the Omnibus Appropriations Bill. Section 207 of this bill allocated money that had previously been appropriated from Section 2507 of the 2002 Farm Bill to provide water and assistance to the three desert terminal lakes in northern Nevada, including $1 million to create a fish hatchery at Walker Lake to benefit the Walker River Paiute Tribe. Additionally, $2 million was provided in equal shares to the states of Nevada and California, the Truckee Meadows Water Authority, and the Pyramid Lake Paiute Tribe to further implement the provisions of the negotiated settlement (P. L. 101-618) of 1990. Finally, section 207 (b) authorized the Secretary of Interior to provide financial assistance to state and local public agencies, Indian tribes, non-profit organizations, and individuals to carry out the terms of Section 207 of the Omnibus bill and Section 2507 of P. L. 107-171 (the 2002 Farm Bill). Section 207 of the Omnibus bill did not include a prohibition against using these funds to purchase or lease water rights.

Additional money from the 2002 Farm Bill was made available when Congress passed the Energy and Water Development Appropriations Act of 2004 (P. L. 108-137). Section 207 provides $2.5 million to the state of Nevada to purchase water rights in Lahontan Valley to improve Carson Lake and Pasture, "notwithstanding" the prohibition against same contained in section 2507 of the 2002 Farm Bill. These funds cannot be expended until the state of Nevada receives title to the Carson Lake and Pasture, as required by the negotiated settlement on the Truckee and Carson rivers. Additionally, one million dollars was provided to the University of Nevada, Reno, for an outsourced public education and outreach initiative focused on the Walker River Basin. This initiative led to the first public proposal to acquire water rights from a specific potential willing seller, who eventually became the first person to sign an option and purchase agreement as part of the University's Walker Basin Project.

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[64] The Farm Bill comes up for reauthorization every five years. Congress then annually appropriates money for agricultural programs as it sees fit during those five years.

Related Legislation

In November 2005, Congress passed P. L. 109-103 (see Appendix C), the Energy and Water Development Appropriations Act of 2006. Section 208 directs the Secretary of Interior (under the provisions of section 2507 of the Farm Bill of 2002) to provide not more than $70 million to the University of Nevada, Reno to accomplish the following goals:

> (A) to acquire from willing sellers land, water appurtenant to the land, and related interests in the Walker River Basin, Nevada; and (B) to establish and administer an agricultural and natural resources center, the mission of which shall be to undertake research, restoration, and educational activities in the Walker River Basin relating to—(i) innovative agricultural water conservation; (ii) cooperative programs for environmental restoration; (iii) fish and wildlife habitat restoration; and (iv) wild horse and burro research and adoption marketing [sec. 208 (a)].

Section 208 (b) of P. L. 109-103 specified that the Secretary shall provide $10 million for a water lease and purchase program for the Walker River Tribe, provided that water be acquired only from willing sellers. The program must be designed to maximize water conveyances to Walker Lake and located only within the reservation. Section 208 (c) provides $10 million for tamarisk eradication, riparian restoration, and channel restoration efforts within the Walker River Basin, "with priority given to activities that are expected to result in the greatest increased water flows to the lake." It also provides $5 million to the U.S. Fish and Wildlife Service, the Walker River Paiute Tribe, and the Nevada Division of Wildlife to complete the design and implementation of the Western Inland Trout Initiative and Fishery Improvements in the State of Nevada, with an emphasis on the Walker River Basin.

Anticipating potential bureaucratic inertia and possible public opposition to the project, the act states that "for each day after June 3, 2006, on which the Bureau of Reclamation fails to comply with subsections (a), (b) and (c), the total amount made available for salaries and expenses of the Bureau of Reclamation shall be reduced by $100,000 per day" [Sec. 208 (d)]. The Bureau accomplished this by initiating a planning process that led to the commitment of the appropriated funds to the University of Nevada before the deadline of June 3. Essentially, Reclamation entered into a master agreement to obligate the entire $70 million. The $14 million of those funds that were dedicated to research in the Walker Basin would only be released based on individual task orders (the planning process mentioned above was the first of these). The remaining $56 million is to be spent on purchase options and purchases of water rights from willing sellers in the basin.

The provisions of P. L. 109-103, section 208 are being implemented through a collaborative effort of the University of Nevada (UNR) and the Desert Research Institute (DRI) under the direction of the Nevada System of Higher Education (NSHE). UNR and DRI provide the scientific expertise for the Walker Basin Project, and the NSHE coordinates the project through the Office of the Chancellor. Broad oversight is provided by the Walker Basin Working Group.[65] NSHE chose to centrally manage the project through its Academy for the Environment (Academy). The Academy, established in 2004, is an interdisciplinary institution whose mission is to develop, improve, and coordinate environmental teaching, research, and service at UNR. DRI's share of the work was administered through its Center for Watersheds and Environmental Sustainability.

The appropriations legislation seeks to take advantage of the University of Nevada, Reno's natural resource management expertise and that of its affiliated sister institution, the Desert Research Institute. This expertise ranges from hydrology to remote imaging to arid land and soils analysis to alternative crops to water quality to limnology and terminal lake fisheries. Money was appropriated to "undertake research, restoration, and educational activities in the Walker River Basin relating to (i) innovative agricultural water conservation; (ii) cooperative programs for environmental restoration; (iii) fish and wildlife habitat restoration; and (iv) wild horse and burro research and adoption marketing." The last component was included to provide an adoption center within Lyon County at the request of local interests and members of the Nevada Congressional delegation (www.unr.nevada/walker).

This effort is to be based on rigorous, objective, scientific research conducted by a land grant university with deep, historic ties to Nevada agricultural interests. The policy goal of this appropriation is to deliver water to Walker Lake to address the increase in lake salinity and eventually reverse it to a level that sustains a robust Lahontan cutthroat trout population and migratory waterfowl, while at the same time maintaining—and perhaps even improving—the economy of the Basin.

THE WALKER BASIN PROJECT

Before the research and acquisitions processes could begin, an acquisitions plan and budget were developed to serve as a long-term "road map" for the project. Eighty percent of the funds ($56 million) were budgeted for the acquisitions program. The other $14 million was budgeted for all other aspects of the project, including research.

Acquisitions

The plan anticipated that the acquisitions process would occur over three stages: the planning and pre-acquisitions period (January 2007–December 2008), the option and due diligence period (January–December 2009),[66] and the acquisitions and stewardship

[65] The NSHE Working Group consisted of Mike Collopy, Director, Academy for the Environment and Co-Chair of the Walker Basin Project Study Group; Milt Glick, UNR President; Marc Johnson, UNR Provost; Dan Klaich, NSHE Executive Vice Chancellor and Chair of the Working Group; Chris Maples, DRI Executive Vice President for Research and Chief Science Officer; Jim Thomas, DRI Associate Research Professor, Director of DRI's Center for Watersheds and Environmental Sustainability, and Co-Chair of the Walker Basin Project Study Group; Steve Wells, DRI Vice President for Research; and John V. White, professor of Law at the University of Nevada, Las Vegas' Boyd School of Law. At Senator Reid's request, Mary Conelly, Senator Reid's State Director, and Robert Dickens, UNR Director of Governmental Affairs, were included as ex-officio members. This group was previously called the Executive Steering Committee.

[66] Due diligence refers to optimizing acquisitions by "evaluating the type of water rights purchases, water losses from the river during transport to the lake, interactions between ground and surface water along the Walker River as it flows to Walker Lake, changes to in-stream biological communities, and total dissolved

phrase (beginning 2010) (NSHE Final Report, 2006). Western Development and Storage, a Los Angeles firm experienced in water storage, conservation, transfers, and banking, was selected to coordinate the water rights acquisitions process. As of July 2009, 11 option and purchase agreements were recorded, with a combined negotiated value of $90 million (subject to appraisal, confirmation of title, and other due diligence issues). Legislation of pending that would substantially restructure and build upon the project's fee acquisition and research efforts to date. It would also end the University of Nevada, Reno's direct involvement with the acquisitions programs and launch a three-year water leasing demonstration program and lead to the University's assignment of its acquisitions-related rights, interests and obligation to the National Fish and Wildlife Federation in early 2010. According to Jim Richardson, a professor at UNR who has been working with the acquisitions team, it is possible that some of the current options may never be exercised, and if they are, it will take four or five years. In the meantime, there is also the possibility that the leasing program will render some of the purchase options moot—and the possibility, as well, that technological advancements may do the same thing. For example, desalination technology is currently under development by Amy Childress and Scott Tyler of the Desert Research Institute (Wolterbeek, 2008).

Walker Basin Project Research (see Appendix D).

Both campuses issued internal requests for proposals (RFPs), which underwent a two-phase review process. The first phase was an internal peer review, judging proposals against the policy directives found in the legislation and appropriations. The second phase was an external review by the Bureau of Reclamation and Senator Reid's staff. Successful proposals were forged into collaborative research teams, with a principal investigator leading each team.

At the end of that process, 13 projects were selected for funding. Two of these were needed to support the acquisitions process: Development of a Water Rights GIS Database of the Walker River Basin, and Development of a Decision Support Tool in Support of Water Rights Acquisitions. Four dealt with potential consequences to agriculture and ecosystems in the basin: Alternative Agriculture and Vegetation Management; Plant, Soil and Water Interactions; Assessing the Importance of Water Acquisitions to the Health of the Instream Environment, Aquatic Ecology, and Lake Health; and Development of Tools to Quantify Sediment Transport within the Walker River Watershed. Two others were selected for their potential contributions to the agricultural economy of the Walker Basin: Water Conservation Practices for Agricultural Producers; and Formulation and Implementation of Economic Development Strategies to Mitigate Economic and Fiscal Dislocations. Three others related to project coordination, communications, and outreach. At the request of local interests and the Nevada Congressional delegation, a Wild Horse and Burro Marketing Study was included. These 13 tasks are funded with a total budget of $10,167,000.[67] Collectively, these tasks will help identify "maximum water delivery combinations in land and water purchases to Walker Lake," as well as the potential consequences of those purchases to the economy

salt (TDS) changes in the river and lake from increased flows of the Walker River" (NSHE Final Report, 2006, p. 15).

[67] The work statement and budget that defined the specific areas of research were developed by Saxon Sharp and Jim Thomas of DRI and Mike Collopy of UNR.

and ecology of the basin (NSHE Final Report, 2006:3).[68] The project coordinator and the NSHE Working Group oversee the project.

The Walker Basin project also includes a contemporaneous policy analysis and project history component linked to a public communications initiative. The experiences of the negotiated settlement on the Truckee and Carson Rivers and other western water resource conflicts suggested the value of including a communications effort from the start of the project. As part of that effort, a Stakeholders Group was formed in late 2006 to represent major interests in the basin. This group includes two at-large members selected by Senators Harry Reid and John Ensign, as well as representatives of the Nevada Department of Conservation and Natural Resources, the U.S. Fish and Wildlife Service, Lyon County, the Bureau of Land Management, the Nevada Division of State Lands, the Walker River Paiute Tribe, the hunting and fishing community, Mono County, the California Department of Water Resources, the Walker River Irrigation District, the Walker Lake Working Group, and Mineral County (www.unr.nevada/walker).

Quarterly meetings were scheduled among the Stakeholders Group, the co-chairs of the Walker Basin Study Group, communication teams from UNR and DRI, the project coordinator, and the chair of the Working Group. The meetings were open to the public.

In addition to the Stakeholders' meetings, the communications team created a website that includes a brief history of Walker Lake, including its current status; the legislation that authorized the $70 million expenditure; project goals; the list of stakeholders, along with contact information; and descriptions of the research projects, including monthly updates. The idea was to create a transparent, ongoing, two-way communication process. Community members were encouraged to attend stakeholders' meetings, where questions were welcome.

Initial opposition to the project in Lyon County was fierce. Public claims were made at these meetings that the stakeholders group did not represent the "real" stakeholders in the valley; that community input was not being taken seriously; and that the research would yield a predetermined set of recommendations. A lawyer representing agricultural and domestic well interests in Mason Valley observed that "the last thing that Nevada needs is to turn the prosperous Mason and Smith Valleys into a mirror image of the now relatively deserted Owens Valley so that they do not disappear the way that Mullholland made the once lush Owens Valley disappear" (Trout, 2007:1).

Many opinion pieces on the project, authored by Jim Sanford, former Mason Valley editor and publisher, appeared in the Mason Valley News. The headlines from these pieces illustrate the sentiment in the basin: "Guest Shot…Any Fight Left in Mason and Smith Valleys?" (July 13, 2007); "A Wake Up Call…If You Don't Think Games are Being Played, You're Naïve" (July 20, 2007); "Saving Walker Lake Really a 'Feel Good' Proposal? Picture Mason Valley without 80% of its Farms (October 5, 2007); "Two Cents Worth: Fair Market Value of Walker River Water is $2,500 Per Acre Foot? (November 16, 2007); and "Two Cents Worth: Is Harry Reid Contributing to Global Warming?" (December 21, 2007).

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[68] The statement of work and budget were developed by Saxon Sharp and Jim Thomas at DRI and Mike Collopy at UNR.

Such criticism began to wane as research team members began their field work, which resulted in positive interactions between the locals and the researchers. The researchers were encouraged by the project coordinator to interact with locals interested in understanding the research aspects of the project. One local farmer, who had consistently opposed any federal role in local agriculture, eventually leased his property to the project to conduct research on water-conserving crops, a sign that the locals were beginning to trust the researchers. Research designs and preliminary results have been presented at community forums and stakeholder meetings. Questions from the community were sought at stakeholder meetings, through telephone calls, and via email messages. Economic analysis of marketable crops was completed and presented to stakeholders and farmers, some of whom sought new crops and additional markets for their enterprises.

As communication increased, newspaper editorials became more supportive of letting the research teams do the science and see where it leads. Even Jim Sanford began taking a more moderate stance:

> Welcome to 2008. Enough sabre rattling. Time to work toward a more palatable solution concerning the Walker River Basin Project…. The basic issue is that there is a lawsuit in the courts seeking changes in the amount of water the downstream tribe receives, plus what can be labeled "an environmental issue" at the end of the system (Walker Lake)…. Both these issues have to be addressed because of the lawsuit and proposed federal legislation…. It's 2008, we have to do something more [than keep calling UNR/DRI names]; time's a wasting." (Sanford, 2008, p. 1-2)

Sanford later observed that the community had come to realize that change was coming whether they liked it or not—and it might as well become part of and help shape that change. Sanford also indicated this change of heart was in part the result of the community coming to trust the researchers and the objectivity of their research. This new-found respect and trust is the result of increased interactions between the researchers and the individuals in the community. The community seems more accepting of the idea that the research might show how to sustain agriculture and diversify the economy while delivering water to Walker Lake.[69]

CONCLUSION

The Walker Basin Project represents a sophisticated attempt to develop and test scientific tools with which to assist achievement of the public policy goals stated in the legislation. Although the legislation authorizes and funds the acquisition of water, that which is acquired must also be *deliverable* to Walker Lake. Data gathered, databases built, decision support tools tested, demonstration of alternative crops, use of natural vegetation to control dust and invasive weeds, economic impact analysis, economic development proposals, and a communicative process with interested local citizens may

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[69] At the public hearings on the Draft EIS conducted by the Bureau Reclamation during the summer of 2009, public comments revealed lingering opposition, however.

yield a set of accommodations that conserve natural resources, local communities, and a rural Nevada lifestyle.

The majority of the original "Farm Bill" appropriation toward the Walker River remains to be committed to the policy goals stated above. There will be water right acquisitions from willing sellers, with purchase and title transfer contingent upon its being shown through the use of the tools developed in this project that water can be delivered to Walker Lake.

In a fundamental sense, this portion of the Walker Basin Project is in "midstream." Evaluation of the use of scientific tools in achieving stated policy goals will continue at least until the authorization of the current project ends in 2010.

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APPENDIX A. CALIFORNIA-NEVADA INTERSTATE COMPACT

NRS 538.600 California-Nevada Interstate Compact: Ratification and approval; text. The Legislature of the State of Nevada hereby ratifies and approves the California-Nevada Interstate Compact as set forth in this section. The provisions of the Compact shall become the law of this state upon the compact becoming operative as provided in Article XXII of the Compact. The provisions of the California-Nevada Interstate Compact are as follows:

ARTICLE I. Purposes

Consistent with the provisions of the authorization Acts of the State of California and the State of Nevada and the United States, the major purposes of this compact are to provide for the equitable apportionment of water between the two states; to promote interstate comity and to further intergovernmental cooperation; to protect and enhance existing economies; to remove causes of present and future controversies; to permit the orderly integrated and comprehensive development, use, conservation and control of the water within the Lake Tahoe, Truckee River, Carson River, and Walker River Basins.

ARTICLE II. Definitions

A. The terms “California” and “Nevada” shall mean respectively the State of California and the State of Nevada.

B. The term “commission” shall mean the administrative agency created by Article IV of this compact.

C. The term “Lake Tahoe Basin” shall mean the drainage area naturally tributary to Lake Tahoe including said Lake or to the Truckee River upstream from the Truckee River intersection with the western boundary of Section 12, Township 15 North, Range 16 East, Mount Diablo Base and Meridian.

D. The term “Truckee River Basin” shall mean the area which naturally drains into the Truckee River and its tributaries and into Pyramid Lake including such lake, but excluding the Lake Tahoe Basin.

E. The term “Carson River Basin” shall mean the area which naturally drains into the Carson River and its tributaries and to the Carson River Sink, but excluding the Humboldt River drainage area.

F. The term “Walker River Basin” shall mean the area which naturally drains into the Walker River and/or Walker Lake upstream from the intersection of the river and/or lake in Mineral County, Nevada, with the northern township line of Tier 10 North, Mount Diablo Base Line.

G. Except as otherwise expressly provided in this compact the terms “existing,” “present” and “presently” shall mean as of 1964.

H. The term “effective date of the compact” shall be the date on which the legislation provided for in Article XXII (1) and (2) shall become law.

I. “Measured” means the determination of the relevant amount of water in cubic feet per second or gallons per minute or acre-feet by the use of a current meter, rated weir, rated flume, pipeline water meter, computation from contour maps, or any other method which results in a reasonably accurate determination based on sound engineering practices.

ARTICLE III. Sovereign Relationship

A. Each state shall have jurisdiction to determine, pursuant to its own laws, the rights to the use of waters allocated to it herein; provided, however, that the right to use such water shall be limited to such quantities of water as shall reasonably be required for the beneficial use to be served and shall not extend to the waste or unreasonable use of water. Such provision shall not be construed to affect the water rights laws of either state with respect to any waters, other than the waters allocated to the state hereunder. Each state will recognize and accept applications for such permits, licenses or other permissions as are required by the law of the state where the application is filed to enable the other state to utilize water allocated to such other state. This provision shall neither require nor prohibit the United States of America from complying with provisions of state law relating to the appropriation of water allocated to the states by this compact.

B. Each state shall cooperate with the other in securing to each the right to fully utilize the rights and privileges granted and waters allocated to each hereunder.

C. The use of water by the United States of America or any of its agencies, instrumentalities or wards shall be charged as a use by the state in which the use is made.

ARTICLE IV. The California-Nevada Compact Commission

A. Creation and Composition

1. There is hereby created an interstate compact commission to be designated as the California-Nevada Compact Commission herein referred to as the commission.

2. The commission shall consist of five members from each state and one member as representative of the United States chosen by the President of the United States who is hereby requested to appoint such a representative. The United States member shall be ex officio chairman of the commission without vote and shall not be a domiciliary of or reside in either state.

(a) The California members of the commission shall consist of the Director of the Department of Water Resources of the State of California, and four (4) members appointed by the Governor of California, all of whom shall be residents of the State of California. One of the four members so appointed shall be a resident of the Lake Tahoe Basin, one shall be a resident of the Truckee River Basin, one shall be a resident of the Walker River Basin and one shall be a resident of the Carson River Basin.

(b) The Nevada members of the commission shall consist of the State Engineer of the State of Nevada (who additionally shall represent all Nevada areas not otherwise represented as herein provided), and four (4) members appointed by the Governor of Nevada, each of whom shall be a resident of the State of Nevada and represent a specific area therein as below defined, provided that the Governor shall not appoint any person a member of such commission if he determines that such person has a conflicting interest in California. One of the four members so appointed shall be a resident real property owner within and represent the Reno-Sparks metropolitan area (including adjacent agricultural area) and be fully qualified by knowledge and experience in connection with the water requirements and supply for such area; the other three members so appointed shall be representative of the common interest and goals of all water users of the area and each shall have broad practical experience in water management, and one shall be a resident real property owner within and represent the Walker River Basin in Nevada, another shall be a resident real property owner within and represent the Carson River Basin in Nevada upstream from Lahontan Reservoir, and the third shall be a resident real property owner within and represent the area within the Truckee-Carson Irrigation District in Nevada.

3. The term of office of the four members of the commission appointed by each Governor shall be four (4) years. The Governor of each state, upon appointment of the first members of the commission, shall designate one member of the commission to serve for a period of one year, one member to serve for a period of two years, one member to serve for a period of three years, and one member to serve for a period of four years. Thereafter, members shall be appointed for the regular term of four years as the terms expire.

4. Interim vacancy, for whatever cause, in the office of any member of the commission shall be filled for the unexpired term in the same manner as hereinabove provided for regular appointment.

5. The appointed members of the California-Nevada Compact Commission shall be designated within ninety (90) days after the effective date of the compact. Within thirty (30) days after such members have been appointed and the federal representative designated, the commission shall meet and organize.

B. Finances

1. The salaries and the personal expenses of each member of the commission shall be paid by the government he represents. All other expenses which are incurred by the commission incident to the administration of this compact and which are not paid by the United States or by other funds received by the commission shall be borne equally by the two states.

2. The commission shall adopt a budget covering the commission's estimate of its expenses for each of the following two fiscal years; provided, that whenever the legislatures of both states appropriate funds on an annual basis the commission shall submit its budget on such annual basis. The commission shall submit said budget to the Governors of the two states for joint review and approval and to the President of the United States at the earliest date prescribed by the two states for submission of proposed budgets. Each state shall appropriate one-half of the funds necessary to meet said budget requirements, which appropriations shall be made available to the commission as of July 1 of each fiscal year for such fiscal year's operations. All unexpended and unencumbered funds from such appropriations shall be returned by the commission in equal proportions to the states to the credit of the state fund from which said appropriation was made. All receipts and disbursements of funds handled by the commission shall be subject to a joint audit by the states and the report of said audit shall be included, and become a part of the annual report of the commission.

3. The commission shall not pledge the credit of any government except by and with the authority of the legislative body thereof given pursuant to and in keeping with the Constitution of said government. The commission shall not incur any obligations prior to the availability of funds adequate to meet the same.

4. The commission shall make and transmit to the Legislature and Governor of each state and to the President of the United States an annual report covering the finances and activities of the commission and embodying such plans, recommendations and findings as may have been adopted by the commission.

C. Meetings and Voting

1. A quorum for any meeting of the commission shall consist of six members of the commission, provided that at least three members are present from each state.

2. All meetings of the commission for the consideration of and action on any matters coming before the commission, except matters involving the management of internal affairs of the

commission and its staff, or involving litigation in which the commission is a party, shall be open to the public. Matters coming within the exception of this paragraph may be considered and acted upon by the commission in executive session under such rules and regulations as the commission may see fit to establish.

3. Each state shall have but one vote and every decision, authorization, determination, order or other action shall require the concurring votes of both states, provided that no state shall vote on any action without the concurring vote of not less than three members of the commission from such state.

D. General Powers

The commission shall have power to:

1. Adopt, amend and revoke bylaws, rules and regulations and prescribe procedures for administration of the provisions of this compact.

2. Establish such offices as it deems necessary, and acquire and hold property either by purchase, lease or otherwise as may be necessary for the performance of its functions under this compact.

3. Employ engineering, legal, clerical and other aid as in its judgment may be necessary for the performance of its functions. Such employees shall be paid by and be responsible to the commission and shall not be considered to be employees of either state. The commission may establish workmen's compensation benefits directly or by insurance. The commission is authorized to contribute to the cost of health and accident insurance for its employees to the same extent as either state contributes to the cost of such insurance for its employees.

4. Perform all functions required of it by this compact and to do all things necessary, proper or convenient in the performance of its duties hereunder, either independently or in cooperation with any state, federal or local agency or other entity or person.

5. Make such findings as are pertinent to this compact including but not limited to findings as to the quantities of water being used in either state, the amount of water available for use pursuant to the allocations made herein, and each state's share of the waters allocated.

6. Install and maintain measuring devices of a type or types approved by the commission in any stream, lake, reservoir, ditch, pumping station or other diversion works on the Truckee, Carson or Walker Rivers or on Lake Tahoe, or on waters tributary thereto, or to require water users at their expense to install and maintain measuring devices, as the commission may determine necessary or proper to carry out the purposes or provisions of this compact. The execution and enforcement of such requirements concerning such measuring devices as shall be enacted by the commission shall be accomplished by the commission directly, or by such federal, state, local or other official or person as the commission may delegate, or by any other agency responsible to or representing a federal court.

7. Accept gifts of money or real property or anything of value.

8. Appoint a hearing examiner or examiners who may be members of the commission to conduct hearings and to make recommendations to the commission on any matter requiring a hearing and decision by the commission.

9. Obtain a right of access to all properties in the Lake Tahoe, Truckee River, Carson River and Walker River Basins whenever necessary for the purpose of administration of this compact. The commission may obtain a court order to enforce this right of access.

10. Take such action as it deems appropriate for the enforcement of the provisions of this compact.

11. Administer oaths or affirmations and to compel the attendance of witnesses and the production of documents by the use of subpoena which may be served anywhere within the territorial limits of the United States; said power to administer oaths and affirmations and to compel the attendance of witnesses and the production of documents by the use of subpoena may also be exercised by any hearing examiner appointed as provided in subsection 8 of this Section D.

12. Contract with the appropriate agency of either state, including the retirement system, to provide retirement and other benefits to commission employees.

E. Whenever the public health or welfare is endangered, the commission may declare the existence of an emergency and, in such event, shall designate the location, nature, cause, area, extent and duration thereof. In the event of an emergency so declared, the commission may, with respect to all matters covered by this compact, do all things necessary, proper or convenient independently or in cooperation with any other agency, person, or entity, to initiate, carry on, and complete any and all remedial measures required to meet said emergency including the adoption and enforcement of any regulations and restrictions necessary for such purpose.

ARTICLE V. Lake Tahoe Basin

A. The right of the United States or its agent to store waters in Lake Tahoe between elevations 6,223.0 and 6,229.1 feet (Lake Tahoe datum) and to release said stored waters for beneficial uses downstream from Lake Tahoe Basin is hereby ratified and confirmed subject to the rights granted in Section D of this article.

B. It is agreed by the states subject to the consent of the head of the federal agency having jurisdiction thereof, that an overflow weir of approximately 140 feet in length with a crest elevation of 6,223.0 feet, Lake Tahoe datum, upstream from the Lake Tahoe outlet gates shall be constructed and installed with necessary channel improvements within four years from the effective date of this compact provided that should the commission decide that it is in the best interests of each of the two states, it may extend such period for such additional period or periods as it may deem reasonable. The cost of this installation shall be borne by the States of California and Nevada in equal amounts. As used herein, Lake Tahoe datum shall be measured with respect to the top surface of the hexagonal brass bolt seven-eighths inch in diameter, projecting one inch from the vertical face of the southerly concrete abutment wall of the present existing Lake Tahoe Dam, at approximately 3.2 feet below the top of the wall and approximately in line with the upstream ends of the cutwaters of the concrete piers between the sluiceways of the dam. This surface of the brass bolt is presumed for the purposes of the compact to have an elevation 6,230.0 feet Lake Tahoe datum, notwithstanding that it was determined by the U.S. Geological Survey on November 15, 1960, to be at an elevation of 6,228.86 feet above sea level datum of 1929.

C. The storage rights in Lake Tahoe shall be operated alone or in conjunction with other reservoirs so as to minimize the period and duration of high and low water elevations in Lake Tahoe, provided that exchanges of water or releases between Lake Tahoe and other reservoirs shall not measurably impair the intended purpose of such reservoirs.

D. Upon construction of the overflow weir provided for in Section B of this article, the total annual gross diversions for use within the Lake Tahoe Basin from all natural sources including ground water and under all water rights in said basin shall not exceed 34,000 acre-feet annually, of which 23,000 acre-feet annually is allocated to the State of California for use within said basin, and 11,000 acre-feet annually is allocated to the State of Nevada for use within said basin.

After use of the water allocated herein, neither export of the water from the Lake Tahoe Basin nor the reuse thereof prior to its return to the lake is prohibited. This allocation is conditioned upon the construction of the overflow weir; however, it is recognized that there may well be a period of time between the effective date of the compact and the construction of the overflow weir; during that period of time both states shall be permitted to use waters within the Lake Tahoe Basin subject to the same conditions, both as to place of use and amounts of use, as are provided in this Article V.

E. In addition to the other allocations made by this compact, transbasin diversions from the Lake Tahoe Basin in both states existing as of December 31, 1959, may be continued, to the extent that such diversions are recognized as vested rights under the laws of the state where each such diversion is made.

The diversion of a maximum of 3,000 acre-feet per annum from Marlette Lake for use in Nevada is hereby recognized as an existing transbasin diversion within the meaning of this Section E.

F. Pumping from Lake Tahoe Basin for the benefit of downstream users within the Truckee River Basin shall be permitted only in the event of a drouth emergency as declared by the commission to the extent required for domestic, municipal, and sanitary purposes, and when it is determined by the commission that all other water available for such uses from all sources is being so utilized. In the event of such declaration of emergency, use of this water for such purposes shall have priority over use of water for any other purpose downstream from Lake Tahoe Basin. Pumping shall be done under the control and supervision of the commission and water pumped shall not be charged to the allocation of water to the Lake Tahoe Basin made herein.

ARTICLE VI. Truckee River Basin

The following allocations of water of the Truckee River and its tributaries, including Lake Tahoe releases, are hereby made in the following order of relative priority as between the states:

A. There is allocated to Nevada water for use on the Pyramid Lake Indian Reservation in amounts as provided in the 1944 Truckee River Decree (Final Decree in United States vs. Orr Ditch Company, et al. United States District Court for the District of Nevada, Equity No. A3). By appropriate court order, the United States, for and in behalf of the Pyramid Lake Indians shall have the right to change points of diversion, place, means, manner, or purpose of use of the water so allocated so far as such change may be made without injury to the allocations to either state.

B. There is allocated to California:

1. The right to divert within the Truckee River Basin in California 10,000 acre-feet of water per calendar year which may be stored in reservoirs at times when the flow in the channel of the Truckee River at the United States Geological Survey Gauging Station at or near the California-Nevada state line exceeds 500 cubic feet per second; provided that such diversions shall not in the aggregate exceed 2,500 acre-feet in any calendar month and the amount of such storage in any one reservoir, except Donner Lake, shall not exceed 500 acre-feet of active storage capacity.

2. The amount of water as decreed to the Sierra Valley Water Company by judgment in the case of United States vs. Sierra Valley Water Company, United States District Court for the Northern District of California, Civil No. 5597, as limited by said judgment.

3. Six thousand acre-feet of water annually from the conservation yield of Stampede Reservoir having a storage capacity of 225,000 acre-feet, subject to the execution of a contract or contracts therefor with the United States of America. California may divert all or any portion of said 6,000

acre-feet of conservation yield from Stampede Reservoir directly or by exchanges from any source on the Truckee River or its tributaries or from Lake Tahoe. California shall be allowed to deplete this allocation; provided, that in ascertaining the amount of depletion, credit for return flow shall be limited to the amounts of water which can be measured as a contribution to the Truckee River system.

4. If and when the water allocated to California in subparagraphs 1 and 3 of this section and in Article V is being used, or such use appears imminent, the commission shall permit California to develop additional yields of water for use in California, either directly or by exchange subject to the following limitations:

(a) All existing beneficial uses of water for domestic, municipal, industrial, and agricultural purposes in Nevada as determined by Nevada law as of that time together with the yield of Stampede Reservoir in excess of 6,000 acre-feet shall be recognized and not impaired by the development of such additional yield.

(b) Additional yields developed for use in California shall be limited to an amount not to exceed an aggregate of 10,000 acre-feet annually, and such development shall be for domestic, municipal, and industrial uses solely. California shall be allowed to deplete this allocation; provided, that in ascertaining the amount of depletion, credit for return flow shall be limited to the amounts of water which can be measured as a contribution to the Truckee River system.

(c) The right of the commission to permit Nevada to share in such additional yield upon participation by Nevada in bearing a proportionate cost of developing such additional yield.

C. The right to store in Prosser Creek Reservoir a maximum of 30,000 acre-feet of water annually with the priority as set forth in California State Water Rights permit 11666 and to release water therefrom as set forth in said permit and any license which may be issued thereunder is hereby recognized and confirmed.

D. There is allocated to Nevada all water in excess of the allocations made in Sections B and C of this article.

ARTICLE VII. Carson River Basin

The following allocations of water of the Carson River and tributaries are hereby made in the following order of priority as between states:

A. There is allocated to the State of California:

1. The right to divert from the natural flow of the West Fork Carson River and its tributaries for existing nonirrigation uses, and for direct irrigation use commencing on March 15 and ending on October 31 of each year on presently irrigable lands determined to be approximately 5,600 acres, an aggregate flow of water equal to a 30-day average of 3 c.f.s. per 100 acres or 168 c.f.s. for the area as a whole; provided that the 3 c.f.s. per 100-acre limitation shall not prevent greater rates of diversion for those areas which have an established greater rate of use; provided further, however, that the maximum aggregate diversion shall not exceed 185 c.f.s. measured at the points of diversion.

Provided, however, diversions for use downstream from the western boundary of Section 34, Township 11 North, Range 19 East, Mount Diablo Base and Meridian, shall be subject to the following limitations:

(a) Whenever, after the first Monday in May or any day in that week or alternate weeks thereafter of any year the flow of the West Fork of the Carson River at said western boundary shall have fallen below 175 cubic feet per second, then, until October 31 next, water users in California who divert from the West Fork of the Carson River downstream from said western boundary shall rotate all or any portion of the natural flow of the West Fork of the Carson River necessary to satisfy the demand of Nevada lands with water users in Nevada every other week beginning with the week following that in which water is used in Nevada, and during each rotation period said California users shall be entitled to divert the natural flow of the West Fork of the Carson River during their rotation weeks.

(b) Rotation between water users in California and Nevada on the West Fork of the Carson River may be terminated in whole or in part upon approval of the commission for such termination, upon provision being made so that sufficient water is available by storage or exchange to assure that the water users in Nevada will receive at the same time the flow of water which would have been available to the Nevada water users under rotation.

(c) Stock water, domestic water, and water for fire protection purposes may be diverted downstream from said western boundary from the natural flow of the West Fork of the Carson River at all times by owners of irrigation water rights in California whose lands are contiguous to the West Fork of the Carson River; provided, however, that such diversion shall be limited to the amounts actually required to deliver water for such purposes, and any excess over the amount so diverted shall be returned to the West Fork of the Carson River whenever practicable. Water diverted under this provision shall not be converted to any other use. The commission or its designee shall rule on any challenge relative to the necessity and amount of water required for such purposes.

2. The right to divert from the natural flow of the East Fork Carson River and its tributaries for existing nonirrigation uses, and for direct irrigation use commencing on March 15 and ending on October 31 of each year on presently irrigable lands determined to be approximately 3,820 acres, an aggregate flow of water equal to a 30-day average of 3 c.f.s. per 100 acres or 115 c.f.s. for the area as a whole; provided that the 3 c.f.s. per 100-acre limitation shall not prevent greater rates of diversion for those areas which have an established greater rate of use; provided further, however, that the maximum aggregate diversion shall not exceed 115 c.f.s. measured at the points of diversion.

3. There is allocated to the State of California the right to store 2,000 acre-feet of water per annum within Alpine County for supplemental use on presently irrigated lands within said county adverse to Lahontan Reservoir but subject to all other existing uses in Nevada. Water stored pursuant to this section remaining at the end of the year shall be deemed to have been stored in the succeeding year.

B. There is allocated to the State of Nevada:

1. The right to divert water from the natural flow of the Carson River and its tributaries during the period commencing March 15 and ending October 31 of each year at the rate of 3 c.f.s. per 100 acres for use on presently irrigated lands in the area above Lahontan Reservoir determined to be approximately 41,320 acres. The rate of 3 c.f.s. per 100 acres is based on a 30-day average for the area as a whole and shall not prevent greater rates of diversion for those areas that have an established greater use; provided that the aggregate diversion measured at the points of diversion shall not exceed 700 c.f.s. on the East Fork of the Carson River, 300 c.f.s. on the West Fork of the Carson River, and 220 c.f.s. on the Main Carson River below the confluence of the East and West Forks.

The combining and exchanging of the use of water between ditches and among users shall be permitted at all times and shall be required whenever necessary in order to obtain reasonable economy in the use of the water of the river or other streams, or in order to give to each ditch or user a more advantageous irrigation head.

2. Subject to allocations made in subsection B.1 and Section C of this article, the right to divert water from the Carson River for irrigation use either by direct diversion or by storage in Lahontan Reservoir or other existing reservoirs for use on the Newlands Project.

C. There is allocated to each state the right to store water in existing reservoirs upstream from Lahontan Reservoir to the extent of existing capacity with the appropriate priority with respect to natural flow rights upstream from Lahontan Reservoir under applicable state law, and use such stored waters on the lands in each state to which the storage is appurtenant.

D. Additional yields shall be available for development under the currently authorized Washoe Project from water available in excess of existing beneficial uses recognized by Nevada law, or under other new projects upon a determination by the commission that there is water available on the Carson River and its tributaries in excess of that required to satisfy existing beneficial uses in Nevada as determined by Nevada law as of the time of authorization or construction of such new projects. Such additional yields shall be allocated between the states with equal priority, 20 percent of which shall be allocated to California and 80 percent to Nevada.

Each state shall have the right to participate in any development project by bearing a proportionate cost of such development. In the event that joint developments are found to be not feasible or desirable, each state may develop separately its proportionate share of the remaining water.

E. Except as provided by Article X of this compact, the waters of the Carson River shall not be used in areas outside the Carson River Basin.

ARTICLE VIII. Walker River Basin

A. Allocation to Present Rights and Uses

1. Except as the rights of the Walker River Irrigation District may be limited by subsections 2 and 3 below, the provisions of the decree in the case of United States v. Walker River Irrigation District, et al., United States District Court for the District of Nevada Equity No. C-125, filed April 15, 1936, as amended by the Order of the Honorable A.F. St. Sure, dated April 24, 1940, hereafter called Decree C-125 are hereby recognized and confirmed.

2. The rights of the Walker River Irrigation District to store water of the West Walker River in Topaz Reservoir with a storage capacity of 59,000 acre-feet, under Part VIII of Decree C-125 and under any other basis of right, and to use such water, are hereby recognized and confirmed, subject to the following:

(a) The maximum quantity of water which can be diverted annually to storage is 85,000 acre-feet. No more than 85,000 acre-feet of water less reservoir evaporation can be rediverted for use within the district annually. The 85,000 acre-feet amount so allowed to be diverted to storage and rediverted to use include water used under direct diversion rights in Decree C-125 acquired by said district prior to 1964. For the purpose of this provision "annually" means the period from November 1 through October 31 of the following year.

(b) The maximum rate of diversion to such reservoir under such rights is 1,000 c.f.s.

(c) For the purpose of determining the availability of water to satisfy rights junior to the Topaz Reservoir storage rights of the Walker River Irrigation District, or for division between the states as unused water, water which has been stored, or is available for storage in and can be physically diverted to such reservoir under such reservoir rights but is released or is allowed to pass through the reservoir and is not rediverted to use in Nevada, shall be deemed to have been held in storage; provided, that until a new major storage project is constructed on the West Walker River, the foregoing shall not apply to the extent that said district with the concurrence of the watermaster determines, prior to the release or passing through of such water from Topaz Reservoir in any year, that it is necessary to release or pass through such water in order to provide storage space in Topaz Reservoir as a means of protecting lands in Nevada against flood damage later in the year.

3. The rights of the Walker River Irrigation District to store water of the East Walker River in Bridgeport Reservoir with a storage capacity of 42,000 acre-feet, under Part VIII of Decree C-125 and under any other basis of right, and to use such water, are hereby recognized and confirmed, subject to the following:

(a) The maximum quantity of water which can be diverted to storage in any year is 57,000 acre-feet. No more than 57,000 acre-feet of water less reservoir evaporation can be rediverted for use within the district in any year. The 57,000 acre-feet amounts so allowed to be diverted to storage and rediverted to use include water used under direct diversion rights in said decree acquired by said district prior to 1964 except for water used under such rights prior to 1964 on lands owned by said district in Bridgeport Valley. For the purpose of this provision "year" means the period from November 1 of one calendar year to October 31 of the following calendar year.

(b) Water of the East Walker River and its tributaries may, adversely to the Bridgeport Reservoir storage rights hereinabove recognized and confirmed, be stored upstream from said reservoir in any year, for later use after the spring flood of the year in which the water was so stored, under rights junior to said reservoir rights; provided, that when the Walker River system is put on priority under Decree C-125 after the annual spring flood, or upon demand made prior to the spring flood for water necessary to satisfy early season demand, the watermaster shall make an accounting and water shall be released from said upstream storage in such amounts as determined by the watermaster to be necessary to satisfy said reservoir rights to the same extent as they would have been satisfied in the absence of said adverse upstream storage.

4. (a) There is allocated to each state respectively the amount of existing diversions and uses of water of the Walker River Basin diverted upstream from Weber Reservoir and not specifically covered in Decree C-125, provided, that this allocation shall not include water distributed under the historical administration of Decree C-125 in excess of the rights set forth in Decree C-125 to lands having rights thereunder. In making this allocation, it is recognized that the amounts of water allocated and the respective priorities are not presently known with certainty. The commission shall as soon as practicable after its effectuation provide for an investigation, either with its own staff or by other agencies or persons, to ascertain with certainty the amounts of water and priorities of such uses. As between the respective states, the priorities shall be determined as follows: In cases of use not under state-recognized rights, the priorities shall be the date of initiation of use; in cases of use under state-recognized rights, the priorities shall be as provided under the law of the state where the diversion is made. Upon approval by the commission, the results of the investigation shall be binding as to the allocation to each state hereunder.

(b) In addition to rights recognized in subsection A.1 of this article there is allocated to Nevada for use on the Walker River Indian Reservation a maximum of 13,000 acre-feet per year for storage in Weber Reservoir and later rediversion to use and in addition 9,450 acre-feet per year to be diverted from natural flow. Both allocations shall have a priority of 1933. The season for diversion of water to storage shall be from November 1 to October 31 of the following year. The season for diversion of water directly for use shall be from March 1 to October 31 and at a maximum rate of 60 cubic feet per second. For the purpose of determining the availability of water to satisfy rights junior to this allocation or for division between the states as unused water,

water which has been stored, or which can be physically stored or diverted to use under this allocation but is released or is allowed to pass through Weber Reservoir and is not rediverted to use on the Walker River Indian Reservation, shall be deemed to have been held in storage or used; provided, that the foregoing shall not apply to the extent that the appropriate representative of said reservation with the concurrence of the watermaster determines prior to the release or passing through of such water from Weber Reservoir in any year, that it is necessary to release or pass through such water in order to provide storage space in Weber Reservoir as a means of protecting lands in Nevada against flood damage later in the year; provided, further, that the foregoing shall not apply to passage of water of inferior quality to the extent that such passage may be necessary to maintain the water of suitable quality for irrigation on said reservation as determined by the commission.

Water of the Walker River and its tributaries may, adversely to the Weber Reservoir storage rights hereinabove recognized and confirmed, be stored upstream from said reservoir in any year, for later use after the spring flood of the year in which the water was so stored, under rights junior to said reservoir rights; provided, that when the Walker River system is put on priority under Decree C-125 after the annual spring flood, or upon demand made prior to the spring flood for water necessary to satisfy early season demand, the watermaster shall make an accounting and water shall be released from said upstream storage in such amounts as determined by the watermaster to be necessary to satisfy said reservoir rights to the same extent as they would have been satisfied in the absence of said adverse upstream storage.

5. In addition to rights recognized in subsections A.1 and A.4(a) above, there is allocated to California water of the West Walker River as follows:

(a) When all direct diversion rights under Decree C-125 are being satisfied and simultaneously water of the West Walker River is being diverted to storage pursuant to the Topaz Reservoir storage rights recognized and confirmed in subsection 2 of this Section A, but there is not flow in excess of that required to fully satisfy Topaz Reservoir storage rights, diversions in Antelope Valley in excess of the amounts to which Antelope Valley lands are entitled under Decree C-125 shall be permitted by the watermaster for such periods and in such amounts as, in the sound professional judgment of the watermaster, will not cause, on an overall irrigation season basis, any discernible net reduction in the amount of water available to satisfy said Topaz Reservoir storage rights.

(b) Such excess diversions may be used only on Antelope Valley lands entitled to water under Decree C-125 which can be served from the ditch systems existing as of the effective date of this compact.

(c) The allocation in this subsection 5 shall terminate after construction of a new major storage project on the West Walker River upstream from Antelope Valley.

B. Allocation of Unused Water

1. The term "unused water" includes all waters of the Walker River and its tributaries in excess of the amounts allocated, or required for satisfaction of rights and uses recognized and confirmed, as provided under Section A of this Article VIII, except that there shall be excluded therefrom natural flow which is not physically available above the head of Mason Valley. There is allocated to the State of California 35 percent of such unused water, and there is allocated to the State of Nevada 65 percent of such unused water. The allocation to each state provided herein in this subsection B.1 shall be equal in priority.

(a) The reregulation by storage of waters allocated for storage shall not be considered as the development of "unused water."

2. Neither state shall be precluded from constructing works for the control, use and development of the water allocated pursuant to subsection B.1 of this article for optimum use of water.

3. While separate development may be undertaken by either state for surface storage of unused water of the West Walker River so allocated, the State Engineer of the State of Nevada and the Department of Water Resources of the State of California shall cooperate in a joint review of all potential developments of unused water of the West Walker River so allocated in subsection B.1 of this Article VIII and shall prepare and present a report of the benefits to be obtained, and other relevant data from each such development to the commission or if the commission has not yet become operative, to the joint commission which negotiated this compact, at a public hearing or hearings held at times and places within the Walker River Basin set by the commission or said joint commission.

(a) Should a separate surface storage project or projects be constructed in Nevada to develop Nevada's share of the unused water of the West Walker River, California may thereafter store and use said unused water allocated to Nevada adverse to such Nevada storage projects, provided that, without charge to Nevada, California makes available for consumptive use in Nevada, water in the same amounts, at the same times, and in the same places as would have been available for use in Nevada from such Nevada storage projects had California not so stored and used said unused water allocated to Nevada; and provided further that Nevada shall not be deprived of water required for: (1) maintenance of a minimum reservoir level for the preservation of fish life and (2) nonconsumptive uses which are found by the commission to be in the public interest of the Walker River Basin as a whole.

(b) From time to time after construction of each surface storage project upstream from Topaz Reservoir, for development of the unused water allocated herein, the commission shall determine the amounts of water which may be diverted and used in each state pursuant to its allocation as the result of the construction and operation of such project. In making such determination the commission shall compute any increase of yield of previously constructed reservoirs which may result from operation of such project constructed to develop unused water and shall include such increase in the amounts of water which may be diverted and used in each of the two states pursuant to its allocation of unused water.

4. Return flow to the Walker River or its tributaries from any source shall be deemed to be natural flow.

5. Unused water shall be used only:

(a) Within the Walker River Basin;

(b) Within the portion of Artesia Lake Basin south of the northern township line of Tier 12 North and west of a line one mile east of the eastern range line of Range 23 East, Mount Diablo Base Line and Meridian;

(c) Within the portion of Mason Valley and Adrian Valley south of the northern township line of Tier 15 North, Mount Diablo Base Line;

(d) Within the area tributary to Topaz Lake; or

(e) Any combination of the above areas.

C. Watermaster

1. A single watermaster shall have the responsibility and power to administer: (a) all rights and uses of water of the Walker River Basin recognized in Section A of this Article VIII, including rights under Decree C-125, (b) the allocation between the states provided for in this compact of

water of the Walker River Basin in excess of that necessary to satisfy such rights and uses, and (c) all rights acquired to use water so allocated.

2. The watermaster shall be nominated by the commission as soon as practicable after this compact goes into effect, but his appointment shall not become effective until approved and confirmed by the Federal District Court for the District of Nevada, it being the intent of this compact that only a person satisfactory to both the commission and said court be the watermaster under this compact and under Decree C-125. At any time either the commission or said court may terminate the appointment of the person serving as watermaster by adopting an appropriate resolution or order, and notifying the other and the watermaster thereof. When a vacancy occurs by such action or by the death or resignation of the person serving as watermaster, a successor shall be selected by the same procedure as provided for the original appointment.

3. Until appointment of the watermaster becomes effective by approval and confirmation of said court, either as to the original selection of the watermaster or subsequent selections to fill a vacancy, a person designated by the commission shall have interim responsibility and power to administer the allocation between the states referred to in subsection 1(b) above and all rights and uses other than the rights under Decree C-125, and the rights and uses under Decree C-125 shall be administered on an interim basis as may be provided by said court.

4. Actions and decisions of the watermaster as to the administration of the rights under Decree C-125 shall be subject to review and modification by said court. Actions and decisions of the watermaster as to the administration of the allocation between the states referred to in subsection 1(b) above and of all rights and uses other than rights under Decree C-125 shall be subject to review and modification by the commission.

5. Said court is requested to appoint a six-member advisory board composed of one person each representing: (1) the East Walker River Basin in California, (2) the West Walker River Basin in California, (3) the East Walker River Basin in Nevada, (4) the West Walker River Basin in Nevada, (5) the Main Walker River Basin in Nevada, and (6) the Walker River Indian Reservation. The watermaster shall prepare an annual budget of proposed expenditures for personnel, equipment, supplies, and other purposes deemed by him to be necessary to carry out his functions. In the formulation of said budget the watermaster shall consult with said advisory board. In the event that said advisory board is not in agreement with the budget proposed by the watermaster, it shall so advise said court. Said budget shall require approval of both the commission and said court to become effective.

6. The expenditures attributable to administration of the rights under Decree C-125 shall be apportioned and collected in accordance with orders of said court. The expenditures attributable to administration of all other rights and uses of the water of the Walker River Basin under this compact shall be equitably apportioned among, and collected from, the users thereof by the watermaster under rules and regulations of the commission, and the commission shall have the power to enforce collection thereof by any reasonable means, including court action in any state or federal court of appropriate jurisdiction. The expenditures attributable to administering the allocation between the states referred to in subsection 1(b) above shall be borne by the commission as part of the expense under Article IV, subsection B.1 of this compact.

ARTICLE IX. Ground Water and Springs

A. Development and Use of Ground Water

1. Both states shall have the right to develop and use ground water within their respective boundaries; provided that development and use of ground water in one state shall not reduce the amount of water which the other state would have received under the allocation herein if ground water were not developed and used.

2. In the development and use of ground water pursuant to this article, wells or other methods of collecting underground water shall be constructed in a manner which will assure that water will not be drawn directly from allocated surface water. In the absence of proof to the contrary made to the commission, wells drilled within 500 feet from any perennial streams which are not sealed from the surface to a depth of at least 50 feet shall be deemed prima facie to draw directly from allocated surface water.

B. Each state shall have the right to use water from springs; provided that the use of water from springs in one state shall not reduce the amount of water which the other state would have received under the allocations herein if water from springs were not used.

C. Effect on Allocations

1. The commission shall have authority to take such action as it deems appropriate, so that the allocations of water made by this compact to either state shall not be adversely affected by ground water withdrawals or use of water from springs in the other state.

2. If either state claims that the development and use of ground water or water from springs in the other state reduces the amount of water which said state would have received under its allocation if such ground water or water from springs were not developed and used, it may file a protest with the commission in accordance with the rules of the commission. The commission is empowered to receive evidence on any protest and make its ruling thereon.

ARTICLE X. Interbasin Transfers of Use

Either state may use directly, by exchange, or otherwise its allocated waters of the Truckee River in the Lake Tahoe Basin or the Carson River Basin, or its allocated waters of the Carson River in the Lake Tahoe Basin or the Truckee River Basin. The commission shall have authority to take such action as it deems appropriate so that the allocations of water made by this compact to either state shall not be adversely affected by such use in the other state.

Nothing herein shall preclude the use of Lake Tahoe as a physical facility to accomplish the use of Truckee River waters in the Carson River watershed or Carson River waters in the Truckee River watershed, but in no event shall the use of Lake Tahoe as such a physical facility be inconsistent with any provision of Article V of the compact.

ARTICLE XI. Suppression of Evaporation

A. Either state is entitled, but not obligated to participate in any project for the conservation of water through the suppression of evaporation. The yield of any such project shall be allocated to each state by the commission in such proportion as shall be determined by the commission, taking into consideration such factors as the commission deems pertinent. Such allocation of yield to each state shall be in addition to the waters allocated to each state by other provisions of this compact.

B. Subject to the power of the commission to allocate the increased yield resulting from suppression of evaporation as set forth above, no existing property right shall be adversely affected except by agreement with the owner, or as may be otherwise permitted by state law. Nothing herein shall diminish or supersede any law of either state regarding water quality, including but not limited to conditions affecting fish and wildlife.

ARTICLE XII. Coordination of Reservoirs

A. The commission shall have the authority to prepare plans for the coordination of reservoirs and the method of implementation of any such plans prepared, and to approve the same and to review and revise such approved plans from time to time as the commission may deem appropriate. Prior to the preparation of any such plan and implementation or review or revision thereof, the owners of all reservoirs to be affected thereby shall be given the opportunity of participating in such preparation, review, or revision.

B. Prior to the approval thereof, the commission shall provide for public hearings concerning such a plan, review, or revision upon such notice as the commission deems appropriate.

C. Any owner of a reservoir shall have the right to refuse to participate in any such plan, or method of implementation, or review or revision thereof, and in such event such reservoir shall be excluded therefrom, and any plan or implementation or review or revision concerning other reservoirs as may be approved shall not adversely affect the use of the reservoir or the right to the use of water therefrom, which has been excluded.

D. Owners of reservoirs may develop plans for coordination thereof, but shall give written notice to the commission at least 60 days prior to their implementation.

ARTICLE XIII. Fish, Wildlife, and Recreation

The use of waters for preservation, protection, and enhancement of fish, wildlife, and recreation is hereby recognized as an inseparable part of the public interest in the use of the waters of Lake Tahoe, Truckee, Carson and Walker River Basins in both states, and is, therefore, beneficial.

ARTICLE XIV. Nonconsumptive Use

Each state may use water for nonconsumptive purposes, including but not limited to flood control, recreation, fishery and wildlife maintenance and enhancement, and hydroelectric power generation, provided that such uses result in no discernible reduction in the water allocated to the other state.

ARTICLE XV. Diversion and Exchange of Yield From Future Reservoirs

Upon the construction of a surface storage project or projects to store unused water herein allocated, users who become entitled to the yield therefrom may, at any point where water is physically available, divert water to use subject to approval of the commission and conditioned upon providing water in exchange for such diverted water as directed by the commission, so that other users, including owners of reservoir storage or owners of interest in waters stored, receive their entitlement of water in time, place, and quality the same as if the diversion and exchange had not been made.

ARTICLE XVI. Change of Point of Diversion, Manner, Purpose, or Place of Use

Any change of point of diversion or of manner, purpose or place of use of the waters of the Carson, Truckee or Walker River Basins may be made in either state pursuant to state law or applicable court decree, provided that such change shall not adversely affect the allocation of water to the other state. Either state, if permitted by state law, may permit a change to other use of water formerly consumed by natural subirrigation on meadows. It shall be the duty of each state to initiate proceedings before the commission if it believes that such change in the other state would adversely affect its allocation. In the event of the initiation of such a proceeding a commission hearing shall be held and the person desiring the change shall have the burden of establishing that such change would not adversely affect the allocation to the complaining state. In the event the person desiring the change does not establish that such change would not adversely affect the allocation to the complaining state, the commission shall enter such order as it deems appropriate to assure that the allocation to the complaining state is not adversely affected.

ARTICLE XVII. Imported Water

The provisions of this compact respecting allocation of water are applicable solely to the waters of the Truckee, Carson, and Walker River Basins and the Lake Tahoe Basin. To the extent that either state imports into the Truckee, Carson or Walker River Basins or the Lake Tahoe Basin water from another river or source the state making the importation shall have the exclusive use of such imported water unless by written agreement between the states it is otherwise provided. Nothing herein shall preclude either state from using such imported water as replacement or exchange water to meet such conditions as may be imposed by the commission pursuant to the provisions of this compact.

ARTICLE XVIII. Compact Effect

A. Each state and all persons using, claiming, or in any manner asserting any right to the use of the waters of Lake Tahoe, Truckee River, Carson River, and Walker River Basins, shall be subject to the terms of this compact.

B. The provisions of this compact shall be self-executing and shall by operation of law be conditions of the various state permits, licenses, or other authorizations relating to the waters of Lake Tahoe, Truckee River, Carson River and Walker River Basins.

C. Nothing in this compact shall abridge, limit or derogate against any claim or right of anyone to the use of water in either state within the allocations to such state that could or may be made or established under state or federal law had this compact not been adopted; provided, that the place of use, under any such right, of water from any of the four basins covered by this compact shall be limited to such basin or such other areas outside such basin as are permissible places of use of water from such basin under this compact.

D. Nothing in this compact shall be construed as granting to any person or entity the right to divert, store, or use water.

ARTICLE XIX. Violations

A. Violations or threatened violations of any of the provisions of this compact which come to the attention of the commission shall be promptly investigated by it. If after such investigation the commission determines further action is necessary it may take such action as it deems advisable including, but not limited to, the commencement of an action injunctive or otherwise in its own name in any court of general jurisdiction of the state where the violation has occurred or is threatened, or the United States District Court for the district where said violation has occurred or is threatened, or if it is determined by the commission appropriate to do so, refer the matter with its recommendations, if any, to an appropriate federal, state, or local official or agency or board for action.

B. In any action concerned with any matter in which the commission has made a decision, the findings of the commission shall constitute prima facie evidence of the facts found.

ARTICLE XX. Recourse to Courts

Nothing in this compact shall be construed to limit or prevent either state or any person or entity from instituting or maintaining any action or proceeding, legal or equitable, in any court of competent jurisdiction for the protection of any right under this compact or the enforcement of its provisions, provided that in all matters in which the commission is given jurisdiction by this compact to make a decision no such court action shall be commenced until the matter has been submitted to the commission for decision and decided by it, unless a decision by the commission has been unreasonably delayed.

ARTICLE XXI. Nonimpairment of Rights of United States

Except as provided in Article XXII nothing in this compact shall be construed as:

A. Affecting the obligations of the United States to the Indians and Indian tribes, or any right owned or held by or for Indians or Indian tribes which is subject to the jurisdiction of the United States.

B. Affecting any rights or powers of the United States of America, its agencies or instrumentalities in or to the waters of the Truckee, Carson, or Walker River Basins or the Lake Tahoe Basin, or its capacity to acquire rights in and to the use of said waters.

C. Subjecting any property of the United States, its agencies or instrumentalities to taxation by either state or subdivision thereof.

D. Subjecting any property of the United States of America, its agencies or instrumentalities to the laws of any state to an extent other than the extent to which such laws would apply without regard to this compact.

ARTICLE XXII. Ratification and Consent

This compact shall become effective when, but only if:

(1) It shall have been ratified by acts of the Legislature of each of the States of California and Nevada;

(2) It shall have been consented to by act of Congress of the United States; and

(3) Congress provides in its consent legislation or by separate legislation that the following provisions of the compact shall be binding on the agencies, wards, and instrumentalities of the United States of America:

Article V, Section D
Article V, Section F
Article VI, Subsection B.1
Article VI, Subsection B.3
Article VI, Subsection B.4
Article VI, Section D
Article VII, Section A
Article VII, Section B
Article VII, Section C
Article VII, Section D
Article VII, Section E
Article VIII, Subsection A.4(b)
Article VIII, Subsection B.1
Article VIII, Subsection B.5

ARTICLE XXIII. Termination

This compact may be terminated any time by legislative consent of both states, but notwithstanding such termination all rights then established hereunder or recognized hereby shall continue to be recognized as valid.

In witness whereof the commissioners have executed six counterparts hereof, each of which shall be and does constitute an original and one shall be deposited with the Administrator of General Services of the United States of America, and two of which shall be forwarded to the Governor of each signatory state, and one of which shall be made a part of the permanent records of the California-Nevada Compact Commission.

(Added to NRS by 1969, 69; A 1969, 1259; 1971, 29)

APPENDIX B. PUBLIC LAW 101-618

An Act to provide for the settlement of water rights claims of the Fallon Paiute Shoshone Indian Tribes and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

Title I—Fallon Paiute Shoshone Tribal Settlement Act

SEC. 101. SHORT TITLE.

This Act may be cited as the "Fallon Paiute Shoshone Indian Tribes Water Rights Settlement Act of 1990".

SEC. 102. SETTLEMENT FUND.

(A) There is hereby established within the Treasury of the United States, the "Fallon Paiute Shoshone Tribal Settlement Fund", hereinafter referred to in the Act as the "Fund".

(B) There is authorized to be appropriated to the Fallon Paiute Shoshone Tribal Settlement Fund $3,000,000 in fiscal year 1992, and $8,000,000 in each year for fiscal years 1993, 1994, 1995, 1996, and 1997 for a total sum of $43,000,000.

(C) (1) The income of the Fund may be obligated and expended only for the following purposes:

(a) Tribal economic development, including development of long-term profit-making opportunities for the Fallon Paiute Shoshone Tribes (hereinafter referred to in the Act as "Tribes") and its tribal members, and the development of employment opportunities for tribal members;

(b) Tribal governmental services and facilities;

(c) Per capita distributions to tribal members;

(d) Rehabilitation and betterment of the irrigation system on the Fallon Paiute Shoshone Indian Reservation (hereinafter referred to in the Act as "Reservation") not including lands added to the Reservation pursuant to the provisions of Public Law 95-337, 92 Stat. 455;

(e) Acquisition of lands, water rights or related property interests located outside the Reservation from willing sellers, and improvement of such lands;

(f) Acquisition of individually-owned land, water rights or related property interests on the Reservation from willing sellers, including those held in trust by the United States.

(2) Except as provided in subsection (C)(3) of this section, the principal of the Fund shall not be obligated or expended.

(3) In obligating and expending funds for the purposes set forth in subsections (C)(1)(d), (C)(1)(e) and (C)(1)(f) of this section, the Tribes may obligate and expend no more than 20 percent of the principal of the Fund, provided that any amounts so obligated and expended from principal must be restored to the principal from repayments of such amounts expended for the purposes identified in this subsection, or from income earned on the remaining principal.

(4) In obligating and expending funds for the purpose set forth in subsection (C)(1)(c), no more than twenty percent of the annual income from the Fund may be obligated or expended for the purpose of providing per capita payments to tribal members.

(D) The Tribes shall invest, manage, and use the monies appropriated to the Fund for the purposes set forth in this section in accordance with the plan developed in consultation with the Secretary under subsection (F) of this section.

(E) Upon the request of the Tribes, the Secretary shall invest the sums deposited in, accruing to, and remaining in the Fund, in interest-bearing deposits and securities in accordance with the Act of June 24, 1938, 52 Stat. 1037, 25 U.S.C. 162a, as amended. All income earned on such investments shall be added to the Fund.

(F) (1) The Tribes shall develop a plan, in consultation with the Secretary, for the investment, management, administration and expenditure of the monies in the Fund, and shall submit the plan to the Secretary. The plan shall set forth the manner in which such monies will be managed, administered and expended for the purposes outlined in subsection (C)(1) of this section. Such plan may be revised and updated by the Tribes in consultation with the Secretary.

(2) The plan shall include a description of a project for the rehabilitation and betterment of the existing irrigation system on the Reservation. The rehabilitation and betterment project shall include measures to increase the efficiency of irrigation deliveries. The Secretary may assist in the development of the rehabilitation and betterment project, and the Tribes shall use their best efforts to implement the project within four years of the time when appropriations authorized in subsection (B) of this section become available.

(3) Upon the request of the Tribes, the Secretary of the Treasury and the Secretary of the Interior shall make available to the Tribes, monies from the Fund to serve any of the purposes set forth in subsection (C)(1) of this section, except that no disbursement shall be made to the Tribes unless and until they adopt the plan required under this section.

(G) The provisions of section 7 of Public Law 93-134, 87 Stat. 468, as amended by section 4 of Public Law 97-458, 96 Stat. 2513, 25 U.S.C. 1407, shall apply to any funds which may be distributed per capita under subsection (C)(1)(c) of this section.

SEC. 103. ACQUISITION AND USE OF LANDS AND WATER RIGHTS.

(A) Title to all lands, water rights and related property interests acquired under section 102(C)(1)(e) within the counties of Churchill and Lyon in the State of Nevada, shall be held in trust by the United States for the Tribes as part of the Reservation, provided that no more than 2,415.3 acres of such acquired lands and no more than 8,453.55 acre feet per year of such water rights shall be held in trust by the United States and become part of the Reservation under this subsection.

(B) Any lands acquired under section 102(C)(1)(e) or (f) shall be subject to the provisions of section 20 of the Act of October 17, 1988, 102 Stat. 2485.

(C) (1) Total annual use of water rights appurtenant to the Reservation which are served by the Newlands Reclamation Project, including Newlands Reclamation Project water rights added to the Reservation under subsection (A) of this section, whether used on the Reservation or transferred and used off the Reservation pursuant to applicable law, shall not exceed the sum of:

(a) 10,587.5 acre feet of water per year, which is the quantum of water rights served by the Newlands Reclamation Project appurtenant to the Fallon Paiute Shoshone Indian Reservation lands that are currently served by irrigation facilities; and

(b) the quantum of active Newlands Reclamation Project water rights currently located outside of the Reservation that may be added to the Reservation or water rights which are acquired by the Secretary and exercised to benefit Reservation wetlands.

(2) The requirements of section 103(C)(1) shall not take effect until the Tribes agree to the limitations on annual use of water rights set forth in subsection (1) of this section.

(D) The Secretary is authorized and directed to reimburse non-Federal entities for reasonable and customary costs for delivery of Newlands Reclamation Project water to serve water rights added to the Reservation under subsection (A) of this section, and to enter into renewable contracts for the payment of such costs, for a term not exceeding forty years.

(E) Subject to the limitation on the quantum of use set forth in subsection (C) of this section, and applicable state law, all water rights appurtenant to the Reservation that are served by the Newlands Reclamation Project, including Newlands Reclamation Project water rights added to the Reservation under subsection (A) of this section, may be used for irrigation, fish and wildlife, municipal and industrial, recreation, or water quality purposes, or for any other beneficial use subject to applicable laws of the State of Nevada. Nothing in this subsection is intended to affect the jurisdiction of the Tribes or the State of Nevada, if any, over the use and transfer of water rights within the Reservation or off the Reservation, or to create any express or implied Federal reserved water right.

(F) (1) The Tribes are authorized to acquire by purchase, by exchange of lands or water rights, or interests therein, including those held in trust for the Tribes, or by gift, any lands or water rights, or interests therein, including those held in trust, located within the Reservation, for any of the following purposes:

(a) Consolidating Reservation landholdings or water rights, including those held in trust;

(b) Eliminating fractionated heirship interests in Reservation lands or water rights, including those held in trust;

(c) Providing land or water rights for any tribal program;

(d) Improving the economy of the Tribes and the economic status of tribal members through the development of industry, recreational facilities, housing projects, or other means; and

(e) General rehabilitation and enhancement of the total resource potential of the Reservation: Provided, That any water rights shall be transferred in compliance with applicable state law.

(2) Title to any lands or water rights, or interests therein, acquired by the Tribes within the counties of Churchill and Lyon in the State of Nevada under the authority of this subsection shall be held by the United States in trust for the Tribes.

SEC. 104. RELEASE OF CLAIMS.

(A) (1) The Secretary of the Treasury and the Secretary of the Interior shall not disburse any monies from the Fund until such time as the following conditions have been met—

(a) the Tribes have released any and all claims they may have against the United States resulting from any failure of the United States to comply with section 7 of Public Law 95-337, 92 Stat. 457;

(b) the Tribes have dismissed with prejudice their claims in Northern Paiute Nation v. United States, Docket No. 87-A, United States Claims Court;

(c) the Tribes have agreed to accept and abide by the limitation on use of water rights served by the Newlands Reclamation Project on the Reservation, as set forth in section 103(C);

(d) the Tribes have dismissed, without prejudice, their claims in Pyramid Lake Paiute Tribe of Indians v. Lujan, No. R-85-197 (D.Nev.) and their objections to the Operating Criteria and Procedures for the Newlands Reclamation Project adopted by the Secretary on April 15, 1988, provided that such dismissal shall not prejudice in any respect the Tribes' right to object in any administrative or judicial proceeding to such Operating Criteria and Procedures, or any revisions thereto, or to assert that any Operating Criteria and Procedures should be changed due to new information, changes in environmental circumstance, changes in project descriptions or other relevant considerations, in accordance with the requirements of all applicable court decrees and applicable statutory requirements;

(e) the Tribes agree to be bound by the plan developed and implemented by the Secretary in accordance with section 106 of this title; and

(f) (1) the Tribes agree to indemnify the United States against monetary claims by any landowners who may hold water rights on the Reservation as of the date of enactment of the Act and who may assert that the provisions of section 103(C) of this title effect an unlawful taking of their rights: Provided, That—

(i) the United States shall defend and resist any such claims at its own expense;

(ii) the Tribes shall be entitled to intervene in any administrative or judicial proceeding on such claims; and

(iii) the United States shall not compromise or settle any such claims without the consent of the Tribes.

(2) The provisions of this section shall not be construed as:

(i) implying that section 103(C) unlawfully takes any water rights;

(ii) conferring jurisdiction on any court or other tribunal to adjudicate any such taking claims;

(iii) waiving any immunities of the United States or the Tribes; or

(iv) otherwise establishing or enhancing any claims to water rights or for the unlawful taking of such rights.

(2) If the appropriations authorized in section 102(B) are not appropriated by the Congress, it shall be deemed that the conditions set forth in this Act have not been satisfied, and the Tribes may rescind their release of claims under this section and its agreement under subsection (c) of this section.

(3) Upon the appropriation of monies authorized in section 102(B) of this Act, and the allocation of such monies to the Fund, section 7 of Public Law 95-337, 92 Stat. 457, shall be repealed.

SEC. 105. LIABILITY OF THE UNITED STATES.

(A) Except with regard to the responsibilities assumed by the United States under section 102(E), and those set forth in section 1301 of the Act of February 12, 1929, 45 Stat. 1164, as amended, U.S.C. 161a, the United States shall not bear any obligation or liability regarding the investment, management, or use of funds by the Tribes.

(B) Except with regard to the responsibilities assumed by the United States under section 102(B), section 102(F)(3), section 103(A), section 103(D), section 103(F)(2), section 104(A)(1), and section 106, the United States shall not bear any obligation or liability for the implementation of the provisions of this Act.

SEC. 106. PLAN FOR THE CLOSURE OF TJ DRAIN.

(A) The Secretary, in consultation with the Tribes and in accordance with applicable law, shall develop and implement a plan for the closure, including if appropriate, modification of components, of the TJ drain system, including the main TJ drain, the TJ-1 drain and the A drain and its sublaterals, in order to address any significant environmental problems with that system and its closure.

(B) The plan shall include measures to provide necessary substitute drainage in accordance with Bureau of Reclamation standards for reservation lands in agricultural production as of the 1990 irrigation season that are served by that system, unless the Tribes and the Secretary agree otherwise.

(C) Implementation of the plan shall not interfere with ongoing agricultural operations.

(D) The United States shall bear all costs for developing and implementing the plan.

(E) There is authorized to be appropriated such sums as may be necessary to carry out the provisions of this section.

SEC. 107. DEFINITIONS.

For the purpose of this title, and for no other purposes—

(A) the term "Fallon Paiute Shoshone Tribal Settlement Fund" or "Fund" means the Fund established under section 102A of this Act to enable the Fallon Paiute Shoshone Tribes to carry out the purposes set forth in section 102(C)(1) of this title;

(B) the term "income" means all interest, dividends, gains and other earnings resulting from the investment of the principal of the Fallon Paiute Shoshone Tribal Settlement Fund, and the earnings resulting from the investment of such income;

(C) the term "principal" means the total sum of monies appropriated to the Fallon Paiute Shoshone Tribal Settlement Fund under section 102(B) of this Act;

(D) the term "Reservation" means the lands set aside for the benefit of the Fallon Paiute Shoshone Tribes by the orders of the Department of the Interior of April 20, 1907, and November 21, 1917, as expanded and confirmed by the Act of August 4, 1978, Public Law 95-337, 92 Stat. 457;

(E) the term "Secretary" means the Secretary of the Department of the Interior;

(F) the term “tribal members” means the enrolled members of the Fallon Paiute Shoshone Tribes; and

(G) the term “Tribe” means the Fallon Paiute–Shoshone Tribe.

Title II—Truckee–Carson–Pyramid Lake Water Settlement

SEC. 201. SHORT TITLE.

This title may be cited as the “Truckee–Carson–Pyramid Lake Water Rights Settlement Act”.

SEC. 202. PURPOSES.

The purposes of this title shall be to—

(a) provide for the equitable apportionment of the waters of the Truckee River, Carson River, and Lake Tahoe between the State of California and the State of Nevada;

(b) authorize modifications to the purposes and operation of certain Federal Reclamation project facilities to provide benefits to fish and wildlife, municipal, industrial, and irrigation uses, and recreation;

(c) authorize acquisition of water rights for fish and wildlife;

(d) encourage settlement of litigation and claims;

(e) fulfill Federal trust obligations toward Indian tribes;

(f) fulfill the goals of the Endangered Species Act by promoting the enhancement and recovery of the Pyramid Lake fishery; and

(g) protect significant wetlands from further degradation and enhance the habitat of many species of wildlife which depend on those wetlands, and for other purposes.

SEC. 203. DEFINITIONS.

For the purposes of this title:

(a) the term “Alpine court” means the court having continuing jurisdiction over the Alpine decree;

(b) the term “Alpine decree” means the final decree of the United States District Court for the District of Nevada in United States of America v. Alpine Land and Reservoir Company, Civ. No. D-183, entered December 18, 1980, and any supplements thereto;

(c) the term “Carson River basin” means the area which naturally drains into the Carson River and its tributaries and into the Carson River Sink, but excluding the Humboldt River drainage area;

(d) the term “Fallon Tribe” means the Fallon Paiute–Shoshone Tribe;

(e) the term “Lahontan Valley wetlands” means wetland areas associated with the Stillwater National Wildlife Refuge, Stillwater Wildlife Management Area, Carson Lake and Pasture, and the Fallon Indian Reservation;

(f) the term “Lake Tahoe basin” means the drainage area naturally tributary to Lake Tahoe, including the lake, and including the Truckee River upstream of the intersection between the Truckee River and the western boundary of Section 12, Township 15 North, Range 16 East, Mount Diablo Base and Meridian;

(g) the term “Lower Truckee River” means the Truckee River below Derby Dam;

(h) the term “Operating Agreement” means the agreement to be negotiated between the Secretary and the States of California and Nevada and others, as more fully described in section 205 of this title;

(i) the term “Orr Ditch court” means the court having continuing jurisdiction over the Orr Ditch decree;

(j) the term “Orr Ditch decree” means the decree of the United States District Court for the District of Nevada in United States of America v. Orr Water Ditch Company, et al.—in Equity, Docket No. A3, including, but not limited to the Truckee River Agreement;

(k) the term “Preliminary Settlement Agreement as Modified by the Ratification Agreement” means the document with the title “Ratification Agreement by the United States of America”, including Exhibit “1” attached thereto, submitted to the Chairman, Subcommittee on Water and Power, Committee on Energy and Natural Resources, United States Senate, by the Assistant Secretary for Water and Science, United States Department of the Interior, on August 2, 1990, as may be amended under the terms thereof. A copy of this agreement is included in the report of the Committee on Energy and Natural Resources as Appendix 1 to the Committee’s report accompanying S. 1554;

(l) the term “Pyramid Lake fishery” means two fish species found in Pyramid Lake, the cuiui (Chasmistes cujus) and the Lahontan cutthroat trout (Salmo clarki henshawi);

(m) the term “Pyramid Lake Tribe” means the Pyramid Lake Paiute Tribe;

(n) the term “Secretary” means the Secretary of the Interior;

(o) the term “Truckee River Agreement” means a certain agreement dated July 1, 1935 and entered into by the United States of America, Truckee–Carson Irrigation District, Washoe County Water Conservation District, Sierra Pacific Power Company, and other users of the waters of the Truckee River;

(p) the term “Truckee River basin” means the area which naturally drains into the Truckee River and its tributaries and into Pyramid Lake, including that lake, but excluding the Lake Tahoe basin;

(q) the term “Truckee River General Electric court” means the United States District Court for the Eastern District of California court having continuing jurisdiction over the Truckee River General Electric decree;

(r) the term “Truckee River General Electric decree” means the decree entered June 4, 1915, by the United States District Court for the Northern District of California in United States of America v. Truckee River General Electric Co., No. 14861, which case was transferred to the United States District Court for the Eastern District of California on February 9, 1968, and is now designated No. S-643;

(s) the term “Truckee River reservoirs” means the storage provided by the dam at the outlet of

Lake Tahoe, Boca Reservoir, Prosser Creek Reservoir, Martis Reservoir, and Stampede Reservoir; and

(t) the term “1948 Tripartite Agreement” means the agreement between the Truckee–Carson Irrigation District, the Nevada State Board of Fish and Game Commissioners, and the United States Fish and Wildlife Service regarding the establishment, development, operation, and maintenance of Stillwater National Wildlife Refuge and Management Area, dated November 26, 1948.

SEC. 204. INTERSTATE ALLOCATION.

(a) **CARSON RIVER.—**

(1) The interstate allocation of waters of the Carson River and its tributaries represented by the Alpine decree is confirmed.

(2) The allocations confirmed in paragraph (1) of this subsection shall not be construed as precluding, foreclosing, or limiting the assertion of any additional right to the waters of the Carson River or its tributaries which were in existence under applicable law as of January 1, 1989, but are not recognized in the Alpine decree. The allocation made in paragraph (1) of this subsection shall be modified to accommodate any such additional rights, and such additional rights, if established, shall be administered in accordance with the terms of the Alpine decree; except that the total amount of such additional allocations shall not exceed 1,300 acre-feet per year by depletion for use in the State of California and 2,131 acre-feet per-year by depletion for use in the State of Nevada. This paragraph shall not be construed to allow any increase in diversions from the Carson River or its tributaries beyond those in existence on December 31, 1992.

(3) If, on or after the date of enactment of this title, all or any portion of the effluent imported from the Lake Tahoe basin into the watershed of the Carson River in California is discontinued by reason of a change in the place of the disposal of such effluent, including underground disposal, to the Truckee River basin or the Lake Tahoe basin, in a manner which results in increasing the available supply of water in the Nevada portion of the Truckee River basin, the allocation to California of the water of the West Fork of the Carson River and its tributaries for use in the State of California shall be augmented by an amount of water which may be diverted to storage, except that such storage:

(A) shall not interfere with other storage or irrigation rights of Segments 4 and 5 of the Carson River, as defined in the Alpine decree;

(B) shall not cause significant adverse effects to fish and wildlife;

(C) shall not exceed 2,000 acre-feet per year, or the quantity by which the available annual supply of water to the Nevada portion of the Truckee River basin is increased, whichever is less; and

(D) shall be available for irrigation use in that or subsequent years, except that the cumulative amount of such storage shall not exceed 2,000 acre-feet in any year.

(4) Storage specified by paragraph (3) of this subsection shall compensate the State of California for any such discontinuance as referred to in such paragraph: Provided, That the augmentation authority by such paragraph shall be used only on lands having appurtenant Alpine decree rights.

Use of effluent for the irrigation of lands with appurtenant Alpine decree rights shall not result in the forfeiture or abandonment of all or any part of such appurtenant Alpine decree rights, but use of such wastewater shall not be deemed to create any new or additional water rights. Nothing in this title shall be construed as prohibiting the use of all or any portion of such effluent on any lands within the State of California. Any increased water delivered to the Truckee River shall only be available to satisfy existing rights under the Orr Ditch decree or, as appropriate, to augment inflows to Pyramid Lake.

(5) Nothing in this title shall foreclose the right of either State to study, either jointly or individually, the use of Carson River surface water, which might otherwise be lost to beneficial use, to enable conjunctive use of groundwater. For purposes of this paragraph, beneficial use shall include the use of water on wetlands or wildlife areas within the Carson River basin, as may be permitted under State law.

(6) Nothing in this title shall preclude the State of Nevada, agencies of the State of Nevada, private entities, or individuals from constructing storage facilities within the Carson River basin, except that such storage facilities shall be constructed and operated in accordance with all applicable State and Federal laws and shall not result in the inundation of any portion of the East Fork of the Carson River within California.

(7) The right of any water right owner to seek a change in the beneficial use of water from irrigation to storage for municipal and industrial uses or other beneficial uses, as determined by applicable State law, is unaffected by this title. Water stored for municipal and industrial uses may be diverted to storage in a given year and held for municipal and industrial uses in that year or subsequent years. Such changes and storage shall be in accordance with the Alpine decree and applicable State law.

(8) Interbasin transfers of Carson River water shall be allowed only as provided by applicable State law.

(b) **LAKE TAHOE.—**

(1) Total annual gross diversions for use within the Lake Tahoe basin from all natural sources, including groundwater, and under all water rights in the basin shall not exceed 34,000 acre-feet per year. From this total, 23,000 acre-feet per year are allocated to the State of California for use within the Lake Tahoe basin and 11,000 acre-feet per year are allocated to the State of Nevada for use within the Lake Tahoe basin. Water allocated pursuant to this paragraph may, after use, be exported from the Lake Tahoe basin or reused.

(2) Total annual gross diversions for use allocated pursuant to paragraph (1) of this subsection shall be determined in accordance with the following conditions:

(A) Water diverted and used to make snow within the Lake Tahoe basin shall be charged to the allocation of each State as follows:

(i) the first 600 acre-feet used in California each year and the first 350 acre-feet used each year in Nevada shall not be charged to the gross diversion allocation of either State;

(ii) where water from the Lake Tahoe basin is diverted and used to make snow in excess of the amounts specified in clause (i) of this subparagraph, the percentage of such diversions chargeable to the gross diversion allocations of each State shall be specified in the Operating Agreement; and Public Law 101-608;

(iii) the provisions of paragraph 204(b)(1) notwithstanding, criteria for charging incidental runoff, if any, into the Carson River basin or the Truckee River basin, including the amount and basin to be charged, from use of water in excess of the amount specified in clause (i) of this subparagraph, shall be specified in the Operating Agreement. The amounts of such water, if any, shall be included in each State's report prepared pursuant to paragraph 204(d)(1) of this title.

(B) Unmetered diversion or extraction of water by residences shall, for the purpose of calculating the amount of either State's gross diversion, be conclusively presumed to utilize a gross diversion of four-tenths of one acre-foot per residence per year.

(C) Where water is diverted by a distribution system, as defined in clause (iii) of this subparagraph, the amount of such water that shall be charged to the gross diversion allocation of either California or Nevada shall be measured as follows:

(i) where a water distribution system supplies any municipal, commercial, and/or industrial delivery points (not including fire hydrants, flushing or cleaning points), any one of which is not equipped with a water meter, the gross diversion attributed to that water distribution system shall be measured at the point of diversion or extraction from the source; or

(ii) where all municipal, commercial, and industrial delivery points (not including fire hydrants, flushing or cleaning points) within a water distribution system are equipped with a water meter, the gross diversion attributed to that water distribution system may be measured as the sum of all amounts of water supplied to each such delivery point, provided there is in effect for such water distribution system a water conservation and management plan. Such plan may be either an individual, local plan or an area-wide, regional, or basin-wide plan, except that such plan must be reviewed and found to be reasonable under all relevant circumstances by the State agency responsible for administering water rights, or any other entity delegated such responsibility under State law. Such plan must be reviewed every five years by the agency which prepared it, and implemented in accordance with its adopted schedule, and shall include all elements required by applicable State law and the following:

(a) an estimate of past, current, and projected water use and, to the extent records are available, a segregation of those uses between residential, industrial, and governmental uses;

(b) identification of conservation measures currently adopted and in practice;

(c) a description of alternative conservation measures, including leak detection and prevention and reduction in unaccounted for water, if any, which would improve the efficiency of water use, with an evaluation of the costs, and significant environmental and other impacts of such measures;

(d) a schedule of implementation for proposed actions as indicated by the plan;

(e) a description of the frequency and magnitude of supply deficiencies, including conditions of drought and emergency, and the ability to meet short-term deficiencies;

(f) an evaluation of management of water system pressures and peak demands;

(g) an evaluation of incentives to alter water use practices, including fixture and appliance retrofit programs;

(h) an evaluation of public information and educational programs to promote wise use and eliminate waste;

(i) an evaluation of changes in pricing, rate structure, and regulations; and

(j) an evaluation of alternative water management practices, taking into account economic and non-economic factors (including environmental, social, health, and customer impact), technological factors, and incremental costs of additional supplies.

(iii) As used in this subparagraph, the term “water distribution system” means a point or points of diversion from a water supply source or sources, together with associated piping, which serve a number of identifiable delivery points: Provided, That the distribution system is not operationally interconnected with other distribution systems (except for emergency cross-ties) which are served from other points of diversion. An agency serving municipal and industrial water may have more than one water distribution system.

(iv) If a program for the review of water conservation and management plans as provided in clause (ii) of this subparagraph is not in effect in that portion of the Lake Tahoe basin within a State, all gross diversions within such State shall be measured at the point of diversion.

(D) For the purpose of this subsection, water inflow and infiltration to sewer lines shall not be considered a diversion of water, and such water shall not be charged to the gross diversion allocation of either State.

(E) Regulation of streamflow for the purpose of preserving or enhancing instream beneficial uses shall not be charged to the gross diversion allocation of either State.

(3) The transbasin diversions from the Lake Tahoe basin in Nevada and California identified in this paragraph may be continued, to the extent that such diversions are recognized as vested or perfected rights under the laws of the State where each diversion is made. Unless otherwise provided in this subsection, such diversions are in addition to the other allocations made by this subsection. Such transbasin diversions are the following:

(A) diversion of a maximum of 3,000 acre-feet per year from Marlette Lake for use in Nevada;

(B) diversion of a maximum of 561 acre-feet per year from Lake Tahoe for use in Nevada as set forth in Nevada Permit to Appropriate Water No. 23017, except that such diversion shall count against the allocation to Nevada made by this subsection;

(C) diversion of water from Echo Lake for use in California, pursuant to rights vested under California law; and

(D) diversion of water from North Creek as set forth in the State of Nevada Certificate of Appropriation of Water No. 4217.

The transbasin diversions identified in subparagraph (A), (C), and (D) of this paragraph may be transferred, for use only in the State where the recognized transbasin diversion exists, by lease of the right of use or by conveyance of the right, to the extent to which the right is vested or has been perfected.

Any such transfer shall be subject to the applicable laws of the State in which the right is vested or perfected. The transbasin diversion described in subparagraph (B) of this paragraph may be transferred in accordance with State law. With the exception of the transbasin diversion described in subparagraph (B), all water made available for use within the Lake Tahoe basin as a result of any such transfer shall not be charged against the allocations made by this section, and such water may be depleted.

(c) **TRUCKEE RIVER.—**

(1) There is allocated to the State of California the right to divert or extract, or to utilize any combination thereof, within the Truckee River basin in California the gross amount of 32,000 acre-feet of water per year from all natural sources, including both surface and groundwater, in the Truckee River basin subject to the following terms and conditions:

(A) maximum annual diversion of surface supplies shall not exceed 10,000 acre-feet; except that all diversions of surface supplies for use within California shall be subject to the right to water for use on the Pyramid Lake Indian Reservation in amounts as provided in Claim Nos. 1 and 2 of the Orr Ditch decree, and all such diversions initiated after the date of enactment of this title shall be subject to the right of the Sierra Pacific Power Company or its successor to divert forty (40) cubic feet per second of water for municipal, industrial, and domestic use in the Truckee Meadows in Nevada, as such right is more particularly described in Article V of the Truckee River Agreement;

(B) all new wells drilled after the date of enactment of this title shall be designed to minimize any short-term reductions of surface streamflows to the maximum extent feasible;

(C) any use within the State of Nevada of any Truckee River basin groundwater with a point of extraction within California shall be subordinate to existing and future uses in California, and any such use of water in Nevada shall cease to the extent that it causes extractions to exceed safe yield;

(D) except as otherwise provided in this paragraph, the extraction and use of groundwater pursuant to this subsection shall be subject to all terms and conditions of California law;

(E) determination of safe yield of any groundwater basin in the Truckee River basin in California shall be made by the United States Geological Survey in accordance with California law;

(F) water shall not be diverted from within the Truckee River basin in California for use in California outside the Truckee River basin;

(G) if the Tahoe-Truckee Sanitation Agency or its successor (hereafter "TTSA") changes in whole or in part the place of disposal of its treated wastewater to a place outside the area between Martis Creek and the Truckee River below elevation 5800 NGVD Datum, or changes the existing method of disposing of its wastewater, which change in place or method of disposal reduces the amount or substantially changes the timing of return flows to the Truckee River of the treated wastewater, TTSA shall:

(i) acquire or arrange for the acquisition of preexisting water rights to divert and use water of the Truckee River or its tributaries in California or Nevada and discontinue the diversion and use of water at the preexisting point of diversion and place of use under such rights in a manner legally sufficient to offset such reduction in the amount of return flow or change in timing, and California's Truckee River basin gross diversion allocation shall continue to be charged the amount of the discontinued diversion; or

(ii) in compliance with California law, extract and discharge into the Truckee River or its tributaries an amount of Truckee River basin groundwater in California sufficient to offset such reduction or change in timing, subject to the following conditions:

(a) extraction and discharge of Truckee River Basin groundwater for purposes of this paragraph shall comply with the terms and conditions of subparagraphs 204(c)(1)(B) and (D) and shall not be deemed use of Truckee River basin groundwater within the State of Nevada within the meaning of subparagraph 204(c)(1)(D); and

(b) California's Truckee River basin gross diversion allocation shall be charged immediately with the amount of groundwater discharged and, when California's Truckee River Basin gross diversion allocation equals 22,000 acre-feet or when the total of any reductions resulting from the changes in the place or method of disposal exceed 1000 acre-feet, whichever occurs first, the California Truckee River basin gross diversion allocation shall thereafter be charged with an additional amount of water required to compensate for the return flows which would otherwise have accrued to the Truckee River basin from municipal and industrial use of the discharged groundwater. In no event shall the total of California's Truckee River gross diversions and extractions exceed 32,000 acre-feet.

(iii) For purposes of this paragraph, the existing method of disposal shall include, in addition to underground leach field disposal, surface spray or sprinkler infiltration of treated wastewater on the site between Martis Creek and the Truckee River referred to in this subsection.

(iv) The provisions of this paragraph requiring the acquisition of water rights or the extraction and discharge of groundwater to offset reductions in the amount or timing of return flow to the Truckee River shall also apply to entities other than TTSA that may treat and dispose of wastewater within the California portion of the Truckee River basin, but only if and to the extent that the treated wastewater is not returned to the Truckee River or its tributaries, as to timing and amount, substantially as if the wastewater had been treated and disposed of by TTSA in its existing place of disposal and by its existing method of disposal. The provisions of this paragraph shall not apply to entities treating and disposing of the wastewater from less than eight dwelling units.

(H) All uses of water for commercial, irrigated agriculture within the Truckee River basin within California initiated after the date of enactment of this title shall not impair and shall be junior and subordinate to all beneficial uses in Nevada, including, but not limited to, the use of water for the maintenance and preservation of the Pyramid Lake fishery. As used in this provision, the term "commercial, irrigated agriculture" shall include traditional commercial irrigated farming operations but shall not include the following uses: irrigated golf courses and other recreational facilities, commercial nurseries, normal silvicultural activities other than commercial tree farms, irrigation under riparian rights on land irrigated at any time prior to the date of enactment of this title, lawns and ornamental shrubbery on parcels which include commercial, residential, governmental, or public buildings, and irrigated areas of two acres or less on parcels which include a residence.

(I) Water diverted within the Truckee River basin and used to make snow shall be charged to California's Truckee River allocation as follows:

(i) the first 225 acre-feet used in California each year shall not be charged to the gross diversion allocation;

(ii) where water from the Truckee River basin is diverted and used to make snow in excess of the amounts specified in clause (i) of this subparagraph, the percentage of such diversions chargeable to such allocation shall be specified in the Operating Agreement; and

(iii) the provision of subparagraph 204(c)(1)(F) notwithstanding, criteria for charging incidental runoff, if any, into the Lake Tahoe basin, including the amount and basin to be charged, from use of water in excess of the amount specified in clause (i) of this subparagraph, shall be specified in the Operating Agreement. The amounts of such water, if any, shall be included in each State's report prepared pursuant to paragraph 204(d)(1).

(J) Unmetered diversion or extraction of water by residences, shall, for the purpose of calculating the amount of California's gross diversion, be conclusively presumed to utilize a gross diversion of four-tenths of one acre-foot per residence per year.

(K) For the purposes of this subsection, water inflow and infiltration to sewer lines is not a diversion of water, and such water shall not be charged to California's Truckee River basin allocation.

(2) There is additionally allocated to California the amount of water decreed to the Sierra Valley Water Company by judgment in the case of United States of America v. Sierra Valley Water Company, United States District Court for the Northern District of California, Civil No. 5597, as limited by said judgment.

(3) There is allocated to the State of Nevada all water in excess of the allocations made in paragraph 204(c)(1) and (2) of this title.

(4) The right to water for use on the Pyramid Lake Indian Reservation in the amounts provided in Claim Nos. 1 and 2 of the Orr Ditch decree is recognized and confirmed. In accordance with and subject to the terms of the Orr Ditch decree and applicable law, the United States, acting for and on behalf of the Pyramid Lake Tribe, and with the agreement of the Pyramid Lake Tribe, or the Pyramid Lake Tribe shall have the right to change points of diversion, place, means, manner, or purpose of use of the water so decreed on the reservation.

(d) **COMPLIANCE.—**

(1) Compliance with the allocations made by this section and with other provisions of this section applicable to each State shall be assured by each State. With the third quarter following the end of each calendar year, each State shall publish a report of water use providing information necessary to determine compliance with the terms and conditions of this section.

(2) The United States District Courts for the Eastern District of California and the District of Nevada shall have jurisdiction to hear and decide any claims by any aggrieved party against the State of California, State of Nevada, or any other party where such claims allege failure to comply with the allocations or any other provision of this section. Normal rules of venue and transfers of cases between Federal courts shall remain in full force and effect. Each State, by accepting the allocations under this section, shall be deemed to have waived any immunity from the jurisdiction of such courts.

(e) **FORFEITURE OR ABANDONMENT.—**The provisions of this section shall not be interpreted to alter or affect the applicability of the law of each State regarding the forfeiture for nonuse or abandonment of any water right established in accordance with State law, nor shall the forfeiture for nonuse or abandonment of water rights under the applicable law of each State affect the allocations to each State made by this title.

(f) **INTERSTATE TRANSFERS.—**

(1) Nothing in this title shall prevent the interstate transfer of water or water rights for use within the Truckee River basin, subject to the following provisions:

(A) Each such interstate transfer shall comply with all State law applicable to transfer of water or water rights, including but not limited to State laws regulating change in point of diversion, place of use, and purpose of use of water, except that such laws must apply equally to interstate and intrastate transfers.

(B) Use of water so transferred shall be charged to the allocation of the State wherein use of water was being made prior to the transfer.

(C) Subject to subparagraph (A) of this paragraph, in addition to the application of State laws intended to prevent injury to other lawful users of water, each State may, to the extent authorized by State law, deny or condition a proposed interstate transfer of water or water rights having a source within the Truckee River basin where the State agency responsible for administering water rights finds, on the basis of substantial evidence that the transfer would have substantial adverse impacts on the environment or overall economy of the area from which the use of the water or water right would be transferred.

(D) Nothing in this paragraph shall be construed to limit the jurisdiction of any court to review any action taken pursuant to this paragraph.

(2) The jurisdiction of the Alpine court to administer, inter alia, interstate transfers of water or water rights on the Carson River under the Alpine decree, pursuant to jurisdiction reserved therein, including any amendment or supplement thereto, is confirmed. Each State may intervene of right in any proceeding before the Alpine court wherein the reserved jurisdiction of that court is invoked with respect to an interstate transfer of water or water rights, and may report to the court findings or decisions concerning the proposed change which have been made by the State agency responsible for administering water rights under any State law applicable to transfers or change in the point of diversion, purpose of use, or place of use of water.

(3) This subsection shall not be construed to authorize the State of California or the State of Nevada to deny or condition a transfer application made by the United States or its agencies if such denial or conditioning would be inconsistent with any clear congressional directive.

(g) **USE OF WATER BY THE UNITED STATES.—**Use of water by the United States of America or any of its agencies or instrumentalities, or by any Indian Tribe shall be charged to the allocation of the State wherein the use is made, except as otherwise provided in subsection (f) of this section.

(h) **COURT DECREES.—**Nothing in this section shall be construed as modifying or terminating any court decree, or the jurisdiction of any court.

(i) **PLACE OF USE TO DETERMINE ALLOCATION.—**Water diverted or extracted in one State for use in the other shall be charged to the allocation under this section of the State in which the water is used, except as otherwise provided in subsection (f) of this section.

(j) **APPLICABILITY OF STATE LAW.—**Nothing in this section shall be construed to alter the applicability of State law or procedures to the water allocated to he States hereunder.

SEC. 205. TRUCKEE RIVER WATER SUPPLY MANAGEMENT.

(a) **OPERATING AGREEMENT.—**

(1) The Secretary shall negotiate an operating agreement (hereafter “Operating Agreement”)

with the State of Nevada and the State of California, after consultation with such other parties as may be designated by the Secretary, the State of Nevada or the State of California.

(2) The Operating Agreement shall provide the operation of the Truckee River reservoirs and shall ensure that the reservoirs will be operated to:

(A) satisfy all applicable dam safety and flood control requirements;

(B) provide for the enhancement of spawning flows available in the Lower Truckee River for the Pyramid Lake fishery in a manner consistent with the Secretary's responsibilities under the Endangered Species Act, as amended;

(C) carry out the terms, conditions, and contingencies of the Preliminary Settlement Agreement as modified by the Ratification Agreement. Mitigation necessary to reduce or avoid significant adverse environmental effects, if any, of the implementation of the Preliminary Settlement Agreement as modified by the Ratification Agreement, including instream beneficial uses of water within the Truckee River basin, shall be provided through one or more mitigation agreements which shall be negotiated and executed by the parties to the Preliminary Settlement Agreement as modified by the Ratification agreement and the appropriate agencies of the States of Nevada and California;

(D) ensure that water is stored in and released from Truckee River reservoirs to satisfy the exercise of water rights in conformance with the Orr Ditch decree and Truckee River General Electric decree, except for those rights that are voluntarily relinquished by the parties to the Preliminary Settlement Agreement as modified by the Ratification Agreement, or by any other persons or entities, or which are transferred pursuant to State law; and

(E) minimize the Secretary's costs associated with operation and maintenance of Stampede Reservoir.

(3) The Operating Agreement may include, but is not limited to, provisions concerning the following subjects:

(A) administration of the Operating Agreement, including but not limited to establishing or designating an agency or court to oversee operation of the Truckee River and Truckee River reservoirs;

(B) means of assuring compliance with the provisions of the Preliminary Settlement Agreement as modified by the Ratification Agreement and the Operating Agreement;

(C) operations of the Truckee River system which will not be changed;

(D) operations and procedures for use of Federal facilities for the purpose of meeting the Secretary's responsibilities under the Endangered Species Act, as amended;

(E) methods to diminish the likelihood of Lake Tahoe dropping below its natural rim and to improve the efficient use of Lake Tahoe water under extreme drought conditions;

(F) procedures for management and operations at the Truckee River reservoirs;

(G) procedures for operation of the Truckee River reservoirs for instream beneficial uses of water within the Truckee River basin;

(H) operation of other reservoirs in the Truckee River basin to the extent that owners of affected storage rights become parties to the Operating Agreement; and

(I) procedures and criteria for implementing California's allocation of Truckee River water.

(4) To enter into effect, the Operating Agreement shall be executed by the Secretary, the State of Nevada, and the State of California and shall be submitted to the Orr Ditch court and the Truckee River General Electric court for approval of any necessary modifications in the provisions of the Orr Ditch decree or the Truckee River General Electric decree. Other affected parties may be offered the opportunity to execute the Operating Agreement.

(5) When an Operating Agreement meeting the requirements of this subsection has been approved by the Secretary, the State of Nevada, and the State of California, the Secretary, pursuant to title 5 of the United States Code, shall promulgate the Operating Agreement, together with such additional measures as have been agreed to by the Secretary, the State of Nevada, and the State of California, as the exclusive Federal regulations governing the Operating Agreement. The Secretary and the other signatories to the Operating Agreement shall, if necessary, develop and implement a plan to mitigate for any significant adverse environmental impacts resulting from the Operating Agreement. Any subsequent changes to the Operating Agreement must be adopted and promulgated in the same manner as the original Operating Agreement. Any changes which affect the Preliminary Settlement Agreement as modified by the Ratification Agreement must also be approved by the signatories thereto. Judicial review of any such promulgation of the Operating Agreement may be had by any aggrieved party in the United States District Court for the Eastern District of California or the United States District Court for District of Nevada. A request for review must be filed not later than 90 days after the promulgation of the Operating Agreement becomes final, and by a person who participated in the administrative proceedings leading to the final promulgation. The scope of such review shall be limited to the administrative record and the standard of review shall be that prescribed in 5 U.S.C. 706(2)(A)-(D): Provided, That the limits on judicial review in this paragraph shall not apply to any claim based on the provisions of the Endangered Species Act, as amended.

(6) The Secretary shall take such other actions as are necessary to implement the Preliminary Settlement Agreement as modified by the Ratification Agreement and to implement the Operating Agreement, including entering into contracts for the use of space in Truckee River reservoirs for the purposes of storing or exchanging water, subject to the preconditions that the Sierra Pacific Power Company and the Secretary shall have executed a mutually satisfactory agreement for payment by Sierra Pacific Power Company of appropriate amounts for the availability and use of storage capacity in Stampede Reservoir and other reservoirs.

(7) As provided in the Preliminary Settlement Agreement as modified by the Ratification Agreement, firm and non-firm municipal and industrial credit water and the 7,500 acre-feet of fishery credit water in Stampede Reservoir to be available under worse than critical drought conditions shall be used only to supply municipal and industrial needs when drought conditions or emergency or repair conditions exist, or as may be required to be converted to fishery credit water. None of these quantities of water shall be used to serve normal year municipal and industrial needs except when an emergency or repair condition exists.

(8) Subject to the terms and conditions of the Preliminary Settlement Agreement as modified by the Ratification Agreement, all of the fishery credit water established thereunder shall be used by the United States solely for the benefit of the Pyramid Lake fishery.

(9) In negotiating the Operating Agreement, the Secretary shall satisfy the requirements of the National Environmental Policy Act and regulations issued to implement the provisions thereof.

The Secretary may not become a party to the Operating Agreement if the Secretary determines that the effects of such action, together with cumulative effects, are likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of any designated critical habitat of such species.

(b) **AUTHORIZATION FOR USE OF WASHOE PROJECT FACILITIES, TRUCKEE RIVER STORAGE FACILITIES, AND LAKE TAHOE DAM AND RESERVOIR.—**

(1) The Secretary is authorized to use Washoe Project facilities, Truckee River Storage Project facilities, and Lake Tahoe Dam and Reservoir for the storage of non-project water to fulfill the purposes of this title, including the Preliminary Settlement Agreement as modified by the Ratification Agreement and the Operating Agreement. The Secretary shall collect appropriate charges for such uses.

(2) Payments received by the Secretary pursuant to this subsection and paragraph 205(a)(6) shall be credited annually first to pay the operation and maintenance costs of Stampede Reservoir, then covered into the Lahontan Valley and Pyramid Lake Fish and Wildlife Fund created pursuant to subsection 206(f) of this title, with funds not needed for those purposes, if any, credited to the Reclamation Fund.

(3) The Secretary is authorized to enter into an interim agreement with the Sierra Pacific Power Company and Pyramid Lake Tribe to store water owned by Sierra Pacific Power Company in Stampede Reservoir, except that the amount of such storage shall not exceed 5,000 acre-feet on

September 1 of any year, such agreement shall be superseded by the Preliminary Settlement as modified by the Ratification Agreement and the Operating Agreement upon the entry into effect of those agreements.

(c) **RELEASE OF WASHOE PROJECT REPAYMENT OBLIGATION.—**The Secretary is released from any obligation to secure payment for the costs of constructing Washoe Project facilities, other than the power plant, including those specified in the Act of August 1, 1956, 70 Stat. 775, and under Federal reclamation laws, and such costs are hereby made non-reimbursable. Authority to construct a reservoir at the Watasheamu site, together with other necessary works for impoundment, diversion, and delivery of water, generation and transmission of hydroelectric power, and drainage of lands as conferred to the Secretary in the Act of August 1, 1956, 70 Stat. 775, is hereby revoked.

SEC. 206. WETLANDS PROTECTION.

(a) **AUTHORIZATION TO PURCHASE WATER RIGHTS.—**

(1) The Secretary is authorized and directed, in conjunction with the State of Nevada and such other parties as may provide water and water rights for the purposes of this section, to acquire by purchase or other means water and water rights, with or without the lands to which such rights are appurtenant, and to transfer, hold, and exercise such water and water rights and related interests to sustain, on a long-term average, approximately 25,000 acres of primary wetland habitat within the Lahontan Valley wetlands in accordance with the following provisions of this subsection:

(A) water rights acquired under this subsection shall, to the maximum extent practicable, be used for direct application to such wetlands and shall not be sold, exchanged, or otherwise disposed of except as provided by the National Wildlife Refuge Administration Act and for the benefit of fish and wildlife within the Lahontan Valley;

(B) the Secretary shall select from any water rights acquired pursuant to this subsection those water rights or portions thereof, if not all, that can be transferred to the wetlands referenced in this subsection consistent with subsection 209(b) of this title; and

(C) in implementing this subsection, the Secretary shall consult with the State of Nevada and affected interests. Those water rights or portions thereof, if not at all, which the Secretary selects for transfer shall then be transferred in accordance with applicable court decrees and State law, and shall be used to apply water directly to wetlands. No water rights shall be purchased, however, unless the Secretary expects that the water rights can be so transferred and applied to direct use to a substantial degree.

(2) Acquisition of water rights and related interests pursuant to this subsection shall be subject to the following conditions:

(A) water right purchases shall be only from willing sellers, but the Secretary may target purchases in areas deemed by the Secretary to be most beneficial to such a purchase program;

(B) water rights acquired by the Secretary shall be managed by the Secretary after consultation with the State of Nevada and affected interests, except that any water rights acquired for Fallon Indian Reservation wetlands shall be managed by the Secretary in consultation with the Fallon Tribe; and

(C) prior to acquiring any water or water rights in the State of California for the Lahontan Valley wetlands, the Secretary shall first consult with the Governor of California and shall prepare a record of decision on the basis of such consultations.

(3) The Secretary is authorized to:

(A) use, modify, or extend, on a non-reimbursable basis, Federal water diversion, storage, and conveyance systems to deliver water to wetlands referenced in paragraph (a)(1) of this subsection, including the Fernley Wildlife Management Area;

(B) reimburse non-Federal entities for reasonable and customary costs for operation and maintenance of the Newlands Project associated with the delivery of water in carrying out the provisions of this subsection; and

(C) enter into renewable contracts for the payment of reasonable and customary costs for operation and maintenance of the Newlands Project associated with the delivery of water acquired by the Secretary to benefit the Lahontan Valley wetlands. The contracts shall be for a term not exceeding 40 years. Any such contract shall provide that upon the failure of the Secretary to pay such charges, the United States shall be liable for their payment and other costs provided for in applicable provisions of the contract, subject to the availability of appropriations.

(4) Consistent with fulfillment of the subsection and not as a precondition thereto, the Secretary shall study and report on the social, economic, and environmental effects of the water rights purchase program authorized by this subsection and the water management measures authorized by subsection 206(c). This study may be conducted in coordination with the studies authorized by paragraph 207(c)(5) and subsection 209(c) of this title, and shall be

reported to the Committees on Energy and Natural Resources, Environment and Public Works, and Appropriations of the Senate, and the Committees on Interior and Insular Affairs, Merchant Marine and Fisheries, and Appropriations of the House of Representatives not later than three years after the date of enactment of this Act.

(b) **EXPANSION OF STILLWATER NATIONAL WILDLIFE REFUGE.—**

(1) Notwithstanding any other provisions of law, the Secretary shall manage approximately 77,520 acres of Federal land in the State of Nevada, as depicted upon a map entitled "Stillwater National Wildlife Refuge," dated July 16, 1990, and available for inspection in appropriate offices of the United States Fish and Wildlife Service, as a unit of the National Wildlife Refuge System.

(2) The lands identified in paragraph (1) of this subsection shall be known as the Stillwater National Wildlife Refuge and shall be managed by the Secretary through the United States Fish and Wildlife Service for the purposes of:

(A) maintaining and restoring natural biological diversity within the refuge;

(B) providing for the conservation and management of fish and wildlife and their habitats within the refuge;

(C) fulfilling the international treaty obligations of the United States with respect to fish and wildlife; and

(D) providing opportunities for scientific research, environmental education, and fish and wildlife oriented recreation.

(3) The Secretary shall administer all lands, waters, and interests therein transferred under this title in accordance with the provisions of the National Wildlife Refuge System Administration Act of 1966, as amended, except that any activity provided for under the terms of the 1948 Tripartite Agreement may continue under the terms of that agreement until its expiration date, unless such agreement is otherwise terminated. The Secretary may utilize such additional statutory authority as may be available to the Secretary for the conservation and development of wildlife and natural resources, interpretive education, and outdoor recreation as the Secretary deems appropriate to carry out the purposes of this title.

(4) The Secretary is authorized to take such actions as may be necessary to prevent, correct, or mitigate for adverse water quality and fish and wildlife habitat conditions attributable to agricultural drain water originating from lands irrigated by the Newlands Project, except that nothing in this subsection shall be construed to preclude the use of the lands referred to in paragraph (1) of this subsection for Newlands Project drainage purposes. Such actions, if taken with respect to drains located on the Fallon Indian Reservation, shall be taken after consultation with the Fallon Tribe.

(5) Not later than November 26, 1997, after consultation with the State of Nevada and affected local interests, the Secretary shall submit to the Congress recommendations, if any, concerning:

(A) revisions in the boundaries of the Stillwater National Wildlife Refuge as may be appropriate to carry out the purposes of the Stillwater National Wildlife Refuge, and the provisions of subsection 206(a) of this section;

(B) transfer of any other United States Bureau of Reclamation withdrawn public lands within existing wildlife use areas in the Lahontan Valley to the United States Fish and Wildlife Service for addition to the National Wildlife Refuge System; and

(C) identification of those lands currently under the jurisdiction of the United States Fish and Wildlife Service in the Lahontan Valley that no longer warrant continued status as units of the National Wildlife Refuge System, with recommendations for their disposition.

(c) **WATER USE, NAVAL AIR STATION, FALLON, NEVADA.—**

(1) Not later than one year after the date of enactment of this title, the Secretary of the Navy, in consultation with the Secretary, shall undertake a study to develop land management plans or measures to achieve dust control, fire abatement and safety, and foreign object damage control on those lands owned by the United States within the Naval Air Station at Fallon, Nevada, in a manner that, to the maximum extent practicable, reduce direct surface deliveries of water. Water saved or conserved shall be defined as reduced project deliveries relative to the maximum annual headgate delivery entitlement associated with recently irrigated water-righted Navy lands. Recently irrigated water-righted Navy lands shall be determined by the Secretary of the Navy in consultation with the Secretary and the State of Nevada.

(2) The Secretary of the Navy shall promptly select and implement land management plans or measures developed by the study described in paragraph (1) of this subsection upon determining that water savings can be made without impairing the safety of operations at Naval Air Station, Fallon.

(3) All water no longer used and water rights no longer exercised by the Secretary of the Navy as a result of the implementation of the modified land management plan or measures specified by this subsection shall be managed by the Secretary for the benefit of fish and wildlife resources referenced in sections 206 and 207 of this title: Provided, That,

(A) as may be required to fulfill the Secretary's responsibilities under the Endangered Species Act, as amended, the Secretary shall manage such water and water rights primarily for the conservation of the Pyramid Lake fishery and in a manner which is consistent with the Secretary's responsibilities under the Endangered Species Act, as amended, and the requirements of applicable operating criteria and procedures for the Newlands Project; and

(B) the Secretary may manage such water or transfer temporarily or permanently some or all of the water rights no longer exercised by the Secretary of the Navy for the benefit of the Lahontan Valley wetlands so long as such management or transfers are consistent with applicable operating criteria and procedures.

(4) The Secretary of the Navy, in consultation with the Secretary of Agriculture and other interested parties, shall fund and implement a demonstration project and test site for the cultivation and development of low-precipitation grasses, shrubs, and other native or appropriate high-desert plant species, including the development of appropriate soil stabilization and land management techniques, with the goal of restoring previously irrigated farmland in the Newlands Project area to a stable and ecologically appropriate dryland condition.

(5) The Secretary shall reimburse appropriate non-Federal entities for reasonable and customary operation and maintenance costs associated with delivery of water that comes under the Secretary's management pursuant to this subsection.

(6) In carrying out the provisions of this subsection, the Secretary of the Navy and the Secretary

shall comply with all applicable provisions of State law and fulfill the Federal trust obligation to the Pyramid Lake Tribe and the Fallon Tribe.

(d) **STATE COST-SHARING.—**The Secretary is authorized to enter into an agreement with the State of Nevada for use by the State of not less than $9 million of State funds for water and water rights acquisitions and other protective measures to benefit Lahontan Valley wetlands. The Secretary's authority under subsection 206(a) is contingent upon the State of Nevada making such sums available pursuant to the terms of the agreement referenced in this subsection.

(e) **TRANSFER OF CARSON LAKE AND PASTURE.—**The Secretary is authorized to convey to the State of Nevada Federal lands in the area known generally as the "Carson Lake and Pasture," as depicted on the map entitled "Carson Lake Area," dated July 16, 1990, for use by the State as a State wildlife refuge. Prior to and as a condition of such transfer, the Secretary and the State of Nevada shall execute an agreement, in consultation with affected local interests, including the operator of the Newlands Project, ensuring that the Carson Lake and Pasture shall be managed in a manner consistent with applicable international agreements and designation of the area as a component of the Western Hemisphere Shorebird Reserve Network. The Secretary shall retain a right of reverter under such conveyance if the terms of the agreement are not observed by the State. The official map shall be on file with the United States Fish and Wildlife Service. Carson Lake and Pasture shall be eligible for receipt of water through Newlands Project facilities.

(f) **LAHONTAN VALLEY AND PYRAMID LAKE FISH AND WILDLIFE FUND.—**

(1) There is hereby established in the Treasury of the United States the "Lahontan Valley and Pyramid Lake Fish and Wildlife Fund" which shall be available for deposit of donations from any source and funds provided under subsections 205(a) and (b), 206(d), and subparagraph 208(a)(2)(C), if any, of this title.

(2) Moneys deposited into this fund shall be available for appropriation to the Secretary for fish and wildlife programs for Lahontan Valley consistent with this section and for protection and restoration of the Pyramid Lake fishery consistent with plans prepared under subsection 207(a) of this title. The Secretary shall endeavor to distribute benefits from this fund on an equal basis between the Pyramid Lake fishery and the Lahontan Valley wetlands, except that moneys deposited into the fund by the State of Nevada or donated by non-Federal entities or individuals for express purposes shall be available only for such purposes and may be expended without further appropriation, and funds deposited under subparagraph 208(a)(2)(C) shall only be available for the benefit of the Pyramid Lake fishery and may be expended without further appropriation.

(g) **INDIAN LAKES AREA.—**The Secretary is authorized to convey to the State of Nevada or Churchill County, Nevada, Federal lands in the area generally known as the Indian Lakes area, as depicted on the map entitled "Indian Lakes Area," dated July 16, 1990, pursuant to an agreement between the Secretary and the State of Nevada or Churchill County, Nevada, as appropriate, for the purposes of fish and wildlife, and recreation. Any activity provided under the terms of the 1948 Tripartite Agreement may continue under the terms of that agreement until its expiration date, unless such agreement is otherwise terminated. The official map shall be on file with the United States Fish and Wildlife Service.

SEC. 207. CUI-UI AND LAHONTAN CUTTHROAT TROUT RECOVERY AND ENHANCEMENT PROGRAM.

(a) **RECOVERY PLANS.—**Pursuant to the Endangered Species Act, as amended, the Secretary shall expeditiously revise, update, and implement plans for the conservation and recovery of the cui-ui and Lahontan cutthroat trout. Such plans shall be completed and updated from time to time as appropriate in accordance with the Endangered Species Act, as amended, and shall include all relevant measures necessary to conserve and recover the species. Such plans and any amendments and revisions thereto shall take into account and be implemented in a manner consistent with the allocations of water to the State of Nevada and the State of California made under section 204 of this title, the Preliminary Settlement Agreement as modified by the Ratification Agreement, and the Operating Agreement, if and when those allocations and agreements enter into effect.

(b) **TRUCKEE RIVER REHABILITATION.—**

(1) The Secretary of the Army, in consultation with and with the assistance of the Pyramid Lake Tribe, State of Nevada, Environmental Protection Agency, the Secretary, and other interested parties, is authorized and directed to incorporate into its ongoing reconnaissance level study of the Truckee River, a study of the rehabilitation of the lower Truckee River to and including the river terminus delta of Pyramid Lake, for the benefit of the Pyramid Lake fishery. Such study shall analyze, among other relevant factors, the feasibility of:

(A) restoring riparian habitat and vegetative cover;

(B) stabilizing the course of the Truckee River to minimize erosion;

(C) improving spawning and migratory habitats for the cui-ui;

(D) improving spawning and migratory habitat for the Lahontan cutthroat trout; and

(E) improving or replacing existing facilities, or creating new facilities, to enable the efficient passage of cui-ui and Lahontan cutthroat trout through or around the delta at the mouth of the Truckee River, and to upstream reaches above Derby Dam, to obtain access to upstream spawning habitat.

(2) There are authorized to be appropriated to the Secretary of the Army such funds as are necessary to supplement the on-going reconnaissance level study, referenced in paragraph (1), to address and report on the activities and facilities described in that paragraph.

(c) **ACQUISITION OF WATER RIGHTS.—**

(1) The Secretary is authorized to acquire water and water rights, with or without the lands to which such rights are appurtenant, and to transfer, hold, and exercise such water and water rights and related interests to assist the conservation and recovery of the Pyramid Lake fishery in accordance with the provisions of this subsection. Water rights acquired under this subsection shall be exercised in a manner consistent with the Operating Agreement and the Preliminary Settlement Agreement as modified by the Ratification Agreement and, to the maximum extent practicable, used for the benefit of the Pyramid Lake fishery and shall not be sold, exchanged, or otherwise disposed of except to the benefit of the Pyramid Lake fishery.

(2) Acquisition of water rights and related interests pursuant to this subsection shall be subject to the following conditions:

(A) water rights acquired must satisfy eligibility criteria adopted by the Secretary;

(B) water right purchases shall be only from willing sellers, but the Secretary may target purchases in areas deemed by the Secretary to be most beneficial to such a purchase program;

(C) prior to acquiring any water or water rights in the State of California for the Pyramid Lake fishery, the Secretary shall first consult with the Governor of California and prepare a record of decision on the basis of such consultation;

(D) all water rights shall be transferred in accordance with any applicable State law; and

(E) water rights acquired by the Secretary shall be managed by the Secretary in consultation with the Pyramid Lake Tribe and affected interests.

(3) Nothing in this subsection shall be construed as limiting or affecting the authority of the Secretary to acquire water and water rights under other applicable laws.

(4) The Secretary is authorized to reimburse non-Federal entities for reasonable and customary costs for operation and maintenance of the Newlands Project associated with the delivery of water in carrying out the provisions of this subsection.

(5) Consistent with fulfillment of this section and not as a precondition thereto, the Secretary shall study and report on the social, economic, and environmental effects of the water rights purchase program authorized by this section. This study may be conducted in coordination with the studies authorized by paragraph 206(a)(4) and subsection 209(c) of this title, and shall be reported to the Committees on Energy and Natural Resources, Environment and Public Works, and Appropriations of the Senate, and the Committees on Interior and Insular Affairs, Merchant Marine and Fisheries, and Appropriations of the House of Representatives not later than three years after the date of enactment of this title.

(d) **USE OF STAMPEDE AND PROSSER RESERVOIRS.—**

(1) The rights of the United States to store water in Stampede Reservoir shall be used by the Secretary for the conservation of the Pyramid Lake fishery, except that such use must be consistent with the Preliminary Settlement Agreement as modified by the Ratification Agreement, the Operating Agreement, and the mitigation agreement specified in subparagraph 205(a)(1)(C) of this title.

(2) The rights of the United States to store water in Prosser Creek Reservoir shall be used by the Secretary as may be required to restore and maintain the Pyramid Lake fishery pursuant to the Endangered Species Act, as amended, except that such use must be consistent with the Tahoe-Prosser Exchange Agreement, the Preliminary Settlement Agreement as modified by the Ratification Agreement, the Operating Agreement, and the mitigation agreement specified in subparagraph 205(a)(1)(C) of this title.

(3) Nothing in this subsection shall prevent exchanges of such water or the use of the water stored in or released from these reservoirs for coordinated non-consumptive purposes, including recreation, instream beneficial uses, and generation of hydro-electric power. Subject to the Secretary's obligations to use water for the Pyramid Lake fishery, the Secretary is authorized to use storage capacity in the Truckee River reservoirs, including Stampede and Prosser Creek reservoirs, for storage of non-project water, including, but not limited to, storage of California's Truckee River basin surface water allocation, through negotiation of appropriate provisions for storage of such water in the Operating Agreement. To the extent it is not necessary for the

Pyramid Lake fishery, the Secretary may allow Truckee River reservoir capacity dedicated to Washoe Project water to be used for exchanges of water or water rights, and to enable conjunctive use. In carrying out the provisions of this subsection, the Secretary shall comply with all applicable provisions of State law.

(e) **OFFSETTING FLOWS.—**Additional flows in the Truckee River and to Pyramid Lake resulting from the implementation of subsection 206(c) of this title are intended to offset any reductions in those flows which may be attributable to the allocations to California or Nevada under section 204 of this title or to the waivers in sections 3 and 21 of article II of the Preliminary Settlement Agreement as modified by the Ratification Agreement.

SEC. 208. PYRAMID LAKE FISHERIES AND DEVELOPMENT FUNDS.

(a) **FUNDS ESTABLISHED.—**

(1) There are hereby established within the Treasury of the United States the "Pyramid Lake Paiute Fisheries Fund" and "Pyramid Lake Paiute Economic Development Fund".

(2) There is authorized to be appropriated to the Pyramid Lake Paiute Fisheries Fund $25,000,000.

(A) The principal of the Pyramid Lake Paiute Fisheries Fund shall be unavailable for withdrawal.

(B) Interest earned on the Pyramid Lake Paiute Fisheries Fund shall be available to the Pyramid Lake Tribe only for the purposes of operation and maintenance of fishery facilities at Pyramid Lake, excluding Marble Bluff Dam and Fishway, and for conservation of the Pyramid Lake fishery in accordance with plans prepared by the Pyramid Lake Tribe in consultation with the concurrence of the United States Fish and Wildlife Service and approved by the Secretary. Of interest earned annually on the principal, 25 percent per year, or an amount which, in the sole judgment of the Secretary of the Treasury, is sufficient to maintain the principal of the fund at $25,000,000 in 1990 constant dollars, whichever is less, shall be retained in the fund as principal and shall not be available for withdrawal. Deposits of earned interest in excess of that amount may be made at the discretion of the Pyramid Lake Tribe, and all such deposits and associated interest shall be available for withdrawal.

(C) All sums deposited in, accruing to, and remaining in the Pyramid Lake Paiute Fishery Fund shall be invested by the Secretary and the Secretary of the Treasury in interest-bearing deposits and securities in accordance with the Act of June 24, 1938, 52 Stat. 1037. Interest earnings not expended, added to principal, or obligated by the Pyramid Lake Tribe in the year in which such earnings accrue to the fund or in the four years that immediately follow shall be credited to the fund established under subsection 206(f) of this title.

(D) Subject to subparagraph (E) of this paragraph, the Secretary and the Secretary of the Treasury shall allocate and make available to the Pyramid Lake Tribe such eligible moneys from the Pyramid Lake Fishery Fund as are requested by the Pyramid Lake Tribe to carry out plans developed under subparagraph (B) of this paragraph.

(E) The Secretary and the Secretary of the Treasury shall not disburse moneys from the Pyramid Lake Paiute Fishery Fund until such time as the following conditions have been met:

(i) The Pyramid Lake Tribe has released any and all claims of any kind whatsoever against the United States for damages to the Pyramid Lake fishery resulting from the Secretary's acts or omissions prior to the date of enactment of this title; and

(ii) The Pyramid Lake Tribe has assumed financial responsibility for operation and maintenance of the fishery facilities located at Pyramid Lake for the benefit of the Pyramid Lake fishery, excluding the Marble Bluff Dam and Fishway.

(3) There is authorized to be appropriated to the Pyramid Lake Paiute Economic Development Fund $40,000,000 in five equal annual installments in the 1993, 1994, 1995, 1996, and 1997 fiscal years.

(A) The principal and interest of the Pyramid Lake Paiute Economic Development Fund shall be available for tribal economic development only in accordance with a plan developed by the Pyramid Lake Tribe in consultation with the Secretary. The objectives of the plan shall be to develop long-term, profit-making opportunities for the Pyramid Lake Tribe and its members, to create optimum employment opportunities for tribal members, and to establish a high quality recreation area at Pyramid Lake using the unique natural and cultural resources of the Pyramid Lake Indian Reservation. The plan shall be consistent with the fishery restoration goals of section 207 of this title. The plan may be revised and updated by the Pyramid Lake Tribe in consultation with the Secretary.

(B) The Pyramid Lake Tribe shall have complete discretion to invest and manage the Pyramid Lake Paiute Economic Development Fund, except that no portion of the principal shall be used to develop, operate, or finance any form of gaming or gambling, except as may be provided by the Indian Gaming Regulatory Act, Public Law 100-497 (102 Stat. 2467), and the United States shall not bear any obligation or liability regarding the investment, management, or use of such funds that the Pyramid Lake Tribe chooses to invest, manage, or use.

(C) If the Pyramid Lake Tribe so requests, all sums deposited in, accruing to, and remaining in the Pyramid Lake Paiute Economic Development Fund shall be invested by the Secretary and the Secretary of the Treasury in interest-bearing deposits and securities in accordance with the Act of June 24, 1938, 52 Stat. 1037. All such interest shall be added to the Pyramid Lake Paiute Economic Development Fund.

(D) The Secretary and the Secretary of the Treasury shall allocate and make available to the Pyramid Lake Tribe such moneys from the Pyramid Lake Economic Development Fund as are requested by the Pyramid Lake Tribe, except that no disbursements shall be made to the Pyramid Lake Tribe unless and until the Pyramid Lake Tribe adopts and submits to the Secretary the economic development plan described in subparagraph (A) of this paragraph, and section 204, the Preliminary Settlement Agreement as modified by the Ratification Agreement, and the Operating Agreement enter into effect in accordance with the terms of subsection 210(a) of this title.

(4) Under no circumstances shall any part of the principal of the funds established under this section be distributed to members of the Pyramid Lake Tribe on a per capita basis.

(5) If, and to the extent that any portion of the sum authorized to be appropriated in paragraph 208(a)(2) is appropriated after fiscal year 1992, or in a lesser amount, there shall be deposited in the Pyramid Lake Paiute Fisheries Fund, subject to appropriations, in addition to the full contribution to the Pyramid Lake Paiute Fisheries Fund, an adjustment representing the interest income as determined by the Secretary in his sole discretion that would have been earned on any unpaid amount had the amount authorized in paragraph 208(a)(2) been appropriated in full for

fiscal year 1992.

(6) If and to the extent that any portion of the sums authorized to be appropriated in paragraph 208(a)(3) are appropriated after fiscal years 1993, 1994, 1995, 1996, and 1997, or in lesser amounts than provided by paragraph 208(a)(3), there shall be deposited in the Pyramid Lake Paiute Economic Development Fund, subject to appropriations, in addition to the full contributions to the Pyramid Lake Paiute Economic Development Fund, an adjustment representing the interest income as determined by the Secretary in his sole discretion that would have been earned on any unpaid amounts had the amounts authorized in paragraph 208(a)(3) been appropriated in full for fiscal years 1993, 1994, 1995, 1996, and 1997.

SEC. 209. NEWLANDS PROJECT IMPROVEMENT.

(a) **EXPLANATION OF AUTHORIZED PURPOSES.—**

(1) In addition to the existing irrigation purpose of the Newlands Reclamation Project, the Secretary is authorized to operate and maintain the project for the purposes of:

(A) fish and wildlife, including endangered and threatened species;

(B) municipal and industrial water supply in Lyon and Churchill counties, Nevada, including the Fallon Indian Reservation;

(C) recreation;

(D) water quality; and

(E) any other purposes recognized as beneficial under the law of the State of Nevada.

(2) Additional uses of the Newlands Project made pursuant to this section shall have valid water rights and, if transferred, shall be transferred in accordance with State law.

(b) **TRUCKEE RIVER DIVERSIONS.—**The Secretary shall not implement any provision of this title in a manner that would:

(1) increase diversions of Truckee River water to the Newlands Project over those allowed under applicable operating criteria and procedures; or

(2) conflict with applicable court decrees.

(c) **PROJECT EFFICIENCY STUDY.—**

(1) The Secretary shall study the feasibility of improving the conveyance efficiency of Newlands Project facilities to the extent that, within twelve years after the date of enactment of this title, on average not less than seventy-five percent of actual diversions under applicable operating criteria and procedures shall be delivered to satisfy the exercise of water rights within the Newlands Project for authorized project purposes.

(2) The Secretary shall consider the effects of the measures required to achieve such efficiency on groundwater resources and wetlands in the Newlands Project area. The Secretary shall report the results of such study to the Committees on Energy and Natural Resources, Environment and Public Works, and Appropriations of the Senate and the Committees on Interior and Insular Affairs, Merchant Marine and Fisheries, and Appropriations of the House of Representatives not later than three years after the date of enactment of this title.

(d) **WATER BANK.—**The Secretary, in consultation with the State of Nevada and the operator of the Newlands Project, is authorized to use and enter into agreements to allow water right holders to use Newlands Project facilities in Nevada, where such facilities are not otherwise committed or required to fulfill project purposes or other Federal obligations, for supplying carryover storage of irrigation and other water for drought protection and other purposes, consistent with subsections (a) and (b) of this section. The use of such water shall be consistent with and subject to applicable State laws.

(e) **RECREATION STUDY.—**The Secretary, in consultation with the State of Nevada, is authorized to conduct a study to identify administrative, operational, and structural measures to benefit recreational use of Lahontan Reservoir and the Carson River downstream of Lahontan Dam. Such study shall be reported to the Committee on Energy and Natural Resources of the Senate and the Committee on Interior and Insular Affairs of the House of Representatives.

(f) **EFFLUENT REUSE STUDY.—**The Secretary, in cooperation with the Administrator of the Environmental Protection Agency, the State of Nevada, and appropriate local entities, shall study the feasibility of reusing municipal wastewater for the purpose of wetland improvement or creation, or other beneficial purposes, in the areas of Fernley, Nevada, the former Lake Winnemucca National Wildlife Refuse, and the Lahontan Valley. The Secretary shall coordinate such studies with other efforts underway to manage wastewater from the Reno and Sparks, Nevada, area to improve Truckee River and Pyramid Lake water quality. Such study shall be reported to the Committees on Energy and Natural Resources, Environment and Public Works, and Appropriations of the Senate and the Committees on Interior and Insular Affairs, Merchant Marine and Fisheries, and Appropriations of the House of Representatives.

(g) **REPAYMENT CANCELLATION.—**Notwithstanding any other provisions of law, the Secretary may cancel all repayment obligations owing to the Bureau of Reclamation by the Truckee-Carson Irrigation District. As a precondition for the Secretary to cancel such obligations, the Truckee-Carson Irrigation District shall agree to collect all such repayment obligations and use such funds for water conservation measures. For the purpose of this subsection and paragraph 209(h)(2), the term “water conservation measures” shall not include repair, modification, or replacement of Derby Dam.

(h) **SETTLEMENT OF CLAIMS.—**

(1) The provisions of subsections 209(d), (e), (f), and (g) of this section shall not become effective unless and until the Truckee-Carson Irrigation District has entered into a settlement agreement with the Secretary concerning claims for recoupment of water diverted in excess of the amounts permitted by applicable operating criteria and procedures.

(2) The provisions of subsection 209(g) of this section shall not become effective unless and until the State of Nevada provides not less than $4,000,000 for use in implementing water conservation measures pursuant to the settlement described in paragraph (1) of this subsection.

(3) The Secretary is authorized to expend such sums as may be required to match equally the sums provided by the State of Nevada under paragraph (2) of this subsection. Such sums shall be available for use only in implementing water conservation measures pursuant to the settlement described in paragraph (1) of this subsection.

(i) **FISH AND WILDLIFE.—**The Secretary shall, insofar as is consistent with project irrigation purposes and applicable operating criteria and procedures, manage existing Newlands Project re-

regulatory reservoirs for the purpose of fish and wildlife.

(j) **OPERATING CRITERIA AND PROCEDURES.—**

(1) In carrying out the provisions of this title, the Secretary shall act in a manner that is fully consistent with the decision in the case of Pyramid Lake Paiute Tribe of Indians v. Morton, 354 F.Supp. 252 (D.D.C. 1973).

(2) Notwithstanding any other provision of law, the operating criteria and procedures for the Newlands Reclamation Project adopted by the Secretary on April 15, 1988 shall remain in effect at least through December 31, 1997, unless the Secretary decides, in his sole discretion, that changes are necessary to comply with his obligations, including those under the Endangered Species Act, as amended. Prior to December 31, 1997, no court or administrative tribunal shall have jurisdiction to set aside any of such operating criteria and procedures or to order or direct that they be changed in any way. All actions taken heretofore by the Secretary under any operating criteria and procedures are hereby declared to be valid and shall not be subject to review in any judicial or administrative proceeding, except as set forth in paragraph (3) of this subsection.

(3) The Secretary shall henceforth ensure compliance with all of the provisions of the operating criteria and procedures referenced in paragraph (2) of this subsection or any applicable provision of any other operating criteria or procedures for the Newlands Project previously adopted by the Secretary, and shall, pursuant to subsection 709(h) or judicial proceeding, pursue recoupment of any water diverted from the Truckee River in excess of the amounts permitted by any such operating criteria and procedures. The Secretary shall have exclusive authority and responsibility to pursue such recoupment, except that, if an agreement or order leading to such recoupment is not in effect as of December 31, 1997, any party with standing to pursue such recoupment prior to enactment of this title may pursue such recoupment thereafter. Any agreement or court order between the Secretary and other parties concerning recoupment of Truckee River water diverted in violation of applicable operating criteria and procedures shall be consistent with the requirements of this subsection and the Endangered Species Act, as amended, and shall be submitted for the review and approval of the court exercising jurisdiction over the operating criteria and procedures for the Newlands Project. All interested parties may participate in such review. In any recoupment action brought by any party, other than the Secretary, after December 31, 1997, the only relief available from any court of the United States will be the issuance of a declaratory judgment and injunctive relief directing any unlawful user of water to restore the amount of water unlawfully diverted. In no event shall a court enter any order in such a proceeding that will result in the expenditure of any funds out of the United States Treasury.

SEC. 210. MISCELLANEOUS PROVISIONS.

(a) **CLAIMS SETTLEMENT.—**

(1) The effectiveness of section 204 of this title, the Preliminary Settlement Agreement as modified by the Ratification Agreement, the Operating Agreement, and the Secretary's authority to disburse funds under paragraph 208(a)(3) of this title are contingent upon dismissal with prejudice or other final resolution, with respect to the parties to the Preliminary Settlement Agreement as modified by the Ratification Agreement and the State of Nevada and the Secretary of California, of the following outstanding litigation and proceedings:

(A) Pyramid Lake Paiute Tribe v. California, Civ. S-181-378-RAR-RCB, United States District Court, Eastern District of California.

(B) United States v. Truckee-Carson Irrigation District, Civ. No. R-2987-RCB, United States District Court, District of Nevada.

(C) Pyramid Lake Paiute Tribe v. Lujan, Civ. S-87-1281-LKK, United States District Court, Eastern District of California;

(D) Pyramid Lake Paiute Tribe v. Department of the Navy, Civ. No. R-86-115-BRT in the United States District Court, District of Nevada and Docket No. 88-1650 in the United States Court of Appeals for the Ninth Circuit; and

(E) All pending motions filed by the Tribe in Docket No. E-9530 before the Federal Energy Regulatory Commission.

(2) In addition to any other conditions on the effectiveness of this title set forth in this title, the provisions of:

(A) section 204, subsections 206(c), 207(c) and (d), subparagraph 208(a)(3)(D), and paragraph 210(a)(3) of this title shall not take effect until:

(i) the agreements and regulations required under section 205 of this title, including the Truckee Meadows water conservation plan referenced in the Preliminary Settlement Agreement as modified by the Ratification Agreement, enter into effect;

(ii) the outstanding claims described in paragraph 210(a)(1) have been dismissed with prejudice or otherwise finally resolved;

(B) section 204 of this title, the Preliminary Settlement Agreement as modified by the Ratification Agreement, and the Operating Agreement, shall not take effect until the Pyramid Lake Tribe's claim to the remaining waters of the Truckee River which are not subject to vested or perfected rights has been finally resolved in a manner satisfactory to the State of Nevada and the Pyramid Lake Tribe; and

(C) section 204 of this title, the Preliminary Settlement Agreement as modified by the Ratification Agreement, the Operating Agreement, and subsection 207(d) shall not take effect until the funds authorized in paragraph 208(a)(3) of this title have been appropriated.

(3) On and after the effective date of section 204 of this title, except as otherwise specifically provided herein, no person or entity who has entered into the Preliminary Settlement Agreement as modified by the Ratification Agreement or the Operating Agreement, or accepted any benefits or payments under this legislation, including any Indian Tribe and the States of California and Nevada, the United States and its officers and agencies may assert in any judicial or administrative proceeding a claim that is inconsistent with the allocations provided in section 204 of this title, or inconsistent or in conflict with the operational criteria for the Truckee River established pursuant to section 205 of this title. No person or entity who does not become a party to the Preliminary Settlement Agreement as modified by the Ratification Agreement or the Operating Agreement may assert in any judicial or administrative proceeding any claim for water or water rights for the Pyramid Lake Tribe, the Pyramid Lake Indian Reservation, or the Pyramid Lake fishery. Any such claims are hereby barred and extinguished and no court of the United States may hear or consider any such claims by such persons or entities.

(b) **GENERAL PROVISIONS.—**

(1) Subject to the provisions of paragraphs (2) and (3) of this subsection, and to all existing property rights or interests, all of the trust land within the exterior boundaries of the Pyramid Lake Indian Reservation shall be permanently held by the United States for the sole use and benefit of the Pyramid Lake Tribe.

(2) Anaho Island in its entirety is hereby recognized as part of the Pyramid Lake Indian Reservation. In recognition of the consent of the Pyramid Lake Tribe evidenced by Resolution No. 19-90 of the Pyramid Lake Paiute Tribal Council, all of Anaho Island shall hereafter be managed and administered by and under the primary jurisdiction of the United States Fish and Wildlife Service as an integral component of the National Wildlife Refuge System for the benefit and protection of colonial nesting species and other migratory birds. Anaho Island National Wildlife Refuge shall be managed by the United States Fish and Wildlife Service in accord with the National Wildlife Refuge System Administration Act, as amended, and other applicable provisions of Federal law. Consistent with the National Wildlife Refuge System Administration Act, as amended, the Director of the United States Fish and Wildlife Service is authorized to enter into cooperative agreements with the Pyramid Lake Tribe regarding Anaho Island National Wildlife Refuge.

(3) Subject to the relinquishment by the legislature of the State of Nevada of any claim the State of Nevada may have to ownership of the beds and banks of the Truckee River within the exterior boundaries of the Pyramid Lake Indian Reservation and of Pyramid Lake, those beds and banks are recognized as part of the Pyramid Lake Indian Reservation and as being held by the United States in trust for the sole use and benefit of the Pyramid Lake Tribe. Nothing in this subsection shall be deemed to recognize any right, title, or interest of the State of Nevada in those beds and banks which it would not otherwise have. No other provision of this title shall be contingent on the effectiveness of this subsection.

(4) Except as provided in paragraphs (2) and (9) of this subsection, the Pyramid Lake Tribe shall have the sole and exclusive authority to establish rules and regulations governing hunting, fishing, boating, and all forms of water based recreation on all lands within the Pyramid Lake Indian Reservation except fee-patented land, provided that the regulation of such activities on fee-patented land within the Pyramid Lake Indian Reservation shall not be affected by this paragraph. Nothing in this paragraph shall be deemed to recognize or confer any criminal jurisdiction on the Pyramid Lake Tribe or to affect any regulatory jurisdiction of the State of Nevada with respect to any other matters.

(5) The consent of the United States is given to the negotiation and execution of an intergovernmental agreement between the Pyramid Lake Tribe and the State of Nevada, which agreement may also include Washoe County, Nevada, providing for the enforcement by the State of Nevada and Washoe County of the rules and regulations referred to in paragraph (4) adopted by the Pyramid Lake Tribe governing hunting, fishing, boating, and all forms of water based recreation against non-members of the Pyramid Lake Tribe and for State courts or other forums of the State of Nevada or its political subdivisions to exercise civil and criminal jurisdiction over violations of the Pyramid Lake Tribe's rules and regulations allegedly committed by such non-members, except as provided by paragraphs (2) and (9) of this subsection.

(6) The consent of the United States is given to the negotiation and execution of an intergovernmental agreement between the Pyramid Lake Tribe and the State of Nevada, which

agreement may also include Washoe County, Nevada, providing for the enforcement of rules and regulations governing hunting, fishing, boating, and all forms of water based recreation on fee-patented land within the Pyramid Lake Indian Reservation, except as provided by paragraphs (2) and (9) of this subsection.

(7) Nothing in this title shall limit or diminish the Federal Government's trust responsibility to any Indian Tribe, except that this provision shall not be interpreted to impose any liability on the United States or its agencies for any damages resulting from actions taken by the Pyramid Lake Paiute Tribe as to which the United States is not a party or with respect to which the United States has no supervisory responsibility.

(8) Subject to the terms, conditions, and contingencies of and relating to the Preliminary Settlement Agreement as modified by the Ratification Agreement, the United States on its own behalf and in its capacity as trustee to the Pyramid Lake Tribe confirms and ratifies the waivers of any right to object to the use and implementation of the water supply measures described in sections 3 and 21 of article II of the Preliminary Settlement Agreement as modified by the Ratification Agreement, and any waivers of sovereign immunity given in connection with that agreement or the Operating Agreement, upon the entry into effect of the Preliminary Settlement Agreement as modified by the Ratification Agreement.

(9) Nothing in this title shall be construed as waiving or altering the requirements of any Federal environmental or wildlife conservation law, including, but not limited to, the Endangered Species Act, as amended, including the consultation and reinitiation of consultation responsibilities of the Secretary under section 7 of the Act, and the National Environmental Policy Act of 1969.

(10) Nothing in this title shall be construed to create an express or implied Federal reserved water right.

(11) Nothing in this title shall subject the United States or any of its agencies or instrumentalities or any Indian Tribe to any State jurisdiction or regulation to which they would not otherwise be subject.

(12) Nothing in this title is intended to abrogate the jurisdiction of or required approvals by the Nevada State Engineer or the California State Water Resources Control Board.

(13) Nothing in this title is intended to affect the power of the Orr Ditch court or the Alpine court to ensure that the owners of vested or perfected Truckee River water rights receive the amount of water to which they are entitled under the Orr Ditch decree or the Alpine decree. Nothing in this title is intended to alter or conflict with any vested and preferred right of any person or entity to use the water of the Truckee River or its tributaries, including, but not limited to, the rights of landowners within the Newlands Project for delivery of the water of the Truckee River to Derby Dam and for the diversion of such waters at Derby Dam pursuant to the Orr Ditch decree or any applicable law.

(14) No single provision or combination of provisions in this title, including interstate allocations under section 204, or associated agreements which may adversely affect inflows of water to Pyramid Lake shall form the basis for additional claims of water to benefit Pyramid Lake, the Pyramid Lake fishery, or lands within the Pyramid Lake Indian Reservation.

(15) Nothing in this title shall affect any claim of Federal reserved water rights, if any, to the Carson River or its tributaries for the benefit of lands within the Fallon Indian Reservation.

(16) The Secretary, in consultation with the State of Nevada and affected local interests, shall undertake appropriate measures to address significant adverse impacts, identified by studies authorized by this title, on domestic uses of groundwater directly resulting from the water purchases authorized by this title.

(17) It is hereby declared that after August 26, 1935, and prior to the date of enactment of this title, there was no construction within the meaning of section 23(b) of the Federal Power Act, as amended, at the four run-of-river hydroelectric project works owned by Sierra Pacific Power Company and located on the Truckee River. Notwithstanding any other provision of law, after the date of enactment of this title, development of additional generating capacity at such project works that is accomplished through replacement of turbine generators and increases in effective head shall not constitute construction within the meaning of section 23(b) of the Federal Power Act, as amended: Provided, That such development may not change the location of or increase any existing impoundments and may not require diversions of water in excess of existing water rights for such project works: And provided further, That the diversions of water for the operation of such project works shall be consistent with the Preliminary Settlement Agreement as modified by the Ratification Agreement, and the Operating Agreement. The Secretary shall take into account the monetary value of this provision to the Sierra Pacific Power Company in calculating the storage charge referred to in paragraph 205(a)(6).

(18) The Secretary is authorized, in accordance with this section and applicable provisions of existing law, to exchange surveyed public lands in Nevada for interests in fee patented lands, water rights, or surface rights to lands within or contiguous to the exterior boundaries of the Pyramid Lake Indian Reservation. The values of the lands or interests therein exchanged by the Secretary under this paragraph shall be substantially equal, but the Secretary is authorized to accept monetary payments from the owners of such fee patented lands, water rights, or surface rights as circumstances may require in order to compensate for any difference in value. Any such payments shall be deposited to the Treasury. The value of improvements on land to be exchanged shall be given due consideration and an appropriate allowance shall be made therefor in the valuation. Title to lands or any interest therein acquired by the Secretary pursuant to this subsection shall be taken in the name of the United States in trust for the Pyramid Lake Tribe and shall be added to the Pyramid Lake Indian Reservation.

(c) **APPROPRIATIONS AUTHORIZED.—**There are authorized to be appropriated such sums as may be required to implement the provisions of this title.

APPENDIX C. PUBLIC LAW 109-103, THE ENERGY AND WATER DEVELOPMENT APPROPRIATIONS ACT, 2006 ENACTED ON NOVEMBER 19, 2005

TITLE II, DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
General Provisions, Department of the Interior

SEC. 208.

(a) (1) Using amounts made available under section 2507 of the Farm and Security Rural Investment Act of 2002 (43 U.S.C. 2211 note; Public Law 107-171), the Secretary [of the Interior] shall provide not more than $70,000,000 to the University of Nevada–

(A) to acquire from willing sellers land, water appurtenant to the land, and related interests in the Walker River Basin, Nevada; and

(B) to establish and administer an agricultural and natural resources center, the mission of which shall be to undertake research, restoration, and educational activities in the Walker River Basin relating to–

(i) innovative agricultural water conservation;

(ii) cooperative programs for environmental restoration;

(iii) fish and wildlife habitat restoration; and

(iv) wild horse and burro research and adoption marketing.

(2) In acquiring interests under paragraph (1)(A), the University of Nevada shall make acquisitions that the University determines are the most beneficial to–

(A) the establishment and operation of the agricultural and natural resources research center authorized under paragraph (1)(B); and

(B) environmental restoration in the Walker River Basin.

(b) (1) Using amounts made available under section 2507 of the Farm and Security Rural Investment Act of 2002 (43 U.S.C. 2211 note; Public Law 107-171), the Secretary shall provide not more than $10,000,000 for a water lease and purchase program for the Walker River Paiute Tribe.

(2) Water acquired under paragraph (1) shall be–

(A) acquired only from willing sellers;

(B) designed to maximize water conveyances to Walker Lake; and

(C) located only within the Walker River Paiute Indian Reservation.

(c) Using amounts made available under section 2507 of the Farm and Security Rural Investment Act of 2002 (43 U.S.C. 2211 note; Public Law 107-171), the Secretary, acting through the Commissioner of Reclamation, shall provide–

(1) $10,000,000 for tamarisk eradication, riparian area restoration, and channel restoration efforts within the Walker River Basin that are designed to enhance water delivery to Walker Lake, with priority given to activities that are expected to result in the greatest increased water flows to Walker Lake; and

(2) $5,000,000 to the United States Fish and Wildlife Service, the Walker River Paiute Tribe, and the Nevada Division of Wildlife to undertake activities, to be coordinated by the Director of the United States Fish and Wildlife Service, to complete the design and implementation of the Western Inland Trout Initiative and Fishery Improvements in the State of Nevada with an emphasis on the Walker River Basin.

(d) For each day after June 30, 2006, on which the Bureau of Reclamation fails to comply with subsections (a), (b), and (c), the total amount made available for salaries and expenses of the Bureau of Reclamation shall be reduced by $100,000 per day.

APPENDIX D: WALKER RIVER PROJECT OVERVIEW

A. HEALTH OF WALKER RIVER AND LAKE:

This project will evaluate and establish a benchmark for the environmental and ecological health of Walker Lake and Walker River. Decision tools will be developed to analyze the efficacy of different water acquisitions for improving future ecological integrity of Walker Lake and Walker River.

B. ALTERNATIVE AGRICULTURE AND VEGETATION MANAGEMENT:

This project will identify the economic potential and cultural practices necessary for low-water-use crops with the aim of minimizing water use, soil erosion and evaporation from soil surfaces. In addition, the research will evaluate methods to re-establish desirable vegetation in areas that may be affected by changing agricultural practices and to anticipate vegetation responses under scenarios identified through modeling efforts.

C. PLANT, SOIL AND WATER INTERACTIONS:

This project will assess likely responses by soils and vegetation to changes in water application and use. Information on the impacts of changes in water table and stream elevation on soil physical and chemical properties, including wind erosion, nutrient cycling and salt accumulation, will aid managers in the preservation of air and water quality adjacent to and within the river and lake itself.

D. PROJECT HISTORICAL ACCOUNT:

This project will provide an overview of the political and historical context in which the acquisition of land and associated water rights for ecosystem restoration in the Walker River system occurs. Key components include arid land agriculture, multi-state involvement and urban/rural interface issues.

E. HEALTH OF RIVER CHANNEL AND LAKE WATER WITH INCREASED FLOWS:

This project will develop a set of recommendations to minimize further sediment and salt loading to Walker Lake and degradation to the lower Walker River under increased water flows. These recommendations will be made available to land and water managers to assess potential impacts resulting from variations in flow, water quality and channel geometry on the transport of sediments and on the flow capacity of the Walker River.

F. WATER FLOW MODEL:

This project will develop a decision-support tool to evaluate the effectiveness of proposed acquisitions of water rights from willing sellers to increase water delivery to Walker Lake. The tool’s water flow model will include aspects of climate and evaporation from different water sources.

G. WATER CONSERVATION PRACTICES FOR AGRICULTURE PRODUCERS:

The project will determine the most economically effective use of water on agricultural lands and provide producers with an estimate of the potential amount of water rights they may be able to offer to the market for lease or sale.

H. ECONOMIC IMPACT AND STRATEGIES:

This project will develop estimates of the economic impacts projected to occur from the acquisition of water rights and changes in agricultural production and land use. The project will also formulate economic development actions to mitigate the projected economic and fiscal dislocations. One benefit of this research will be to identify appropriate sustainable economic development actions and related public policy alternatives.

I. GIS DATABASE DEVELOPMENT:

This project will develop a geographic information systems (GIS) framework for linking water rights with water distribution networks and points of diversion for the Walker Basin. The resulting GIS database may be used to assess how water and land acquisitions will affect the entire Walker Basin system. The economic component of this project will develop a GIS database of properties, businesses and local demographics in close proximity to the Walker River and its tributaries.

J. WILD HORSE AND BURRO MARKETING:

The project will determine which characteristics of wild horses and burros increase adoption rates. It will also investigate alternative auction procedures which could increase adoption rates and simultaneously increase revenues to support wild horse and burro programs.

PROJECT E: DEVELOPMENT OF RECOMMENDATIONS TO MAXIMIZE WATER CONVEYANCE AND MINIMIZE DEGRADATION OF WATER QUALITY IN WALKER LAKE DUE TO EROSION, SEDIMENT TRANSPORT, AND SALT DELIVERY

HISTORIC EROSION AND SEDIMENT DELIVERY TO WALKER LAKE FROM LAKE-LEVEL LOWERING: IMPLICATIONS FOR THE LOWER WALKER RIVER AND WALKER LAKE UNDER INCREASED FLOWS

Contributing Authors:

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The surface elevation of Walker Lake has dropped by about 50 m in the last 100 years or so, causing Walker River to extend by about 20 km across the former lake bed. In addition to lengthening, the river has also severely down cut in response to lowering of base level. In this study we use rectified aerial photographs, beginning in 1938 and proceeding to the present, in combination with detailed topography from 1995, 1997, and 2005 in a GIS database to document the conditions under which lateral and vertical erosion have occurred. From 1995 to 1997, approximately 1.02 million metric tons (MT) of sediment was eroded from the bed and banks of the lowermost Walker River. Over the next seven years (1997-2005) about 430,000 MT of sediment was eroded. During the spring 2005 runoff season, approximately 477,000 MT of sediment was eroded and during the spring 2006 runoff season another 936,000 MT of sediment was flushed into the lake from bed and bank erosion. The amount of erosion in a given year does not only depend on peak discharge but also is directly related to the duration of the runoff event. Complementing the image analysis approach, we also use a 2D sediment transport model to simulate the amount of sediment transport and vertical erosion that may occur under a variety of flow scenarios. It is difficult to directly compare the estimates of erosion made from aerial photography to those made from modeling because the former is better at documenting lateral erosion and the latter focuses on vertical erosion. Regardless, the results from both of these approaches indicate that hundreds of thousands of metric tons of sediment are eroded from the bed and banks of the lower Walker River during an "average" runoff year, attesting to the instability of this system. Most of this instability is concentrated in the lowermost reaches of the river. The only way to reverse this trend and to help the ecology of Walker Lake is to provide more water, which will likely be supplied via the Walker River. Instead of increasing peak flows, a more sound option would be to increase the durations of spring runoff events or to establish minimum base flows that cumulatively would supply the additional water volume to the lake but at the same time minimize further erosion. An additional pressing issue for the lower Walker River is the poor condition of the siphon, which currently is holding in place the historic head cut that migrated upstream after the lake lowered from its historic highstand position in 1868. The failure of this structure would likely allow the rapid migration of this head cut upstream where it would threaten bridges and other infrastructure in the town of Schurz in addition to destabilizing the relatively intact Walker River reach that extends from Weber Dam downstream to the siphon. Measures should be taken to stabilize the siphon reach that would also allow effective fish passage.

INTRODUCTION

Walker Lake is located in west-central Nevada and is one of the few perennial, terminal lakes in the Great Basin (Figure 1). Due to upstream flow diversions and consumption, the surface elevation of Walker Lake has dropped by about 50 m over the last 100 years. This has caused a surface area reduction of about a factor of two and a volumetric reduction by about a factor of seven (Lopes and Smith, 2007). Consequently, the ecology of Walker Lake is at a critical threshold because of rising salinity and the only way to reverse this trend is to deliver more water to the lake. In all likelihood, if more water is provided to Walker Lake it will be delivered via the Walker River, the principal tributary to the lake.

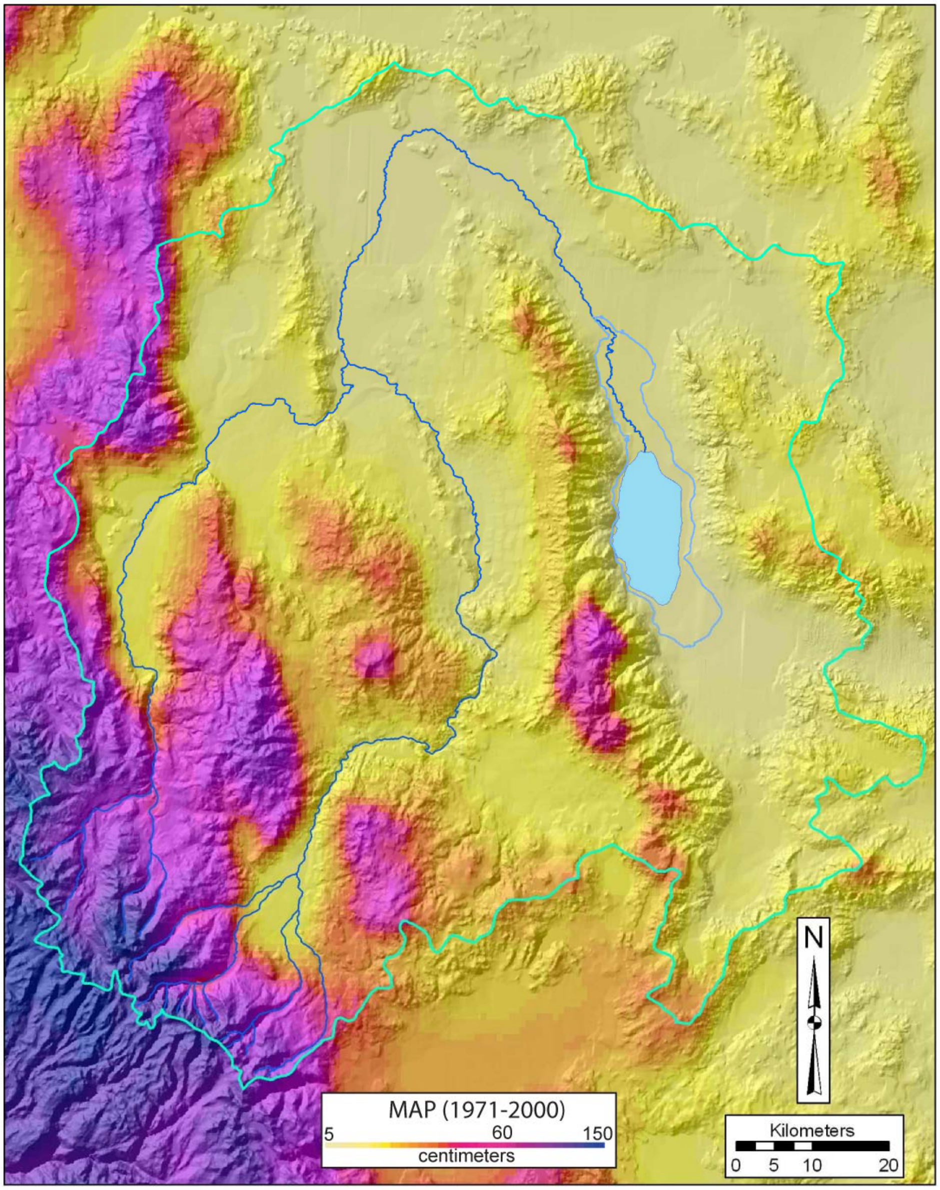


Figure 1. Map of the Walker Lake drainage basin showing the Walker River, Walker Lake (2006) and drainage basin boundary. Also shown is the distribution of mean annual precipitation (MAP) within the basin and the approximate outline of the lake in 1868 (light blue line).

Increasing peak flows in the Walker River, however, may not be the best way to deliver additional water to Walker Lake. Historically, large peak flows along the lower Walker River (LWR) have caused severe erosion and down cutting that have flushed large masses of fine sediment and dissolved salts into the lake. Hence, high flows may have unintended negative consequences to the water quality of the lake. Therefore, the goal of this research is develop recommendations on how best to deliver the maximum volume of water while minimizing erosion and flushing of fine sediment and salts to Walker Lake. The implementation of these recommendations should help optimize the health of both the lake and river.

BACKGROUND

Geologic Setting

The geomorphology and processes associated with the modern Walker River are likely greatly influenced by the effects of past climate changes and base-level changes. An understanding of the ancient history of this system is therefore important for placing the modern river and lake into a long-term context and to provide critical information on how they have evolved and may continue to change in the future. The following is a brief review of the long-term evolution of the Walker River and Lake with an emphasis on their late Pleistocene and Holocene history.

During the late Pleistocene (30,000 to 10,000 years ago), large glaciers covered the crest of the Sierra Nevada and the Walker River flowed into the Mason Valley arm of Lake Lahontan, a large lake that covered more than 20,000 km^2 of northwest Nevada and adjacent northeastern California when it reached its last highstand at about 15,500 years ago (Morrison, 1991; Adams and Wesnousky, 1998).

Walker Lake was the site of the southernmost arm of Lake Lahontan. Evidence from cores collected from the bed of Walker Lake indicate that Walker Lake was dry for much of the late Pleistocene, while the subbasins of Lake Lahontan to the north contained large but fluctuating lakes (Bradbury et al., 1989). This situation suggests that Walker River was likely flowing through Adrian Valley and was a tributary to the Carson River. As the Lahontan subbasins coalesced through rising lake levels toward the end of the Pleistocene, Walker Lake was finally integrated with the rest of the subbasins just prior to the highstand at about 15,500 years ago. In Mason Valley, Lake Lahontan reached a maximum elevation of about 1,330 m (4363 ft) or about the present location of Yerington.

The Lake Lahontan highstand was a relatively brief event, lasting years to a decade or two, and receded rapidly from this level (Adams and Wesnousky, 1998). Walker Lake became separated from the rest of the Lahontan system when lake level receded below the sill in northern Mason Valley (~1,310 m) shortly after ca. 15.5 ka (Thompson et al., 1986; Adams and Wesnousky, 1998). Walker Lake desiccated and probably remained a shallow, ephemeral playa lake until the late Holocene, when the lake abruptly flooded around 5,500 years ago (Benson and Thompson, 1987). This history strongly suggests that the Walker River was flowing into the Carson Sink for much of the time from shortly after the Lahontan highstand to the late Holocene. During the late Holocene, the level of Walker Lake has fluctuated in response to climate changes, as well as to the occasional shifting of Walker River flow through Adrian Valley to the Carson Sink and back again (Benson and Thompson, 1987; King, 1993, 1996; Adams, 2003). Preliminary work along the paleochannel through which the river was diverted indicates that the Walker River was flowing toward the Carson Sink at times during the periods from ca. 1,500 to 1,000 and 500 to 300 years ago (Adams, 2004). Holocene lake-level fluctuations at Walker Lake, therefore, may not be attributable solely to changes in climate.

Figure 2 presents the late Holocene record of lake-level fluctuations at Walker Lake (Adams, 2007). This curve is based on detailed stratigraphic, sedimentologic, and geomorphic evidence preserved along the LWR downstream from Schurz, NV. The historic incision that has occurred since the late 19th century has exposed this record, making it one of the better late Holocene lake-level records in the western Great Basin. In addition to modern incision along the LWR, previous incised channels are exposed in the walls of the modern trench (Figure 3) which is part of the evidence for past lake-level changes (Figure 2).

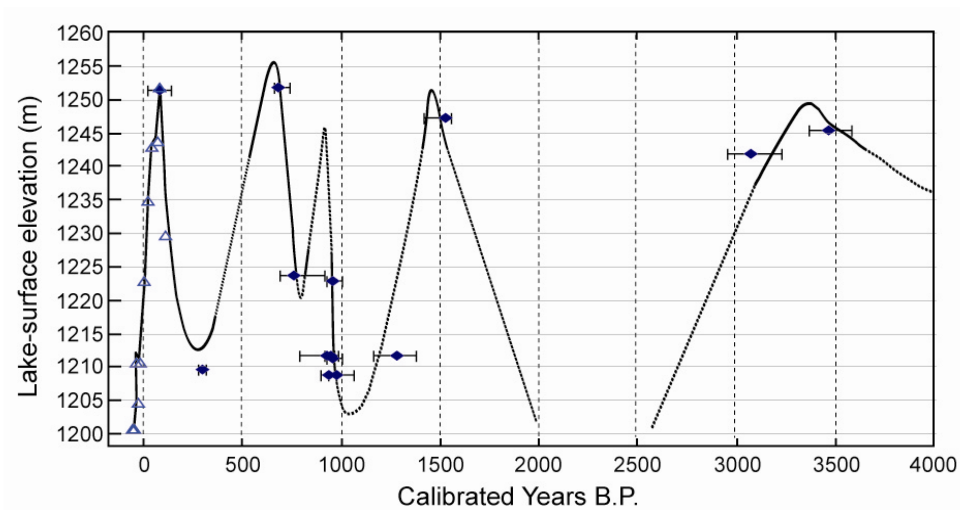


Figure 2. Lake-level curve for the past 4000 years for Walker Lake (From Adams, 2007).

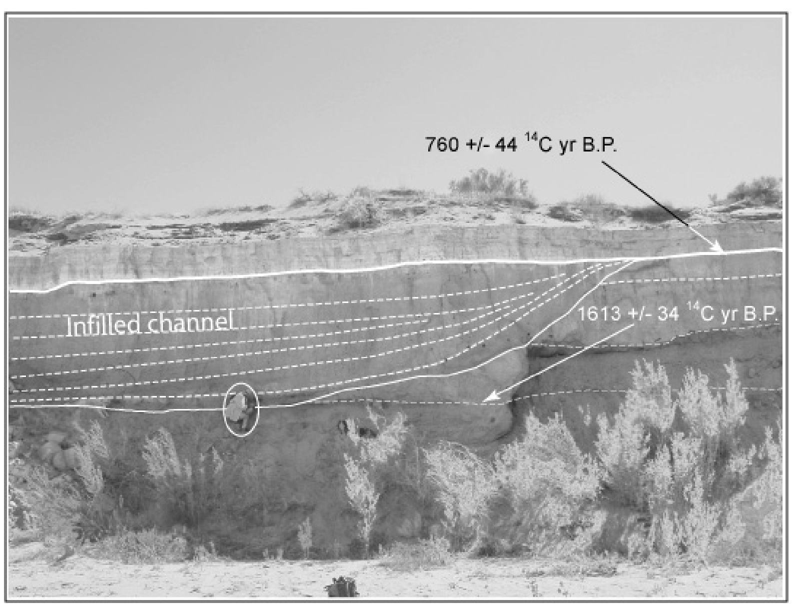


Figure 3. Infilled channel exposed in the wall of the Walker River trench near VK 16. Circled person for scale (After Adams, 2007).

The net result of lake-level changes and their influence on deposition is the presence of abundant deltaic and lacustrine deposits adjacent to the LWR. These deposits are commonly fine grained and composed of various mixtures of sand, silt, clay, and salt. Due to their erosive nature, the Walker River has incised through these deposits forming a trench of varying width and depth. Along much of its course, the river flows over an alluvial bed and floodplain composed of fluvial deposits but inset within the larger trench. Erosion of the margins of the trench introduces abundant fine sediment and salts directly into the river, which are then flushed into the lake.

Hydrology

The Walker River has its headwaters along the crest of the Sierra Nevada (~3,050 to 3,070 m) and generally flows to the north and then to the southeast before ending at endorheic Walker Lake. The basin encompasses about 10,500 km^2 and its hydrology is largely driven by the melting of winter snows. Mean annual precipitation ranges from about 150 cm/yr along the crest of the Sierra, most of which is snow, to about 5 cm/yr near Walker Lake (Figure 1). Thus, the Walker is an allogenic stream, one that derives its water from relatively humid areas and then flows through semiarid basins. Multiple reservoirs have been built on the system since the late 19th century including Topaz Lake (1922), Bridgeport Reservoir (1923), and Weber Reservoir (1934) (Horton, 1996). Numerous check dams and ditches also withdraw water from the Walker River.

The USGS has maintained a gauging network on the Walker and its tributaries for over 100 years. In this study we focused on the lower river where three gauges were used to characterize the hydrology of this part of the system (Table 1). Although Weber Reservoir is located between Wabuska (10301500) and the two lower gauges, the discharge records are similar for the period of overlap (Figure 4). This is probably because of the relatively small capacity (~13,000 acre-ft) of Weber Reservoir. In addition, using the USGS program PEAKFQ a flood frequency analysis has been done for both Wabuska and Little Dam (10301745) gauges (Figure 5). Similar flood frequency curves were obtained for the two gauges. Therefore, it seems reasonable to use the Wabuska record as a proxy for moderate to high flows below Weber Reservoir for the period prior to 1994. Collectively, this discharge data provide a detailed discharge record from 1938 to the present (Figure 6) that can be directly compared to geomorphic changes observed through time in the rectified imagery.

The largest floods over the last 100 years or so along the LWR ranged from 2,000 to 3,000 cfs and occurred relatively frequently, or at a rate of a few per decade. More common yearly snowmelt peaks along the LWR are in the 1,000 to 2,000 cfs range. It is interesting to note that even under relatively undisturbed conditions, prior to the operation of the three principal reservoirs on the system, large flow events appear to have decreased in size downstream. For example, peak discharge at the West Walker River near Coleville gauge in July 1907 was 4,170 cfs but reached only 2,810 cfs at the Wabuska gage several days later, even though Wabuska is also below the confluence with the East Walker River. This downstream decrease in peak flows may have been due to floodplain storage or from irrigation diversions, which were well-developed by that time. Natural attenuation, however, should not necessarily decrease annual volumetric contributions to Walker Lake.

Table 1. Stream gage records along the lower Walker River used in this study. The shortened names used throughout the report are in bold.

Station Name	Station number	Number of years of record	Period of record*	Instantaneous peak (cfs) [date]
Walker River near **Wabuska**, NV	10301500	88	1902-1904, 1920-1935, 1938-2008	3,280 [7/10/06]
Walker River above **Little Dam** near Schurz, NV	10301745	12	1995-2001 2004-2008	2,310 [7/14/95]
Walker River at **Lateral 2A** Siphon near Schurz, NV	10302002	15	1994-2008	2,400 [1/9/97]

*Minor gaps in time are present in the records.

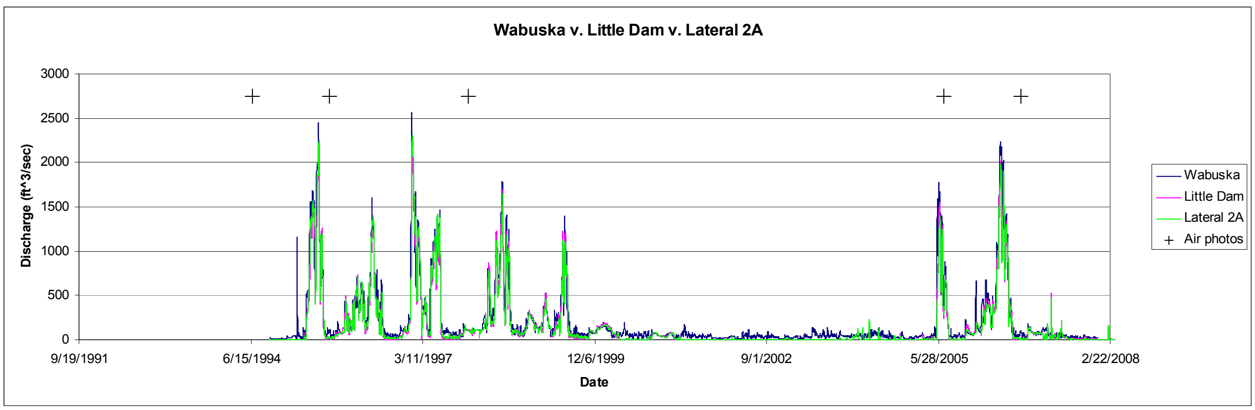


Figure 4. Comparisons between discharges recorded at the Wabuska, Little Dam, and Lateral 2A gauges. Note that even though the Wabuska gauge is upstream from Weber Reservoir, discharge values are similar.

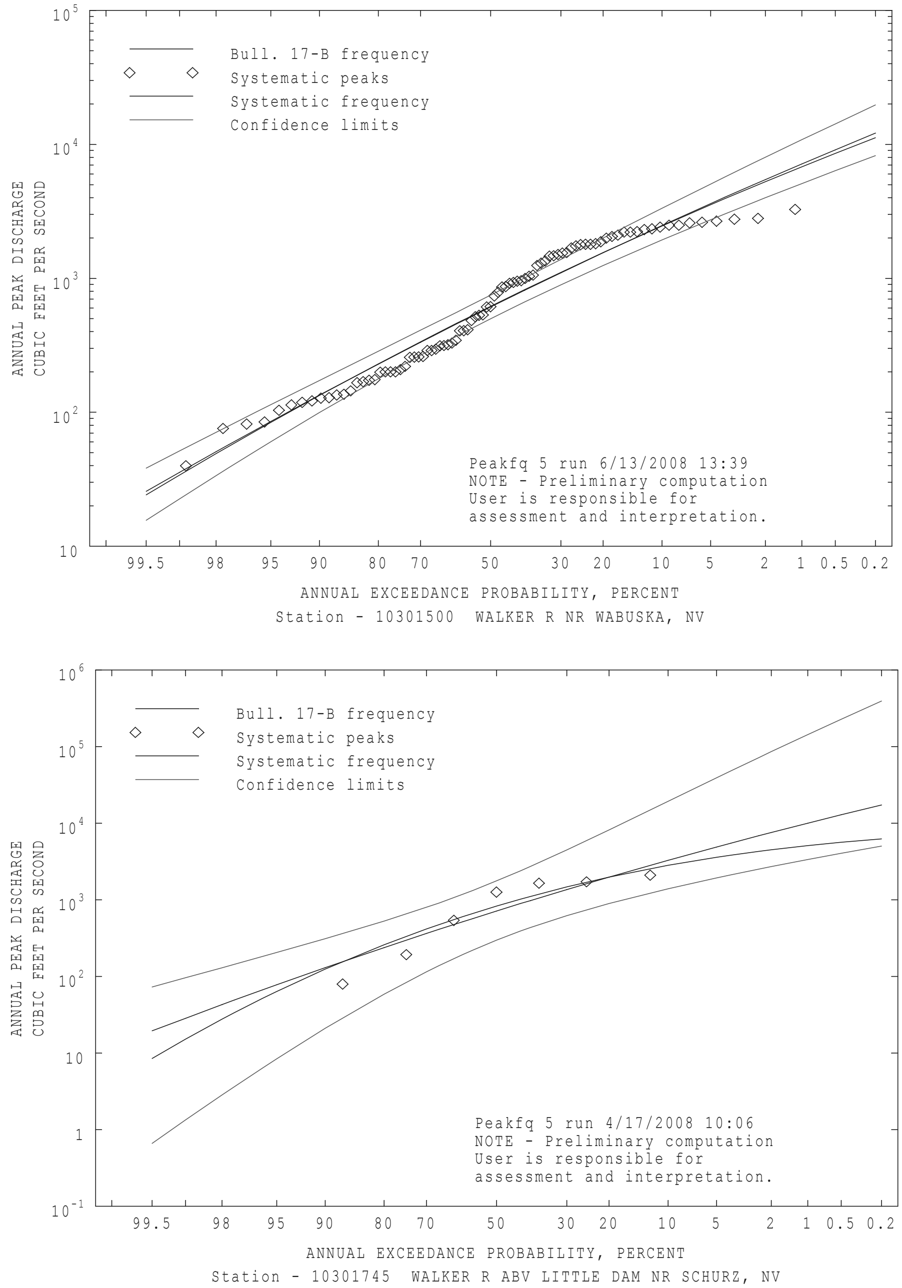


Figure 5. Flood frequency curves for Wabuska (10301500) and Little Dam (10301745) stations using USGS program PEAKFQ.

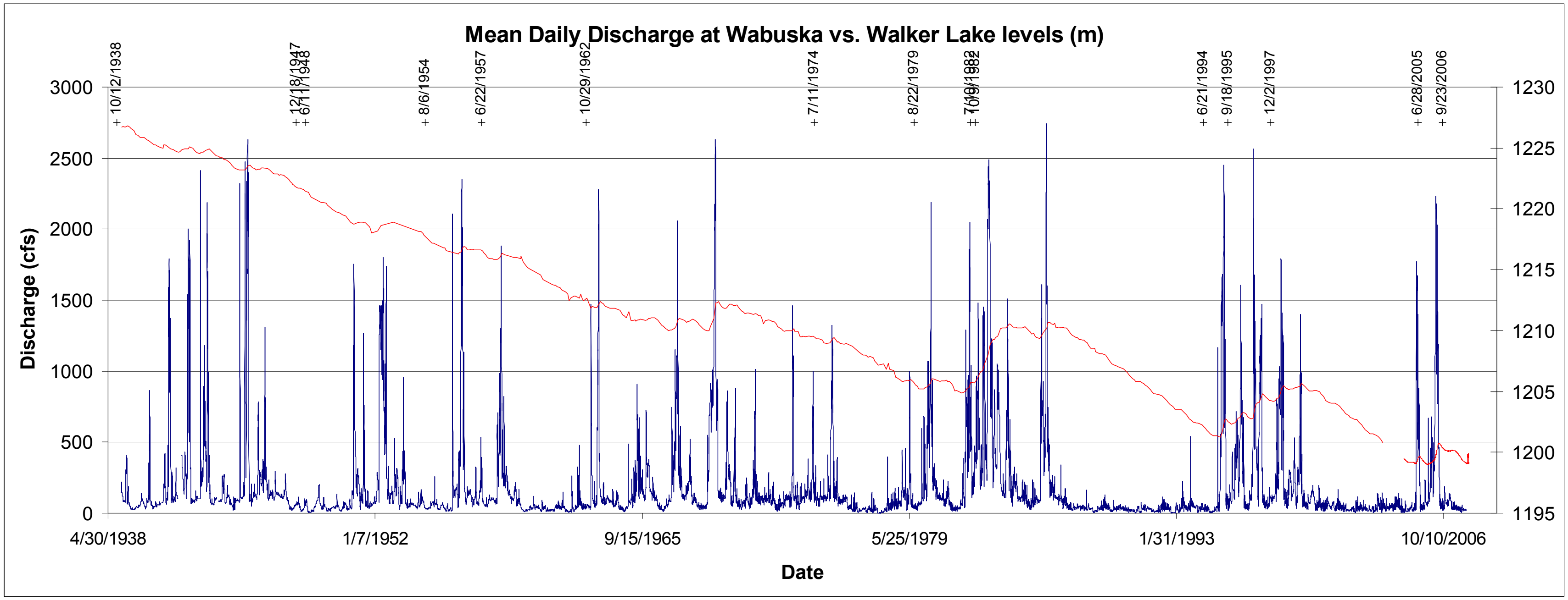


Figure 6. Mean daily discharge recorded at the Wabuska gauge compared to lake-level changes at Walker Lake.

Notable recent low flow periods along the LWR occurred from 1986 to 1995 and from 1999 to 2005 (Figure 6), when virtually no water reached Walker Lake from the river. This hydrology is highly restricted from the natural flow regime because of upstream impoundments and diversions. As a result, the surface of Walker Lake has declined almost continuously over the last 100 years or so, save for two periods when lake level rose appreciably because of a series of relatively wet years in the mid-1980s and mid-1990s (Figure 6). Lake water balance modeling by Milne (1987) suggests that Walker Lake would be near its historic highstand level (1245-1250 m) had there not been any diversions on this system.

METHODS

This study combines analysis of a GIS database of rectified historical aerial photos and high resolution topography with sediment transport modeling and field studies. The GIS database allows a detailed look at changes to the river beginning in 1938 and the quantification of the mass of sediment eroded from the LWR for the period from 1995 to 2006 and documentation of the conditions under which it occurred. Field studies focused on confirming the aerial photo interpretations and collecting samples for bulk density measurements, particle size distributions, and salt content. Modeling efforts focused on several different flow scenarios to determine the likely erosive effects of each of the scenarios.

Aerial imagery Acquisition and Rectification

Aerial imagery for the LWR was acquired from three principal sources that include Nevada Bureau of Mines and Geology (NBMG), the W.M. Keck Earth Sciences and Mining Information Center (http://keck.library.unr.edu/), and the U.S. Geological Survey. Aerial photographs from 1995 and 1997 were obtained from Spencer Gross, Inc. Table 2 outlines relevant data for the aerial imagery.

Imagery from 1938, 1948, 1954, 1957, 1974, and 1997 was obtained as hard copies of printed aerial photographs. Imagery from 1962, 1982, 1994, 1995, 2005, and 2006 was obtained in digital form. Aerial photographs were scanned on a large format flatbed scanner at a rate of 1,200 dots per inch (dpi) in grayscale or color, depending on the original photograph. Because the original imagery was produced at different scales (1:15,000 to 1:60,000), a scan rate of 1200 dpi produced different resolutions on the ground ranging from about 0.3 to 1.25 m. Digital imagery from 1994, 2005, and 2006 have on-the-ground resolutions of about 1 m.

The image sets from 1994, 2005, and 2006 were supplied orthorectified and were directly imported into ArcMap 9.2 for analysis. Georectification of the scanned images was accomplished using the georeferencing tools in ArcMap 9.2. The 2005 imagery (both natural color and color infrared) was used as the base to which the scanned imagery was rectified. From three to five common ground control points (GCPs) were preferentially selected along the river corridor from the scanned and base images so that rectification of the aerial photographs is most accurate adjacent to the channel. This number of points allowed for a first-order polynomial transformation to be performed, which was found to be adequate and efficient for the goals of this project. Common ground control points were generally selected at a scale of 1:2,000 or larger and commonly consisted of shrubs, rocks, and sometimes buildings, bridge abutments, road intersections, and other anthropogenic features.

Table 2. Summary of aerial photography for the lower Walker River.

Date	Coverage	Source	Walker Lake levels (m)*	Discharge (cfs)		
				Wabuska	Little Dam	Lateral 2A
10-12-1938	VK 5.5 to 9.5	NBMG	1,226.73	ND	ND	ND
12-18-1947 6-11-1948	VK 0 to 7	NBMG	1,220.7 1,220.5	67 77	ND	ND
8-6-1954	VK 0 to 10 and 15 to 35	NBMG	1,217.72	35	ND	ND
6-22-1957	VK 3 to 37	NBMG	1,216.62	280	ND	ND
10-29-1962	VK 3 to 33	USGS	1,212.5	35		
7-11-1974	VK 0 to 37	NBMG	1,209.48	134	ND	ND
8-22-1979	VK 0 to 37	NBMG	1,205.68	43	ND	ND
7-10-1982 10-9-1982	VK 0 to 37	USGS	1,205.7	435 414	ND	ND
6-17-1994 6-21-1994 6-23-1994	VK 0 to 37	Keck	1,202.15	23 25 22	ND	ND
9-18-1995	VK 0 to 37	Spencer Gross	1,202.57	115	12	25
12-2-1997	VK 0 to 37	Spencer Gross	1,204.25	114	112	106
6-28-2005	VK 0 to 37; Natural color and Color infrared	USGS	1,199.58	407	255	305
9-23-2006	VK 0 to 37; Natural color and Color infrared	Keck	1,200.35	79	3.3	5.2

Notes: * Walker Lake levels are from U.S. Geological Survey data and were recorded on average once or twice per month prior to 2004. Altitudes prior to 2004 were interpolated from closest readings.

In addition to rectified imagery, detailed topography for the study area was also obtained from 1995, 1997, and 2005. Both the 1995 and 1997 topography data sets (2-ft contours) were produced by standard photogrammetric techniques from the 1995 and 1997 aerials by Spencer Gross, Inc. and supplied as digital AutoCad files. These files were converted into Arc shapefiles and also into seamless digital elevation models (DEMs) for comparison. LIDAR topographic data was flown for the project reach in late May, 2005 and processed to pixel sizes of 4 m^2 by the U.S. Geological Survey in Carson City, NV. This data was contoured and hillshaded for ease of interpretation.

Change Analysis and Mass Calculations

All of the geospatial data for this project was maintained and analyzed in a GIS database, which facilitated the change analysis. Qualitative comparisons were made for the years 1938 to 1994 and quantitative comparisons of channel and floodplain changes were made for the years 1995 to 2006 (Table 3).

Table 3. Summary of eroded sediment estimated from aerial photo comparisons.

Years compared	# of years	Lake-level change (m)	Coverage	Total mass eroded (MT)
1995 vs. 1997	2	+1.68	Weber to Walker	1,027,785
1997 vs. 2005	7	-4.67	Weber to Walker	429,955
May 2005 vs. June 2005	0.08	+0.43	Weber to Walker	477,291
2005 vs. 2006	1	+0.77	Weber to Walker	936,715

Despite the relatively high theoretical resolutions of the acquired imagery, the amount of landscape detail that was able to be resolved on the different images varied greatly. This variation depends on other image qualities such as contrast and brightness. These properties in turn depend on the time of day and/or year that the images were acquired, the reflectance or albedo of the materials imaged, shadows, different types of vegetation, and whether the image was acquired in black and white or color. All of these factors contribute to the practical resolution of an image. Although the practical resolution of an image could in some cases be increased by adjusting the contrast or brightness or by stretching, the limitations are such that channel boundaries and other landforms were more easily resolved on some images than others. Oftentimes the practical resolution of an image varies within the same photo set and sometimes even on the same photo. This is particularly true for the older photo sets but this effect is also pronounced in the 1994 DOQs.

In mapping channel boundaries, there was also the issue of how to define the channel. Is the channel defined by the boundaries of the wetted perimeter at the time of image acquisition, or are the channel boundaries defined by the high water marks of the previous or recent runoff season? The problem with the latter criterion is that evidence for recent high flow is not always visible on the images. And in a near-continuously evolving system, such as the LWR, apparent evidence of recent high flow conditions can also be readily preserved high above the active channel on terrace surfaces. In this study, most of the noted changes occurred in the lower, incised part of the system. Therefore, the migrating channel commonly cut into adjacent fluvial terraces or the former lakebed, which made mapping eroded areas relatively straight forward.

Channels, floodplains, and terraces were mapped for the 1995, 1997, 2005, and 2006 photo years using polyline shapefiles within ArcMap. The entire fluvial system was not mapped for these years. Instead, a preliminary visual comparison was made and only areas where perceptible changes were noted was that part of the channel system mapped and calculations made. Once, the map line work for a given year was completed, it was combined with line work from a preceding or subsequent photo year and polygons were formed using the “Features to Polygon” tool in ArcToolbox. This step allows for the surface areas of eroded polygons to be calculated. The thickness of each of the polygons was estimated using the topographic data sets from 1997 and 2005. For relatively small polygons that have relatively horizontal upper (terrace treads) and lower (channel bottom) surfaces a single average thickness was used. For larger or more complex polygons that encompass more than one terrace level, the polygon was often split into two or more polygons and average thicknesses applied. The volume of eroded areas was converted to a mass by multiplying by an appropriate density derived from field samples. Sediment samples were collected from the bed and banks or terrace risers along the LWR and in most cases, the bulk density and salt concentration from the nearest sediment sample location was applied to the eroded areas. Samples were analyzed for bulk density, particle size distribution, and salt content (Table 4) in the DRI Soil Characterization and Quaternary Pedology Laboratory.

For discussion purposes, a common reference frame was established for comparing different photo years by drawing a generalized line down the axis of the river valley and marking that line at 1 km spacing. Valley kilometer 0 (VK 0) begins at Weber Dam and extends downstream to VK 37 in modern Walker Lake (Figure 7). All locations discussed in this paper are in reference to the NAD 1983 UTM Z11N datum.

Sediment Transport Modeling

The sediment transport modeling work was conducted using the CCHE-1D model. This modeling tool was developed by the National Center of Computational Hydroscience and Engineering (NCCHE) at the University of Mississippi. The model solves one-dimensional (1D) open channel flow dynamic equations, i.e., the St. Venant equations, coupled with sediment transport equations and a channel bed deformation equation. It was developed to resolve unsteady, non-equilibrium sediment transport problems, which avoids intrinsic limitations of steady/equilibrium sediment transport theories (Chen and Stone, 2007). In addition, the model computes sediment transport by size classes, which enables the treatment of non-uniform sediments. The governing equations in the model read

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q$$
$$\frac{\partial}{\partial t}\left(\frac{Q}{A}\right) + \frac{\partial}{\partial x}\left(\frac{\beta Q^2}{2A^2}\right) + g\frac{\partial h}{\partial x} + g\left(S_f - S_0\right) = 0 \quad (1)$$

$$\frac{\partial A C_{tk}}{\partial t} + \frac{\partial Q_{tk}}{\partial x} + \frac{1}{L_s}\left(Q_{tk} - Q_{t*k}\right) = q_{lk} \quad (2)$$

$$\left(1 - p'\right)\frac{\partial A_{bk}}{\partial t} + \frac{\partial A C_{tk}}{\partial t} + \frac{\partial Q_{tk}}{\partial x} = q_{lk} \quad (3)$$

where x and t are spatial and temporal coordinates, A is the cross-sectional area of the flow, Q is the flow discharge, β is a correction coefficient for momentum, q is the lateral inflow of unit width, h is the flow depth, S_f and S_0 are friction slope and channel bed slope; C_{tk} is the cross section-averaged sediment concentration of size fraction k, Q_{tk} is the actual sediment transport rate of size class k, Q_{t*k} is the sediment transport capacity, L_s is the adaptation length of non-equilibrium, and q_{lk} is the side inflow or outflow sediment discharge from bank boundaries or tributary streams per unit channel length; p' is the porosity of bed material, and $\partial A_{bk} / \partial t$ is the bed deformation rate of size class k.

Table 4. Particle size distributions, salt content, and bulk density for sediment samples collected along the lower Walker River. All locations are UTM Z11N NAD 83 datum.

Sample	Easting	Northing	Setting	Particle Size Distribution of < 2 mm fraction: SAND >62.5 um (%)	SILT 15 um (%)	SILT 3 um (%)	CLAY <3 um (%)	Σ fractions of < 2 mm	Sol. Salts (mg kg-1)	Bulk Density (g cm-3)	Wax Bulk Density
KDA052108 S1	348849	4297086	bank	37.4	38.4	16.4	7.8	100.0	974	1.231	
KDA052108 S2	348911	4297046	**bed**	99.7	0.1	0.1	0.1	100.0		1.619	
KDA052108 S3	349166	4297054	bank	29.8	37.1	21.8	11.3	100.0	2,797	1.280	
KDA052108 S4	349166	4297054	bank	8.2	61.5	19.8	10.5	99.9	3,384	1.239	
KDA052108 S5	349329	4296864	bank	75.9	10.3	8.7	5.1	100.0	4,352	1.334	
KDA052108 S6	349329	4296864	bank	9.5	42.7	33.3	14.5	100.0	2,122	1.338	
KDA052108 S7	349437	4296503	bank	83.1	10.9	3.4	2.5	99.9	486	1.387	
KDA052108 S8	349591	4296360	bank	92.8	3.4	2.2	1.5	99.9	432	no data	
KDA052108 S9	349591	4296360	bank	53.4	23.9	15.7	7.0	100.0	2,929	1.311	
KDA052108 S10	349767	4296100	bank	15.0	46.8	27.3	10.9	100.0	5,966	1.160	
KDA052108 S11	349767	4296100	bank	20.1	51.6	18.6	9.6	100.0	6,077	1.205	
KDA052208 S12	349768	4295661	bank	57.5	27.0	9.5	5.9	100.0	7,244	1.309	
KDA052208 S13	349660	4295248	bank	78.9	11.8	5.7	3.6	99.9	3,369	1.231	
KDA052208 S14	349767	4294853	bank	88.0	6.3	3.2	2.4	99.9	2,298	no data	
KDA052208 S15	350485	4294272	bank	96.8	1.0	1.1	1.0	100.0	2,867	1.257	
KDA052208 S16	350671	4294331	bank	95.7	1.4	1.6	1.1	99.8	3,733	1.334	
KDA052208 S17	350444	4295342	bank	71.9	18.2	5.9	4.0	100.0	687	1.258	
KDA052208 S18	350294	4295382	bank	36.1	46.4	10.4	7.0	100.0	2,211	1.269	
KDA052208 S19	350294	4295382	bank	21.9	44.9	23.2	9.9	99.9	3,160	1.495	
KDA052208 S20	350294	4295382	bank	69.5	18.5	7.0	5.0	100.0	958	1.201	
KDA052208 S21	350165	4295734	bank	20.5	44.6	22.5	12.5	100.0	2,728	1.530	
KDA052208 S22	350165	4295734	bank	79.6	9.2	6.5	4.7	100.0	3,046	1.431	
KDA052208 S23	350051	4295946	bank	4.2	51.4	30.9	13.5	100.0	4,046	1.268	
KDA052208 S24	350051	4295946	bank	70.2	16.6	9.5	3.7	100.0	6,961	1.118	
KDA052208 S25	349910	4296302	bank	1.5	45.0	37.1	16.4	100.0	457	1.409	
KDA052208 S26	349910	4296302	bank	41.8	33.1	16.3	8.8	100.0	1,116	1.597	
KDA052208 S27	349744	4295910	bank	16.5	41.5	28.7	13.3	100.0	5,330	1.308	

Table 4. Particle size distributions, salt content, and bulk density for sediment samples collected along the lower Walker River. All locations are UTM Z11N NAD 83 datum (continued).

					Particle Size Distribution of < 2 mm fraction							
					SAND	**SILT**		**CLAY**				
Sample		**Easting**	**Northing**	**Setting**	**>62.5 um (%)**	**15 um (%)**	**3 um (%)**	**<3 um (%)**	**Σ fractions of < 2 mm**	**Sol. Salts (mg kg-1)**	**Bulk Density (g cm-3)**	**Wax Bulk Density**
KDA052308	S28	349608	4296806	bank	14.8	41.7	30.1	13.5	100.0	1,706	1.433	
KDA052308	S29	349608	4296806	bank	14.5	49.3	23.7	12.5	99.9	1,505	1.345	
KDA052308	S30	349505	4296962	bank	7.7	40.4	34.4	17.6	100.1	5,462	1.539	
KDA052308	S31	349505	4296962	bank	57.1	25.7	10.3	6.9	100.0	3,606	1.413	
KDA052308	S32	349456	4297061	**bed**	97.8	1.0	0.7	0.5	100.0	243	1.399	
KDA052308	S33	349243	4297188	bank	3.6	40.2	38.2	18.0	100.0	2,448	1.430	
KDA052308	S34	348942	4297397	bank	8.1	36.1	42.0	13.8	100.0	10,158	1.312	
KDA052308	S35	348942	4297397	bank	5.1	39.6	42.4	12.9	100.0	4,989	1.215	
KDA052308	S36	348930	4297402	**bed**	98.7	0.3	0.6	0.4	100.0	668	1.564	
KDA071708	S37	339217	4322897	bank	98.6	0.4	0.5	0.5	100.0	125.8	1.652	
KDA071708	S38	339021	4322505	bank	98.8	0.4	0.4	0.4	100.0	54.3	1.878	
KDA071708	S39	339632	4319090	bank	80.6	8.9	5.6	4.8	99.9	8,476.4		1.222
KDA071708	S40	339632	4319090	**bed**	59.5	21.0	11.3	7.9	99.7	430.9	1.513	
KDA071708	S41	339970	4317928	bank	47.7	33.8	10.7	7.2	99.3	1,299.0		1.313
KDA071708	S42	343987	4311621	bank	57.4	23.0	11.9	7.6	99.9	6,820.9		1.230
KDA071708	S43	344452	4311075	bank	23.8	28.3	30.9	17.0	100.0	4,450.6		1.346
KDA071708	S44	344461	4311083	**bed**	96.6	1.4	1.2	0.8	100.0	417.2	1.952	
KDA071808	S45	348718	4297701	bank	44.8	26.3	18.6	10.1	99.9	1,324.0		1.350
KDA071808	S46	348721	4297711	**bed**	99.2	0.4	0.3	0.2	100.0	452.4	1.553	
KDA071808	S47	347278	4299552	bank	5.9	31.5	45.5	17.2	100.1	883.5		1.362
KDA071808	S48	347278	4299552	**bed**	99.4	0.2	0.2	0.1	100.0	157.1	1.447	
KDA071808	S49	346020	4301985	**bank**	45.9	24.0	19.1	11.0	99.9	8,535.7		1.391
KDA071808	S50	346024	4301995	**bed**	98.3	0.7	0.5	0.4	100.0	204.8	1.458	
KDA071808	S51	345175	4303494	bank	3.5	29.6	46.3	20.5	100.0	9,153.8		1.339
KDA071808	S52	345175	4303494	**bed**	99.5	0.2	0.2	0.1	100.0	157.3	1.691	
KDA071808	S53	345288	4306707	bank	5.6	44.9	35.9	13.5	99.9	7,239.4		1.286
KDA071808	S54	346105	4309724	bank	62.1	19.9	9.9	6.0	97.9	3,976.1		1.225
KDA071808	S55	345574	4310142	bank	9.4	27.5	45.5	17.6	100.0	2,678.2		1.372

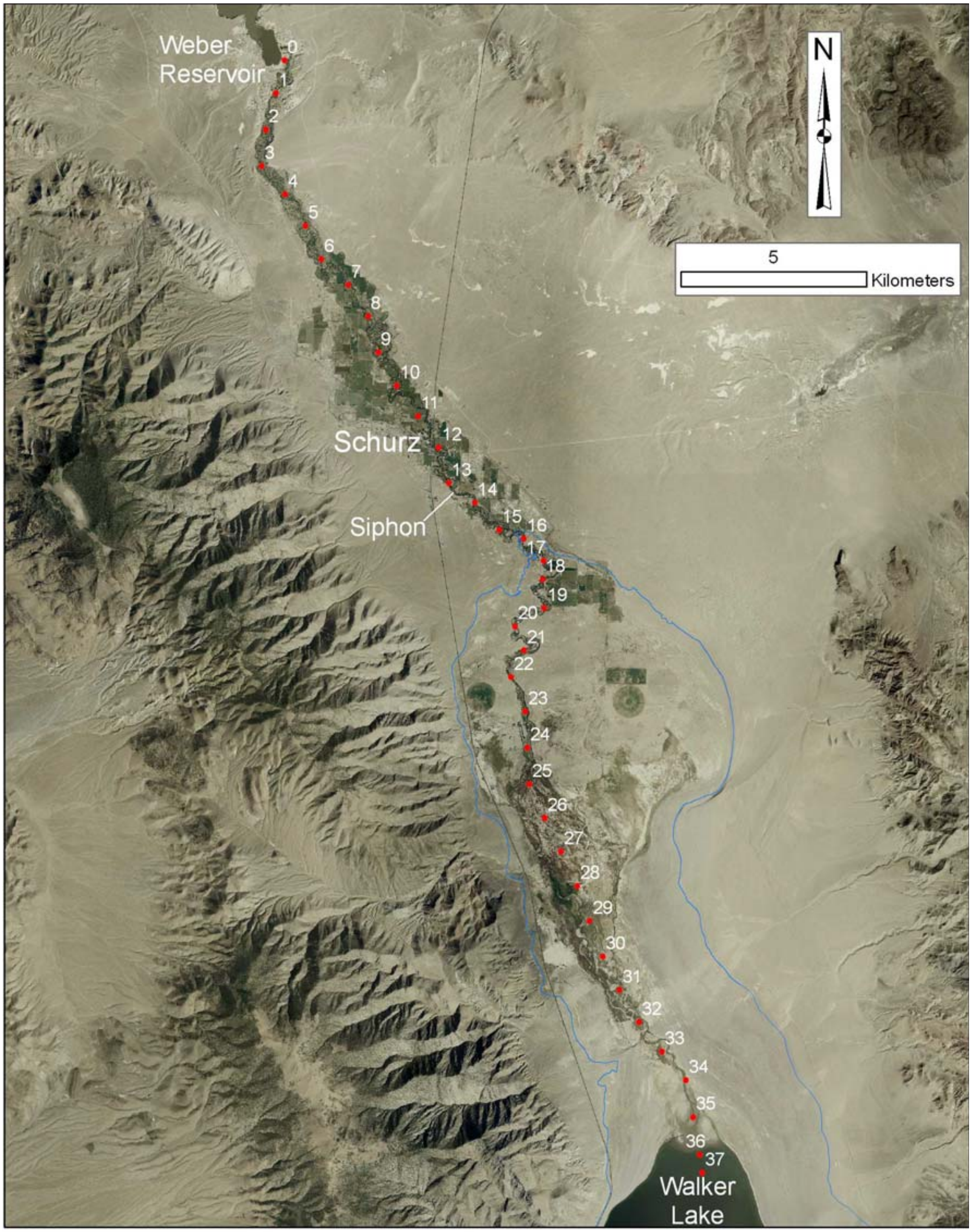


Figure 7. Overview map of the study area long the lower Walker River marked in valley kilometers (VKs). Dark blue line represents Walker Lake historic highstand of 1,252 m in AD 1868. Aerial imagery is from September 2006, when Walker Lake was at about 1,200 m.

Boundary conditions need to be provided for solving the equations in the modeling. In this study, we provided the discharge as the upstream boundary condition and lake level as the downstream boundary condition for the flow. These data were obtained from the records of USGS surface water stations on the study reach. The sediment input was neglected under the assumption that Weber Reservoir effectively intercepts the incoming sediment from upstream. Therefore the studied sediment transport problem is equivalent to a clear water scouring problem.

Besides hydrological data, other basic input data for modeling includes cross section geometry and sediment particle size distributions. The 47 kilometer study reach has been segmented into 113 sub-reaches by 114 cross sections. These cross sections have been constructed using the 1997 2-ft topography. The sediment data were obtained from the sediment samples collected in the river (Table 4). These data were compiled and imported into the model through the Graphic User Interface (GUI) of the CCHE-1D model. A screen capture is shown in Figure 8.

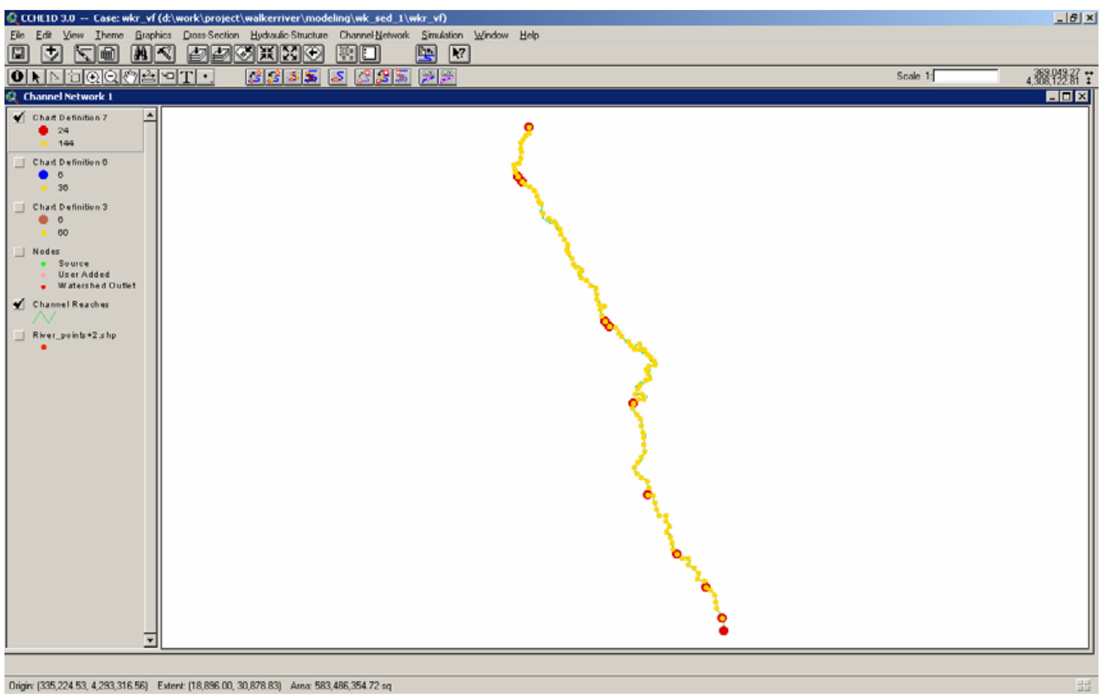


Figure 8. The graphic interface of CCHE-1D program.

RESULTS AND DISCUSSION

In order to better understand how the LWR may respond to increased flows and to develop recommendations on how to minimize further incision, we have documented the progression of historic incision and performed sediment transport modeling to gain insight into these processes. We have also quantified the mass of sediment and salts eroded from the bed and banks of the LWR and delivered to the lake using the detailed topographic data sets from 1995, 1997, and 2005. This section presents the results of these analyses and discusses their implications.

Historic Erosion and Geomorphic Change

Walker Lake reached its historic highstand of about 1252 m in 1868. The 1860s were a particularly wet decade (Morrison, 1964) and the lake probably rose from relatively low levels in the 1840s to attain its 1868 highstand (Harding, 1965; Adams, 2007). In 1868, the LWR was likely a single stem meandering stream with an open, cottonwood gallery forest similar to what the Truckee River looked like at that time (Hersh, 2000). Remnants of the former floodplain graded to 1251-1252 m are still preserved as terraces near the historic highstand and are characterized by a depauperate population of large dead and dying cottonwoods. These terraces are inset about 1-2 m into a broader surface that was last occupied by Walker Lake about 700 years ago (Adams, 2007).

The earliest aerial imagery we have for the LWR is from 1938 but only a single image covering about 4 km of river (VK 5.5 to 9.5) was available. Even with this limited view of the river, it can be seen that this reach of the river has not changed very much in the ensuing 70 years or so (Figure 9). This reach of river in 1938 was a single stem meandering stream with abundant evidence of sediment movement in the form of high-albedo point bars. Relatively recent meander cutoffs were also present, indicating that this reach was fairly dynamic. Since 1938, there has been some meander extension and translation, but the essential character of the river has remained intact. Sediment samples and field observations from this reach of river indicate that the banks are primarily composed of silty fine sand or fine sandy silt (Table 4). Bedload is primarily medium to coarse sand with a few patches of fine gravel.

In 1938 Walker Lake was at an elevation of about 1227 m, which would place its northern lake shore near the toe of a compound paleodelta complex that was probably deposited over several late Holocene highstands, all of which reached elevations ranging from 1245-1255 m (Figure 2) (Adams, 2007). The net effect of these multiple highstands reaching about the same elevation is that the river deposited a thick, wedge-shaped package of sediment that has since been incised during historic down cutting (Figure 10). Maximum incision occurs through this reach of river and was probably already well in progress in 1938, although we are lacking photo coverage for this time.

The first view that we have of the LWR in the vicinity of the historic highstand (VK 15 to 16) is from 1954, when lake level had already dropped to about 1,218 m, or about 9 m lower than in 1938. Although there is evidence of some down cutting, in the form of terraces adjacent to the channel, cottonwoods and other riparian vegetation suggests that incision was not yet severe near the location of the highstand. Proceeding downstream in 1954, cottonwoods decrease in density until they completely disappear by about VK 18.5. Upstream from this point, cottonwoods are found on terrace surfaces ranging from 1,250 to 1,252 m, or about the elevation of the historic highstand. Although there are surfaces whose elevations are at 1,250 m downstream from VK 18.5 m there are no cottonwoods, which may be because incision was more pronounced in the reach from VK 18.5 to 24 as the river was dissecting through the compound delta.

Figure 9. Two views of the lower Walker River just upstream from Schurz. In 1938, the LWR was a single stem stream meandering through an open cottonwood forest. Light colored point bars and a recent cutoff meander are evidence of sediment transport and dynamism. Sixty-seven years later in 2005, the river had essentially the same character along this reach. Numbers are valley kilometers from Weber Dam.

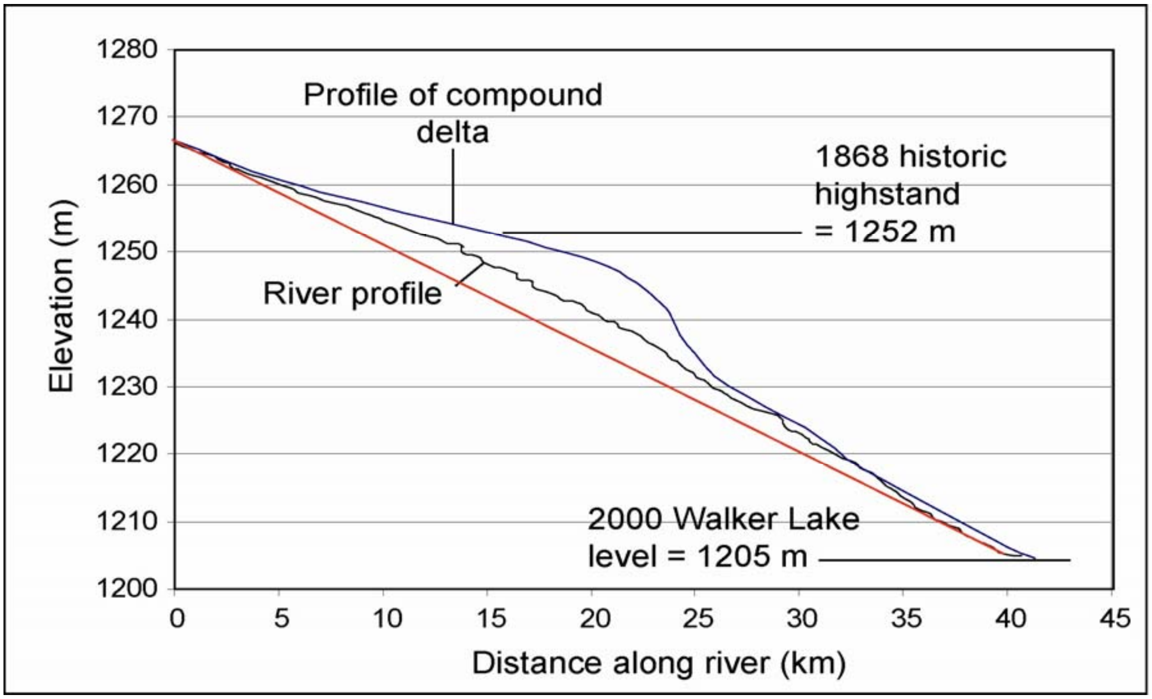


Figure 10. Long profile of lower Walker River from 1997 topographic data. The profile of the compound delta and a hypothetical linear river profile are also shown for comparison.

Once the river exits the front of the compound paleodelta at an elevation of about 1,229 m, it becomes much less confined and many distributary channels can be seen on the 1954 image. In addition to the distributary channels, the flats adjacent to the main channel are characterized by numerous avulsion or crevasse splay deposits that indicate that flow frequently went out of the channel as lake level was receding over this relatively flat surface. Four distinct delta complexes are also visible at about 1,227 m, 1,225 m, 1,223 m, and 1,218 m, all of which are characterized by fan-shaped deposits with fine scale distributaries on their surfaces adjacent to or straddling the channel. Each of these minor deltas is associated with a slight rise in lake level or stillstands that occurred in 1938, 1942, 1945, and 1952, respectively. Between these periods, flow in the river was low and lake level was falling (Figure 6). At the time of the 1954 photographs, lake level was falling and little sediment was accumulating at the 1954 river-lake interface, probably due to low flows.

Changes to the LWR in the three year period between 1954 and 1957 appear to be minimal, except for minor changes to crevasse splay deposits from VK 26 to 29. During this period there were two spring runoff periods that exceeded 2,000 cfs (Figure 6), which according to the flood frequency curve for Wabuska puts these flows in the range of 5 or 6 year flood events.

By 1962, lake level had fallen an additional 4 m (Figure 6) causing the river channel to extend by approximately 1.8 km (Figure 11). Most of this lake-level lowering took place after the spring runoff season of 1958, when peak flows were generally below 200 cfs except for the spring of 1962 when peak flow exceeded 400 cfs for a single day.

The net effect of this series of events was that the lowermost reach of the LWR was likely adjusted to flows of 100 to a few hundred cfs. Hence, the relatively small channel size in the lower few km of river in 1962 (Figure 11). Upstream from VK 29, there is evidence of minor meander extension, which probably occurred as a result of the 1958 runoff season when peak flows exceeded 1200 cfs for a period of about two weeks (Figure 6).

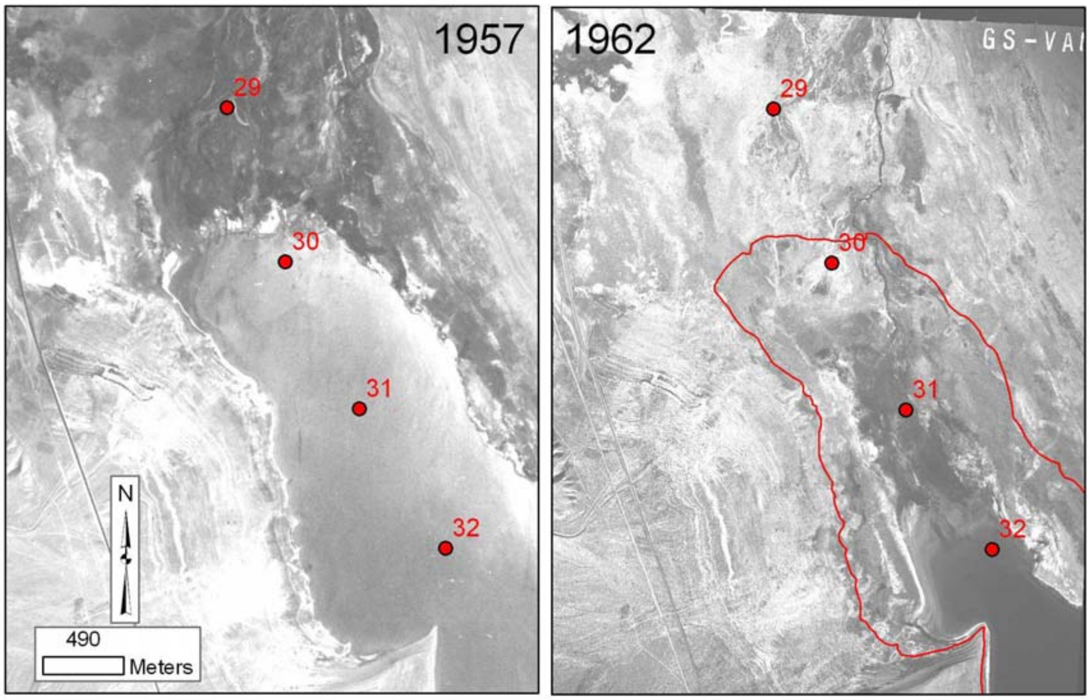


Figure 11. Between 1957 and 1962, the LWR extended by about 1.8 km due to continuing lake-level lowering. The relatively low flows during this time were not sufficient to excavate more than a minor channel. This red line is 1957 shoreline.

The next view of the river is in 1974, after lake level fell an additional net 3 m (Figure 6) and the river had extended about 1 km to VK 33. This overall decline was interrupted in the spring of 1969 when peak discharge exceeded 2,600 cfs and lake level rose about 2 m to about 1,212 m before again receding to about 1,210 m. Between 1962 and 1974 the LWR avulsed from its existing channel upon exiting the trench cut through the compound paleodelta complex near VK 24.5 and formed a new channel on the west side of the valley. This new channel appears relatively coherent (single stem) until about VK 31 where it transforms into a series of braided, distributary channels. Flow was then concentrated into two distinct channels near Pelican Point (VK 32-33) before flowing into the lake at about VK 33. The period between 1962 and 1974 was also when many of the incised meanders from VK 14 to 21 enlarged and migrated downstream, a pattern that has continued to the present.

The period between 1974 and 1979 was one of relatively low flow on the LWR, with only two significant flow events of about 1,300 and 1,000 cfs in 1975 and 1979, respectively (Figure 6). Consequently, lake level fell an additional 4 m and the river downcut through the 1979 delta, extending an additional 600 m downstream. Little geomorphic change to the LWR occurred during this period, save for some channel widening in the lower 2 km of river and the formation of a new delta about 600 m downstream.

During the three years between 1979 and 1982 lake level was relatively stable before it began to climb about 6 m into the mid-1980s after a series of exceptionally wet winters (Figure 6). Lake level was about the same in 1982 as it was in 1979 but the delta had prograded about 300 m lakeward and filled in the upper part of the lake (Figure 12). This sediment was likely eroded from the extension of upstream meanders, particularly in the deeply incised part of the system between the siphon (VK 13.2) and the front of the compound delta at about VK 24.

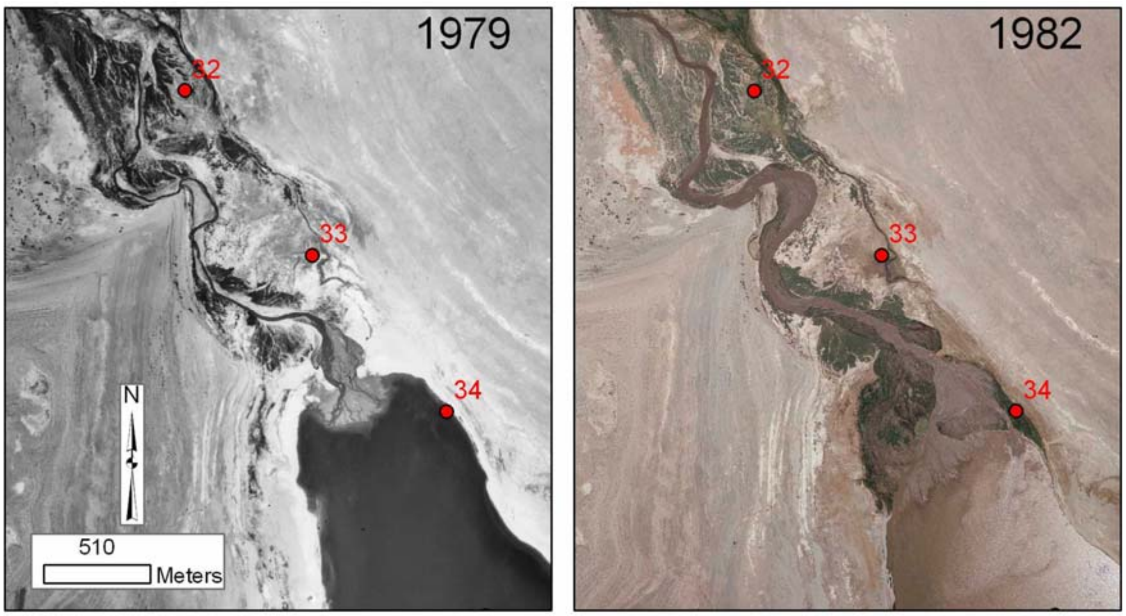


Figure 12. Between 1979 and 1982, the LWR delta prograded lakeward about 300 m and filled the upper part of the lake as lake level fluctuated less than 1 m.

Between 1982 and 1994 Walker Lake first rose about 5 m (1984-1986) and then fell about 8 m because of a severe and prolonged drought (Figure 6). The mid-1980s was a period when flow not only exceeded 2000 cfs in three separate runoff years (1982, 1983, and 1986), but also when periods of relatively high flow (>500 cfs) were maintained for months at a time. It is no surprise then that abundant geomorphic change is evident in this comparison. As in previous comparisons, there was little change from Weber Dam (VK 0) to the siphon (VK 13.2), save for a few small meander cutoffs and slight meander growth near VK 5. Downstream from the siphon, however, many of the meanders experienced dramatic changes by increasing their amplitudes by 50 to 100 m, particularly in the reach from VK 14 to VK 24. It is interesting to note that the LWR below VK 24 experienced much less change during this period, but must have transported most of the eroded sediment from upstream. This mass of sediment was probably deposited in the delta area between VK 33 and 34. As in previous comparisons when lake level was falling between photo years, the lowermost 1.2 km of the channel was relatively small and had not yet adjusted to larger flows that would come later.

For Walker Lake, the drought essentially ended in early May 1995 when flows began to increase in the LWR, reaching a peak of about 1,700 cfs in mid-June and a second peak of about 2,450 cfs in mid-July (Figure 4). Overall, there were almost 100 straight days of discharge of > 500 cfs that runoff season, which resulted in a lake-level rise of about 1.5 m by the end of summer. Although there was slight meander extension and/or translation in places in the upper part of the study reach (VK 7 and 8, 15, 16, and 19 through 21), overall there was not much geomorphic change from 1994 to 1995. The lower part of the study reach, however, experienced a major avulsion and widening.

The channel that had first formed between 1962 and 1974 below VK 24.5, when the river had avulsed to the west, had avulsed back to the east at VK 31 (Figure 13) to occupy a minor but preexisting channel in the spring of 1995. This avulsion event apparently enlarged the preexisting channel and excavated it to a depth of about 3 m, before the river rejoined the 1994 channel near Pelican Point (VK 32.2). Downstream from Pelican Point (VK 32-35) the 1995 spring runoff had dramatically widened and deepened the 1994 channel (Figure 13), which up to this point had only experienced relatively low flows as it was lengthening across the newly exposed lakebed during the eight year drought.

The next view that we have of the river is in December 1997 after three significant runoff events occurred, including the January 1997 flood that reached a peak discharge of about 2,300 cfs (Figure 4). Because we have detailed topography from 1995, 1997, and 2005, we can estimate the total mass of eroded sediment between these photo years. Although approximately 1.02 million metric tons (MT) of sediment was eroded from throughout the study reach between September 1995 and 1997, about 75% of the total mass of bed and bank erosion occurred in the lower 6 km of the river (VK 29-35) (Figure 14). This includes the reach of river that had only experienced significant flows since 1995, so it was still undergoing major adjustments to the higher flows. We lack the temporal resolution, however, to determine how much erosion was associated with each particular runoff event, although we suspect that most of the erosion occurred during two significant, long duration runoff events in January-February 1997 and May-June 1997 . On the other hand, LIDAR topographic data and imagery from 2005 provide an opportunity to resolve the geomorphic effects of a single, moderate-magnitude runoff event.

The LIDAR data were collected during the period May 29 to June 2, 2005 but the imagery for the same project was not collected until about a month later (June 28). Coincidently, the LIDAR data happened to have been collected on the rising limb of the spring runoff hydrograph and the imagery collected after the peak on the falling limb of the hydrograph for that year (Figure 15). During that single runoff event, approximately 477,000 MT of sediment was eroded from the banks of the lowermost 1.5 km of the river channel (Figure 16), which includes most of the area newly exposed since 1997 due to an overall lake-level lowering of 4.7 m. This estimate was derived from mapping out discrete areas that were eroded between May 29 and June 28, 2005, estimating their thickness, and multiplying the derivative volume by bulk density estimates (Table 4) to attain the mass of material removed. About 1420 MT of salt was also flushed into the lake from bank erosion during the 2005 runoff season.

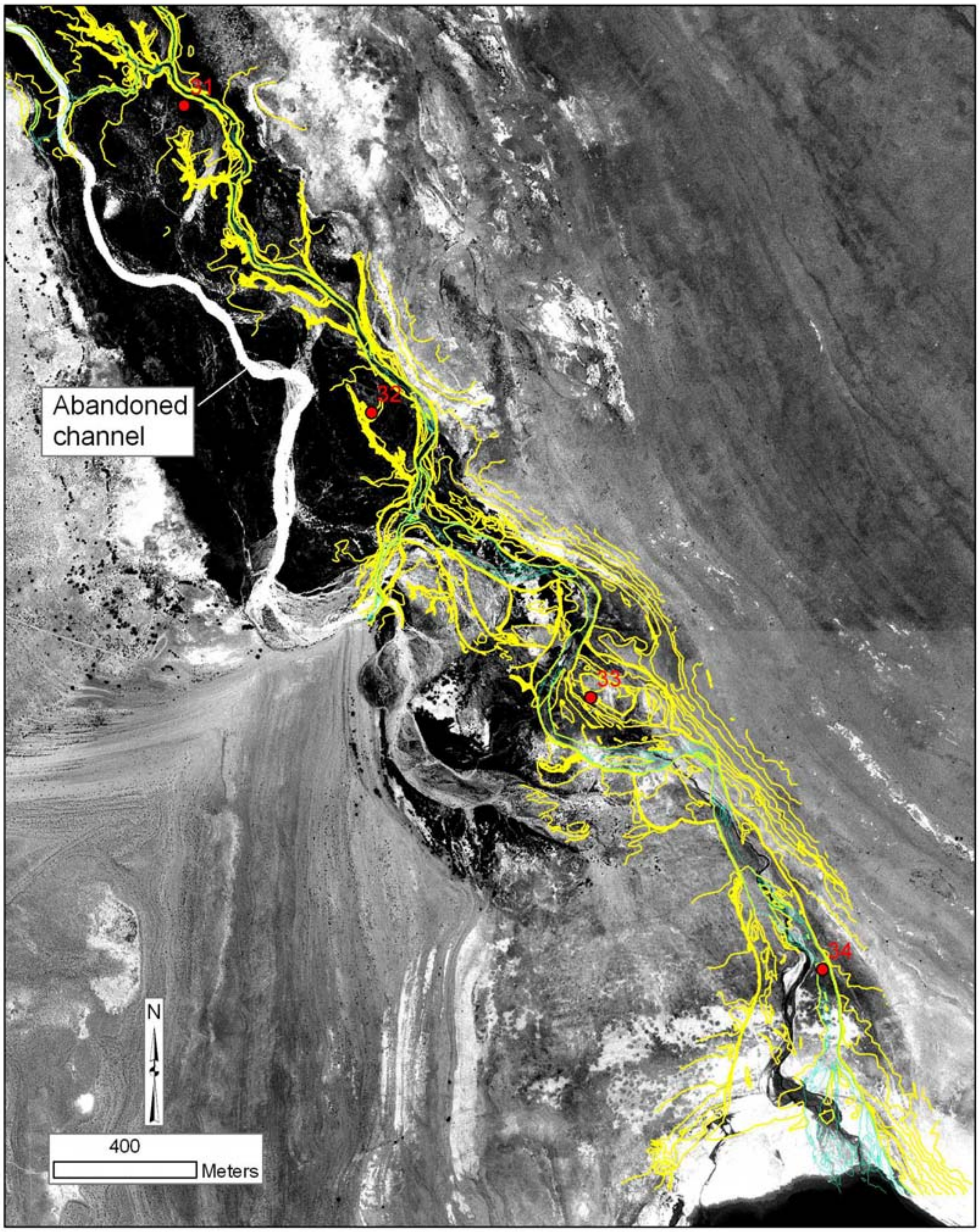


Figure 13. Map of the LWR showing the avulsion and channel widening that occurred in the spring of 1995. The base image is from June 1994 and yellow contours (2-ft interval) and blue channel are from September 1995.

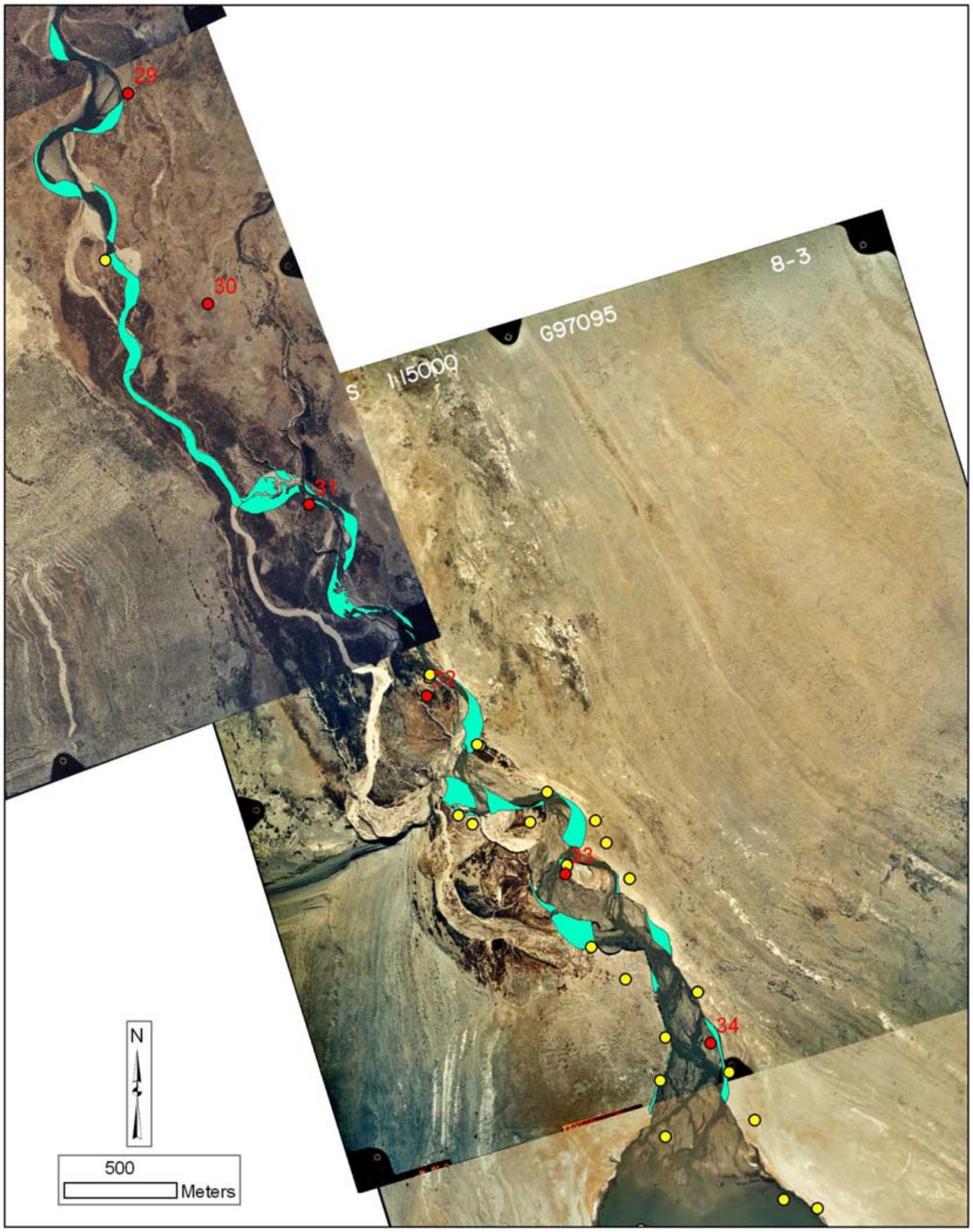


Figure 14. Map showing the locations of bank and bed erosion between 1995 and 1997. Although erosion also occurred in upstream areas, about 75% of the erosion occurred in the lowermost reaches of the river. Yellow dots are sediment sample locations.

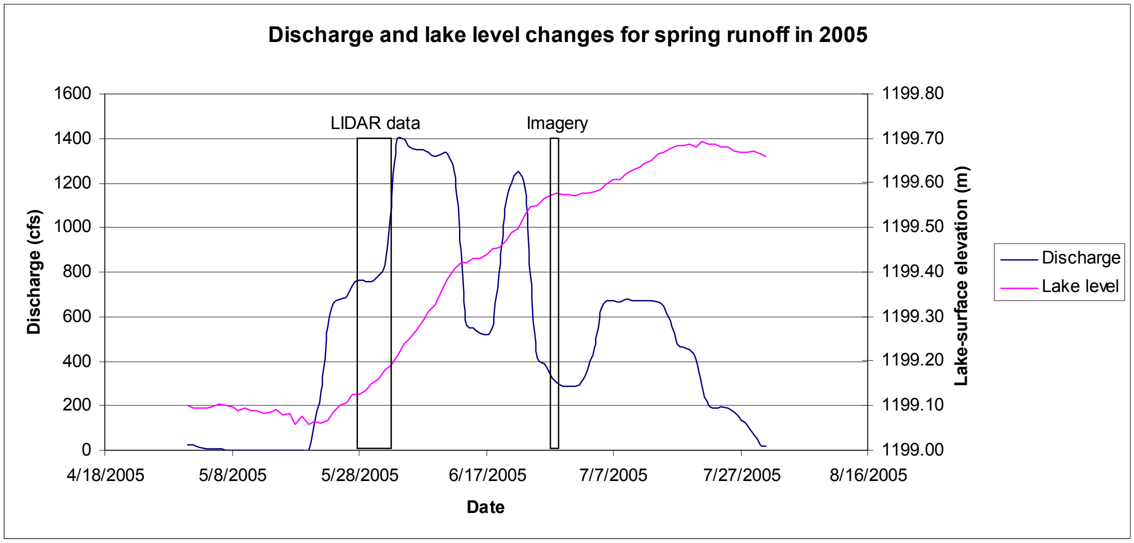


Figure 15. Combined curves showing the spring runoff hydrograph for 2005 and associated lake-level rise with respect to when the LIDAR topographic data and imagery were collected (vertical bars). Note that the LIDAR data was collected on the rising limb and the imagery was collected on the falling limb of the hydrograph.

During the 2005 runoff event, most of the erosion also occurred relatively close to the lake, in this case in about the lowermost 1 km of channel. Farther upstream, less erosion was noted but some meander bends still showed evidence of migration during this period. This pattern was also noted for the comparisons between the 1995 and 1997 images and topographic data (2 foot contours) as well as for the 2005 vs. 2006 comparisons.

Between June 2005 and September 2006, discharge reached a peak of about 2000 cfs and remained above 500 cfs for a period of 72 days during the spring 2006 runoff season (Figure 4). During this runoff season, an additional 936,000 MT of sediment were eroded from the bed and banks of the LWR, about 75% of which was eroded from the lower 3 km of river channel (Figure 17). The rest of the mass of eroded sediment came from slight meander enlargements farther upstream. For this period about 2970 MT of salt were flushed into Walker Lake from bank erosion.

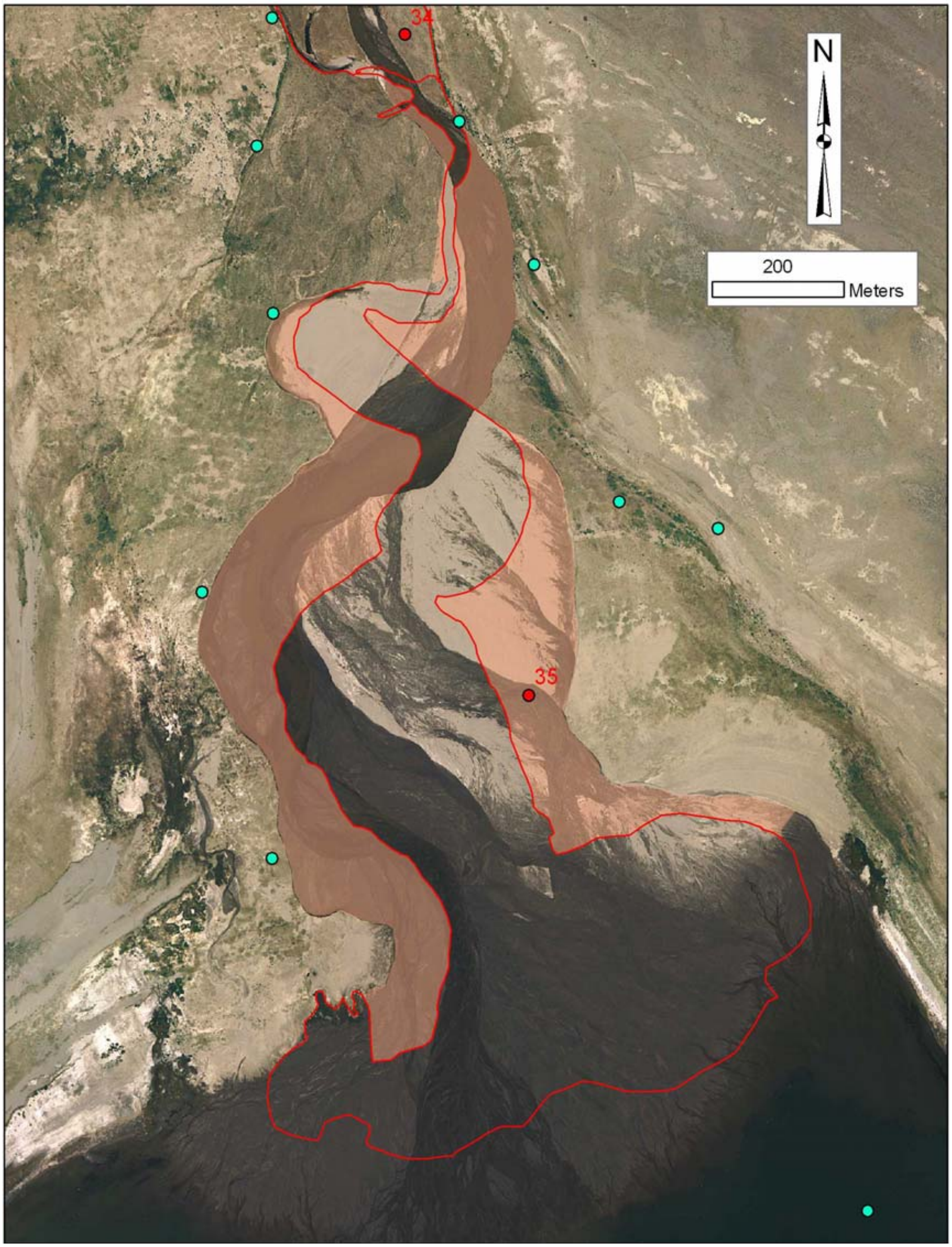


Figure 16. Walker River delta on June 28, 2005, just after peak discharge for that year (~1,400 cfs) had occurred. The red line signifies the boundaries of the channel and delta in late May of that year and the orange-shaded area indicates the areas that were eroded in that one-month time span. Blue dots are sediment sample locations.

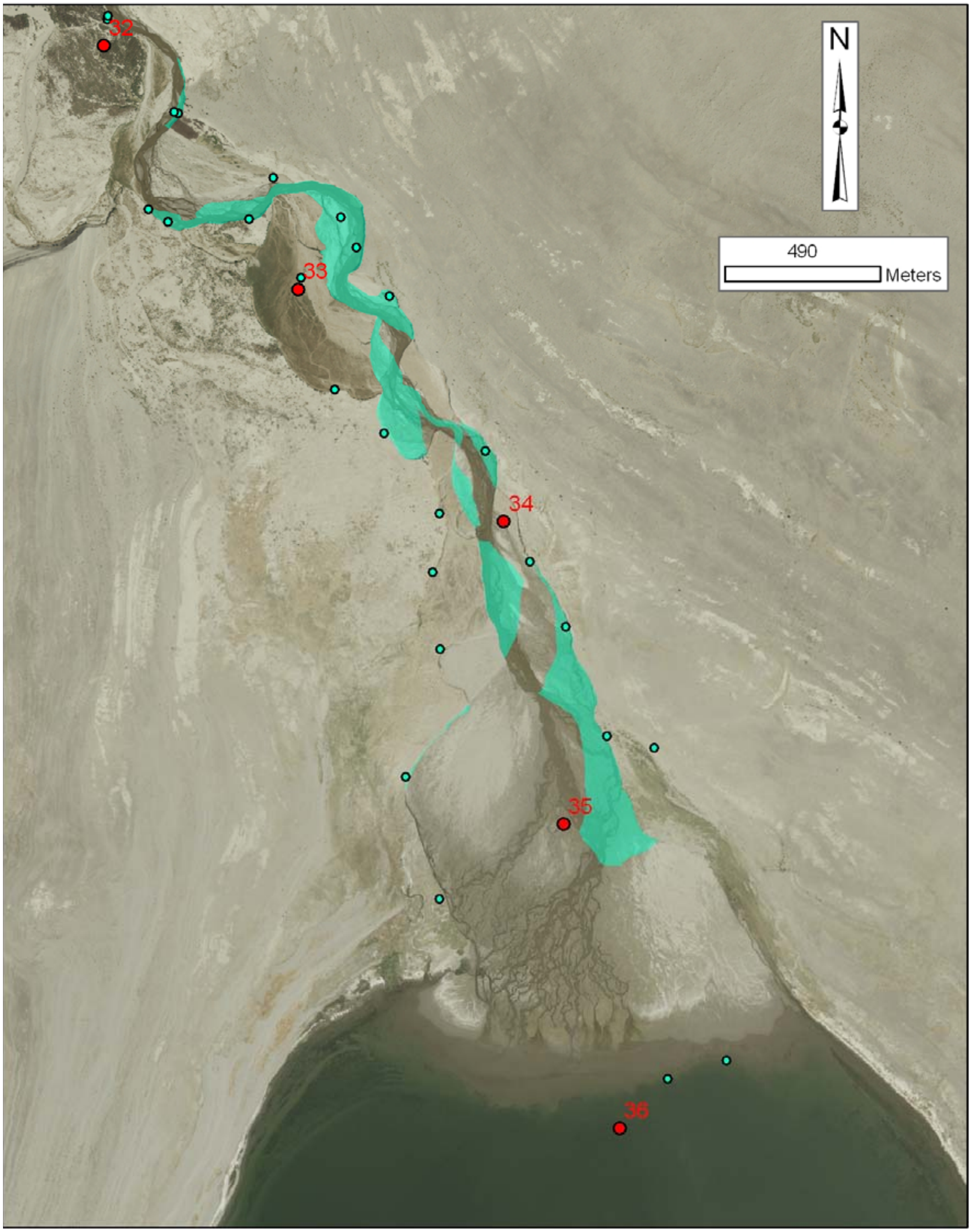


Figure 17. Map showing the areas of erosion (green) caused by the spring 2006 runoff event. Although there are areas of erosion upstream, about 75% of the erosion occurred in the lower few kilometers of river. Green circles represent locations of sediment samples.

In summary, when we have been able to quantify the mass of sediment eroded for a particular year, it seems that it is not only peak discharge that is the primary driver but also the duration of relatively high flow. This concept has been referred to as geomorphically effective floods by Costa and O'Conner (1994).

Sediment Transport Modeling Results

Because the imagery study is appropriate for documenting lateral channel deformation (bank erosion and channel deformation), and modeling is applicable for estimating vertical deformation (stream bed aggradation or degradation), a combination of these two studies can lead to a better understanding of geomorphic change to the stream. For this purpose, we have conducted a sediment transport simulation for the 2005 spring runoff hydrograph (Figure 15) which was also analyzed using the imagery. The simulation covered a 70-day time period from May 20 to July 29, 2005. The hydrograph was used as the upstream boundary condition for discharge. The measured lake level time series rather than a constant (averaged) value was used as the downstream boundary condition to ensure accurate input for the modeling. Modeling results are shown in Figure 18.

The total sediment yield shows the accumulated sediment transport along the stream at the end of the simulation. Generally, it increases downstream. At some locations the sediment yield is lower than that in the upstream cross sections, which is mainly caused by local channel expansion. The expansion of the channel increases the flow area and reduces flow velocity and shear stress, thus reducing the sediment transport capacity of the flow. At these places, a portion of sediment carried by the flow settles and deposition occurs. The sediment yield per unit longitudinal distance is the sediment yield rate at each reach. It is a direct measurement of local vertical stream bed deformation. Positive rates indicate scour and negative values indicate deposition. The general trend of this variable is interesting. The sediment yield rate in the mid stream is generally smaller than both upstream and downstream. The reason is a combination of several factors. At the upstream boundary, the flow does not carry sediment and is "hungry", thus the scouring rate is high. As the flow gains more and more sediment the scouring rate reduces. In downstream reaches, however, because the slope of the stream increases (Figure 10), the flow velocity, shear stress, and scouring rate increase again.

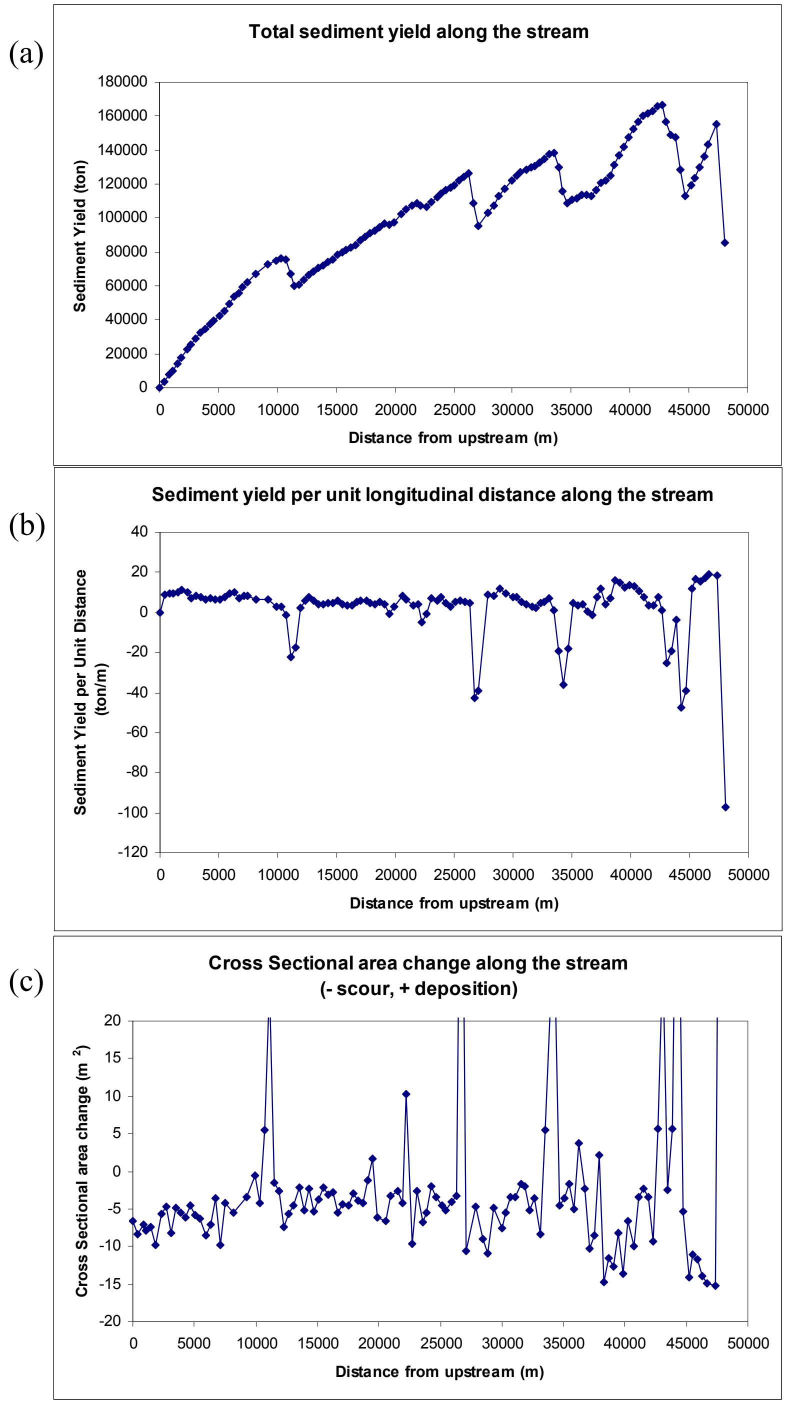
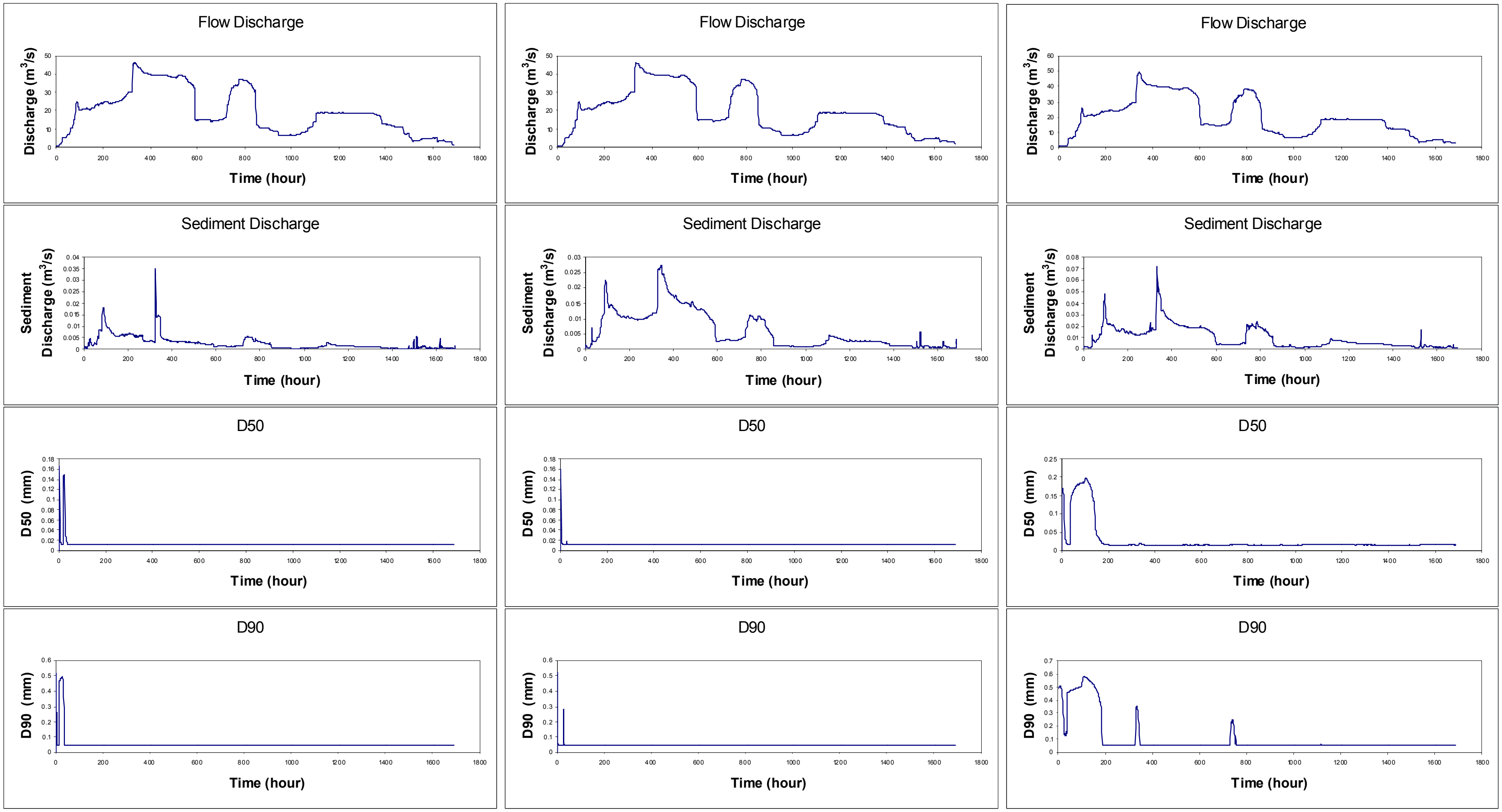


Figure 18. The sediment transport simulation for the 2005 spring runoff hydrograph. (a) Total sediment yield along the stream; (b) Sediment yield per unit longitudinal distance along the stream; (c) Bed deformation shown by cross sectional area change along the stream. Positive values indicate deposition and negative values scour.

Figure 19 shows the flow, sediment discharge, bed sediment size D_{50} and D_{90} (50% and 90% of sediments are finer) as a function of time for the 2005 runoff event at three representative cross sections in up stream, mid stream, and downstream locations, respectively. It is found that the sediment discharge waves attenuate faster than the flood wave, especially in the upstream cross section (Figure 19A). This indicates that the sediment transport process during this period is sediment supply limited. After the peak flows scour, the bed material available for entrainment is largely reduced. The bed surface at this time consists of mostly silt and clay particles (see D_{50} and D_{90} in Figure 19) because coarser particles are largely removed. This fine particle dominated bed surface is more resistant to scouring and forms a relatively restrictive layer reducing sediment entrainment. The bed will remain stable until a larger flood comes. This process is more distinct in the upstream areas. In the mid and downstream reaches, because there is a fair amount of incoming sediment from upstream erosion, the sediment discharge waves have longer time spans but are still shorter than flood waves, which imply the limited sediment source. On the other hand, the feature of particle size changing with time also reveals the supply limited transport feature. The particle size distribution in the surface layer of bed material quickly becomes finer soon after the scouring started. This implies that the relatively coarser material is easier to be entrained and transported in our modeling cases so that more fine particles remain. When coarse particles become unavailable in the top layer of the stream bed, the scouring will largely be impeded. In the downstream location this fining process is relatively slower because the flow carried material scoured from upstream to downstream and provided more sediment there. Because this simulation only accounted for the bed deformation, the simulation results imply that, if significant sediment transport occurred in a long time period, the lateral erosion in LWR may be a more important source of sediment supply than the bed material and the sediment transport process may be different than the supply-limited transport shown in the modeling. Therefore, the sediment transport process in LWR may be dominated by the bank erosion/migration rate and time of occurrences, and the part of the stream with higher lateral deformation, which happens more easily in the downstream reach due to the lake-level lowering, can contribute more to the sediment load into Walker Lake.



(a) upstream (b) mid-stream (c) downstream

Figure 19. Simulated time series for flow, sediment discharge, bed sediment D50 and D90 at three representative cross sections in upstream, mid stream, and downstream locations, respectively.

34

To better understand the relationship of flow magnitude and sediment transport rate, we have simulated the sediment transport process in the LWR under hypothetical flow events based on flood-frequency and flow-duration curves. Six flood events were simulated that include 100-year, 50-year, 25-year, 10-year, and 2-year floods as well as the annual mean flow. All of them were assumed to have a triangular hydrograph (Figure 20) and the receding period is three times as long as the rising period. The 100-year flood was set to have a 2-hour duration (equivalent to a constant 1-hour 100-year flood event in volume). The durations of other flood events were calculated with the same flood volume. An extra day was added to each simulation to allow the flood wave to pass through the stream. The simulation results are shown in Figure 21. It is found that large floods transport much more sediment than small floods. However, the 100-year flood does not transport the most sediment, lower than the 50-year and 25-year events, which may because of the lag effect between flood wave and sediment wave. Since flood waves move faster than sediment waves, the receding tail water may not have enough capability to transport all eroded sediment, thus flood duration may play a more important role.

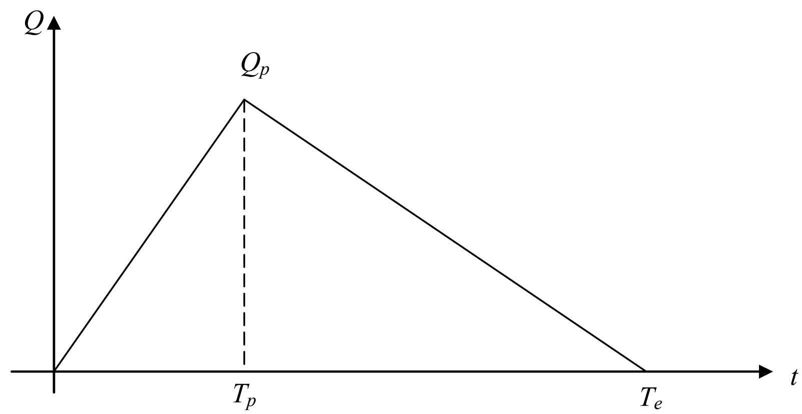


Figure 20. The triangular flood hydrograph.

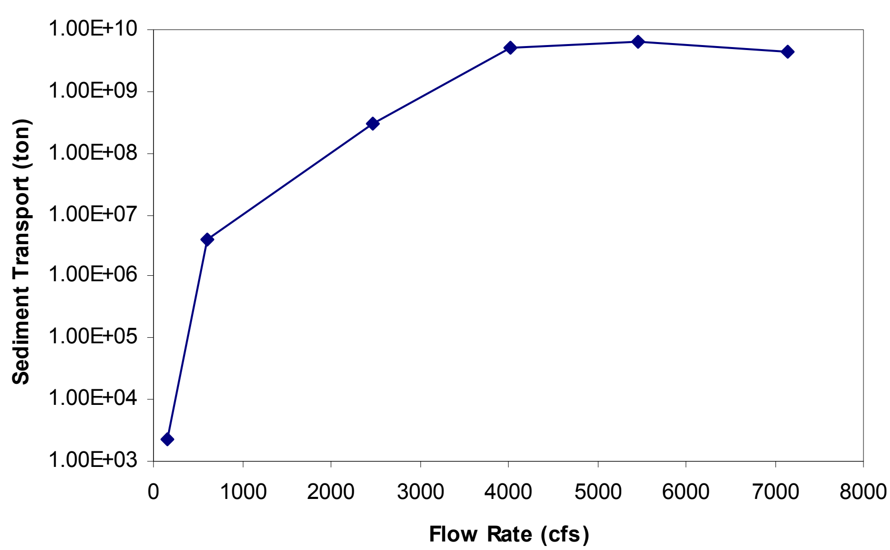


Figure 21. The total sediment transport for flood events of different frequencies.

Another simulation based on the flow-duration curve was also conducted as a complementary study. Twenty flow events of different durations with a sum of 365 days were simulated. Different from the flood events, each flow was set to steady for the duration of the flow event, which is more suitable for the investigation of sediment transport dynamics under relatively constant flow events. The total sediment yield for each flow level is shown in Figure 22a. It is found that the flow that transports the most sediment in a hypothetically typical year is not the largest flow but a moderate flow which is about one half of the largest flow in magnitude and ~30 times in duration. This is consistent with the concept of effective discharge, which is defined as the discharge that, on average, transports the largest proportion of the annual sediment load (Wolman and Miller, 1960). However, if normalized by flow volume, we obtained the general trend that large flows transport more sediment (with same volume of flow) (Figure 22b). Therefore, to minimize further erosion along the LWR, flows should be kept below about 2000 cfs.

(a)

(b)

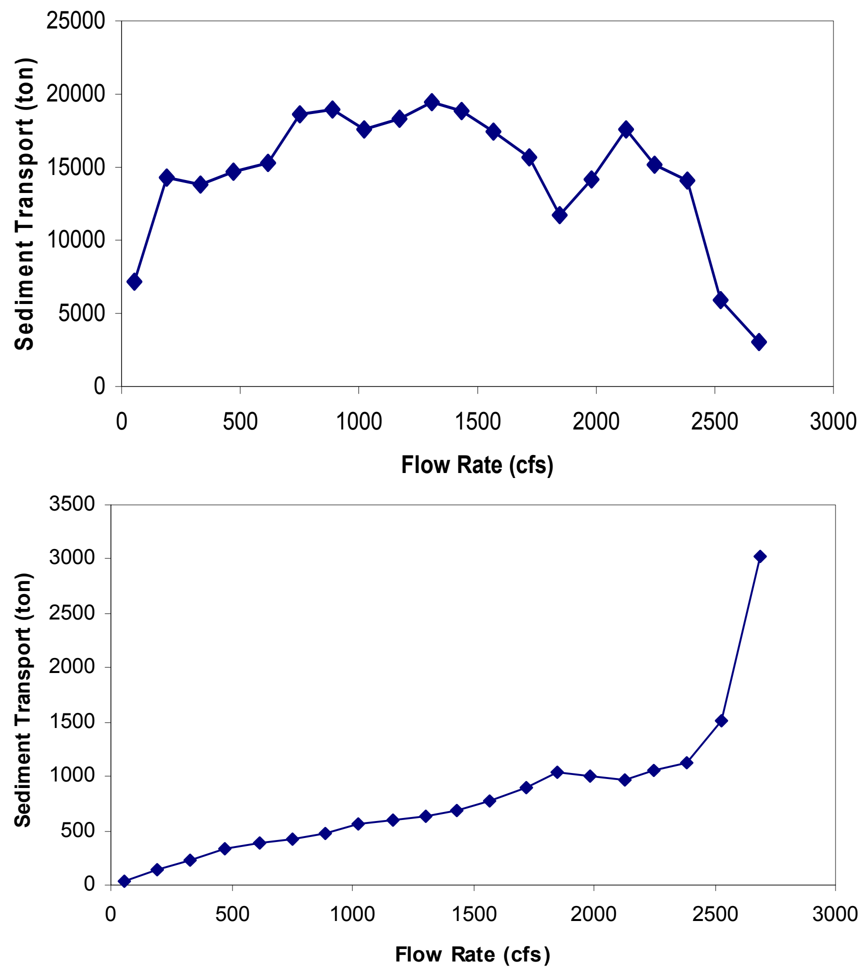


Figure 22. Sediment transport analysis based on flow-duration curve. Each value shows the total sediment transport amount for a certain flow in a given duration. (a) the results based on a standard flow-duration curve. The sum of all durations is 365 days; (b) durations are scaled based on the largest flow so that all flows have the same volume.

CONCLUSIONS AND RECOMMENDATIONS

In summary, the lower Walker River (LWR) is a dynamic system that has responded to fluctuating flows as well as the lowering of Walker Lake, which serves as base level for this system. Geomorphic change, however, has not been equally distributed along the lower river. The upstream reach from Weber Dam (VK 0) to the siphon (VK 13.2) has undergone the least amount of change, although slight changes in channel alignment and meander migration were noted for the period 1938 to 2005 (Figure 9). Below the siphon is a different story.

The LWR has severely incised its channel upon receding from its historic highstand about 100 years ago. Although this incision was well on its way by 1954, when the first air photos are available for the lowermost river, incision and channel widening has proceeded to the present. The most dynamic part of the system is the lowermost reaches of the river, where the newly formed channel has extended across the former lakebed as lake level dropped and is still adjusting to relatively large flows. This dynamic will probably continue with further lake-level lowering but may be arrested if lake level increases. Therefore, increasing lake level by increasing flows down the Walker River is an obvious goal and recommendation.

During low flow periods, such as from 1987 to 1995 and from 1999 to 2005, very little change occurs along the river but the lake continues to fall. Because little to no flow reached the lake during these periods, lake level fell about 9 m and 5 m, respectively. These drops in base level resulted in the LWR channel extending across the unincised former bed of the lake. From 1987 to 1995 and again from 1999 to 2005, the length of the LWR was extended by several kilometers. When flow returned to the river after each of these dry periods, the net effect was that the easily eroded, formerly unchannelized (lakebed) surface was modified by an incising and widening channel (Figure13). Essentially, the LWR is doing what alluvial rivers do, forming a channel that is trying to adjust to the prevailing slope, base level, hydrologic regime, and sediment supply. Unfortunately, the severe instability evident in the LWR is a product of the near continuous changing of its controlling parameters. This type of major instability, however, appears to be limited to the lowermost reaches of the river where the channel is continually adjusting to changes in slope and base level.

The LWR is a "live-bed" stream which means that transport of its unconsolidated sandy bed occurs at virtually all discharges. In places along the bed, silt- and clay-rich lacustrine sediments are exposed indicating that certain reaches of the LWR are sediment starved. Therefore, the sediment-transporting capacity of the LWR is rarely exceeded and the system will likely continue to down cut and widen, flushing all of that sediment and salt into Walker Lake.

The masses of eroded sediment estimated from analysis of aerial images and topography are complementary to those estimated from sediment transport modeling, although they are not strictly comparable. This is because estimates derived from image analysis are primarily reflective of lateral erosion, whereas estimates derived from modeling reflect vertical incision. As an example, the mass of sediment eroded from the banks of the LWR during the spring 2005 runoff season was estimated through image analysis to be about 477,000 MT, whereas the mass eroded from the bed was estimated by sediment transport modeling to range from about 80,000 to 160,000 MT, depending on location (Figure 18a). Although values derived from both approaches are probably not strictly additive, they certainly reflect at least order of magnitude estimates. Therefore, in years of "average" discharge, hundreds of thousands of metric tons of fine sediment and thousands of metric tons of salt can be expected to be flushed into Walker Lake from bed and bank erosion along the lower Walker River (Table 3). Although this amount of sediment is considered large, the amount of salt introduced through this process is small compared to the annual salt budget for Walker Lake (Thomas, 1995).

Clearly, the only way to help the ecology and decrease the salinity of Walker Lake is to get more water to the lake and if it comes, that water will likely be delivered down the river. Based on our analyses, increasing peak flows would likely have negative effects in the form of eroding more sediment and salts and flushing these constituents into the lake. A more reasonable way to maximize the benefits of delivering more water to Walker Lake, while minimizing the negative effects, would be to increase the durations of spring runoff hydrographs and/or to establish minimum base flows. Although the logistics and legality of storing and releasing water at appropriate times for Walker Lake in the Walker River system's reservoirs (Bridgeport, Topaz, and Weber) was not specifically part of this study, various scenarios and their relative benefits should be investigated.

Another pressing issue with respect to the health of the lower Walker River and Walker Lake is the condition of the siphon, which is a steel pipe across the bed of the river that once transferred ditch water from one side of the river to the other but is no longer operational. A major change in the geomorphology of the LWR occurs at the siphon (VK 13.2). Upstream from this point the LWR remains a single stem meandering stream that is relatively unincised and unchanged from 1938 to the present (Figure 9). Below the siphon, however, the LWR has severely incised into its bed and is continuing to evolve as lake level continues to fall. What is abundantly clear from our analyses is that the siphon has acted to arrest the historic headcut that propagated upstream from the vicinity of the 1868 highstand.

The siphon is no longer operating, but remains somewhat effective in arresting the progression of the headcut. This situation, however, is tenuous as the river has begun undercutting the siphon (Figure 23) and may soon fail. Given the relative "health" of the fluvial system upstream from this point, relative to that downstream, it is imperative that the headcut not be allowed to progress past this point. If the siphon is removed by a future large flood, which is likely, incision will probably rapidly progress upstream affecting bridges, roads, and other infrastructure in Schurz, in addition to negatively impacting the riparian ecology of that part of the stream. Therefore, we recommend an engineered solution that would stabilize the headcut in place but also allow effective fish passage.

Figure 23. Photograph of the siphon, which is a steel pipe extending across the bed of the river. This structure has served to arrest the upstream migration of the historic head cut. By 2008 flow had undercut the siphon, which may be a precursor to failure.

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PROJECT E: DEVELOPMENT OF RECOMMENDATIONS TO MAXIMIZE WATER CONVEYANCE AND MINIMIZE DEGRADATION OF WATER QUALITY IN WALKER LAKE DUE TO EROSION, SEDIMENT TRANSPORT, AND SALT DELIVERY

EVALUATION OF THE POTENTIAL FOR EROSION AND SEDIMENT TRANSPORT IN THE UPPER WALKER RIVER AND ASSOCIATED IMPACTS ON WATER QUALITY

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Yoganathan Thierumaran, University of Nevada, Reno
James W. Schoenleber, University of Nevada, Reno

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report addresses *Project E* of the Walker River Project: *"Impacts of Increased Flows on the River Channel and Water Quality in Walker Lake"*. This report describes the results of various tasks that were completed in order to accomplish the project objectives. These tasks included: 1) performing a detailed engineering survey along the upper Walker River; 2) developing a hydraulic model of the upper Walker River using HEC-RAS; 3) collecting and characterizing sediment samples from the upper Walker River and performing laboratory flume studies to determine the hydrodynamic conditions resulting in erosion; and 4) collecting and analyzing water samples and comparing the observed water quality with historical water quality data.

A detailed engineering survey was performed along the upper Walker River to measure channel cross section geometry and flow velocity. Approximately 30 miles of the West Walker River (from Topaz Lake to the confluence), 50 miles of the East Walker River (from 10 miles below Bridgeport to the confluence) and 20 miles of the Walker River (from the confluence to the boundary of the Walker River Indian Reservation) were surveyed.

The river cross section data gathered during field surveying were used to develop a hydraulic model of the upper Walker River using the Hydrologic Engineering Center River Analysis System (HEC-RAS) software developed by the United States Army Corps of Engineers. The velocity profiles and bed shear stresses predicted by the HEC-RAS model were used to estimate the potential for erosion and sediment transport with anticipated increases in flows as a result of the acquisition of additional water rights along the Walker River. The HEC-RAS model was also used to evaluate the potential of localized flooding along the upper Walker River due to the anticipated increases in flow.

Sediment samples were collected from several channel reaches and characterized according to particle size distribution and mineralogy. Sediment samples were used in laboratory flume studies in order to identify the hydrodynamic conditions resulting in erosion and sediment transport.

Water samples were collected and analyzed monthly since significant variations in water chemistry can influence the surface properties of fine grained sediments (i.e., silts and clays) which could impact the erodibility of sediments. The results of field and laboratory analyses of water samples collected monthly from the upper Walker River (i.e., temperature, velocity of flow, depth of flow, electrical conductivity, dissolved oxygen, pH, turbidity, total organic carbon, anions, cations, and total dissolved solids) were presented along with a comparison with historical water quality data.

In summary, the HEC-RAS model developed during this project can be used to evaluate the potential for erosion, sediment transport, and localized flooding along the upper Walker River for various flow scenarios. The HEC-RAS model can be used to assess the potential impacts due to the delivery of increased flows to the lower Walker River resulting from the acquisition of additional water rights within the upper Walker River basin.

MATERIALS AND METHODS

This section describes the materials and methods used to:

1. gather river cross section data and velocity measurements;
2. develop a hydraulic model using the United States Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS);
3. collect water samples and perform field measurements;
4. perform water quality analyses in the laboratory;
5. perform standard classification and X-ray diffraction analyses of sediment samples; and
6. perform sediment transport analyses.

Gathering River Cross Section Data

A Trimble Survey Controller (TSC2) system was used to gather river cross section data. The TSC2 system consisted of the TSC2 data controller, the rover, the base station and the repeater. The TSC2 provided the X-Y-Z coordinates (e.g., longitude, latitude, and elevation) of each location where measurements were taken. The X-Y coordinates were stored in two forms in the data controller, as longitude and latitude and as northing and easting.

At the beginning of the project, survey control points were established along the West Walker River, the East Walker River, and the combined Walker River. All of the control points were calibrated and established using a United States Geological Survey (USGS) flow gauging station with USGS number 10302002.

River cross section data was gathered by surveying one hundred and thirteen cross sections in increments of approximately one mile. Approximately 30 miles was surveyed along the West Walker River starting from Topaz Lake to the confluence with the East Walker River. Similarly, approximately 50 miles was surveyed along the East Walker River starting about 10 miles below Bridgeport Reservoir to the confluence with the West Walker River. Then, approximately 20 miles of the combined Walker River was surveyed beginning at the confluence and ending at the boundary of the Walker River Indian Reservation.

The number of coordinates gathered at each river cross section depended on the width of the channel. Typically, coordinates were taken at intervals ranging from 2 to 6 feet across the river channel. The horizontal and vertical accuracy of the TSC2 GPS surveying instrumentation used during this project was +/- 0.5 inches and +/- 1.0 inches, respectively. The vertical accuracy was maintained by holding the rover rod in a vertical position.

At each river cross section, several coordinates were collected in the overbank section. The edge of the water on each side of the channel section was also recorded as coordinates in order to determine the water surface elevation. The elevations of the channel bottom were surveyed at each cross section by placing the base of the rover rod on the bottom of the channel. The cross section coordinates gathered in the field were entered into HEC-RAS.

Each location where a cross section was measured was assigned a unique river station (RS) number. The entire length of the river that was surveyed was converted into feet. The resulting number was assigned as the river station number for the uppermost cross section. For example, the lengths of the combined Walker River and the East Walker River were approximately 20 miles and 50 miles, respectively. Thus, the total length was approximately 70 miles or 369600 feet. So, the location of the uppermost cross section along the East Walker River was designated as river station number 369600. Then, additional station numbers were assigned by deducting the reach length between the upstream cross section and the next downstream cross section.

Similarly, the total lengths of the West Walker River and the combined Walker River were considered for designating the locations of cross sections along the West Walker River. When it came to the confluence, the lowermost cross section of the east fork and the west fork had a slightly different numbers as their station numbers. There, the station numbering for the west fork was selected for numbering stations along the combined Walker River since the West Walker River had proportionally more surveyed cross sections than East Walker River.

Table 1 summarizes the locations and river station numbers for fourteen specific cross sections within the Walker River Basin that were considered for detailed analyses. The locations of these river stations are also depicted in Figure 1. As can be seen, the locations of the cross sections were selected along each reach of the river in an attempt to be representative of the entire river.

Table 1. Locations of river stations selected for detailed analyses.

River Station		**Latitudes (deg-min-sec)**	**Longitudes (deg-min-sec)**
East Walker River	369600	38-25-01.26477	119-09-38.09200
	345682	38-26-24.84021	119-05-21.78011
	300177	38-29-00.83240	118-59-41.69942
	206202	38-43-07.21309	118-58-47.45622
	183775	38-46-04.44400	119-01-28.57070
	120799	38-53-20.98428	119-10-05.14199
West Walker River	263638	38-41-43.95436	119-30-29.55304
	237597	38-43-32.54394	119-25-54.17581
	188746	38-49-16.06543	119-20-09.99997
	149187	38-48-32.57787	119-13-19.09483
	113443	38-53-22.16495	119-10-46.05453
Combined Walker River	100229	38-55-16.44447	119-11-28.07428
	49536	39-02-53.84740	119-07-59.76392
	9895	39-09-00.76147	119-06-04.62827

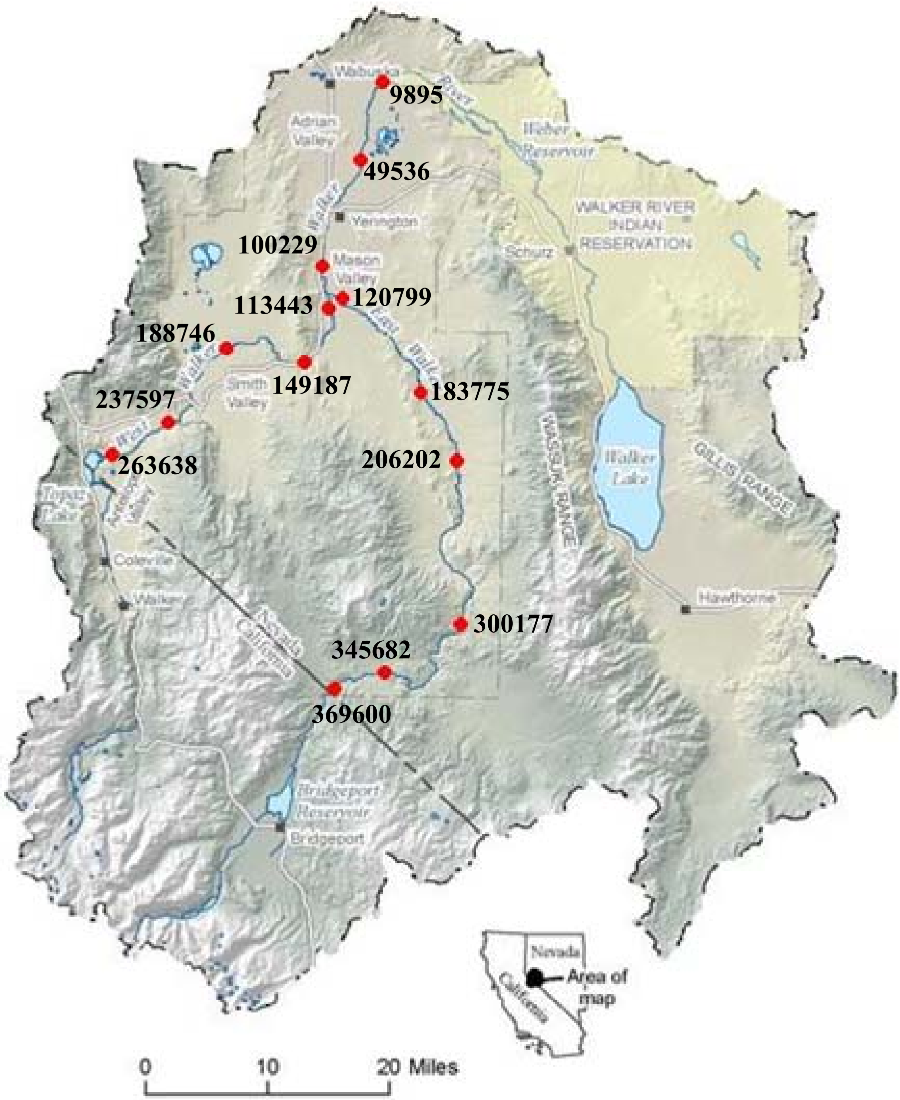

Figure 1. Cross sections along the Walker River selected for detailed analyses.

Measuring Velocities across River Cross Sections

A portable electromagnetic flow meter (Flo-Mate, Model 2000, Marsh-McBirney, Inc.) was used to measure velocities across each cross section. The flow sensor operated based on Faraday's Law. The sensor was mounted on a wading rod which was positioned at about 0.6 of the depth from the water surface at each location where measurements were taken (Gupta, 2001; Lazorchak *et al.*, 1998; Rantz, 1982). A single point reading was appropriate since the water depth was usually less than 2.5 feet in all three forks of the Walker River. The velocity was recorded after a period of 2 to 3 minutes. The velocity readings were later used to calculate the flow at each river cross section using the techniques summarized by Gupta (2001) and Lazorchak *et al.* (1998).

There are several ways to calculate flow such as the midsection method and the mean section method (Gupta, 2001). The mean section method was selected for the analyzing the data collected along the upper Walker River. To calculate flow at a given cross section, the depth of water at each point across the cross section was determined. The distance between each point across the cross section was noted as a segment width. The average water depth for each segment across a cross section was calculated. Similarly, the average velocity for each segment across a cross section was calculated. Then, the flow within each segment of a cross section was determined by multiplying the segment width by the average water depth by the average velocity. These data were subsequently used as input into the HEC-RAS model in order to validate the performance of the model. Table 2 compares the flows calculated using the velocities and cross section data measured in the field with the flows recorded at various USGS flow gauging stations on the days when the cross section data was collected.

Table 2. Comparison of flows at USGS gauging stations with calculated flows.

USGS Gauging Station	Flow (cfs)		Distance between the USGS Gauging Station and Measured Point (miles)
	Reported by USGS	Calculated from Field Data	
10301500	37	34.3	0.22
10300000	48	44.3	0.20
10297500	93	102.7	0.28
10293500	37	31.2	0.38
10293000	99	78.5	6.31

Compiling River Cross Section Data

Various calculations were performed in a spreadsheet to compile the cross section data that were used to develop the HEC-RAS model. The file containing river cross coordinates was exported from the TSC2 survey controller to the computer and then copied into a spreadsheet. Each data point consisted of the Point Number, the X-Y-Z coordinates (i.e., Northing, Easting, Elevation), and type of point (i.e., Base Station, Riverbank, Edge of Water, or River Bottom). The river cross sections were measured from one side of the river to the other depending on the site access. For consistency and the standard method for inputting cross section data into HEC-RAS, the riverbank on the left when facing downstream in the direction of flow was designated as the left side. The first point on the left overbank was taken as the reference point and the length between each point and the reference point was calculated. This was then used to input the coordinates of each point across a cross section. The overall width of each cross section was determined as the distance between the reference point and last point. The reach length (i.e., distance between two adjacent cross sections) was calculated by considering the points with the lowest elevation between two adjacent cross sections (Hoggan, 2001). As mentioned previously, the entire length of the river that was surveyed was converted into feet. This distance was then used to assign a unique river station (RS) number to each location where a river cross section was measured.

Development of the HEC-RAS Model

The HEC-RAS 4.0 modeling software was developed by the United States Army Corps of Engineers Hydrologic Engineering Center as the preeminent software for calculating and analyzing one-dimensional steady-flow, predicting water surface profiles in unsteady flows, and estimating sediment transport. The general steps executed in developing the HEC-RAS model included creating a project file, defining the river network, entering geometric data, defining flow and boundary conditions, performing hydraulic analyses, reviewing the results, and producing reports. With regard to the application of the HEC-RAS model developed as part of this study, the flow was assumed to be steady.

The general procedures followed in creating the model are summarized below. The schematic configuration of the project plan was drawn and the river reaches and junction were labeled as shown in Figure 2. Then, cross section data were entered and river station numbers were assigned. A typical cross section data screen is shown in Figure 3. The distance to each point across the cross section from the initial point on the left bank and the elevation were entered as X-Y-Z coordinates.

The values of Manning's *n* at each cross section (like those shown in Figure 3) were selected based on the characteristics of the channel bed. The bed type (e.g., sandy clay soil, cobble-bottom channel, coarse gravel, boulders, etc.,) was selected using photographs and notes taken at each cross section on the day it was surveyed. Representative photographs of the channel cross sections are shown in Figures 4 through 10.

Various factors influence Manning's *n* including (Dyhouse *et al.*, 2007):

- bed material and average grain size
- surface irregularities and channel bed forms (e.g., ripples and dunes)
- channel meandering
- channel obstructions (e.g., trees, roots, and debris)
- changes in channel geometry and alignment
- vegetation along the channel banks and within the channel.

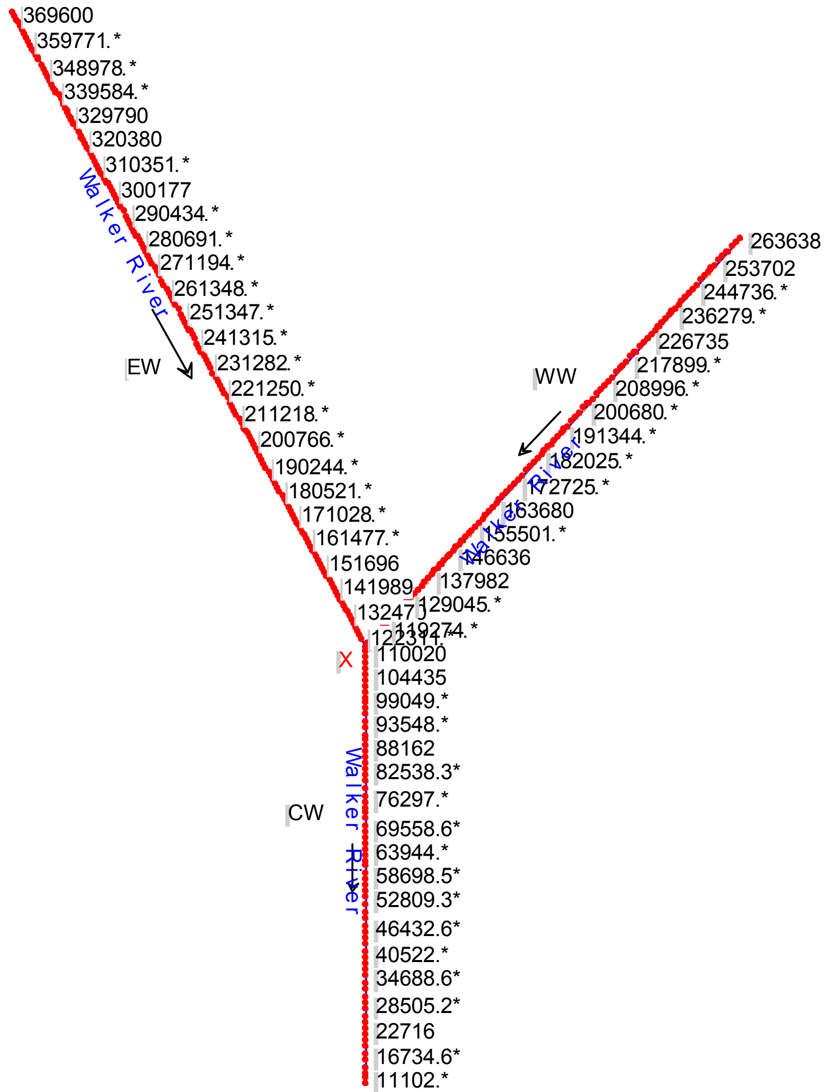

Figure 2. Schematic diagram of the upper Walker River Basin within HEC-RAS.

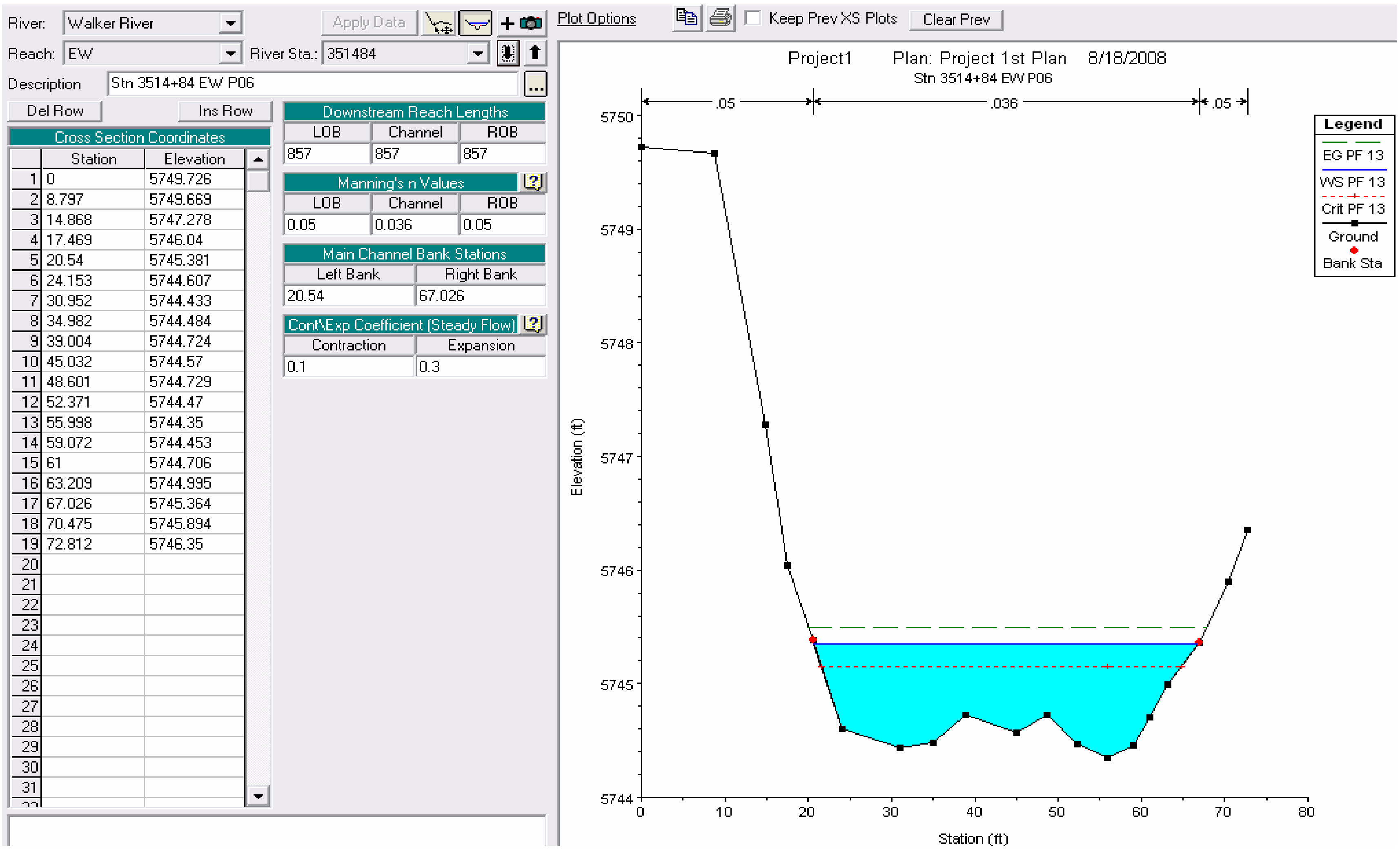

Figure 3. Typical HEC-RAS cross-section data screen.

Figure 4. Channel characteristics at RS 113443.

Figure 5. Channel characteristics at RS 117827.

Figure 6. Channel characteristics at RS 303129.

Figure 7. Channel characteristics at RS 156862.

Figure 8. Channel characteristics at RS 122168.

Figure 9. Channel characteristics at RS 177612.

Figure 10. Channel characteristics at RS 193942.

Cowan (1956) developed a procedure for estimating the effects of these factors to determine the value of *n* for a channel (Arcement, 1989). The value of *n* may be calculated using the expression;

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \qquad (1)$$

where: n_b = a base value of *n* for a straight, uniform, smooth channel in natural material

n_1 = a correction factor for the effect of surface irregularities

n_2 = a value for variations in shape and size of the channel cross section

n_3 = a value for obstructions

n_4 = a value for vegetation and flow conditions

m = a correction factor for meandering

A sample calculation of Manning's *n* for the cross section at RS 136167 is

$\mathrm{n = (n_b + n_1 + n_2 + n_3 + n_4)m}$

n = (0.035 + 0.015 + 0.015 + 0.015 + 0.005)*1.30

= 0.111

Representative values of Manning's *n* used to develop the HEC-RAS model are summarized in Table 3.

Table 3. Summary of Manning's *n* values for selected cross sections.

River Station	Manning's Roughness Coefficient		
	LOB	Channel	ROB
369600 (EW)	0.090	0.070	0.090
345682 (EW)	0.110	0.100	0.110
300177 (EW)	0.100	0.090	0.100
206202 (EW)	0.030	0.025	0.030
183775 (EW)	0.050	0.038	0.050
120799 (EW)	0.100	0.090	0.100
263638 (WW)	0.100	0.085	0.090
237597 (WW)	0.030	0.025	0.030
188746 (WW)	0.090	0.060	0.080
149187 (WW)	0.100	0.080	0.090
113443 (WW)	0.050	0.040	0.050
100229 (CW)	0.050	0.037	0.050
49536 (CW)	0.080	0.070	0.080
9895 (CW)	0.050	0.042	0.050

Figure 11 shows the variation of the bed elevation along the East Walker River. The bed slope for the East Walker River was relatively constant within the range of 0.003 to 0.013 ft/ft. Figure 12 shows the variation of the bed elevation along the West Walker River. The west fork had two relatively steep channel sections where the bed slope was around 0.014 ft/ft. Along other sections, the bed slope varied from around 0.001 to about 0.002 ft/ft. Figure 13 indicates that the bed slope along the combined Walker River was relatively constant around 0.0014 ft/ft.

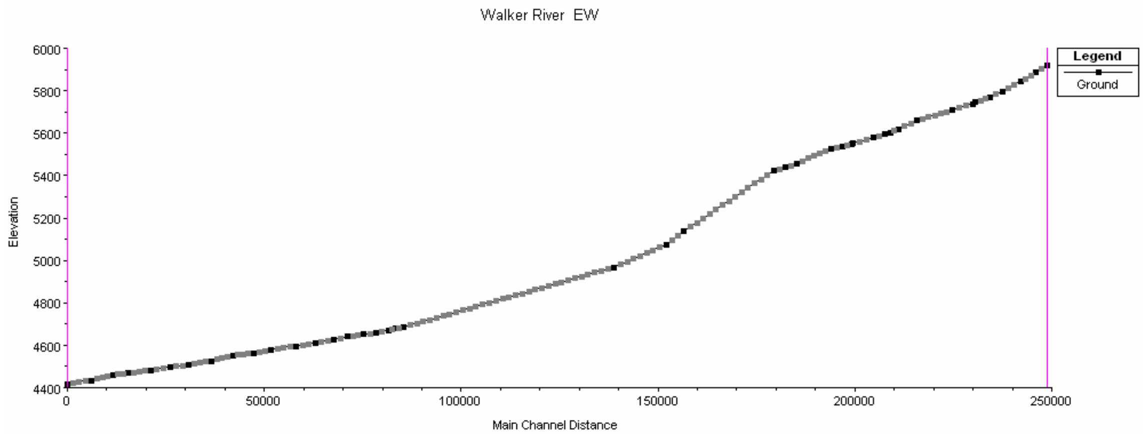

Figure 11. Elevation of main channel along the east Walker River.

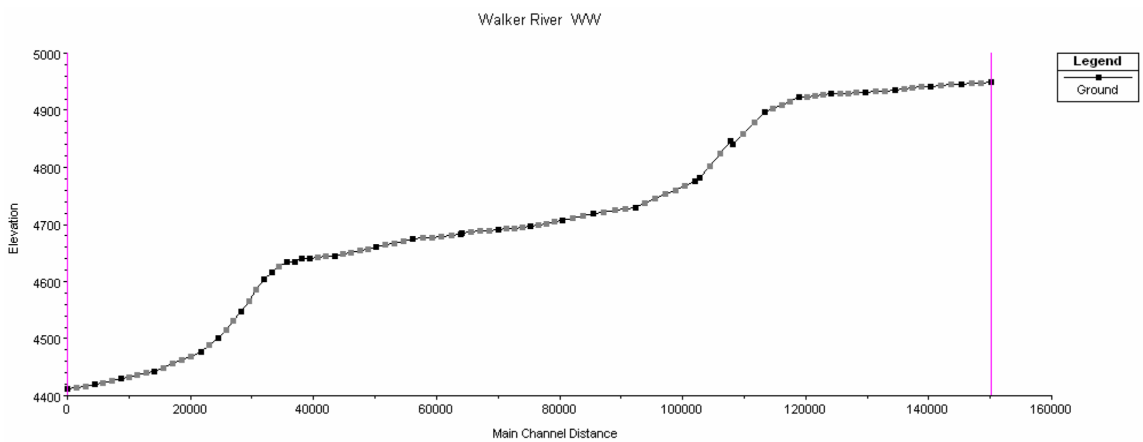

Figure 12. Elevation of main channel along the west Walker River.

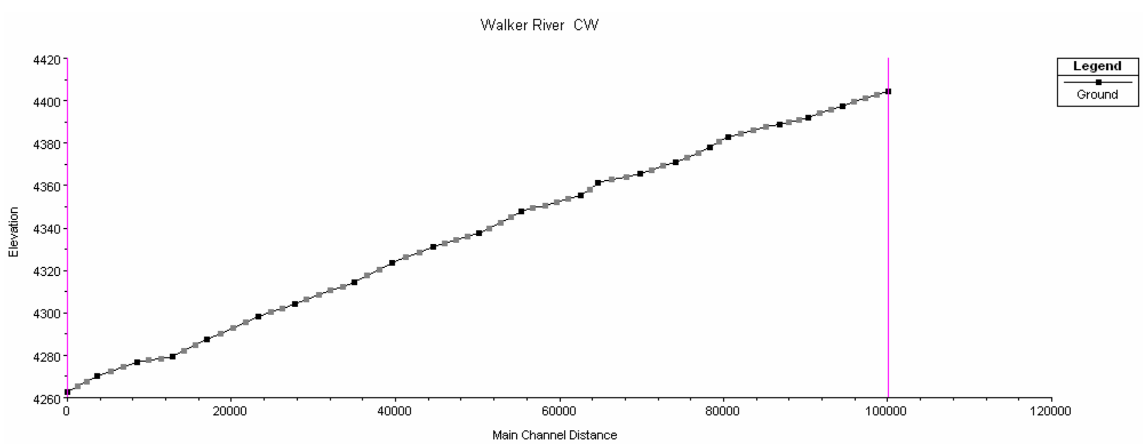

Figure 13. Elevation of main channel of the combined Walker River.

Validation of Performance of HEC-RAS Model

In order to validate the performance of the HEC-RAS model, the predicted water surface elevations at the river cross sections selected for detailed analyses were compared to the observed water surface elevations when cross section data were collected. The results of this comparison are summarized in Table 4. Figure 14 shows a comparison of water surface elevations predicted by the HEC-RAS model at RS 237597 over a range of flow conditions and the rating curve for the USGS flow gauging station 10297500 located near RS 237597. The depth of flow recorded at the USGS gauging station on the day that cross section data were gathered at RS 237597 for a flow of 102.7 cfs was 1.80 feet. The depth of flow predicted by the HEC-RAS model was about 1.90 feet.

Table 4. Comparison of observed and predicted water surface elevations.

River Station	Flow (cfs)	Water Surface Elevation (ft)		Percentage Error	Maximum Channel Depth (ft)		Average Velocity (fps)
		Observed	Calculated		Observed	Calculated	
369600 (EW)	78.5	5922.70	5922.65	2.18	2.29	2.23	1.85
345682 (EW)	69.4	5711.62	5711.54	2.65	3.05	2.97	1.71
300177 (EW)	31.1	5424.83	5424.78	3.18	1.57	1.52	1.61
206202 (EW)	125.0	4686.00	4686.04	-4.15	1.09	1.13	2.73
183775 (EW)	185.8	4611.40	4611.42	-0.73	2.59	2.61	2.82
120799 (EW)	45.5	4419.51	4419.47	3.71	1.13	1.09	3.81
263638 (WW)	14.8	4950.64	4950.63	0.92	1.30	1.29	0.83
237597 (WW)	102.7	4930.46	4930.49	-1.67	1.80	1.83	1.75
188746 (WW)	47.4	4698.52	4698.53	-0.71	1.70	1.71	0.92
149187 (WW)	42.8	4637.50	4637.44	2.57	2.26	2.20	2.07
113443 (WW)	49.9	4413.85	4413.87	-1.55	1.16	1.18	3.31
100229 (CW)	101.7	4393.90	4393.94	-2.25	1.82	1.86	1.11
49536 (CW)	8.4	4324.41	4324.38	3.12	0.96	0.93	0.56
9895 (CW)	34.3	4265.05	4265.05	-0.09	2.18	2.18	1.45

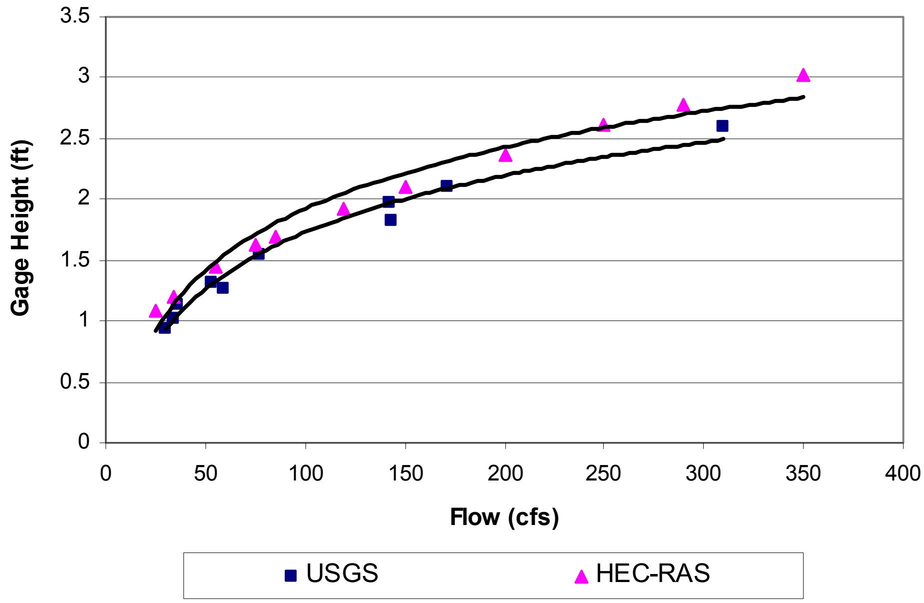

Figure 14. Comparison of rating curve for USGS gauging station 10297500 and rating curve generated using the HEC-RAS model.

Water and Sediment Sampling Sites

Field sampling was performed approximately every 30 days between July 2007 and June 2008 at nine different locations along the Walker River. All water and sediment samples were collected from the center of stream. The locations of the sampling sites are indicated in Figure 1 and were established to reflect headwater, midsection flow, and tail water locations for each branch of the Walker River as described below.

Combined Walker River 1 (CWR #1) at River Station 100229: N38° 55.273', W119° 11.508', Elevation: 4434'. This location was south of the confluence between the East and West Walker Rivers, north of the bridge off Snyder Lane.

Combined Walker River 2 (CWR #2) at River Station 49536: N39° 02.890', W119° 08.011', Elevation: 4366'. This location was approximately halfway between CWR #1 and CWR #3, slightly north of bridge B-1519 off Miller Lane.

Combined Walker River 3 (CWR #3) at River Station 9895: N39° 09.107', W119° 06.016', Elevation: 4279'. This location was adjacent to the boundary of the Walker River Paiute Indian Reservation at the north end of culvert, approximately 500 feet south of the USGS Gauging Station 10301500 at Wabuska, Nevada

East Walker River 1 (EWR #1) at River Station 350627: N38° 26.423', W119° 6.391', Elevation: 5794'. This location was north and east of the Bridgeport Reservoir within Nevada on the west side of the bridge approximately 11 miles northeast of the USGS Gauging Station 10293000 at Bridgeport, California.

East Walker River 2 (EWR #2) at River Station 206202: N38° 43.105', W118° 58.796', Elevation: 4724'. This location was approximately halfway between EWR #1 and EWR #3 on the north side of bridge, approximately 8 miles southeast of the USGS Gauging Station 10293500 at Mason, Nevada.

East Walker River 3 (EWR #3) at River Station 120799: N38° 53.332', W119° 10.094', Elevation: 4460'. This was the last sampling location prior to the confluence of the East and West Walker Rivers approximately 10 miles north-northwest (downstream) from the USGS Gauging Station 10293500 at Mason, Nevada, located off Nordyke Road approximately 100' from the north side of the east bridge.

West Walker River 1 (WWR #1) at River Station 263638: N38° 41.746', W119° 30.501', Elevation: 5004', located just downstream of the outlet from Topaz Reservoir on the Topaz Canal, approximately ½ mile downstream of the reservoir outlet and 6 miles southwest (upstream) of the USGS Gauging Station 10297500 at Wellington, Nevada.

West Walker River 2 (WWR #2) at River Station 188746: N38° 49.387', W119° 19.715', Elevation: 4734'. This location was about halfway between WWR #1 and WWR #3, approximately 10 miles northwest (downstream) of the USGS Gauging Station 10297500 at Wellington , Nevada, and approximately 7.5 miles west (upstream) of the USGS Gauging Station 10300000 at Hudson, Nevada, on the west side of Bridge B-822.

West Walker River 3 (WWR #3) at River Station 113443: N38° 53.348', W119° 10.769', EL: 4447'. This was the last sampling location prior to the confluence of the East and West Walker Rivers, located at the west side of the bridge off Nordyke Road, approximately 6.7 miles north-northeast (downstream) of the USGS Gauging Station 10300000 at Hudson, Nevada.

Collection of Water and Sediment Samples

Prior to each sampling event, fresh DDW (double distilled water) was obtained for use as field blanks and for rinsing equipment and sampling probes. During each sampling event, two water samples were collected at each sampling location from the center of the river after rinsing each container with river water three times. A 2-liter volume was used for anion (e.g., Cl^{-1} and SO_4^{-2}), total dissolved solids (TDS), total organic carbon (TOC), and turbidity analyses. A separate 150 mL sample was preserved onsite (with 9 drops of undiluted HNO_3 per 150 mL) and subsequently used for cation (i.e., Ca^{+2}, Fe^{+2}, K^{+1}, Mg^{+2}, and Na^{+1}) analyses.

During the sampling event in the March 2008, 5 gallons of river bottom sediment and 30 gallons of river water were collected from the center of the river at six sampling locations for use during the sediment transport analyses. The surface of the riverbed was too armored at three locations (i.e., EWR #1, EWR #2, and WWR #1) to obtain sediment samples. Church *et al*. (1987) provided recommended procedures for collecting sediment samples.

The water samples were transported in an ice chest back to the University of Nevada at Reno where they were stored at +4°C. All laboratory water quality analyses commenced within 24 hours of sample collection with the exception of the cation analyses since the samples were preserved in the field.

Field Measurements

Field measurements were performed at each sampling location using a YSI 556 MPS (Yellow Springs Instruments, Inc.) for field measurement of water quality parameters. The parameters which were measured in the field in accordance with *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, and WEF, 1998) included:

- Temperature (°C), *Standard Methods* 2550 B
- pH, *Standard Methods* 4500-H^+ B
- Dissolved oxygen (DO) (mg/L), *Standard Methods* 4500-O G
- Electrical conductivity (EC) ($\mu S/cm^3$), *Standard Methods* 2510 B

The concentration of dissolved oxygen (DO) was observed to be near or at saturation during the entire project period. The YSI was calibrated every three months in accordance with the user's manual. A HACH 2100P portable turbidimeter (HACH Company) was used to measure turbidity (NTU) by *Standard Methods* 2130 B.

Laboratory Water Quality Analyses

Water quality analyses that were performed in the laboratory included total dissolved solids (TDS), anions (e.g., Cl^{-1} and SO_4^{-2}), cations (e.g., Ca^{+2}, Fe^{+2}, K^{+1}, Mg^{+2}, and Na^{+1}), and total organic carbon (TOC).

Total dissolved solids analyses were performed in accordance with *Standard Methods* 2540 C. Triple replicates were analyzed for all samples, field blanks, and process blanks. A total of 33 samples were analyzed for each run.

Anion analyses were performed using a Dionex Corporation ICS-2000 with an AS-40 autosampler in accordance with *Standard Methods* 4500-Cl^- F and –SO_4^{2-} B. Standards were used to calibrate the instrument and then samples were analyzed. Two replicates of all samples, field blanks, and process blanks were analyzed. A total of 22 samples and 4 standards were analyzed for each run.

Cation analyses were performed using a Perkin Elmer Optima-2100 DV ICP (Ion Coupled Plasma Atomic Spectrometer - ICP) with an autosampler in accordance with *Standard Methods* 3500-: Ca C, Fe C, K C, Mg C, and Na C. Standards were used to calibrate the instrument and then samples were processed. Two replicates of all samples, field blanks, and process blanks were analyzed with triple analyses occurring within the instrument for each of the analytes. A total of 22 samples and 4 standards were analyzed for each run.

Total organic carbon (TOC) was determined utilizing a Shimadzu Corporation TOC-V_{csh} (TOC) with an autosampler in accordance with *Standard Methods* 5310 C. Standards were used to calibrate the instrument and then samples were analyzed. Two replicates of all samples, field blanks, and process blanks were analyzed with triple analyses occurring within the instrument. A total of 22 samples and 4 standards were analyzed for each run.

Charge Balance of Analytes

The analyses performed on water samples were assessed by performing a charge balance between anions and cations. Data from field and laboratory measurements were combined with inorganic carbon (IC) data from the TOC analyses. The IC concentrations were converted to total alkalinity and then to equivalent concentrations of bicarbonate ions (HCO_3^-) (Adams, 2005). Then, the data needed to complete a charge balance were compiled using the following relationships:

Total Alkalinity (as $CaCO_3$) = IC mg/L / Conversion Factor

1 mg/L alkalinity as $CaCO_3$ = 1.22 mg/L as HCO_3^-

Table 5 provides an example how a mass balance was calculated.

Table 5. Sample calculation of charge balance.

Cations	Concentration (mg/L)	meq/L	Anions	Concentration (mg/L)	meq/L
Ca^{+2}	26.2	1.3	HCO_3^-	120.6	2.0
Fe^{+2}	0.4	0.0	Cl^-	17.2	0.5
K^+	3.4	0.1	SO_4^{-2}	30.8	0.6
Mg^{+2}	6.5	0.5			
Na^+	32.3	1.4			
	Total	**3.3**		**Total**	**3.1**

A charge balance of the water quality parameters monitored at RS 100229 (CWR #1) is summarized in Table 6. Similar charge balances were performed for each of the sites where water quality was monitored.

Tables 7 through 9 summarize the charge balances for each reach of the upper Walker River. A threshold level of 10% difference was designated as the level representing a reduction in the level of confidence associated with laboratory analyses. All laboratory analyses were examined except those which experienced instrumentation problems with the ion chromatograph (IC) (i.e., WWR #3 for 9-23-07 and all sites for 3-22-08). Seven reconciliations out of a total of 98 exceeded the threshold level of 10%. Five of these occurred during the first two months of sampling after which duplicate samples were routinely analyzed using the IC (i.e., Cl^- and SO_4^{-2}) and TOC (i.e., IC, TC, and TOC) instruments. The maximum percent difference in mass balance analyses for the 2 remaining exceptions was a value of 13.7%. Overall, the data indicate improved analytical techniques and accuracies as the sampling period progressed.

Table 6. Charge balance for RS 100229 (CWR #1).

Date	Water Temp (°C)	pH	IC (mg/L)	Conversion Factor	Conv→$CaCO_3$ (mg/L)	Conv→HCO_3^- (mg/L)	Cl^{1-} (mg/L)	SO_4^{2-} (mg/L)	Ca^{+2} (mg/L)	Fe^{+2} (mg/L)	K^{+1} (mg/L)	Mg^{+2} (mg/L)	Na^{+1} (mg/L)	Σ Anions	Σ Cations	% ▲
7/24/2007	22.8	8.1	23.7	0.24	98.9	120.6	17.2	30.8	26.2	0.4	3.4	6.5	32.3	3.1	3.4	3.8
8/21/2007	20.5	8.2	28.8	0.24	119.9	146.2	22.9	49.2	32.2	0.2	4.4	7.6	46.2	4.1	4.4	3.5
9/23/2007	12.6	8.1	31.2	0.24	130.0	158.5	12.6	31.8	29.0	0.6	4.0	7.0	33.9	3.6	3.6	0.0
10/26/2007	10.4	8.1	33.2	0.24	138.4	168.9	22.4	45.5	35.6	0.3	4.6	8.6	47.0	4.3	4.7	3.4
11/23/2007	3.1	8.1	33.2	0.25	132.7	161.9	26.8	48.2	37.8	0.2	4.1	9.0	49.2	4.4	4.9	5.0
12/21/2007	2.8	7.9	35.7	0.25	142.6	174.0	28.0	55.6	43.5	0.5	4.8	10.5	55.7	4.8	5.6	7.6
1/26/2008	5.2	7.8	35.0	0.25	139.8	170.6	24.8	48.9	40.5	0.8	4.6	9.9	49.1	4.5	5.1	6.2
2/23/2008	5.7	8.3	34.1	0.24	142.0	173.3	23.3	58.0	40.6	0.5	4.1	9.9	47.4	4.7	5.0	3.3
3/22/2008	12.5	8.1	30.7	0.24	127.8	156.0	Eqp	44.9	34.4	3.1	4.7	8.7	42.8	n/a	4.6	n/a
4/26/2008	19.9	8.3	27.0	0.24	112.4	137.1	19.5	39.4	29.2	0.8	4.2	7.5	34.4	3.6	3.7	1.2
5/22/2008	14.6	7.9	15.3	0.25	61.3	74.8	7.7	12.5	16.2	3.0	2.5	4.9	13.4	1.7	2.0	7.1
6/22/2008	22.9	8.4	17.9	0.24	74.7	91.1	7.1	14.9	17.9	1.1	2.5	4.9	17.3	2.0	2.2	3.5

Table 7. Charge balance summary for sampling sites along the CWR.

	CWR #1			CWR #2			CWR #3		
Date	Σ Anions	Σ Cations	% ▲	Σ Anions	Σ Cations	% ▲	Σ Anions	Σ Cations	% ▲
7/24/2007	3.1	3.4	3.8	3.4	3.7	4.4	4.1	4.6	5.4
8/21/2007	4.1	4.4	3.6	3.9	4.2	3.8	3.9	4.5	7.3
9/23/2007	3.6	3.6	0.0	3.7	3.8	1.3	2.9	3.9	13.7
10/26/2007	4.3	4.7	3.4	4.3	4.7	3.8	4.4	4.8	4.2
11/23/2007	4.4	4.9	5.0	4.4	4.9	4.7	5.0	5.6	5.4
12/21/2007	4.8	5.6	7.6	4.1	4.8	8.0	4.5	5.3	9.1
1/26/2008	4.5	5.1	6.2	4.2	4.8	6.6	4.6	5.6	10.0
2/23/2008	4.7	5.0	3.3	4.6	5.1	4.6	5.0	5.5	4.3
3/22/2008	n/a	4.5	n/a	n/a	4.4	n/a	n/a	5.5	n/a
4/26/2008	3.6	3.7	1.4	3.6	3.8	1.8	4.0	4.3	3.1
5/22/2008	1.7	2.0	7.1	1.8	2.0	7.1	2.4	2.6	5.3
6/22/2008	2.0	2.2	3.5	2.2	2.3	3.1	2.9	3.1	2.6

Table 8. Charge balance summary for sampling sites along the EWR.

	EWR #1			EWR #2			EWR #3		
Date	Σ Anions	Σ Cations	% ▲	Σ Anions	Σ Cations	% ▲	Σ Anions	Σ Cations	% ▲
7/24/2007	1.6	2.5	22.4	2.2	2.8	11.1	3.0	4.1	15.7
8/21/2007	2.3	2.4	3.3	2.7	2.8	0.8	3.1	3.3	2.9
9/23/2007	1.9	2.3	8.7	2.5	2.7	4.1	2.7	2.9	3.3
10/26/2007	2.2	2.3	2.7	2.8	3.0	3.1	3.2	3.4	3.1
11/23/2007	2.2	2.4	3.7	2.9	3.2	5.5	3.3	3.6	5.0
12/21/2007	2.3	2.8	9.5	2.4	3.0	9.4	2.6	3.3	12.3
1/26/2008	2.5	2.9	8.0	2.8	3.3	9.4	3.0	3.6	10.0
2/23/2008	2.9	3.1	4.0	3.2	3.3	2.9	3.2	3.5	4.6
3/22/2008	n/a	3.8	n/a	n/a	3.9	n/a	n/a	4.0	n/a
4/26/2008	2.5	2.6	1.2	3.0	3.1	0.3	3.3	3.4	1.5
5/22/2008	2.5	2.5	0.1	2.6	2.9	5.9	2.8	3.1	5.4
6/22/2008	2.3	2.4	2.1	2.5	2.7	3.8	2.7	2.8	2.6

Table 9. Charge balance summary for sampling sites along the WWR.

	WWR #1			WWR #2			WWR #3		
Date	Σ Anions	Σ Cations	% ▲	Σ Anions	Σ Cations	% ▲	Σ Anions	Σ Cations	% ▲
7/24/2007	1.9	1.5	11.1	2.7	2.8	1.0	3.5	3.9	5.6
8/21/2007	1.3	1.6	11.6	3.9	3.3	8.8	4.9	4.9	0.4
9/23/2007	1.5	1.5	1.0	3.5	3.7	2.7	n/a	4.4	n/a
10/26/2007	1.6	1.5	1.9	4.2	4.5	3.7	4.9	5.2	3.7
11/23/2007	1.5	1.6	3.5	4.3	4.6	3.0	4.5	5.0	5.6
12/21/2007	1.4	1.7	8.9	5.5	6.6	9.6	6.0	7.0	7.5
1/26/2008	1.5	1.6	1.8	5.0	5.8	7.2	5.5	6.1	5.2
2/23/2008	1.5	1.6	3.5	5.8	6.3	4.3	6.1	6.5	3.5
3/22/2008	n/a	1.6	n/a	n/a	4.6	n/a	n/a	5.1	n/a
4/26/2008	1.7	1.6	1.6	3.3	3.3	0.6	3.6	3.7	1.3
5/22/2008	1.3	1.3	1.1	1.7	2.0	7.8	1.6	1.9	6.5
6/22/2008	1.1	1.1	0.4	1.7	1.8	1.0	1.9	2.0	3.3

Sediment Gradations and Classifications

Particle size distribution can be used to characterize the morphological differences between sand bed streams and gravel bed streams (Garcia, 2008). Alluvial rivers can be broadly classified into two types: sand bed streams and gravel bed streams (Garcia, 2008). A sand-bed stream generally has a median size d_{50} of the surface material or substrate which is less than 2 mm (Garcia, 2008). In most cases, the median bed sediment size for sand bed streams is between 0.1 mm and 1 mm. Gravel bed streams typically have values of median size of the bed sediment exposed on the surface of 15 mm to 200 mm or larger; the substrate is usually finer by a factor of 1.5 to 3. Sand bed streams are in the transition region between smooth and hydraulically rough conditions while gravel bed streams are always hydraulically rough (Garcia, 2008).

The characteristics of the sediment samples which were collected from several locations along the upper Walker River are summarized in Table 10. Samples were collected from four locations along East Walker River, three locations along West Walker River, and four locations along combined Walker River in an attempt to broadly characterize the properties of the river sediments. At each location the sediments were collected from the bed surface in the center of the main channel. There was no armor layer in the channel at the locations where these samples were collected.

Table 10. Summary of sediment classifications.

River Station	d_{84} (mm)	d_{60} (mm)	d_{50} (mm)	d_{10} (mm)	Uniformity Coefficient (d_{60}/d_{10})	Remarks
100229 (CW)	4.00	0.76	0.60	0.18	4.22	Well sorted sand.
83976 (CW)	23.00	11.30	7.20	0.65	17.38	Poorly sorted gravel sand.
72451 (CW)	4.60	1.60	1.20	0.26	6.15	Moderately sorted sandy gravel.
49536 (CW)	3.30	1.70	1.40	0.52	3.27	Well sorted sandy gravel.
Average	3.97	1.35	1.07	0.32		
120799 (EW)	10.00	4.00	2.60	0.35	11.43	Poorly sorted sandy gravel.
136167 (EW)	12.50	4.40	2.90	0.55	8.00	Moderately sorted sandy gravel.
168046 (EW)	8.90	4.60	3.20	0.43	10.70	Poorly sorted sandy gravel.
191905 (EW)	9.00	4.20	2.90	0.43	9.77	Moderately to poorly sorted sandy gravel.
Average	10.10	4.30	2.90	0.44		
113443 (WW)	4.80	2.40	1.80	0.40	6.00	Moderately sorted sandy gravel.
141639 (WW)	4.80	2.50	1.80	0.29	8.62	Moderately sorted sandy gravel.
188746 (WW)	22.00	4.30	1.80	0.28	15.36	Poorly sorted sandy gravel.
Average	4.80	3.07	1.80	0.32		

The customary engineering representation of the grain size distributions of the sediment samples were determined by performing standard sieve analyses (Das, 1990; Garcia, 2008). A representative grain size distribution curve is presented in Figure 15. Sediment samples were classified according to ASTM D- 2487 (ASTM, 1948). The uniformity coefficient is defined as d_{60}/d_{10} and is indicative of how well-sorted (poorly-graded) or poorly-sorted (well-graded) a sample of sediment is. In general, a poorly-sorted (well-graded) sample has a flatter, broader grain size distribution curve since a larger variety of particle sizes are present. In contrast, a well-sorted (poorly-graded) sample has a much steeper, narrower grain size distribution curve indicating that most are the particles are about the same size. Generally, a well-graded sediment has a uniformity coefficient greater than about 4 for gravels (Fetter, 2001; Das, 2002) and greater than 10 for sands (McCarthy, 2002). A uniform soil has a uniformity coefficient of less than about 5 (McCarthy, 2002).

X-ray diffraction analyses were performed for sediment samples collected from sampling locations RS 100229 (CWR #1), RS 49536 (CWR #2), RS 9895 (CWR #3), RS 120799 (EWR #3), RS 188746 (WWR #2), and RS 113443 (WWR #3). All samples were found to have major quartz and minor plagioclase and K feldspar.

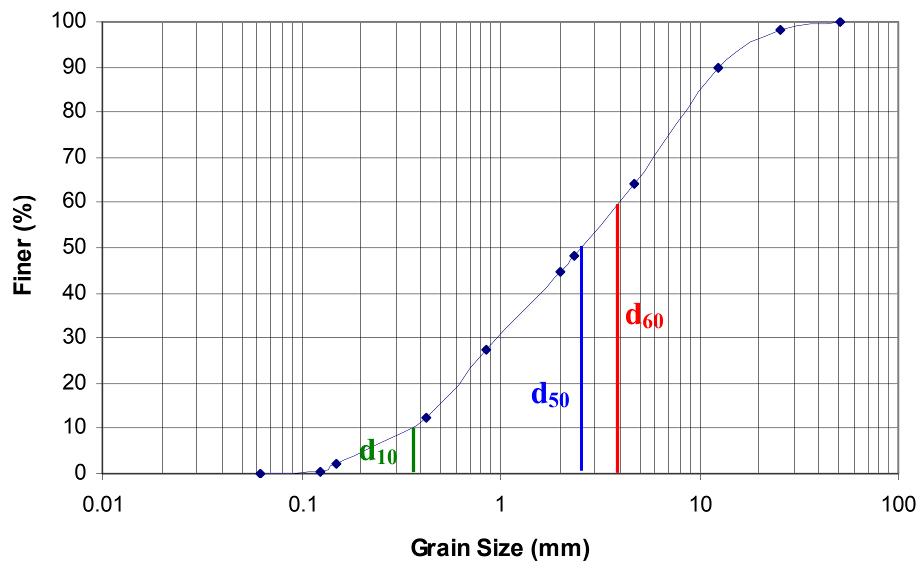

Figure 15. Sediment grain size distribution curve for CWR #3.

Sediment Transport using a Recirculating Flume

Sediment transport analyses were conducted using a 2.44 m (8 feet) long tilting, recirculating flume as shown in Figure 16 . A representative sample of sediment which was 1.22 m (4 feet) long x 5.08 cm (2 inches) wide x 5.08 cm (2 inches) deep was placed between two 0.61 m (2 feet) long x 5.08 cm (2 inches) wide x 5.08 cm (2 inches) deep blocks. The sump for the flume was filled with river water collected at the same location that the sediment sample was collected. After 5 minutes, baseline water quality parameters were measured including temperature (°C), electrical conductivity (µS/cm), TDS (g/L), and pH using the YSI. The slope of the flume was adjusted to the slope of the channel bottom at the sampling location as determined from field surveying measurements. The water level in the flume was established 4.45 cm (1-3/4 inches) higher than the surface of the saturated sediment prior to starting the flume pump. Once the pump was turned on, the weir was slowly removed and the flow was allowed to stabilize while the background particle measurements were recorded using a HACH 2200 PCX Particle Counter (PCX). The PCX was used as a means of indicating the onset of sediment transport by monitoring the concentrations of particles in suspension. Once the flow and background particle count measurements stabilized, the flow was gradually increased every 15 minutes in increments of ½ gallon per minute (gpm) up to the maximum flow of 30 gpm over the duration of each experiment. The PCX monitored particle concentrations every 10 seconds. The depth of flow was monitored throughout the duration of each experiment.

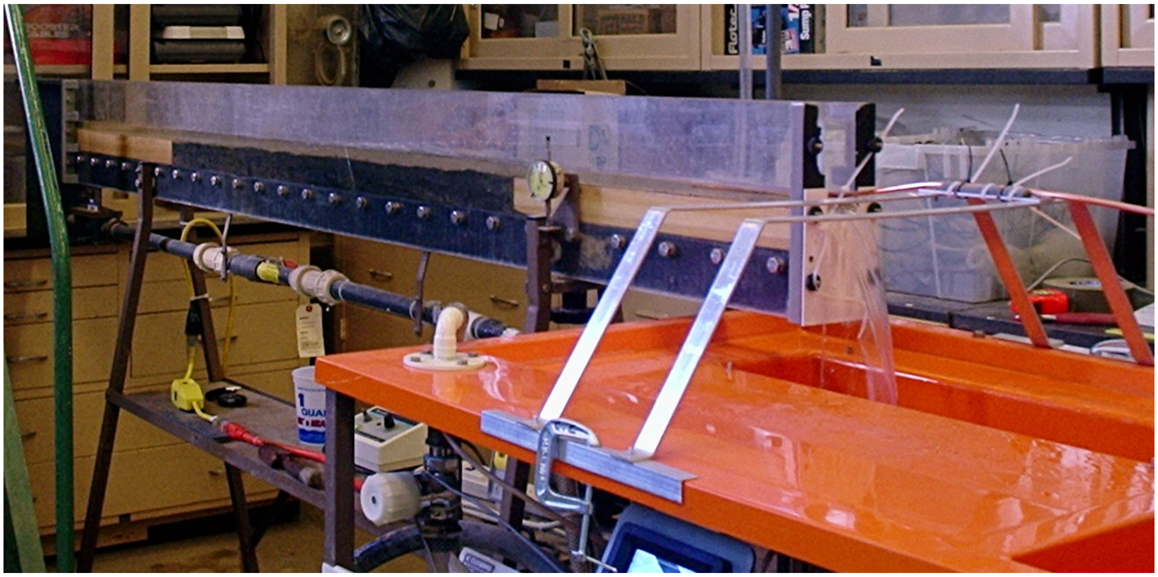

Figure 16. Recirculating, tilting flume.

Flume experiments were performed on sediment samples collected from six sampling locations. These included RS 100229 (CWR #1), RS 49536 (CWR #2), RS 9895 (CWR #3), RS 120799 (EWR #3), RS 188746 (WWR #2), and RS 113443 (WWR #3). The surface of the sediment bed at EWR #1, EWR #2, and WWR #1 were too hard to obtain samples of river bed sediments during the March 2008 sampling event.

A total of three flume experiments were performed for each sample location. The data from the three experiments were examined to determine when sediment transport was initiated. The threshold condition at which sediment transport begins may be described in terms of a critical velocity V_c or a critical shear stress τ_c (Sturm, 2001; Garcia 2008; Parker, 2008). The critical velocity V_c and the critical shear stress τ_c corresponding to the initiation of sediment transport for each sample location was then determined. Results of the flume experiments are summarized in Chapter 3.

RESULTS AND DISCUSSION

This chapter discusses the output of the HEC-RAS model that was developed for the upper Walker River. The primary objectives for the development of this model were:

1. to predict velocity profiles and characterize the hydrodynamic conditions along the river (e.g., determine the bed shear stresses under varying flow conditions);
2. to predict the potential for erosion and sediment transport and compare with results from laboratory flume studies; and
3. to identify the potential for localized flooding along the upper Walker River due to anticipated increases in flow.

This chapter also discusses the results of analytical work performed on water quality samples. This was followed by an analysis of historical water quality data and water quality data collected during this project. Maximum and minimum concentrations of various parameters were identified along with statistical trends of interest.

Application of the HEC-RAS Model for Various Flow Conditions

The HEC-RAS model was run for a variety of flow conditions including the most recent maximum flow recorded in 1997 flood event. The model predicted the bed shear stresses which were used to determine the potential for erosion and sediment transport along the upper Walker River. The model also predicted the depths of flow which were used to determine the potential for localized flooding due to overtopping of the stream banks.

Figures 17 and 18 summarize USGS flow data for 1997 for two locations along the East Walker River. The data in Figure 17 were collected along the upper reach of the East Walker River near Bridgeport, California. The data in Figure 18 were collected along the lower reach of the East Walker River near Mason, Nevada. As indicated in both figures, the most recent maximum flow event along the East Walker River which occurred in 1997 was approximately 2000 cubic feet per second (cfs). As shown in Figures 17 and 18, the maximum median daily flow, averaged over 84 and 44 years, respectively, was between 250 and 300 cfs for the East Walker River.

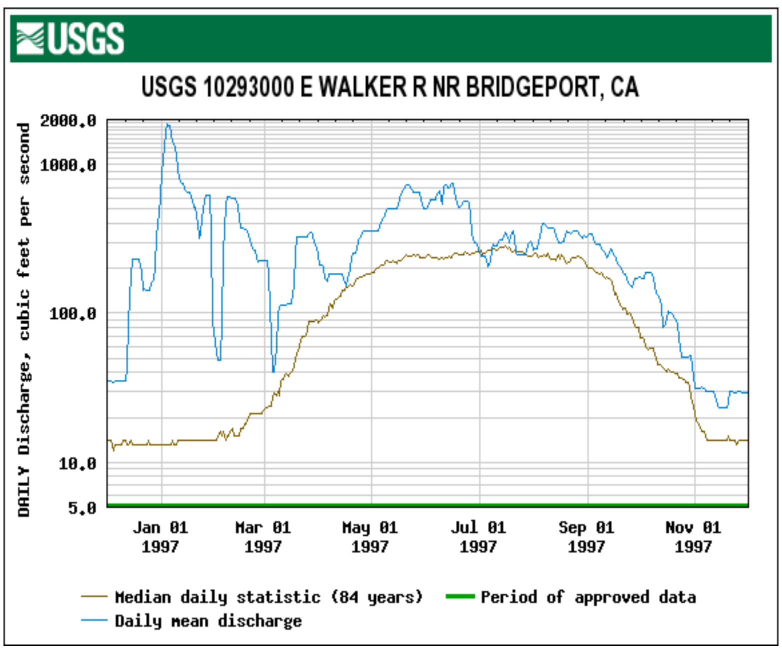

Figure 17. USGS flow data in 1997 for the east Walker River near Bridgeport, California (USGS, 2008).

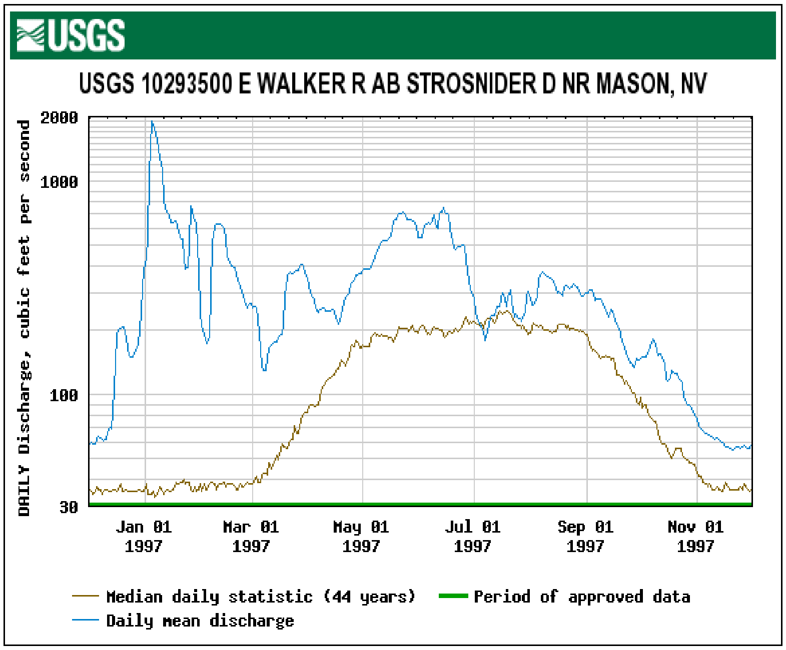

Figure 18. USGS flow data in 1997 for the east Walker River near Mason, Nevada (USGS, 2008).

Figures 19 and 20 summarize USGS flow data for 1997 for two locations along the West Walker River. The data in Figure 19 were collected along the West Walker River near Wellington, Nevada. The data in Figure 20 were collected along the lower reach of the West Walker River near Hudson, Nevada. As indicated in both figures, the most recent maximum flow event along the West Walker River which occurred in 1997 was approximately 4000 cubic feet per second (cfs). As shown in Figures 19 and 20, the maximum median daily flow, averaged over 61 and 54 years, respectively, was between 400 and 700 cfs for the West Walker River.

Figure 21 summarizes USGS flow data for 1997 collected along the combined Walker River near Wabuska, Nevada. The most recent maximum flow event along the mainstem occurred in 1997 and was approximately 2000 cubic feet per second (cfs). As shown in Figure 21, the maximum median daily flow, averaged over 83 years, was approximately 200 cfs for the combined Walker River. The maximum flow typically occurred during the month of June.

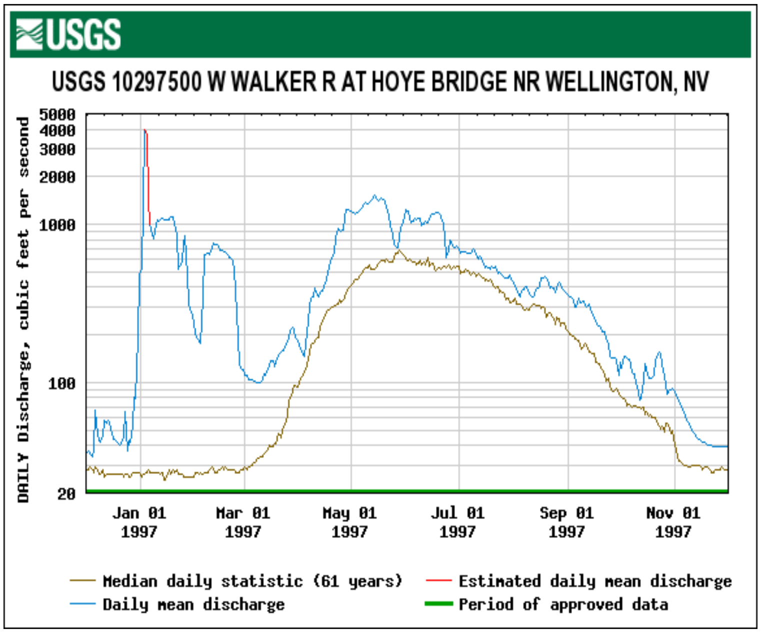

Figure 19. USGS flow data in 1997 for the west Walker River near Wellington, Nevada (USGS, 2008).

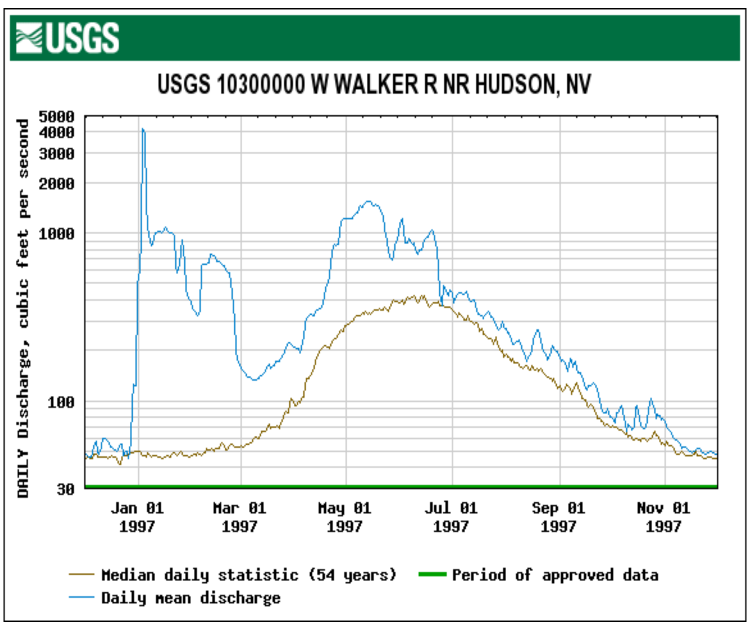

Figure 20. USGS flow data in 1997 for the west Walker River near Hudson, Nevada (USGS, 2008).

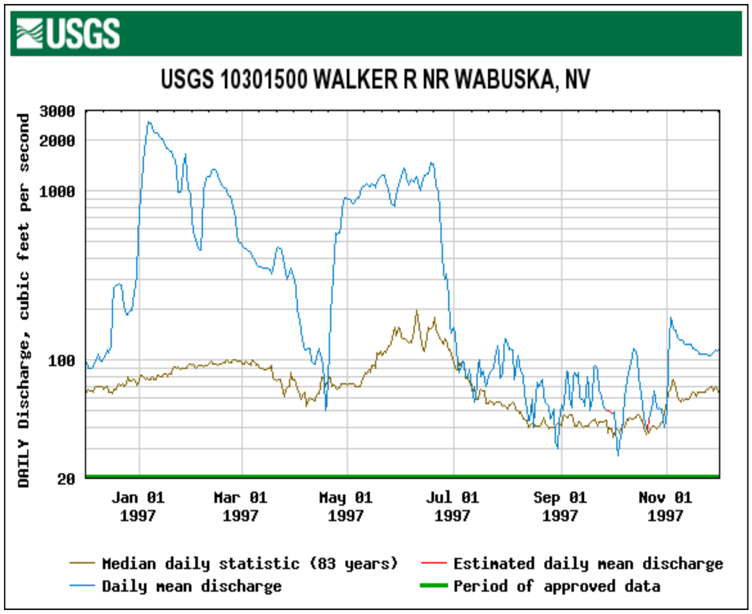

Figure 21. USGS flow data in 1997 for the combined Walker River near Wabuska, Nevada (USGS, 2008).

Incipient Motion Sediment Particle Size as an Indicator of Channel Stability

A number of methods were used to determine the susceptibility of the upper Walker River to erosion and sediment transport under varying flow conditions. The various methods were chosen following a review of techniques presented in current literature related to sediment transport (Garcia, 2008; Parker, 2008; Sturm, 2001). The selected methods included:

1. the calculation of incipient motion sediment particle size presented by Lagasse *et al.* (1995);
2. the determination of the Shields parameter (Brownlie, 1981) and the estimation of the critical bed shear stress (Garcia, 2008; Parker, 2008);
3. a comparison of sediment size to the size of rip rap required for a stable channel lining (Garcia, 2008); and
4. an analysis of the results of the laboratory flume experiments.

Lagasse *et al.* (1995) presented a method to estimate the potential for erosion by comparing the observed sizes of particles in the sediment samples with the calculated incipient motion sediment particle size D_c. The definition of incipient motion is based on the critical or threshold conditions where the hydrodynamic forces acting on one grain of sediment have reached a value that, if increased even slightly, will cause the grain to be transported. If the river sediment is composed of particles that are larger than D_c, the sediment would be considered to be stable with a lower potential for erosion.

The following expression for the incipient motion of sediment particle size D_c was derived from the Shields diagram and is considered appropriate for rivers with sand-sized particles in bed sediments (Lagasse *et al.*, 1995):

$$D_c = \frac{\tau}{0.047(\gamma_s - \gamma)} \qquad (2)$$

where: D_c = diameter of the sediment particle at incipient motion conditions (m)

τ = bed shear stress (N/m^2)

γ_s and γ = specific weights of sediment and water, respectively (N/m^3)

0.047 = dimensionless coefficient often referred to as the Shields parameter τ_c^*.

The incipient motion sediment particle size D_c was calculated for a range of flow conditions at each of the fourteen river stations selected for detailed analyses. The bed shear stresses τ predicted using the HEC-RAS model at each river station for the various flow conditions were used. The typical value for the specific weight of the sediment γ_s was 2.65. This was appropriate since the X-ray diffraction analyses indicated that the sediments were composed predominantly of quartz. A value of 0.047 was used for the dimensionless Shields parameter. Lagasse *et al.* (1995) indicated that the Shields parameter is not constant and that values may range from 0.02 to 0.10, depending on the sizes of sediment particles at the bed surface and within the subsurface. The use of 0.047 was considered appropriate since it generally provides reasonable results for channels having sand beds. This was considered appropriate for the upper Walker River since the sediments consisted mainly of quartz sand particles.

Figure 22a shows the variation in incipient motion sediment particle size over a range of flows for selected locations along the East Walker River. Figure 22b shows the variation in Froude numbers with the flows for the same locations along the East Walker River. Table 11 summarizes the predicted properties at RS 369600. At that location, it was observed that the incipient sediment particle size suddenly decreased when the flow increased from 25 cfs to 50 cfs. These variations were a result of the interrelationships between variations in depth, velocity, channel geometry, cross sectional area of flow, hydraulic radius, and bed shear stress. The incipient motion sediment size D_c is directly proportional to the bed shear stress τ. The reason for this was that the variation in channel geometry (*i.e.,* hydraulic radius R) resulted in a lower shear stress at a higher flow. As depicted in Figure 23 when the flow was 25 cfs, it was constricted to a relatively narrow, V-shaped portion of the channel. When the flow was increased to 50 cfs, the flow widened into a larger cross section of the channel as depicted in Figure 24. Also according to the Froude numbers predicted using the HEC-RAS model as shown in Table 11, the flow was essentially critical at 25 cfs and was subcritical at 50 cfs. Also, it was noted that the incipient motion sediment size for RS 369600 increased dramatically when the flow increased from 300 cfs to 400 cfs. The flow at 300 cfs was predicted to be subcritical while at 400 cfs it was predicted to be supercritical.

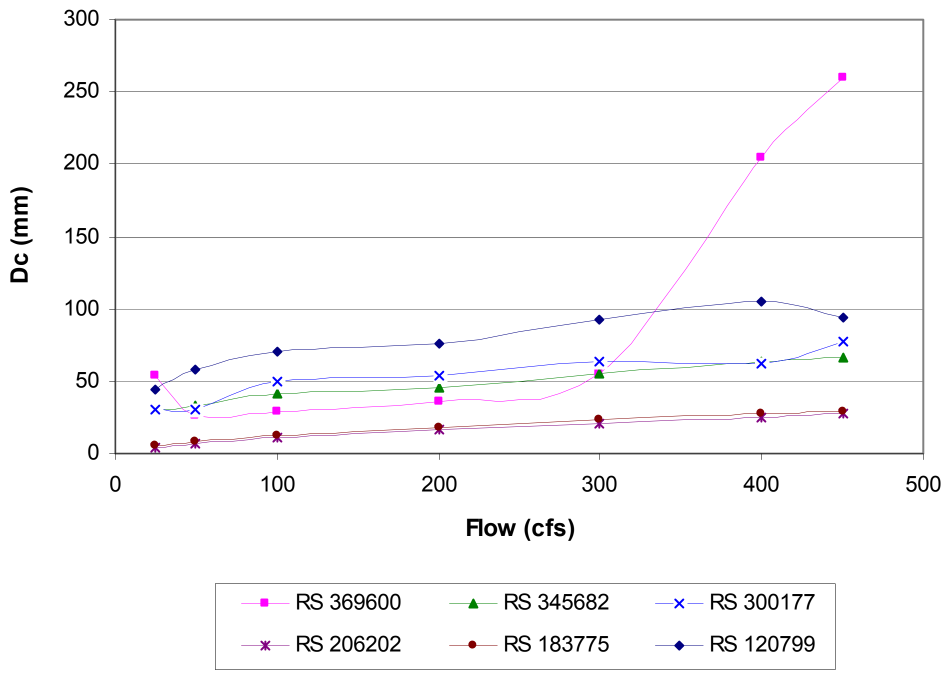

Figure 22a. Variation of incipient motion sediment size with flow along the east Walker River.

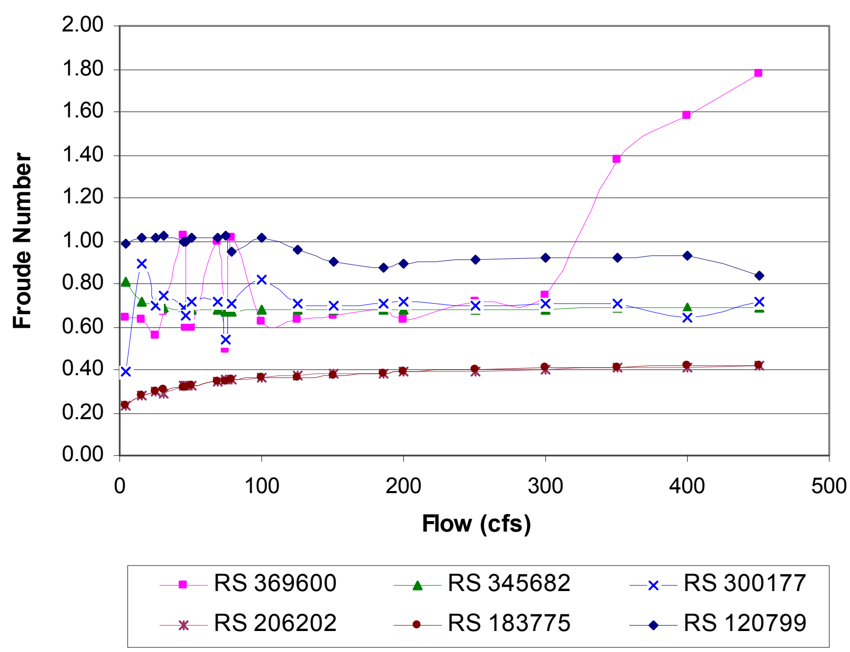

Figure 22b. Variation of Froude number with flow along the east Walker River.

Table 11. Predicted properties for RS 369600 along the east Walker River.

Flow *Q* (cfs)	**Depth *y* (ft)**	**Velocity *v* (fps)**	**Froude Number**	**Bed Shear Stress τ_b Predicted by HEC-RAS (psf)**	**Critical Particle Diameter *Dc* (mm)**
25	0.96	4.06	1.01	0.85	53.5
50	1.52	3.02	0.62	0.41	25.8
100	1.96	3.25	0.65	0.47	29.6
200	2.44	3.84	0.63	0.58	36.5
300	2.65	4.87	0.74	0.88	55.4
400	2.29	8.9	1.58	3.26	205.2

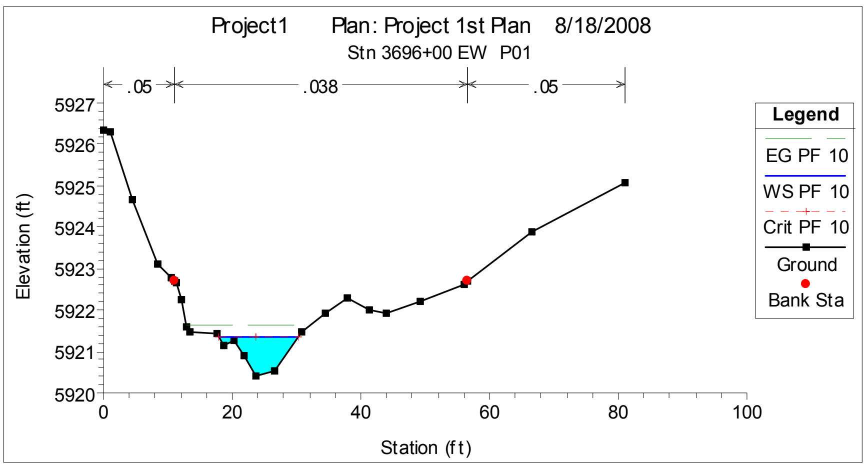

Figure 23. Water surface elevation at River Station 369600 for a flow of 25 cfs.

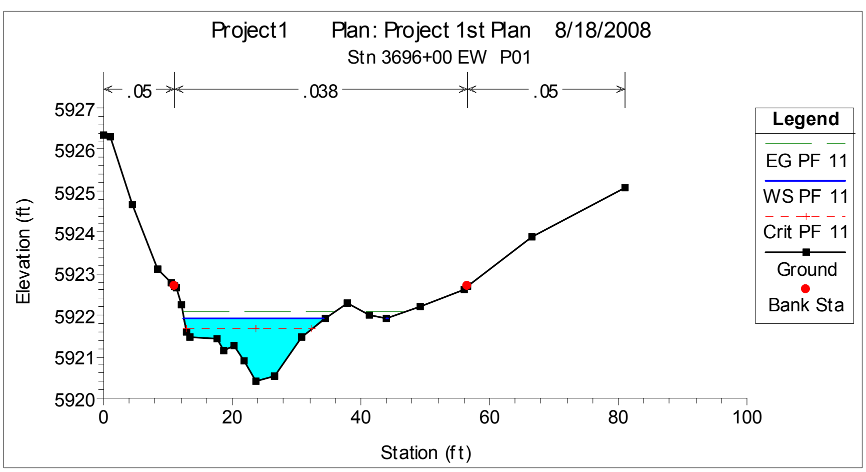

Figure 24. Water surface elevation at River Station 369600 for a flow of 50 cfs.

Results for the variations in incipient motion sediment particle size with the flow and variations in Froude numbers for locations along the West Walker River are included in Figures 25a and 25b, respectively.

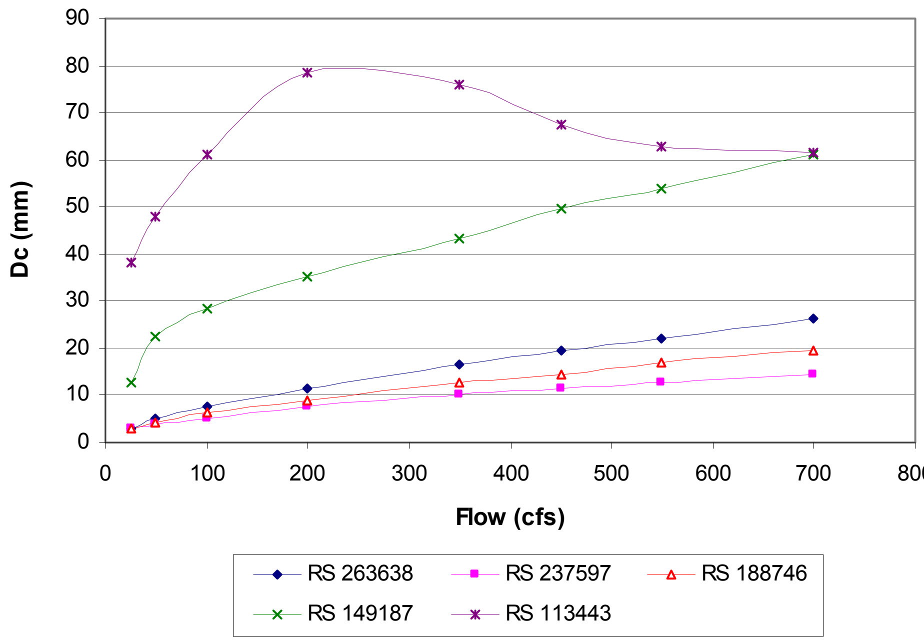

Figure 25a. Variation of incipient motion sediment size with flow along the west Walker River.

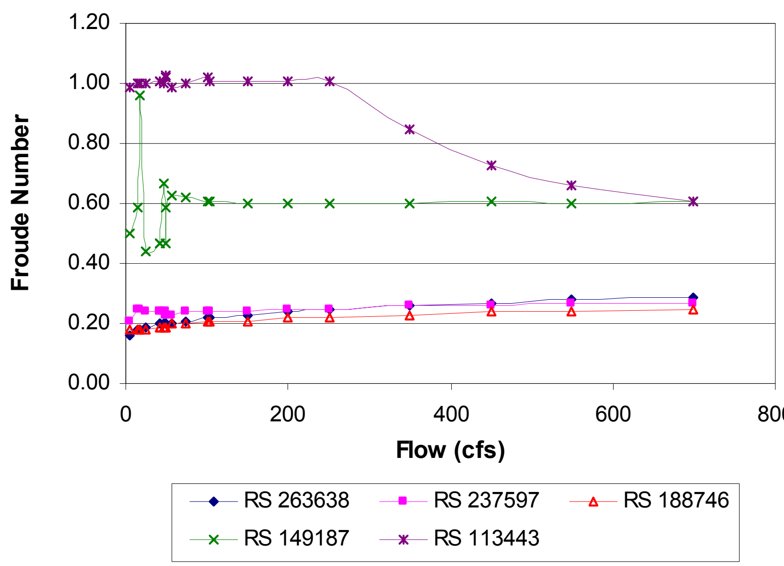

Figure 25b. Variation of Froude number with flow along the west Walker River.

Table 12 summarizes the predicted properties for RS 113443 along the West Walker River. At that location, the incipient sediment particle size gradually increased and then decreased as flows continued to increase as demonstrated in Figure 25a. Figure 25b demonstrates a corresponding trend in the values of the Froude number. These variations were a result of the interrelationships between variations in depth, velocity, channel geometry, cross sectional area of flow, hydraulic radius, and bed shear stress.

Table 12. Calculated properties for RS 113443 along the west Walker River.

Flow Q (cfs)	**Depth y (ft)**	**Velocity v (fps)**	**Froude Number**	**Predicted Bed Shear Stress τ_b (psf)**	**Critical Particle Diameter D_c (mm)**
25	0.53	2.94	1.00	0.61	38.4
50	0.70	3.44	1.03	0.76	47.8
100	0.91	4.13	1.02	0.97	61.1
200	1.22	5.03	1.01	1.25	78.7
350	1.70	5.38	0.85	1.21	76.2
450	2.08	5.27	0.73	1.07	67.3
550	2.43	5.27	0.66	1.00	62.9
700	2.89	5.39	0.61	0.98	61.7

Results for the variation in incipient motion sediment particle size with flow and variations in Froude numbers for locations along the combined Walker River are included in Figures 26a and 26b, respectively. Table 13 summarizes the predicted properties for RS 9895 along the combined Walker River. At that location, both the incipient motion particle size and the Froude number increased as flows increased. Again, these variations were a result of the interrelationships between variations in depth, velocity, channel geometry, cross sectional area of flow, hydraulic radius, and bed shear stress.

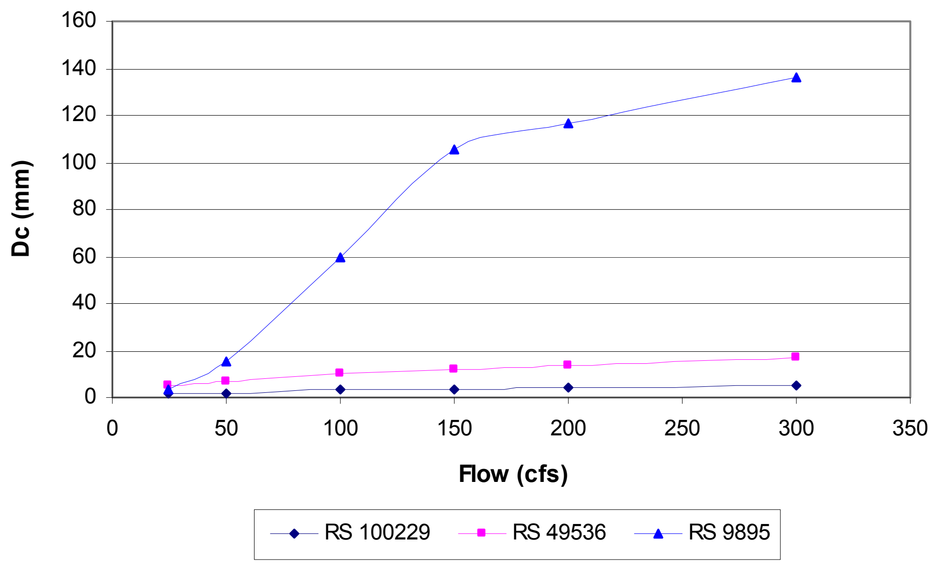

Figure 26a. Variation of incipient motion sediment size with flow along the combined Walker River.

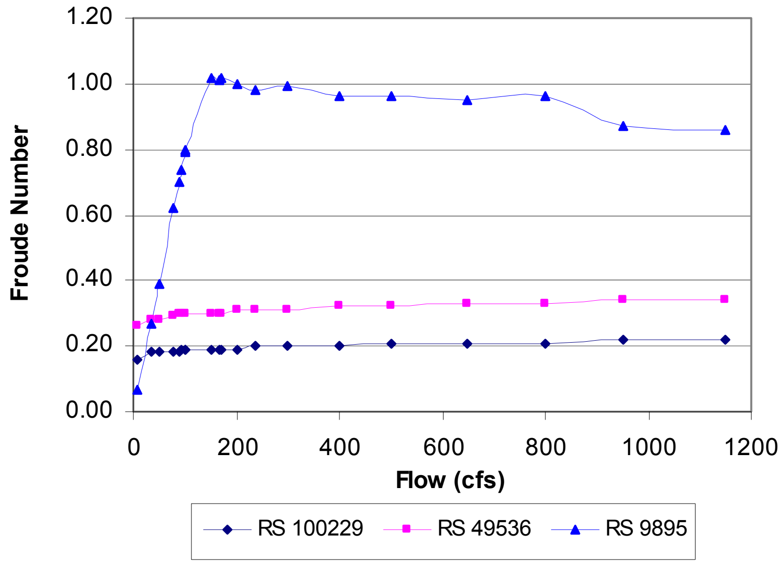

Figure 26b. Variation of Froude number with flow along the combined Walker River.

Table 13. Calculated properties for RS 9895 along the combined Walker River.

Flow Q (cfs)	**Depth y (ft)**	**Velocity v (fps)**	**Froude Number**	**Predicted Bed Shear Stress τ_b (psf)**	**Critical Particle Diameter D_c (mm)**
25	2.18	1.06	0.20	0.06	3.8
50	2.18	2.11	0.39	0.24	15.1
100	2.18	4.23	0.79	0.94	59.2
150	2.27	5.73	1.02	1.67	105.1
200	2.49	6.23	1.00	1.85	116.4

In general, the calculated incipient motion sizes were typically an order of magnitude larger than the mean sediment size at most of the locations in the Upper Walker River. This indicated that the bed sediments were unstable and suggested that erosion and sediment transport was anticipated.

Shields Parameter as an Indicator of Channel Stability

Parker (2008) summarized the findings of Buffington and Montgomery (1997) who reviewed eight decades of incipient motion data, with a special emphasis on gravel-bed rivers. They concluded that the majority of the data (laboratory and field) generally followed the overall relationship defined by the Shields diagram and the modified Shields diagram which uses the critical Shields parameter proposed by Brownlie (1981). Observations by Neill (1968), Neill and Yalin (1969), Gessler (1970) and Gessler (1971) indicated that values for initiation of motion of coarse material determined using the original Shields diagram were too high and suggested modifications. Accordingly, Garcia (2008) and Parker (2008) suggested that the expression proposed by Brownlie (1981) should be divided by 2 to define a lower boundary of the modified Shields diagram that is more consistent with observed data from Buffington and Montgomery (1997) for streams having d_{50} greater that 1 mm. The resulting values were found to be more relevant for engineering applications (Garcia, 2008). In a similar but smaller overview of the methods used for predicting incipient motion in sand bed streams, Marsh *et al.* (2004) also considered the Shields diagram as one of the best methods after comparing it along with three other methods (Garcia, 2008). In summary, Garcia (2008) indicated that there is sufficient evidence to conclude that the Shields diagram is quite useful for field application.

As indicated above, Brownlie (1981) proposed a useful fit to the Shields data based on the properties of the water and sediment and the particle Reynolds number R_{ep}. The particle Reynolds number R_{ep} may be determined from the expression:

$$R_{ep} = \frac{\sqrt{gRD}}{\nu} D \qquad (3)$$

where: R_{ep} = particle Reynolds number

$R = (\rho_s - \rho)/\rho$ = submerged specific gravity of the sediment

g = gravitational acceleration

D = mean sediment diameter d_{50}

ν = kinematic viscosity of the water

The Shields parameter τ_c^*, which is a dimensionless measure of bed shear stress, can be estimated using the expression (Brownlie, 1981):

$$\tau_c^* = 0.22 R_{ep}^{-0.6} + 0.06 \exp(-17.77 R_{ep}^{-0.6}) \qquad (3a)$$

τ_c^* = critical Shields parameter

R_{ep} = particle Reynolds number

In Figure 27, the results obtained for eleven sediment samples from the upper Walker River are shown on the modified Shields diagram (Garcia, 2008). In accordance with the recommendations made by Garcia (2008) and Parker (2008), the values of the critical Shields parameter τ_c^* given by Equation 3a were divided by 2 for engineering purposes resulting in the expression:

$$\tau_c^* = \frac{1}{2}\left(0.22 R_{ep}^{-0.6} + 0.06 \exp(-17.77 R_{ep}^{-0.6})\right) \qquad (3b)$$

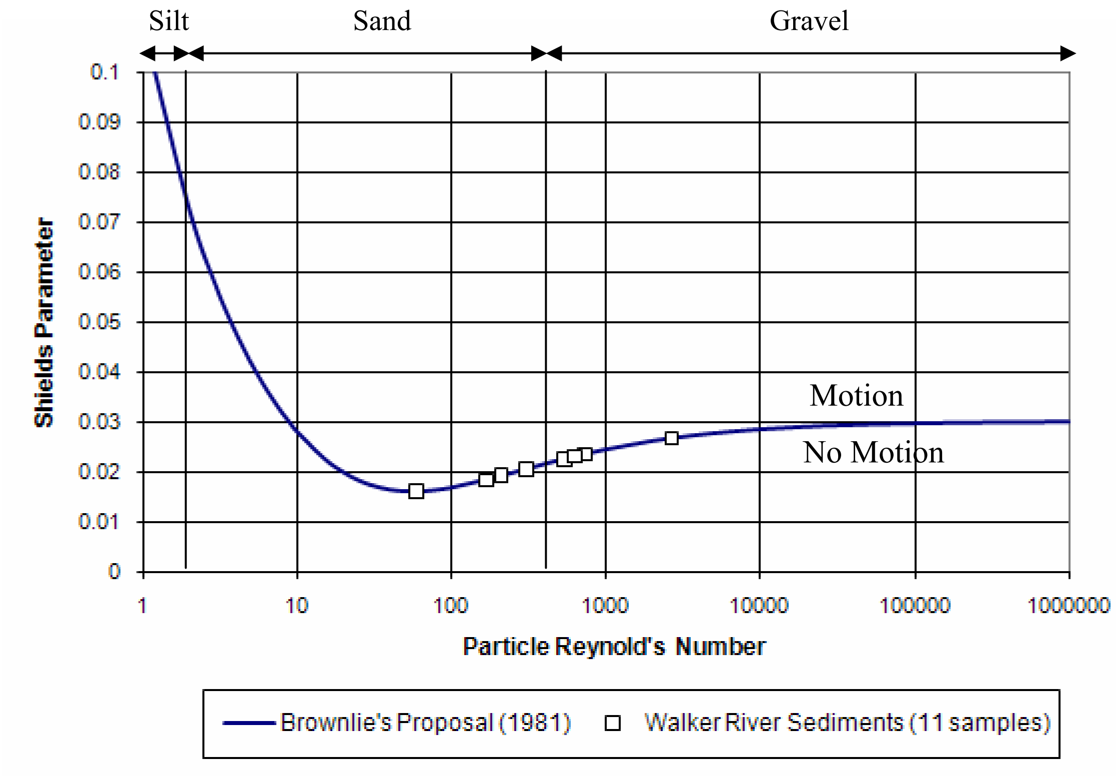

Figure 27. Characteristics of Walker River sediment on the modified shields diagram (in Garcia, 2008).

By applying Equation 3b, the modified Shields curve was used to estimate the values of the critical Shields parameter τ_c^* for each of the sediment samples collected from the upper Walker River. The results indicated that the sediments found in these portions of the upper Walker River consisted mainly of particles in the size range of sand and gravel.

Critical Bed Shear Stress as an Indicator of Channel Stability

The critical bed shear stress τ_{bc} for initiation of sediment motion is related to the critical Shields parameter τ_c^* by the expression:

$$\tau_c^* = \frac{\tau_{bc}}{\rho g R D} \qquad (4)$$

where: τ_{bc} = the critical bed shear stress

$R = (\rho_s - \rho)/\rho$ = the submerged specific gravity of the sediment

D = the mean sediment diameter d_{50}

g = gravitational acceleration

ρ = the density of the water

Using Equation 3b to determine values of the critical Shields parameter τ_c^*, the critical bed shear stress τ_{bc} was calculated using Equation 4 for eleven locations where sediment samples were collected along the upper Walker River. The calculated critical bed shear stresses τ_{bc} were then compared to the bed shear stresses τ_b predicted by the HEC-RAS model at each location. If the predicted bed shear stress was greater than the calculated critical bed shear stress at any given location, then the sediment was considered more susceptible to erosion.

Tables 14 through 16 summarize the bed shear stresses predicted by the HEC-RAS model compared with the critical bed shear stresses calculated using the modified Shields parameter. The results indicated that erosion and sediment transport was expected at essentially every location, even under flow conditions as low as 25 cfs. These findings were confirmed by visual observations of active sediment transport in the field even at relatively low flow conditions.

Table 14. Summary of predicted bed shear stresses and calculated critical bed shear stresses along the east Walker River.

Flow (cfs)	**RS 191905**		**RS 168046**		**RS 136167**		**RS 120799**	
	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)
25	0.11	0.039	0.07	0.0045	0.07	0.051	0.71	0.045
50	0.14	0.039	0.10	0.0045	0.09	0.051	0.92	0.045
100	0.18	0.039	0.13	0.0045	0.14	0.051	1.11	0.045
200	0.26	0.039	0.18	0.0045	0.21	0.051	1.21	0.045
300	0.33	0.039	0.23	0.0045	0.26	0.051	1.47	0.045

Table 15. Summary of predicted bed shear stresses and calculated critical bed shear stresses along the west Walker River.

Flow (cfs)	**RS 188746**		**RS 141639**		**RS 113443**	
	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)
25	0.05	0.043	0.20	0.025	0.61	0.025
50	0.07	0.043	0.80	0.025	0.76	0.025
100	0.10	0.043	0.99	0.025	0.97	0.025
200	0.14	0.043	1.29	0.025	1.25	0.025
350	0.20	0.043	1.61	0.025	1.21	0.025
450	0.23	0.043	1.84	0.025	1.07	0.025
550	0.27	0.043	1.86	0.025	1.00	0.025
700	0.31	0.043	2.12	0.025	0.98	0.025

Table 16. Summary of predicted bed shear stresses and calculated critical bed shear stresses along the combined Walker River.

Flow (cfs)	**RS 100229**		**RS 83976**		**RS 72451**		**RS 49536**	
	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)	Predicted Bed Shear Stress τ_b (psf)	Calculated Critical Bed Shear Stress τ_{bc} (psf)
25	0.03	0.006	0.08	0.137	0.04	0.015	0.08	0.018
50	0.03	0.006	0.07	0.137	0.06	0.015	0.11	0.018
100	0.05	0.006	0.10	0.137	0.10	0.015	0.16	0.018
150	0.06	0.006	0.13	0.137	0.12	0.015	0.19	0.018
200	0.07	0.006	0.15	0.137	0.15	0.015	0.22	0.018

Required Rip Rap Diameter as an Indicator of Channel Stability

In order to stabilize a channel bed and reduce the potential for erosion, a layer of rip rap is often installed. The required diameter of the rip rap (D_{RR}) needed to ensure channel stability can be determined using the methods summarized by Garcia (2008). If the mean size d_{50} of the particles in a sediment sample was greater than the calculated required size of the rip rap D_{RR}, the channel would be expected to be stable.

By combining the Manning-Strickler relation for flow resistance with the critical condition for motion of the coarse material composing the rip rap, the following expression was obtained (Garcia, 2008):

$$\frac{U}{\sqrt{RgD_{RR}}} = 8.1\left(\tau_c^*\right)^{1/2} \alpha_s^{-1/6} \left(\frac{H}{D_{RR}}\right)^{1/6} \qquad (5)$$

where: U = mean flow velocity

H = depth of flow

D_{RR} = riprap size

R = submerged specific gravity of the sediment

g = gravitational acceleration

Using τ_c^* = 0.03 and α_s = 3.3 (Neill, 1968; Garcia, 2008), the above expression was used to calculate D_{RR} and the results were compared with the values of d_{50} for the sediment gathered at each location.

Tables 17 through 19 summarize the results for the three separate locations along the combined Walker River. In order to ensure channel stability, the bed surface would need to be lined with rip rap having sizes equal to or larger than the calculated D_{RR}. In most cases, the particle sizes of the existing bed sediments are smaller than the calculated values of D_{RR}. Thus, it is anticipated that the existing sediments would be eroded and transported under the typical flow conditions in the combined Walker River.

Table 17. Rip rap size calculated for RS 100229 along the combined Walker River (d_{50} = 0.60 mm).

Flow Q (cfs)	Depth y (ft)	Velocity v (fps)	D_{RR} (mm)
25	1.09	0.74	0.3
50	1.41	0.91	0.5
100	1.87	1.11	0.9
150	2.19	1.29	1.2
200	2.47	1.43	1.6
300	2.95	1.66	2.3

Table 18. Rip rap size calculated for RS 49536 along the combined Walker River (d_{50} = 1.40 mm).

Flow Q (cfs)	Depth y (ft)	Velocity v (fps)	D_{RR} (mm)
25	1.05	1.13	1.2
50	1.34	1.46	2.3
100	1.75	1.87	4.3
150	2.04	2.11	5.7
200	2.29	2.31	7.0
300	2.71	2.64	9.6

Table 19. Rip rap size calculated for RS 9895 along the combined Walker River.

Flow Q (cfs)	Depth y (ft)	Velocity v (fps)	D_{RR} (mm)
25	2.18	1.06	0.7
50	2.18	2.11	5.5
100	2.18	4.23	44.1
150	2.27	5.73	107.4
200	2.49	6.23	131.8
300	2.87	7.04	177.2

Results of Laboratory Flume Studies to Evaluate Sediment Transport

Laboratory flume studies were performed using sediment samples and water samples collected from six locations along the upper Walker River. Samples were collected from one location along the East Walker River (EWR) at RS 120799. Samples were collected from two locations along the West Walker River (WWR) at RS 188746 and RS 113443. Samples were collected from three locations along the combined Walker River (CWR) at RS 9895, RS 49536, and RS 100229.

The flume experiments were performed three times for each location where sediment samples were collected. The objective of the flume experiments was to determine the critical velocity V_c and the critical bed shear stress τ_{bc} for each sediment sample. During the flume experiments, the flow was systematically increased in increments of ½ gpm over time intervals of 15 minutes. Once significant sediment transport was detected by the HACH PCX particle monitor, the velocity corresponding to the flow was indicative of the critical velocity V_c. An average critical velocity V_c was determined for each sediment sample by averaging the results obtained from the three consecutive flume experiments. The results for the flume experiments are summarized in Tables 20 through 25.

Table 20. Summary of flume experiments for sediment from RS 100229.

	Flow *Q* (m^3/s)	**Depth *y* (mm)**	**Velocity *v* (m/s)**	**Normalized Particle Count (>20μm)**
Run 1, 6/08/08				
	5.62E-07	34.00	0.15	0.64
	7.03E-07	34.50	0.18	0.47
	8.43E-07	35.00	0.21	0.80
	9.84E-07	37.00	0.23	0.65
	1.12E-06	39.00	0.25	0.58
	1.27E-06	40.50	0.28	0.40
Run 2, 6/17/08				
	4.22E-07	27.00	0.14	0.44
	4.92E-07	28.50	0.15	0.35
	7.03E-07	33.50	0.19	0.37
	8.43E-07	35.00	0.21	0.42
	9.84E-07	37.00	0.23	0.32
	1.12E-06	39.50	0.25	0.32
	1.27E-06	41.50	0.27	0.25
Run 3, 6/29/08				
	7.03E-07	31.50	0.20	0.37
	8.43E-07	34.00	0.22	0.34
	9.84E-07	36.50	0.24	0.33
	1.12E-06	38.50	0.26	0.37
	1.27E-06	41.00	0.27	0.38
	1.41E-06	43.00	0.29	0.32
	1.55E-06	45.00	0.30	0.36
Average:	**9.37E-07**		**0.23**	
Incipient		**$S_{\bar{X}}$ =**	**0.03**	
Motion		**RSD =**	**11.44%**	

(yellow)	Indicates conditions which initiated sediment transport

Table 21. Summary of flume experiments for sediment from RS 49536.

	Flow *Q* (m^3/s)	**Depth *y* (mm)**	**Velocity *v* (m/s)**	**Normalized Particle Count (>20µm)**
Run 1, 5/11/08				
	1.58E-04	22.50	0.14	0.88
	2.21E-04	25.00	0.17	1.08
	2.84E-04	27.50	0.20	1.52
	3.47E-04	30.00	0.23	2.89
	4.10E-04	31.50	0.26	1.12
Run 2, 5/13/08				
	1.58E-04	22.50	0.14	0.89
	2.21E-04	26.00	0.17	0.92
	2.84E-04	28.00	0.20	1.73
	3.47E-04	31.00	0.22	0.91
	4.10E-04	32.50	0.25	1.13
Run 3, 5/16/08				
	1.58E-04	23.00	0.13	0.65
	2.21E-04	25.50	0.17	0.74
	2.84E-04	28.50	0.20	2.78
	3.47E-04	31.00	0.22	2.18
	4.10E-04	33.00	0.24	1.71
Average:	**2.84E-04**		**0.20**	
Incipient		**$S_{\bar{X}}$ =**	**0.00**	
Motion		**RSD =**	**1.79%**	

	Indicates conditions which initiated sediment transport

Table 22. Summary of flume experiments for sediment from RS 9895.

	Flow Q (m^3/s)	**Depth y (mm)**	**Velocity v (m/s)**	**Normalized Particle Count (>20µm)**
Run 1, 6/6/08				
	9.84E-07	32.50	0.27	0.13
	1.12E-06	35.00	0.28	0.96
	1.27E-06	36.50	0.31	0.13
	1.41E-06	38.50	0.32	0.17
Run 2, 6/11/08				
	9.84E-07	33.00	0.26	0.40
	1.12E-06	35.00	0.28	0.43
	1.27E-06	37.00	0.30	0.49
	1.41E-06	39.00	0.32	0.62
	1.55E-06	40.00	0.34	0.66
	1.69E-06	43.00	0.35	0.87
	1.83E-06	44.00	0.37	0.89
	1.90E-06	46.00	0.36	0.66
Run 3, 6/18/08				
	7.03E-07	24.50	0.25	0.18
	8.43E-07	27.00	0.28	0.25
	9.84E-07	29.00	0.30	3.92
	1.12E-06	31.00	0.32	0.47
	1.27E-06	33.00	0.34	8.39
Average:	**1.27E-06**		**0.31**	
Incipient		**$S_{\bar{X}}$ =**	**0.03**	
Motion		**RSD =**	**10.51%**	

(yellow)	Indicates conditions which initiated sediment transport

Table 23. Summary of flume experiments for sediment from RS 120799.

	Flow *Q* (m^3/s)	**Depth *y* (mm)**	**Velocity *v* (m/s)**	**Normalized Particle Count (>20µm)**
Run 1, 6/9/08				
	4.22E-07	17.00	0.22	2.70
	5.62E-07	18.00	0.28	3.29
	7.03E-07	21.00	0.30	4.86
	8.43E-07	23.50	0.32	2.48
	9.84E-07	24.50	0.35	2.14
Run 2, 6/15/08				
	2.81E-07	13.50	0.18	5.99
	4.22E-07	14.50	0.26	10.25
	5.62E-07	15.50	0.32	8.85
	7.03E-07	17.00	0.37	8.52
	8.43E-07	18.00	0.41	14.13
	9.84E-07	19.00	0.46	10.14
	1.12E-06	20.00	0.50	8.87
	1.27E-06	21.50	0.52	7.86
	1.41E-06	24.00	0.52	42.90
Run 3, 6/28/08				
	2.81E-07	12.00	0.21	6.65
	4.22E-07	14.00	0.27	7.78
	5.62E-07	17.00	0.29	7.24
	7.03E-07	18.50	0.34	6.67
	8.43E-07	20.50	0.36	7.97
	9.84E-07	22.50	0.39	7.52
	1.12E-06	25.00	0.40	12.45
Average:	**5.15E-07**		**0.27**	
Incipient		**$S_{\bar{X}}$ =**	**0.02**	
Motion		**RSD =**	**7.42%**	

(yellow)	Indicates conditions which initiated sediment transport

Table 24. Summary of flume experiments for sediment from RS 188746.

	Flow *Q* (m^3/s)	**Depth *y* (mm)**	**Velocity *v* (m/s)**	**Normalized Particle Count (>20µm)**
Run 1, 5/27/08				
	1.05E-06	36.00	0.26	2.64
	1.19E-06	38.50	0.27	2.02
	1.34E-06	40.50	0.29	2.52
	1.55E-06	43.50	0.31	1.43
	1.62E-06	44.00	0.32	1.43
Run 2, 6/10/08				
	9.84E-07	33.00	0.26	0.68
	1.12E-06	35.50	0.28	0.69
	1.27E-06	37.50	0.30	1.82
	1.41E-06	38.50	0.32	1.60
	1.55E-06	41.00	0.33	1.74
Run 3, 6/18/08				
	9.84E-07	34.50	0.25	3.68
	1.12E-06	37.00	0.27	3.95
	1.27E-06	39.00	0.29	4.49
	1.41E-06	41.50	0.30	5.20
	1.55E-06	43.50	0.31	4.85
Average:	**1.29E-06**		**0.29**	
Incipient		**$S_{\bar{X}}$ =**	**0.01**	
Motion		**RSD =**	**1.97%**	

Indicates conditions which initiated sediment transport

Table 25. Summary of flume experiments for sediment from RS 113443.

	Flow Q (m^3/s)	Depth y (mm)	Velocity v (m/s)	Normalized Particle Count (>20µm)
Run 1, 6/7/08				
	9.84E-07	31.00	0.28	0.70
	1.12E-06	34.00	0.29	0.77
	1.27E-06	36.00	0.31	0.93
	1.41E-06	39.00	0.32	0.85
	1.55E-06	41.00	0.33	0.54
Run 2, 6/16/08				
	1.55E-06	43.50	0.31	0.26
	1.69E-06	45.00	0.33	0.20
	1.83E-06	48.00	0.34	0.67
	1.97E-06	49.50	0.35	0.23
	2.11E-06	52.50	0.35	0.21
Run 3, 6/19/08				
	1.27E-06	38.50	0.29	0.33
	1.41E-06	41.50	0.30	0.32
	1.55E-06	43.50	0.31	0.85
	1.69E-06	45.50	0.33	0.28
	1.83E-06	48.00	0.34	0.26
Average:	**1.55E-06**		**0.32**	
Incipient		**$S_{\bar{X}}$ =**	**0.01**	
Motion		**RSD =**	**4.38%**	

(yellow)	Indicates conditions which initiated sediment transport

As mentioned above, the main objective of the flume experiments was to determine the critical velocity V_c and the critical bed shear stress τ_{bc} for each sediment sample. The critical velocities V_c observed during the flume experiments can be used to determine the corresponding values of the critical Shields parameter τ^*_c by using the expressions summarized by Sturm (2001). According to Sturm (2001), the Keulegan equation can be applied for fully rough turbulent flows over sediment beds. The Keulegan equation is given by the expression:

$$V_c = 5.75\left(\sqrt{\tau_c^*(\gamma_s - 1)gd_{50}}\right)\log\left[\frac{12.2R}{k_s}\right] \quad (6)$$

where: V_c = the critical velocity which initiates sediment movement

τ^*_c = the critical Shields parameter

γ_s = the specific gravity of the sediment

R = the hydraulic radius

k_s = the equivalent grain size roughness.

The value of k_s was determined using two different approaches. Neill (1968) suggested that $k_s = 2d_{50}$ for gravel-bed streams. A second approach was based upon Sturm's (2001) compilation of work performed by Bathurst (1985), Dickman (1990), Limerinos (1970), and Thein (1993) which indicated that $k_s = 1.4d_{84}$ provided a best fit for experimental data collected for a number of gravel-bed streams.

Once the Shields parameter τ_{*c} was calculated by rearranging the Keulegan equation (Equation 6), the critical bed shear stress τ_{bc} could then be determined using the expression:

$$\tau_c^* = \frac{\tau_{bc}}{\rho g R D} \quad (7)$$

where: τ_{bc} = the critical bed shear stress

$R = (\rho_s - \rho)/\rho$ = the submerged specific gravity of the sediment

D = the mean sediment diameter d_{50}

g = gravitational acceleration

ρ = the density of the water

The estimated critical bed shear stresses τ_{bc} for the six locations where sediment was gathered for flume experiments are summarized in Tables 26 and 27. The particle Reynolds numbers R_{ep} observed during the flume experiments are also summarized in Tables 26 and 27. These magnitudes corresponded to turbulent flow conditions. The calculated values of the Shields parameter τ^*_c fall within the range of 0.020 to 0.056 with associated critical bed shear stresses τ_{bc} ranging from 0.007 to 0.030 psf when $k_s = 2.0d_{50}$. When $k_s = 1.4d_{84}$, τ_{*c} ranged from 0.03 to 0.09 and the associated critical bed shear stresses τ_{bc} ranged from 0.012 to 0.058 psf . These results are reasonably comparable to those shown in Tables 14 through 16.

Table 26. Calculation of critical bed shear stress for flume experiments with $k_s = 2d_{50}$.

River Station	V_c (m/s)	d_{50} (mm)	k_s (m)	Particle Reynolds Number (R_{ep})	Critical Shields Parameter (τ_{*c})	Critical Bed Shear Stress τ_{bc} (psf)
100229 (CW)	0.21	1.07	0.0021	107.3	0.02083	0.008
100229 (CW)	0.21	1.07	0.0021	110.2	0.02083	0.008
100229 (CW)	0.26	1.07	0.0021	111.0	0.03137	0.011
49536 (CW)	0.20	1.07	0.0021	104.0	0.01985	0.007
49536 (CW)	0.20	1.07	0.0021	103.3	0.01978	0.007
49536 (CW)	0.20	1.07	0.0021	102.8	0.01970	0.007
9895 (CW)	0.28	1.07	0.0021	114.5	0.03703	0.013
9895 (CW)	0.35	1.07	0.0021	106.4	0.05579	0.020
9895 (CW)	0.30	1.07	0.0021	111.5	0.04416	0.016
120799 (EW)	0.30	2.90	0.0058	480.8	0.03033	0.030
120799 (EW)	0.26	2.90	0.0058	479.0	0.02628	0.026
120799 (EW)	0.27	2.90	0.0058	480.5	0.02877	0.028
188746 (WW)	0.29	1.80	0.0043	268.7	0.02942	0.018
188746 (WW)	0.30	1.80	0.0043	241.2	0.03197	0.019
188746 (WW)	0.29	1.80	0.0043	243.3	0.02964	0.018
113443 (WW)	0.31	1.80	0.0043	260.0	0.03443	0.021
113443 (WW)	0.34	1.80	0.0043	238.2	0.03921	0.024
113443 (WW)	0.31	1.80	0.0043	236.4	0.03317	0.020

Table 27. Calculation of critical bed shear stress for flume experiments with $k_s = 1.4d_{84}$.

River Station	V_c (m/s)	d_{84} (mm)	k_s (m)	Particle Reynolds Number (R_{ep})	Critical Shields Parameter (τ_{*c})	Critical Bed Shear Stress τ_{bc} (psf)
100229 (CW)	0.21	3.97	0.0056	107.3	0.03384	0.012
100229 (CW)	0.21	3.97	0.0056	110.2	0.03384	0.012
100229 (CW)	0.26	3.97	0.0056	111.0	0.05073	0.018
49536 (CW)	0.20	3.97	0.0056	104.0	0.03271	0.012
49536 (CW)	0.20	3.97	0.0056	103.3	0.03254	0.012
49536 (CW)	0.20	3.97	0.0056	102.8	0.03238	0.012
9895 (CW)	0.28	3.97	0.0056	114.5	0.06016	0.022
9895 (CW)	0.35	3.97	0.0056	106.4	0.08975	0.032
9895 (CW)	0.30	3.97	0.0056	111.5	0.07250	0.026
120799 (EW)	0.30	10.10	0.0141	480.8	0.05846	0.057
120799 (EW)	0.26	10.10	0.0141	479.0	0.05369	0.053
120799 (EW)	0.27	10.10	0.0141	480.5	0.05918	0.058
188746 (WW)	0.29	4.80	0.0067	268.7	0.04143	0.025
188746 (WW)	0.30	4.80	0.0067	241.2	0.04515	0.027
188746 (WW)	0.29	4.80	0.0067	243.3	0.04180	0.025
113443 (WW)	0.31	4.80	0.0067	260.0	0.04870	0.030
113443 (WW)	0.34	4.80	0.0067	238.2	0.05489	0.033
113443 (WW)	0.31	4.80	0.0067	236.4	0.04659	0.028

In Figure 28, the averages of the particle Reynolds numbers and the critical Shields parameter for each set of flume experiments are shown on the modified Shields diagram (Garcia, 2008). Since all the data fall above the curve in the modified Shields diagram, this was consistent with the observation of active sediment transport during the flume experiments once the bed shear stress exceeded the critical bed shear stress (i.e., the observed Shields parameter exceeded the critical Shields parameter).

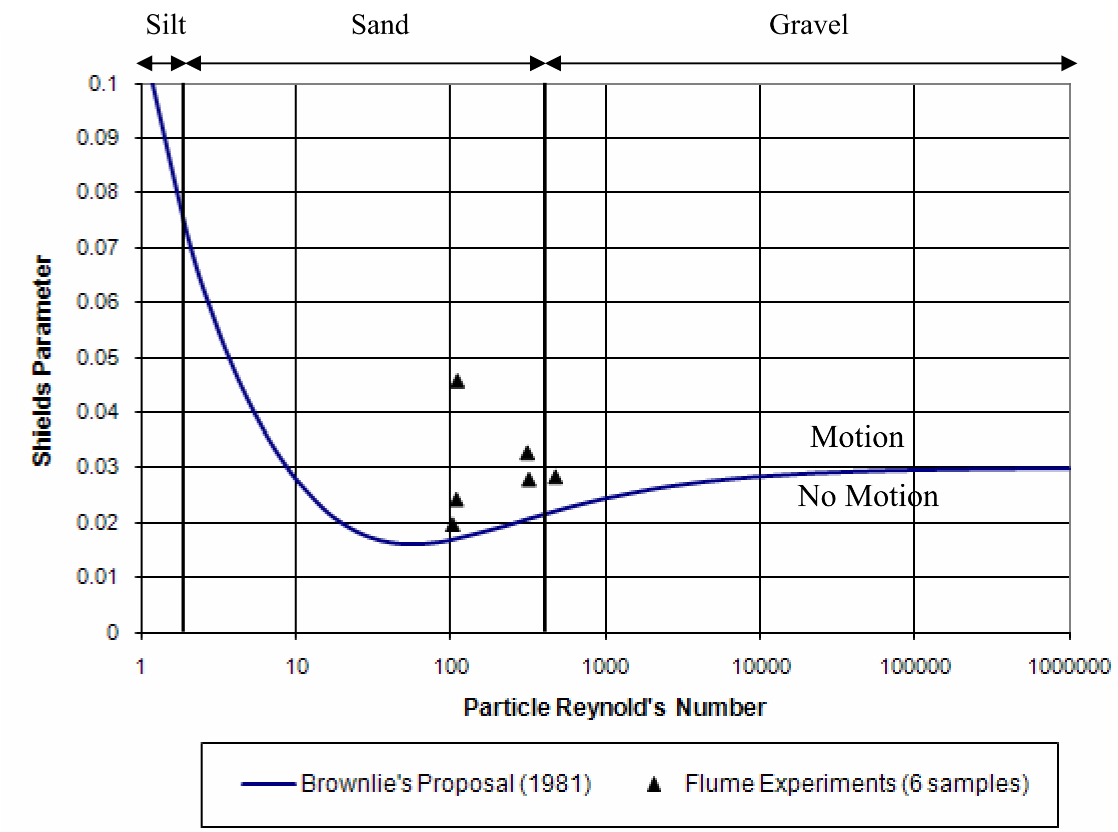

Figure 28. Characteristics of Walker River sediment on the modified shields diagram (in Garcia, 2008).

Cross Sections with Susceptibility to Flooding

In an attempt the predict the potential for flooding along the upper Walker River due to projected increases in flows associated with the acquisition of additional water rights and as a result of extreme flow events, the HEC-RAS model was run at a series of flows beginning at 125 cfs up to 2000 cfs.

Figure 29 indicates the cross sections where localized flooding is probable when the flow is 125 cfs. The predicted depths of overbank flow at two cross sections along the lower reaches of the EWR were 0.22 and 0.28 feet. Along the WWR, the predicted depth of overbank flow at one cross section was 0.54 feet. Along the lower reaches of the CWR, the predicted depths of overbank flow at eight different cross sections ranged from 0.44 ft to 0.89 feet.

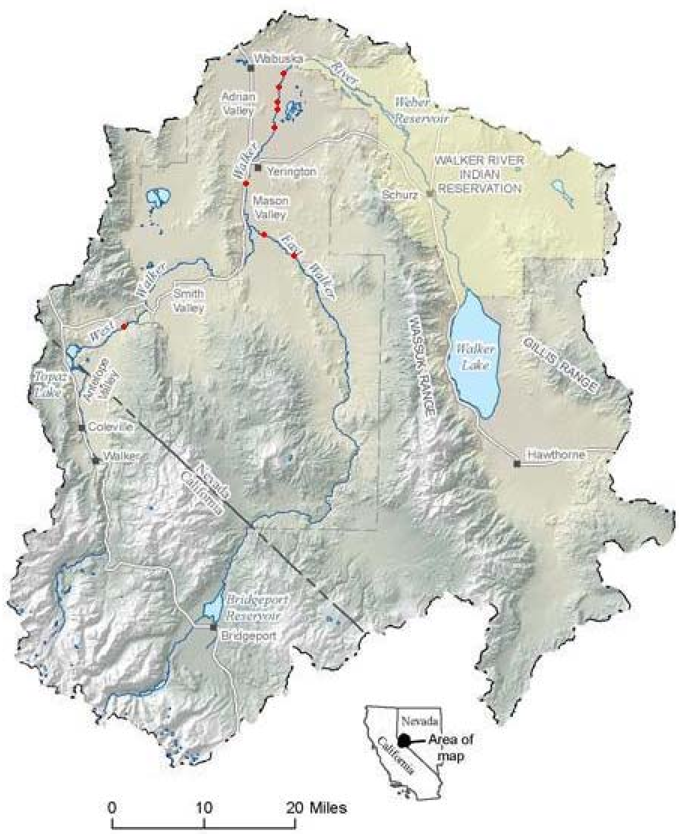

Figure 29. Localized flooding predicted for a flow of 125 cfs.

When the projected flow along each reach of the EWR, WWR, and CWR was 250 cfs, localized flooding was predicted at several locations as summarized in Figure 30. The predicted depths of overbank flow ranged from 0.41 to 1.11 feet along the EWR, from 0.48 to 1.46 feet along the WWR, and from 0.27 ft to 1.61 feet along the CWR.

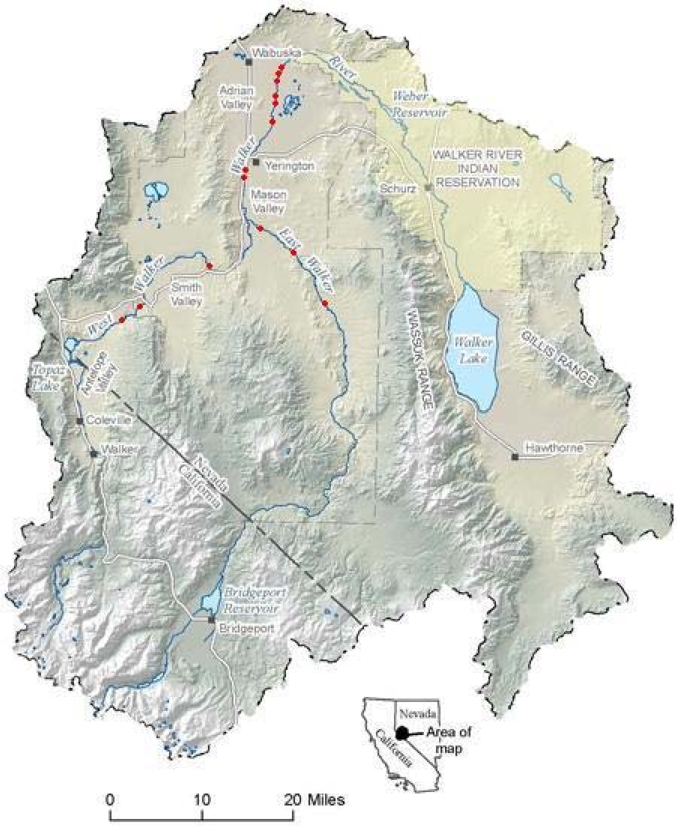

Figure 30. Localized flooding predicted for a flow of 250 cfs.

When the projected flow along each reach of the EWR, WWR, and CWR was 500 cfs, localized flooding was predicted at a number of locations as summarized in Figure 31. The predicted depths of overbank flow ranged from 0.43 to 2.28 feet along the EWR, from 0.36 to 2.84 feet along the WWR, and from 0.27 ft to 1.61 feet along the CWR.

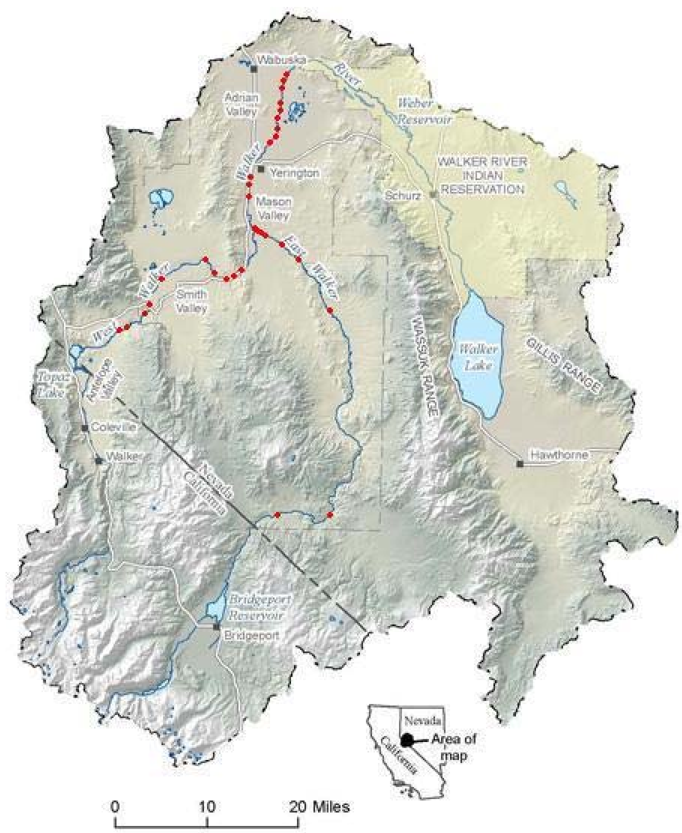

Figure 31. Localized flooding predicted for a flow of 500 cfs.

When the projected flow along each reach of the EWR, WWR, and CWR was 1000 cfs, localized flooding was predicted at numerous locations as summarized in Figure 32. The predicted depths of overbank flow ranged from 0.25 to 3.86 feet along the EWR, from 0.36 to 4.60 feet along the WWR, and from 0.30 ft to 4.37 feet along the CWR.

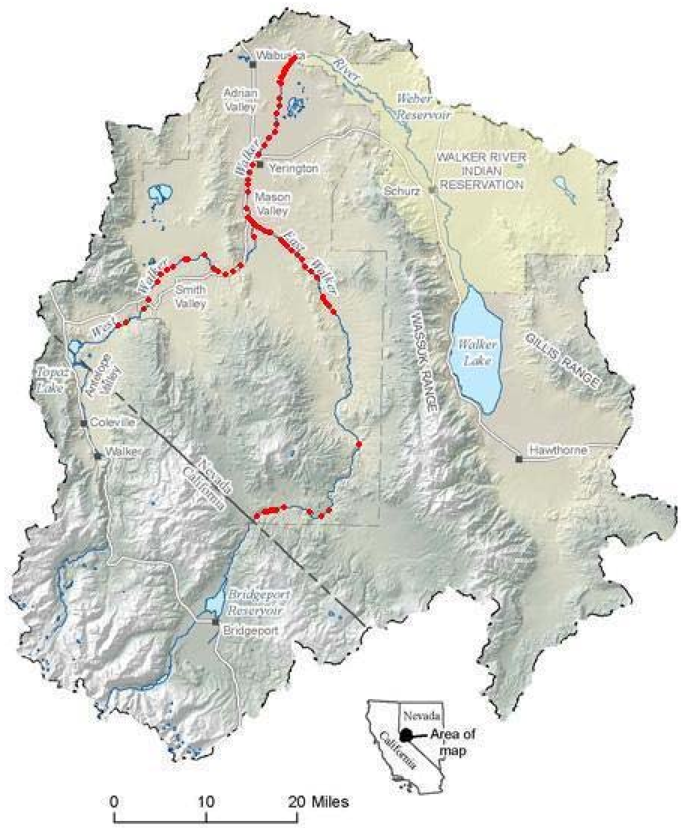

Figure 32. Localized flooding predicted for a flow of 1000 cfs.

Analysis of Historical and Current Water Quality

The results of water quality data collected during this project and a thorough a review historical water quality data for the upper Walker River are discussed in this section along with statistical trends of interest. Appropriate comparisons were made between historical and project data collected. Selected analytes are defined as those which demonstrated significance after statistical analyses were performed. Significance corresponded to a probability of occurrence (i.e., confidence factor of 95%) in conjunction with a coefficient of determination R^2 value greater than 0.5 and a corresponding ANOVA Regression Significant F value less than 0.07 (7%) indicating both a reasonable fit and a relative high probability of occurrence.

USGS flow analyses

In order to perform a comparative analysis between historical water quality data and data gathered during this project, flow rates for each of the sampling locations needed to be determined. Flow data gathered from the USGS were analyzed and reduced to determine approximate flows at the sampling locations and at USGS flow gauging station Wabuska, NV to determine volumetric discharges from July 1995 through 2008. The following assumptions were used in the flow determinations:

1. No significant infiltration or exfiltration of ground water was occurring.
2. All reductions associated with stream flow measurements along a given reach were the result of withdrawals (e.g., irrigation).
3. All increases associated with stream flow measurements along a given reach were associated with inflows (e.g., surface runoff).
4. A linear relationship was applied to these withdrawals and inflows based upon the measured riverbed miles.
5. Provisional USGS data for 2008 will not change.
6. Flow data from the USGS gauging station at Wabuska, NV was appropriate for determining volumetric discharges.

Table 28 and Figure 33 summarize the reduction of fourteen years of USGS water gauging data at Wabuska allowing for a comparison of volumetric discharges and concentrations of various historical and current water quality parameters. The above assumptions resulted in the determinations of flows at each sampling site as summarized in Table 29.

Table 28. Average volume of water at USGS 10301500 Wabuska, NV.

Year Ending	Volume (ft^3)	Volume (acre-ft)	Volume (m^3)
1995	6.37E+09	1.46E+05	1.80E+08
1996	1.39E+10	3.19E+05	3.94E+08
1997	1.55E+10	3.57E+05	4.40E+08
1998	8.72E+09	2.00E+05	2.47E+08
1999	9.48E+09	2.18E+05	2.68E+08
2000	2.81E+09	6.44E+04	7.95E+07
2001	1.67E+09	3.82E+04	4.72E+07
2002	9.63E+08	2.21E+04	2.73E+07
2003	1.12E+09	2.57E+04	3.18E+07
2004	1.60E+09	3.67E+04	4.52E+07
2005	4.86E+09	1.11E+05	1.37E+08
2006	1.27E+10	2.91E+05	3.59E+08
2007	3.39E+09	7.77E+04	9.59E+07
2008	1.18E+09	2.71E+04	3.34E+07
One year is defined from July 1st to June 30th (typ.).			

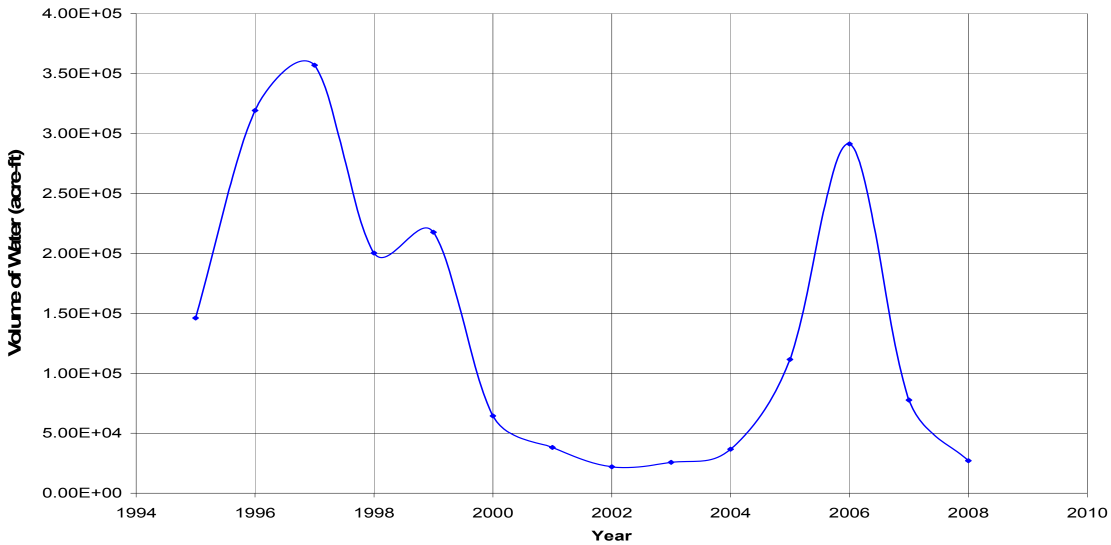

Figure 33. Annual volume of water at Wabuska, NV.

Figure 33 shows the annualized volume of water transiting Wabuska. Except for 2005 and 2006 the general trend suggests decreasing flows along the lower Walker River. The volumes of 1.08 x 10^8 m^3 (87,557.0 acre-feet in 1995), and 3.34 x 10^7 m^3 (27,077.8 acre-feet in 2008) were used in analysis of historical and project water quality data.

Historical and project water quality: Data for the combined Walker River

Historical water quality data at Wabuska, NV (USGS 10301500) are summarized in Table 32 for the period from April 24, 1991 through April 5, 1995. During this period, the analytes tested by the USGS coincided with those monitored during this project.

Table 29. Summary of in-stream flows during sampling events (cfs).

River Station	7/24/07	8/21/07	9/23/07	10/26/07	11/23/07	12/21/07	1/26/08	2/23/08	3/23/08	4/26/08	5/22/08	6/22/08
RS 350627	102.8	69.6	66.5	47.6	24.1	32.2	33.9	24.6	105.8	57.8	246.1	199.0
RS 206202	56.7	45.6	57.2	38.5	26.9	38.1	44.2	34.1	105.4	55.3	195.3	175.2
RS 120799	28.1	30.7	51.5	32.9	28.6	41.7	50.5	39.9	105.2	53.8	163.8	160.5
RS 263638	143.4	91.9	66.1	51.3	48.9	32.2	32.7	32.5	74.8	135.4	502.9	490.4
RS 188746	93.7	51.5	62.9	46.5	47.3	33.3	32.4	36.7	55.7	101.2	410.8	378.7
RS 113443	78.5	39.2	61.9	45.0	46.8	33.7	32.3	37.9	49.9	90.7	382.7	344.6
RS 100229	88.3	57.6	97.6	67.0	66.0	65.3	72.9	69.3	127.5	121.0	452.0	400.8
RS 49536	53.6	34.4	67.7	46.4	48.1	46.3	54.2	53.0	75.1	76.2	272.7	202.9
RS 9895	23.7	14.3	42.0	28.7	32.7	30.0	38.0	39.0	30.0	37.7	118.3	32.7

Table 30. Summary of historical water quality data at Wabuska, NV.

Date	Water Temp (°C)	EC (µS/cm)	pH	Turbidity (NTU)	Q (cfs)	Depth (ft)	TDS (mg/L)	Cl^- (mg/L)	SO_4^{-2} (mg/L)	Ca^{+2} (mg/L)	Fe^{+2} (mg/L)	K^{+1} (mg/L)	Mg^{+2} (mg/L)	Na^{+1} (mg/L)
4/24/1991	17.5	474	8.3	6.5	33.0	3.5	294.0	21.0	56.0	36.0	0.0	4.8	8.8	54.0
6/26/1991	21.5	262	8.3	6.1	52.0	3.8	157.0	9.9	20.0	22.0		3.2	5.3	24.0
8/28/1991	19.0	307	8.3	10.0	31.0	3.8	185.0	10.0	26.0	27.0	0.0	3.5	6.3	29.0
10/10/1991	15.2	360	8.3	6.3	29.0	3.8	249.0	20.0	46.0	30.0	0.0	4.1	7.4	38.0
12/17/1991	0.2	420	8.2	4.6	7.4	3.5	269.0	19.0	48.0	35.0		3.7	8.0	44.0
2/20/1992	8.8	460	8.3	4.1	11.0	3.4	291.0	21.0	57.0	37.0	0.0	4.5	8.6	50.0
4/29/1992	23.0	273	8.2	15.0	35.0	3.9	159.0	12.0	22.0	21.0	0.0	3.4	5.3	25.0
8/25/1992	22.0	290	8.3	6.0	34.0	4.2	173.0	11.0	27.0	23.0	0.0	3.5	5.8	27.0
10/29/1992	12.5	381	8.4	2.0	1.5	3.4	234.0	15.0	40.0	28.0		4.0	7.2	41.0
2/24/1993	8.8	436	8.1	9.3	33.0	4.2	276.0	20.0	57.0	33.0	0.0	4.7	7.7	47.0
4/27/1993	17.5	293	8.1	11.0	56.0	4.7	171.0	10.0	24.0	23.0	0.0	4.2	5.3	28.0
6/22/1993	24.0	214	7.9	2.9	60.0	4.7	125.0	6.4	17.0	17.0		3.3	4.1	18.0
8/24/1993	26.0	251	8.4	0.8	26.0	4.5	155.0	6.5	23.0	23.0	0.0	3.7	5.1	21.0
5/2/1994	17.5	460	8.2	4.4	11.0	3.7	285.0	18.0	56.0	37.0	0.0	5.2	8.4	47.0
6/14/1994	16.0	338	8.1		29.0		211.0	12.0	31.0	29.0	0.0	3.5	7.1	32.0
6/28/1994	20.0	289	8.2	4.7	33.0	4.2	170.0	11.0	26.0	23.0	0.0	3.5	5.8	27.0
8/30/1994	16.4	294	8.2	5.1	52.0	4.6	173.0	7.7	25.0	24.0	0.0	3.9	5.8	26.0
11/8/1994	4.0	476	8.2	0.6	1.9	3.3	306.0	23.0	69.0	37.0	0.0	4.8	8.9	57.0
4/5/1995	7.8	459	8.0	5.8	11.0	3.4	285.0	22.0	63.0	37.0	0.0	5.1	8.4	46.0
Average:			8.2	5.8	28.8		219.4			28.5	0.0	4.0	6.8	35.8

Parameters in Table 30 were statistically analyzed with regard to flows during the historical interval and results are summarized in Table 31.

Table 31. Wabuska statistical analyses of analytes against flow.

					ANOVA			
	Regression Analysis				Regression		Intercept	
Analyte	**Multiple R**	**R^2**	**Std. Error**	**# Observ.**	***F***	***Sig. F***	***t Stat***	***P-value***
EC	0.732	0.536	61.373	19	19.627	0.000	16.855	0.000
pH	0.319	0.102	0.125	19	1.925	0.183	149.206	0.000
TDS	0.742	0.551	41.293	19	20.824	0.000	15.917	0.000
Cl^-	0.695	0.482	4.205	19	15.847	0.001	11.203	0.000
SO_4^{-2}	0.729	0.531	11.960	19	19.258	0.000	11.047	0.000
Ca^{+2}	0.753	0.567	4.468	19	22.304	0.000	18.477	0.000
Fe^{+2}	0.059	0.003	0.010	15	0.045	0.835	2.272	0.041
K^+	0.506	0.256	0.568	19	5.849	0.027	18.111	0.000
Mg^{+2}	0.766	0.586	0.985	19	24.071	0.000	19.828	0.000
Na^+	0.719	0.516	8.602	19	18.143	0.001	13.065	0.000
EC	0.732	0.536	61.373	19	19.627	0.000	16.855	0.000

(Highlighted) Signifies statistically significant correlation

The results indicated a moderate fit (i.e., R^2 greater than 0.5) between the nominal values in Table 30 and regression analyses for EC, TDS, SO_4^{-2}, Ca^{+2}, Mg^{+2}, and Na^+ when the analytes of interest were compared with respect to typical flows (i.e., excluding flood events). TDS, SO_4^{-2}, Ca^{+2}, Mg^{+2}, and Na^+ exhibited inverse relationships with regard to flow as demonstrated in Figures 34 and 35. During this period, Fe^{+2} concentrations were consistently less than 0.1 mg/L, pH fluctuated between 7.9 and 8.4, and flow fluctuated between 0.04 m^3/s (1.5 cfs) and 1.7 m^3/s (60.0 cfs).

The water quality data gathered during this project are summarized in Tables 32 through 34. The results of statistical analyses of the data are summarized in Tables 35 through 37.

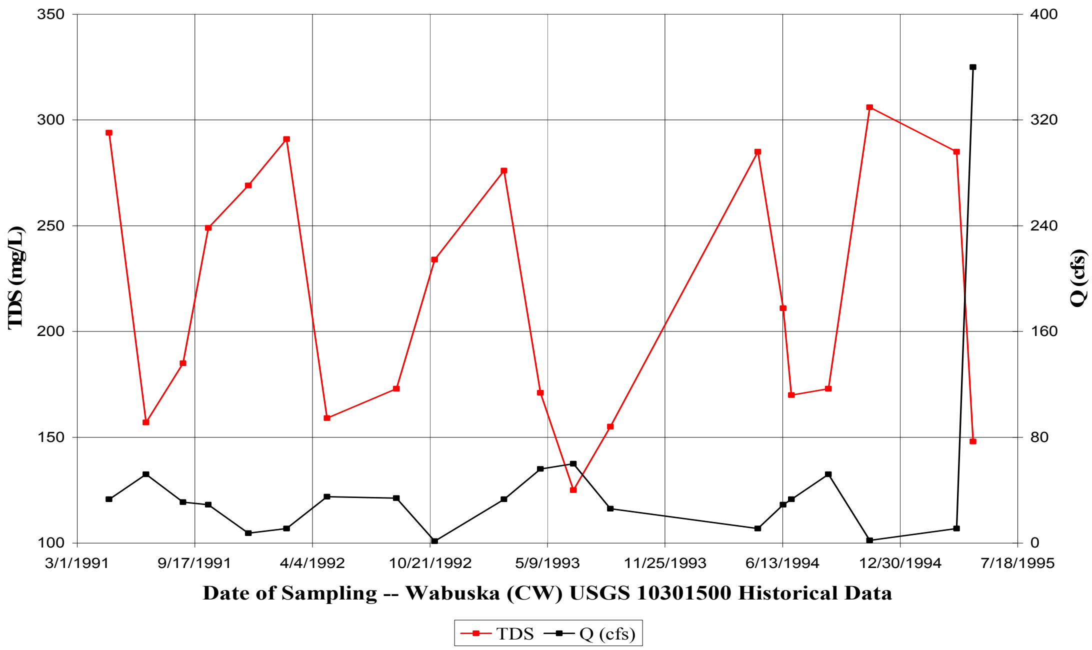

Figure 34. Historical TDS and flow for Wabuska, NV (USGS 10301500).

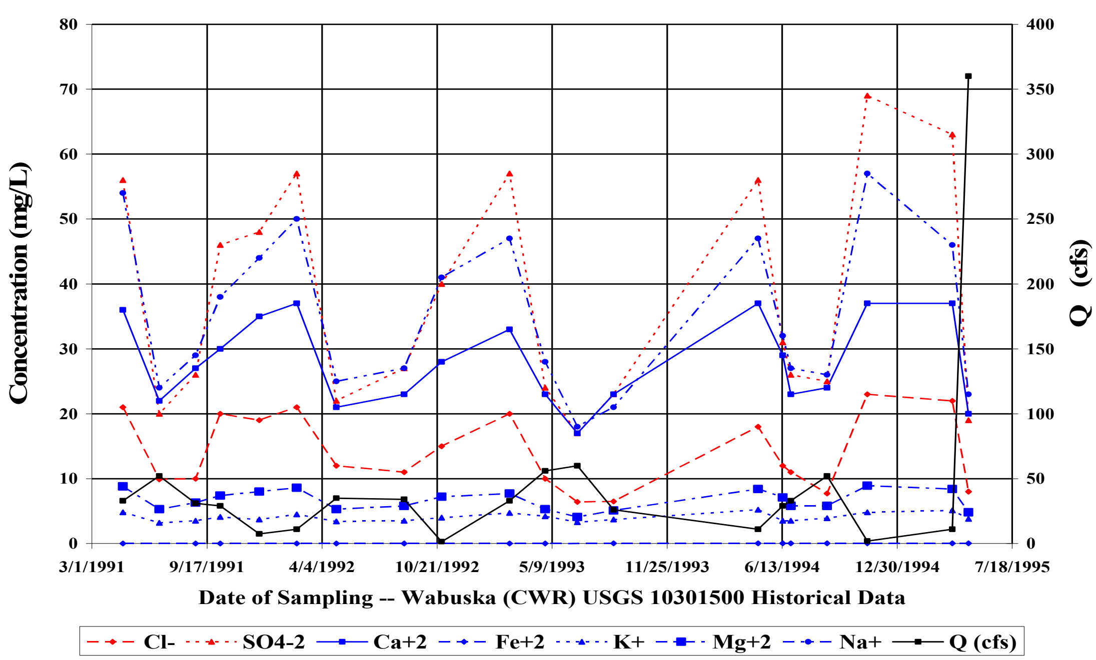

Figure 35. Selected analytes and flows at Wabuska, NV.

Table 32. Summary of water quality at RS 100229.

Date	Water Temp (°C)	EC (µS/cm)	*pH*	Turbidity (NTU)	Flow *Q* (cfs)	Velocity (ft/s)	Flow Depth (ft)	TDS (mg/L)	TOC (mg/L)	Cl^- (mg/L)	SO_4^{-2} (mg/L)	Ca^{+2} (mg/L)	Fe^{+2} (mg/L)	K^{+1} (mg/L)	Mg^{+2} (mg/L)	Na^{+1} (mg/L)
7/24/2007	22.8	301.0	8.1	4.4	88.3	n/a	n/a	183.0	3.6	17.2	30.8	26.2	0.4	3.4	6.5	32.3
8/21/2007	20.5	350.0	8.2	2.3	57.6	1.6	n/a	229.7	4.2	22.9	49.2	32.2	0.2	4.4	7.6	46.2
9/23/2007	12.6	258.0	8.1	7.3	97.6	1.8	n/a	227.7	0.5	12.6	31.8	29.0	0.6	4.0	7.0	33.9
10/26/2007	10.4	312.0	8.1	3.0	67.0	1.6	1.2	261.7	1.3	22.4	45.5	35.6	0.3	4.6	8.6	47.0
11/23/2007	3.1	264.0	8.1	2.1	66.0	1.5	1.8	279.2	2.1	26.8	48.2	37.8	0.2	4.1	9.0	49.2
12/21/2007	2.8	287.0	7.9	4.9	65.3	1.8	1.4	289.8	2.5	28.0	55.6	43.5	0.5	4.8	10.5	55.7
1/26/2008	5.2	324.0	7.8	9.2	72.9	1.7	1.5	294.5	0.9	24.8	48.9	40.5	0.8	4.6	9.9	49.1
2/23/2008	5.7	318.0	8.3	6.1	69.3	1.9	1.4	266.3	2.3	23.3	58.0	40.6	0.5	4.1	9.9	47.4
3/22/2008	12.5	332.0	8.1	41.5	127.5	1.9	2.1	279.8	4.4	Eqp	44.9	34.4	3.1	4.7	8.7	42.8
4/26/2008	19.9	337.0	8.3	8.1	121.0	1.6	1.8	249.5	3.6	19.5	39.4	29.2	0.8	4.2	7.5	34.4
5/22/2008	14.6	143.0	7.9	43.6	452.0	0.9	2.6	112.7	3.4	7.7	12.5	16.2	3.0	2.5	4.9	13.4
6/22/2008	22.9	205.0	8.4	14.2	400.8	2.8	2.4	161.5	3.7	7.1	14.9	17.9	1.1	2.5	4.9	17.3
Average:			8.1	12.2	140.4			236.3				31.9	0.9	4.0	7.9	39.1

Maximum   Minimum

Table 33. Summary of water quality at RS 49536.

Date	Water Temp (°C)	EC (µS/cm)	*pH*	Turbidity (NTU)	Flow *Q* (cfs)	Velocity (ft/s)	Flow Depth (ft)	TDS (mg/L)	TOC (mg/L)	Cl^- (mg/L)	SO_4^{-2} (mg/L)	Ca^{+2} (mg/L)	Fe^{+2} (mg/L)	K^{+1} (mg/L)	Mg^{+2} (mg/L)	Na^{+1} (mg/L)
7/24/2007	24.6	342	8.2	4.0	53.6	n/a	n/a	202.3	2.6	16.5	36.9	29.9	0.3	4.4	7.5	34.5
8/21/2007	20.5	342	8.2	3.2	34.4	2.5	n/a	232.7	3.1	18.6	47.3	33.3	0.3	4.8	8.6	38.9
9/23/2007	12.2	267	8.2	9.0	67.7	1.8	n/a	226.3	0.8	12.6	35.3	30.6	0.8	4.2	7.5	34.9
10/26/2007	10.1	318	8.2	4.9	46.4	2.1	0.8	247.7	0.9	23.2	45.7	36.0	0.4	4.7	8.6	46.6
11/23/2007	1.1	245	8.1	6.8	48.1	2.2	1.0	277.2	2.1	25.7	49.6	37.8	0.5	4.2	9.1	48.5
12/21/2007	2.4	241	8.0	8.4	46.3	2.0	0.8	254.2	2.0	17.9	44.4	38.0	0.7	4.4	9.1	46.3
1/26/2008	4.6	294	7.8	18.7	54.2	1.7	1.0	279.8	0.8	20.6	47.2	38.5	1.7	4.6	9.6	44.3
2/23/2008	5.8	314	8.4	6.6	53.0	1.9	0.8	271.7	2.3	22.9	57.3	40.6	0.5	4.2	9.9	48.2
3/22/2008	17.6	373	8.3	18.7	75.1	1.6	0.7	261.5	2.7	Eqp	46.0	34.1	1.3	4.3	8.2	42.3
4/26/2008	20.5	343	8.4	12.1	76.2	2.1	1.5	174.5	2.8	19.2	39.2	30.3	0.9	4.4	7.9	33.4
5/22/2008	16.2	158	8.0	41.8	272.7	2.2	0.7	111.0	3.5	6.4	13.2	16.7	2.6	2.7	4.9	14.5
6/22/2008	26.4	239	8.3	12.8	202.9	1.8	0.9	174.8	3.5	7.5	17.2	19.4	0.9	2.8	5.2	18.5
Average:			8.1	12.3	85.9			226.1				32.1	0.9	4.1	8.0	37.6

Maximum   Minimum

Table 34. Summary of water quality at RS 9895.

Date	Water Temp (°C)	EC (µS/cm)	*pH*	Turbidity (NTU)	Flow *Q* (cfs)	Velocity (ft/s)	Flow Depth (ft)	TDS (mg/L)	TOC (mg/L)	Cl^- (mg/L)	SO_4^{-2} (mg/L)	Ca^{+2} (mg/L)	Fe^{+2} (mg/L)	K^{+1} (mg/L)	Mg^{+2} (mg/L)	Na^{+1} (mg/L)
7/24/2007	24.8	418	8.3	8.1	23.7	n/a	n/a	254.3	3.5	19.8	45.4	34.8	0.6	5.6	8.7	45.5
8/21/2007	18.7	398	7.1	4.4	14.3	2.3	n/a	186.7	3.8	24.4	54.7	35.2	0.5	5.1	8.8	43.8
9/23/2007	12.0	292	6.8	10.3	42.0	3.4	n/a	213.7	0.7	12.7	37.2	31.2	0.6	4.1	7.6	35.8
10/26/2007	8.2	307	7.9	5.8	28.7	2.2	2.8	272.3	1.5	21.3	48.7	35.2	0.7	5.1	8.6	50.7
11/23/2007	1.4	287	8.1	4.6	32.7	1.0	2.2	326.8	2.8	28.2	57.4	40.3	0.4	5.5	9.7	61.2
12/21/2007	1.1	245	7.8	6.2	30.0	1.2	4.0	260.8	2.1	22.7	51.9	42.8	0.7	4.8	9.3	52.9
1/26/2008	3.8	321	7.6	36.6	38.0	3.8	3.1	320.5	0.8	26.4	54.6	42.0	3.0	5.4	10.7	54.8
2/23/2008	6.0	347	8.4	9.2	39.0	2.9	2.6	315.7	2.3	25.1	65.1	41.0	0.8	4.7	10.1	56.0
3/22/2008	18.1	461	8.1	11.7	30.0	1.7	2.6	337.8	2.7	Eqp	61.8	39.3	0.9	5.2	9.4	59.1
4/26/2008	21.8	394	8.2	21.9	37.7	2.5	3.8	240.8	3.0	21.2	46.7	32.7	1.8	5.5	8.7	40.0
5/22/2008	14.5	194	8.0	34.2	118.3	0.5	3.3	154.0	4.2	9.3	21.3	20.8	2.1	3.7	5.7	21.6
6/22/2008	27.6	325	8.4	16.6	32.7	0.8	3.9	210.2	4.2	10.3	26.3	24.2	1.1	4.5	6.4	27.0
Average:			7.9	14.1	38.9			257.8				35.0	1.1	4.9	8.6	45.7

Maximum Minimum

Table 35. RS 100229 Statistical analyses of analytes against flow.

					ANOVA			
	Regression Analysis				Regression		Intercept	
Analyte	**Multiple R**	**R^2**	**Std. Error**	**# Observ.**	***F***	***Sig. F***	***t Stat***	***P-value***
EC	0.853	0.727	33.207	12	26.693	0.000	24.058	0.000
pH	0.093	0.009	0.186	12	0.087	0.774	102.366	0.000
TDS	0.827	0.684	33.512	12	21.650	0.001	20.010	0.000
TOC	0.342	0.117	1.278	12	1.324	0.277	4.136	0.002
Cl^-	0.846	0.715	4.111	11	22.567	0.001	14.202	0.000
SO_4^{-2}	0.869	0.756	7.646	12	30.931	0.000	16.387	0.000
Ca^{+2}	0.840	0.706	4.937	12	23.981	0.001	18.811	0.000
Fe^{+2}	0.621	0.386	0.834	12	6.289	0.031	0.827	0.427
K^+	0.865	0.748	0.428	12	29.687	0.000	25.910	0.000
Mg^{+2}	0.789	0.623	1.201	12	16.519	0.002	18.480	0.000
Na^+	0.890	0.793	6.279	12	38.297	0.000	19.184	0.000

(highlighted) Signifies statistically significant correlation

Good correlations were observed for EC, TDS, Cl^-, SO_4^{-2}, Ca^{+2}, K^+, Mg^{+2}, and Na^+. This was significant due to the wide variation in flow rates between 1.85 and 12.8 m^3/s or 65.3 and 452.0 cfs. R^2 values greater than 0.62 and associated significant *F* values less than 1% would indicate that the values shown in Table 32 could be anticipated for similar flows in the future.

Table 36. RS 49536 Statistical analyses of analytes against flow.

					ANOVA			
	Regression Analysis				Regression		Intercept	
Analyte	**Multiple R**	**R^2**	**Std. Error**	**# Observ.**	***F***	***Sig. F***	***t Stat***	***P-value***
EC	0.687	0.472	46.811	33	27.659	0.000	30.730	0.000
pH	0.141	0.020	0.351	33	0.629	0.434	98.530	0.000
TDS	0.686	0.471	40.840	33	27.578	0.000	28.394	0.000
TOC	0.345	0.119	1.100	33	4.179	0.050	8.340	0.000
Cl^-	0.671	0.450	4.976	33	25.354	0.000	19.781	0.000
SO_4^{-2}	0.767	0.588	9.138	33	44.251	0.000	24.144	0.000
Ca^{+2}	0.759	0.576	5.219	33	42.137	0.000	31.420	0.000
Fe^{+2}	0.499	0.249	0.670	33	10.276	0.003	3.781	0.001
K^+	0.840	0.706	0.452	33	74.441	0.000	47.016	0.000
Mg^{+2}	0.745	0.556	1.134	33	38.778	0.000	35.137	0.000
Na^+	0.755	0.570	8.440	33	41.083	0.000	24.793	0.000

Signifies statistically significant correlation

The statistical analyses for RS 49536 showed only moderate correlations to flow with the exception of K^+. The R^2 values ranged between 0.556 and 0.588 which were not close enough to be able to predict anything other than a tendency to follow an inverse trend of increased concentrations with decreased flows. A somewhat surprising observation was that Fe^{+2} concentrations were at their highest during periods of highest flow which is likely due to runoff leaching the metal from the surrounding area.

Table 37 presents the statistical analyses for RS 9895 and demonstrated minimal correlations between the analytes being investigated and flow. Flows for this location fluctuated between 0.40 and 3.35 m^3/s or 14.3 and 118.3 cfs with an average of 1.10 m^3/s (38.9 cfs). If flooding events were eliminated (i.e., 3.35 m^3/s or 118.3 cfs) the average flow would drop to 0.90 m^3/s (31.7 cfs) which would increase the R^2 for this site and allow for significant statistical correlation to be noted.

Table 37. RS 9895 Statistical analyses of analytes against flow.

	Regression Analysis				ANOVA			
					Regression		Intercept	
Analyte	Multiple R	R^2	Std. Error	# Observ.	*F*	*Sig. F*	*t Stat*	*P-value*
EC	0.636	0.404	61.492	12	6.792	0.026	12.313	0.000
pH	0.053	0.003	0.529	12	0.028	0.870	27.784	0.000
TDS	0.446	0.199	55.904	12	2.486	0.146	9.960	0.000
TOC	0.236	0.056	1.220	12	0.591	0.460	3.381	0.007
Cl^-	0.571	0.326	5.639	11	4.347	0.067	8.221	0.000
SO_4^{-2}	0.614	0.377	11.106	12	6.047	0.034	10.089	0.000
Ca^{+2}	0.612	0.374	5.764	12	5.973	0.035	13.415	0.000
Fe^{+2}	0.494	0.244	0.723	12	3.226	0.103	1.307	0.221
K^+	0.695	0.483	0.455	12	9.339	0.012	22.845	0.000
Mg^{+2}	0.597	0.356	1.214	12	5.531	0.041	15.275	0.000
Na^+	0.597	0.356	1.214	12	5.531	0.041	15.275	0.000

Figure 36 shows the tendency of an inverse relationship of TDS with regard to flow an exception to this was the spring runoff in March where TDS increased with flow to its maximum value of 337.8 mg/L. During the low flow period of January 2008 both RS 100229 (294.5 mg/L) and RS 49536 (279.8 mg/L) exhibited their peak TDS measurements. Averages, maximum, and minimum readings for each of these locations were summarized in Tables 32 through 34. Figures 37 through 39 demonstrate this trend with regard to analytes of interest and flow.

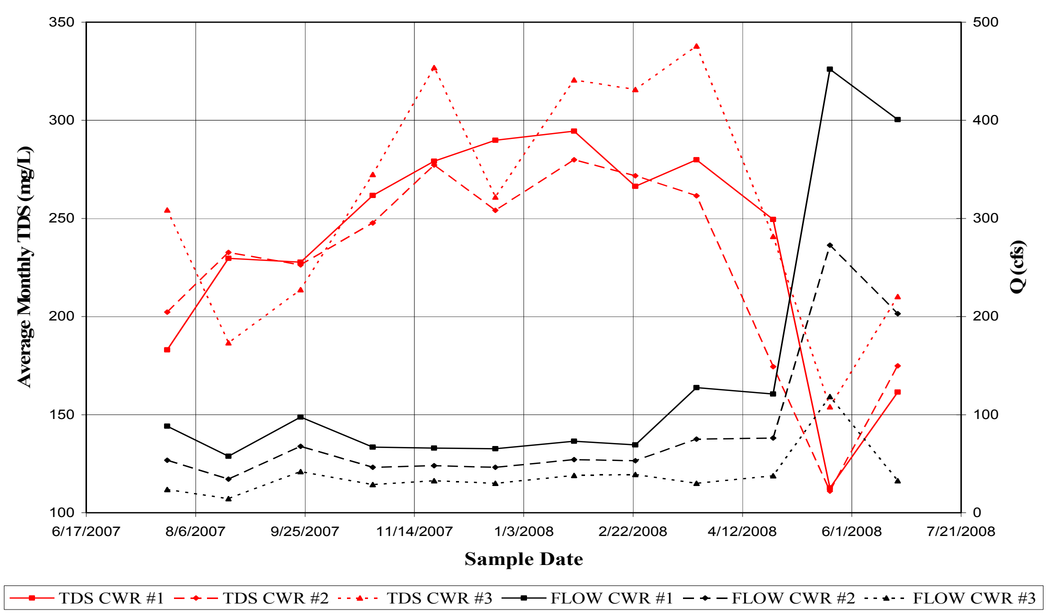

Figure 36. Average monthly TDS and flow for CWR.

Figure 37 for RS 100229 illustrates maximum concentrations for TOC (4.4 mg/L), Fe^{+2} (3.1 mg/L), and K^+ (4.7 mg/L) associated with the March 2008 sampling. Maximum concentrations for Cl^- (28.0 mg/L), Ca^{+2} (43.5 mg/L), Mg^{+2} (10.5 mg/L), and Na^+ (55.7 mg/L) are associated with the December 2007 sampling. The maximum SO_4^{-2} (58.0 mg/L) concentration occurred during the February 2008 sampling.

Minimum concentrations for all analytes except TOC and Fe^{+2} are associated with the maximum flow sampling dates of May and June 2008. Interestingly, minimum concentration of Fe^{+2} occurred during the August 2007 sampling and minimum TOC during the September 2007 sampling. While both minimum concentrations occurred during lower flows they are not directly connected with flow.

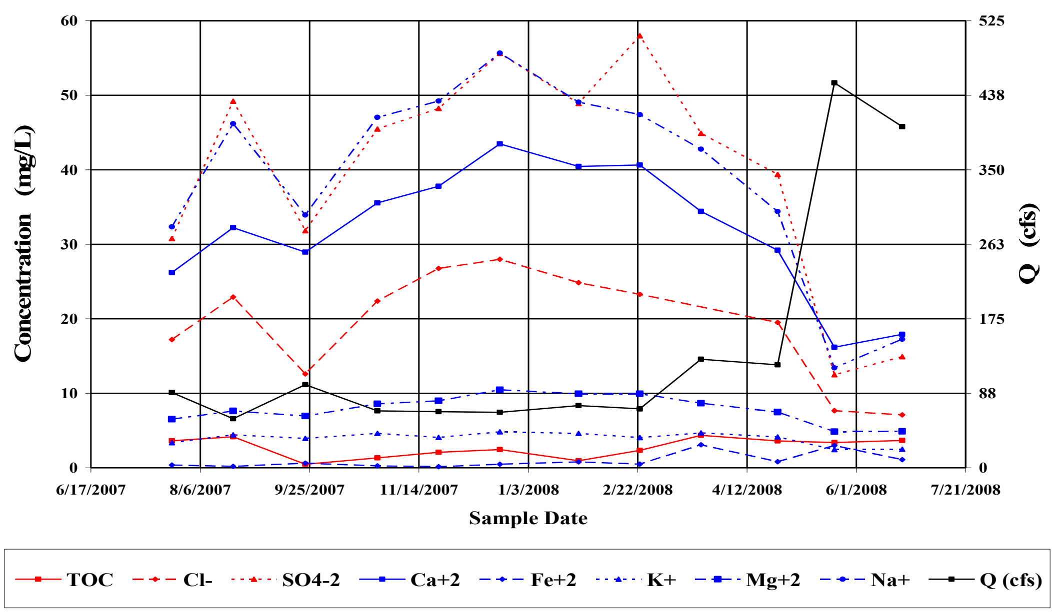

Figure 37. Selected analytes and flow for RS 100229.

Figure 38 for RS 49536 illustrates maximum concentrations for TOC (3.5 mg/L) and Fe^{+2} (2.6 mg/L) are associated with the May 2008 sampling. Maximum concentrations for Cl^- (25.7 mg/L) and Na^+ (48.5 mg/L) occurred during the November 2007 sampling. Maximum concentrations for SO_4^{-2} (57.3 mg/L), Ca^{+2} (40.6 mg/L), and Mg^{+2} (9.9 mg/L) were observed during the February 2008 sampling. The maximum concentration for K^+ (4.8 mg/L) was observed during the August 2007 sampling. Minimum concentrations for all analytes except TOC and Fe^{+2} are associated with the maximum flow sampling dates of May 2008.

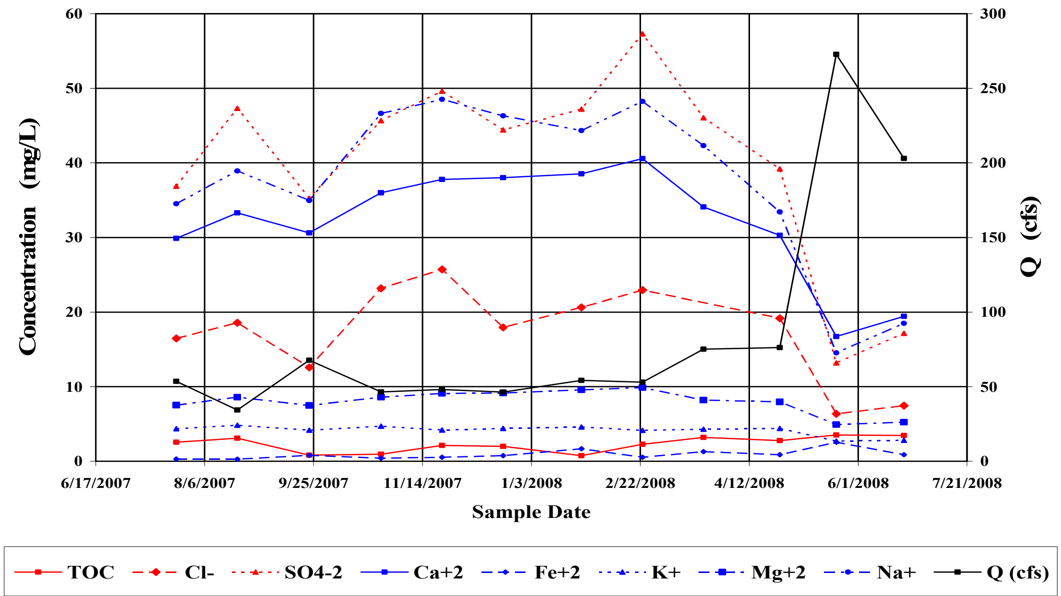

Figure 38. Selected analytes and flow for RS 49536.

Figure 39 for RS 9895 illustrates maximum concentrations for the selected analytes. More randomness was noted with regard to maximum concentrations and sampling dates with TOC (4.2 mg/L) in May/June 2008, Cl^- (28.2 mg/L) and Na^+ (61.2 mg/L) in November 2007, SO_4^{-2} (65.1 mg/L) in February 2008, Ca^{+2} (42.8 mg/L) in December 2007, Fe^{+2} (3.0 mg/L) and Mg^{+2} (10.7 mg/L) in January 2008, and K^+ (5.6 mg/L) in July 2008. Minimum concentrations for all analytes except TOC and Fe^{+2} are associated with the maximum flow sampling dates of May 2008.

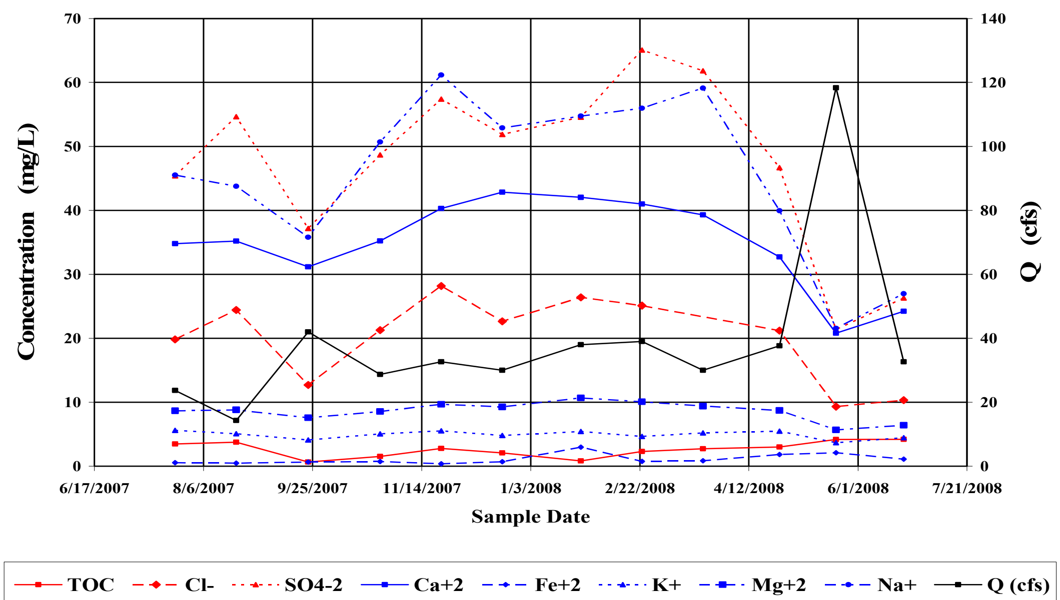

Figure 39. Selected analytes and flow for RS 9895.

Volumetric flow past the Wabuska USGS gauge in 1995 (defined project year) was 1.80×10^8 m^3 (87,557.0 acre-feet) against 3.34×10^7 m^3 (27,077.8 acre-feet) for 2008 (defined project year). This represents an approximate 70 to 80% reduction in volumetric discharge for the two periods. Direct comparisons between pH, TDS, Cl^-, Fe^{+2}, and K^+ while not statistically relevant may be completed with regard to general observations for RS 9895 and Wabuska and are summarized in Table 38.

Table 38. Comparison between analytes at RS 9895 and Wabuska.

Parameter	Wabuska 1995		RS 9895 Current	
	maximum	**minimum**	**maximum**	**minimum**
pH	8.4	7.9	8.4	7.1
Turbidity NTU)	11	0.6	36.6	4.4
TDS (mg/L)	306	125	337.8	154
Cl^- (mg/L)	23	6.4	28.2	9.3
Fe^{+2} (mg/L)	0	0	3	0.4
K^+ (mg/L)	5.1	3.2	5.6	3.7

	Increase
	Reduction

Water quality has remained somewhat static despite the reduction in flow. TDS which leaves the upper Walker River had a maximum concentration increase of 10.39%. Table 39 shows total salts leaving Wabuska in 1995 and compared to the current project has been reduced by approximately 81.7% while flow has been reduced 81.4% or the river is slightly less salty leaving Wabuska now than in 1995. Between 1882 and 2007, the TDS for Walker Lake has reportedly increased from 2,500 mg/L to about 11,000 mg/L (an increase of 340%), about half the salinity of seawater (Sharpe *et al.*, 2007). This increase in TDS was directly related to the influx of salts contained within the Walker River TDS. Currently, approximately 66,000 tons of TDS added to Walker Lake per year.

Table 39. Mass of salts passing Wabuska.

	Ca^{+2} (mg/L)	**Fe^{+2} (mg/L)**	**K^{+1} (mg/L)**	**Mg^{+2} (mg/L)**	**Na^{+1} (mg/L)**	**Σ**
RS 9895						
Average:	35.0	1.1	4.9	8.6	45.7	
Volume (m^3)	3.34E+07	3.34E+07	3.34E+07	3.34E+07	3.34E+07	
Volume (L)	3.3E+10	3.3E+10	3.3E+10	3.3E+10	3.3E+10	
Mass of Salts (g)	1.17E+09	3.67E+07	1.64E+08	2.87E+08	1.53E+09	3.18E+09
Mass of Salts (Kg)	1.17E+06	3.67E+04	1.64E+05	2.87E+05	1.53E+06	**3.18E+06**
Wabuska Historical						
4/5/1995	37.0	0.0	5.1	8.4	46.0	
Volume (m^3)	180000000	180000000	180000000	180000000	180000000	
Volume (L)	1.8E+11	1.8E+11	1.8E+11	1.8E+11	1.8E+11	
Mass of Salts (g)	6.66E+09	2.70E+06	9.18E+08	1.51E+09	8.28E+09	1.74E+10
Mass of Salts (Kg)	6.66E+06	2.70E+03	9.18E+05	1.51E+06	8.28E+06	**1.74E+07**
% Reduced Flow		**% Reduced Salts**				
81.4%		**81.7%**				

CONCLUSIONS

After completing a detailed engineering survey of the upper Walker River, a HEC-RAS model was developed and run for various flow scenarios in order to predict the hydrodynamic characteristics of the flows (i.e., bed shear stresses, mean velocities, water surface elevations, Froude numbers, and maximum channel depths). The flows which were evaluated were based on historical variations of flows observed along the upper Walker River. The primary application of the HEC-RAS model was to predict the hydrodynamic conditions that would result in erosion, sediment transport, and localized flooding along the upper Walker River.

A number of methods were used to determine the susceptibility of sediments in the upper Walker River to erosion and transport under varying flow conditions. The various methods were chosen following a review of techniques presented in current literature and included: 1) the calculation of incipient motion sediment particle size; 2) the determination of the Shields parameter and the estimation of the critical bed shear stress; 3) a comparison of sediment size to the size of rip rap required for a stable channel lining; and 4) an analysis of the results of the laboratory flume experiments.

The resulting analyses consistently indicated that the sediments in the upper Walker River would be expected to be actively transported under most of the anticipated flow conditions, even at flows as low as 25 cfs. This was consistent with what was observed in the field at each of the locations where sediment samples were collected. Even at relatively low flow conditions, active sediment transport was visually observed. Particles were being transported along the surface of the sediment beds.

The sources of sediment in the watershed are largely the result of natural processes such as erosion during surface runoff and weathering of minerals. There is very little development within the watershed relative to its overall size. Much of the sediment is introduced into the river channel during seasonal runoff events (i.e., spring runoff) and during periodic intense thunderstorms during the summer months.

The installation of settling basins or grit tanks in series throughout the watershed could be considered as a potential solution for excessive sediment transport into the lower Walker River. This would intercept and retain some of the sediments being transported. Periodically, these basins would require cleaning to remove settled materials. This material could potentially be used for different types of building construction or road construction projects. Settling basins have been suggested simply as a means of capturing some of the sediment in the lower reaches of the river. Clearly, these basins will not mitigate the source of the sediments. In addition, the combined Walker River could be lined with rip rap in order to stabilize the channel section. However, the upper reaches of the river would still continue to transport significant quantities of sediment. Further, in order to maintain stability of the river channel during extreme flow events, the required size of the rip rap would be relatively large. Because of the length of the river channel and the required size of the rip rap, lining the river channel with rip rap is not considered to be an economically practical solution.

The flows that particular reaches of the upper Walker River can handle without excessive flooding were predicted using the HEC-RAS model. Except for a few locations, the East Walker River could handle flow up to 400 cfs which is higher than the average annual maximum flow. For flows exceeding 400 cfs, localized flooding was predicted at a few locations along the West Walker River. When flows were around the average annual maximum flow of 700 cfs, localized flooding occurred at a number of locations.

Water quality analyses performed during the current project indicated increased turbidity and slightly higher concentrations of TDS when compared to historical water quality data from 1995. When considered in terms of mass loading, the current quantity of TDS was reduced by approximately 82% when compared with the data from 1995. However, this corresponds to a decrease in flow of approximately 82%.

In summary, the HEC-RAS model developed during this project can be used to evaluate the potential for erosion, sediment transport, and localized flooding along the upper Walker River for various flow scenarios. The HEC-RAS model can be used to assess the potential impacts due to the delivery of increased flows to the lower Walker River resulting from the acquisition of additional water rights within the upper Walker River basin.

In order to minimize the quantities of sediments which are eroded and transported and to limit the potential for localized flooding, water obtained through the acquisition of additional water rights could be delivered to Walker Lake during the months of August, September, and October since historical data indicates that the flows in the combined Walker River at Wabuska are typically lowest during these months, around 40 cfs.

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PROJECT F: DEVELOPMENT OF A DECISION SUPPORT TOOL IN SUPPORT OF WATER RIGHT ACQUISITIONS IN THE WALKER RIVER BASIN

DEVELOPMENT OF A DECISION SUPPORT TOOL IN SUPPORT OF WATER RIGHT ACQUISITIONS IN THE WALKER RIVER BASIN

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Nevada's Walker Lake is one of few desert terminal lakes in North America that supports a diverse fresh water ecosystem. The lake's sole contributing perennial stream, the Walker River, provides a ready source of surface water for crop and pasture irrigation in several desert valleys. Upstream agricultural diversions, beginning in the 1880s, have resulted in a continuous decline in lake level and subsequent increase in salinity, threatening the lake's ecosystem and recreational uses. To balance the demands for water to support local agriculture, preserve the ecosystem, and maintain lake levels, a comprehensive investigation has been undertaken to evaluate the effectiveness of proposed water rights acquisitions with the goal of increasing water deliveries to the lake.

A computer-based Decision Support Tool (DST) is developed, tested, and implemented to evaluate the effectiveness of proposed water rights acquisitions in the Walker River basin. The DST is a combination of three hydrologic models of the Walker River basin developed to capture the spatial and temporal complexity of important relationships among climate, evapotranspiration, river flows, groundwater-surface water exchange along the river, irrigation practices, and groundwater pumping. It uses information gained from other hydrologic modeling studies and incorporates state-of-the-art software and high-resolution spatial products to enhance the accuracy of predicted hydrologic responses. The modeling effort incorporates a geographic information systems (GIS) database of both surface water and groundwater data collected by other investigators on the project (Minor et al., 2009).

PURPOSE AND SCOPE

The purpose of this project is to develop, test, and implement a DST to evaluate the effectiveness of proposed water rights acquisitions in the Walker River basin. The DST is a combination of three hydrologic models developed to capture the complexities of the Walker River system. In this context, the effectiveness of water rights acquisitions is measured by changes in flow in the Walker River near Wabuska, Nevada. The DST will be used to evaluate different water right acquisition options in terms of delivering the maximum amount of water to Walker Lake and providing the best possible opportunities for meaningful research to accomplish the goals specified in the University of Nevada's Desert Terminal Lakes Program; for example, evaluating different water delivery scenarios, determining the consequences of purchasing or leasing junior versus senior water rights, and investigating the practicality of water banking.

Three models are combined to create the DST. First, a physically based hydrologic model (PRMS; Leavesley et al., 1983) of the headwater supply areas is developed. This model is not directly linked to the others, but will be instrumental in future scenarios that may involve potential climate change. Second, groundwater flow models (MODFLOW; Harbaugh et al., 2000) are developed for Smith and Mason valleys, the primary agricultural areas in the Walker River basin. The groundwater models focus on agricultural demand areas and groundwater-surface water interaction in the river corridor. Finally, a streamflow routing and reservoir operations model (MODSIM; Labadie and Larson, 2007) is developed for the entire basin. This encompassing model simulates reservoir operations in the headwaters, incorporates output from the groundwater models, and routes streamflow through the river and its delivery system based on water rights allocations and historical observations (Figure 1). The development of these models and their integration is discussed in detail below.

The DST simulates conditions in the Walker River basin from 1996 to 2006. It encompasses a majority of the Walker River basin, from the headwaters of both the East and West Walker rivers to the U.S. Geological Survey (USGS) gage on the Walker River near Wabuska.

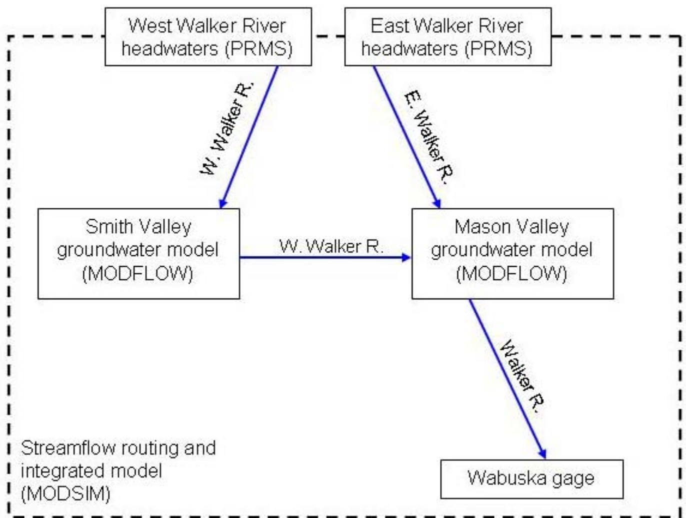


Figure 1. Conceptualization of the DST. The exchange of information between models follows the flow of water through the basin. PRMS models the headwater supply areas. MODFLOW simulates agricultural demand areas in Smith and Mason valleys. MODSIM controls streamflow routing and reservoir operations from the headwaters to the Wabuska gage. Output from the MODFLOW models is used in the MODSIM model.

SITE DESCRIPTION

The Walker River basin straddles the California-Nevada state line, occupying an area of approximately 4,154 mi^2 that includes portions of Mono County in California, and Lyon, Mineral, Douglas, and Churchill counties in Nevada (Figure 2). Altitudes range from about 12,000 ft (3,700 m) in the eastern Sierra Nevada to about 4,200 ft (1,300 m) at Walker Lake. Bridgeport Reservoir (42,450 acre-feet, 52 million m^3, of storage) on the East Walker River, and Topaz Lake (59,400 acre-feet, 73 million m^3, of storage) on the West Walker River provide storage and control downstream flow (Sharpe et al., 2007). From Coleville, CA (near USGS gage 10296500, not shown in Figure 2), the river flows northeast through Antelope Valley and Smith Valley and then into southern Mason Valley. The East Walker River flows northeast from Bridgeport Reservoir before converging with the West Walker River in Mason Valley just south of Yerington, Nevada. Upon exiting Mason Valley near Wabuska, the river turns southward before terminating in Walker Lake. Figure 2 shows the relative locations of these features.

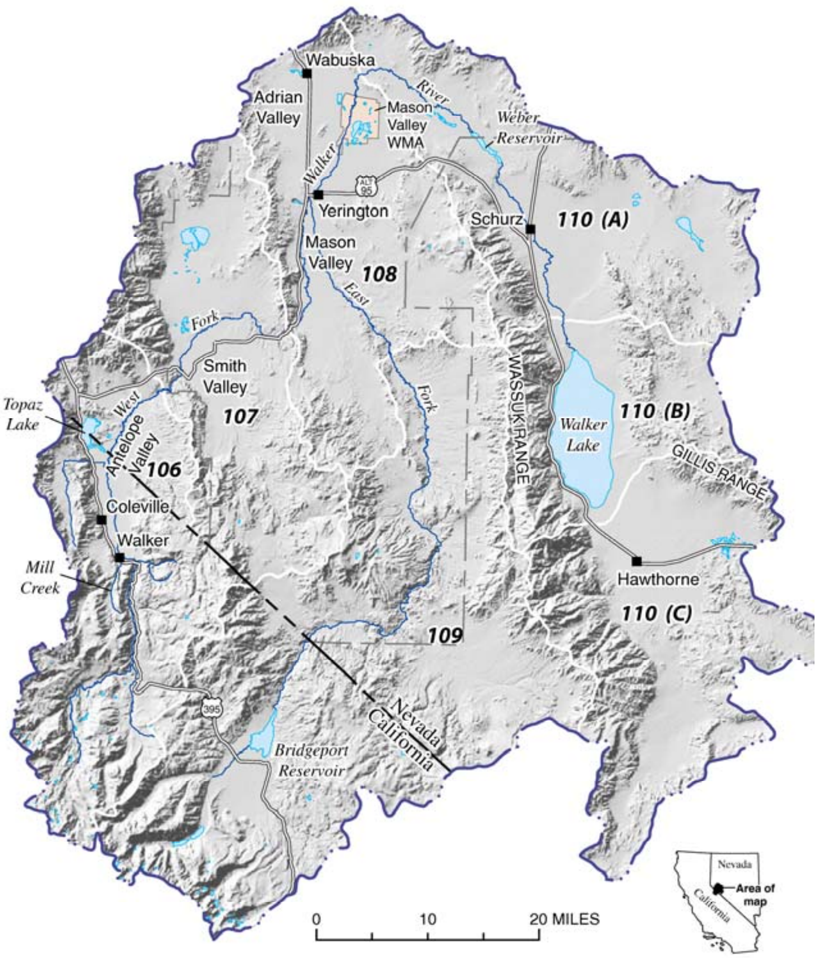


Figure 2. Walker River basin in eastern California and western Nevada (USGS, 2006).

Climate varies significantly with elevation within the basin. At high elevations, most precipitation falls as snow in the cold winter months. Average January temperatures at Sonora Pass (elevation 8,827 ft, 2,690 m) range from 17ºF (-8ºC) to 35ºF (1.7ºC); July temperatures range from 44ºF (6.7ºC) to 72ºF (22ºC). At the lower elevations, there is very little precipitation and summers are dry and hot. Average January temperatures at Yerington (elevation 4,380 ft, 1,340 m) range from 18ºF (-8ºC) to 46ºF (8ºC); July temperatures range from 52ºF (11ºC) to 92ºF (33ºC).

METHODS

The primary objective of this study is to develop, test, and implement a computer-based DST for the Walker River basin to evaluate the effectiveness of proposed water rights acquisitions for increasing water deliveries to Walker Lake. The general approach includes the following: (1) development of a physically based hydrologic model of the headwater supply areas (e.g., snow accumulation and melt, runoff, infiltration, evaporation, etc.); (2) development of a dynamic simulation model of the reservoir and river systems (e.g., streamflow routing and losses, diversions and returns, etc.); (3) development of a physically based hydrologic model of the agricultural demand areas (e.g., irrigation deliveries, evapotranspiration, infiltration, groundwater pumping, groundwater-surface water interaction, etc); and (4) development and implementation of an integrated hydrologic model that combines the first three components to create the DST that will allow other researchers to easily setup, test, and evaluate different water rights acquisition scenarios in the Walker River basin.

The USGS's Precipitation-Runoff Modeling System (PRMS) watershed model will be used to model the headwater supply areas (1). This model is a physically based, distributed hydrologic model that uses empirical relationships and physical laws to represent the hydrologic cycle within a watershed, and has been successfully used to model other complex snowmelt-driven basins in the eastern Sierra Nevada (Jeton, 1999; Rajagopal, 2006). MODSIM will be used to dynamically simulate reservoir operations and river systems within the basin (2). It uses a network approach to model river basins with respect to specific management problems, such as water rights allocations and water distribution. Agricultural demand areas will be simulated using MODFLOW (3). This model is capable of incorporating the complex mechanisms linking irrigation deliveries, evapotranspiration, infiltration, groundwater pumping, and groundwater-surface water interaction. MODSIM will again be used to link the different models into one, integrated DST accessible to planners and managers (4). By modeling the system in this comprehensive way, the available data (Minor et al., 2009) are effectively utilized, and affects of water rights transfers within the basin will be apparent.

The datasets developed by Minor et al. (2009) are utilized in all the models discussed here. For more detail on data sources, development, spatial and temporal extents, etc., please refer to Minor et al. (2009).

HEADWATER SUPPLY AREAS OF THE WALKER RIVER BASIN

The first step in developing the DST, and the purpose of this portion of the study, is to develop a physically based hydrologic model of the headwater supply areas of the Walker River basin. Two PRMS (Leavesley et al., 1983) models will describe the upstream factors that control flow in the East and West Walker rivers. These models will provide upstream boundary conditions for the dynamic simulation model of the reservoir and river systems discussed below. Incorporating physically based hydrologic models of the supply areas will facilitate possible climate change scenarios that may affect flows in the Walker River

The PRMS models developed in this study encompass the headwaters of the East and West Walker rivers as well as some upstream sections (Figure 2). Subbasins within the model domain are defined at seven USGS gages: three on or tributary to the West Walker River, and four on or tributary to the East Walker River (Figure 3). Subbasin characteristics and abbreviations are shown in Table 1. These sections of the Walker River basin supply water to the lower portions of the watershed where most of the demands exist. The East Walker model includes an area of approximately 1,097 mi^2 (2,840 km^2) above USGS streamflow gage 10293500 (E Walker R AB Strosnider D NR Mason, NV). The West Walker model includes an area of approximately 244 mi^2 (630 km^2) above USGS streamflow gage 10296500 (W Walker R NR Coleville, CA). This model includes some lower elevation areas south of Mason Valley as well as the headwaters area (East Walker River subbasin, Figure 3). USGS gages and subbasin abbreviations and characteristics are shown in Table 1; locations are shown in Figure 3. The models run for a period of about 28 years, from October 1980 through September 2008. The calibration period is October 1996 through September 2007.

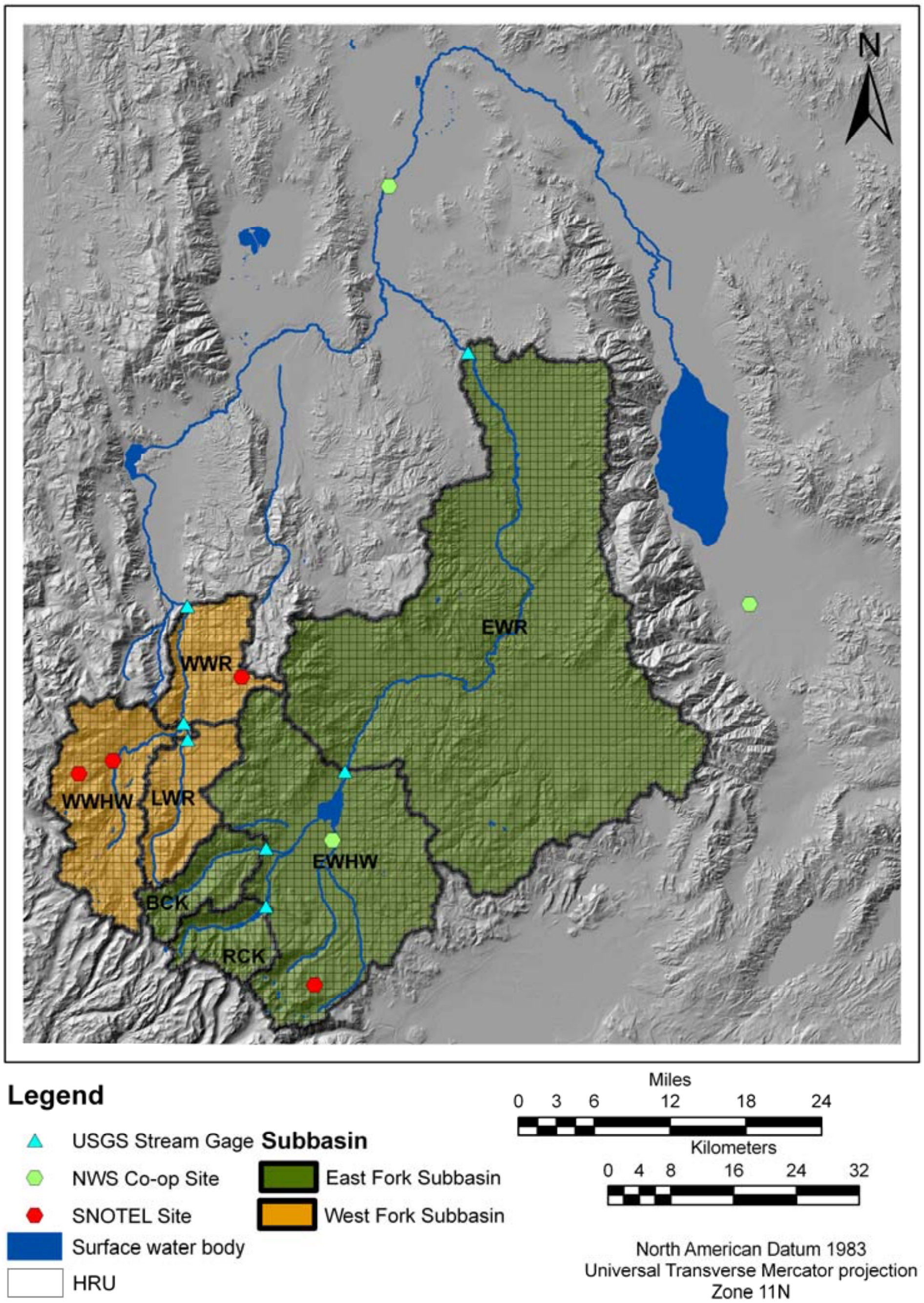


Figure 3. Meteorological sites, streamflow gages, subbasins, and hydrologic features of the Walker River basin. Only gages used in the PRMS headwaters model are shown.

Table 1. Subbasins and gages used in the headwaters model. Gage area refers to the area contributing to flow at the gage (USGS). Subbasin area is the area of the subbasin, not including upstream reaches. The total area for the West Walker subbasins (5, 6, and 7) is 244 mi^2. The total area for the East Walker subbasins (1, 2, 3, and 4) is 1,097 mi^2.

Subbasin Number	Subbasin Name	Subbasin Abbr.	USGS Gage	Gage Area (mi^2)	Subbasin Area (mi^2)	Range of mean HRU elevation (ft)
1	East Walker River near Mason	EWR	10293500	1,100	738.93	4,641 to 11,447
2	E. Walker River Headwaters	EWHW	10293000	359	276.06	6,453 to 12,086
3	Robinson Creek	RCK	10290500	39.1	38.44	7,119 to 12,073
4	Buckeye Creek	BCK	10291500	44.1	43.83	7,018 to 11,368
5	W. Walker River Headwaters	WWHW	10296000	181	117.49	6,758 to 11,273
6	Little Walker River	LWR	10295500	63.1	62.96	6,891 to 11,364
7	W. Walker River near Coleville	WWR	10296500	250	63.65	5,681 to 11,424

PRMS Description

PRMS is a physically based, distributed hydrologic model that uses empirical relationships and physical laws to represent the hydrologic cycle within a watershed (Leavesley et al., 1983). It combines climate variables and physical watershed characteristics (e.g., soil properties, land cover, topography) that affect hydrologic system responses to analyze the system dynamics. The study area is divided into hydrologic response units (HRU), each of which is assumed to respond uniformly to a given input, such as precipitation or snowmelt. An area-weighted sum of daily water and energy balances for each HRU represents the total system response (Jeton, 1999). PRMS requires daily precipitation and maximum and minimum daily air temperature. The precipitation and temperature data are used to simulate the accumulation and depletion of the snowpack. This water is then distributed into a series of tanks based on hydrologic and physical parameters: major tanks include the upper soil zone tank, subsurface tank, and groundwater tank. The sum of the output from each of these tanks is streamflow.

PRMS Model Development

PRMS models are developed for the West Walker River and the East Walker River. Subbasins are delineated for seven gages within the Walker River basin using a digital elevation model (DEM): three on or tributary to the West Walker River, and four on or tributary to the East Walker River (Figure 3). The West Walker model has two internal nodes and one outlet node. The East Walker model has three internal nodes and one outlet node. All nodes correspond to streamflow gages (Table 1). Water is routed from the internal nodes to the outlet node.

Average daily streamflow data are available from the USGS for the seven gages listed in Table 1. These data are used as observed streamflow at the internal and outlet nodes of the East and West Walker headwaters models (Figure 3). Figure 4 shows the average monthly streamflow at the outlets of the East Walker River and west Walker River subbasins. A majority of streamflow occurs between April and July, which is typical of a snowmelt-driven basin.

Three Natural Resource Conservation Service (NRCS) snow-telemetry (SNOTEL) sites and three National Weather Service Co-operative (NWS Co-op) sites are located in the headwaters of the Walker River basin (Figure 3). Daily precipitation and minimum and maximum air temperature data at the centroid of each HRU are required to drive the PRMS model. The HRUs used in the PRMS model are based on a 1-kilometer grid, and because HRU centroids and weather stations rarely align, a ratio of average monthly precipitation from the Parameter-elevation Regression on Independent Slopes Model (PRISM) at the centroid to the PRISM precipitation station is used to adjust the daily timeseries of precipitation and air temperatures (Daly et al., 1994).

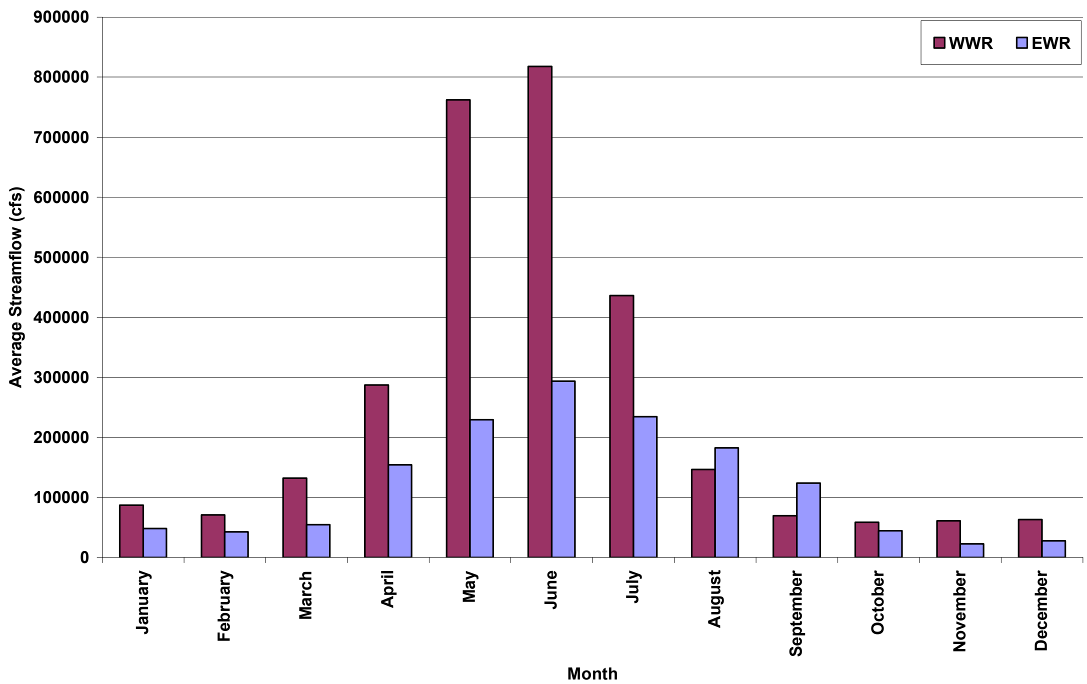


Figure 4. Average monthly streamflow at the outlets of West Walker River and East Walker River.

PRMS uses approximately 80 parameters in its simulation of hydrologic processes (Jeton, 1999). Key parameters and their sources are shown in Table 2, where they are classified into four groups: GIS-derived, Computed, Default, and Calibrated. The GIS-derived parameters are established from digital spatial data. The GIS procedure is based on a spatial dataset that includes surface elevation, slope and aspect; vegetation type and density; and soil depth, rooting depth, and average sand and clay content. Elevations are used to delineate subbasins and route water. Soil data are used to calculate maximum soil moisture and recharge potential based on soil type. Computed parameters are first derived from literature and then modified to represent the conditions in the study area. Calibrated parameters are adjusted during model runs to fit the observed data.

Table 2. PRMS parameter sources and range of values.

Model Parameters	Description of Parameter	Range of Parameter Values	Source of Parameter Values			
			GIS-derived	Computed	Default	Calibration
HRU-based parameters						
CAREA_MAX	Maximum area contributing to surface runoff	0.0 - 1.0				X
COV_TYPE	Vegetation cover type (bare, grass, shrub, and tree)	0 - 3	X			
COVDEN_SUM	Vegetation cover density (in decimal percent) for summer	0.0 - 1.0	X			
COVDEN_WIN	Vegetation cover density (in decimal percent) for winter	0.0 - 1.0	X			
HRU_AREA	HRU area (in acres)		X			
HRU_ASP	HRU aspect (in 45 degree classes)	0 - 315	X			
HRU_DEPLCRV	Index number for snowpack depletion				X	
HRU_ELEV	Mean HRU altitude (in feet)		X			
HRU_GWRES	Index for groundwater reservoir		X			
HRU_LAT	Mean HRU lattitude (in degrees)		X			
HRU-PERCENT_IMPERV	HRU impervious area (in decimal percent) of total HRU area	0.0 - 1.0				X
HRU_SLOPE	Mean HRU slope (in decimal percent)	0.0 - 1.0	X			
HRU_SSRES	Index number of the subsurface reservoir receiving excess water from the HRU soil zone		X			
IMPERV_STOR_MAX	Maximum impervious retention storage for the HRU (in inches)	0.0 - 10.0		X		
JH_COEF-HRU	Air temperature coefficient used in the Jensen-Haise potential-evapotranspiration computations for each HRU	0.005 - 0.6		X		

Table 2. PRMS parameter sources and range of values (continued).

Model Parameters	Description of Parameter	Range of Parameter Values	Source of Parameter Values			
			GIS-derived	Computed	Default	Calibration
RAD-TRNCF	Transmission coefficient for short-wave radiation through winter canopy	0.0 - 1.0		X		
SMIDX_COEF	Coefficient in non-linear contributing area algorithm (computing surface runoff)	0.0001 - 1.0				X
SMIDX_EXP	Exponent in non-linear contributing area algorithm (computing surface runoff)	0.2 - 0.8				X
SNAREA_THRESH	Maximum snow water equivalent below which the snow-covered area depletion curve is applied	0.0 - 200.0		X		
SNOW_INTCP	Snow interception storage capacity for the major vegetation type on an HRU	0.0 - 5.0	X			
SNOW_INFIL_MAX	Maximum infiltration rate for snowmelt (in inches per day)	0.0 - 20.0				X
SOIL2GW_MAX	Amount of soil water excess for an HRU that is routed directly to the associated groundwater reservoir	0.0 - 5.0				X
SOIL_MOIST INIT	Initial value for available water in the soil profile (in inches)	0.0 - 20.0		X		
SOIL_MOIST_MAX	Maximum value for available water in the soil profile (in inches)	0.0 - 20.0	X			
SOIL_RECH_INIT	Initial value for available water in the soil recharge zone (in inches)	0.0 - 10.0		X		
SOIL_RECH_MAX	Maximum value for available water in the soil recharge zone (in inches)	0.0 - 10.1	X			
SOIL_TYPE	HRU soil type (clay, loam, or sand)	1 - 3	X			
SRAIN_INTCP	Summer interception storage capacity for major vegetation type on an HRU (in inches)	0.0 - 5.0		X		
TMAX_ADJ	HRU maximum temperature adjustment to HRU temperature based on aspect and slope	-10.0 - 10.0		X		
TMIN_ADJ	HRU minimum temperature adjustment to HRU temperature based on aspect and slope	-10.0 - 10.0		X		
TRANSP_BEG	Month to begin summing maximum temperature for each HRU; when sum is greater than or equal to TRANSP_MAX transpiration begins	1 - 12			X	
TRANSP_END	Last month for transpiration computations	1 - 12			X	
TRANSP_TMAX	Temperature index to determine the specific date of start of transpiration period	0.0 - 1000.0			X	
WRAIN_INTCP	Winter rain interception storage capacity for major vegetation type on an HRU (in inches)	0.0 - 5.0		X		

Table 2. PRMS parameter sources and range of values (continued).

Model Parameters	Description of Parameter	Range of Parameter Values	Source of Parameter Values			
			GIS-derived	Computed	Default	Calibration
Subsurface and groundwater reservoir-based parameters						
SSR2GW_RATE	Coefficient to route water from the subsurface to groundwater reservoir	0.0 - 1.0				X
SSRCOEF_LIN	Linear subsurface routing coefficient to route subsurface storage to streamflow	0.0 - 1.0				X
SSRCOEF_SQ	Non-linear subsurface routing coefficient to route subsurface storage to streamflow	0.0 - 1.0				X
GWFLOW_COEF	Groundwater routing coefficient to obtain groundwater flow contribution to streamflow	0.0 - 1.0				X
GWSINK_COEF	Groundwater sink coefficient to compute seepage from each reservoir to groundwater sink	0.0 - 1.0				X
GWSTOR_INIT	Storage in each groundwater reservoir at the beginning of the simulation (in inches)	0.0 - 20.0				X
Distributed temperature- and precipitation-dependent parameters						
HRU_MONTH_MAX	Average monthly maximum temperature for each HRU (in F)			X		
HRU_MONTH_MIN	Average monthly minimum temperature for each HRU (in F)			X		
HRU_MONTH_PPT	Average monthly precipitation for each HRU (in inches)			X		
PSTA_NUSE	Index of rain stations used for precipitation calculations in (sub)basin		X			
TSTA_NUSE	Index of temperature stations used for temperature calculations in (sub)basin		X			
Selected non-distributed parameters						
ADJMIX_RAIN	Monthly factor to adjust rain proportion in a mixed rain/snow event	0.0 - 3.0				X
DEN_MAX	Average maximum snowpack density	0.1 - 0.8				X
EMIS_NOPPT	Emissivity of air on days without precipitation	0.757 - 1.0				X
FREEH2O_CAP	Free-water holding capacity of snowpack expressed as decimal fraction of total snowpack water equivalent	0.01 - 0.2				X
JH_COEF	Monthly air temperature coefficient used in Jensen-Haise potential evapotranspiration computations	0.005 - 0.06			X	
MELT_FORCE	Julian date to force snowpack to spring snowmelt	1 - 366				X

Table 2. PRMS parameter sources and range of values (continued).

Model Parameters	Description of Parameter	Range of Parameter Values	Source of Parameter Values			
			GIS-derived	Computed	Default	Calibration
MELT_LOOK	Julian date to start looking for spring snowmelt	1 - 366				X
POTET_SUBLIM	Proportion of potential ET that is sublimated from snow surface	0.1 - 0.75				X
SETTLE_CONST	Snowpack settlement time constant	0.01 - 0.5				X
TMAX_ALLRAIN	Maximum temperature above which all precipitation is simulated as rain	0 - 90				X
TMAX_ALLSNOW	Maximum temperature below which all precipitation is simulated as snow	-10 - 40				X

PRMS calibration

Calibration focuses on fitting water balance components such as precipitation, snow water equivalent, and streamflow. A manual, step-wise calibration method is used to modify parameter values such that simulated results fit the observed water balance: peak flows, snow melt timing, and baseflow. The calibration period is October 1996 through September 2007.

Observed and simulated streamflow for the calibration period are shown in Figures 5 through 11. The West Walker models have better fit than the East Walker models, largely due to the complications introduced by Bridgeport Reservoir. Robinson Creek and Buckeye Creek, both above the reservoir, show a much better fit than the lower subbasins on the East Walker River.

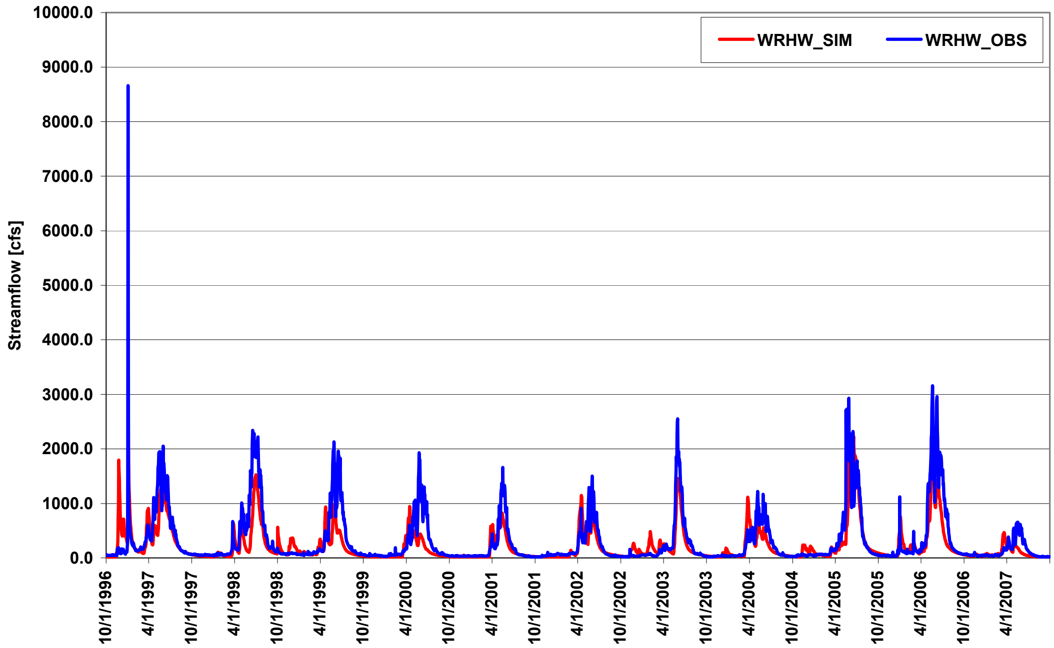


Figure 5. Observed and simulated streamflow at the outlet of the West Walker headwaters subbasin for the calibration period.

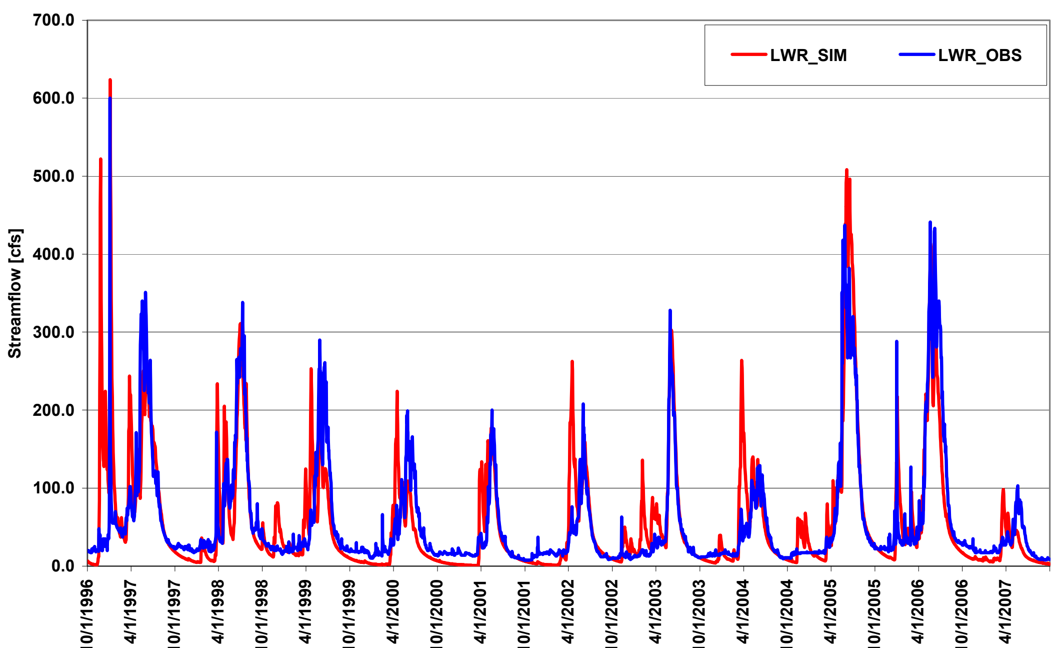


Figure 6. Observed and simulated streamflow at the outlet of the Little Walker River subbasin for the calibration period.

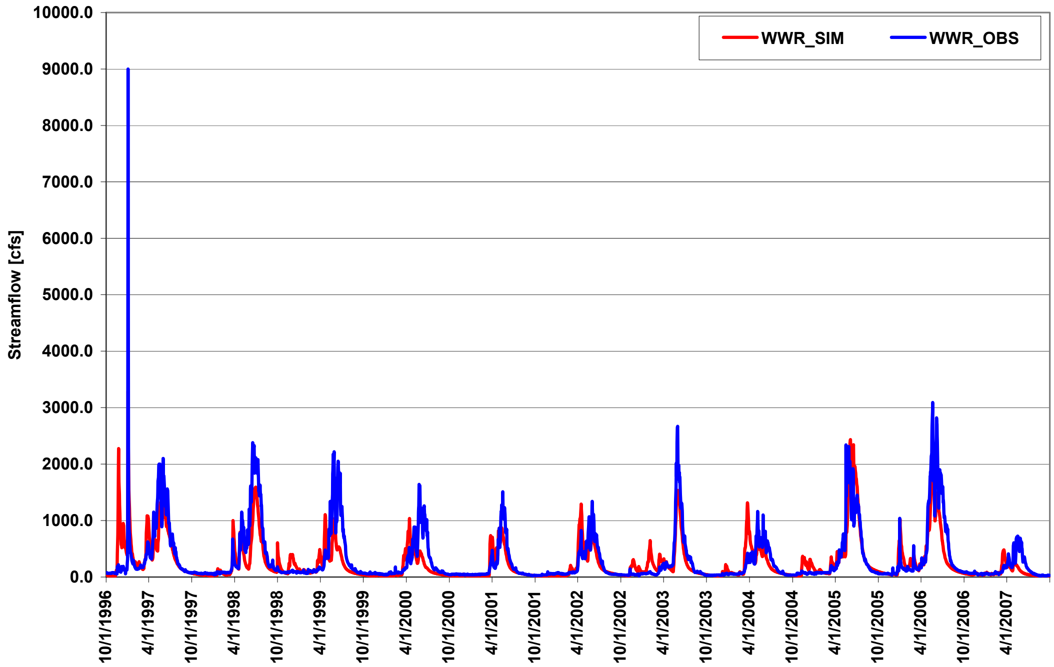


Figure 7. Observed and simulated streamflow at the outlet of the West Walker River subbasin for the calibration period.

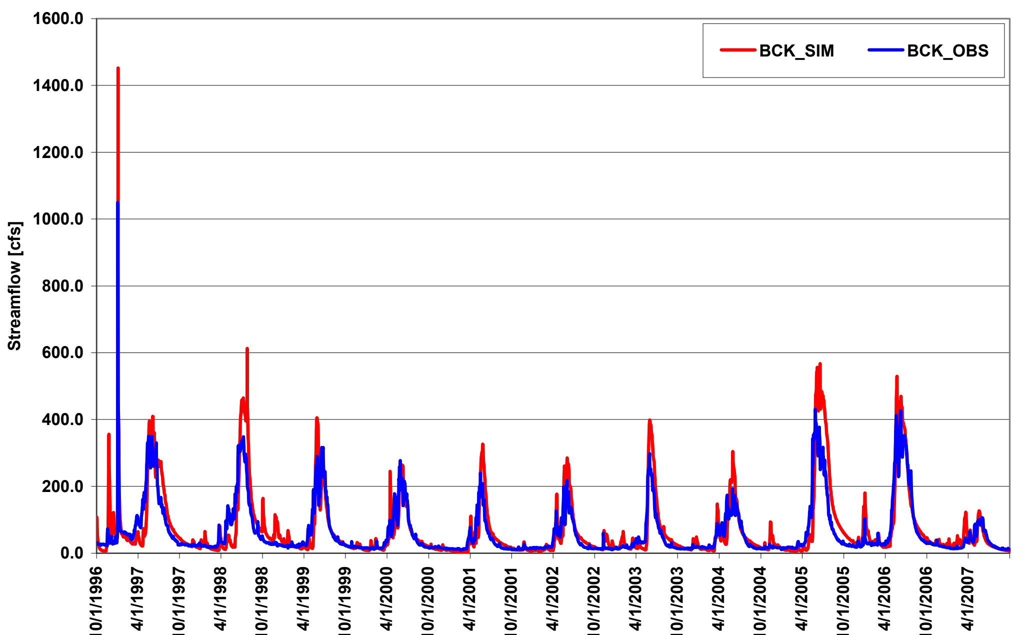


Figure 8. Observed and simulated streamflow at the outlet of the Buckeye Creek subbasin for the calibration period.

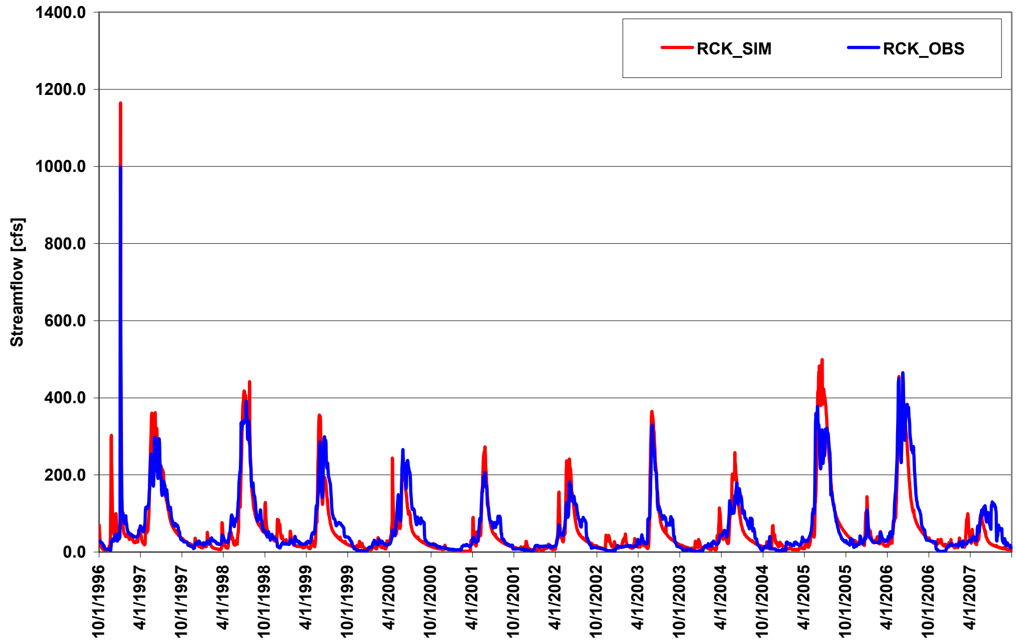


Figure 9. Observed and simulated streamflow at the outlet of the Robinson Creek subbasin for the calibration period.

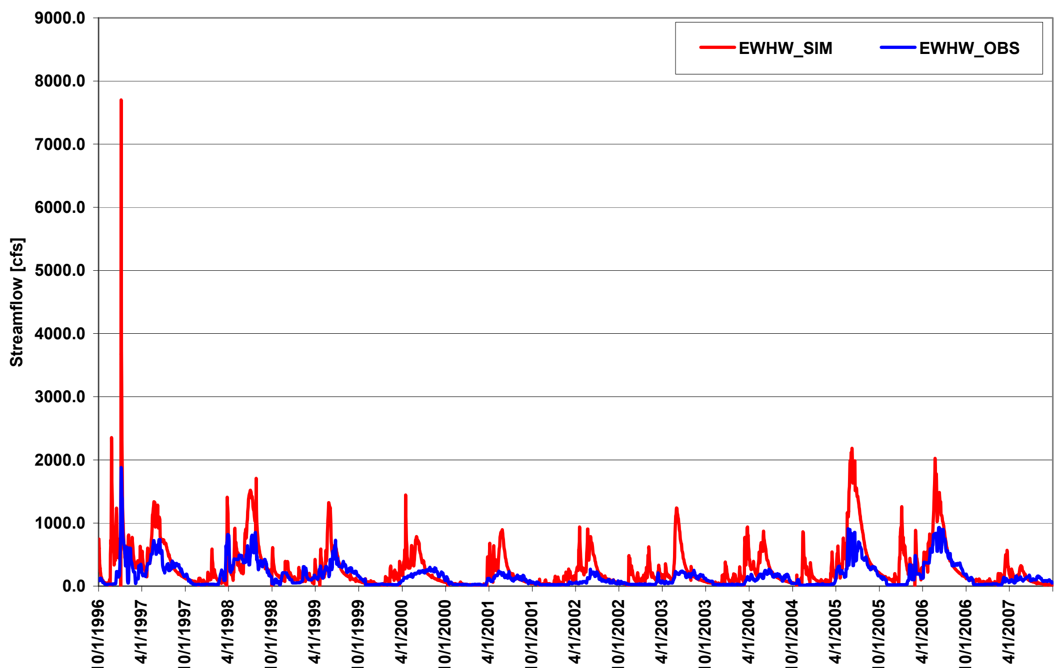


Figure 10. Observed and simulated streamflow at the outlet of the East Walker headwaters subbasin for the calibration period.

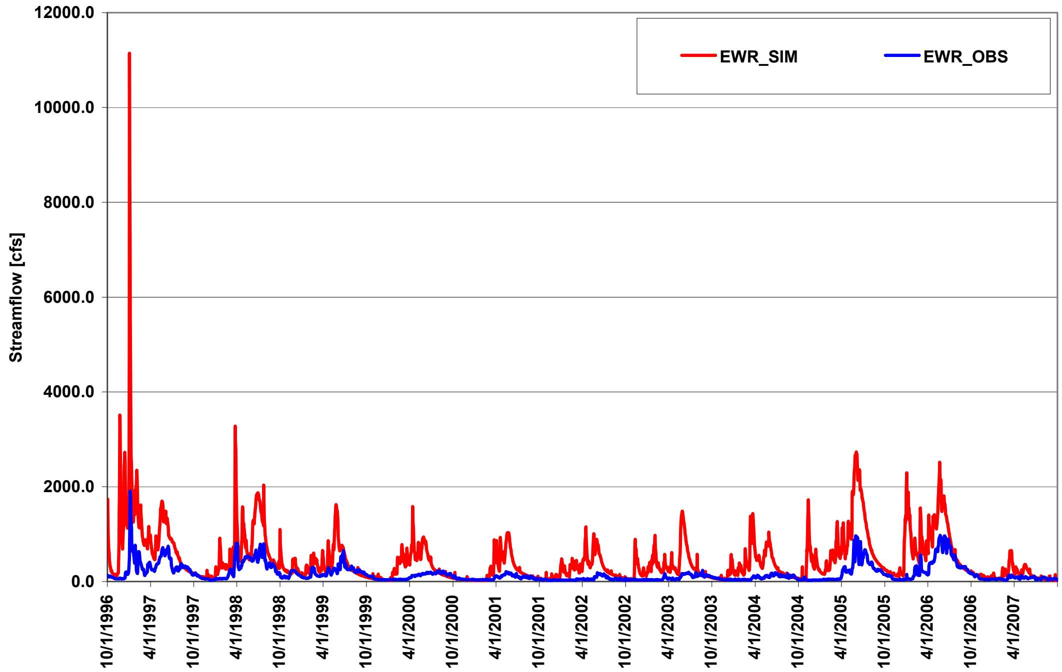


Figure 11. Observed and simulated streamflow at the outlet of the East Walker River subbasin for the calibration period.

PRMS Model Evaluation

All subbasins in the West Walker River basin show reasonable streamflow results. In general, simulated streamflow begins to rise earlier than the observed, which is likely related to early snowmelt in the model. The model does not represent rain on snow events well; for example the flood in January 2007 is underpredicted. In the West Walker headwaters subbasin, the model generally underpredicts streamflow peaks, but the timing is well represented (Figure 12). In the Little Walker River subbasin, the model represents streamflow peaks and timing well, but is unable to reproduce the observed baseflow (Figure 13). In the West Walker River subbasin, the model is again underprediciting peaks, which is directly related to the underprediciting in West Walker headwaters as water is routed from the West Walker headwaters to the West Walker River subbasin gage (Figure 14).

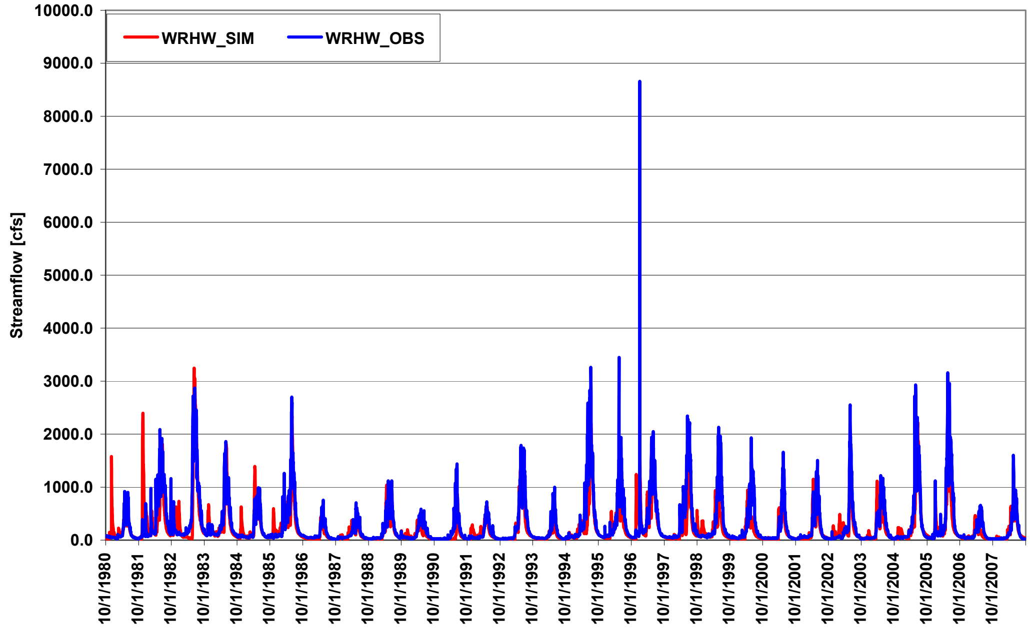


Figure 12. Observed and simulated streamflow at the outlet of the West Walker headwaters subbasin from water year 1980 through 2007.

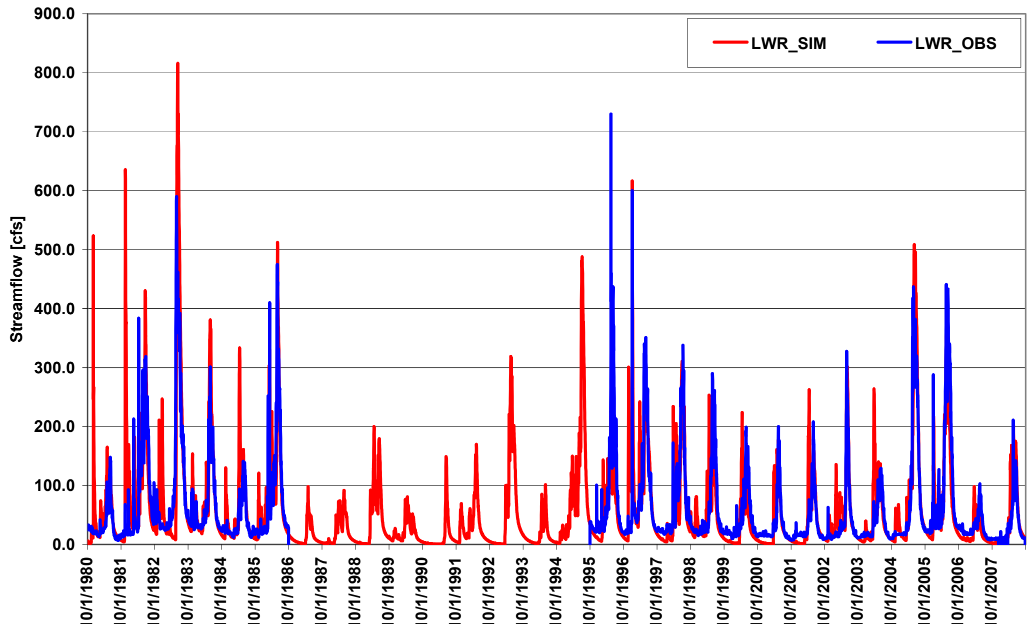


Figure 13. Observed and simulated streamflow at the outlet of the Little Walker River subbasin from water year 1980 through 2007.

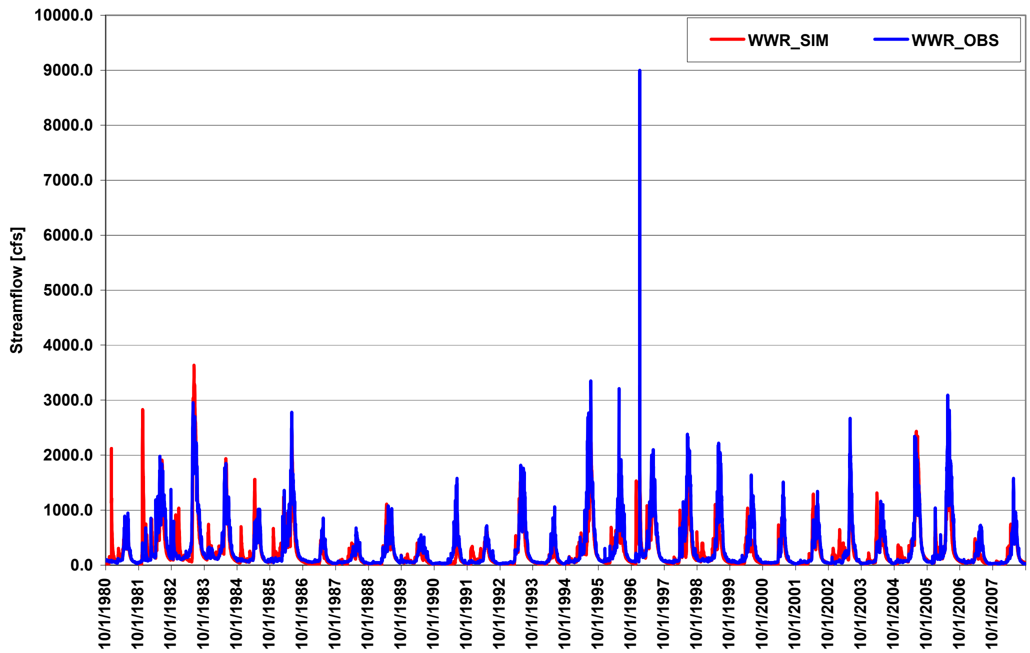


Figure 14. Observed and simulated streamflow at the outlet of the West Walker River subbasin from water year 1980 through 2007.

The results for the East Walker River basin are mixed. Both the Buckeye Creek (Figure 15) and Robinson Creek (Figure 16) models reasonably simulate the timing and amount of peak streamflow. The observed streamflow in Robinson Creek shows a delay in the late spring; however, the streamflow gage is located below the Twin Lakes, which could explain the delay in observed snowmelt. The two lower subbasins, East Walker headwaters subbasin and East Walker River subbasin, both overpredict streamflow and poorly represent the annual hydrograph, which is expected in developed or controlled basins (Figures 17 and 18, respectively). The East Walker headwaters gage is directly downstream from Bridgeport Reservoir, which strongly effects streamflow. Additionally, streamflow in the East Walker River subbasin is affected by diversions for agricultural irrigation.

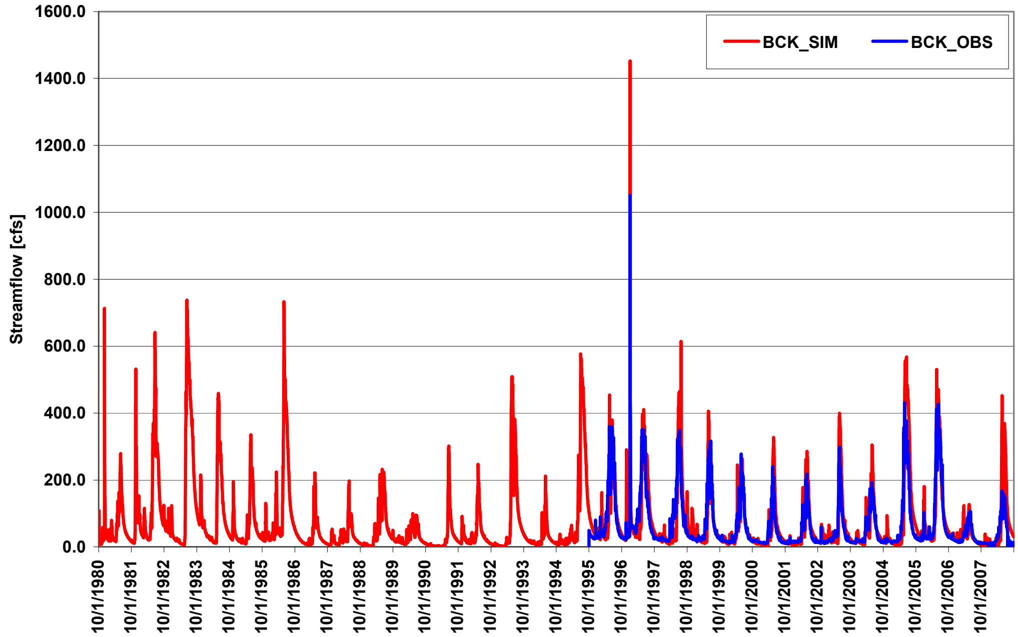


Figure 15. Observed and simulated streamflow at the outlet of the Buckeye Creek subbasin from water year 1980 through 2007.

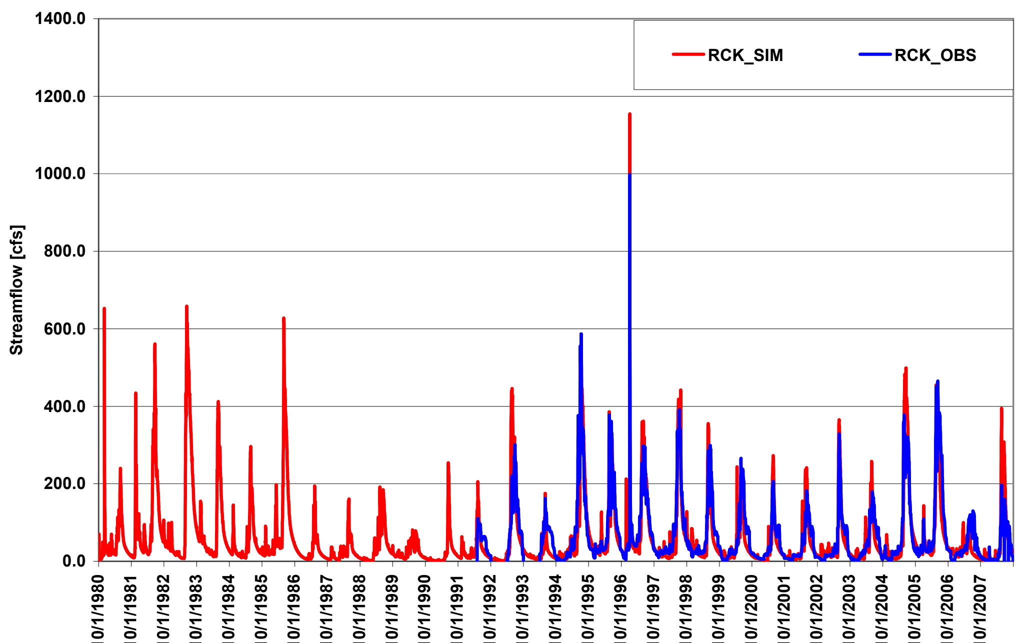


Figure 16. Observed and simulated streamflow at the outlet of the Robinson Creek subbasin from water year 1980 through 2007.

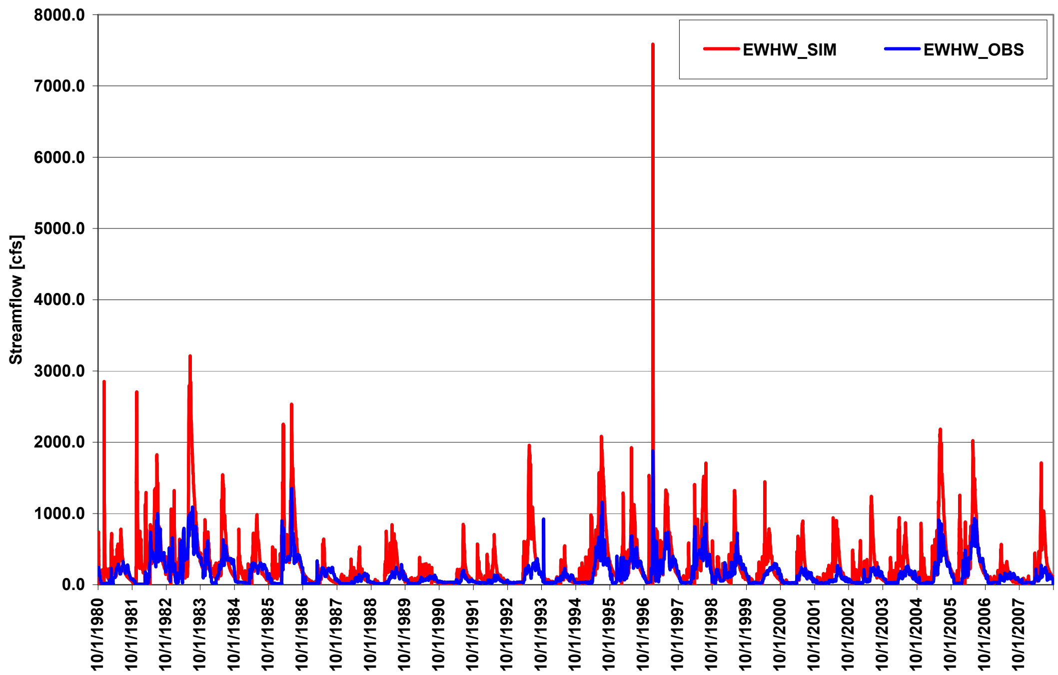


Figure 17. Observed and simulated streamflow at the outlet of the East Walker headwaters subbasin from water year 1980 through 2007.

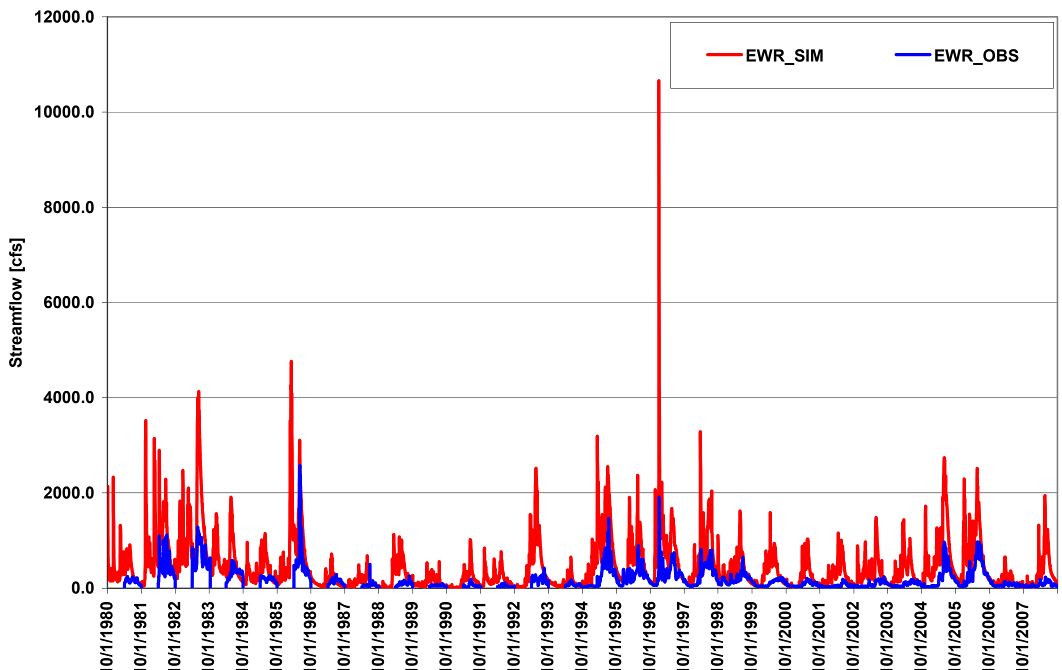


Figure 18. Observed and simulated streamflow at the outlet of the East Walker River subbasin from water year 1980 through 2007.

PRMS Conclusions

The PRMS models perform well in the West Walker River headwaters: timing of the annual hydrograph was well represented, although streamflow peaks were slightly underestimated. The affects of reservoir operations and diversions for agricultural irrigation in the East Walker River basin are not captured by the model, which causes poor representation of annual hydrograph timing as well as overestimation of streamflow peaks. The models of the headwater supply areas of the Walker River basin are developed primarily as an upstream boundary condition to facilitate climate change scenarios in the demand-driven models discussed below. The current models are adequate for this purpose; however, including operations at Bridgeport Reservoir could improve the East Walker model predictions.

LINKING SURFACE WATER AND GROUNDWATER PROCESSES IN THE WALKER RIVER BASIN: MASON AND SMITH VALLEY GROUNDWATER MODELS

A physically based hydrologic model of the agricultural demand areas is developed using MODFLOW (Harbaugh *et al*., 2000). The MODFLOW models will focus on the nature of groundwater-surface water exchange in the river corridor and consumptive use by groundwater pumping and evapotranspiration (ET) in Mason and Smith valleys, intensively irrigated agricultural basins adjacent to the Walker River. Separate groundwater models are used to simulate the unconsolidated basin-fill aquifers within Mason and Smith valleys. These models are linked to surface water models via the streamflow-routing (SFR1) package (Prudic et al., 2004) and a water balance method applied to agricultural demand areas, referred to as hydrologic response units (HRUs). The groundwater models are calibrated and verified using groundwater levels as well as observed river flows and diversions to capture diverse climatic conditions and associated groundwater-surface water responses. The models simulate the period from 1996 to 2006.

Site Description

Mason Valley

Mason Valley (Figure 19) is the largest irrigated agricultural area within the Walker River basin. Relatively large volumes of groundwater pumping supplement existing surface water rights. Figure 19 shows irrigation wells in production from 1996 to 2006. Mason Valley includes irrigated areas along the West, East, and Main Walker rivers and the town of Yerington, Nevada.

The Mason Valley Groundwater Model (MVGM) domain encompasses the alluvial portion of Mason Valley, an area of 230 mi^2 (595 km^2). All crop irrigation and groundwater development in Mason Valley occurs on the alluvium, which consists of unconsolidated gravel, sand, silt, and clay (Huxel and Harris, 1969; Hess and Johnson, 1997). Surrounding bedrock has a low hydraulic conductivity when compared to the valley-fill deposits; therefore, the alluvial aquifer is considered an isolated unit within the valley with negligible groundwater flowing out of the valley through consolidated rock units. Valley-fill deposits near the river are well-sorted beds of clay, silt, sand, and gravel. Huxel and Harris (1969) estimate transmissivities from several pump tests from less than 14,000 gal/d/ft (174 m^2/d) to 270,000 gal/d/ft (3,353 m^2/d). Low transmissivities are associated with fan deposits, while the largest transmissivities are found in sand and gravels deposited by persistent courses of the river. Wells are primarily screened in the upper 426 ft (130 m) of alluvium. However, some wells are listed as penetrating to depths greater than 800 ft (243 m) without encountering bedrock and it is believed the sediments may be more than 1,000 ft (304 m) deep in the deeper parts of the valley (Huxel and Harris, 1969).

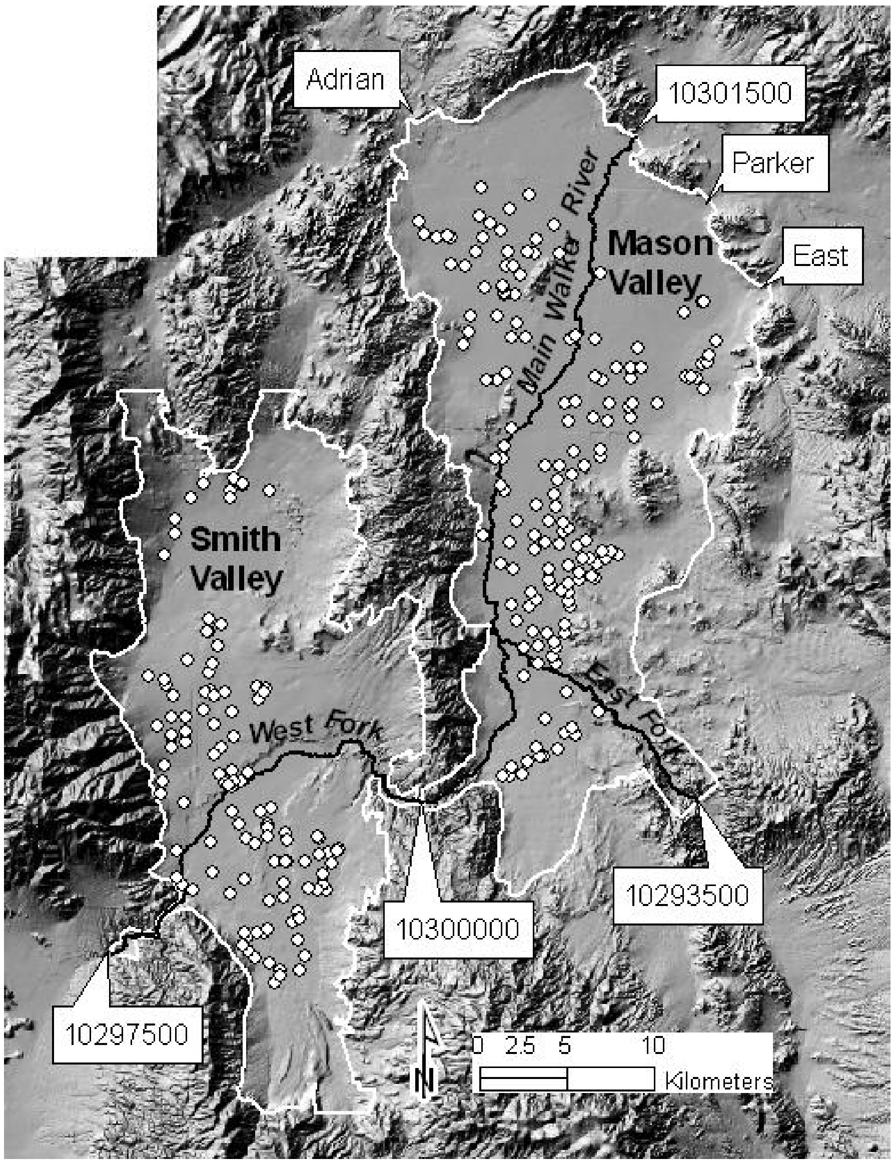


Figure 19. Model domains (white outline) for Smith Valley and Mason Valley groundwater models. USGS gaging stations (Hoye = 10297500; Hudson = 10300000; Strosnider = 10293500; Wabuska = 10301500) and groundwater gaps (Adrian, Parker, and East) are marked. Irrigation wells (1996-2006) are shown with white circles.

Percolation of irrigation water from diversions along the Walker River (West, East, and Main) is the primary source of groundwater recharge to the alluvial aquifer. Huxel and Harris (1969) estimate irrigation recharge at 70,000 acre-feet per year (AFY) (86 million m^3 per year; MPY), while Myers (2001a) estimates 57,500 AFY (71 million MPY). Huxel and Harris (1969) and Myers (2001a) agree that mountain-block recharge is significantly less than irrigation recharge. Huxel and Harris (1969) estimate total interbasin groundwater inflow beneath the East and West Walker rivers at 500 AFY (617,000 MPY), while total groundwater outflows are estimated at 1,550 AFY (2 million MPY) via Wabuska, Adrian Gap, and Parker Gap. Significant water discharge from the basin occurs as ET from irrigated crops as well as phreatophytes, riparian vegetation, and wetlands. Huxel and Harris (1969) estimate crop consumption at 41,000 AFY (51 million MPY), with phreatophytes consuming an additional 57,000 AFY (70 million MPY). Myers (2001a) lumps crop, riparian, and wetland vegetation ET into a total of 77,100 AFY (95 million MPY). Huxel crop ET rates range between 0.5 ft per year (0.15 m per year) for irrigated native pastures to 1.6 ft per year (0.046 m per year) for croplands (Houston, 1950), while non-agricultural vegetation ET rates ranged from 0.1 ft per year (0.030 m per year) for phreatophytes at edges of valley floor, to 2.0 ft per year (0.61 m per year) for willows (White, 1932; Young and Blaney, 1942; Houston, 1950; Robinson, 1958). Myers (2001a) ET rates for irrigated lands (2.0 ft per year; 0.61 m per year), wetlands (1.25 ft per year; 0.38 m per year), riparian vegetation (3.0 ft per year; 0.91 m per year), and phreatophytes (2.8 ft per year; 0.85 m per year) are determined via calibration to best match observed water levels in a steady-state groundwater model of Mason Valley. Rates used by Huxel and Harris (1969) are quite low, while Myers (2001a) rates compare more favorably to recent work by Maurer and Berger (2006) and Maurer et al. (2005) and the Nevada State Engineer (Justin Huntington, written communication, July 2008), where ET rates adjusted for precipitation for non-agricultural vegetation range from 1.43 ft per year (0.44 m per year) to nearly 4.0 ft per year (1.22 m per year), and crop consumption rates from 2.63 ft per year (0.80 m per year) to 3.62 ft per year (1.10 m per year).

River flows enter the MVGM domain at Hudson (USGS gage 10300000) on the West Walker River and Strosnider (USGS gage 10293500) on the East Walker River. The main Walker River exits the valley at Wabuska (USGS gage 10301500). During the irrigation season, discharge at Wabuska is substantially less than the combined flow from the two forks because of diversions for irrigation.

<u>Smith Valley</u>

Smith Valley (Figure 19) is located directly upstream of Mason Valley on the West Walker River. The West Walker River enters the valley at Hoye (USGS gage 10297500) and exits at Hudson. Similar to the MVGM, the Smith Valley Groundwater Model (SMGM) domain is defined as the alluvial area, 176 mi^2 (455 km^2), in the basin based on geologic maps (Hess and Johnson, 1997). Irrigation wells in Smith Valley are shown in Figure 19. Hydraulic conductivity zones are defined based on transmissivity data collected by Rush and Schroer (1975), modeled units from Myers (2001b), and two pumping tests performed by the Desert Research Institute (Anna Knust, DRI, written communication, July 2008) near Artesia Lake. A fault runs north-south to the southeast of Artesia Lake. Rush and Schroer (1975) and Myers (2001b) suggest the fault is a barrier to flow.

Perennial yield estimates, representing mountain-block recharge, are much more substantial than estimates for mountain-block recharge in Mason Valley. Differences are attributed to large volumes of water originating in the mountains to the south of the SVGM domain. Approximately 118 AFY (145,000 MPY) of groundwater moves into Smith Valley through the alluvial sediments in Hoye Canyon (Myers, 2001b). Little water leaves Smith Valley as interbasin flow at the Hudson gage: estimates range from 132 AFY (163,000 MPY) (Myers, 2001b) to 250 AFY (308,000 MPY) (Huxel and Harris, 1969). Primary discharge of water from Smith Valley occurs via river flows exiting at Hudson and from ET from crops, phreatophytes, and riparian and wetland vegetation.

Hydrologic response units

Agricultural demand areas are represented by HRUs. Of the 28 HRUs in Mason Valley, 23 are tied to major delivery ditches, five are associated with river pumps, and one is defined as using only groundwater to meet irrigation requirements (Figure 20). Of the 11 HRUs in Smith Valley, nine are associated with major delivery ditches, one with Desert Creek and one with groundwater (Figure 22). Major crops for each agricultural field (Figure 21 for Mason Valley and Figure 23 for Smith Valley) are determined using aerial photos from 2005 through 2007 (Minor et al., 2009). Crop types are then separated into four categories based on crop ET demand (Table 3). Fallow fields are assumed a leafy crop (e.g., alfalfa) if irrigation water is available. Table 4 shows the area of each crop type for HRUs in Mason and Smith valleys.

Monthly crop ET demands are obtained from the Nevada State Engineer (Justin Huntington, written communication, July 2008) and are provided in Table 5. Negative ET values indicate precipitation is greater than crop ET and is recharging the soil column to reduce the annual water requirement.

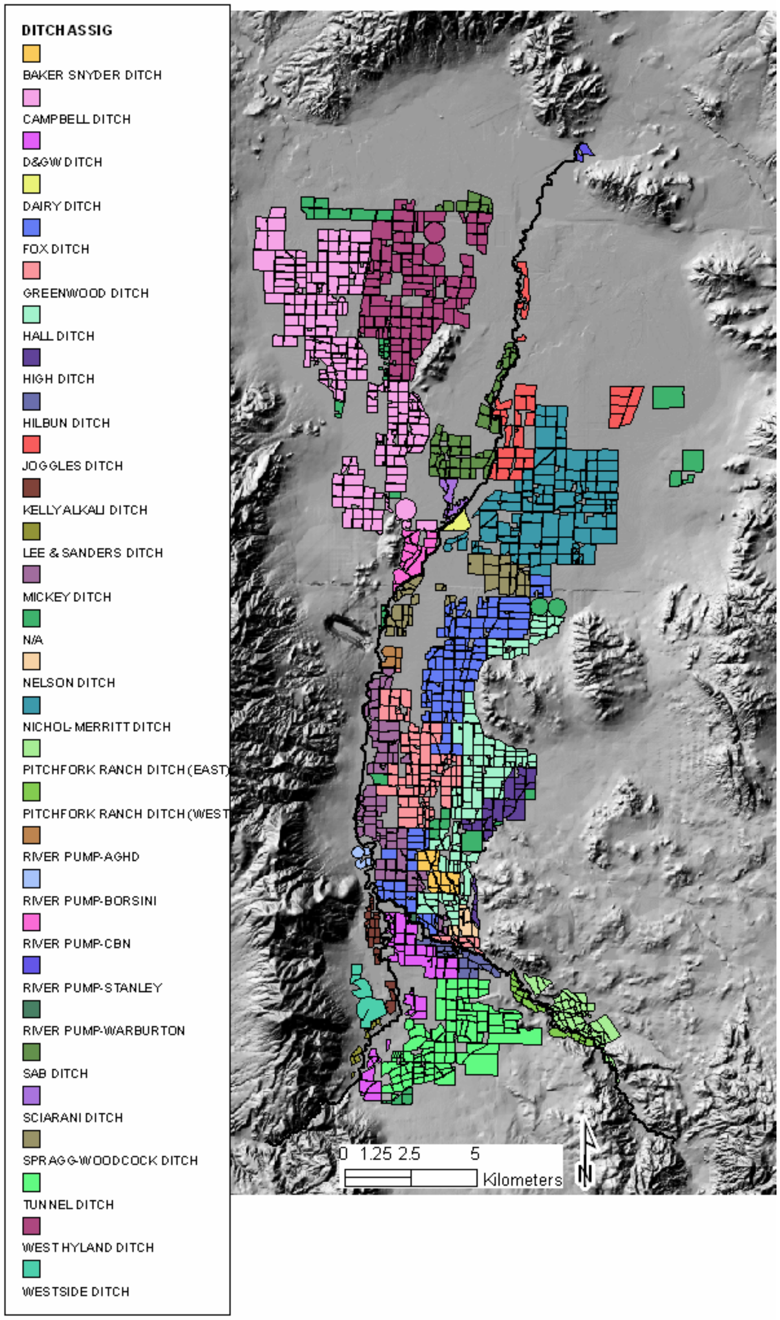


Figure 20. Mason Valley HRUs based on major delivery ditches, river pumps, and groundwater demand. NA = Groundwater HRU. River is shown as a black line.

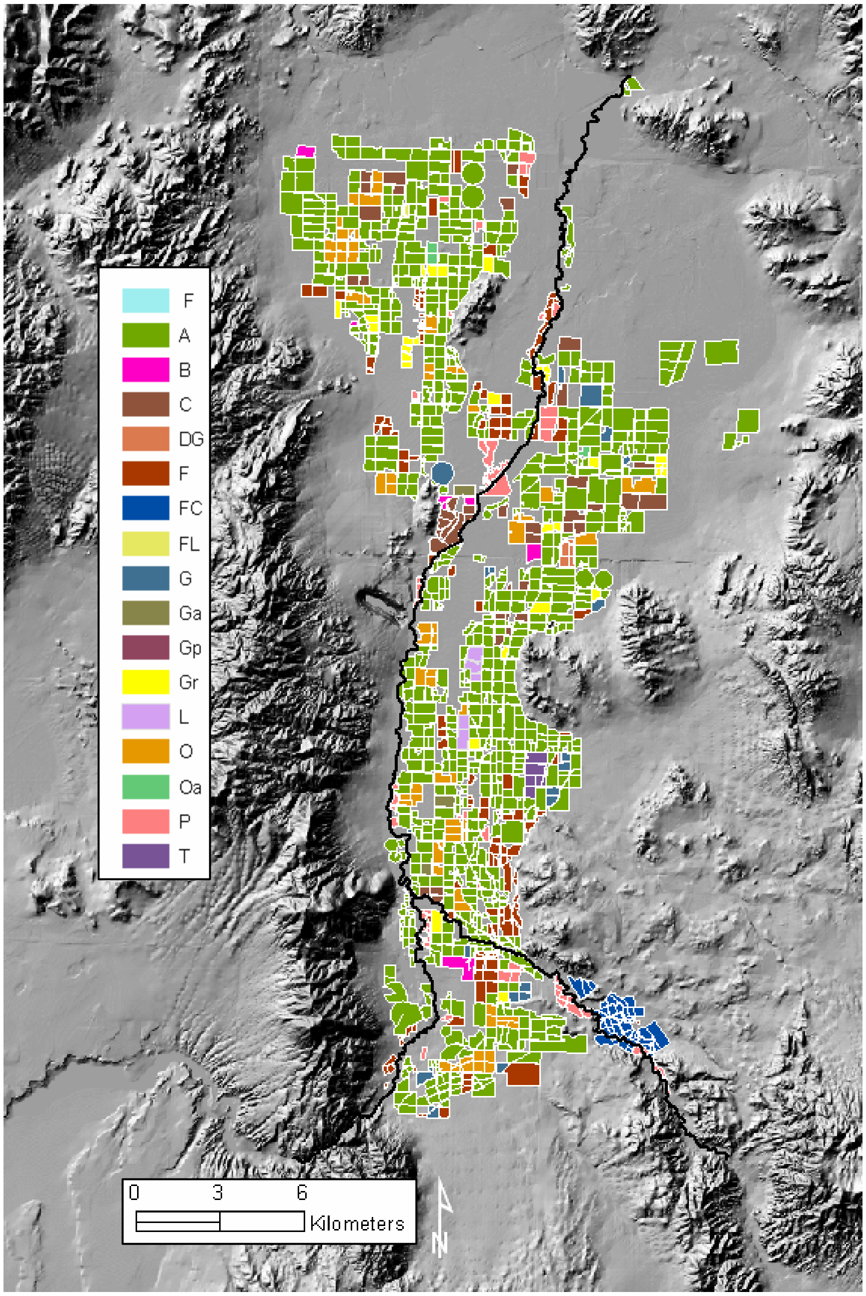


Figure 21. Mason Valley major crop types for each agricultural field. Crop symbols are defined in Table 3 with consumption demand provided in Table 5. River is shown as a black line.

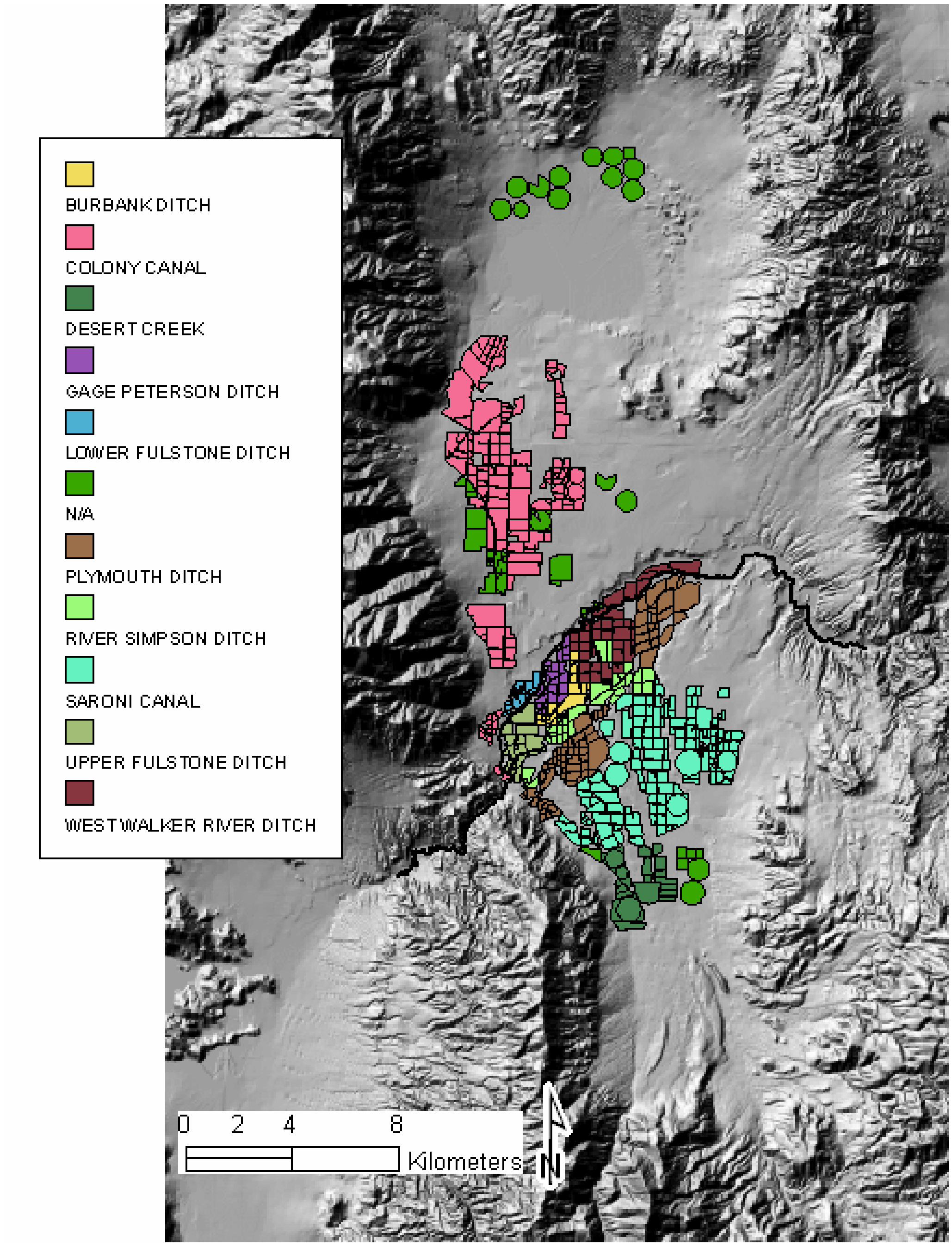


Figure 22. Smith Valley HRUs based on major delivery ditches and groundwater demand. NA = Groundwater HRU. River shown as black line.

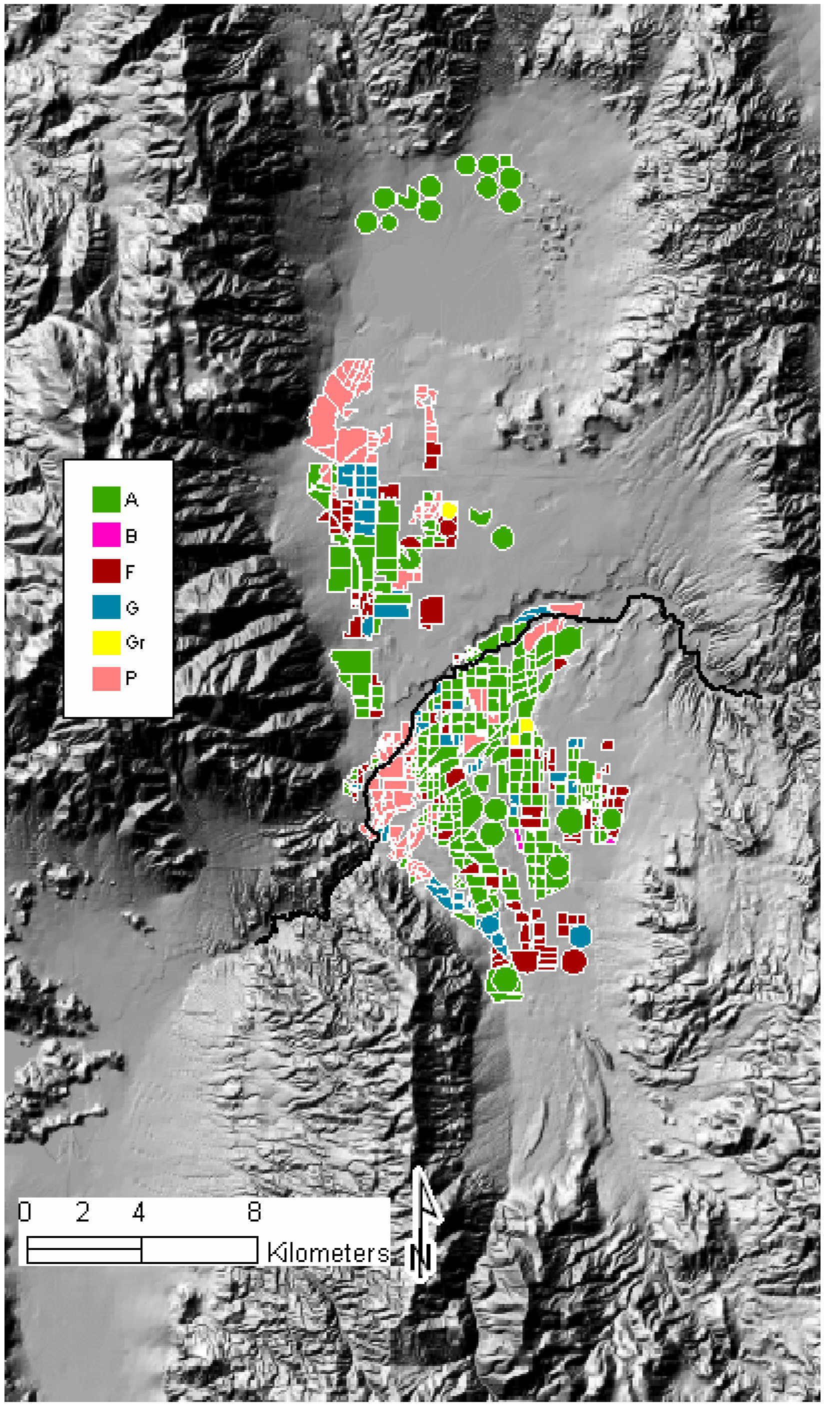


Figure 23. Smith Valley major crop types for each agricultural field. Crop symbols are defined in Table 3 with consumption demand provided in Table 5. River shown as black line.

Table 3. Individual crops separated into four broad categories for model use.

type	symbol	Leafy	Root	Low Duty	Non-Irrigated
Alfalfa	A	x			
Grain	Gr	x			
Corn	C	x			
Onion	O		x		
Oat	Oa	x			
Fallow	F	x			
Garlic	Ga		x		
Grass	G			x	
Pasture	P			x	
Turf	T		x		
Lettuce	L		x		
Dry Grass	DG			x	
Brush	B				x
Grapes	Gp		x		
Feed Lot	FL				x
Forage Crop	FC			x	

Table 4. Designated crop areas (acres) per HRU in Mason Valley and Smith Valley.

	HRU Name	ID	Total	Leafy	Root	Low	Not Irrigated
Mason Valley	Baker Snyder	1	351	346	0	5	0
	Pitchfork-East&West	2	1,016	2	0	1,014	0
	East Walker Pumps-Warburton	3	17	17	0	0	0
	Fox	4	3,305	3,025	280	0	0
	Greenwood-Howard	5	1,961	1,550	393	17	0
	Hall	6	2,787	2,417	304	66	0
	High	7	788	626	40	122	0
	Hilbun	8	369	269	0	100	0
	Mickey	9	1,679	1,378	243	58	0
	Nelson	10	168	168	0	0	0
	Campbell-McLeod	11	6,323	5,220	883	154	66
	Dairy	12	110	0	0	110	0
	Joggles	13	1,342	1,143	0	199	0
	Nichol-Merritt	14	4,684	4,160	315	209	0
	SAB	15	1,200	1,165	26	9	0
	Sciarani	16	167	0	0	167	0
	Spragg	17	1,002	684	111	133	74
	West Hyland	18	4,021	3,784	67	142	29
	Main River Pumps-AGHD	19	130	0	130	0	0
	D&GW	20	1,165	898	0	116	152
	Kelly Alkali	21	285	285	0	0	0
	Lee Sanders	22	82	82	0	0	0
	Tunnel	23	2,972	2,396	411	165	0
	West Side	24	387	387	0	0	0
	Groundwater	25	1,761	1,694	0	66	0
	West Walker Pumps-Borsini	26	105	105	0	0	0
	Main River Pumps-CBN	27	443	383	0	0	60
	Main River Pumps-Stanley	28	107	107	0	0	0
Smith Valley	Burbank	1	380	279	0	101	0
	Colony	2	5,711	3,042	0	2,669	0
	Desert Creek	3	1,213	1,000	0	213	0
	Gage Peterson	4	442	291	0	151	0
	Lower Fulstone	5	207	24	0	183	0
	Plymouth	6	2,182	1,673	0	509	0
	River Simpson	7	977	665	0	308	4
	Saroni	8	4,687	4,150	0	479	59
	Upper Fulstone	9	596	0	0	596	0
	West Walker Ditch	10	1,392	1,124	0	268	0
	Groundwater	11	2,982	2,775	0	207	0

Table 5. Monthly ET rates (m/month) accounting for precipitation.

Mason Valley Crop Consumption (m/month)				
Month	**Leafy**	**Root**	**Low Duty**	**Non-irrigated**
Jan	-0.0028	0.0003	-0.0062	0.0037
Feb	0.0003	0.0014	-0.0028	0.0078
Mar	0.0242	0.0084	0.0298	0.0161
Apr	0.1227	0.0651	0.0972	0.0207
May	0.1894	0.1407	0.1311	0.0239
Jun	0.1671	0.1920	0.1515	0.0264
Jul	0.2124	0.2195	0.1727	0.0288
Aug	0.1953	0.1500	0.1411	0.0254
Sep	0.1245	0.0321	0.0819	0.0177
Oct	0.0741	-0.0009	0.0298	0.0093
Nov	0.0051	-0.0036	-0.0048	0.0021
Dec	-0.0037	-0.0022	-0.0071	0.0025
Total m/yr)	1.11	0.80	0.81	0.18
Total (ft/yr)	3.63	2.63	2.67	0.60
Smith Valley Crop Consumption (m/month)				
Month	**Leafy**	**Root**	**Low Duty**	**Non-irrigated**
Jan	-0.0101	-0.0025	-0.0067	0.0023
Feb	-0.0042	0.0027	-0.0034	0.0078
Mar	0.0163	0.0130	0.0164	0.0163
Apr	0.1004	0.0807	0.0855	0.0210
May	0.1762	0.1386	0.1274	0.0234
Jun	0.1686	0.1869	0.1556	0.0263
Jul	0.2148	0.2210	0.1770	0.0279
Aug	0.1776	0.1717	0.1505	0.0253
Sep	0.1274	0.0479	0.0870	0.0168
Oct	0.0595	-0.0006	0.0209	0.0090
Nov	0.0006	-0.0057	-0.0101	0.0017
Dec	-0.0088	-0.0043	-0.0110	0.0012
Total m/yr)	1.02	0.85	0.79	0.18
Total (ft/yr)	3.34	2.78	2.59	0.59

Non-agricultural areas

Non-agricultural areas are those that contain wetlands (open water or marsh lands), phreatophytes, or riparian vegetation (Figure 24). Riparian zones are based on the combined spatial extent of riparian areas from six different years (Minor et al., 2006). In Mason Valley, phreatophytes are relatively extensive in the northern portion of the model in the vicinity of the Nevada Division of Wildlife wetlands, as well as in the marshy zone near Adrian Gap (Huxel and Harris, 1969). Phreatophytes in Smith Valley center on Artesia Lake with a few smaller phreatophyte areas located throughout the valley floor (Rush and Schroer, 1975). Riparian zones are interspersed between HRUs, wetland regions and along the river corridor. Monthly ET rates (Table 6) for phreatophytes are based on a study of the Carson Basin, Nevada (Maurer et al., 2005; Maurer and Berger, 2006) and modified to account for local precipitation. Annual ET measurements for wetland and riparian vegetation are divided into monthly values based on the ratio of phreatophyte monthly consumption to its annual consumption (Maurer et al., 2005; Maurer and Berger, 2006).

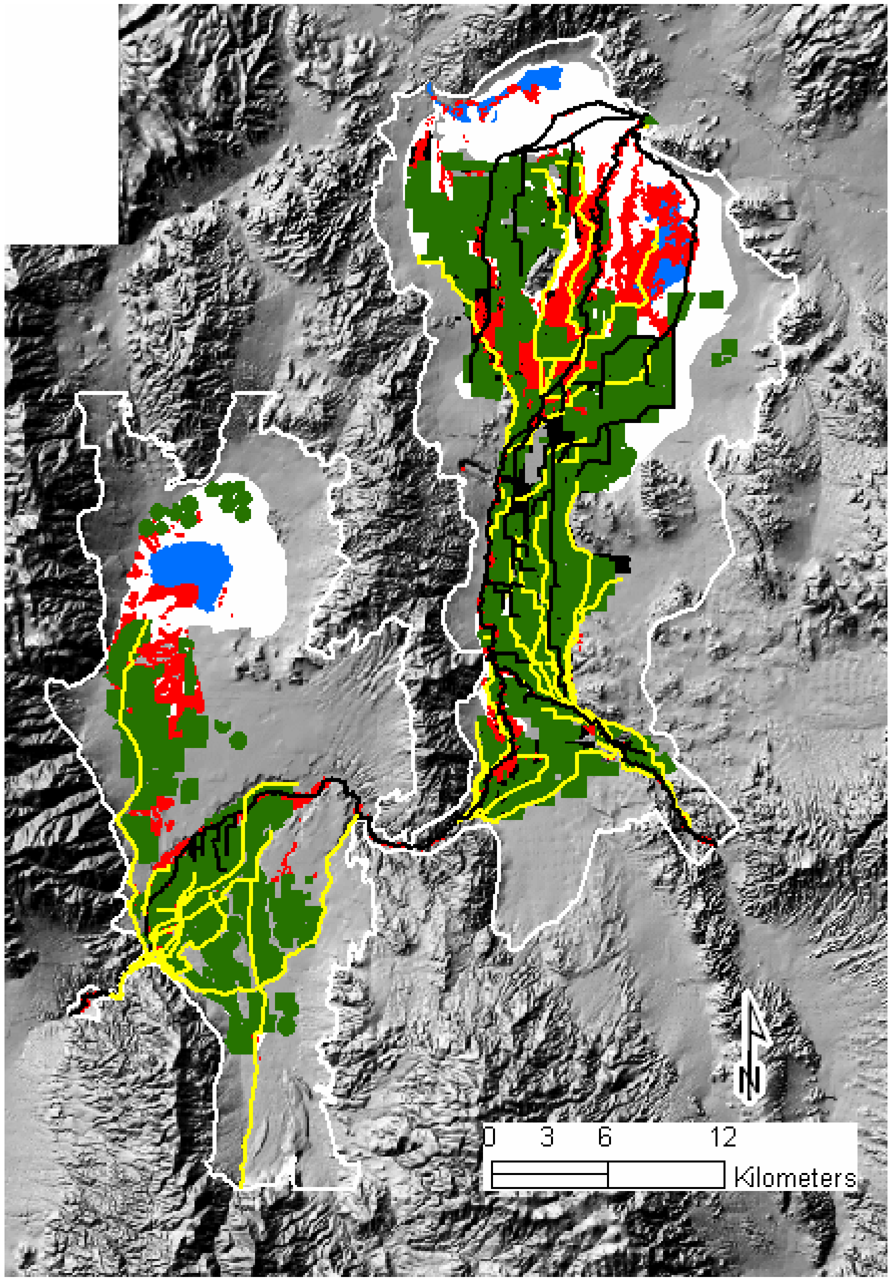


Figure 24. Vegetation zones in Smith Valley and Mason Valley. Green = irrigated HRUs, Red = riparian, White = phreatophytes, Blue = wetlands (Artesia Lake in Smith Valley). Black lines represent river and return drains modeled with the SFR1 package and yellow lines represent major delivery ditches (and Desert Creek) modeled with the WEL package.

Table 6. Modeled monthly ET for phreatophytes, and riparian and wetland vegetation. Rates taken from (Maurer et al., 2005; Maurer and Berger, 2006) and adjusted using monthly average precipitation in Yerington, Nevada (Mason Valley), and Smith 6N and Wellington Stations (Smith Valley) (WRCC, 2008a).

Mason Valley Non-Agricultural Vegetation Consumption (m/month)				
Month	**Precip.**	**Wetlands**	**Phreatophytes**	**Riparian**
Oct	0.0089	0.0633	0.0216	0.0486
Nov	0.0107	0.0459	0.0132	0.0343
Dec	0.0130	0.0448	0.0114	0.0330
Jan	0.0147	0.0419	0.0091	0.0303
Feb	0.0135	0.0467	0.0119	0.0344
Mar	0.0109	0.0830	0.0287	0.0638
Apr	0.0104	0.1172	0.0434	0.0911
May	0.0163	0.1679	0.0615	0.1303
Jun	0.0119	0.1765	0.0676	0.1379
Jul	0.0066	0.1818	0.0729	0.1433
Aug	0.0066	0.1397	0.0551	0.1097
Sept	0.0064	0.1026	0.0396	0.0803
Total (m/yr)	0.13	1.21	0.44	0.94
Total (ft/yr)	0.43	3.97	1.43	3.07
Smith Valley Non-Agricultural Vegetation Consumption (m/month)				
Month	**Precip**	**Wetlands**	**Phreatophytes**	**Riparian**
Oct	0.0103	0.0619	0.0202	0.0472
Nov	0.0185	0.0380	0.0053	0.0265
Dec	0.0218	0.0359	0.0025	0.0241
Jan	0.0276	0.0290	-0.0037	0.0174
Feb	0.0232	0.0370	0.0022	0.0246
Mar	0.0201	0.0738	0.0196	0.0546
Apr	0.0104	0.1172	0.0434	0.0911
May	0.0187	0.1655	0.0591	0.1278
Jun	0.0149	0.1736	0.0646	0.1350
Jul	0.0093	0.1791	0.0702	0.1406
Aug	0.0079	0.1384	0.0538	0.1085
Sept	0.0081	0.1008	0.0378	0.0785
Total (m/yr)	0.19	1.15	0.38	0.88
Total (ft/yr)	0.63	3.77	1.23	2.87

River, drains, and delivery ditches

Figure 24 shows the Walker River and its forks, major delivery ditches, and major return drains. The USGS gages define river flows entering and exiting each model domain. Surface diversions remove water from the river at points of diversion, which is conveyed to agricultural areas (HRUs) via delivery ditches. Drains transport seeping groundwater and surface return flows in excess of HRU crop requirements back toward the river channel. Desert Creek (USGS gage 10299100) enters Smith Valley from the south, is routed over Saroni Ditch, and intersects Plymouth Ditch. For modeling purposes, Desert Creek is treated as a delivery ditch.

MODFLOW Description

To capture the interaction between surface water and groundwater, each modeled basin is sectioned into three conceptual units: the river and drain network, the agricultural areas as HRUs, and the groundwater system. Figure 25 depicts this approach, with modeled fluxes shown as arrows linking each conceptual unit. All units contribute flow and receive flow from the other units, producing a complex system capable of modeling feedback mechanisms. Specific modeled processes include river flows, surface water diversions, delivery ditch leakage, crop consumption, irrigation recharge, return flows from HRUs to the river/drain network, mountain-block recharge, interbasin groundwater flow, non-agricultural ET, groundwater pumping, changes in groundwater storage, and the flux of water into and out of the river from the groundwater system.

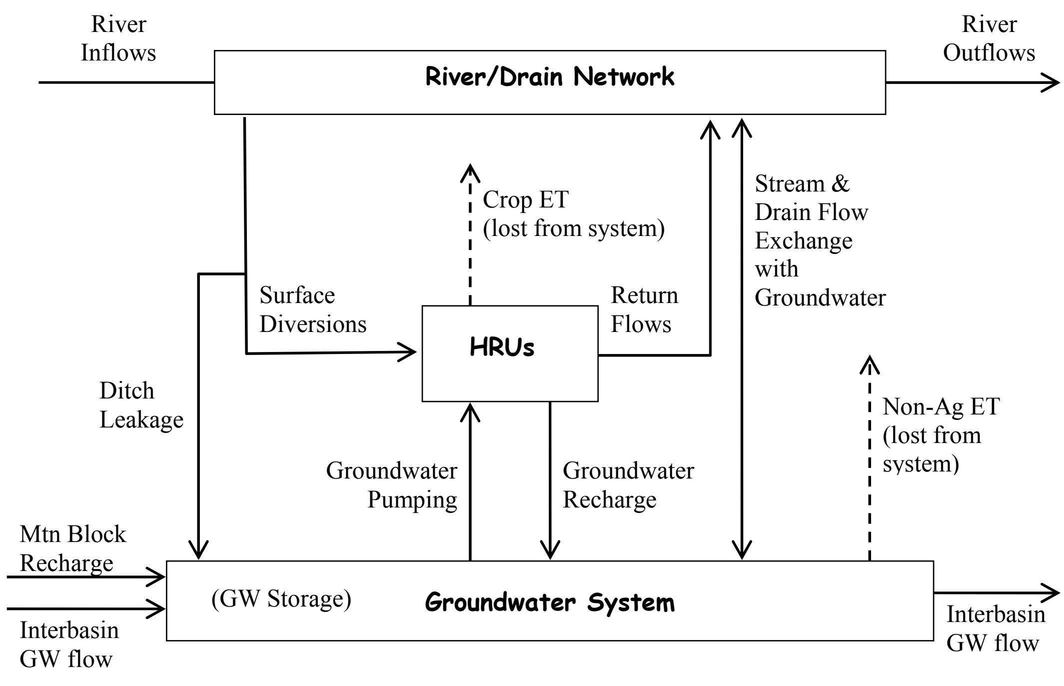


Figure 25. Conceptual diagram depicting model linkage between the river/drain network, the agricultural regions (i.e., HRUs), and the groundwater system. Simulated annual budgets (i.e., volumes associated with each arrow in this diagram) for Mason Valley are provided in Table 10, and for Smith Valley in Table 11.

Groundwater model

Both the MVGM and SMGM were built with MODFLOW-2000 (Harbaugh et al., 2000), a public domain, finite-difference code developed by the USGS, capable of simulating groundwater flow in transient, three-dimensional, anisotropic and heterogeneous systems. MODFLOW's governing three-dimensional flow equation for a confined aquifer combines Darcy's Law and the principle of conservation of mass:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - G = S_S\frac{\partial h}{\partial t} \tag{1}$$

where *x*, *y,* and *z* are Cartesian coordinates (L), K_{xx}, K_{yy}, and K_{zz} are the principal components of saturated hydraulic conductivity along the *x, y*, and *z* axes, respectively (L/T); *h* is hydraulic head (L); *G* is a volumetric source/sink term (1/T); S_S is specific storage (L^{-1}); and *t* is time *(T).* Conversely, Equation (2) defines groundwater flow given unconfined conditions, where *h* (L) is the phreatic surface elevation and S_y is specific yield (dimensionless).

$$\frac{\partial}{\partial x}\left(K_{xx}h\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}h\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}h\frac{\partial h}{\partial z}\right) - G = S_y\frac{\partial h}{\partial t} \tag{2}$$

Solving for *h* in Equation (2) is a non-linear problem because *h* depends on hydraulic conductivity and saturated thickness, which depends on the water table elevation. Model layers were simulated as convertible such that confined conditions are used when a model cell is fully saturated, but unconfined conditions are simulated when the phreatic surface drops below the top elevation (i.e., land surface) of the modeled cell. Instability in model convergence when simulating unconfined conditions was mitigated by using the Geometric Multi-grid (GMG) linear equation solver package (Wilson and Naff, 2004).

Surface water linking program

A series of FORTRAN codes automatically create input files for the groundwater model. These codes describe surface processes occurring in the river/drain network and the HRU conceptual units shown in Figure 25. Specifically, MODFLOW input files (RCH, SFR1, and WEL) are created to incorporate ditch delivery and leakage, groundwater delivery, as well as crop consumption, groundwater recharge, and return flows based on irrigated volumes. The Surface Water Linking (SWL) program is run in batch-mode with MODFLOW to provide greater flexibility in calibration and parameter sensitivity. This flexibility will aid the future development of water resources management scenarios.

MODFLOW Model Development

The MVGM and SVGM are developed in two steps. First, steady-state models are developed to test the validity of the conceptual model in producing appropriate basin-wide water balances and to establish initial values of hydraulic conductivity. After validation of the conceptual approach with steady-state models, transient models are constructed for the period 1996 to 2006 using 132 monthly stress periods. The MVGM was calibrated from 1996 to 2003 using water level, streamflow, and diversion data along the river. Verification was accomplished using data from 2004 to 2006. The SVGM was developed after the MVGM with minor adjustments, if any, to input parameters as determined by the MVGM calibration and verification.

Model grids and hydraulic parameters

The MVGM is modeled with two layers. Cell dimensions in the x-y direction are 100 m by 100 m for a total of 213,248 cells (476 rows, 224 columns, 2 layers). Top elevations for Layer 1 are defined by mean land surface elevation for each modeled cell, as determined from a DEM. Bottom elevations for the layers are constant: 3,740 ft (1,140 m) above mean sea level (aMSL) for Layer 1 and 3,280 ft (1,000 m) aMSL for Layer 2. As a result, cell thickness in Layer 1 ranges from 560 ft (170 m) in the north to approximately 1,000 ft (300 m) in the south where surface elevations are higher. Total basin-fill thickness is approximately 1,000 ft (300 m) as established by Huxel and Harris (1969) and modeled by Myers (2001a). Six zones of hydraulic conductivity are based on Huxel and Harris (1969) transmissivity regions. Hydraulic conductivity in Zones 1 through 4 are adjusted using MODFLOW's observation, sensitivity, and parameter estimation process (Hill et al., 2000) to best match water level data collected from 1996 to 2003. Calibrated hydraulic conductivity values are presented in Table 7. Using saturated cell thicknesses (h) computed for February 2000, calibrated hydraulic conductivity values correspond to transmissivity values ranging from 12,880 gal/d/ft (160 m^2/d) to 402,600 gal/d/ft (5,000 m^2/d), using

$$T = Kh \tag{3}$$

where T is transmissivity (L^2/T), K is hydraulic conductivity (L/T), and h is the saturated thickness (L). While the model captures the lower range of transmissivity presented by Huxel and Harris (1969), transmissivity in the lower river sediments (Zone 2) are nearly 50 percent higher than expected. Specific yield (S_y) equal to 0.20 (Huxel and Harris, 1969) is used throughout the model domain, as is a constant storativity (S) equal to 1×10^{-5} (Myers, 2001b). Vertical hydraulic conductivity was modeled as one-tenth the value of horizontal hydraulic conductivity.

The SVGM grid is modeled as one layer where top elevations for each modeled cell are defined using the DEM. Little is known about the depth of alluvium in the valley. The bottom elevation of the layer is set at 3,940 ft (1,200 m) based on information from well logs and Myers (2001b). The layer thickness is 500 ft (155 m) at the northern end of the valley, but increases towards the south end of the valley where surface elevations are higher. The total number of cells in the model is 80,556: 196 columns, 411 rows, 1 layer. Seven hydraulic conductivity zones are used in the SVGM (Figure 26b). These zones are determined by published transmissivities (Rush and Schroer, 1975; Myers, 2001b) and from unpublished pump tests performed by DRI north of Artesia Lake. Original hydraulic conductivity estimates are maintained in the model (Table 7), with the exception of increasing Zone 7 to reflect the highest recorded hydraulic conductivity in the basin and to mimic large calibrated hydraulic conductivity values adjacent to the river in the MVGM. Constant storage parameters are used equal to 1×10^{-5} and 0.25 for S and S_y, respectively (Myers, 2001b).

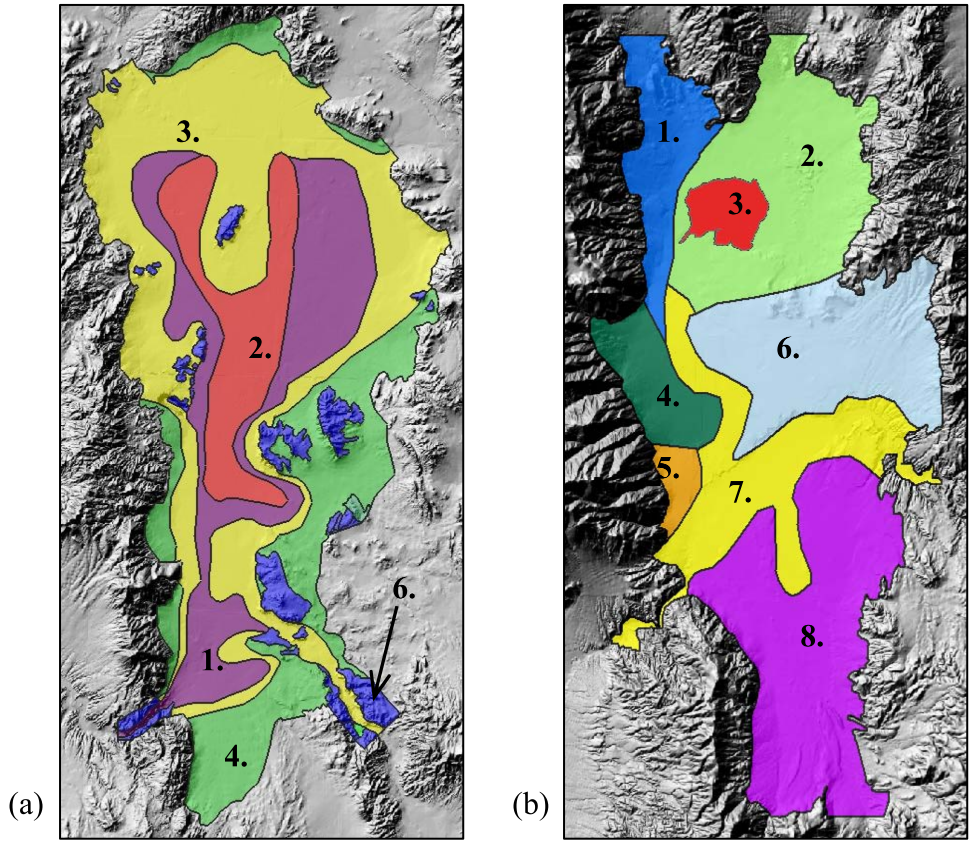


Figure 26. Zones of hydraulic conductivity (K) in the top layer for (a) six zones in the MVGM and (b) eight zones in the SMGM. MVGM zone 5 represents deeper and older alluvium and fan deposits. It is modeled in Layer 2 and is not shown.

Table 7. Hydraulic conductivity (K, m/d) for Mason Valley and Smith Valley zones. Myers (2001b) is used for Smith Valley.

	Zone	Unit	K (m/d)	Source
Mason Valley	1	Upper River	3.76	Calibrated to predict 1996-2003 Water Levels
	2	Lower River	25.0	Calibrated to predict 1996-2003 Water Levels
	3	Younger Alluvium	1.0	Calibrated to predict 1996-2003 Water Levels
	4	Younger Fans	1.0	Calibrated to predict 1996-2003 Water Levels
	5	Older/Burried Alluvium	0.5	Fetter (1994) upper end of silty sands and fine sands
	6	Bedrock	0.01	Low permeability of consolidatd sediments and crystaline/volcanic rocks
Smith Valley	1	Northwest Sediments	3.0	Rush and Schroer (1975); Myers (2001), Unpublished DRI pump tests
	2	Northeast Sediments	6.0	Rush and Schroer (1975); Myers (2001), Unpublished DRI pump tests
	3	Artesia Playa	2.41	Rush and Schroer (1975); Myers (2001), Unpublished DRI pump tests
	4	West Central Sediments	9.62	Rush and Schroer (1975); Myers (2001)
	5	West Central above River	1.6	Rush and Schroer (1975); Myers (2001)
	6	East Central Sediments	1.6	Rush and Schroer (1975); Myers (2001)
	7	River Gravels	9.62	Increased to reflect highest K in basin (zone 4)
	8	Southern Sediments	1.6	Rush and Schroer (1975); Myers (2001)

Boundary conditions and applied stresses

Boundary conditions include all observed or estimated water fluxes into and out of the model domain. Specifically, boundary conditions constrain the water budget to better predict groundwater levels, groundwater interaction with the river, and river volumes exiting the model domain. Boundary conditions include streamflows entering the model domain, mountain-block recharge, interbasin groundwater flows, surface diversions, delivery ditch leakage, ET from agricultural and non-agricultural vegetation, groundwater recharge, groundwater pumping, incoming streamflows, and return flows along drains.

The groundwater models are run using 132 monthly stress periods from January 1996 to December 2006. Initial groundwater levels in the MVGM and the SVGM are determined by interpolating 1996 observed water levels across the entire model domain. Water levels in the river canyons near the Hoye, Hudson, and Strosnider gages are based on general head boundary (GHB) calibrated elevations.

Higher streamflows occur during the periods 1996 to 1999 and from 2005 through 2006. Low water years, or drought conditions, occur from 2000 to 2004. Average monthly streamflows for Hoye, Hudson, Strosnider, Wabuska, and Desert Creek gages are obtained from the USGS. The Desert Creek gage is missing data for most of the modeled time period. Flows for missing Desert Creek data are based on monthly average flows for the periods of record: December 1964 to September 1969, and August 2006 to September 2007.

Rating curves for width and depth as a function of river flow are developed using USGS measurements spanning years 1947 to 2007 at Hudson, Strosnider, and Wabuska gages (Figure 27). In general, depth measurements show little variation in observed values while width measurements vary greatly. For the Hudson gage, width measurements are separated into two groups, high and low measurements, in an attempt to mitigate peak flows in Mason Valley.

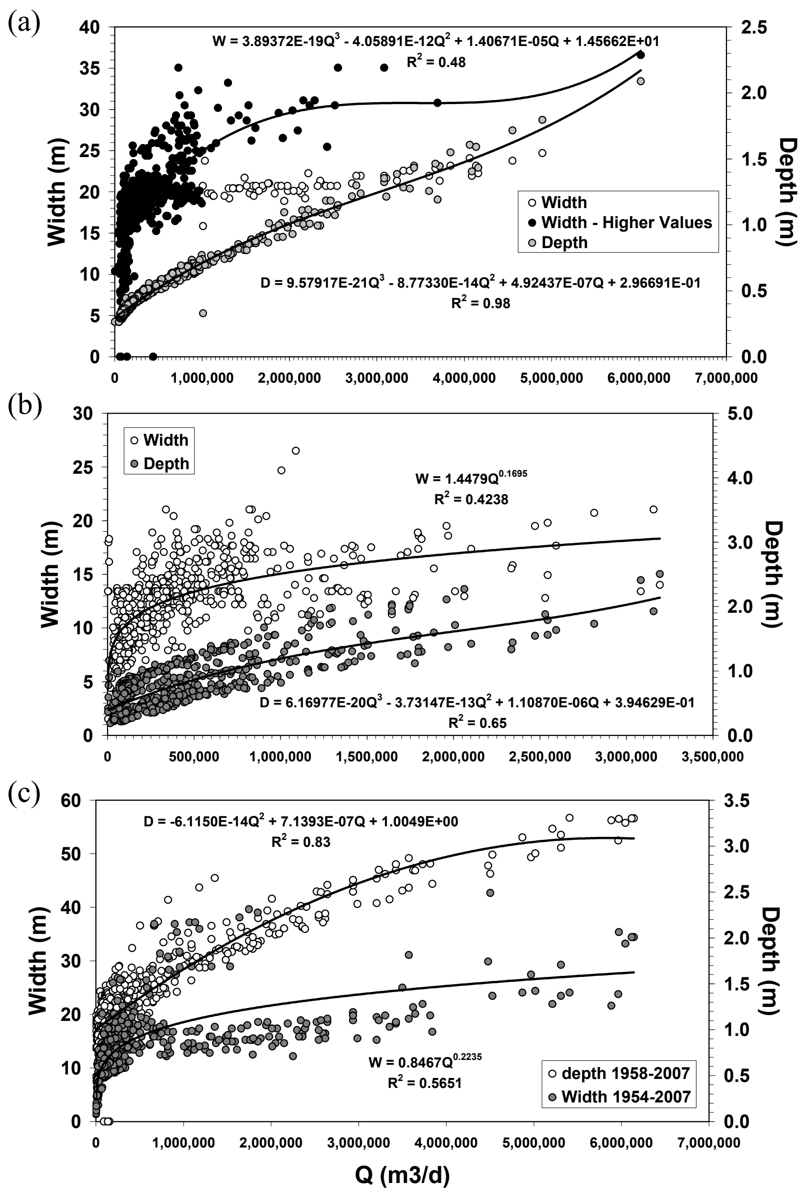


Figure 27. Rating curves defining depth and width for USGS gages at (a) Hudson, (b) Strosnider and (c) Wabuska.

Monthly estimates for each HRU diversion are developed using recorded annual and daily diversion data. Total diversions for a given HRU are the sum of decree, storage, and flood water. Daily decree and storage diversions are available from 1996 to 2006; annual decree, storage, and flood diversions are available from 1996 to 2007. A record of days on which flood water was distributed for sections of each basin is also available (Figure 28). Section designations and the corresponding HRUs for the MVGM and SVGM are shown in Table 8.

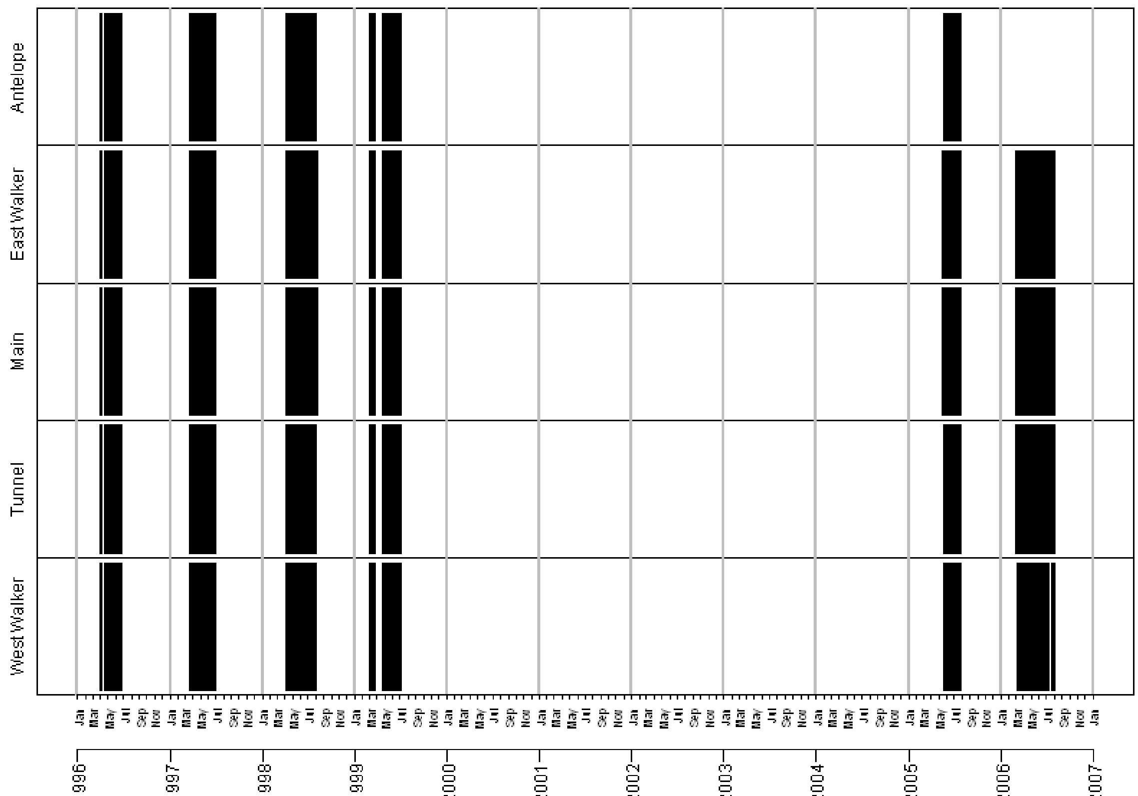


Figure 28. Dates of flood diversions from 1996 to 2006 for each listed section in the Walker River basin. No flood diversions occurred during the drought from 2000 to 2004.

Table 8. HRU section designations used to quantify flood diversions. HRUs are limited to those modeled with the MVGM and the SVGM. Antelope HRUs and Upper East HRUs are not included.

Section	Ditches/HRU
East Walker	Baker Snyder, Fox, Mickey, Greenwood, Hall, High, Hilbun, Nelson, Pitchfork East, Pitchfork West, East Walker, Hall, Howard
Main	Campbell, Joggles, Nichol-Merritt, River Pump AGHD, River Pump CBN, River Pump Stanley, River Pump Warburton, SAB, Sciarani, Spragg-Woodcock, West Hyland, Dairy, McLeod, SAB, Sciarani Pipe
Tunnel	D&GW, Kelly Alkali, Lee Sanders, Tunnel, Westside, Nordyke-Quail
West Walker	River Pump Borsini, Burbank, Colony, Gage Peterson, Lower Fulstone, Plymouth, River Simpson, Saroni, Smith Groundwater, Upper Fulstone, West Walker River, West Walker Pumps

If flood water is diverted to the section containing an HRU, and that HRU is already receiving decree or storage water, then the annual flood water volume for a given HRU is evenly distributed between all days that satisfy the first two criteria. As an example, in 1996, the Baker Snyder ditch received 166.98 acre-feet (206,000 m^3) of flood water. The Baker Snyder ditch is in the East Walker section, which received flood diversions April 1 to April 8 and from April 15 to June 27, for a total of 82 days in 1996. However, decree or storage water was diverted into Baker Snyder only 52 of these 82 days; therefore, Baker Snyder can receive flood water for 52 days in 1996. As a result, daily flood diversions for Baker Snyder in 1996 were estimated to be 3.21 acre-feet (3,960 m^3) per day for those 52 days. Figure 29 shows the Baker Snyder example for monthly decree, storage, and estimated flood diversions for 1996 through 2006 in acre-feet per month. Total daily diversions (decree, storage, and estimated flood) for each HRU are summed monthly for model input.

Groundwater withdrawals are estimated for each HRU and each irrigation well for the period 1948 to 2007. The groundwater model only uses information during the modeled period from 1996 to 2006. Groundwater pumping records for many irrigation wells are incomplete and it is necessary to use estimated volumes for periods missing data. To accommodate missing data, a method is developed to distribute basin-wide estimates of pumped groundwater to each HRU. Steps in developing these volumes are:

1. Develop a regression between streamflow and groundwater withdrawals for Mason and Smith valleys. Regressions produce estimated annual groundwater withdrawals for the period of record.
2. Determine the fraction of the annual basin-wide total each agricultural field will receive. Apply these fractions to the annual estimates to get an annual estimate of groundwater applied to each agricultural field.
3. Determine annual estimates for each HRU by aggregating the estimates for each agricultural field.
4. Divide the HRU estimates evenly among all associated irrigation wells.

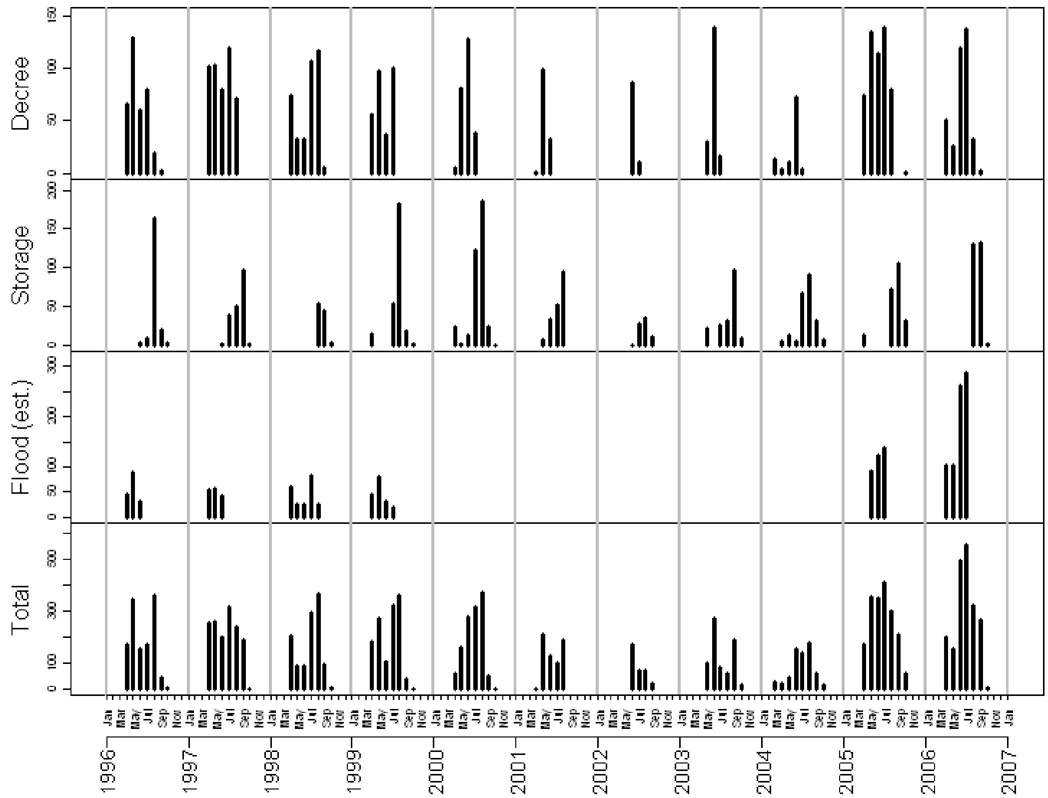


Figure 29. Baker Snyder monthly diversions in acre-feet per month.

Regressions are developed in Smith Valley using Hoye gage data (1994 to 2003) and groundwater withdrawals (Gallagher, 2004), and in Mason Valley using the combined Hudson and Strosnider gage data (1995 to 2002) and groundwater withdrawals (Gallagher, 2004). These regressions allow basin-wide groundwater withdrawals to be estimated from 1996 to 2007 for Smith and Mason valleys.

A comparison between annual surface diversions (decree, storage, and flood) and groundwater withdrawals is provided in Figure 30. Desert Creek flows are included in Smith Valley surface diversions although the creek does not originate from the West Walker River. Both basins obtain 10 to 20 percent of their irrigation water from groundwater resources during wet years and 35 to 45 percent during dry years. Surface diversions in Smith Valley are approximately half those in Mason Valley. Smith Valley groundwater withdrawals are about one third those estimated in Mason Valley.

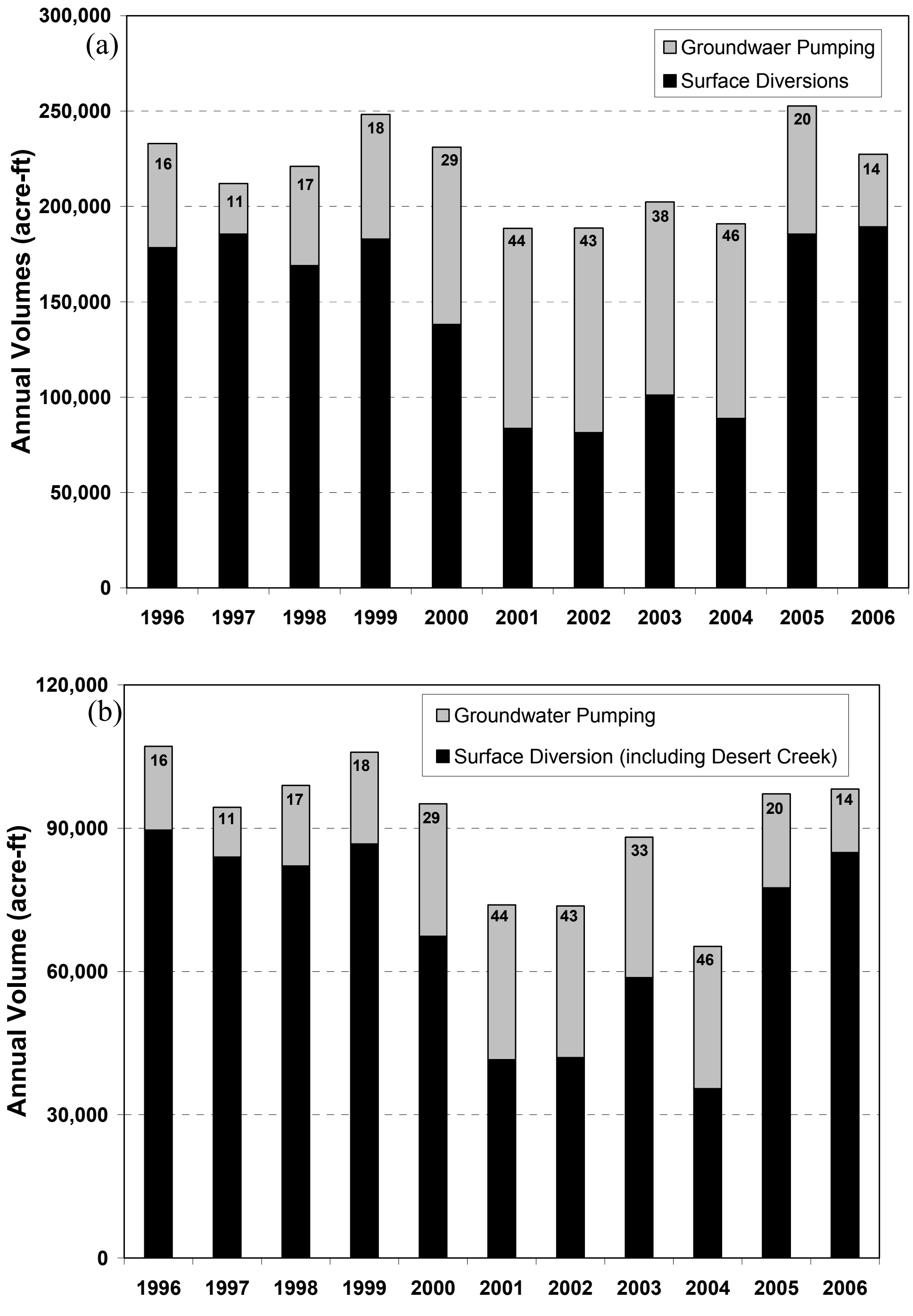


Figure 30. A comparison of surface diversions (sum of decree, storage, and flood) with groundwater withdrawals 1996-2006 in AFY for (a) Mason Valley and (b) Smith Valley. Percentage of total water that is groundwater is shown at the top of each column.

Groundwater applied to each HRU is determined by dividing the basin-wide total among all agricultural fields and summing field volumes by HRU. Each agricultural field is assigned a weight based on its area and annual consumptive use. Consumptive use values for Mason Valley and Smith Valley are developed using ET estimates for crop type categories (Table 5). Fields with larger areas receive a larger portion of the basin-wide groundwater total, as do fields with crop types that require more water. The weighted fraction of groundwater for each agricultural field is computed by multiplying its consumptive use by its area, and then dividing by the basin total product of consumptive use and area. An estimate of groundwater withdrawal for each agricultural field for each year is then determined by applying the weighted fraction for each field to the basin-wide total groundwater withdrawals for each year. These values are then summed by HRU and used in the HRU water balance model described below.

According to the Nevada Division of Water Resources records, every irrigation well is assigned to one place of use or agricultural field. Annual estimates of groundwater applied to an HRU are divided evenly among all the wells associated with that HRU (Figure 31). Tables 9 and 10 show the number of irrigation wells associated with each HRU. Groundwater pumping is assumed to occur from April through October. March was excluded even though surface diversions occur because crop production and crop ET are low. Irrigation wells were modeled with MODFLOW's WEL package.

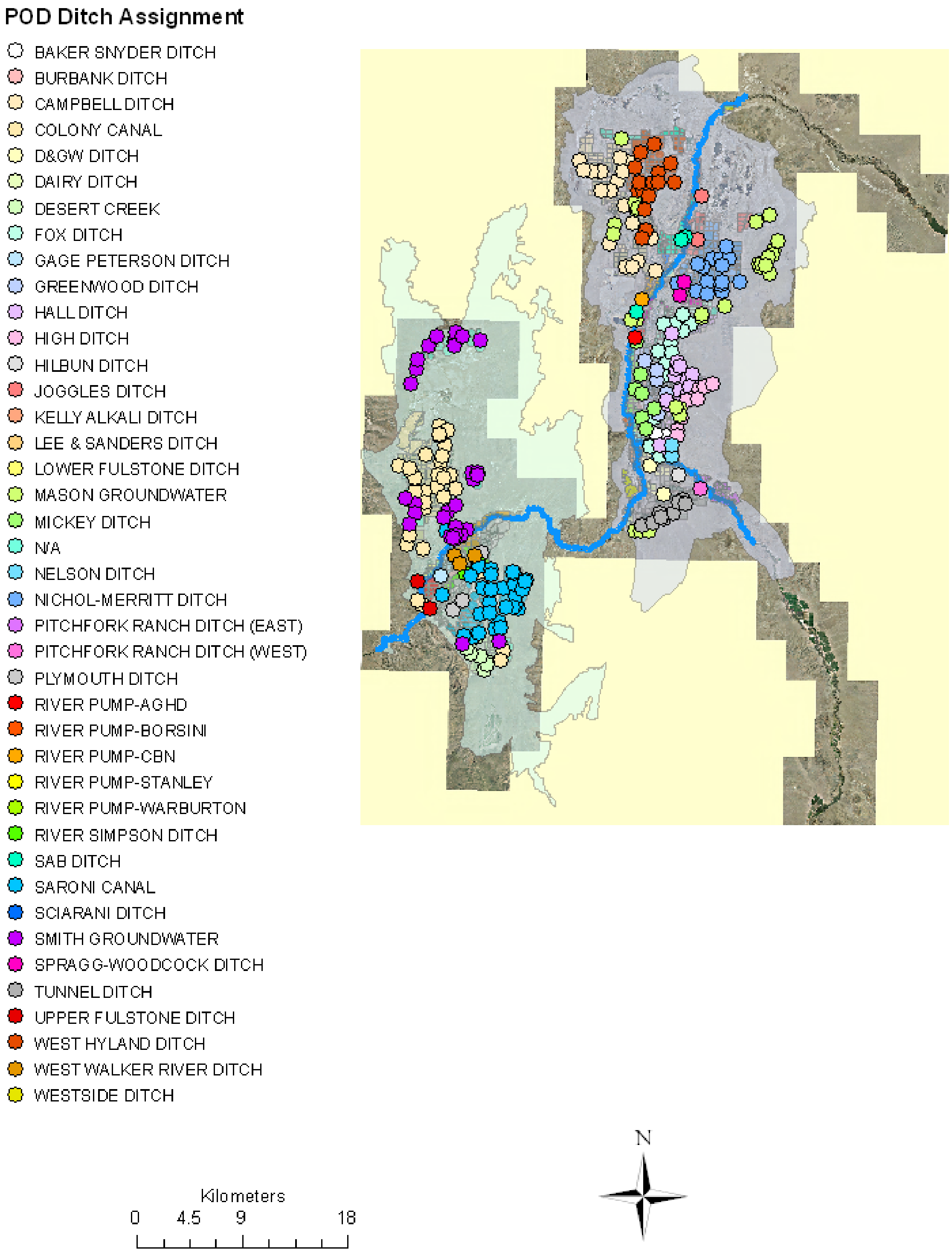


Figure 31. HRU assignments for irrigation wells. Wells (or points of diversion; POD) are associated with one agricultural area or point of use. Wells are assigned to an HRU based on the location of their point of use.

Table 9. Number of irrigation wells per HRU, Mason Valley.

HRU	Number of Wells	HRU	Number of Wells
Baker Snyder	3	Nelson	2
Campbell	30	Nichol-Merritt	20
D&GW	2	Pitchfork West	1
Fox	23	River Pump AGHD	1
Greenwood	6	River Pump CBN	1
Hall	25	River Pump Stanley	1
High	12	SAB	5
Hilbun	1	Spragg-Woodcock	8
Joggles	3	Tunnel	14
Mason Groundwater	37	West Hyland	24
Mickey	8		

Table 10. Number of irrigation wells per HRU, Smith Valley.

HRU	Number of Wells
Colony	35
Desert Creek	14
Gage Peterson	1
Plymouth	3
River Simpson	3
Saroni	47
Smith Groundwater	63
Upper Fulstone	3
West Walker River	6

Mountain-block recharge is modeled as a specified flux boundary condition using MODFLOW's WEL package. The MVGM mountain recharge fluxes are computed by applying the Maxey-Eakin approach (Maxey and Eakin, 1949) to the mountains surrounding each modeled domain. Precipitation falling directly on the model domain is not included in the calculation of mountain-block recharge. Instead, this precipitation is incorporated into ET estimates as soil storage. Mountain-block recharge in Mason Valley is approximately 2,000 AFY (2.5 million MPY). Figure 32 shows mountain-block recharge boundaries assigned along most of the model domain boundary, excluding regions pertaining to interbasin groundwater flow. Most mountain-block recharge originates from the mountains to the south of Mason Valley.

	Zone	Flux (acre-feet/year)	Fraction
Mason Valley	1	85	0.04
	2	27	0.01
	3	75	0.04
	4	9	0.00
	5	593	0.30
	6	1,211	0.61
	Total	2,000	1.00
Smith Valley	7	340	0.02
	8	956	0.06
	9	764	0.04
	10	1,881	0.11
	11	1,511	0.09
	12	430	0.03
	13	606	0.04
	14	571	0.03
	15	1,269	0.07
	16	106	0.01
	17	89	0.01
	18	42	0.00
	19	8,436	0.50
	Total	17,000	1.00

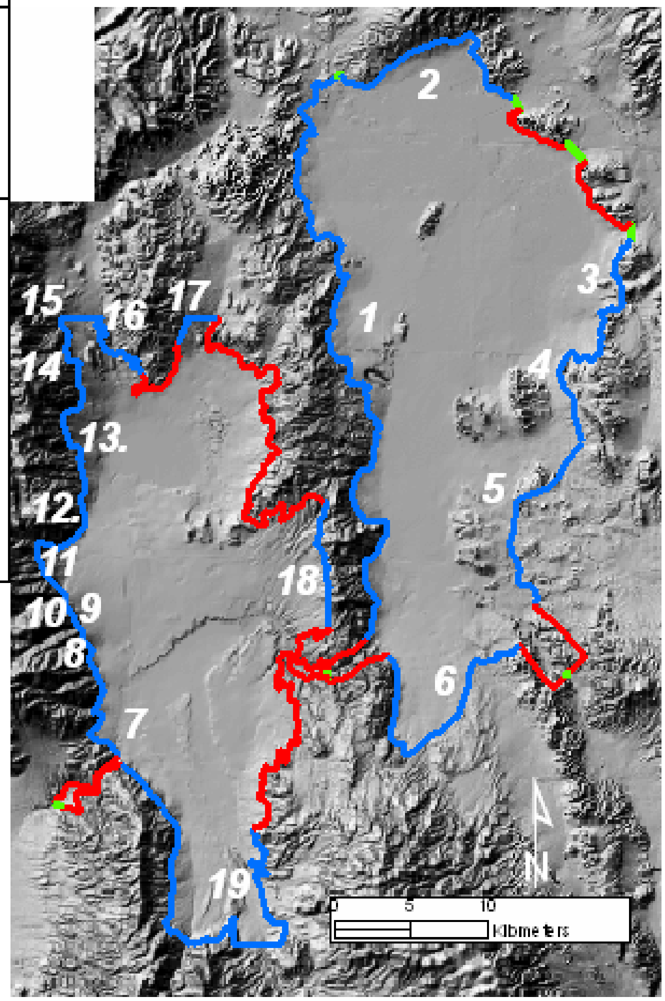


Figure 32. Boundary flux conditions used in the MVGM and SVGM. Red lines = no flux boundary; blue = mountain block recharge; green = interbasin groundwater flow. Table insert corresponds to mountain block recharge fluxes across specified regions, acre-feet per year.

Mountain-block recharge in Smith Valley is modeled as 17,000 AFY (21 million MPY), which is also the perennial yield assigned by the Nevada State Engineer (Rush and Schroer, 1975). Myers (2001b) estimated mountain-block recharge as 16,327 AFY (20 million MPY). The perennial yield is distributed among sub-watersheds based on the Maxey-Eakin method. Flux boundaries were assigned primarily along the southern, western, and northern portions of the domain, with the largest fluxes originating in the south (Figure 32).

Groundwater flowing into and out of the model domain beneath the river channel or through geologic gaps in the surrounding bedrock (i.e., Adrian, Wabuska, Parker, and East (Figure 32) is modeled using the GHB package in MODFLOW. GHB elevations are adjusted to approximate estimates of boundary fluxes (Huxel and Harris, 1969; Rush and Schroer, 1975; Myers, 2001a) using MODFLOW's general head boundary observation package. Calibrated groundwater elevations in the MVGM are approximately 10 ft (3 m) below land surface at the Hudson and Wabuska gages, 20 ft (6 m) below land surface at the Strosnider gage and Adrian Gap, and 36 ft (11 m) below the lowest point in Parker Gap. East Gap GHB elevations were not calibrated because no estimated fluxes were available; instead, heads were assigned to model cells based on groundwater contours (Huxel and Harris, 1969) at approximately 138 ft (42 m) below the lowest point in the gap. For the SVGM, GHB elevations at the inflowing Hoye gage were adjusted to 1 m below land surface, while elevations at the Hudson gage were adjusted to 8 ft (2.5 m) below land surface. Because of the lack of available data, the conductance values at the GHB boundaries are set to high values, causing the general head boundary to operate more like a constant head boundary.

A geologic fault residing in the northern portion of Smith Valley, southeast of Artesia Lake, is modeled running north-south using the horizontal flow barrier package (HFB) in MODFLOW (Hsieh and Freckleton, 1993; Harbaugh et al., 2000) with a low hydraulic conductivity (3.28×10^{-5} ft/d; 1×10^{-5} m/d) limiting flow across the fault. The fault forces mountain-block recharge entering hydraulic conductivity Zone 4 to move either north toward Artesia Lake or south toward the river. Water moved north and not consumed by phreatophytes or pumped for irrigation needs will move clockwise around the fault and down the eastern side of the basin toward the river.

Major delivery ditches are assumed to lose 20 percent of the surface diversion to the groundwater. These losses are modeled as a specified flux boundary condition via MODFLOW's WEL package, which is generated in the SWL program. Annual losses due to ditch leakage are shown in Table 11 for Mason Valley and Table 12 for Smith Valley. Modeled Mason Valley ditch leakage ranges from approximately 16,300 acre-feet (20 million m^3) in 2002 to 37,900 acre-feet (47 million m^3) in 2006. Modeled Smith Valley annual ditch losses range from 8,300 acre-feet (10 million m^3) in 2001 to 19,300 acre-feet (24 million m^3) in 2006.

Evapotranspiration in non-agricultural areas is modeled using MODFLOW's EVT package. Monthly ET rates given in Table 6 define potential ET. Bare soil is assumed to consume soil moisture rather than groundwater resources and is assigned a potential groundwater ET of zero. The ET surface is defined by land surface elevation from the DEM. The modeled extinction depth for phreatophytes is set to 33 ft (10 m) and 3.3 ft (1.0 m) for perennial wetlands and riparian vegetation (Table 6). MODFLOW uses a linear approach to compute the modeled ET rate, with the maximum ET occurring at the surface and decreasing to zero if the water table drops below the given extinction depth. Therefore, while wetlands have the potential for large consumption of groundwater resources, if the water table drops more than 3.3 ft (1.0 m) below land surface, the ET in these regions is zero. Phreatophytes can access groundwater to much greater depths due to extensive tap roots.

Table 11. Annual volumetric water balance (based on Figure 8) for Mason Valley, AFY. Model error is calculated as predicted (P) minus observed (O).

			1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
River/Drain Network	Inflows	River Inflow	397,172	546,862	428,834	328,122	189,587	125,318	120,534	155,487	138,347	345,822	493,135
		Return Flows	16,643	13,604	14,612	18,728	12,950	6,977	7,090	8,419	7,002	19,448	16,285
	Outflows	Diversions	178,408	185,521	168,968	182,930	138,138	83,607	81,397	101,110	88,869	185,499	189,314
		Net SW-GW Exchange	25,032	5,943	10,044	5,633	12,047	21,120	28,299	33,062	34,328	30,355	21,942
		River Outflow	210,352	368,978	264,417	158,260	52,328	27,552	17,913	29,718	22,139	149,378	298,134
	Volumetric Error (%)		0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Observed River Outflow		217,000	344,384	271,346	147,397	52,035	30,236	22,962	30,219	30,618	147,968	300,584
	Model Error (P-O)		-6,648	24,594	-6,929	10,863	293	-2,684	-5,049	-501	-8,479	1,409	-2,450
HRUs	Inflows	Diversions	178,408	185,521	168,968	182,930	138,138	83,607	81,397	101,110	88,869	185,499	189,314
		GW Pumping	54,543	26,519	52,122	65,314	92,907	104,902	107,242	101,285	102,038	67,102	38,056
	Outflows	Ditch Leakage	35,682	37,104	33,794	36,586	27,628	16,721	16,279	20,222	17,774	37,100	37,863
		Crop ET	127,684	125,603	126,471	130,037	130,477	120,789	120,718	126,784	123,894	129,661	126,444
		Return Flows	16,643	13,604	14,612	18,728	12,950	6,977	7,090	8,419	7,002	19,448	16,285
		GW recharge	52,942	35,729	46,215	62,894	59,990	44,022	44,551	46,970	42,237	66,393	46,780
	Volumetric Error (%)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater System	Inflows	Storage	51,818	32,815	37,014	38,247	56,517	81,086	78,680	64,080	69,074	28,974	24,382
		Mtn Block Recharge	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
		GW Interbasin Flow	320	290	323	348	378	395	404	404	412	390	378
		GW recharge	52,942	35,729	46,215	62,894	59,990	44,022	44,551	46,970	42,237	66,393	46,780
		Net SW-GW Exchange	25,032	5,943	10,044	5,633	12,047	21,120	28,299	33,062	34,328	30,355	21,942
		Ditch Leakage	35,682	37,104	33,794	36,586	27,628	16,721	16,279	20,222	17,774	37,100	37,863
	Outflows	Storage	90,233	61,710	49,421	50,627	35,044	31,208	35,800	39,285	37,791	70,942	65,133
		GW Interbasin Flow	501	627	682	724	746	769	783	815	831	875	919
		GW Pumping	54,543	26,519	52,122	65,314	92,907	104,902	107,242	101,285	102,038	67,102	38,056
		non-Ag ET	23,778	27,216	28,691	30,103	29,878	28,256	26,437	25,377	24,996	27,170	30,105
	Volumetric Error (%)		-0.75	-1.89	-1.17	-0.72	-0.01	0.13	-0.03	-0.01	0.10	-0.53	-0.65

Table 12. Annual volumetric water balance (based on Figure 8) for Smith Valley, AFY. Model error is calculated as predicted (P) minus observed (O).

			1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
River/Drain Network	Inflows	River Inflow	266,252	353,979	278,877	250,575	147,125	95,594	106,583	135,460	121,174	253,184	321,519
		Return Flows[a]	5,586	4,354	4,132	5,189	3,358	2,082	1,946	3,088	2,315	5,072	6,000
		Net SW-GW Exchange	11,392	14,301	12,564	13,355	12,010	7,842	5,447	5,743	5,391	8,053	10,852
	Outflows	Diversions^	79,267	74,181	71,722	76,403	56,965	30,993	31,453	48,275	32,693	77,039	84,323
		River Outflow	203,963	298,453	223,851	192,717	105,527	74,526	82,523	96,015	96,186	189,270	254,047
	Volumetric Error (%)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Observed River Outflow		216,917	313,098	215,264	200,225	113,148	71,999	80,394	94,825	83,225	187,548	263,619
	Model Error (P-O)		-12,954	-14,645	8,587	-7,508	-7,621	2,526	2,129	1,190	12,961	1,721	-9,571
HRUs	Inflows	Diversions*	89,976	84,881	82,422	87,103	67,675	41,693	42,153	58,976	43,394	88,158	96,648
		GW Pumping	17,547	10,411	16,888	19,192	27,727	32,441	31,769	29,397	29,797	19,642	13,277
	Outflows	Ditch Leakage	17,995	16,976	16,484	17,421	13,535	8,339	8,431	11,795	8,679	17,632	19,330
		Crop ET	52,599	50,567	52,681	53,927	56,096	49,092	49,391	53,263	48,017	54,465	53,653
		Return Flows	10,297	8,305	8,406	9,569	6,378	3,509	3,372	5,522	3,639	9,834	10,733
		GW recharge	26,632	19,444	21,739	25,378	19,392	13,194	12,729	17,792	12,856	25,869	26,210
	Volumetric Error (%)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundwater System	Inflows	Storage	124,087	51,038	39,514	33,166	34,195	35,705	30,558	24,425	25,626	17,068	15,780
		Mtn Block Recharge	16,962	16,923	16,923	16,917	16,995	16,968	16,970	16,956	17,016	16,925	16,911
		GW Interbasin Flow	418	402	413	417	431	439	436	432	435	418	410
		GW recharge	26,632	19,444	21,739	25,378	19,392	13,194	12,729	17,792	12,856	25,869	26,210
		Ditch Leakage	17,995	16,976	16,484	17,421	13,535	8,339	8,431	11,795	8,679	17,632	19,330
	Outflows	Net SW-GW Exchange	11,392	14,301	12,564	13,355	12,010	7,842	5,447	5,743	5,391	8,053	10,852
		Storage	153,576	76,826	62,280	57,459	41,739	31,601	29,190	33,364	26,716	46,958	51,173
		GW Interbasin Flow	53	56	54	53	50	49	49	49	49	53	55
		GW Pumping	17,547	10,411	16,888	19,192	27,727	32,441	31,769	29,397	29,797	19,642	13,277
		non-Ag ET	2,835	2,650	2,597	2,573	2,470	2,373	2,351	2,351	2,353	2,469	2,563
	Volumetric Error (%)		0.37	0.52	0.73	0.72	0.66	0.46	0.46	0.70	0.48	0.96	0.93

^ Desert Creek not included
* Desert Creek included
[a] Adjusted for Colony flows going to Artesia Lake

HRU water balance

Using the SWL program, a water balance for every HRU is computed and MODFLOW input files are generated. First, irrigation water is applied on a monthly basis. The SWL program combines total surface diversions, less 20 percent lost to ditch leakage, plus any groundwater pumped for a given HRU. The area of irrigated land varies by month. The monthly area of irrigated land is dependent on the volume of irrigation water as well as crop consumption needs for the month based on an area-weighted average of the crop types in the HRU. Crop consumption is based on Table 5, but adjusted to account for soil storage, such that excess precipitation is used to reduce ET demand during subsequent months until all soil-stored precipitation is removed. If monthly crop consumption exceeds the irrigated volume to the HRU, then crops are pulled from production in the following order: (1) low duty/management, (2) leafy crops, and (3) root crops. This approach inherently assumes that all available water is used during the irrigation season: available water will go to irrigating more acres if they exist.

Excess water is water remaining after all crop consumption needs are met. Excess water can become groundwater recharge, or it can return water to the river or to the return drain network. The partitioning of excess water to either groundwater recharge or surface return flows was done via calibration to best match net river gains and losses between Mason Valley's upstream gages and Wabuska.

The fraction of excess water that becomes surface return flow (*f*) is limited to that portion of irrigated water derived from surface diversions. The calibrated *f* is the maximum fraction of excess water that can become surface return flow if all irrigation water originates from surface diversions. If all irrigation water comes from groundwater sources, then no excess water can become surface return flow: groundwater resources in excess of crop consumption can only return to the groundwater system. This approach produces variable return flows over time: months more dependent on groundwater resources produce lower surface return flow volumes and relatively larger groundwater recharge. Surface return flow locations for each HRU are determined by proximity to drains or points of return along the river. For HRUs with multiple surface return flow locations, surface return flow volumes are divided among the return location based on contributing area.

The fraction (*f*) of excess water beyond total HRU crop consumption was adjusted to best match MVGM net river gains and losses. An *f*-value of 0.3 was determined to best replicate system behavior while maintaining acceptable hydraulic conductivity values. This value was then used in the SVGM with no additional calibration. Water not considered surface return flow is automatically assumed to recharge the groundwater.

Excess water designated as groundwater recharge is used to build the RCH input file for MODFLOW. Excess water designated as surface return flow is used in the development of MODFLOW's streamflow routing package (SFR1) described below. Water consumed by crops is lost from the model domain. It is assumed that no groundwater resources are directly used by crops because crop ET can only consume irrigation water or stored soil moisture, and irrigated water is applied at the minimum rate to satisfy crop needs. Therefore, the EVT package was not necessary for simulating crop ET.

The SWL program uses observed river inflows at USGS gages, surface diversions, and computed return flows to generate the SFR1 input file for MODFLOW. Surface diversions are extracted at points of diversion for each major delivery ditch, while return flows, computed in the HRU water balance, are added at designated points of return. Eighty-five percent of the return flows generated by the Colony HRU in the SVGM do not return to the river or drain network. Instead, these flows are transported to Artesia Lake and lost from the system by evaporation.

MODFLOW limits the user to Manning's wide channel assumption for predicting stream depths and velocities when using the observation and sensitivity package for calibration. During calibration of MVGM hydraulic conductivity Zones 1 to 4, the river is assigned a constant width of 66 ft (20 m). Once hydraulic conductivity and river conductance values are calibrated, the model is rerun using widths and depths determined from rating curves (Figure 27). Drains are modeled using Manning's wide channel assumption with constant widths of 10 ft (3.0 m) for all model runs. Minimum land surface elevations from light detection and ranging (LIDAR) data define the stream and drain bed elevations. A value of 3.3 ft/d (1.0 m/d) is used for stream bed hydraulic conductivity in rivers and drains. Large values of conductance cause model instability. Conductance values below 3.3 ft/d (1.0 m/d) effectively isolate the river from the aquifer.

MODFLOW Model Evaluation

<u>Mason Valley groundwater model</u>

Final hydraulic conductivity values produced a root mean squared error (RMSE) equal to 3.38 ft (1.03 m) using 1996 to 2003 groundwater levels (n = 120). Verification conducted with 2004 to 2006 groundwater levels produced an RMSE equal to 4.30 ft (1.31 m) (n = 73). The RMSE for all groundwater level observations is 3.74 ft (1.14 m) (n = 193). Figure 33 shows observed and simulated water levels for the calibration and verification periods. Locations of observation wells are shown in Figure 34. Both figures illustrate that observed water levels are reproduced by the MVGM with a high degree of accuracy. Water table elevations increase from the 1996 initial levels to peak during winter 2000, and subsequently decline during the drought of 2000 to 2004. Water levels rebound from 2005 to 2006. Observed water levels are limited to winter water levels, which do not illustrate the maximum fluctuation in water levels over the entire model period. Model results suggest significant drawdown occurs during the irrigation season in most wells, with up to 98 ft (30 m) of drawdown simulated in several wells by the end of October 2004. Wells with large drawdown occur throughout the model domain, with the greatest clustering in the West Hyland, Campbell, and Fox-Mickey HRUs.

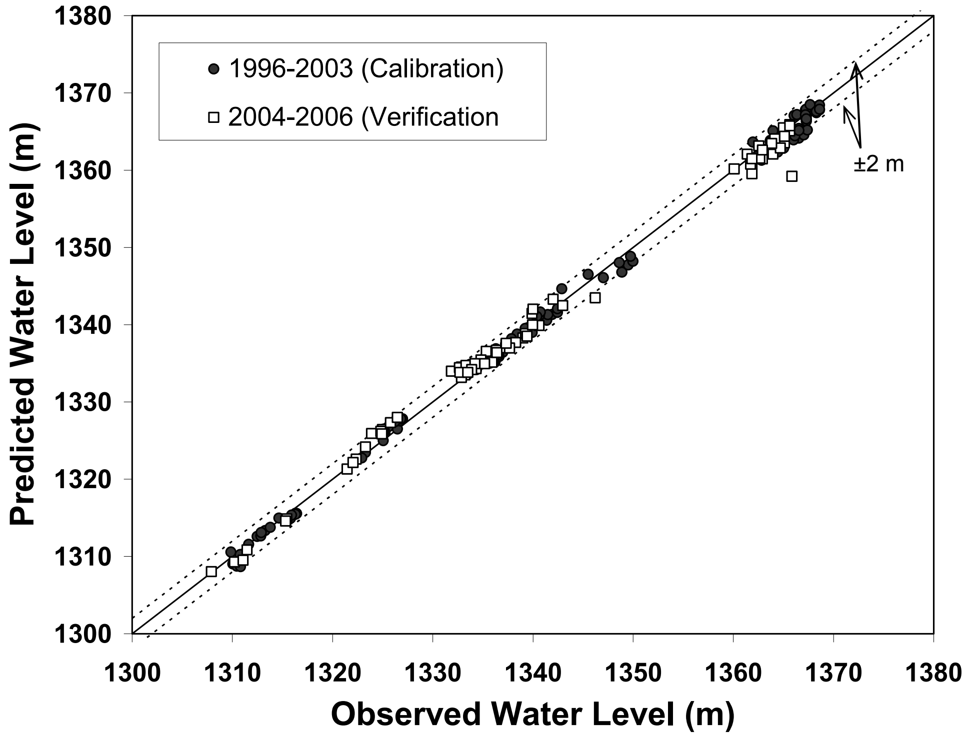


Figure 33. Predicted and observed winter water levels 1996-2006 for the MVGM.

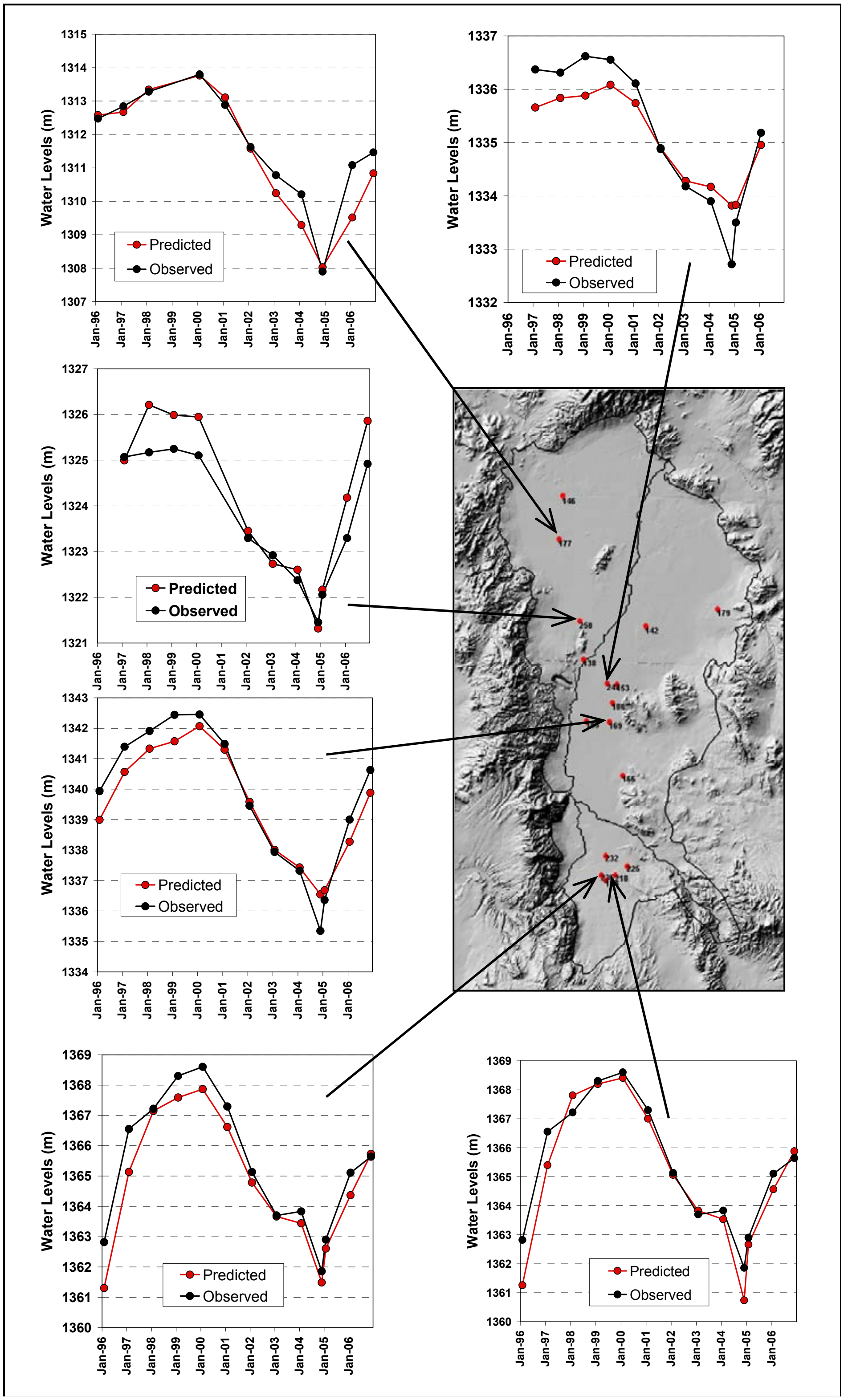


Figure 34. Predicted (red) and observed (black) winter water levels (1996-2006) for selected individual wells in Mason Valley. All wells with observation data are shown in red on the map. Grid lines represent 1.0 m.

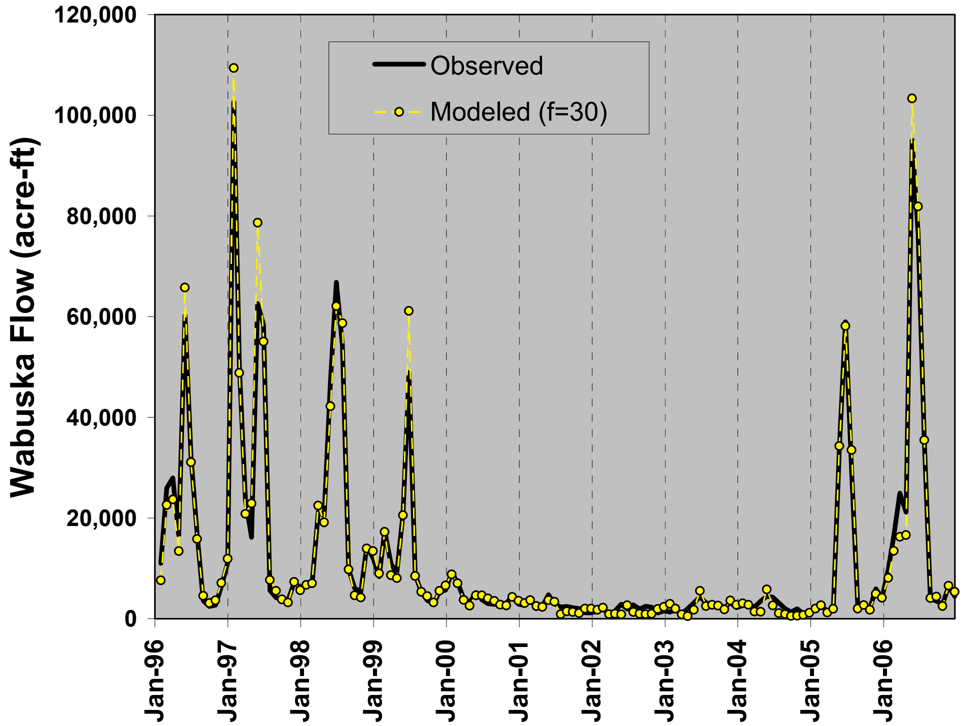
River flows at Wabuska are well modeled except that peak discharge during several years is overpredicted. Otherwise, the model reproduces streamflows exiting Wabuska (Figure 35a). Net river gains and losses are computed by comparing the total gage inflow (east and west forks) minus surface diversions to the outflow at Wabuska. When Wabuska flows are higher than the adjusted inflows, then the river is assumed to be gaining on a net basis. These gains can occur as either return flows from the HRUs or as groundwater fluxes into the river. On the other hand, if Wabuska flows are less than inflows minus diversions, than the river must lose water to the aquifer. This is only possible if the water table is lower than river stage. Results in Figure 35b show that the model captures net gains and losses of water to the river. In general, wet years produce a system gaining water during the irrigation season as either return flows or groundwater flux. The system is losing during winter months and the drought of 2000 to 2004.

The net gain and loss of river flow between its upstream gages and Wabuska (accounting for diversions) cannot identify interaction between streamflow and groundwater because of the implicit inclusion of surface return flows in the calculation. Using the SFR1 simulated streamflow and groundwater fluxes, excluding return flows, are evaluated. Streamflow and groundwater fluxes for the West, East, and Main Walker rivers, and basin-wide totals are provided in Figure 36. Negative fluxes denote a losing stream, and positive values indicate a gaining stream. The gradient between stream stage and adjacent water table elevations controls the flow direction into or out of the river.

During the irrigation season, two competing stresses are applied to the system. First, river stages decline as water is diverted. Simultaneously, diverted water is applied to agricultural fields, increasing groundwater levels over time. Both processes support a gaining system; however, it can take several months for the water table to rise and there is an additional delay for mounded groundwater to reach the river. Second, groundwater pumping reduces groundwater levels, which can draw water towards cones of depression rather than the river to promote a losing system.

Simulated stream-aquifer interactions in Mason Valley show that the West Walker River is almost always gaining, although gains decrease during the winter. Maximum gains decline beginning in 2000 until the West Walker River becomes a losing stream in the beginning of each irrigation season from 2003 to 2005. With wetter climatic conditions returning in 2005, the West Walker River begins to rebound to pre-drought conditions. The East Walker River in Mason Valley is similar to the West Walker River, except losses are more pronounced: the river is a losing system during late winter months even during wet years. With dry conditions, the East Walker River becomes a continually losing system from the end of 2000 until the end of the irrigation season in 2005. These losses are less than 1,000 acre-feet per month (1,233 m^3/mo). The Main Walker River is almost always a losing system with losses spiking to 6,000 acre-feet per month (7,400 m^3/mo). During the drought years of 2000 to 2004, the Main Walker River becomes increasingly losing. Large losses in 2006 show a system still recovering from the drought despite relatively large streamflows and surface diversions in 2005 and 2006. Figure 37 shows the spatial and temporal changes in stream-aquifer interactions in Mason Valley.

(a)



(b)

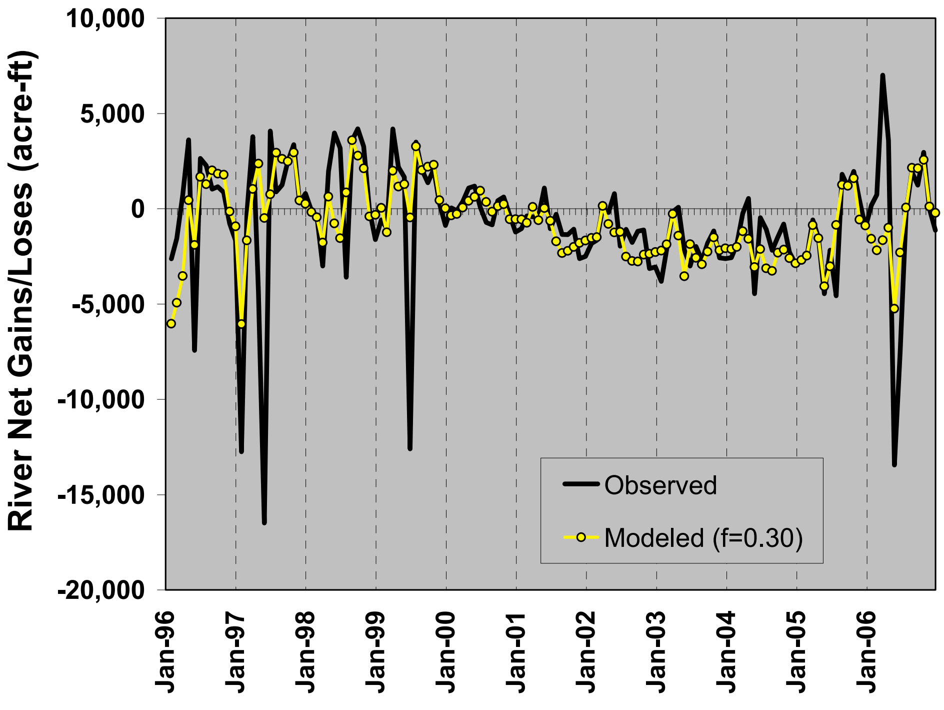


Figure 35. Comparison of modeled flows to observed flows, (a) at Wabuska gage exiting Mason Valley, (b) calibrated net gains/losses equal to Wabuska flow (sum upstream gage inflows - surface diversions). Net river gains and losses account for both return flows and stream-groundwater interaction

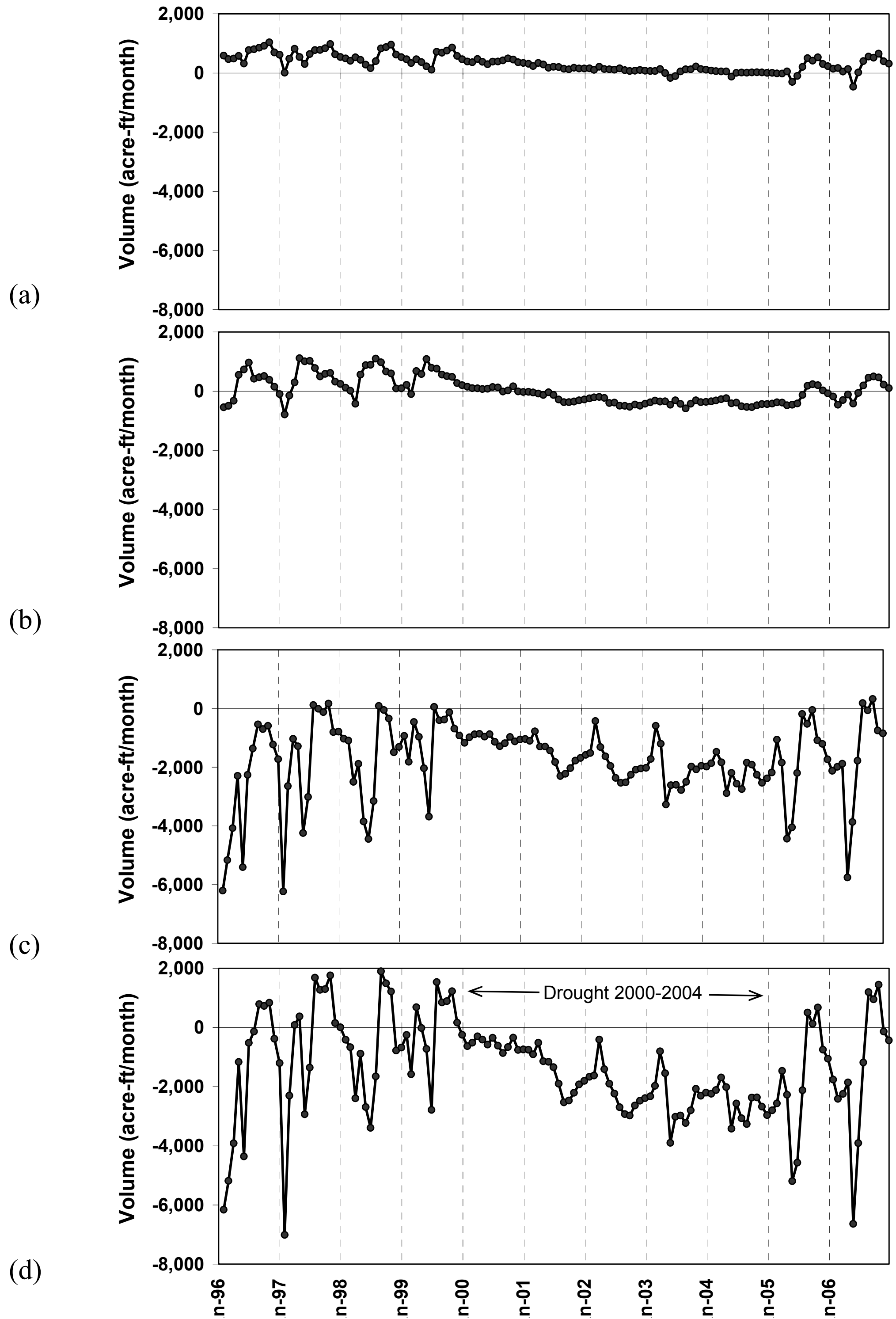


Figure 36. Simulated stream-aquifer fluxes (acre-feet/month) in Mason Valley for the (a) West Walker River, (b) East Walker River, (c) Main Walker River, and (d) all river reaches.

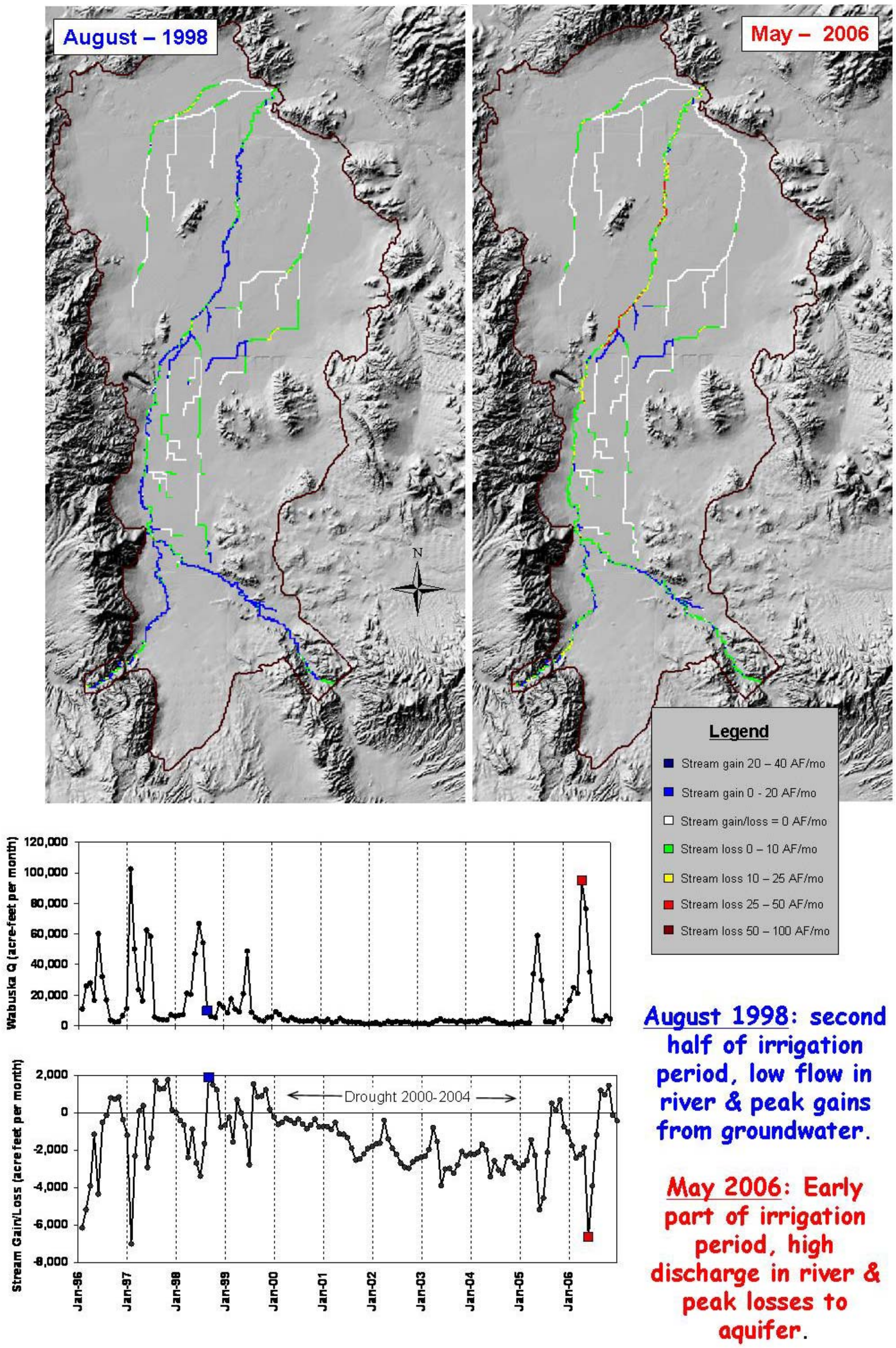


Figure 37. Simulated stream-aquifer fluxes (acre-feet/month) in Mason Valley for model cells in the river/drain network.

Seepage rates calculated from temperature profiles measured near the Wabuska gage (Tyler et al., 2008) are positively correlated with river discharge. Losing periods tend to be long lasting. Gaining periods are of short duration, occurring only during very low flow events, and therefore considered anomalous. The MVGM trends in groundwater-surface water interaction near the Wabuska gage agree with the findings of Tyler et al. (2008), despite covering a larger area and longer time period. Simulated seepage is consistently toward the groundwater system. Simulated seepage diminishes substantially with declining river stage in the late summer months.

Annual basin-wide water balances for the river/drain network, HRUs, and the groundwater system are provided in Table 11 (MVGM) and Table 12 (SMVG). Volumetric error (%) reflects error in modeled inflows and subsequent outflows. Volumetric error is most pronounced in the groundwater system as a result of conversion error introduced when HRU groundwater recharge volumes calculated in the SWL program using GIS-derived areas are translated to the MODFLOW grid.

Review of the HRU water balance shows that crop ET requirements in Mason Valley remain relatively consistent. This consistency reflects supplemental groundwater pumping that allows crops irrigation even during drought years. Crop consumption is greater than estimates presented by Huxel and Harris (1969) and Myers (2001a). These studies use crop demand rates of 1.0 ft (0.30 m) per year and 1.6 ft (0.49 m) per year for crops, respectively. Evapotranspiration rates in the MVGM and SVGM assign higher crop demands (2.6 to 3.6 ft per year; 0.79 to 1.09 m per year), which may account for some of the differences in crop consumption between studies.

Using a calibrated *f*-term equal to 0.3 to partition excess irrigation water into surface return flow produces return volumes on the order of 7,000 AFY to 19,400 AFY (8.6 million MPY to 24 million MPY). Lower volumes occur during dry years. Groundwater recharge from excess irrigation water ranges from 35,700 AFY to 66,400 AFY (44 million MPY to 82 million MPY). The total volume of water returned to the groundwater system is 60,400 AFY to 99,400 AFY (75 million MPY to 123 million MPY) when ditch leakage is included. This appears reasonable when compared to groundwater recharge volumes set forth by Myers (2001a) and Huxel and Harris (1969) at 57,500 AFY to 70,000 AFY (71 million MPY to 86 million MPY), respectively.

Annually, the Walker River in Mason Valley is losing water to the groundwater system: volumes leaving the river range from 5,600 AFY (7 million MPY) during a wet year (1999) to 34,300 AFY (42 million MPY) at the end of a four year drought (2004). Elevated river stages, non-agricultural ET, and basin-wide pumping all contribute to river losses during wet years. In dry years, extensive groundwater pumping and loss of irrigation recharge from HRUs are the main contributors to stream losses.

Smith Valley groundwater model

Water levels in Smith Valley are poorly represented by the model, with an RMSE equal to 40 ft (12.3 m) (n = 547). Error can be attributed to lack of adequate data to properly assign initial conditions and the model's inability to replicate large variations in water levels over time. Water levels in wells adjacent to the river, however, are reasonably represented, with an RMSE equal to 7 ft (2.0 m) (n = 43). Figure 38 shows that outgoing streamflows at the Hudson gage are well modeled despite the model's inability to capture groundwater levels in the basin. Unlike the MVGM, peak discharge is underpredicted during wet years, but error is relatively low. The river is largely gaining through Smith Valley, and remains gaining even during the winter months, indicating that groundwater levels are higher than stream stages during non-irrigation periods. Observed gains are only moderately reduced during the drought years and periods of loss are not sustained. Simulated gains and losses are more moderate in their fluctuations than the observed, and while gains are reduced during drought years, the model does not become losing, even for the brief episodes observed.

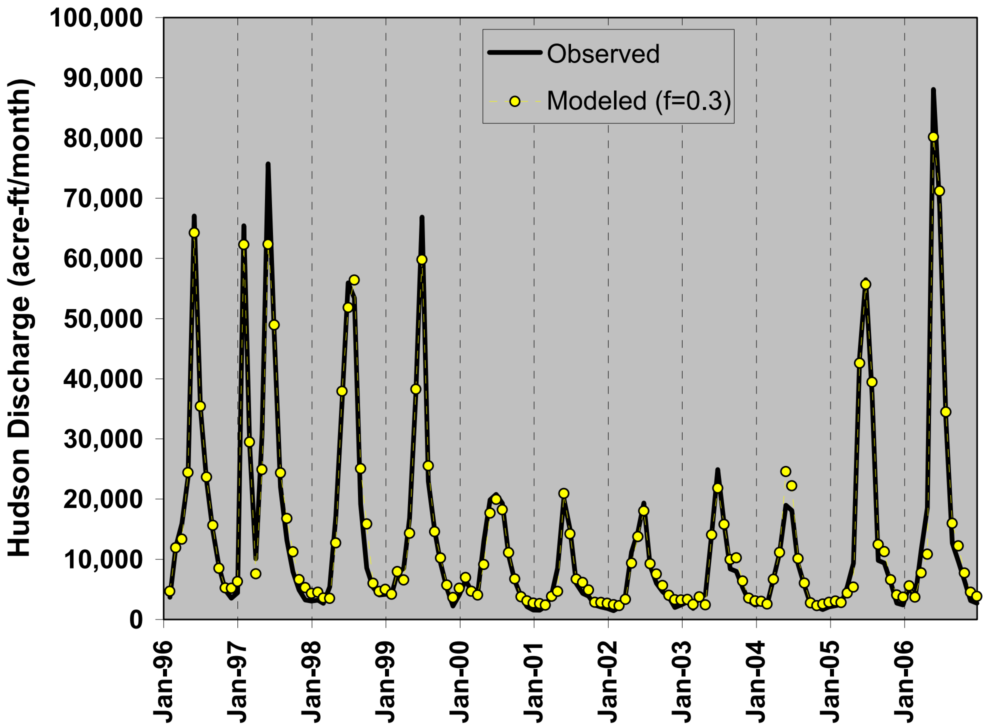


Figure 38. Modeled flows compared to observed flows at Hudson gage exiting Smith Valley, acre-feet per month.

Results show a system gaining groundwater most of the year, even in periods of extended drought (Figure 39). The only modeled periods of streamflow loss to the groundwater system occur in May and June. This loss is based on elevated river stages during peak streamflows, forcing water into groundwater storage. While the stream is losing water to the aquifer, simulated surface return flows during the early irrigation season prevent a net computed loss in the river between the Hoye and Hudson gages.

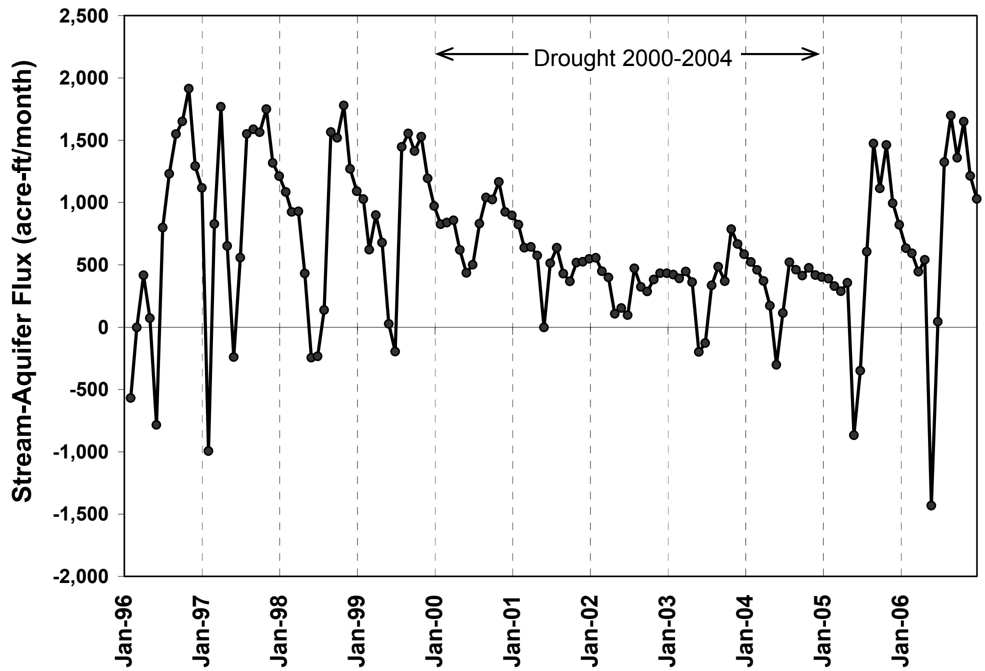


Figure 39. Simulated stream-aquifer fluxes in Smith Valley, acre-feet per month.

The SVGM water balance is presented in Table 12. Crop ET in the basin consumes approximately 50,000 to 56,000 AFY (62 million MPY to 69 million MPY) with groundwater recharge ranging from 12,700 AFY (16 million MPY) during dry years to 26,600 AFY (33 million MPY) during wetter periods. Return flows are 3,509 AFY to 10,700 AFY (4.3 million MPY to 13 million MPY). River gains from the groundwater are 5,400 AFY to 14,301 AFY (6.7 million MPY to 18 million MPY). The West Walker River through Smith Valley remains a gaining stream despite much lower groundwater recharge volumes from excess irrigation than Mason Valley. This is primarily from the large amount of mountain-block recharge as well as lower pumping demands.

Irrigated areas

The irrigated areas for June 9, July 27, and September 15, 2000 are estimated using Landsat Thematic Mapper satellite imagery with an observation error of approximately 7.5 percent (Minor et al., 2009). The simulated irrigated area for the three observation dates is estimated using linear interpolation. Basin total irrigated area was lowest in early June and increases through July. A decline in irrigated area occurs between July and mid-September.

Modeled results show a steep rise in irrigated area at the beginning of the irrigation season, but the simulated irrigated area remains fairly constant through the rest of the irrigation season. Irrigated areas are generally at, or near, the total area of each HRU from April through October. Predicted and observed irrigated areas are shown in Figure 40 for both Mason Valley and Smith Valley. In general, the MVGM over irrigates HRUs. Because diversion rates are based on observed values, and drawdown estimates are reasonable, this error is likely related to the extent of the irrigated area, rather than the volume of water applied per acre. The error becomes more pronounced for larger HRUs. The RMSE in prediction is 312 acres (n = 84); however, accounting for observed error mitigates discrepancies between Mason Valley observed and modeled irrigated area.

Predicted SVGM irrigated areas are more variable in time compared to the MVGM because supplemental groundwater pumping is lower in Smith Valley and is therefore unavailable to offset lower surface diversions. Large error in predicted volumes occurs in the Smith Groundwater and Colony HRUs: irrigated areas in both are severely underestimated. Reasons for these discrepancies are unclear, but suggest that groundwater pumping is underestimated for these HRUs. If the Smith Groundwater and Colony HRUs are included in the analysis, then the RMSE for Smith Valley is 1,175 acres (n = 33). Removing these HRUs produces an RMSE equal to 79 acres (n = 27), showing that the SVGM accurately irrigates the basin, aside from the Smith Groundwater and Colony HRUs.

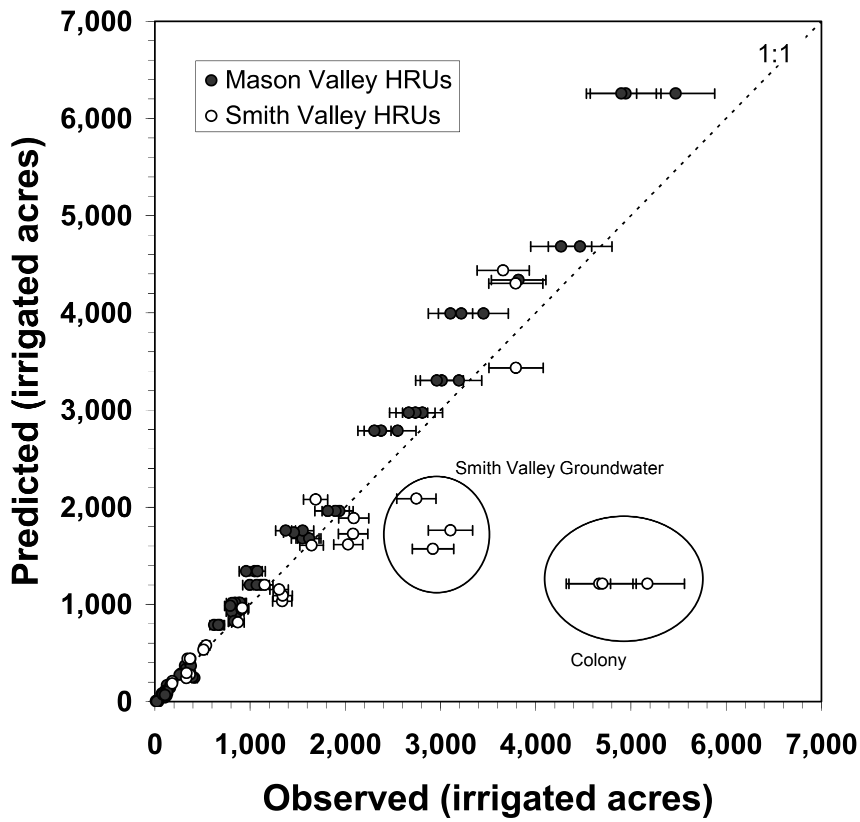


Figure 40. A comparison of observed and predicted HRU irrigated area based on Landsat imagery taken June 9, July 27, and September 15, 2000. Linear interpolation was used to extract modeled area from SWL program output. Assumed error in observed values is ±7.5 percent. Smith Groundwater and Colony HRUs are marked.

MODFLOW Model Sensitivity

A sensitivity analysis is conducted on the MVGM by adjusting input parameters independently and quantifying changes in model output compared to the baseline simulation. Baseline refers to the calibrated and verified MVGM. River flows exiting the model domain at the Wabuska gage and volumetric changes in fluxes between the river and groundwater system (groundwater-surface water flux) are evaluated for each parameter adjustment. Groundwater-surface water fluxes are included in the analysis primarily to identify parameter impacts on the river's hydraulic status (gaining or losing) from surface return flows and drain interactions with groundwater.

Parameters adjusted include hydraulic conductivity zones 1 through 4 (K1, K2, K3, and K4), storage terms (S, S_y) adjusted simultaneously, river/drain conductance (C), agricultural ET, non-agricultural ET, the fraction of surface diversions lost to ditch leakage (L), and the maximum fraction (*f*) of excess irrigation water allowed to return to the river/drain network from each HRU. Table 13 shows changes in total volumes (δV) over the entire modeled period (1996 to 2006) in both acre-feet and percent (%). A normalized change in volume (δV_N) is also shown where the percent volume change is divided by the absolute change in the magnitude of the input parameter (δM), defined as the logarithm of the ratio of the adjusted parameter value to the baseline parameter value (Hill and Tiedeman, 2007).

Results show that ET for both crops and non-agricultural land is particularly important to flow output in the MVGM. However, model fluxes are two to three times more sensitive to crop ET than to non-agricultural ET. Increasing ET produces large volumetric losses from the river to the groundwater and large losses of water from drains to the groundwater. Increases in crop ET also leads to reduction of surface return flows. In contrast, decreasing ET forces water into the river via groundwater fluxes and surface return flows. Properly quantifying ET is imperative to understanding and accurately allocating water budget components, as well as predicting basin response to changing conditions.

The MVGM is most sensitive to changes in hydraulic conductivity in the alluvial deposit (K3) and upper river deposit (K1) zones. The alluvial deposit zone is also important in the calibration process because most observation wells are located there.

River fluxes are not sensitive to K4, the fan material located along the model domain margins, which is expected. Model output is less sensitive to lower river deposits (K2), which is unexpected. Model calibration assigns a very high conductance to sediments surrounding the northern portion of the river (K2 = 82 ft/d; 25.0 m/d), but considering the model's insensitivity, lowering K2 to a more reasonable value may be possible without large impacts to predicted Wabuska flows.

Modeled flows are relatively insensitive to ditch leakage below 30 percent. Ditch leakage above 30 percent becomes increasingly important to river interactions with the groundwater, as well as river flows exiting at Wabuska. Increasing the percent of surface diversions lost to ditch leakage results in fewer irrigated acres. This decline in crop production lowers the volume of water lost to crop ET. Instead, more water is forced into the groundwater system, which increases water table elevations and results in greater groundwater inflows to the river/drain network.

Table 13. Sensitivity results for the MVGM obtained by adjusting each listed parameter independently. Changes in volumes (δV) are presented in acre-feet and percent (%). Normalized volume change (δV_N) is defined as δV(%)/abs(δM), where δM is the magnitude change in the parameter. δM = log (adjusted value/baseline value).

				SW-GW Flux[a,b]			Wabuska Outflow[a,b]		
Parameter	Description	New Value	δM	δV (acre-feet)[c]	δV (%)	δV_N (%)	δV (acre-feet)[c]	δV (%)	δV_N (%)
K1	Hydraulic Conductivity	18.80	0.70	-92,168	-50	-71	-92,928	-6	-8
	Upper River Deposits	0.75	-0.70	45,268	24	35	46,627	3	4
K2	Hydraulic Conductivity	125.00	0.70	-55,312	-30	-43	-48,638	-3	-4
	Lower River Deposits	5.00	-0.70	50,511	27	39	59,010	4	5
K3	Hydraulic Conductivity	5.00	0.70	-100,042	-54	-77	-86,327	-5	-8
	Younger Alluvium	0.20	-0.70	48,954	26	38	46,000	3	4
K4	Hydraulic Conductivity	5.00	0.70	6,350	3	5	4,217	0	0
	Fan Deposits	0.20	-0.70	-9,732	-5	-7	-8,900	-1	-1
Ss *Sy*	Storage Terms	0.00004 0.80	0.60	-27,095	-15	-24	-32,641	-2	-3
		0.0000025 0.05	-0.70	-16,380	-9	-13	-6,651	0	-1
C	Stream/Ditch	2	0.30	-30,794	-17	-55	-3,302	0	-1
	Conductance	0.1	-1.00	62,498	34	34	68,024	4	4
Ag ET	HRU Crop ET	multiplier 1.5	0.18	-151,144	-81	-461	-184,447	-12	-65
		multiplier 0.5	-0.30	206,484	111	369	344,740	22	72
non-Ag ET	Phreatophyte, etc	multiplier 1.5	0.18	-80,130	-43	-244	-83,011	-5	-29
	ET	multiplier 0.5	-0.30	91,730	49	164	95,077	6	20
L	Ditch leakage	0.02	-1.00	-44,102	-24	-24	-23,737	-1	-1
		0.30	-0.30	28,495	15	51	18,613	1	4
		0.50	0.40	186,124	100	251	75,086	5	12
		1.00	0.30	403,329	217	720	453,213	28	94
f	Fraction excess HRU	0.30	-1.00	46,755	25	25	1,353	0	0
	Water to return drains	1.00	0.52	-126,504	-68	-130	28,601	2	3

[a] Flow into the river (SW) from the groundwater (GW) is positive; flow out of the river into the groundwater is negative.
[b] Change in volume represents change from baseline simulation over the entire modeled period 1996-2006, or 11 years.
[c] Fluxes pertain only to the river. They do not include flows to/from the return drain network.

Model output is not sensitive to reductions in *f* below its calibrated value of 0.3. In fact, negligible changes are observed in river flows when *f* is decreased by an order of magnitude. Increasing *f* to a value of 1.0 lowers the water table appreciably as well and increases river stages, forcing the river to lose substantial volumes to the groundwater.

Wabuska flows remain fairly stable because the net increase in surface return flows balances the increased loss from gradient changes. Therefore, *f* is not a good calibration parameter for matching net gains and losses observed at Wabuska.

MODFLOW Model Limitations

The solutions to the groundwater models are non-unique. This minimizes the implications of any single set of calibration parameters because another, different, set might be able to represent the observed behaviors equally well.

Hydraulic conductivity zones in the SVGM do not adequately represent water levels throughout the domain. Wells adjacent to the river are well represented; however, these wells are more influenced by streamflows and the local gradient than by hydraulic conductivity in the aquifer. Attempts to calibrate the SVGM in a fashion similar to the MVGM to better match observed groundwater levels were unsuccessful. The current hydraulic conductivity zones need to be revisited and modified.

While groundwater fluxes are sensitive to f greater than 0.3, modeled Wabuska streamflow is not greatly impacted by how excess irrigation water from the HRUs is partitioned. The lack of model output sensitivity to f reduces the effectiveness of accurately partitioning excess HRU water.

The level of error and uncertainty associated with stream-groundwater interactions is not quantified. The significance of modeled fluxes in this context is therefore unclear.

MODFLOW Conclusions

The conceptual model, and subsequent numeric codes, couple surface processes along the river/drain network with agricultural demand areas and the groundwater system to simulate complex system behavior in Mason Valley and Smith Valley. Mason Valley, in particular, is well modeled: low RMSE values are calculated for water levels, stream flows and river responses. Smith Valley is not modeled with the same degree of accuracy as Mason Valley, but the SVGM provides insight to the system by its contrast with the MVGM.

The MVGM suggests that groundwater fluxes into the river/drain network account for about four percent of the river's water budget during wet periods, but account for nearly 25 percent of the river's budget during extended drought. Mason Valley contains a net gaining river system during summer months of wet years. Most gains from groundwater occur along the West and East Walker rivers. The main Walker River is generally losing, but less water is lost to the groundwater system during the irrigation season than during other parts of the year. Groundwater inflows during the irrigation season are the result of increasing groundwater levels as excess irrigation water infiltrates and reduced river stages as water is removed by diversions. These processes force the hydraulic gradient toward the river. During winter months the hydraulic gradient reverses, producing a net losing river. Groundwater pumping greatly increases in dry years, with extended drought periods causing the river to become continually losing, and losing greater volumes over time, even during the summer months.

In contrast to Mason Valley, Smith Valley appears to be mostly a gaining river, but gains are only three to seven percent of the river's water budget for all years modeled. These gains may not be significant when model error is considered. Calibration of the SVGM to better reflect observed groundwater levels is necessary to reduce this error and should be considered in the future. Elevated water levels simulated in Smith Valley are the result of higher mountain-block recharge (20 percent of the groundwater budget compared to one percent in Mason Valley), lower groundwater pumping (an average of 28 percent of the groundwater budget compared to an average of 47 percent in Mason Valley), and lower losses from non-agricultural vegetation ET (three percent of the groundwater budget compared to 18 percent in Mason Valley).

Preliminary modeling shows that reducing surface diversions and associated supplemental groundwater pumping from the river in Mason Valley would increase river stages and decrease groundwater mounding from lack of irrigation recharge. Those HRUs with significant supplemental groundwater rights and closer proximity to the river experience greater efficiency because lost irrigation recharge and lost irrigation return flow are balanced by reduced well drawdown. The fraction of diversion left in the river, but then lost to the aquifer, ranges from four to 97 percent depending on the HRU. Average losses are 16 percent, but if several river pumps are excluded from the analysis, then average losses reach 42 percent.

Simulating the agricultural demand areas in the Walker River basin requires a robust model capable of simulating the complex relationships between irrigation deliveries, crop demands, groundwater withdrawals and recharge, surface runoff, and ET. Considering the complexity of this system, the Mason Valley model performs extremely well in estimating groundwater-surface water interactions in the river corridor and water distribution and consumption throughout the valley. The Smith Valley model is less effective in reproducing observed groundwater levels, but river discharge is simulated well and is able to provide valuable insight to system dynamics.

STREAMFLOW ROUTING AND WATER RIGHTS ALLOCATIONS

MODSIM (Labadie and Larson, 2007) will be used to dynamically simulate reservoir operations and river systems within the Walker River basin. This model uses a network approach, and is capable of incorporating all known water rights (decree, storage, and flood), streamflow routing and losses, reservoir operations, and diversions and returns. MODSIM will also be used to combine the models described above (headwaters supply areas, Smith Valley groundwater model, and Mason Valley groundwater model) into one, integrated DST accessible to planners and managers.

A conjunctive surface and groundwater use model is developed to simulate the allocation of water in the Walker River basin based upon legal and administrative constraints. The model couples MODSIM with MODFLOW output and water rights information. In the future, the model will be used to understand the effect of possible water rights acquisitions in Mason and Smith valleys on the volume of water that reaches Walker Lake.

The MODSIM model extent begins just below Bridgeport Reservoir, CA at USGS gage 10293000 on the East Walker River, and at Coleville, CA at USGS gage 10296500 on the West Walker River and continues downstream to Wabuska, NV, at USGS gage 10301500 (Figure 41). Agricultural demands in Antelope Valley, Smith Valley, Mason Valley, and on the East Walker River from Bridgeport to Mason Valley are represented in the model. A monthly time step is used for the model and all volumes are calculated in acre-feet. The model is calibrated over the period 1996 to 2006 and simulations cover the same period.

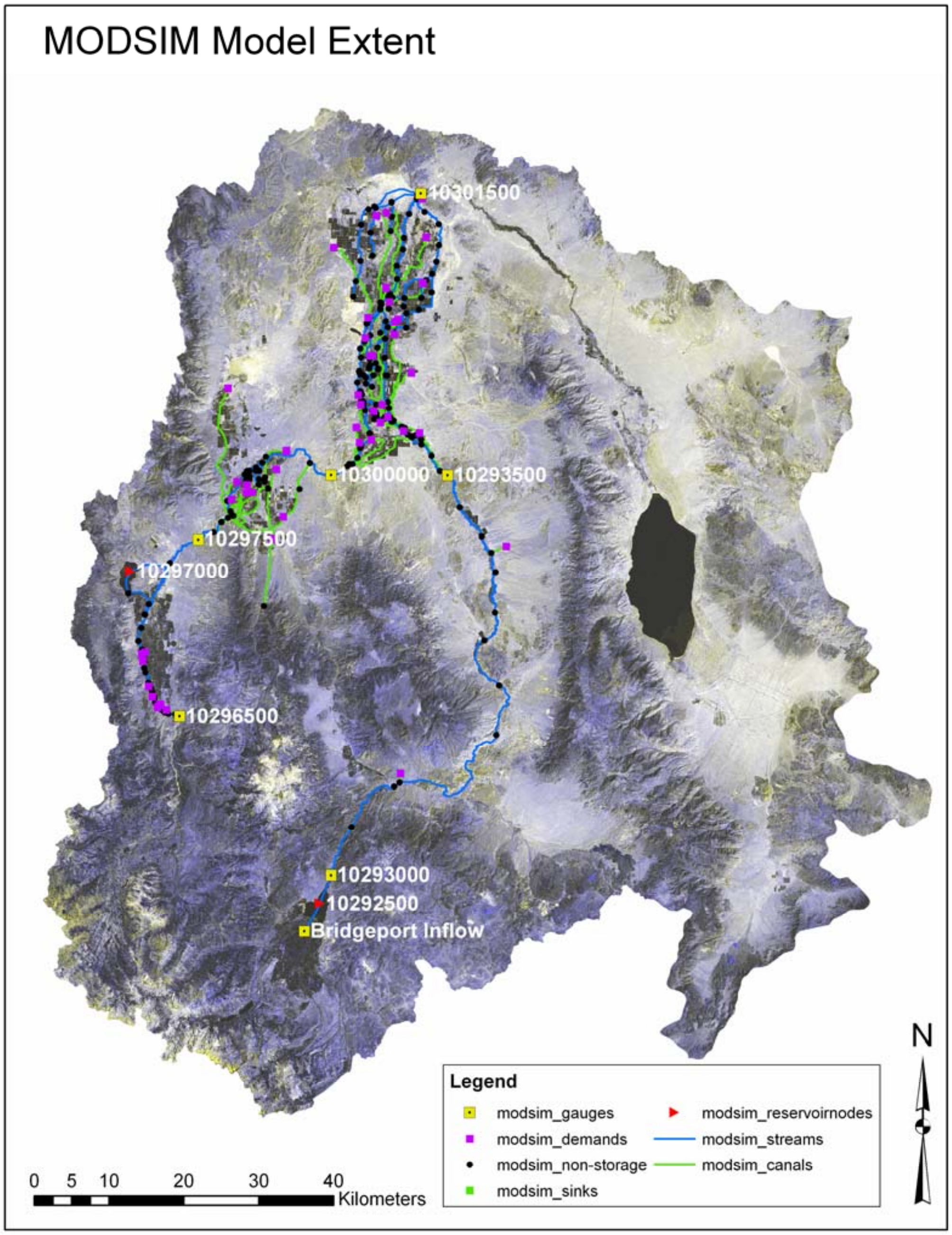


Figure 41. MODSIM model extent. Reaches 2 and 4 (Mason and Smith valleys) have MODFLOW models to simulate field operations on the demands, the groundwater system, and the stream's response to perturbations in the aquifer. Demands in Reaches 2 and 4 have water rights information and diversion data. Diversions to the demands in these reaches are simulated in MODSIM according to water rights information up to the total observed amount diverted. Groundwater deliveries are handled by MODFLOW and the MODFLOW preprocessor.

MODSIM Description

MODSIM is a generalized, management-based river basin model designed for use as a decision support tool (Labadie and Larson, 2007). It uses a network flow approach to model river basins with respect to specific management problems, such as water rights allocations, water planning and distribution, and disputes between stakeholders (Labadie and Larson, 2007). It has been used in studies ranging from water rights transfers to increase endangered species' habitat (Houk and Frasier, 2002), to the development of a decision support tool for conjunctive stream-aquifer management (Fredericks et al., 1998).

MODSIM 8 has no proprietary licensing requirements and is developed under the Microsoft™ NET Framework environment, which allows unique customization functionality. No one river basin model can include all features needed to simulate behaviors of a river basin. MODSIM models can be customized with user-created .NET code to define complex operating rules or policies. MODSIM customization allows the user to develop powerful pre- and post-processing interfaces, linking the model with data sources and facilitating integration with other models such as MODFLOW (Labadie and Larson, 2007).

A MODSIM network is comprised of interconnected nodes with unidirectional links. Nodes can be classified as non-storage nodes, demand nodes, reservoir nodes, or network sinks. Non-storage nodes are inflow locations where water can flow into the system. Demand nodes represent consumptive uses, where flow leaves the system. Reservoir nodes are storage nodes that simulate reservoir operations. Network sinks convey flow out of the network. Links convey flow from node to node. MODSIM optimizes the network flow-cost problem to distribute water among competing users in the system. Cost is a way of preferentially driving flow to one place in the network over another. The more negative the cost, the more the model will drive water in that direction. The design of cost structures in the MODISM network allows simulation of the prior appropriation doctrine and other complex administrative rules. The model converts node priorities to costs, using

$$\text{Cost} = -50{,}000 + (10 * \text{Priority}) \tag{4}$$

The node costs are then combined with the costs of the model links. The sum of all flows multiplied by the cost at each time step is minimized to solve the network flow-cost problem.

Since MODSIM is capable of differentiating between direct flow and storage water, it has the capability to simulate the allocation of different categories of water. For example, in the Walker River basin, water is generally placed in one of three categories: decree, flood, or storage. In the model presented here, each HRU represents an aggregate of farms with a collection of water rights fed by a common delivery ditch. The model uses historical water deliveries to the HRU to capture both the unit water requirement and historical operations of the individual ditches. The MODSIM model is not explicitly modeling the demand on the HRU, but rather matching the observed diversion at each point of diversion in the system. As discussed above, MODFLOW is modeling the consumptive use of each HRU, while MODSIM is attempting to deliver the correct diversion to each HRU, with the correct proportion of the different categories of water. In this section, HRUs represent demand areas, and will sometimes be referred to as demands.

The MODFLOW models of Smith and Mason valleys, described above, simulate the regional groundwater system using historical data. The MODSIM model is directly coupled to the MODFLOW output to import the SFR1 fluxes into MODSIM. Direct coupling between MODFLOW river cells and MODSIM links using a custom module provided an unprecedented conjunctive surface water and groundwater modeling system. The coupling of the models in GIS was achieved by geo-referencing the MODFLOW grid and using tools (e.g., Geo-MODFLOW, Geo-MODSIM) incorporated in the River GeoDSS, a generalized spatial decision support system for conjunctive surface and groundwater river basin management (Triana and Labadie, 2007). Spatial overlay processing of both models' objects allowed simulation of spatial and temporal complexities of the non-linear stream-aquifer interaction directly in the MODSIM modeling system.

MODSIM Model Development

Base network development

MODSIM networks can be developed manually in the standard MODSIM-DSS Graphical User Interface (GUI) (Labadie and Larson, 2007), or in an ArcMap extension called Geo-MODSIM (Triana and Labadie, 2007). The advantage to using Geo-MODSIM is that the network can be developed, parameterized, populated with timeseries data, and queried for results all within the ArcMap interface and the Geo-MODSIM toolset. Generating a large complicated network with many nodes and links is made much easier with the geometric network capabilities of ArcGIS.

The Walker River base network is constructed by converting the ditches, streams, drains, demands, and sinks into the appropriate MODSIM feature class in the Geo-MODSIM geometric network. The streams and drains are identical to those used in the MODFLOW-SFR package to ensure that MODFLOW input to MODSIM would be compatible with the MODSIM network layout. The network connectivity analyst in ArcGIS is used to validate the network topology, and the network flow direction is set using ArcHydro tools. Once the network flow direction and topology are validated, the network is exported as a file read by the standard MODSIM GUI. Although the base model was developed in Geo-MODSIM, subsequent model development, calibration, and simulation involved only the standard MODSIM GUI.

The model domain is divided into four reaches to highlight differences in parameterization of model demands, illustrate data availability, and facilitate analysis and validation of the model performance (Figure 41). Reach 1, which contains Antelope Valley and Topaz Reservoir, extends from Coleville, CA (USGS gage 10296500) to Hoye Canyon (USGS gage 10297500). Reach 1 does not include any MODFLOW information. Deliveries to demands in Reach 1 are allocated based on observed diversion data because water rights information is not available. A high negative cost was assigned to the links conveying flow to these demands to ensure that diversions to these demands were met. Groundwater pumping data are not available in Reach 1. Reach 2, which contains Smith Valley, extends from Hoye Canyon to near Hudson, NV (USGS gage 10300000). Reach 2 includes the entire extent of the Smith Valley groundwater model. Reach 3, which contains Bridgeport Reservoir, upper East Walker, and East Walker demands, extends from above Bridgeport Reservoir to Strosnider Dam (USGS gage 10293500). MODFLOW information and groundwater pumping are not available for Reach 3, but water rights information and surface diversions for the East Walker and upper East Walker demands are available. Reach 4, which contains Mason Valley, extends from Hudson, NV and Strosnider Dam on the West Walker River and East Walker River, respectively, to near Wabuska, NV (USGS gage 10301500). Reach 4 includes the entire extent of the Mason Valley groundwater model.

MODSIM input data

MODFLOW river fluxes (fluxes in the SFR1 cells), MODFLOW fast response (surface return flow from HRUs), timeseries data (e.g., observed diversions, boundary condition streamflow, reservoir storage, and evaporation), and water rights information (e.g., priority dates, maximum diversion rates, annual limits, and capacity for reservoir accounts) are all used as input to the MODSIM model. Where possible, boundary condition streamflow and diversion data are taken directly from the MODFLOW input files to ensure identical inputs. Diversion data includes the monthly decree, storage, and flood allocations for each demand. Boundary condition streamflow to Bridgeport reservoir is not available because the reservoir has multiple contributing streams, few of which are gaged during the modeling period. The inflow to Bridgeport Reservoir is calculated as the change in reservoir storage minus the flow at the Bridgeport outflow gage. Average monthly free water evaporation for both Topaz and Bridgeport reservoirs is assumed to be equivalent and equal to the monthly average published by the Western Regional Climate Center (WRCC, 2008b). Observed storage for both reservoirs is available from the USGS (USGS 10292500 for Bridgeport Reservoir, USGS 10297000 for Topaz).

Water rights information for each demand (HRU) is available for the Walker River basin (Minor et al., 2009), including type of use (decree or storage), diversion rate, irrigated acres, annual duty, and annual volume. In the Walker River basin, multiple accounts distributed over a wide geographic area can have identical priority dates, but unique priority dates are advised in MODSIM to avoid random water allocation among users with the same priority date. To achieve a unique priority scheme, demands are ranked in the downstream direction such that the most downstream owner of a commonly owned right would be assigned the lowest priority for that common date, promoting a water reuse scheme in the basin. Thus, if several demands have a priority date of 1880, the most upstream demand is assigned a priority data of January 1, 1880, the next January 2, 1880, and so on.

Storage account holders in Mason Valley below the confluence of the East and West Walker rivers may store up to one third of their storage right in Bridgeport Reservoir and up to two thirds in Topaz Reservoir. To accommodate for these dual storage account holders, one account was created in each reservoir and the capacity of each account was sized according to the one third-two thirds rule.

Water rights were ranked based on the priority date and from this priority ranking, a cost structure was assigned with -10,000 corresponding to the oldest water right. Each subsequent right was incremented by 10 so that the next oldest right would be assigned -9,990 and so on. The rights with the most negative cost have the highest priority.

Importing data

A custom modeling module was developed in Visual Basic .NET to import the MODFLOW information (fluxes and surface response), observed timeseries data, and water rights information into the MODSIM base network. The customized module has a flexible GUI where the user inputs the location of the files needed to run module and import the necessary data (Figure 42). The custom module provides access to pre-processing procedures that are able to modify the network topology and load timeseries and water rights information for building calibration and simulation networks.

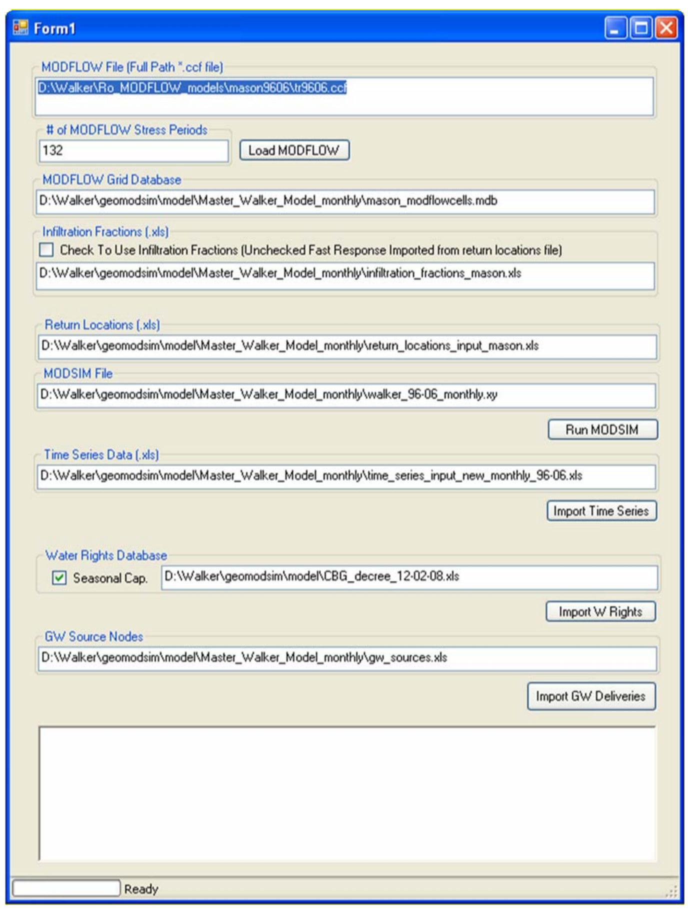


Figure 42. User interface form for custom module.

An enhanced version of the Geo-MODFLOW module of River GeoDSS (Triana and Labadie, 2007) is implemented in the custom modeling module for this application. The module is able to read MODFLOW-2000 binary output files and provide direct linkage between the MODFLOW predicted stream-aquifer interactions and the MODSIM network. Geo-referenced MODFLOW-SFR1 cells and MODSIM network objects are linked using a spatial overlay relationship. An Arc Macro Language (AML) script was written to extract the spatial relationship between these objects to a shape file. The shape file was exported to a personal geodatabase file. The custom module utilizes the geodatabase to import the fluxes in each of the MODFLOW-SFR1 cells below a particular MODSIM link (red cells in Figure 43), and then sums the gains and losses for that link. The module creates a new node object in the MODSIM model called *GW_sink* that is connected to the downstream node for that link (15_8608 in Figure 43), and places the timeseries of the summed losses into the capacity timeseries for that link. A very high negative cost is placed on this link to ensure that the model satisfied the link's capacity for depletions. The simulated MODFLOW-SFR1 gains in this link were placed in the downstream node (15_8608 in Figure 43) as a timeseries of inflows. This process was repeated for each link in the model.

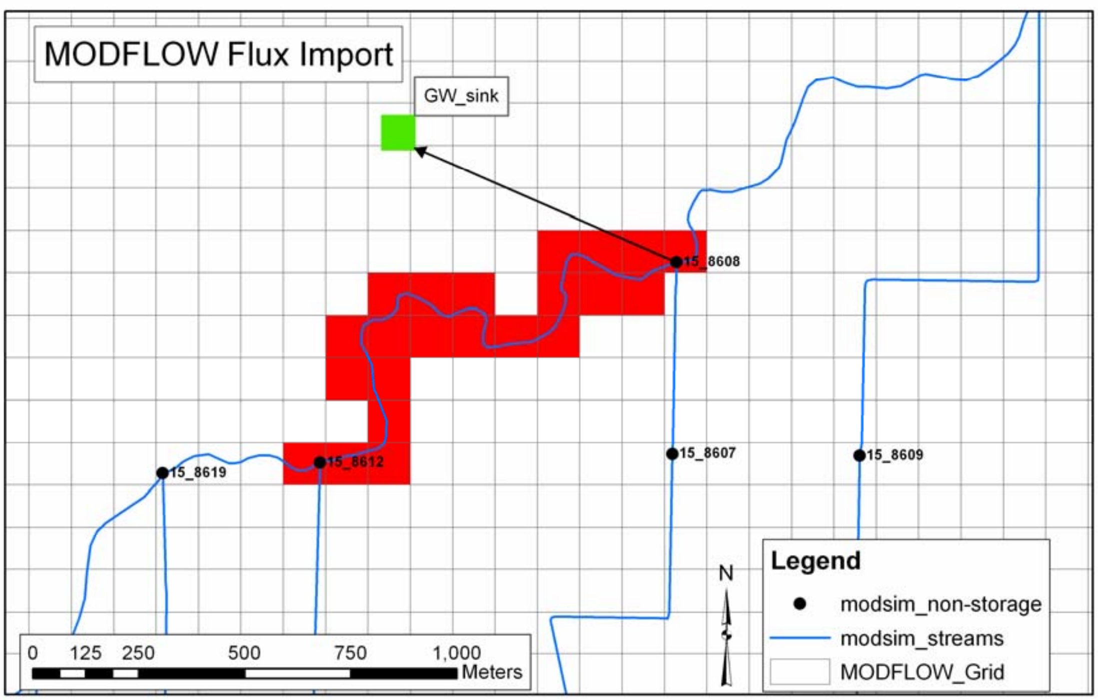


Figure 43. MODFLOW flux import diagram.

Geo-MODFLOW provides graphical tools in ArcMap to summarize and visualize the MODFLOW model binary output for the MODSIM network objects, allowing the imported MODFLOW fluxes to be quality checked. Each binary MODFLOW file is imported into Geo-MODFLOW and verified to ensure that the correct fluxes were imported into the MODSIM model. Differences in the MODFLOW and MODSIM fluxes are attributed to discrepancies in accounting for SFR cells that underlie multiple links in the AML script versus the Geo-MODFLOW code. Overall, the differences were minimal and assumed to be negligible.

Before the MODFLOW models are run, a preprocessor (SWL program) is used to calculate the water balance on each demand (HRU) and provide estimates of ET and irrigation recharge for the MODFLOW model. The SWL program also provides a timeseries of the fast response or surface return flow for each demand in the MODSIM model. The fast response represents the surface runoff from the HRU after crop requirements are satisfied. Each HRU or demand has a return node(s) to which the fast response is returned in the model. If an HRU has multiple return nodes, the fast response is partitioned between return nodes based on the contributing area. Return nodes in MODFLOW correspond to those in MODSIM. This method of importing the fast response is independent of MODSIM's ability to meet the diversion to a particular demand.

The module also imports the timeseries data for demands (HRUs), streamflow gages, target storage in both reservoirs, and the evaporation timeseries for Walker River basin reservoirs from Microsoft™ Excel spreadsheets that are used as the data subsystem in this modeling tool.

Water rights information is critical for simulating water allocation based on water law. The custom module imports the processed water rights information and builds the necessary model objects to accommodate storage operations and allocation of decree and flood water. The model uses the cost structure to simulate the prior appropriation doctrine, allocating available water in order of appropriation.

The model structure and logic required to represent the operating rules of water allocation in the Walker River basin are complex. In MODSIM, water rights allocation is made possible by a feature called a multilink. A multilink has multiple links where water of different categories can be delivered to a demand (HRU) or accrued as storage right water in the two reservoirs in the system. Figure 44 shows a simplified example of the two types of multilinks. This example shows the connection via multilinks between the Upper Fulstone HRU and Topaz Reservior. When importing the water rights, the module attaches accrual links (e.g., multilink between Topaz Reservoir and node 15_8493 in Figure 44) so that the reservoir accounts can accrue water. The multilink contains one link for each Upper Fulstone storage right in the reservoir. Each HRU has a storage account that accrues water in the order specified by its cost, at the specified accrual rate, and up to the size of the account for that right. The multilink between node 15_8720 and the Upper Fulstone HRU (Figure 44) delivers storage, decree, and floodwater to the Upper Fulstone HRU (demand). It contains one link for each storage right or decree right owned by the Upper Fulstone HRU, and one link for floodwater deliveries.

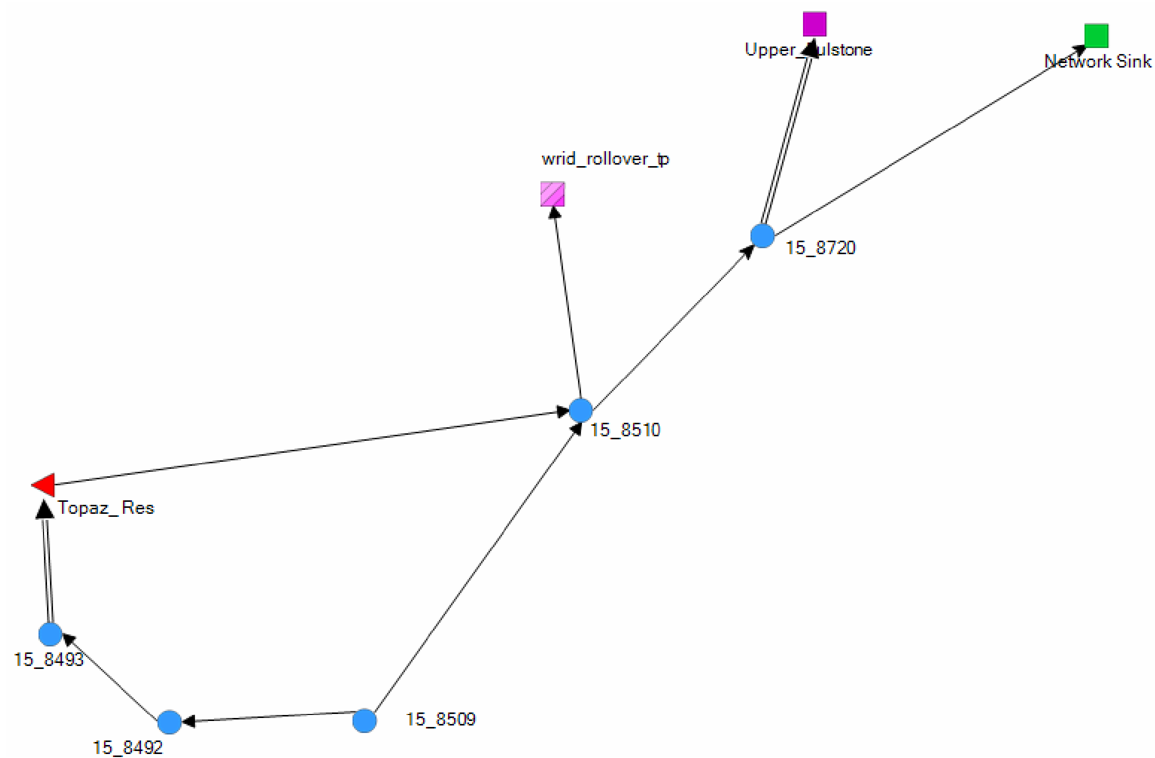


Figure 44. Simplified schematic of accrual and delivery multilinks.

The cost structure on the delivery side is such that once decree rights have been satisfied, additional water in the system (e.g., flood water) is allocated to demands that have not been satisfied. Storage water is supplied as a supplemental source to decree and flood water for unsatisfied demands. Each decree link is implemented with a cost, from the cost structure, that controls the legal availability of water, a maximum delivery rate, and an annual capacity. For flood rights, a standard natural flow link is used to allow flood water to reach the demand. It has no cost and can be delivered at any rate (if natural flow water is available) needed to satisfy the diversion above what was satisfied by the decree rights. Each storage link can call water at the specified rate at any time step in a model run.

Table 14 summarizes the reservoir storage capacity, storage right volume, and initial storage for each reservoir in the model. Two important points are apparent from the table: the storage right volume is smaller than the capacity, and the initial storage is bigger than the storage right volume.

Table 14. Characteristics of major reservoirs in the Walker River basin.

Reservoir	Capacity (AF)	Storage Right Volume (AF)	Initial Storage (AF)
Topaz	59,440	43,314	45,911
Bridgeport	42,460	33,322	38,027

To accommodate the difference between reservoir capacity and storage right volume, a Walker River Irrigation District (WRID) account was established in each reservoir whose capacity was equal to the difference between the storage right volume and the reservoir capacity. A flow-through demand node is added to accept any water in the WRID account at the end of the irrigation season (Figure 44) and allow it to roll over into the next year, and reaccrue to the reservoir accounts according to the cost structure. Storage water that was not called by the end of the irrigation season is left in the storage accounts, and can be called at the beginning of the next irrigation season. A subroutine is included in the custom module, to allocate the initial storage to the storage right owners first, with the remaining volume going into the WRID account using

initial account volume = min((initial storage/# of reservoir owners)*
(account capacity/storage right volume), capacity owned) (5)

MODSIM Calibration and Validation

All the necessary timeseries information, water rights information, and MODFLOW output are imported into the MODSIM model via the custom module as described above. In the initial model run, the target storage in both reservoirs is satisfied, but there are shortages at most demands (HRUs). In addition, the fit to the observed flow at the USGS gaging locations is poor, and the simulated storage water deliveries are much less than the observed volumes. In other words, the deliveries to the demands were being satisfied primarily by decree and floodwater. Attempts to manually calibrate this model from a top-down perspective beginning in Reach 1 (Antelope Valley) by implementing losses in the channel and return flows from each demand in Antelope Valley, did not significantly improve the results. These initial problems indicate that gains and losses occur, which are not explicitly represented in the model structure. This produces difficulties in reproducing the historical reservoir account operations due to timing issues in the decree and flood water usage. The streamflow dynamics in Hoye Canyon are strongly influenced by reservoir operations at Topaz; however, records of reservoir inflows, outflows, or flows bypassing the reservoir are severely limited, making it difficult to determine water balance aspects missing in the model structure. The lack of information on the reservoir operations caused large uncertainty within the reach, which in turn increased error throughout the model.

The goals of the modeling effort are to reasonably simulate the allocation of water based on water rights, and match the observed data. It is not clear why the model is not initially matching gage data or allocating the categories of water in the correct proportion. A calibration approach was developed to isolate the problem by (1) accruing storage water at the rate required to meet observed storage, (2) giving each demand a single storage delivery link with a high negative cost (high priority), (3) setting the upper bound on this delivery link to the observed storage delivered, (4) retaining decree and flood links for each demand, and (5) implementing calibration structures. This approach removes uncertainty related to storage allocation from the overall uncertainty to focus on analyzing direct flow (decree and flood deliveries), and natural gains and losses not simulated by MODFLOW.

A calibration structure is a MODSIM structure that provides additional water at the upstream boundary condition for a reach and removes excess water at the downstream end of the reach with the goal of satisfying demands and accounting for unknown gains or losses in the reach that are not captured by the model structure. In Figure 45, the calibration structure concept is illustrated with a hypothetical MODSIM model comprised of three reaches. Streamflow gaging stations are represented by *Flowthru* demands (Figure 45). The additional water needed to satisfy all demands in *R1* is provided in the link from *source* to *observed_inflow_R1*. This is accomplished by implementing an inflow node and a sink node, where the inflow has a high inflow, and the sink has a high cost. Flow above the amount needed to match demands in the reach (*R1*) enters the sink. This accounts for shortages in the reach, or unknown gains. The excess water in *R1* not needed to meet demands is removed from the system in the link between *Nonstorage* and *Network Sink*. This accounts for unknown losses in the reach. Similarly, in *R2*, additional water needed to satisfy all demands in the downstream reach is provided in the link from *source2* to *ReturnNode2*. Water in *R2* not needed to meet demands is removed from the system in the link between *Nonstorage* and *Network Sink2*. The same procedure is repeated for *R3*. The end result is that all demands are satisfied and there is a perfect match to the observed flow at the three gages in this hypothetical model. In principle, Figure 45 is an accurate illustration of how calibration structures are used in the model, although the MODSIM model of the Walker River system is much more complex: reservoir operations, MODFLOW input, and a water rights structure are all included.

If the target storage in the reservoirs is being met, and the observed storage diversion for each demand (HRU) is met, the storage allocation is assumed to be accurate in calibration and will be tested in simulation. The calibration run focuses on analyzing direct flow (decree and flood) diversions and natural gains and losses not accounted for by MODFLOW stream-aquifer interaction. Because manual calibration is ineffective in matching observed flow at any of the gages, the Walker River basin MODSIM model requires calibration structures for all reaches. This could be attributed to a combination of factors, such as underestimation of demands in Antelope Valley, unrealistic reservoir operations, human error/data importing error, or the residual error in the MODFLOW models.

MODSIM Model Evaluation

Calibration results

In the calibration run, all demands (HRUs) receive the appropriate observed storage delivery, and decree and floodwater deliveries are reasonable. This validates the model's ability to convey direct flow diversions via the water rights information and flow constraints. Observed and simulated storage correspond in both reservoirs (Figures 46 and 47). Calibration results also show that additional inflows and outflows were calculated at each calibration structure. The fact that MODSIM calibration structures adjusted river flows while MODFLOW model output is included indicates that

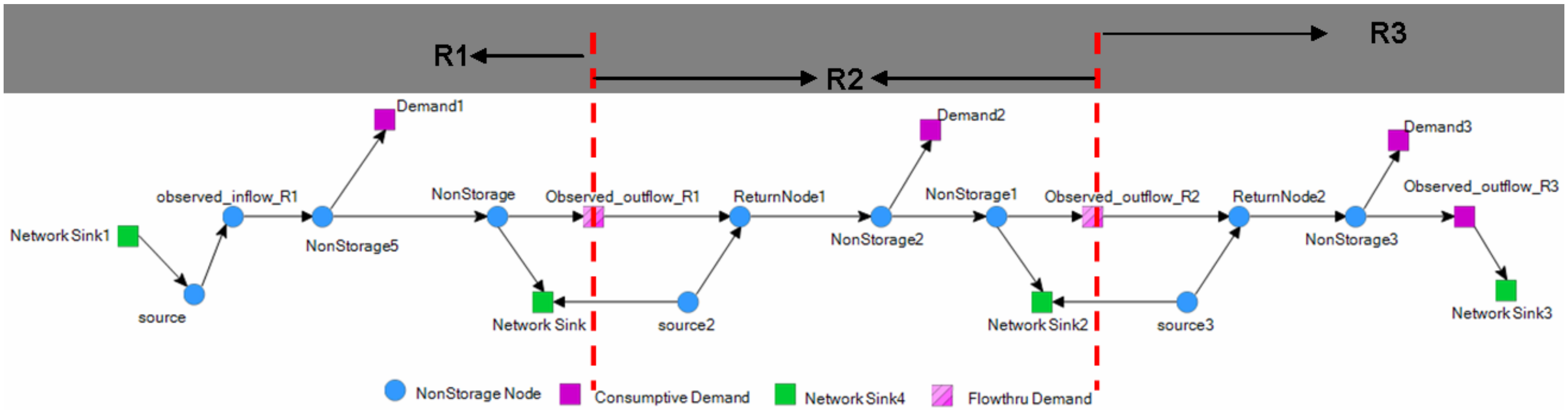


Figure 45. Schematic of MODSIM calibration structures.

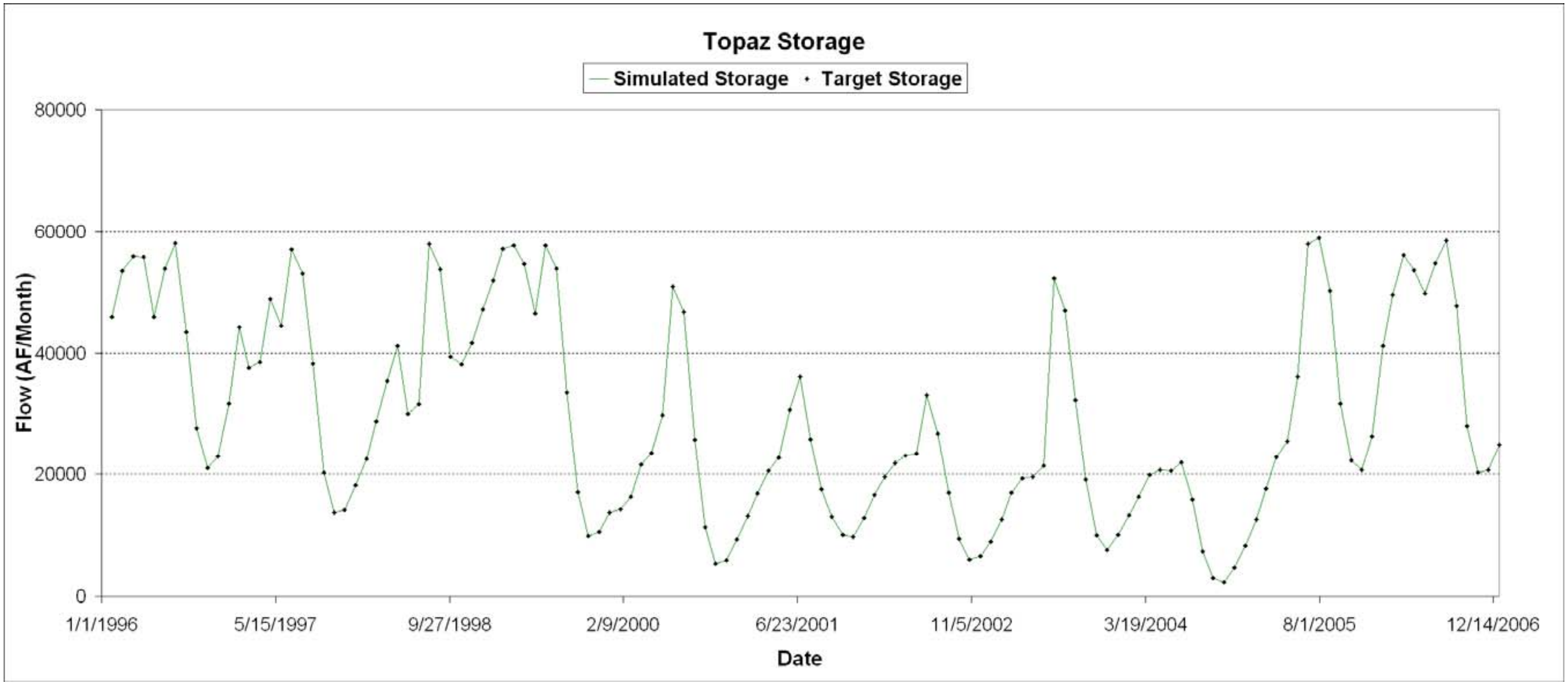


Figure 46. Topaz Reservoir observed and simulated storage for simulation run.

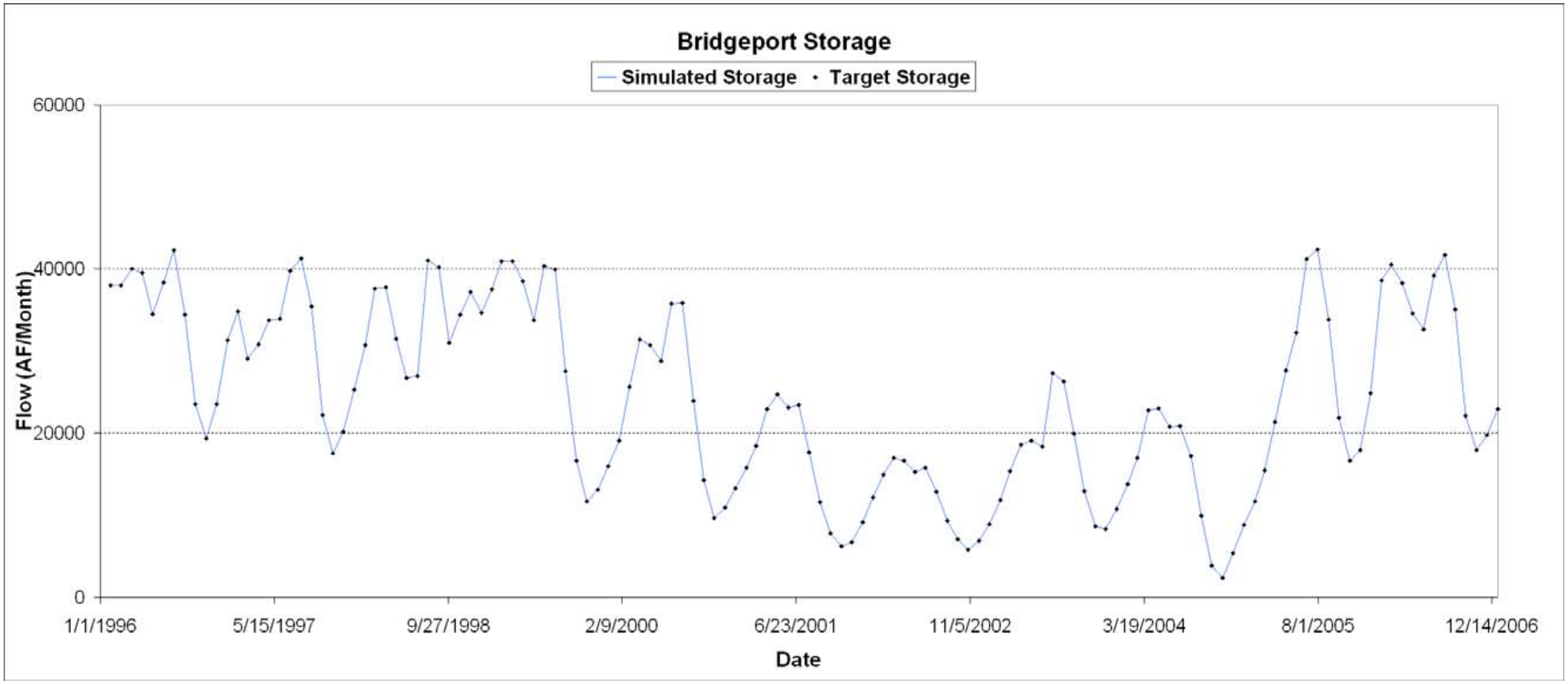


Figure 47. Bridgeport Reservoir observed and simulated storage for simulation run.

MODFLOW is not precisely simulating the gains and losses in the system. In Figures 48 and 49, the MODFLOW residuals are compared to the MODSIM calibration gains and losses. The correlation between MODSIM calibration structures and MODFLOW residuals varies in Reaches 2 and 4. Theoretically, the positive and negative MODFLOW residuals and the MODSIM calibration gains and losses should correspond. Differences in the traces fall into four categories. First, there are periods when the MODSIM additional flow is less than the MODFLOW underprediction, which indicates that the calibration structure estimated more flow in the reach than calculated by MODFLOW. This could occur because the MODSIM model is returning more water to the system than predicted by MODFLOW, or a return flow used in MODFLOW was not used in MODSIM. Second, there are periods when the MODSIM additional flow is greater than the MODFLOW underprediction. In this situation, the MODSIM model is returning less water than predicted by MODFLOW, which could also be attributed to discrepancies in return flows used in the two models.

Third, there are periods when the MODSIM flow removal is less than MODFLOW overprediction. In this situation, MODSIM had to take out less water than the MODFLOW overprediction, or in other words, MODSIM may have used more return flows to meet demands than predicted by MODFLOW. Fourth, there are periods when the MODSIM flow removal is greater than MODFLOW overprediction. In this category, MODSIM is potentially using less return flow to meet demands than predicted by MODFLOW, which produces more water downstream.

MODFLOW and MODSIM account for the water balance with similar methods, so the amount of return flow should be the same in both models unless the model return flow nodes and locations are not identical. In any case, all four of the problems above point to generalized inconsistencies between MODFLOW output and MODSIM input. It seems that the two models are not perfectly integrated even though all efforts were made to maintain consistency. Due to time constraints, better synchronization of MODSIM with MODFLOW could not be pursued, and the MODFLOW calibration could not be improved. In spite of this, Figures 50 and 51 show that if the MODSIM calibration structures are removed from MODSIM's simulated hydrographs at Hudson and Wabuska, the fit is very similar to that of the MODFLOW model. The fact that the MODFLOW and MODSIM simulated flows are different is an expression of the discrepancy between the MODFLOW residual and the MODSIM calibration gains and losses. The MODSIM calibration structures account for MODFLOW residuals and any problems translating MODFLOW output to MODSIM or other error. Because of this capability, calibration gains and losses and all categories of water with the full assortment of water rights could be implemented in the MODSIM simulation model.

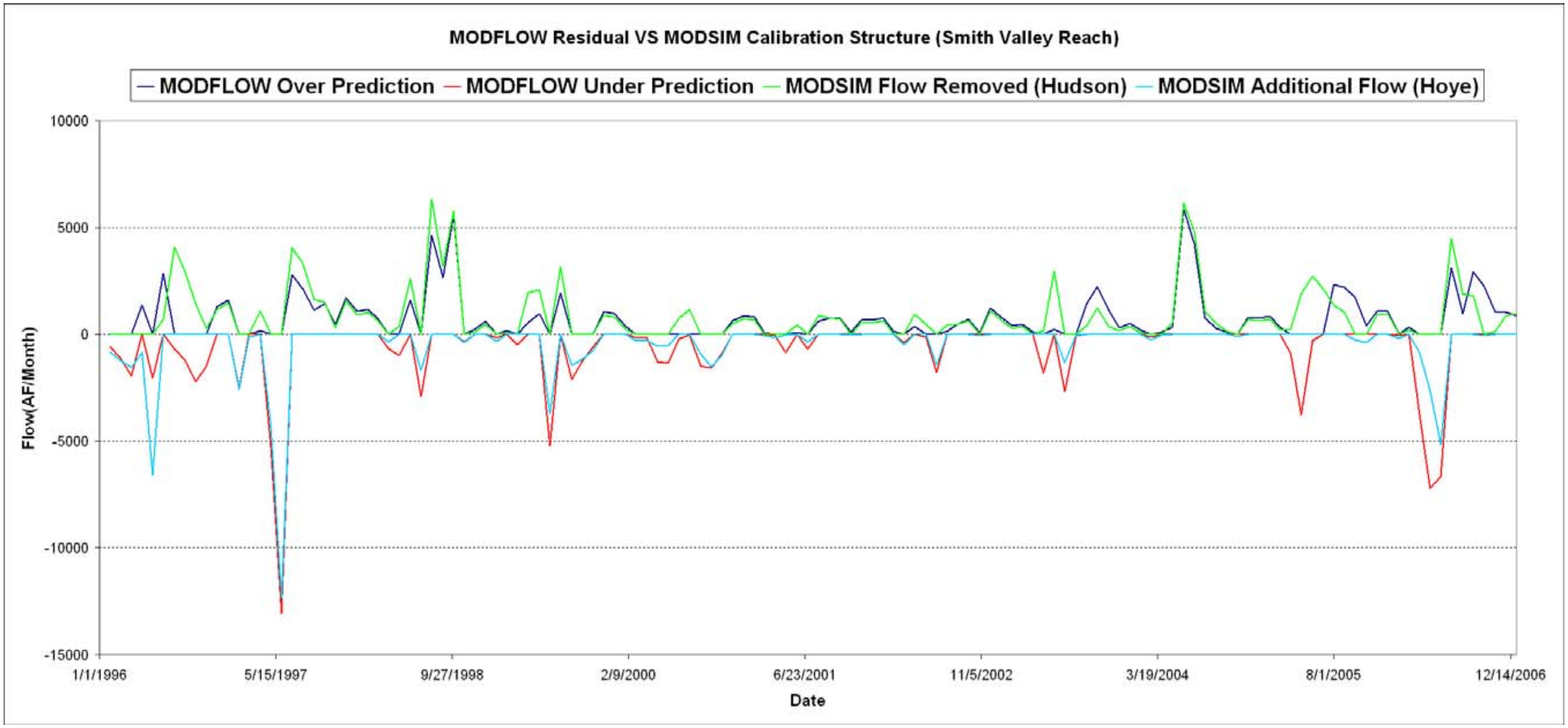


Figure 48. MODFLOW residuals versus MODSIM calibration gains and losses (Smith Valley).

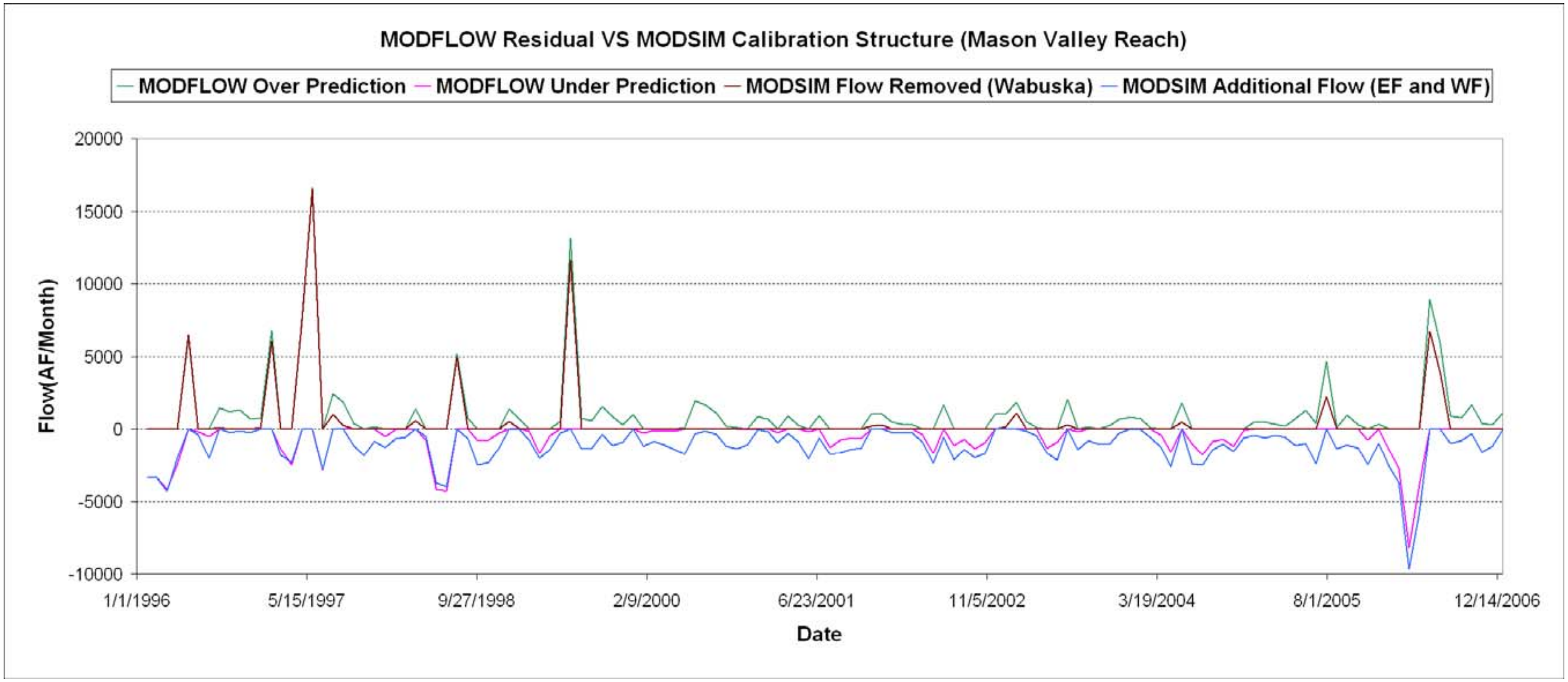


Figure 49. MODFLOW residuals versus MODSIM calibration gains and losses (Mason Valley).

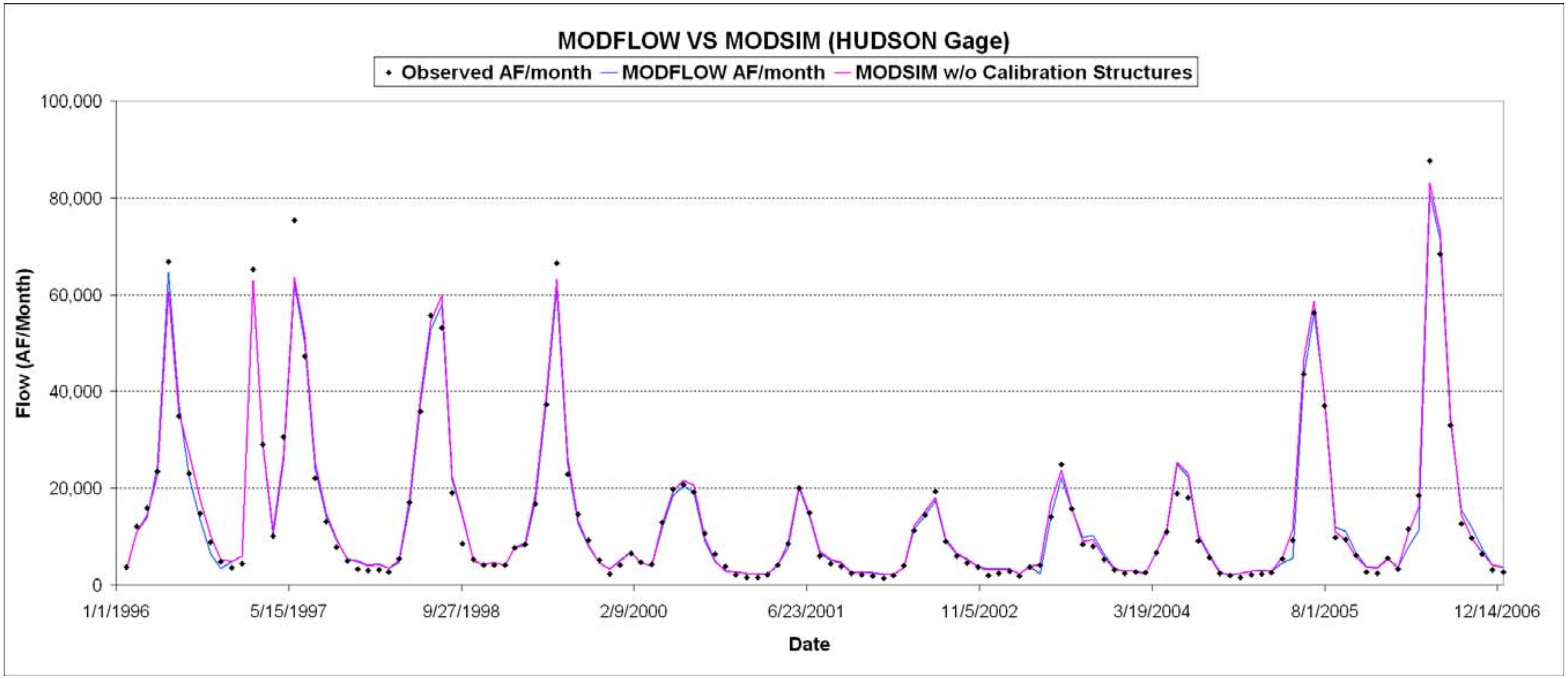


Figure 50. A comparison between the observed streamflow, MODFLOW simulated flow, and MODSIM simulated flow at the Hudson gage. The MODSIM simulated flow is the trace that MODSIM would have produced at Hudson without calibration structures. The fact that it does not match the MODFLOW simulation exactly is an expression of the discrepancy between the MODFLOW residual and the MODSIM calibration gains and losses.

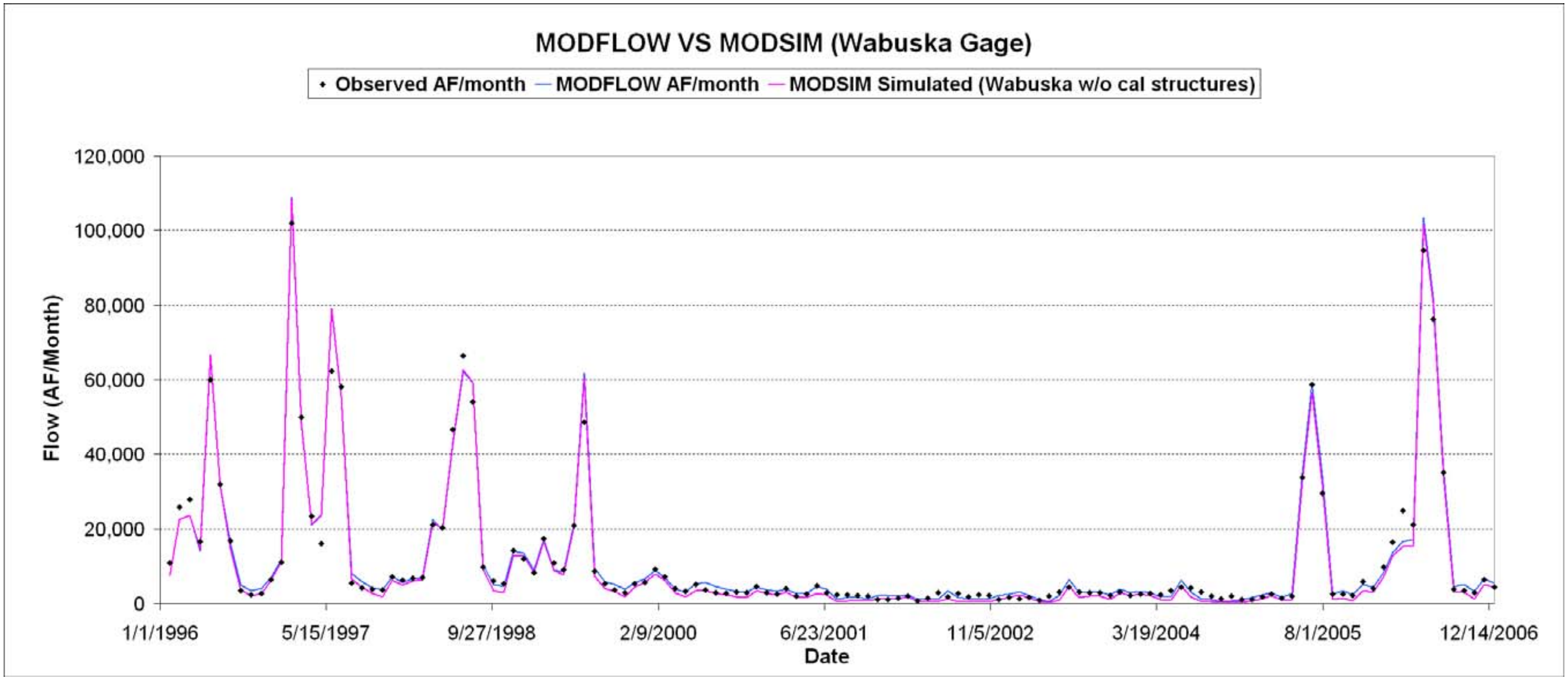


Figure 51. A comparison between observed streamflow, MODFLOW simulated flow, and MODSIM simulated flow at the Wabuska gage. The MODSIM simulated flow is the trace that MODSIM would have produced at Wabuska without calibration structures. The fact that it does not match the MODFLOW simulation exactly is an expression of the discrepancy between the MODFLOW residual and the MODSIM calibration gains and losses.

Simulation results

After the calibration run, the calibrated gains and losses for each reach are explicitly included as sources and sinks in the simulation model. The storage rights and accrual links to reservoirs are re-imported into the simulation model to test whether the model can more accurately allocate water after calibration. The simulation model contains all the observed data, MODFLOW output, water rights information, and the calibration flows from the MODSIM calibration run.

For model simulation, the key factor in evaluating the model performance is whether the model could correctly simulate the allocation of the categories of water after being supplied the necessary gains and losses by calibration structures. Results show a perfect match to the streamflow at gaging stations and no demand shortages, which is expected because of the calibration structures. Observed storage is also matched exactly. Antelope Valley demands are all satisfied, but are not included in this comparison because water was not allocated to these demands based on water rights information.

Results are shown in Figures 52 through 61. Figure 52 shows the total annual MODSIM simulated delivery and the total annual observed delivery. Figure 53 shows the total MODSIM simulated delivery and the total annual observed delivery by demand (HRU) for the entire simulation period (1996 to 2006). Annually, and by demand, the model matches the observed data very well. Small differences between the observed and simulated volumes are attributed to the fact that the observed data are annual volumes and the model simulations are calculated monthly. Figure 54 shows the annual MODSIM simulated direct flow delivery and the annual observed direct flow delivery.

Figure 55 shows the MODSIM simulated direct flow delivery and the observed direct flow delivery (decree and flood) by demand. Annually, the model overpredicts the direct flow delivery by a similar amount each year. However, when broken down by demand (HRU), it is clear that most of the annual error is attributable to a few HRUs (i.e. Colony, East Walker + PF, and Saroni). Figure 56 shows the annual MODSIM simulated storage delivery and the annual observed storage delivery. Figure 57 shows the MODSIM simulated storage delivery and the observed storage delivery by demand (HRU). Overall, MODSIM underpredicts the storage delivered for each year, but again Figure 57 shows that this error can largely be attributed to Colony, East Walker + PF, and Saroni HRUs. In general, storage is underallocated and direct flow is overallocated. Because direct flow includes both decree and flood deliveries, it is difficult to determine the category that contributes most to the underprediction of storage.

To further investigate the storage underallocation, the decree and flood deliveries are plotted separately. Figure 58 shows the annual MODSIM simulated decree delivery and the annual observed decree delivery. Figure 59 shows the MODSIM simulated decree delivery and the observed decree delivery by demand (HRU). Annually, the simulated decree delivery shows a fairly close fit, with underprediction in wet years and overprediction in dry years. Some demands are overallocated decree water while others are underallocated, but overall the fits are reasonable. Figure 60 shows the annual MODSIM simulated flood delivery and annual observed flood delivery. Figure 61 shows the MODSIM simulated flood delivery and observed flood delivery by demand.

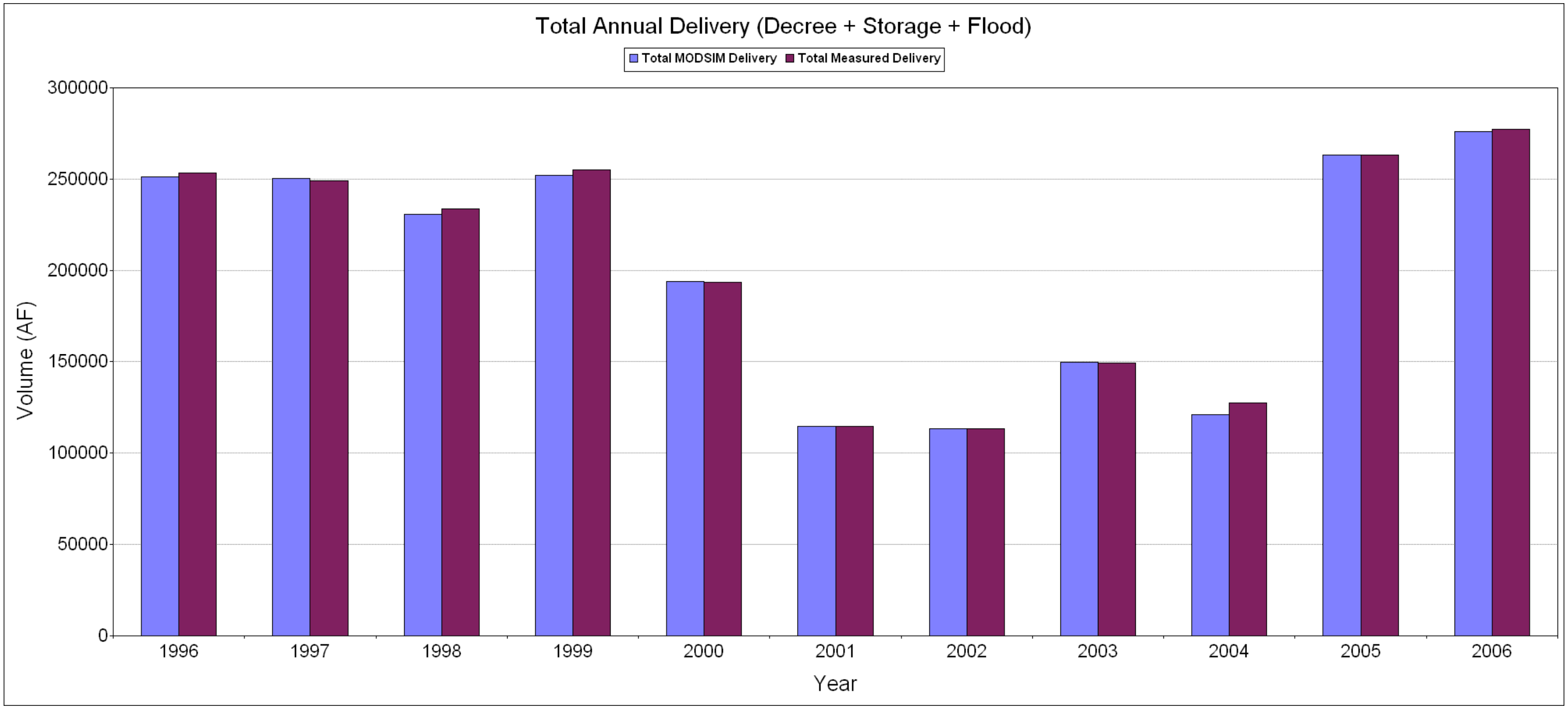


Figure 52. Total annual delivery for the simulation period (1996 to 2006).

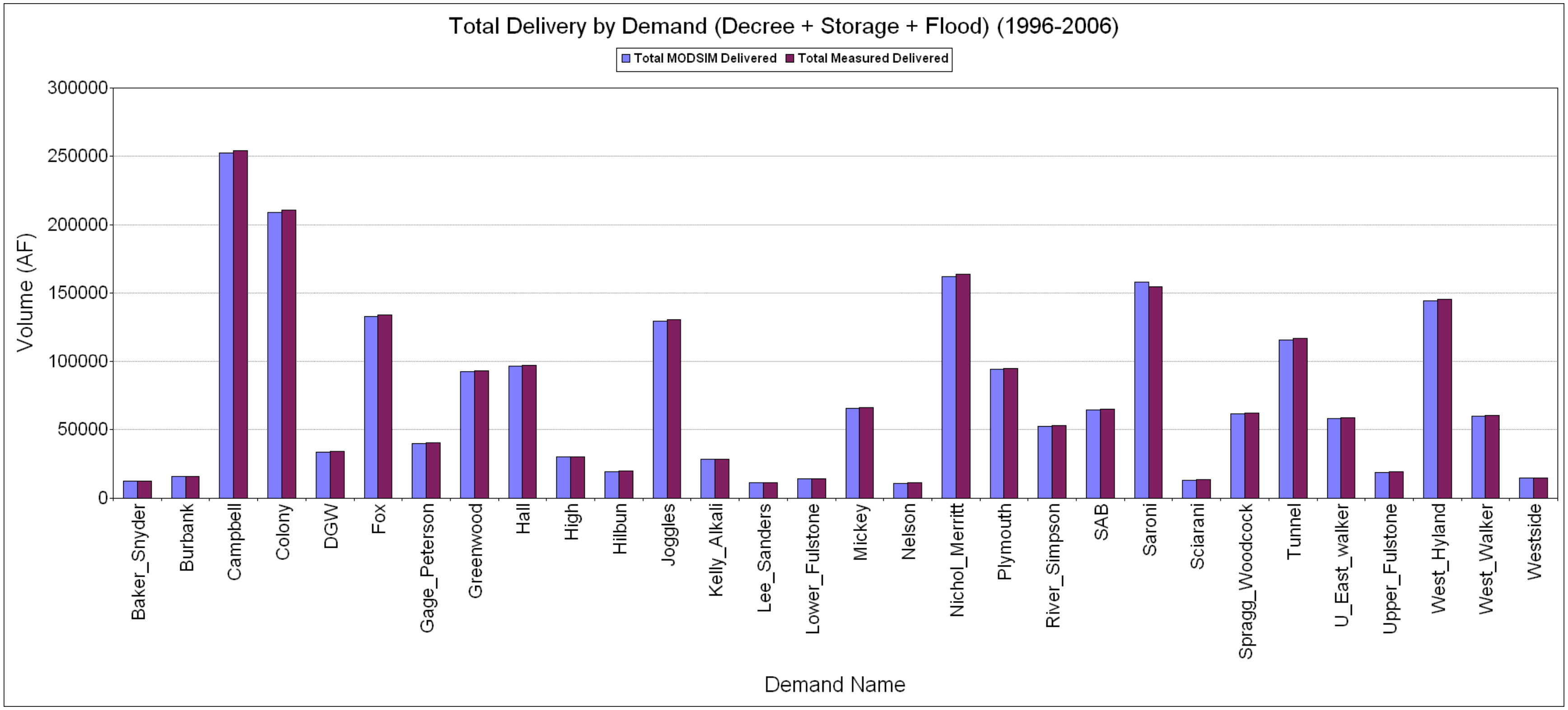


Figure 53. Total delivery by demand for the simulation period (1996 to 2006).

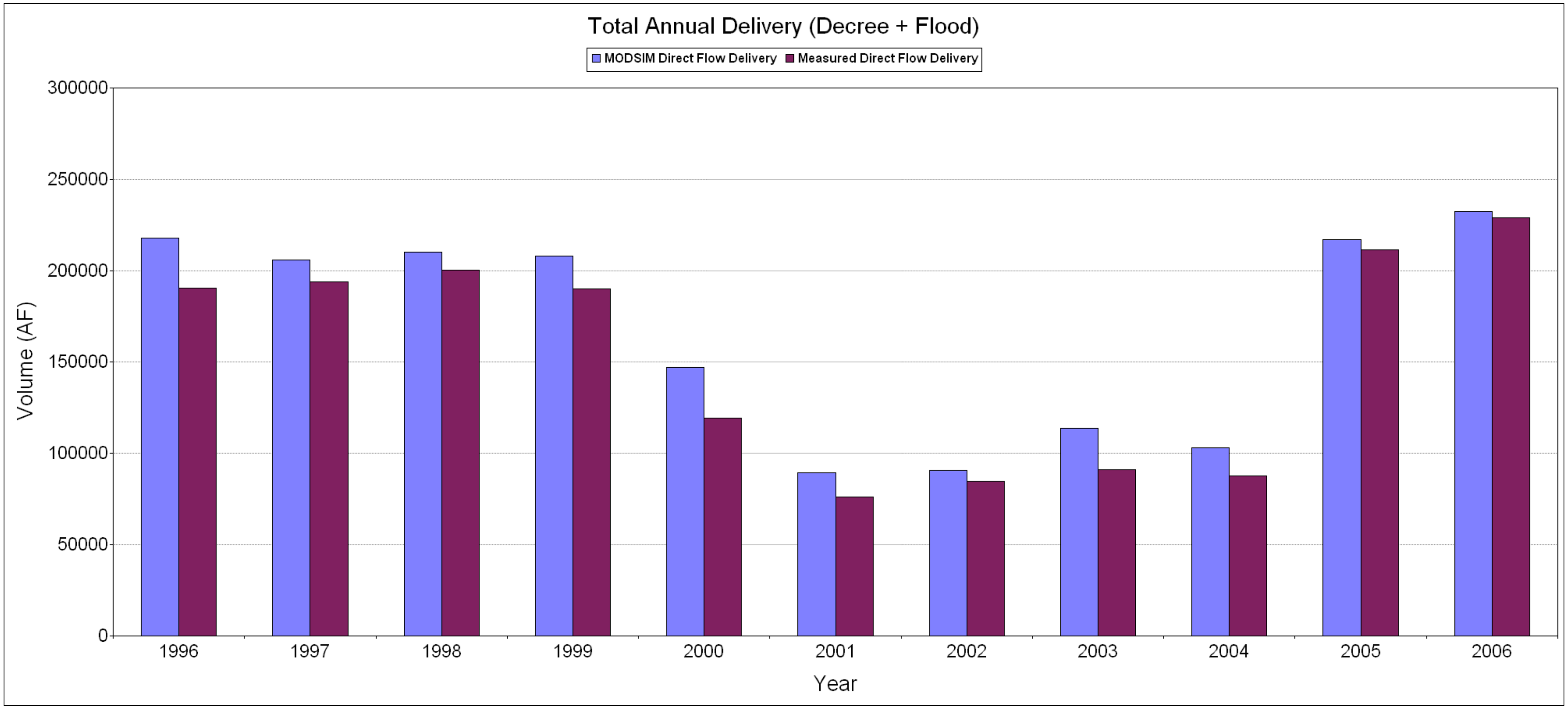


Figure 54. Total annual delivery (Decree + Flood).

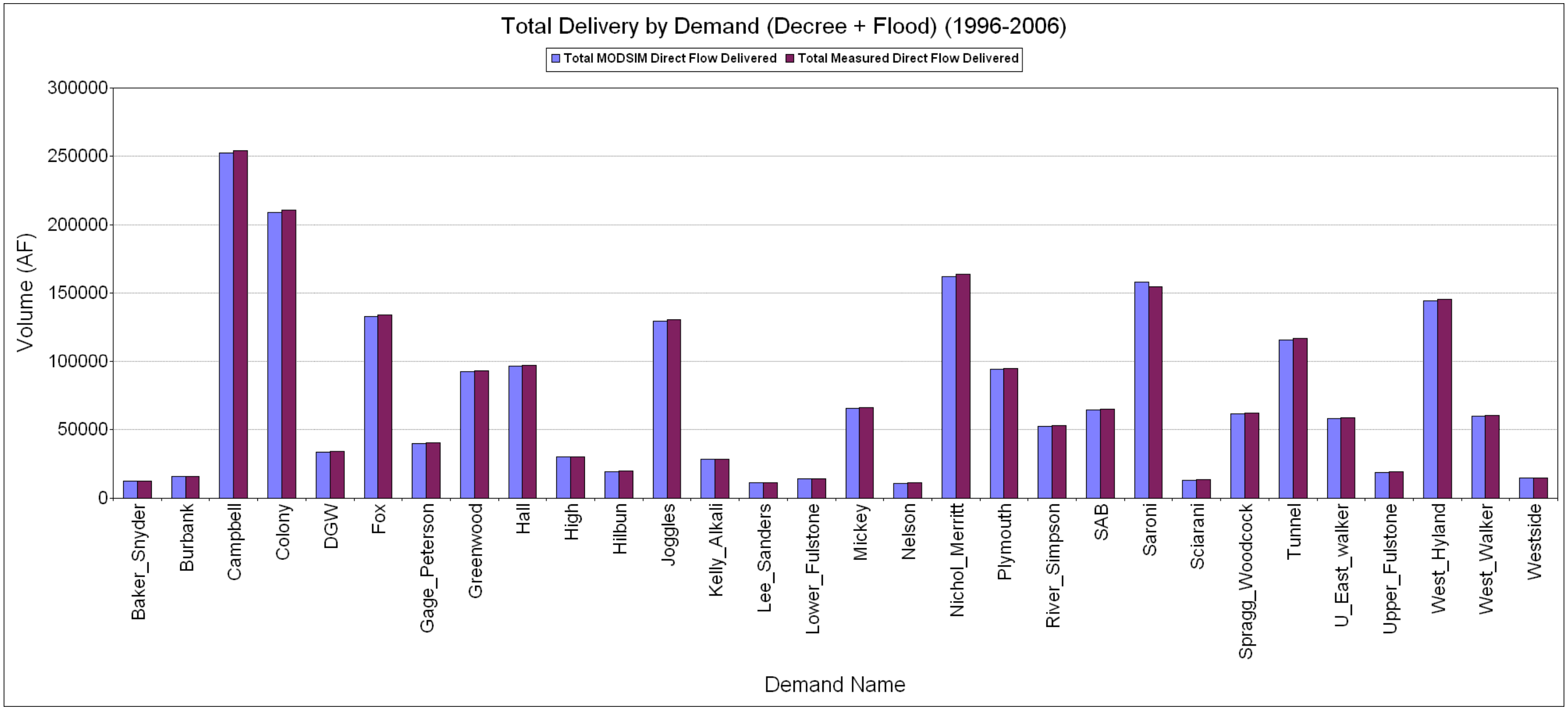


Figure 55. Total delivery by demand for the simulation period (1996 to 2006).

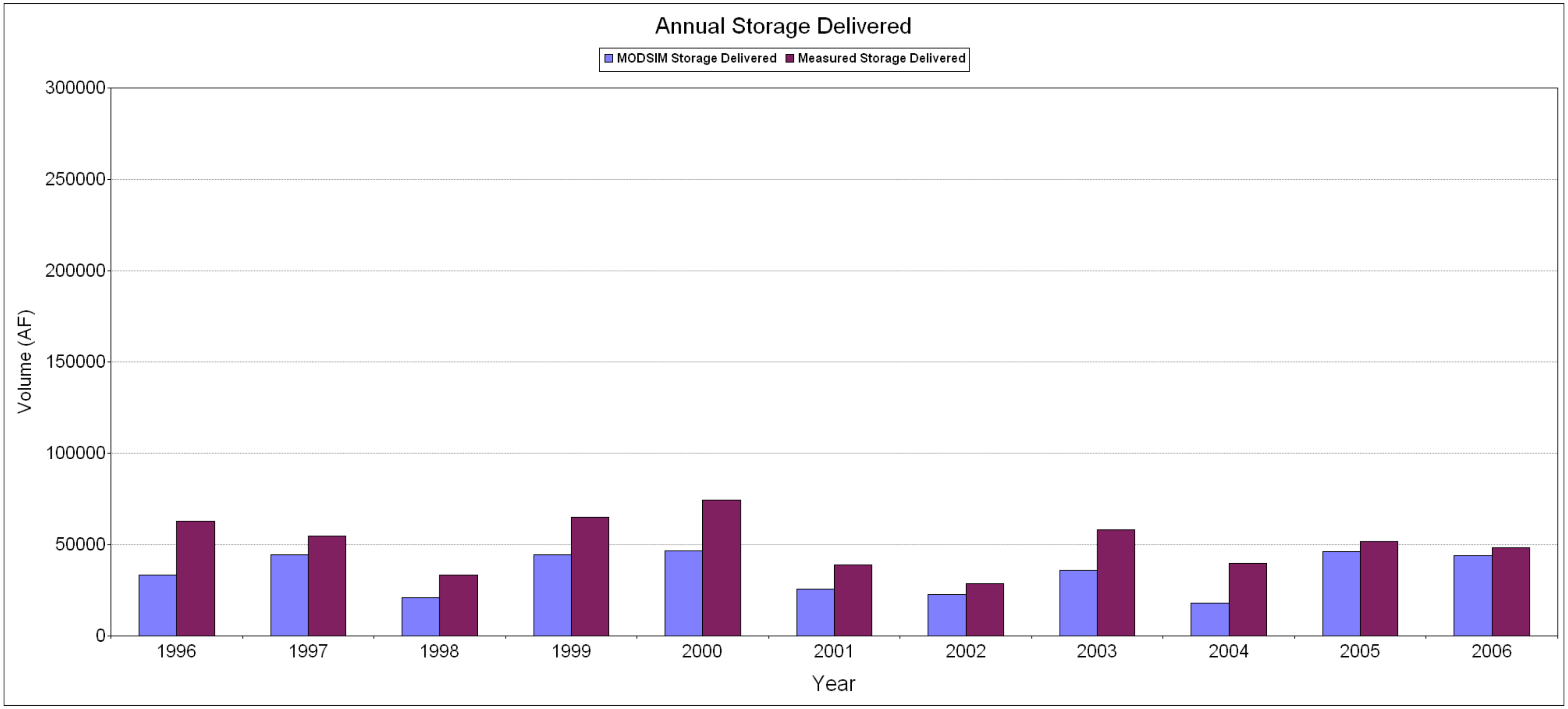


Figure 56. Total annual storage delivery.

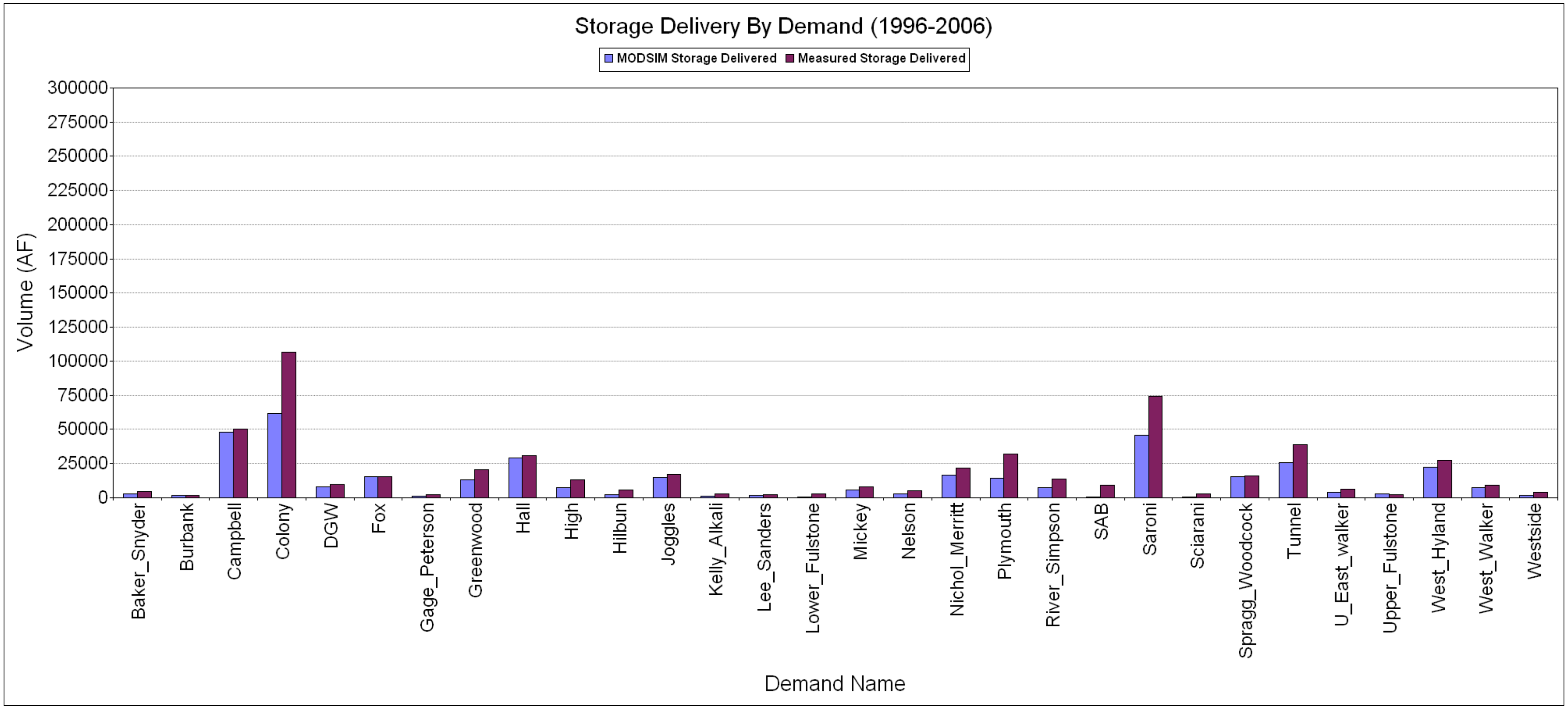


Figure 57. Total storage delivery by demand for the simulation period (1996 to 2006).

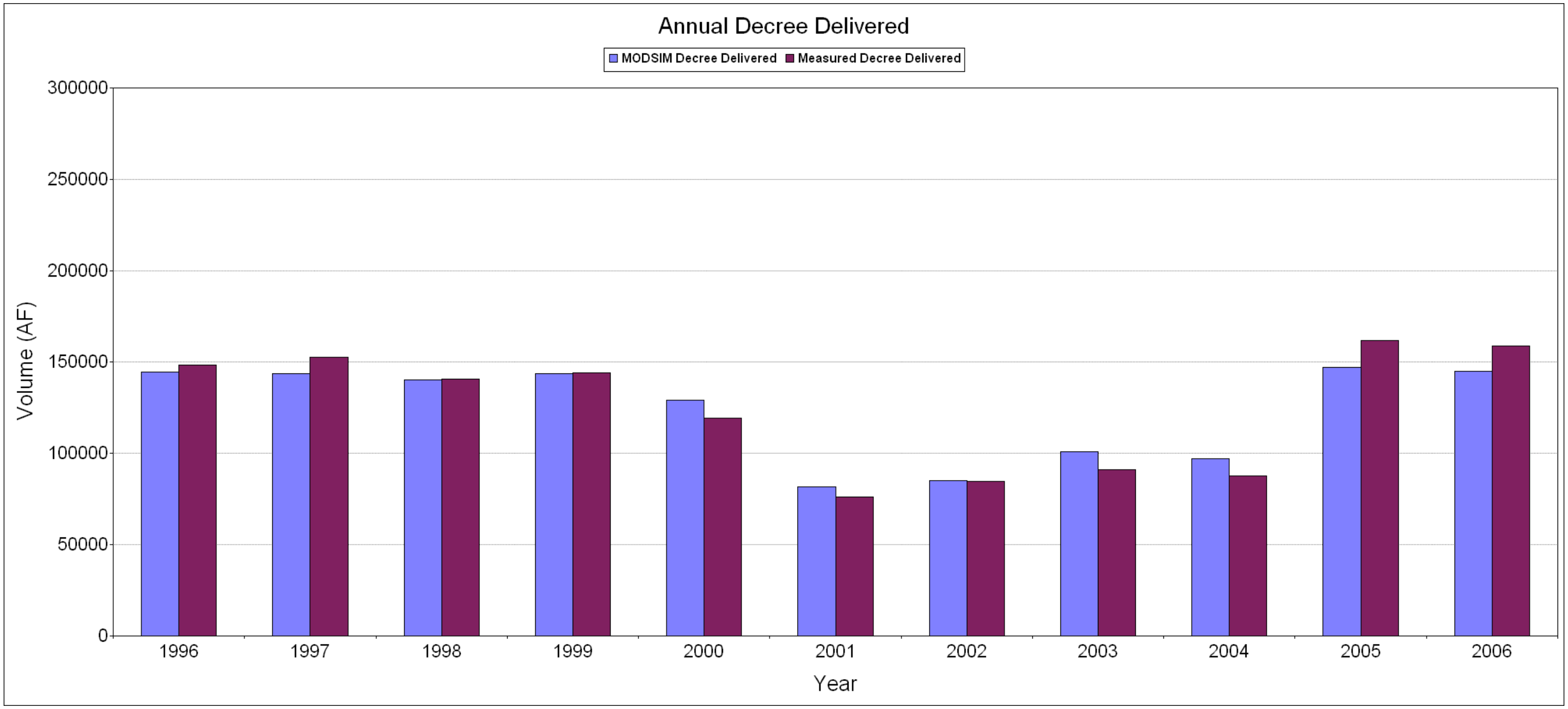


Figure 58. Total annual decree delivery.

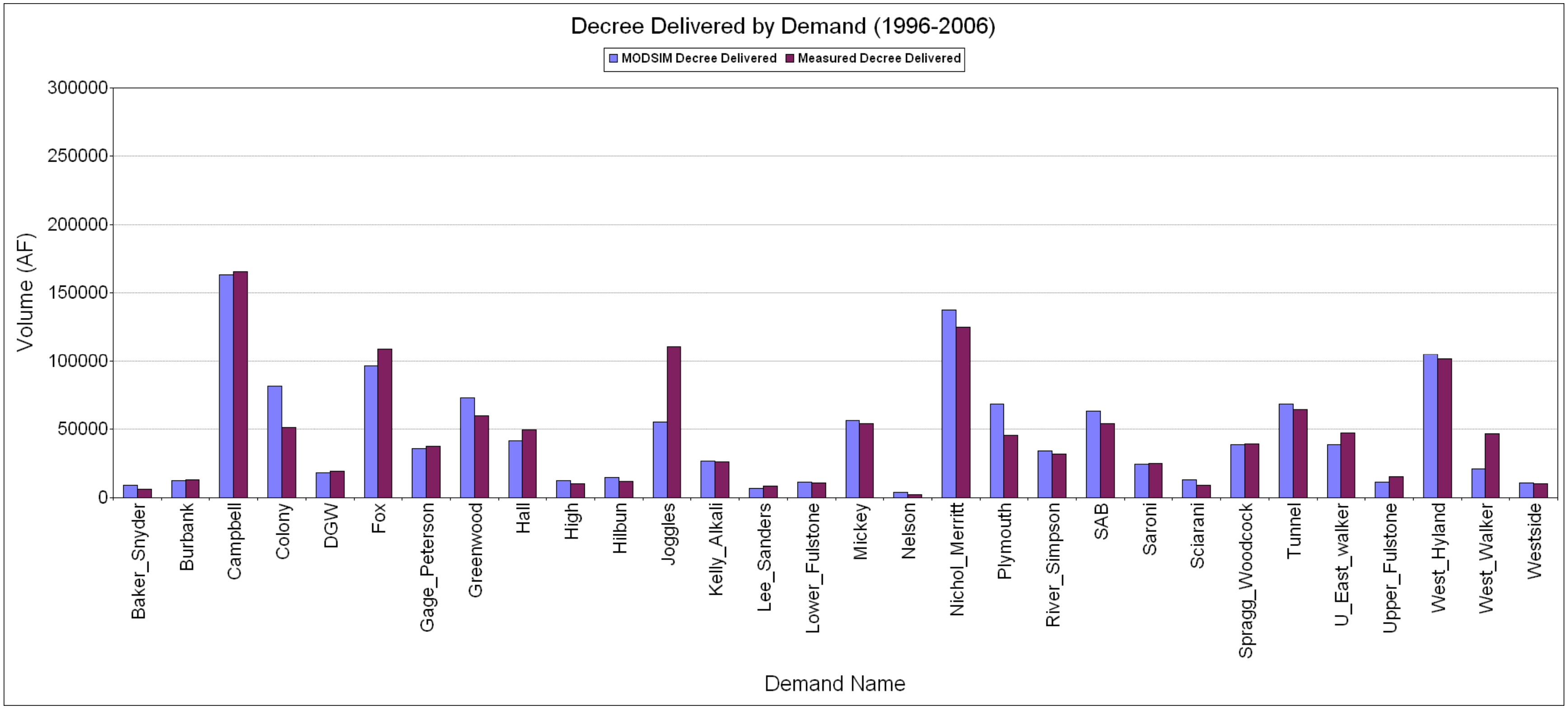


Figure 59. Total decree delivery by demand.

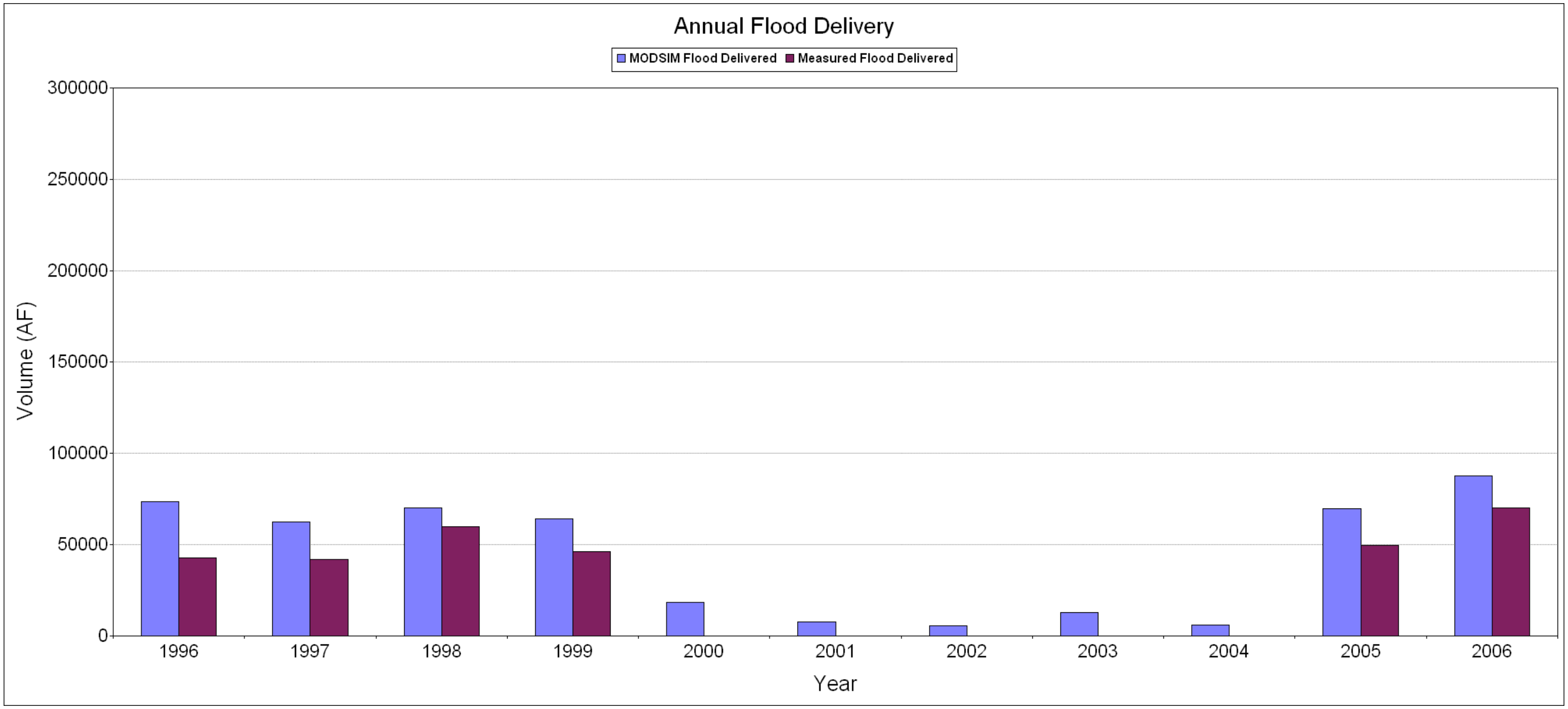


Figure 60. Total annual flood delivery.

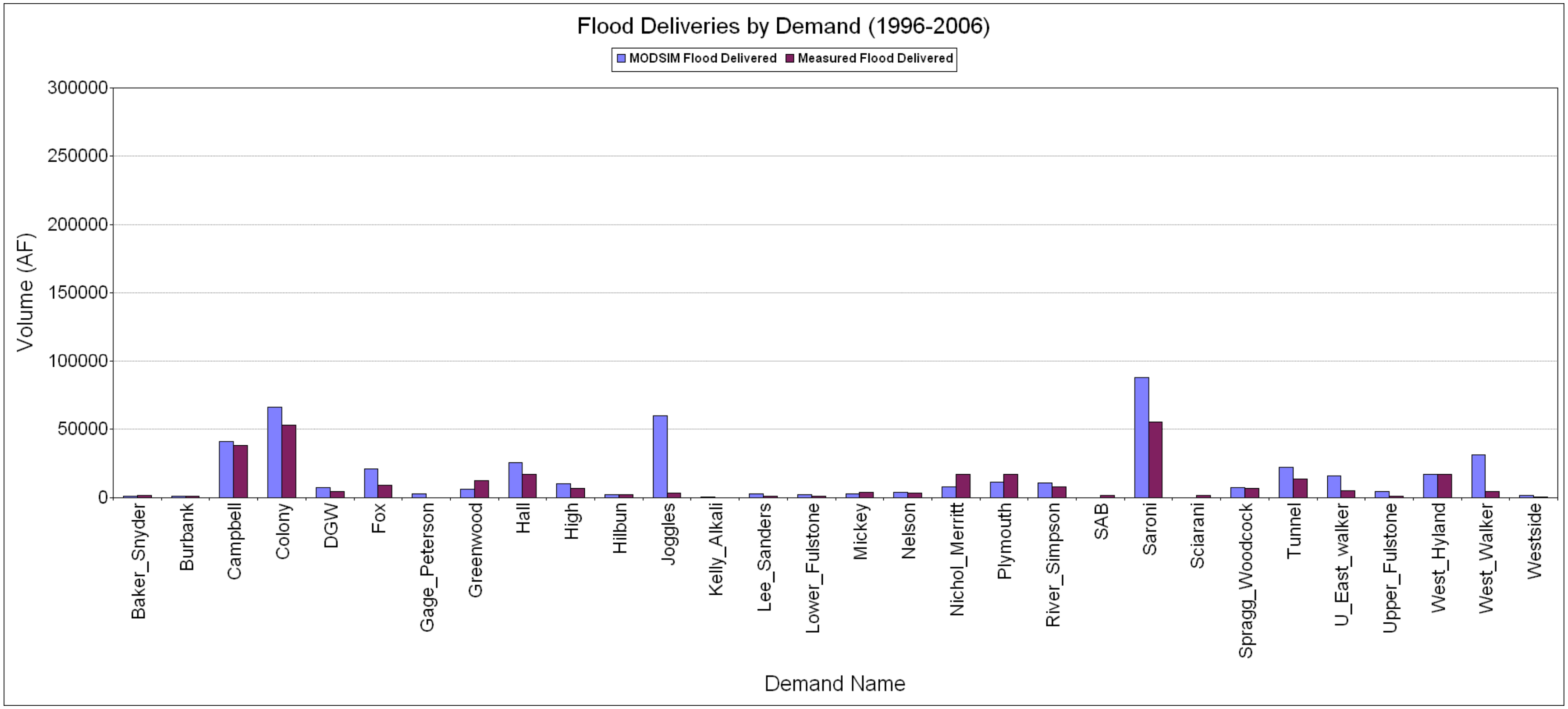


Figure 61. Total flood delivery by demand.

Annually, flood deliveries are overpredicted in all the years of the simulation, and the same general trend is reflected in the plots by HRU.

From these figures, it is apparent that most of the error is associated with the overallocation of direct flow, which then causes an underallocation of storage water. Some demands are more affected by this misallocation than others. Flood water appears to be overallocated more frequently than decree water. The general proportion of categories of water delivered in the simulation matches the observed data much better than in the initial model.

MODSIM Conclusions

A calibration approach is developed to understand how the model is allocating the categories of water. Some general issues relate to importing MODFLOW output to MODSIM, but the cause for this has not yet been isolated. MODSIM calibration structures are implemented to account for error at the gaging stations. The calibration structures match the observed streamflow data exactly by accounting for unknown gains and losses in each reach. The calibration process provides a better foundation for simulation, in which the model's ability to match the historical allocation of water can be tested.

In the simulation model, the observed storage in both reservoirs is matched perfectly and the proportion of the different categories of water is reasonably close to the observed. However, there are still some unidentified problems as the delivery proportions differ from the observed. The model overallocates flood and decree water and underallocates storage. This discrepancy likely occurs because the model simulates excess water in the river, which allows users to divert flood water when it was not historically available. Sources of this error could include unrealistic reservoir operations or storage parameters in the model. Disagreement between the MODFLOW residuals and MODSIM calibrated gains and losses are also a source of uncertainty, which could be contributing to the disproportional allocation of the categories of water.

Future work should include improvements to the MODFLOW calibration in both Mason and Smith valleys. The information imported from MODFLOW must be quality checked so that the MODSIM gains and losses match the MODFLOW residuals exactly. Even with a perfect match between MODFLOW residuals and MODSIM calibration gains and losses, MODSIM calibration structures would still be required to account for the MODFLOW error. Other work could include a MODFLOW model in Antelope Valley, as well as inclusion of water rights information for the Antelope Valley demands. Groundwater pumping data in the East Walker River reach above Mason Valley, and better information on the operation of the system's reservoirs, would also improve the ability of the model to represent the system.

Given the complexity of this modeling effort, the results are reasonable. The model is able to maintain target volumes in the reservoirs while supplying water to downstream demands, which indicates that storage water from the previous year and redistribution of water from the WIRD storage account adequately describe reservoir operations. Generally, simulated water allocations correspond to historical allocations during the simulation period. In spite of the problems encountered with model calibration, the simulation model does perform reasonably well at allocating the different categories of water. Given more time and a chance to resolve the main problems identified here, the model could match the historical water allocation even more closely.

The models are effectively integrated when the MODFLOW residuals match the MODSIM gains and losses. The unknown gains and losses identified in MODSIM calibration are assumed to occur during all future simulations or scenarios. If a water right is purchased and moved downstream, the MODFLOW model would be rerun to simulate the relocation of the water associated with that right. The updated MODFLOW results would then be imported into MODSIM and finally the scenario could be tested. This process could be simplified if the MODFLOW models correspond more closely to observations, which might preclude the use of MODSIM calibration structures altogether.

DST SUMMARY AND LIMITATIONS

A computer-based DST capable of evaluating the efficacy of proposed water rights acquisitions in the Walker River basin is developed and tested. The development of the new DST of the Walker River basin represents a major step forward in understanding the complex hydrologic relationships within the real system. Climate, streamflow, upstream storage areas, irrigation practices, crop and non-agricultural ET, groundwater-surface water exchange in the river corridor, groundwater pumping and recharge, and all known existing water rights (decree, storage, and flood) all play a role in the Walker River system and are simulated by the DST. The DST allows users to track water from the headwaters, where streamflow originates, through the complicated deliveries and returns in the heavily irrigated Smith and Mason valleys, to the USGS gage near Wabuska.

PRMS is used to model the headwater supply areas of the Walker River basin. It performs well in the West Walker headwaters: timing of the annual hydrograph was well represented, although streamflow peaks were slightly underestimated. The affects of reservoir operations and diversions for agricultural irrigation in the East Walker are not captured by the model, which causes poor representation of annual hydrograph timing as well as overestimation of streamflow peaks. The East Walker model, or at least estimated inflows to Bridgeport Reservoir, might be improved by simulating additional subbasins utilizing historic streamflow data from discontinuous USGS gages. As MODSIM uses the observed outflow from Bridgeport Reservoir as an input, this is perhaps more relevant for climate change scenarios than incorporating the reservoir operations and irrigation affects in PRMS.

MODFLOW is used to model the agricultural demand areas and groundwater-surface water interaction in Mason and Smith valleys. Mason Valley, in particular, is well modeled: low RMSE values are calculated for water levels, streamflows, and river responses. The MVGM suggests that groundwater fluxes into the river/drain network account for about four percent of the river’s water budget during wet periods, but nearly 25 percent during extended drought. Smith Valley is not modeled with the same degree of accuracy as Mason Valley, but the SVGM provides insight to the system by its contrast with the MVGM. Calibration of the SVGM to better reflect observed groundwater levels is necessary to reduce this error and should be considered in the future. The groundwater models are limited by their non-unique solutions, poor representation of water levels in parts of Smith Valley, and the unknown errors associated with the simulated groundwater-surface water interaction.

MODSIM simulates reservoir operations, streamflow routing, and water rights allocations in the Walker River basin from the headwaters to Wabuska. Given the complexity of the water distribution system in the Walker River basin, the results are reasonable. The model is able to maintain target volumes in the reservoirs while supplying water to downstream demands, which indicates that reservoir operations are simulated realistically. Generally, simulated water allocations correspond to historical allocations during the simulation period. In spite of the problems encountered with model calibration, the simulation model allocates the different categories of water reasonably well.

FUTURE WORK

Implementation of the DST and scenarios evaluation will be addressed in the future. The DST will be used to evaluate different water rights acquisition options in terms of delivering the maximum amount of water to Walker Lake. Ideally, these scenarios will also provide opportunities for meaningful research addressing the goals specified in the University of Nevada's Desert Terminal Lakes Program, such as evaluating water delivery scenarios, determining the consequences of purchasing or leasing junior versus senior water rights, and investigating the practicality of water banking.

Currently, the DST ends at the Wabuska gage, where the Walker River exits Mason Valley. The current DST assumes that increases in flow at Wabuska indicate increased deliveries to Walker Lake; however, this may not be accurate. The river reach from Wabuska to Walker Lake is complex, incorporating significant channel losses, agricultural areas, and storage capabilities at Weber Reservoir. There is a serious need to include this reach in the new DST to support the proposed water rights acquisitions in the Walker River basin in a timely manner. Including this reach will significantly reduce uncertainties in estimates of water deliveries to Walker Lake, improving estimates of impacts to lake volume and total dissolved solids levels.

The current DST is capable of performing scenarios; however, none have yet been implemented. In the future, the DST will be used to evaluate a series of scenarios, such as those discussed above. Scenario development will involve close interactions with basin stakeholders to identify possible future water acquisitions and a variety of possible future climate regimes for the headwater areas. Scenarios will combine these possible water acquisitions and climate regimes into a series of alternative futures. The results of these scenarios will provide a comprehensive understanding of the impacts of proposed water acquisitions on Walker Lake and various important hydrologic characteristics within Mason and Smith Valleys under a variety of different possible climate regimes. Stakeholders involved in this process will include the Water Acquisition Team, Walker River Irrigation District, the Federal Water Master, the EIS Team, and the Walker River Piute Tribe.

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PROJECT F: DEVELOPMENT OF A DECISION SUPPORT TOOL IN SUPPORT OF WATER RIGHT ACQUISITIONS IN THE WALKER RIVER BASIN

USE OF FIBER-OPTIC AND VERTICAL TEMPERATURE SENSING FOR WATER RESOURCE MANAGEMENT AND DECISION SUPPORT IN THE WALKER BASIN

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CONTENTS

LIST OF FIGURES

INTRODUCTION

Detailed knowledge of inflows and outflows in stream systems is crucial to understanding the hydrology of river basins and accurate assessment and management of water resources therein. Interaction between surface waters and groundwater can be accurately quantified using heat as a tracer (see for example: Anderson, 2005; Stonestrom and Constantz, 2003; Conant, 2004), taking advantage of the naturally occurring thermal signal present in most stream systems, and using both well-established and new methods to interpret the results.

Recent developments in Raman Spectra temperature sensing (frequently called Distributed Temperature Sensing, or DTS) now allow for the nearly continuous in time and space, measurement of temperatures in both soil and water mediums (Selker et al., 2007; Moffett et al., 2008, Tyler et al., 2008). DTS systems have the potential to distinguish continuously, or in campaign mode, the locations of groundwater exchanges within the Walker River. Determining the location of inflows, and their magnitude is critical to develop an inventory of salinity and nutrient loading to both the river and the lake. Understanding and quantifying these inflows are also critical for the development of hydrologic models of the basin, both at the individual field scale as well as at the basin scale. Without a clear knowledge of the interaction between the groundwater and surface water, accurate models of the role of water use changes in the basin cannot be made with confidence. These ground water/surface water connections may be the result of natural ground water conditions, but in the agriculture areas, more saline groundwater may be from subsurface agricultural return flows. Using DTS, these inflowing zones can be quickly identified, as the ground water temperature should typically be warmer than the Walker River during winter months. Once identified, these sites can easily be sampled to calculate the magnitude of both water and salinity loading.

In addition to horizontal profiling of river temperatures, vertical temperature profiles beneath the streambed allow accurate estimates of groundwater inflows and outflows at point locations within the streambed. Because thermal loggers are relatively inexpensive, readily available, and neither require external power nor produce large volumes of data, temperature measurements may be made over much longer periods than DTS. Vertical temperature profiles yield time series of seepage rates, both into and out of the streambed (Hatch et al., 2006), and used in combination with DTS measurements, can provide a long-term, thorough assessment of inflows and outflows in hydrologic systems.

By determining the variation, both geographically and seasonally, of water and salinity from ground water sources to the Walker River, water and salinity management controls, ranging from improved irrigation efficiency or crop rotation can be implemented on a site-by-site basis, thereby improving the efficiency of water purchases. At the present time, there are no other practical techniques to measure water and salinity loading at the resolution of individual fields and drains.

In order to assess the efficacy of utilizing fiber optic temperature sensing and vertical temperature measurements as tools for water resource management and eventually as a decision support tool, we have been conducting investigations of surface water – groundwater dynamics in the Walker River. This report summarizes studies in the stream channel of Walker River near the USGS Wabuska stream gage site conducted throughout the study. In this location, the USGS maintains a gauging site where stream water level, discharge, temperature, and specific conductance (indicative of salinity) are measured continuously. Here, after winding northward through the dominantly agricultural basin of Mason Valley, Walker River is constricted by an outcropping of bedrock hills, turns to the east, and eventually flows to the south into Walker Lake. This geomorphology provides the ideal setting for diverse hydrologic conditions and an attractive natural laboratory for testing new tools to support water management decisions.

The results are designed to demonstrate the appropriateness of thermal measures to quantify the interaction between surface water resources (the Walker River), and the regional groundwater systems that are strongly connected to the river. Through this analysis, it will be shown that thermal methods provide a low cost and effective tool to understand the local hydrology including the role of agricultural water management as they affect the sustainability of the Walker River/Walker Lake system.

METHODS AND APPROACH

Distributed Temperature Sensing

The sensing system consists of a laser source, and Raman Scatter detector at the head of the fiber optic cable. The optical laser pulse that propagates down the fiber induces Raman Scattering, and this signal is propagated back to the detector. The position of the temperature reading is determined by measuring the arrival time of the returned scattered pulse. The temperature at that location is determined by the intensity of the backscattered light. The system is somewhat analogous to radar and is commonly used in atmospheric applications as LIDAR (Tyler et al., 2008). Examination of thermal data as compared with synchronous temperature measurements from deeper sources such as piezometers or wells, allows for interpretation and location of groundwater inflows. For example, during winter months, groundwater is typically warmer than stream temperatures; while in summer months, groundwater is cooler than the stream. DTS systems have been recently applied to a variety of stream systems and have proven very successful in identifying ground-water exchanges (Selker et al., 2006b, Westoff et al., 2007).

Improvement of DTS Sensitivity

In addition to field applications of DTS, we have also tested the possibility of improving the sensitivity of DTS measurements through a series of laboratory experiments. The basic properties of any electromagnetic (EM) wave are amplitude, $\boldsymbol{A}$, frequency, $\boldsymbol{f}$, and phase, $\boldsymbol{\phi}$. Whenever an electromagnetic wave is subjected to pressure, temperature or other change in conditions, it responds with a change in amplitude, frequency or phase. Depending on how these parameters ($\boldsymbol{A}$, $\boldsymbol{f}$, $\boldsymbol{\phi}$) change, we can determine the temperature or pressure to which the EM wave was subjected (this is the basic concept of optical sensors). In this study we are specifically interested in temperature change (DTS).

In theory, the laboratory experiments would utilize the raw amplitude (at specific Stokes and Anti-Stokes frequencies) generated by the DTS system laser, and attempt to enhance this signal. These amplitude values are later converted to temperature based on calibration points and a proprietary algorithm within the DTS system. Each raw data value represents dimensionless signal amplitude (intensity) integrated over a meter of fiber. Because the DTS unit's laser source transmits light at an infrared wavelength (1064nm) not visible to the naked eye, specialized equipment is needed to analyze the resulting images, and a free-space (open-air, not enclosed) optical system is not ideal for conducting this experiment with the DTS unit. In addition, the Electro-optic modulator used in this experiment is not suited to the wavelength of the DTS's laser. Therefore, laboratory experiments utilized a different, visible-light laser source with similar properties to serve as proof of concept. For these experiments, we alter phase in a specific, controlled fashion, and use the response to improve the resolution of the signal frequency we are interested in. Phase was chosen because it is the most sensitive parameter, allowing for the maximum improvement in sensitivity.

In the lab, a 890 nm laser diode with an output power of 10 mW is split into two beams in a free space optical system as shown in Figures 1 and 2. Half of the beam (reference beam) is left unaltered and directed to the screen, and the other half (modulated beam) is passed through a ThorLabs Electro Optic Modulator (EOM, or electro-optic phase shift modulator) regulated by a frequency generator. This EOM is capable of modulating (changing the phase) of any wavelength laser source between 600 and 900 nm by passing it through an electro-optic crystal that refracts the beam in a predictable way. The EOM maintains the same, constant reference frequency, but subjects the EM wave to an electric field which changes the phase of the modulated beam by subjecting it to a known radio frequency between 1 GHz and 1000 GHz. The modulated and reference beams are then combined and projected together onto a screen, forming a sinusoidal interference figure. This figure is the result of interference between the reference beam (wave) and the modulated beam (wave), and appears as varying intensity across the image (Figure 3). Where the interference is constructive, intensity is brighter, and where it is destructive, intensity is less bright. Multiple figures are created, using different frequency values. For each experiment, the frequency imposed on the modulated beam is noted, and a 7.2 megapixel (MP) photograph is taken of the interference figure (or fringe pattern) projected on the screen.

A more robust laboratory experiment would be set-up in a closed environment so that no light would be lost (and non-visible spectra could be used), and a charge-coupled device (CCD) would be used to record the fringe image information, instead of a digital camera capturing an image projected on a screen. A CCD is a light-sensitive integrated circuit that stores and displays the data for an image in such a way that each pixel (or picture element) in the image is converted into an electrical charge, the intensity of which is related to a color in the color spectrum. For a system supporting 65,535 colors, there would be a separate value for each color that can be stored and recovered.

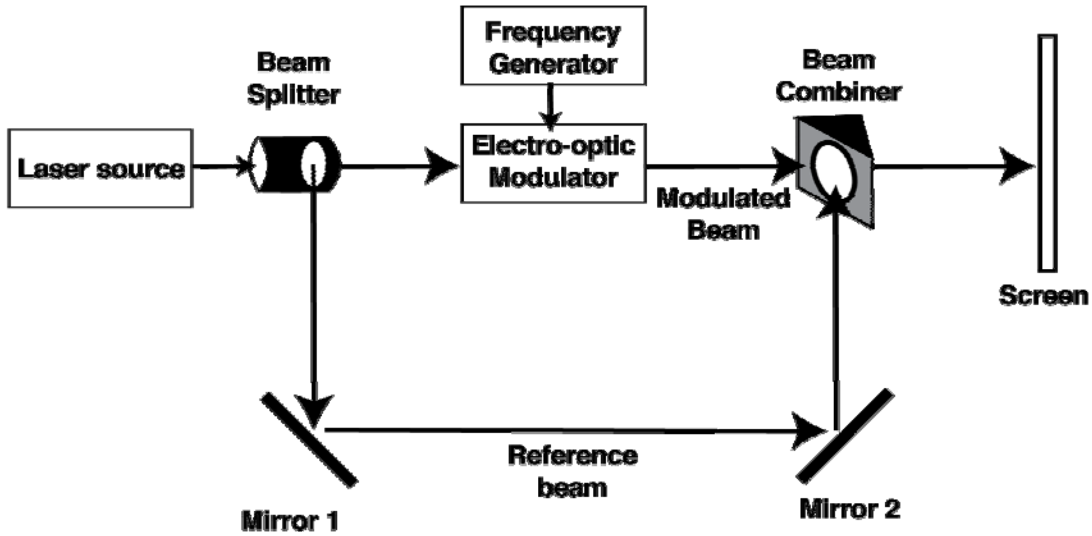


Figure 1. Basic block diagram of proposed experimental set-up for interferometric experiments designed to improve the sensitivity of DTS measurements. The light from the laser beam is split with a beam splitter. One half of the beam serves as the reference beam, and the other passes through Electro Optic modulator (EOM) which is modulated using a frequency generator. The two beams then re-combine, and are projected onto a screen as a "fringe" or interference figure.

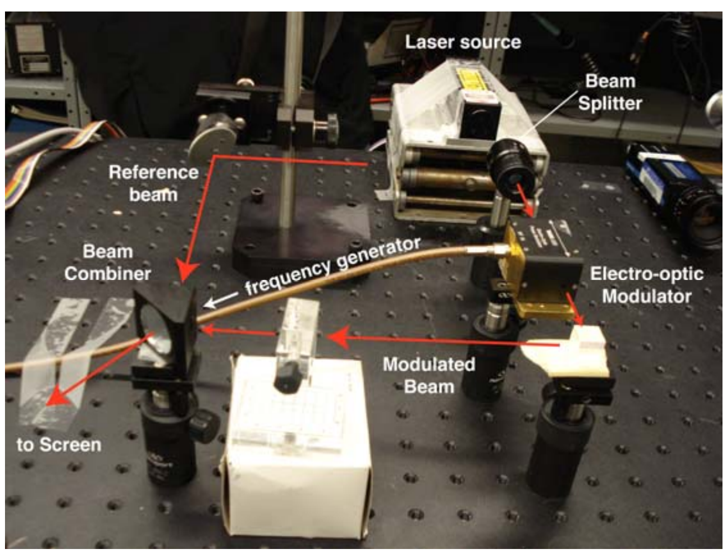


Figure 2. Photograph of free-space optical system set-up for interferometric experiments designed to improve the sensitivity of DTS measurements. The light from the laser beam is split with a beam splitter. One half of the beam serves as the reference beam, and the other passes through Electro Optic modulator (EOM) which is modulated using a frequency generator. The two beams then re-combine, and are projected onto a screen as a "fringe" or interference figure.

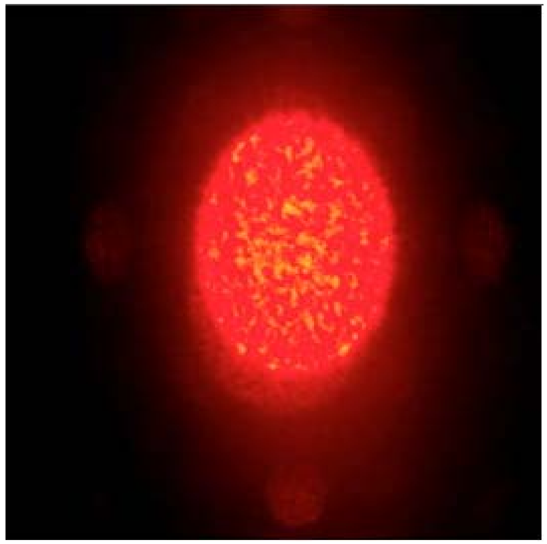


Figure 3. Example of an optical fringe pattern created by constructive and destructive interference between a (890nm) reference beam and a frequency-modulated beam that has been passed through the Electro Optic modulator (EOM). The variations in intensity of the laser beam projection correspond to phase shifts caused by refraction of the beam in response to an imposed electric field. Phase shifts can be extracted from pairs of overlapped fringes through demodulation using image-processing software. Generation of multiple fringes and synthesis of resulting phase shifts can be used to improve the spatial resolution of DTS measurements.

This way, the interferometry could be automated, and thousands of images could be collected and stored with the CCD for much greater resolution. For each optical fringe pattern created by a specific radio frequency from the EOM, the image is demodulated to get the desired parameters. These images can each be described by the linear equation (Estrada et al., 2007):

$$In\theta = a(x,y) + b(x,y) \cos (\phi(x,y) + n\theta) \quad (1)$$

where $In\theta$ is the intensity of the grey scale at each pixel in a digital image, $a(x,y)$ and $b(x,y)$ are unwanted speckle noise and modulation terms, θ is the phase step (the known difference between the reference beam and the modulated beam), n is an integer and $\Delta\phi$ is the phase shift, or information of interest. Fringes are seldom visible with the naked eye, even when the image is generated in the spectrum of visible light, so specialized software in necessary to accurately analyze the images. To do this, pairs of fringes (such as the one shown in Figure 3) are overlapped, compared using Image Processing 5 software, and the phase shifts between the two images are extracted using the equation above (and more complex forms for color images; e.g. with a CCD, as described above).

In our laboratory experiment, for each pair of fringe images (the result of one input intensity value modulated by two different radio frequencies) overlapped and demodulated, three phase shift values result (limited by the resolution provided by the screen projection and digital camera). The three phase shifts can be returned to intensities, using the equation (Udd, 1991):

$$\Delta\phi = \frac{\pi n_0^3 r L V}{\lambda d} \qquad (2)$$

where $\Delta\phi$ is the phase shift, n_0 is the refractive index of the Electro-Optic modulator (EOM; index varies depending on the type of crystal inside the instrument), r is an electro-optic tensor defined by instrument materials, L is the length of the EOM, V is the voltage applied to the system at radio frequency, λ is the wavelength of the laser source (λ = 890nm in this experiment), and d is the distance between electrodes (= width) inside the EOM. Using this process, a single intensity values returns three phase shifts → three intensity values, effectively improving the resolution of the signal three times.

Vertical Temperature Profiling

Determining a time series of seepage rates (rather than a single value in time) allow us to understand dynamic stream processes. Established methods for estimating seepage from streambed thermal data can be time consuming, are usually applied to relatively short periods, and can require independent determination of hydraulic properties and sensor depths, which may reduce the length of useable thermal record. For time series data collected over multiple depths, we apply a time series method for estimating seepage rates from thermal data measured at multiple depths beneath the streambed (Hatch et al., 2006). The governing equation for heat and fluid flow (one-dimensional conduction-advection dispersion e.g., Anderson, 2005; Carslaw and Jaeger, 1959; Goto et al., 2005; Stallman, 1965) is:

$$\frac{\partial T}{\partial t} = \kappa_e \frac{\partial^2 T}{\partial z^2} - \frac{n v_f}{\gamma} \frac{\partial T}{\partial z} \qquad (3)$$

where T is temperature (varies with time, t, and depth, z), κ_e is effective thermal diffusivity, $\gamma = \rho_c / \rho_f c_f$, the ratio of heat capacity of the streambed to the fluid ($\rho_f c_f$ is heat capacity of the fluid, ρ_c is heat capacity of the saturated sediment-fluid system), n is porosity, and v_f is vertical fluid velocity (positive = up). This equation is solved for fluid velocity, or seepage, as a function of the amplitude ratio and phase shift in the thermal wave between temperature records at any two depths. To calculate seepage rates, thermal records are paired, filtered, and processed through a series of programs that iterate to solve for seepage rates, yielding one average seepage rate for each day. Because pairs of records are used, regardless of their absolute depth, these calculations remain insensitive to sedimentation and scour.

Streambed Piezometers

In addition to thermal data from DTS measurements and thermal profilers, piezometers driven into streambed sediments can provide a direct measurement of hydraulic head and indicate the direction of groundwater flow. When equipped with pressure transducers, time series of water levels at depth compared with time series of stream stage illustrate the dynamics of the stream system through time, specifically how gains and losses to channel flows vary on a daily or seasonal basis.

EXPERIMENTAL SITE DESCRIPTION

The interim data reported here was collected on the Walker River near USGS stream gage site 10301500 (Walker R near Wabuska, NV). The gage, established in 1902, is located at 39°09'08.86" latitude and 119°05'56" longitude (NAD83) in Lyon County, Nevada, and is 4300 feet above mean sea level (NGVD29). Continuous Stage (stream water level), discharge, temperature, and specific conductance (indicative of salinity) are monitored at this site. Walker River drains a 2600 mi^2 (6734 km^2) basin before arriving at the Wabuska site, where valley fill sediments through which it flows are constricted by bedrock hills to the north (USGS, 2008). This geography suggests that groundwater inflows to the river are likely to occur at this site. We installed cross-section "W7" comprised of three PVC piezometers in the streambed using a fencepost driver to push piezometers directly into the streambed with minimal sediment disturbance at the site, ~80 m downstream of a culvert/ road crossing at Stanley Ranch. Two additional cross-sections of three thermal profilers each were installed via direct push and soil-sampling slide hammer where necessary ~150 m (immediately adjacent to the USGS stream gage) and ~200 m (near the gauging line overhead) downstream of the culvert, named "W6" and "W5", respectively.

FIELD DATA COLLECTION

The PVC piezometers at cross-section ***W7***, were outfitted with Schlumberger mini-diver pressure transducers for continuous 15-minute monitoring of ground water elevations and Onset Computer WaterTemp Pro temperature loggers at various depths beneath the streambed elevation to record subsurface temperatures every 15 minutes. Manual measurements of vertical hydraulic gradient were taken periodically in all three piezometers, and stage at the USGS gage was noted. Vertical thermal profilers and external Campbell Scientific water-temperature probes (one per profiler) at ***W6*** and ***W5*** were connected to two solar-powered Campbell Scientific data loggers, one at each site. Each thermal profiler recorded temperature at seven thermister locations within the probe at 15-minute intervals. All 9 instruments (3 piezometers and 6 profilers) were installed in the early Summer 2008 and were continuously logged through October 2008 in order to provide estimates of seepage dynamics through time (Hatch et al., 2006).

DTS measurements were made with a Sensornet Sentinel unit over one single-day and two, week-long campaigns under different flow and temperature conditions. For each DTS survey, fiber-optic cable was fixed in place along the streambed and in a calibration bath of known, constant temperature at each end for calibration purposes (Selker et al., 2007; Tyler et al., 2008). Cables were interrogated by laser pulse every minute, and returned Stokes amplitude information that is converted to temperature by an algorithm in the instrument, averaged over each meter of cable. Resulting temperatures are corrected for any deviation from known bath temperatures recorded with an independent, calibrated logger. Three different DTS fiber optic cables were deployed since the mid winter 2008:

- February 26, 2008 14:00 – 18:00: 1000 m of Brugg Inc. stainless steel wrapped cable was deployed downstream from the road crossing downstream of W7 (Figure 4); measurements were made every 10s with a Sensornet Sentinel DTS system in single-ended mode (Tyler et al., 2008).
- July 30-August 4, 2008: 850 m of black AFL Telecommunications cable was deployed over a 500 meter reach of the stream upstream from the road crossing. The fiber was interrogated with a Sensornet Halo DTS system in single-ended mode.
- October 21-27, 2008: 1000 m of white AFL Telecommunications cable was deployed over a 600 meter reach of the stream upstream from the road crossing. The fiber was interrogated with a Sensornet Sentinel DTS system in single-ended and double-ended mode.

For all DTS deployments, standard calibration procedures were followed, and the fiber was interrogated in single- or double-ended mode (Tyler et al., 2008), temperature resolution is less than 0.1 °C, and spatial resolution is 1 meter (Sentinel) or 2 meters (Halo). Figures 4 and 5 show the general location of the instrumentation and the shaded topography of the study reach.

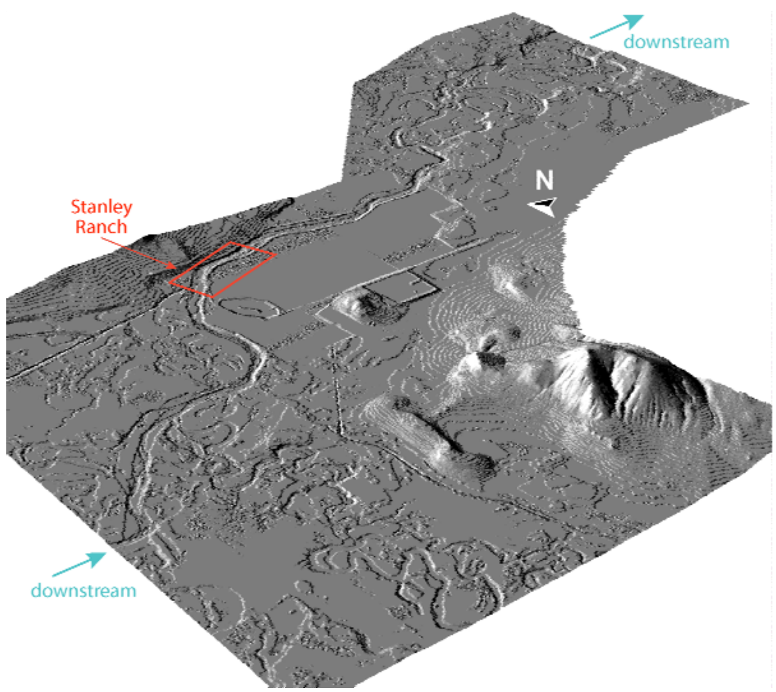


Figure 4. Field site on Walker River near Wabuska, NV, showing location of the Stanley Ranch area where the USGS stream gage is located. Inset expanded in Figure 5.

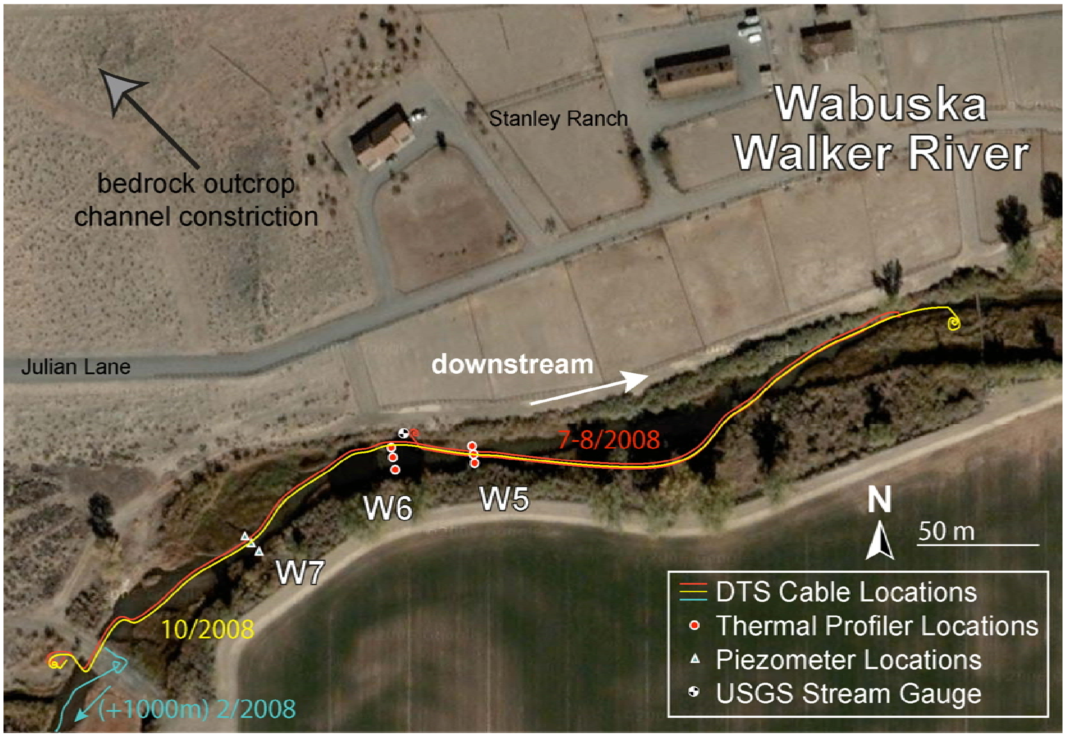
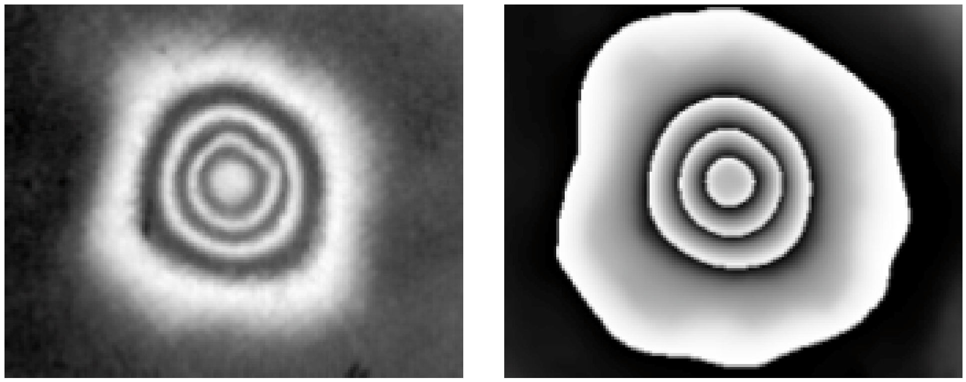


Figure 5. Field site on Walker River near Wabuska, NV, showing locations of streambed piezometers, thermal profilers, DTS fiber optic cable deployments, and USGS stream gage.

Results: Improving DTS Sensitivity

Distributed Sensing is used to describe a technique whereby one sensor (in this case the DTS unit which interprets the signal from along an entire fiber-optic cable) yields data spatially distributed over many thousands of individual measurement points. Specifically, DTS measures temperature collected along the entire length of the fiber, which acts as a sensor, with a spatial integration interval of one meter. DTS measurements are essentially ***intensity*** values at a specific frequency (Stokes and Anti-Stokes), one for each meter. For example, if we have a 1000-meter cable (typical for Walker River deployments), the DTS returns 1000 Stokes intensities ("reference" values, which are affected to a very limited extent by changes in temperature), and 1000 Anti-Stokes intensities (altered by temperature), which together yield 1000 temperature measurements, one integrated over each meter of cable. Now, if that backscattered optical signal, which contains information for all 1000 intensities, is split, modulated in a known way (using an EOM), recombined, and interpreted (using a CCD), a total of 3000 intensities are returned. These can be compared with the same "known" or "reference" signal, the Stokes signal, as before to yield temperatures. Based on the 890-nm laser laboratory experiment we conducted, each intensity yielded 3 phase shifts. So, extended to this theoretical DTS example, now instead of being integrated over each meter, the resulting temperature values could now be integrated over each 1/3 meter, or ~0.33 m, which would theoretically be a three-fold improvement in spatial resolution of DTS measurements. An example of a fringe (processed to allow visibility) is shown in Figure

6. The apparent improvement in clarity from the left (a) to the right panel (b) of the figure is the result of this type of demodulation and improvement in resolution. Furthermore, with an improved laboratory set-up, implementation of CCDs and other resolution-enhancing equipment, a increase in resolution of up to 100 times could be achieved, or an improvement from one-meter to one-centimeter resolution.



(a) **(b)**

Figure 6. Illustration of improvement in resolution generated by the projection-modulation technique, from Estrada et al., 2007. Here, a pair of optical fringe patterns have been overlapped to create an interferogram (a), generated with a moiré technique. This image is then demodulated (b); the phase (and associated improvement in resolution) was obtained using Local Adaptable Quadrature Filters (LAQF). In theory, a similar process can be used to improve the spatial resolution of DTS measurements.

Results: DTS Campaigns

We conducted three DTS runs on Walker River. During two of these, February and October, stream temperatures (~4-6°C and ~0-16°C, respectively) were cooler than the groundwater (≈ 20°C), so increases in stream temperatures measured by DTS indicate groundwater discharge, or gains to stream flow (Figure 7 and 9). During the summer experiment, peak stream temperatures (up to 28°C) were warmer than groundwater, so cooling indicates gaining, or groundwater inflows (Figure 8). Based on these preliminary observations, thermal trends are consistent with gaining stream conditions were present in all three DTS runs. A detailed explanation and interpretation of these trends is presented in the discussion section.

Results: Vertical Temperature

Large differences in daily minimum and maximum temperatures throughout the study (up to ~15 degrees Celsius) facilitated the use of heat as a tracer to estimate seepage into and out of the Walker River channel near Wabuska. To illustrate how this works, we plot temperature (vertical axis) versus time (horizontal axis) for a short period in June and August for the river and three subsurface (shallow ground water) temperature loggers in a single piezometer, ***W7-L*** (Figure 10). Looking downstream, this piezometer is located 2-3m from the left bank, approximately in the thalweg of the channel. The fiber optic cable was deployed immediately adjacent to this piezometer in both July and October. River temperatures show a thermal signal that oscillates ~15 degrees Celsius on a daily basis. These temperature oscillations penetrate the subsurface sediments via conduction, and to a much greater degree, advection, as down-going fluid pushes the thermal signal downward. From July 18 to 30, 2008, the oscillating thermal signal from the surface penetrates readily to a depth of 45 cm, suggesting little to no ground water inflows to the river, and instead likely losing conditions in the channel. The amplitude of the signal at 10 cm is very nearly the same as that of the surface signal. By contrast, the reduction in amplitude in thermographs with depth from July 30 to August 4, 2008 is markedly greater, and little if any of the surface oscillation reaches the 45 cm depth, indicating the lack of downward fluid movement to carry the thermal signal. This period is consistent with the decrease in stream flow and suggests that upward movement of ground water was induced by the reduction in stream flow.

Discussion: Combining DTS and Vertical Temperature Data

Temperature data were collected from the Walker River using combined DTS and vertical temperature sensing throughout the period with the lowest flows between June and October 2008. Walker River is used for conveyance of irrigation waters, and is theoretically maintained at a minimum flow rate of 0.74 m^3/s at the USGS gauge near Wabuska during the growing season. Occasionally flows decrease to much lower levels (inadvertently coinciding with our DTS deployments; Figures 11A and 12A). During these periods, water that had saturated the riverbanks, now at a higher level than the stream, flowed back into the channel. These short-term gains to the stream were recorded both by DTS instrumentation during relatively short-duration campaigns as well as longer-duration data from vertical piezometers and profilers.

Interpreting DTS Data

Figure 7 shows the calibrated DTS temperature time and space series collected on February 26, 2008 from 14:00 – 18:00. The vertical axis is time increasing downward, t, and the horizontal axis is distance, x, along the fiber. The color contours are temperature, T, in degrees Celsius. With >15°C difference between stream and groundwater temperatures in February, the 0.5°C of heating downstream over 200 to 300 m observed in DTS data appears to indicate groundwater inflows to the stream (Figure 7 A-B). However, this trend lessens later in the day. On careful examination, it was noted that from ~150 m on, the cable followed a bend in the river and was exposed directly to the setting sun in the west. Once the sun set around 16:50, the apparent warming trend nearly disappears. We therefore conclude that during this deployment, the warming observed here indicates influence of solar radiation on the cable and stream temperature, rather than definitive groundwater gains that would continue throughout the night.

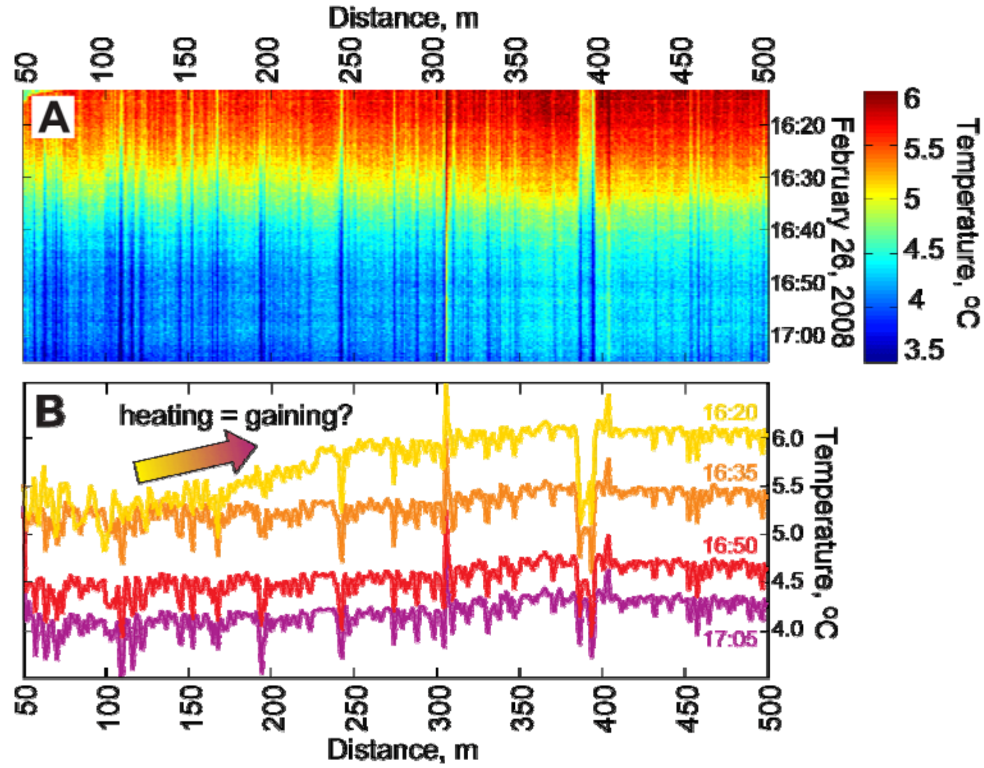


Figure 7. A. DTS data from Walker River near Wabuska February 26, 2008 14:00 – 18:00. Horizontal axis is distance along the fiber, vertical axis is time, and contours are temperature, in degrees Celsius. B**.** Detail; Horizontal axis is distance along the fiber, vertical axis is temperature, and each trace represents 20 minutes of data averaged together to reduce noise. Groundwater is significantly warmer than surface water this time of year, so heating would indicate warming. However, in this case, the warming trend "disappears" as the sun sets, indicating that the apparent warming observed here is an effect of solar radiation on the cable.

Figure 8 shows the calibrated DTS temperature time and space series collected from July 30-August 4, 2008. The vertical axis is time increasing downward, t, and the horizontal axis is distance, x, along the fiber. The color contours are temperature, T, in degrees Celsius. From 0 to ~55 m, the cable is located in an ice bath for calibration (not shown), from ~55 to ~65 m the cable is in the air (note the larger amplitude temperature swings) and the remaining portions of the cable are on the river bottom. On July 29, large sections of the cable were exposed to the air, and show higher maximum and lower minimum temperatures than the water temperatures measured by the rest of the cable (exposed sections include from 120 – 130 m, 315 – 330 m, 345 – 365 m). We returned to the site on July 30 to tie down the cable and ensure it was well-placed in the channel thalweg. However, during the deployment, stream levels dropped considerably, and several additional portions of the cable came out of the water (for example, near ~105 m, ~145 m, ~155 m, ~200 m, ~260 m, ~300 m and ~350 m) and were exposed to the air. These portions of the cable began to show much larger swings in daily temperature, and result from rapid heat exchange with the atmosphere and solar radiation which is otherwise buffered when the cable is underwater. In addition, the cable was buried in several locations by bedload sediments, damping the amplitude swing of the stream temperatures (near ~110 m and 400 – 430 m).

Evidence of ground-water inflows are typically identified by their thermal response. In July and August, peak stream temperatures were nearly 10°C greater than mean groundwater temperature (Figure 8 A, B-D). Because groundwater is colder than surface water during summer months, cooler temperatures indicate gaining reaches. During the hottest hours of the day, a cooling trend of ~ 0.2°C was observed between ~100 and 225 m (Figure 8 B-D). At this time of day, the only explanation for cooling downstream, then warming again (from ~225 m on), is diffuse inflows of cooler groundwater throughout this reach. In one location around 90 m, cool upwelling was volumetrically significant enough when compared to the stream volume (and fiber optic cable was serendipitously well-placed) to be recorded throughout the deployment (Figure 8 A and D). Because this deployment lasted several days, careful documentation of locations where sediment accumulated over the cable was crucial in separating these from areas where inflow may occur, as buried cable generates a similar thermal signal to inflow.

In October, cooler stream temperatures allowed for unequivocal DTS measurements of clearly gaining conditions (Figure 9 A-D). Groundwater is warmer than surface water this time of year, and a heating trend of 0.6°C downstream over 300 m is consistent throughout the day and into the evening, even as air temperatures cool, consistent with diffuse groundwater inflow over the entire reach. As with the previous deployment, stage in the stream dropped over the course of the installation, exposing cable in several areas (~605 – 615 m, and 795 – 820 m). During this campaign, the cable was buried in more locations by bedload sediment, again, damping the amplitude swing of the stream temperatures (near ~560 m, 570 m, 630 m, 670 m, 780 m, 820 m, 980 m, 990, and 915 – 960 m). Of particular interest during this deployment is the behavior of streambed sediment. Walker River has a very active bed in this location, and anecdotally, field workers observed bedforms migrating downstream throughout the experiment. However, on close examination, DTS data also document bedform migration (Figure 9 A). Note that during the night (dark blue tones) on the first three days of deployment, there are light blue (warmer) “wisps” that travel from left (upstream) to right (downstream) through time (down). During the hottest hours of the day (yellow tones), these same wisps are now darker green (cooler), indicating an overall damping of temperature amplitude by shallow, and migrating, sediment cover.

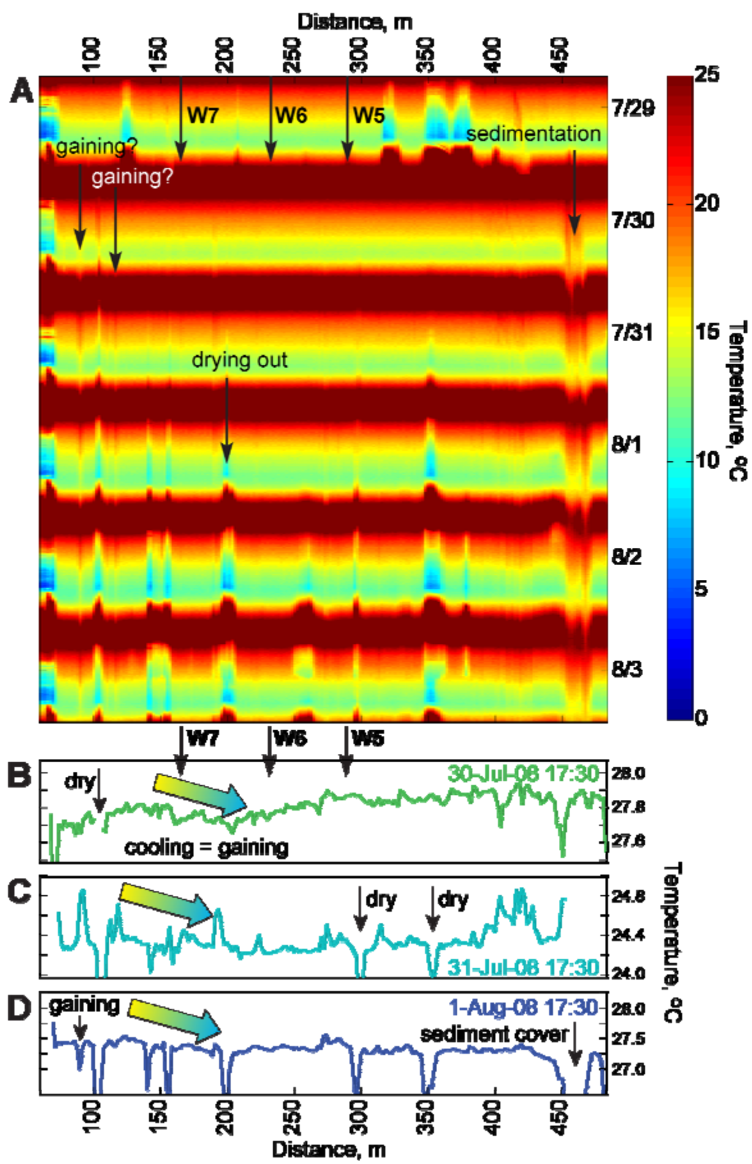


Figure 8. **A**. DTS data from Walker River near Wabuska July 29-August 4, 2008. Horizontal axis is distance along the fiber, vertical axis is time, and contours are temperature, in degrees Celsius. On 7/29, large sections of the cable were exposed to the air, and show higher maximum and lower minimum temperatures than the water temperatures measured by the rest of the cable (exposed sections include from 120 – 130 m, 315 – 330 m, 345 – 365 m). We returned to the site on 7/30 to tie down the cable and ensure it was well-placed in the channel thalweg, however, as stream stage continued to drop, new areas of cable became exposed (near 100 – 110 m, 140 – 160 m, 190 – 205 m, 250 – 265 m, 290 – 300 m, and 345 – 360 m). In addition, the cable was buried in several locations by bedload sediments, damping the amplitude swing of the stream temperatures (near ~110 m and 400 – 430 m). **B, C, D**. Detail on July 30, July 31 and August 1, 2008; Horizontal axis is distance along the fiber, vertical axis is temperature, and each trace represents one hour of data (from 17:00 to 18:00) averaged together to reduce noise. Groundwater is cooler than surface water this time of year (in the middle of the day), so the cooling trend observed between ~100 and 225 m indicates a region of diffuse groundwater inflow. In addition, on August 1, 2008, Figure 8B shows a local inflow point of large enough magnitude to measure directly near ~90 m.

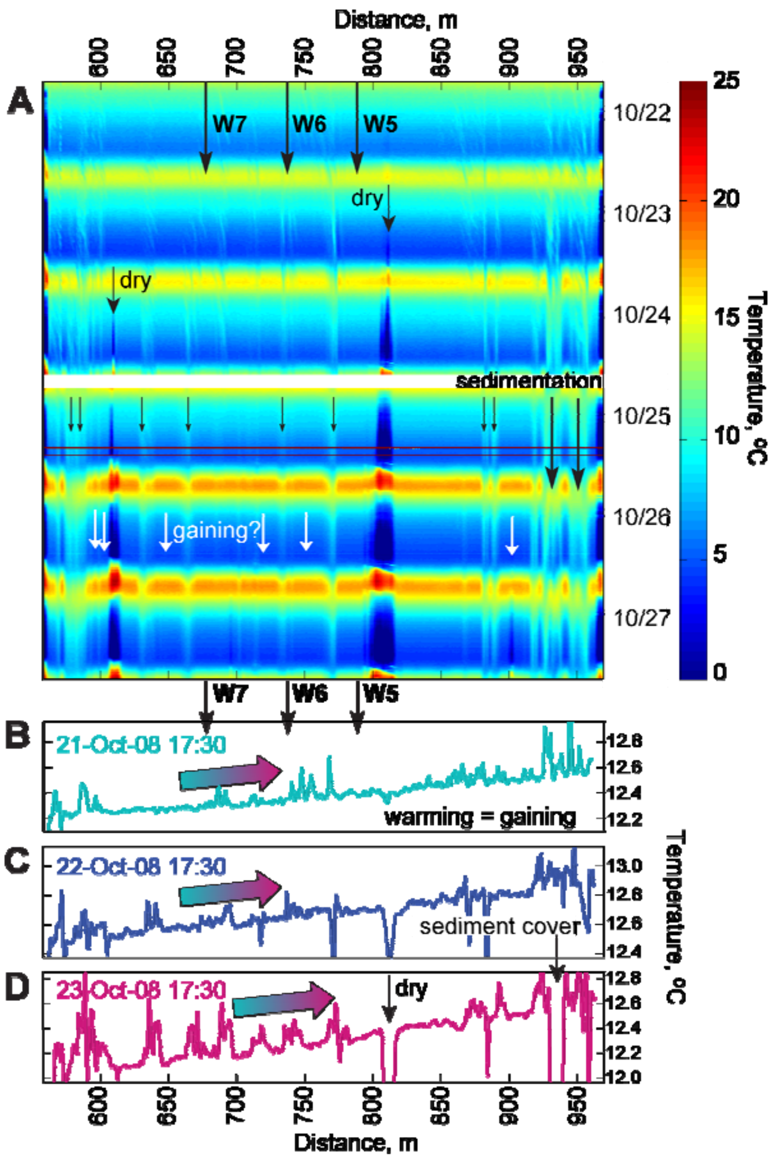


Figure 9. A. DTS data from Walker River near Wabuska October 21-27, 2008. Horizontal axis is distance along the fiber, vertical axis is time, and contours are temperature, in degrees Celsius (using the same color scale as Figure 8). As in Figure 8, stage in the stream dropped over the DTS deployment, exposing cable in several areas (~605 – 615 m, and 795 – 820 m). During this campaign, the cable was buried in more locations by bedload sediment, again, damping the amplitude swing of the stream temperatures (near ~560 m, 570 m, 630 m, 670 m, 780 m, 820 m, 980 m, 990, and 915 – 960 m). Note that early in the deployment "wispy" stripes of buried cable signal (warmer than surrounding night water temperatures) appear, and migrate downstream; effectively "tracking" the movement of bedforms down the channel until the cable is fully buried by them. B, C, D. Detail on October 21, 22 and 23, 2008; Horizontal axis is distance along the fiber, vertical axis is temperature, and each trace represents one hour of data (from 17:00 to 18:00) averaged together to reduce noise. Groundwater is warmer than surface water this time of year, so the warming trend observed over the entire length of cable indicates diffuse groundwater inflow. This phenomenon persists throughout the day and night.

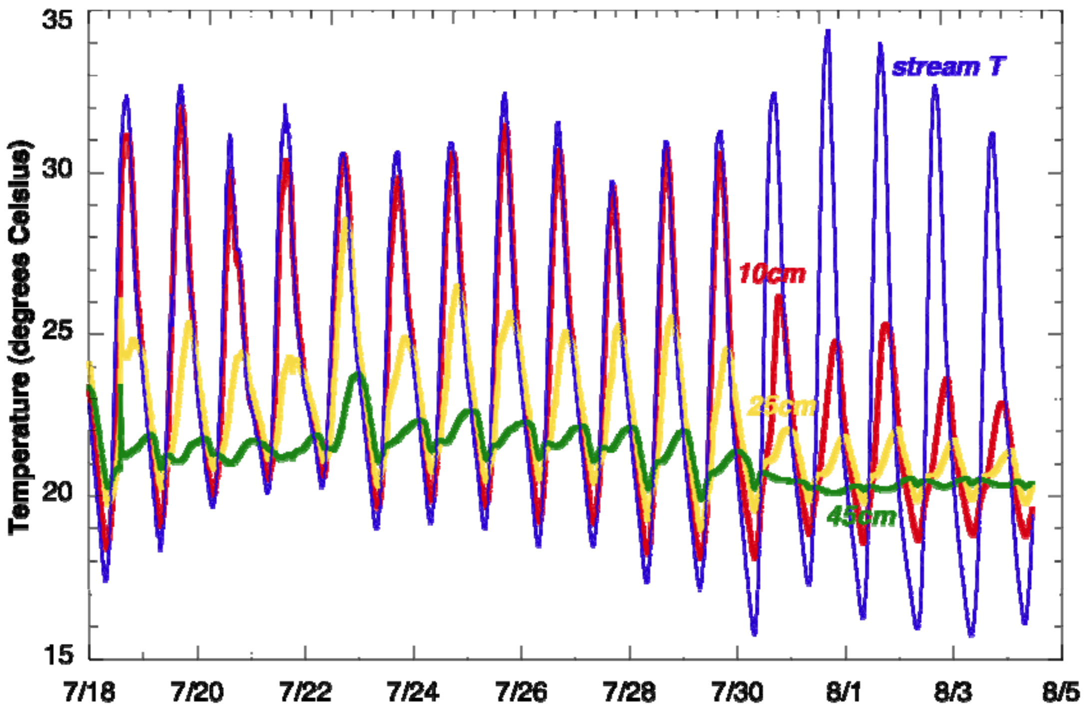


Figure 10. Temperature time series (in degrees Celsius) from the stream water column (blue), and at three depths (z=10 cm, red, 25 cm, yellow, and 45 cm, green) below the streambed surface from the left piezometer at W7, at the Wabuska Gage site on Walker River from July 18 to August 4, 2008.

Long Time Series of Seepage Rates from Vertical Temperature Profiles

Seepage rates were estimated from thermal time series recorded in profilers and piezometers, then compared to stream discharge. Seepage rates that positively correlate with discharge are particularly noticeable at ***W7***, the upstream-most site (Figure 11D and Figure 12). Seepage losses generally increase downstream, and decrease toward the right bank (inside edge of meander). Within a relatively narrow range of discharges about the target discharge for irrigation conveyance of ~ 1 $m^3/s \pm 0.2$ m^3/s, increases in channel discharge (and stage) yield increases in seepage losses. However, as noted above, during and following periods of particularly low discharge (>0.5 m^3/s), gaining conditions exist for limited periods and over limited spatial extent. Water levels, hydraulic gradients, and seepage rates from piezometers and thermal profilers all indicate gaining conditions during these periods of low discharge (Figures 11 and 12). The data from thermal profilers allowed us to resolve the limited times over which these gaining conditions existed at specific points in the channel, while DTS permitted assessment of where specifically along a much longer reach these gains to channel flow were occurring during those periods.

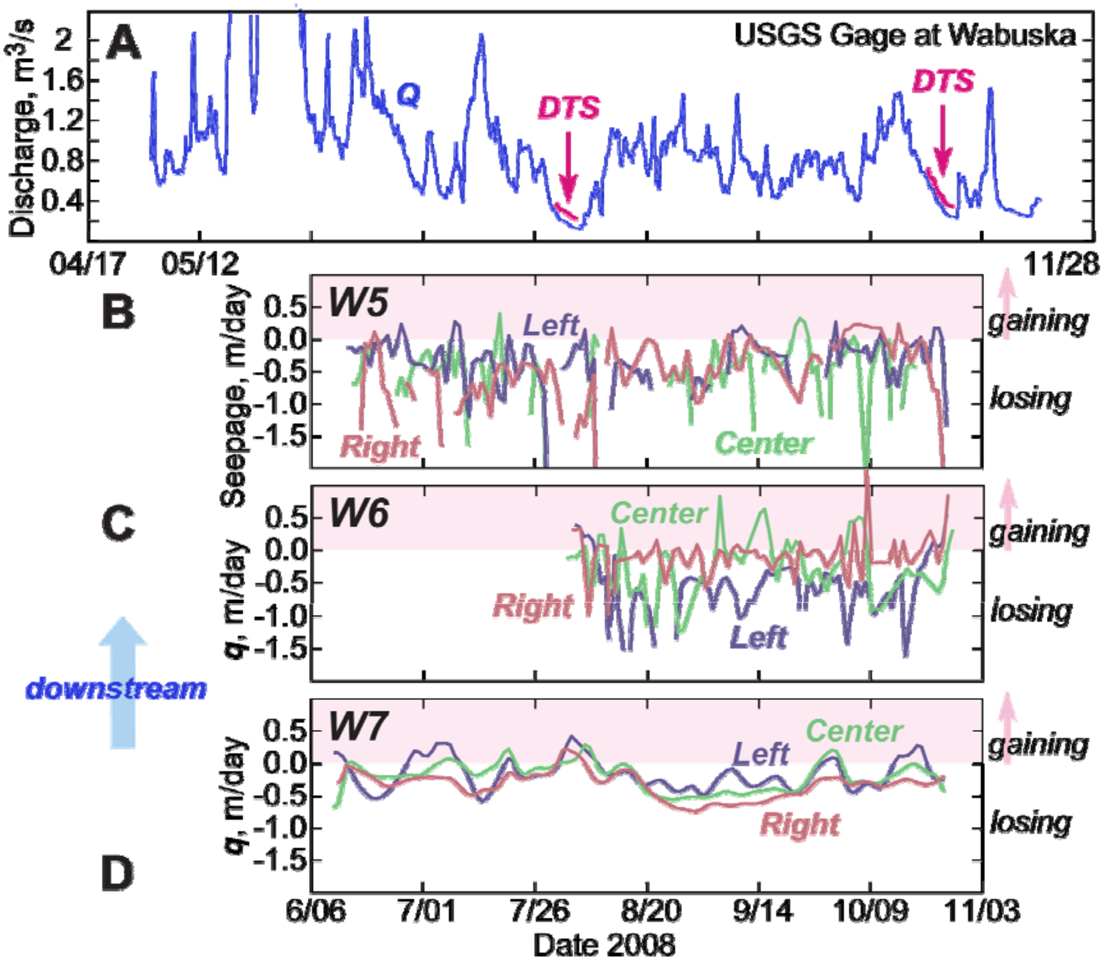


Figure 11. Summary of seepage rates derived from thermal data collected in vertical piezometers and thermal profilers at Wabuska on the Walker River. A. (E.) Daily mean discharge at USGS Wabuska gauging station (#10301500) near observation site W6, Q [m3/s]. B. Seepage rates, q, [m/day] derived from thermal data collected in streambed thermal profilers at W5, C. W6, and D. streambed piezometers at **W7**. In general, greater discharge is correlated to increasing seepage losses.

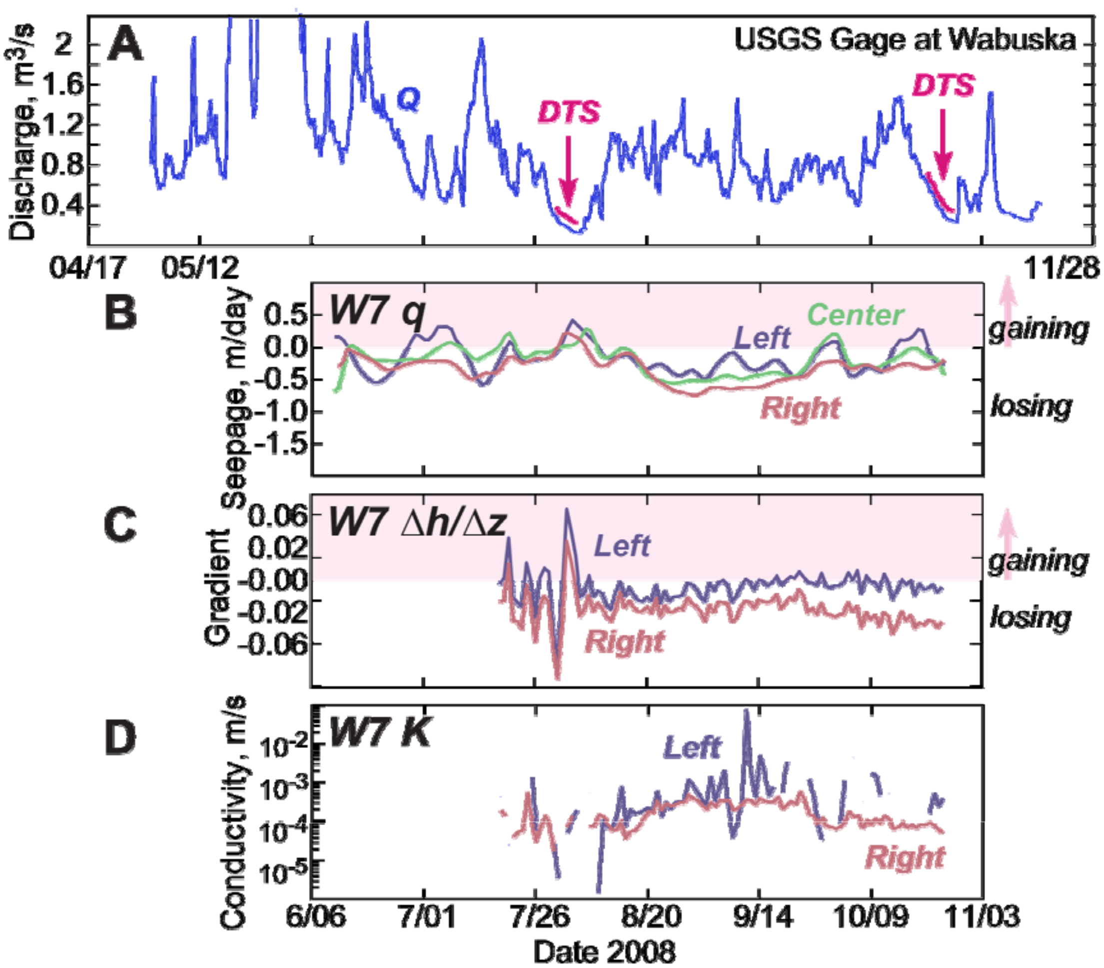


Figure 12. Summary of seepage rates and hydraulic properties derived from thermal and pressure data collected in vertical piezometers at cross-section W7 at Wabuska on the Walker River. A. Daily mean discharge at USGS Wabuska gauging station (#10301500) near observation site W6, Q [m3/s]. B. Seepage rates, q, [m/day] derived from thermal data collected in streambed piezometers at W7. C. Hydraulic gradient, Δh/Δz, derived from water levels in streambed piezometers at W7 and USGS stage at W6, and D. hydraulic conductivity, K [m/s] at W7. In general, greater discharge is correlated to increasing seepage losses. Periods of least discharge correspond to gaining conditions in piezometers at W7.

CONCLUSIONS

The combination of horizontal and vertical temperature distributions can provide significant improvement over either method used alone. The analysis in this study shows the groundwater - surface water interaction to be highly variable in both space and time. Ground water inflows and outflows to and from the river were easily identifiable and quantifiable using the combination of DTS and vertical temperature measurements.

DTS measurements indicate gaining conditions over short periods of time and long spatial extent. DTS permitted assessment of where specifically along a much longer reach these gains to channel flow were occurring during the limited periods with gaining conditions. However, hydraulic gradients and vertical temperature profiles yield seepage rates of long duration that suggest these gaining periods are anomalous, rather than status quo. In addition, hydraulic conductivities derived from seepage rates and gradients are relatively constant through time, reinforcing the supposition that rare low-flow events yield short-lived gaining conditions on Walker River. Because these records are of longer duration, vertical thermal profilers allowed us to resolve the limited times over which these gaining conditions existed at specific points in the channel. DTS is a valuable tool for measuring groundwater inflows to stream environments year round. Care must be exercised when choosing the season or time of day for measurement, and knowledge or independent measurement of groundwater temperatures is essential to successful assessment of surface-water groundwater interactions with DTS. Use of time series from vertical temperature profilers and piezometers outfitted with temperature and water level loggers yields long records of seepage rates, hydraulic gradients, and hydraulic conductivity, providing insight into the dynamics of stream-groundwater systems over time. While vertical temperature methods are unaffected by sedimentation or scour, accumulation of bed load on top of fiber-optic cable may facilitate misleading temperature information (which can be mitigated by careful observation and documentation).

Laboratory experiments show promise for the potential to improve the spatial resolution of DTS measurements. Further application of these principles to DTS systems could be extremely beneficial to applications where detailed spatial temperature data is needed.

Based on the successful results of this study, water managers may use these tools and insights into surface water – groundwater interactions at this site and the likelihood or frequency for natural gaining conditions to exist in this reach to inform potential future water purchases, thereby maintaining the long term flows and sustainability of the Walker River/Walker Lake system.

Related Efforts

As a result of the acquisition of two DTS systems and associated fiber, several other research projects have been initiated during periods when the systems were idle. Measurements of salt marsh/groundwater interaction were undertaken with collaborators from Stanford University and the University of Connecticut (Moffet et al., 2007). Measurement of basal snow temperatures and melting patterns has been conducted in collaboration with researchers from the University of California-Santa Barbara and Boise State University (Tyler et al., 2008). Studies of cave air circulation were conducted (during spring higher flow periods of the Walker when DTS cables could not be deployed) at Carlsbad Caverns National Park in New Mexico with collaborators from the New Mexico Institute of Mining and Technology. Stream surveys for ground water/surface water interaction were conducted with researchers from the University of California-Merced in Sequoia National Park, and in the salmon spawning grounds of the Scott River with University of California –Davis researchers. DTS cable heating experiments to study the impact of solar radiation on stream bed temperatures were recently conducted in concert with the Utah State University (Neilson et al., 2010). Finally, the University of Nevada, Reno has been a co-sponsor of four National Science Foundation workshops on fiber optic temperature sensing (Selker et al., 2008; Tyler et al., 2008, Tyler and Selker, 2009). These collaborations and workshops have led to the significant expansion of research potential at UNR and several new projects are either underway or proposed to utilize DTS in studies of water resources of national parks and in the study of canal and dam seepage.

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PROJECT G: ECONOMIC ANALYSIS OF WATER CONSERVATION PRACTICES FOR AGRICULTURAL PRODUCERS

ECONOMIC ANALYSIS OF ALTERNATIVE WATER-CONSERVING CROPS FOR THE WALKER RIVER BASIN

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Walker Lake is facing critical water shortages and becoming excessively saline due to surface water withdrawals from its sources, endangering its ecosystem and economic resources. Water diverted from surface inputs for agricultural use is one cause of this shortage. Unless agricultural water use can be reduced, the ecology of Walker Lake will be altered. This study examined alternative crops that would enable producers to remain economically viable while using less water. A combination of a crop yield model, WinEPIC, and a risk simulation model, SIMETAR, were used to analyze and answer the agronomic and economic questions. This study determined that there are alternative crops that could be feasibly substituted for alfalfa and reduce water use by at least one-half while providing net returns that meet or exceed returns from alfalfa and keep producers profitable in agriculture.

INTRODUCTION

Walker Lake is a rare freshwater terminal lake in northern Nevada, one of six in the world (Partners 2007). Its inflows come from the West Fork and East Fork of the Walker River, which have their origins in the Sierra Nevada of California, and join in the Mason Valley of Nevada to become the Walker River, terminating at Walker Lake. In the last one hundred and fifty years, water has been diverted from these inflows for irrigation purposes at five major agricultural areas along the rivers. These diversions have resulted in dramatic drops in the level of the lake and in dramatic increases in the salinity of the lake. The increased salinity and lower lake levels are negatively impacting the habitat and populations of Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi)*, a federally recognized threatened species and the Nevada state fish (Dickerson and Vinyard 1999). Tui chubs (*Gila bicolor)* and other native aquatic life are being severely reduced in number (Marioni, Tracy, and Zimmerman 2005); some species of zooplankton, an important link in aquatic food webs, have become extirpated (Beutel et al. 2001). Walker Lake is one of few terminal lakes with an endemic trout fishery, and these changes are negatively impacting recreational use of the lake. These changes also have negative consequences on the more than two hundred species of migrating birds that visit the lake, a biannual food and rest stop on the Pacific Flyway for thousands of birds and a favorite destination of bird watchers (Partners 2007).

It is necessary to increase inflows to Walker Lake to be able to preserve this important natural resource. The Walker Basin Project, funded by Congress through Public Law 109-103, Section 208 in November 2005, is involved in purchasing water rights from agricultural producers in order to be able to leave this previously appropriated water in the rivers where it will make its way downstream to the lake. Agricultural production is the major source of revenue for local residents, and producers are dependent on irrigation for their livelihoods. Buying out agricultural producers and removing all irrigation from the fields without planting cover crops is not a sensible option; leaving the ground fallow in these areas could result in these previously verdant areas becoming sources of dust bowls. This problem has already occurred in the Swingle Bench area just north of the Walker Basin in Churchill County, where dust storms are resulting from non-productive farmland. These areas where irrigation has been removed are creating hazards to health, poor air quality, and impeding vehicle safety, among other hazards caused by wind erosion; federal and local agencies are working to alleviate the situation (Service 2004). A proposed possible solution to increasing lake levels without further economic or environment damage is for producers to plant alternative crops that consume less water.

The major crop grown in these areas is alfalfa *(Medicago sativa)*, an extremely high water user commonly irrigated by flood methods. Due to the quality of the alfalfa grown and current hay shortages, alfalfa production yields high prices and is an excellent source of revenue. In order to be able to feasibly sell water while continuing to grow crops, producers would have to be able to grow a crop with less water, yet yield equal or greater profit. An alternative crop would need to be able to thrive under the sometimes harsh conditions that exist in northern Nevada. Research was conducted to determine a number of crops that fit within these constraints. Additionally, local university and extension faculty were consulted about experimental crops that are being grown in test plots in the region. A list of possible alternative crops meriting further study was then compiled from this investigation. The alternative crops under study fall into differing categories: onions, an annual market crop already grown in the region; leaf lettuce, an easily marketable annual; wine grapes, a high-end market perennial; teff, a specialty annual grain used for market or forage; two-row malt barley, an annual used in the niche market of beer brewing; Great Basin wild rye, a native perennial grass that can be used for restoration or forage; and switchgrass, a native perennial grass with potential as a biofuel. The variety of crops under study offers producers more than one option when considering alternatives.

To determine the viability of these crops for both the region and the market, WinEPIC and SIMETAR were used. WinEPIC is a simulation model developed by researchers at Texas A & M extension that incorporates both agronomics and economics, forecasting yields under varying irrigation, weather conditions and soil types. Yields can be compared for the same crop using flood, sprinkler or drip irrigation. The model has been calibrated to use data from long-term existing weather stations in northern Nevada, and uses soil data from the USDA Natural Resources Conservation Service for the areas under consideration. The model is able to forecast yields for up to one hundred and fifty years. SIMETAR is a risk analysis modeling program that is able to take the yield results obtained from differing crops in WinEPIC, multiply those results with current and fluctuating market prices, and then compare the resulting amount of variance in returns between crops to determine those alternative crops that would incur the least amount of risk for producers.

The results of this study will be useful not only to area producers and those involved in the Walker Basin Study, but also to producers in other areas of the West. Water is an increasingly scarce commodity in the west, and as more water is diverted from agricultural use to residential and industrial purposes, producers in other areas will be facing similar challenges.

RELATED LITERATURE

Water Availability

In the western United States, hydrological cycles have changed considerably in the last fifty years, due in a large part to anthropogenic intervention, and research predicts water supplies will reach a crisis stage (Barnett et al. 2008). As populations in western states increase, municipal supply, recreation, hydropower generation, and other in-stream uses all increase competition for available supplies away from agricultural uses (Diaz and Anderson 1995). Because snowpack is the dominant source of streamflow in most of the western United States, researchers are concerned with snow-water equivalent levels and examine historical and current data for statistical trends (Kalra et al. 2008). In addition to the chronic challenge of limited water supplies, paleo-climatic records show that in the ninth through the fourteenth centuries, native American populations were subject to mega-drought conditions; a recurrence of these conditions is possible (MacDonald 2007).

Even in years with adequate or above average stream flows at the headwaters, downstream users are faced with chronic low supplies (Gaur et al. 2008). While downstream agricultural producers are able to somewhat adapt to these conditions, ecosystems do not fare as well. Studies have been conducted in the Deschutes River Basin in Oregon in two different irrigation districts on the trade-offs between ecosystem health and agricultural use, examining strategies to increase stream flows (Turner and Perry 1997). In the Rio Grande Basin, economic analyses of reducing allowable diversions to central New Mexico irrigators results in economic damage to those producers, but produces benefits to downstream users in southern New Mexico while additionally protecting critical habitat of the Rio Grande Silvery Minnow, their endangered species of interest (Ward and Booker 2006).

Reducing Water Use

Planting alternative crops that use less acre feet of water is one way producers may reduce the amount of irrigation water they consume; this provides a way for producers to remain solvent in regions where water is scarce and they are under social pressure to reduce use (Gaur et al. 2008). Farmers in the Punjab region of India have replaced rice and wheat with cotton and soybeans while farmers in the Lower Rio Grande Basin of Texas have replaced sugar cane with corn (Jalota et al. 2007; Santhi et al. 2005). We offer in this study several alternatives to alfalfa that reduce water consumption.

Alternative Crops

In order for an alternative crop to be considered economically feasible by this study, it must meet several criteria: it must be able to thrive under climatic conditions that exist in northern Nevada such as aridity and high winds; it must be suitable for the soil types prevailing in the Great Basin; it must be a low or reduced water use crop when compared to alfalfa; the transition to alternative crops should have minimal impacts on investment such as equipment and machinery; it must be able to be harvested and shipped to market with no degradation in product quality; there must exist a market within shipping distance for the product; and yields and market prices must be high enough to allow producers to switch crops and receive as much, if not more, profit from their efforts than from the previously planted crop. Published information of crop parameters was reviewed and numerous crops in several categories were submitted for consideration as possible alternatives. The categories of crops under consideration were vegetables, herbs, fruits, cereals and legumes, and industrial crops and grasses. Allowing for climate and market considerations, a potential optimal crop was chosen from each category.

Of the vegetables under consideration, bulb onions (*Allium cepa)* and leaf lettuce (*Lactuca sativa*) were chosen as the optimal alternatives. Bulb onions are a proven producer in the area, currently being grown on six percent of the acreage in Mason Valley. They utilize drip irrigation, using one acre foot less water than alfalfa per acre. Possible impediments to onion production are the necessary investment in costly specialized equipment, and the large amount of herbicides, insecticides, fumigants, and hand labor needed to bring the crop to harvest.

Leaf lettuce is currently grown on a small scale in the basin, but has been shown to be successful on a large scale in other arid environments (Meister 2004). It requires only one acre foot of water to be harvested as baby greens when grown using drip irrigation and commands premium prices. It requires a large amount of labor and investment in some of the same equipment used for onions; it could prove to be a good choice for rotation with onions, allocating costs over both crops.

Of the herbs under consideration, none were chosen, as the growing conditions in northern Nevada were not conducive to any of the crops researched due to either temperature or water use limitations.

Fruit crops that fell within the threshold limits for irrigation needs also required a large establishment investment and were susceptible to numerous changes in conditions, making them a bad risk as an alternative to alfalfa. Wine grapes (*Vitis interspecific*) however, increase in quality with decreased irrigation, using less than one-half acre foot per year per acre. Wine grapes have been grown on small scale trial plots by area producers since 1990, and the first commercial wine in Nevada was a Chardonnay produced in 2001 (Halbardier 2006). Tahoe Ridge Winery has planted over 20,000 vines to research thirty-seven cultivars since 1990, and the University of Nevada, Reno has been testing twelve trial varieties in its experimental vineyard on Valley Road in Reno since 1995 (Cramer 2008; Halbardier 2006). Preliminary investigations into the economic comparison between alfalfa and wine grapes show substantial improvements in returns from grapes (Henry 2005).

In the cereal and legumes category, teff (*Eragrostis tef*) is one of the optimal choices for numerous reasons, one of which is its ability to provide both a source of grain for human consumption, or as a pasture, hay, or silage crop (Extension 2007). A drawback of this crop is its less than optimal water use for seed production, using three acre feet. Although teff is fairly new to the United States, it has been cultivated in other parts of the world since 3359 BC (Stallknecht, Gilbertson, and Eckhoff 1993). It can be grown under a wide range of soil and moisture conditions and can produce a crop in a very short amount of time. Teff grain is most commonly made into flour, but can be added as a thickener to soups, stews, and gravies, added to various types of baked goods, made into porridge, or used to make home-brew (Stallknecht 1998). Teff is virtually gluten-free; this quality makes it highly desirable for those with wheat allergies and increases its marketability. It has a high protein content and a high calcium content along with high levels of other trace minerals (Stallknecht, Gilbertson, and Eckhoff 1993). Teff can be ready for harvest as soon as fifty days after planting (Extension 2007). Because it is able to be grown in such a short amount of time, it can act as a high quality emergency hay crop. Few disease or pest problems are associated with teff and it can be planted and harvested with conventional forage equipment, eliminating the costs of new equipment investment. Teff can be stored for a minimum of three years and up to five years with no loss of viability (Stallknecht, Gilbertson, and Eckhoff 1993) and has been modeled for its production potential (Yizengaw and Verheye 1994).

Two row malt barley appears to be another good choice in the cereal and legumes category. It is easily grown using the same equipment as other grain crops and most of northern Nevada is suitable for its production; malting barley has been produced in Nevada in the past (Davison, Schultz, and Widaman 2001). It uses half of the water that alfalfa does, needing only two acre feet. Two row malting barley is grown for making malt, a main ingredient in beer production. This crop has increased demand and decreasing supply, making it a profitable prospect. From 1990 to 2003, the number of microbreweries in the United States increased by seven times and this trend is continuing, ensuring demand for malt barley as an input (Taylor, Boland, and Brester 2003). Many former barley producers switched to corn when prices increased for that crop and maltsters are currently facing shortages, increasing prices (Hildebrant 2008). Two row is the preferred variety because of its higher extract (Schwarz and Horsley 1997). The downside of this crop is that there are high standards that it must meet, or be sold as feed barley which commands significantly lower prices. In addition, contracts should be negotiated with a brewery prior to establishment.

Great Basin wildrye (*Leymus cinereus*) is a native perennial grass that was once abundant in the region. It has been grown for seed production using only one acre foot of irrigation. The Aberdeen Plant Materials Center, Natural Resource Conservation Service branch of the USDA lists the 'Magnar' variety of Great Basin wildrye as one of its "plants for solving resource problems" because of its ability to be used for rangeland and forage, erosion control, mine reclamation, and critical area stabilization, as well as its lack of problems with disease and insect pests (Center 2006). Additionally, wildrye enhances wildlife habitat and acts as a competitor to invasive weeds, making it highly desirable as a major component in revegetation planting (Perryman 2006). This myriad of uses gives wildrye potential economic benefits with regard to seed production. When Great Basin wildrye was being grown in test plots in the area under study through the University system, it grew well and showed promise as a revegetation and forage alternative (Perryman 2008).

Switchgrass (*Panicum virgatum*) is under consideration as a forage and biofuel source. It is an American native that was once widespread (Wolf and Fiske 1995) in its native region east of the Rocky Mountains where precipitation is more abundant; here in the arid west it requires three acre feet of irrigation to reach its full potential. It is a very tall growing warm-season perennial grass that produces large biomass yields. Although it was not a well-known species, our growing desire for energy independence has brought it to the forefront of ongoing research. Research into its potential as biomass for ethanol production has been ongoing since approximately 2001 (Fransen, Collins, and Boydston 2006); economic studies have also been undertaken on the costs to produce the crop at a commercial level (Duffy and Nanhou 2002). Its economic potential has also been investigated with regard to greenhouse gas emission mitigation (Schneider and McCarl 2003). It was widely introduced to the public when President George W. Bush mentioned it in his 2006 state of the union address as a source of bio-based fuel for transportation (Bush 2006). Switchgrass has been modeled to verify mean yields at sites in the southern United States (Kiniry et al. 2005), and its potential production has been modeled under both current and greenhouse-altered climatic conditions (Brown et al. 2000). In 1993, five varieties were planted in test plots at the Newlands Research Center in Fallon, Nevada; all appear to be well adapted for the climate and soils in the area (Davison 1999).

Cropping Practices

Changing cropping systems or water usage on agricultural fields can potentially have adverse effects on yields, soil productivity, or environmental quality; practices therefore, are an important consideration when evaluating suggested changes in production. Soil quality is a large determinant of yield; should soil modification to improve soil structure and root growth be a consideration? While soil modification increases yields on small plots, studies of large plots have found that it does not improve yields of irrigated forages and is not feasible on a commercial scale (Greenwood et al. 2006). Increasing the amount of nitrogen in the soil does result in increased crop vigor, but also increases total water use with a slight increase in water efficiency due to decreased evaporation (Norton and Wachsmann 2006); this trade-off needs to be considered when determining amounts of applied nutrients.

One practice which is beneficial with regard to environmental considerations and in optimizing water use is no-till cropping. In sandy loam soils, which are prevalent in the study area, no-till cropping was found to increase soil carbon storage and soil aggregation (Grandy et al. 2006). Carbon storage has become an important issue with the advent of global warming; tilling soil releases carbon into the air and reduced tillage, also known as conservation tillage, has been estimated by the USDA to increase carbon storage by eight million metric tons a year in the United States (Comis, Becker, and Stelljes 2001). Soil aggregation, or clumping of particles of different sizes, allows for pores to form between the particles which results in the ability of well aggregated soil to store air, water, nutrients, microbes, and organic matter and makes these soils less vulnerable to erosion (Australia 2004). No-till practices have been found to considerably increase the amount and diversity of soil macroinvertebrates, decrease run-off and nitrogen loss, and increase soil moisture due to greater water infiltration (Gregory, Shea, and Bakko 2005). Conservation tillage has been found to greatly enhance water conservation, especially in semi-arid regions (Unger et al. 1991). Because no-till practices are an optimal choice with no apparent disadvantages, we have incorporated them for all crops under consideration.

DATA AND METHODS

Model Choice

In reviewing the literature to ascertain which model would best suit our purpose of determining crop yields under reduced irrigation, one model repeatedly appeared in the literature: the Environmental Policy Integrated Climate model commonly referred to as the EPIC model. The EPIC model, which was previously known as the Erosion Productivity Impact Calculator, was first developed in 1981 by researchers at the USDA as a response to the need for assessment of productivity of U.S. soils with regard to the impacts of erosion (Gassman 2005). The first major application of the model was undertaken in 1985, when it was used to evaluate one hundred and thirty five regions across the nation in an appraisal for the Resources Conservation Act (Gassman 2005). Since its inception, numerous functional additions have been made to the model including water quality, atmospheric CO_2 change, and enhanced carbon cycling routines; these additions prompted the changing of the model name to its current one while keeping the acronym intact (Gassman 2005).

Over the last twenty seven years this model has been used for numerous applications world-wide. It has been used to model crop production in arid regions of Brazil (de Barros, Williams, and Gaiser 2005); determine impacts of adopting alternative practices such as organic or sustainable farming (Archer 2006; Wicks, Howitt, and Klonsky 2006); compare yields under reduced irrigation from Georgia to France (Guerra et al. 2005; Cabelguenne, Jones, and Williams 1995) both for production of known crops such as alfalfa (Tayfur et al. 1995), and alternative crops including switchgrass (Brown et al. 2000). "This model improves water management and leads to substantial reduction of water consumed"(Bontemps, abstract, 1999).

The Blackland Research and Extension Center of the Texas Agricultural Experiment Station further developed the EPIC model and created a user friendly platform called WinEPIC for its widespread application; WinEPIC is a Windows® EPIC interface. It was designed as a comprehensive simulation model for researchers that would analyze the effects of production practices and differing cropping systems on yields, the quality of the soil, water quality, erosion from wind and water, and profits; it was developed with a focus on research applications with the ability to make multiple comparison runs (Gerik et al. 2006; Center 2006) . It has been used for varied applications: to reduce environmental damage in developing countries (Gandonou et al. 2004); by the U.S. Agricultural Resource Service to study the impacts of manure bans on nutrient losses (Torbert III 2005); for modeling wheat and corn rotation effects in China (Wang , Li, and Fan 2008); and for economic evaluations of integrated cropping systems (Martin 2005). EPIC and WinEPIC have consistently proven their abilities to be able to provide accurate projections with regard to water use and crop yields after being calibrated to regional specific weather and soils data, making WinEPIC an optimal model choice for conducting this study.

SIMETAR is a risk analysis management modeling program developed by James W. Richardson at Texas A&M in 1999 in their Ag & Food Policy Center. It became commercialized in 2005 by SIMETAR, Inc. under a licensing agreement with Texas A&M University (Richardson, 2006). It is used for risk based policy analysis at both the farm and sector levels and runs as an add-in to Excel (Richardson 2002). It uses a Monte Carlo simulation analysis to make spreadsheet models stochastic and is one of the programs developed for this purpose; others include @Risk and Crystal Ball (Richardson, 2007). Using SIMETAR in conjunction with WinEPIC allows decision makers to select possible alternative crops based on a distribution of returns rather than on a point estimate, incorporating risk into economic feasibility.

Nevada Database

The first step in utilizing the WinEPIC model was to create a database specific to Nevada. This involved importing Nevada weather stations and soils; data were imported for forty-eight Nevada weather stations and included minimum and maximum daily air temperature, the monthly average standard deviations of those temperatures, the amount of daily precipitation, number of days with precipitation, the monthly standard deviation and skew coefficient for daily precipitation, the monthly probability of a wet day after a dry day, the monthly probability of a wet day after a wet day, the relative humidity or dew point, and the amount of solar radiation as measured in Langleys. Soil data was imported from the United States Department of Agriculture Natural Resource Conservation Services (NCRS) Soil Data Mart under Soil Survey Geographic (SSURGO) Data formatting for all counties in Nevada.

Areas of Focus

The two largest irrigated agricultural areas downstream on the Walker River are the Smith and Mason Valleys. Smith Valley has 20,400 acres in production and the Mason Valley has 38,159 irrigated acres. This study focuses on these two areas, as reducing the water use there would have the largest possible impact on raising lake levels. The weather station used for the Smith Valley simulations was Smith 6N (267612) located at an altitude of 5000 feet (38°57'N, -199°20'W); the complete weather data mentioned above has been available for this station since 1973. Yerington (269229) located at an altitude of 4378 feet, (39°00'N, -119°09'W) was used for the Mason Valley simulations. Complete weather data has been available for this weather station since 1960. Using the NCRS Web Soil Survey to map specific areas of interest of both valleys that were in agricultural production enabled the determination of the most common soils by percentage. Three representative soil types, Dithod, Eastfork, and Sagouspe, were chosen with increasing percentages of sand content. Dithod has a soil composition of 36.6% sand, 38.9% silt, and 24.5% clay in the first five feet of soil; Eastfork is 51.5% sand, 19.9% silt, and 28.6% clay; Sagouspe is 77.8% sand, 18.8% silt, and only 3.4% clay.

WinEPIC Model Setup

Many of the alternative crops of interest were not in the WinEPIC database so other crops were used as a template for these missing crops and the parameters were adjusted based upon the recommendations of the staff agronomist at the Blackland Research Center (Blackland 2007). Teff was created from spring wheat, spring onions from winter onions, and Great Basin wildrye from western wheatgrass by altering price, seed cost, plant population, seeding rate, biomass energy ratio, leaf area index decline factor, lower limit of harvest index, maximum leaf area index, minimum temperature for plant growth, optimal temperature for plant growth, and yield decrease by salinity increase parameters in the WinEPIC crop data screen under data/setup.

The next inputs necessary to the WinEPIC model were agronomic data with regards to production practices, and economic data such as equipment prices to create budgets for each individual crop under consideration. The most efficient way to assemble this data was to create enterprise budgets. Producer panels were conducted to gather information on practices and costs for those crops that were already under production in the focus areas or in the region. For those crops not currently grown by commercial enterprises, results from university experiment station test plots and/or information from enterprise budgets from similar semi-arid areas were used. This information was amassed into enterprise budgets which were reviewed by the producers or other knowledgeable individuals for completeness and accuracy before being inputted to crop budgets in the WinEPIC model.

The irrigation type selected for each crop varied and was chosen based on common production practices (Curtis et al. various 2008). Alfalfa, teff, Great Basin wildrye and switchgrass budgets were chosen to use flood irrigation. Onions and leaf lettuce budgets use a combination of sub-surface or buried drip irrigation and set spot sprinklers. Set spot sprinklers are used for germination of crops and used as primary irrigation until plant roots are sufficiently long to reach the buried drip tape; as the crop grows they are used to apply chemicals and liquid fertilizers. Wine grapes use solely surface and sub-surface drip irrigation. Two-row malt barley was chosen to use center pivot irrigation with Low Energy Precision Application, as some producers in the region utilize center pivots to grow alfalfa and it was desirable to be able to offer them an alternative with the same irrigation system. All irrigation types with the exceptions of center pivot for two row malt barley and drip irrigation for wine grapes use surface water as their irrigation source. Irrigation amounts followed producer and research recommendations (Curtis et al. various 2008). Alfalfa was given 48” of irrigation, onions, teff and switchgrass were irrigated with 36”, however 8” of the water allotted to onions was for its cover crop of winter wheat; the actual irrigation applied to onions was 28”. Two-row malt barley received 24” of irrigation, Great Basin wildrye and leaf lettuce were irrigated with 12” of water, and wine grapes were simulated with only 4” of irrigation.

Alfalfa was run with six years of alfalfa production followed by a year of winter wheat production which is a common practice in the region; returns from winter wheat were not included in this analysis. Onions, which are an annual crop, were intercropped with winter wheat which was later sprayed out. Teff, another annual, was double-cropped with winter wheat as teff has a growing season of only three months. As with alfalfa, returns from winter wheat were not included in this analysis, however, as this analysis was conducted with growing teff for seed production, returns from the chaff produced as a function of seed production were included in returns. Great Basin wildrye was grown on a seven year rotation with harvesting occurring during six years of the rotation. Switchgrass is grown on an eleven year rotation; the first year consists of land preparation, the second year is an establishment year, and the switchgrass is harvested during the next nine years. Two-row malt barley and lettuce are both annuals that could be grown with winter cover crops, but that practice was not considered in this study. Wine grape vineyards of interspecific grapes have an expected production cycle of thirty-five years; no harvest occurs in the first two years with a small harvest in the third year continuing to build to maximum production at approximately ten years.

WinEPIC Validation and Simulation

The WinEPIC model was validated using known yields from Churchill County and 40 years of actual weather data from the weather station in Fallon to verify the efficacy of the model. The model correctly predicted known alfalfa yields for Churchill County. National Agricultural Statistics Service (NASS) records show that alfalfa yields in Lyon County are consistent with those in Churchill County which was used as the baseline for yield validation. Planting dates and amounts, irrigation regimes, amount and timing of fertilizer applications, and other budget inputs were altered to produce verifiable yields under simulation for all crops using actual weather conditions. Prior to simulation, all crops were put through a 'pre-run' of twelve years beginning in 1960 to set up the soil properties, allowing them to be adjusted by the local climate and cropping practices. Pre-run also considers the number of years that the location has been in cultivation, which affects soil parameters.

Runs for all crops were made in both Smith and Yerington, in Lyon County, with good infiltration land conditions, with all three soil types, and with the appropriate weather station. The control record chosen for each crop was set for 100 years of simulation; starting the simulations in 1973 maximized known data, enabling the use of 34 years actual weather and 66 years of predicted weather for each crop. The combination of three soils and two locations resulted in six runs per batch for each crop. Batches were varied by irrigation amounts from 48" to 0" in intervals of 2", resulting in twenty-five batches of six runs each per crop for a total of 1200 runs under consideration by this study.

Analysis

The 100 year average yield output data from each irrigation level in WinEPIC was combined with economic data from the correlated enterprise budget for each crop to create graph data on break-even yields with all soil types (Curtis, various 2008). Tabular data on break-even prices for average yields under alternative watering strategies by location, a comparison of current returns for all crops under optimal watering strategies, and a comparison of investment costs for the proposed alternative crops.

To forecast future returns and incorporate risk into the formulation, SIMETAR was used to calculate the variation in yield using output from WinEPIC (marketable yield adjusted), in addition to forecasting prices and variation in prices. Yields from all crops were simulated using Dithod soil and Yerington as the location for each crop using a WinEPIC run of 100 years. Yields were checked for normality of distribution and the appropriate distribution was used to generate stochastic yield variables. Dithod soil was chosen due to its prevalence in Mason Valley/Yerington area. Yerington was chosen as it has more area dedicated to agricultural production in the Walker River Basin. Similar analysis could be conducted over other soils and for Smith Valley, but would likely be trivial to the discussion.

In SIMETAR's terminology, a stochastic input in a Monte Carlo simulation has two component parts: the deterministic component which is that part of a variable that can be forecast with certainty such as the mean ($\hat{z}$ in Equation 1), and the stochastic component, which cannot be forecast with certainty ($\tilde{a}$ in Equation 1) (Richardson 2006; Richardson 2007). The stochastic component cannot be explained by the data and is the source of the risk; it is forecast by simulating values from a probability distribution (Richardson 2007).

$$\tilde{z} = \hat{z} + \tilde{a} \qquad (1)$$

After separating and quantifying these components, also known as whitening the data, stochastic residuals were created and added to mean yields to create stochastic yield variables (Equation 2).

$$\tilde{y} = \bar{y} + \tilde{e} \qquad (2)$$

Stochastic residuals were created by finding the mean of y, computing the deviation from the mean, or residuals, finding the mean of the residuals and the standard deviation of the residuals, and creating a uniform standard deviation (Equation 3). This function generates a random number between 0 and 1.

$$usd = uniform() \qquad (3)$$

Yields and their residuals as determined by the data, following either a normal or beta distribution. For alfalfa, onions, teff, two-row malt barley, and leaf lettuce, whose residuals followed a normal distribution, Equation 4 was used to create the stochastic residuals.

$$\tilde{e} = norm(mean, stdev, usd) \qquad (4)$$

For Great Basin wildrye, switchgrass, and wine grapes, whose residuals followed a beta distribution, Equation 5 was used to create the stochastic residuals.

$$\tilde{e} = betainv(usd, \alpha, \beta, \min, \max) \qquad (5)$$

Alpha and Beta parameters for the beta distributions were as follows: Great Basin wildrye (1.478, 2.261), switchgrass (1.401, 2.072), and wine grapes (2.198, 0.774). Adding the stochastic residuals to the mean yields allowed the generation of random yields (Equation 2).

Historical pricing data was only available for alfalfa, onions and leaf lettuce. With more than minimal data lacking for a majority of crops under consideration, it was determined to forecast returns no further than 2009 to reduce the amount of error. The approach to calculating stochastic pricing for individual crops was determined by the amount of information available. For those crops with minimal pricing data available, a triangular distribution was used. This distribution uses the minimum, mid-point, and maximum known values as the boundaries for the assumed values (Equation 6).

$$\tilde{p} = triangle(\min, mid, \max, usd) \qquad (6)$$

For those crops with at least ten years of historical pricing, ordinary least squares (OLS) regressions were run to estimate the deterministic portion of price. Some crops in this category fit a trend model. Twenty or more observations are required to prove conclusively that a distribution is normally distributed or to estimate the parameters of a distribution with a high degree of certainty (Richardson 2006). A non-parametric empirical distribution, where the shape of the distribution is defined by the data was used to create the stochastic residuals for those crops by estimating the empirical distribution and generating a random residual using actual data (Equation 7).

$$\tilde{e} = empirical(Si, F(Si), usd) \quad (7)$$

Si represents the sorted data, and *F (Si)* is the probability of that sorted data.

The stochastic residuals were added to the appropriate regression to create stochastic prices based upon the pricing data (*T*) (Equation 8).

$$\tilde{p} = b_0 + b_1T + \tilde{e} \quad (8)$$

Multiplying stochastic yields by stochastic prices resulted in stochastic total returns for all crops (Equation 9).

$$\tilde{y} * \tilde{p} = t\tilde{r} \quad (9)$$

After total returns were calculated, costs were subtracted to determine stochastic net returns which were then simulated for 1000 iterations (standard number) in SIMETAR (Equation 10).

$$t\tilde{r} - c = n\tilde{r} \quad (10)$$

In order to simulate through 2009, costs were calculated by multiplying current costs from enterprise budgets by 1.066, the index of increase in farm production costs between 2007 and 2009 forecast by NASS (USDA-NASS 2007a). The results for net returns were compared using a combined cumulative distribution function graph, a stoplight chart that determines the probability of a favorable, cautious, or unfavorable outcome under lower and upper cutoff values, by analyzing stochastic dominance with respect to a function at different risk aversion levels: a decision maker with risk neutrality, and of a somewhat risk adverse decision maker, and by comparing stochastic efficiencies using a negative exponential utility weighted risk premium relative to alfalfa.

RESULTS OVERVIEW

Yield Analysis

<u>Alfalfa</u>

At 48” of irrigation, alfalfa yields in the Mason Valley with an average yield of 6.66 tons per acre were much higher than those in the Smith Valley, where the average yield was only 4.81 tons per acre; at both locations, alfalfa planted to dithod soil performed slightly better than alfalfa planted on other soils (Figure 1).

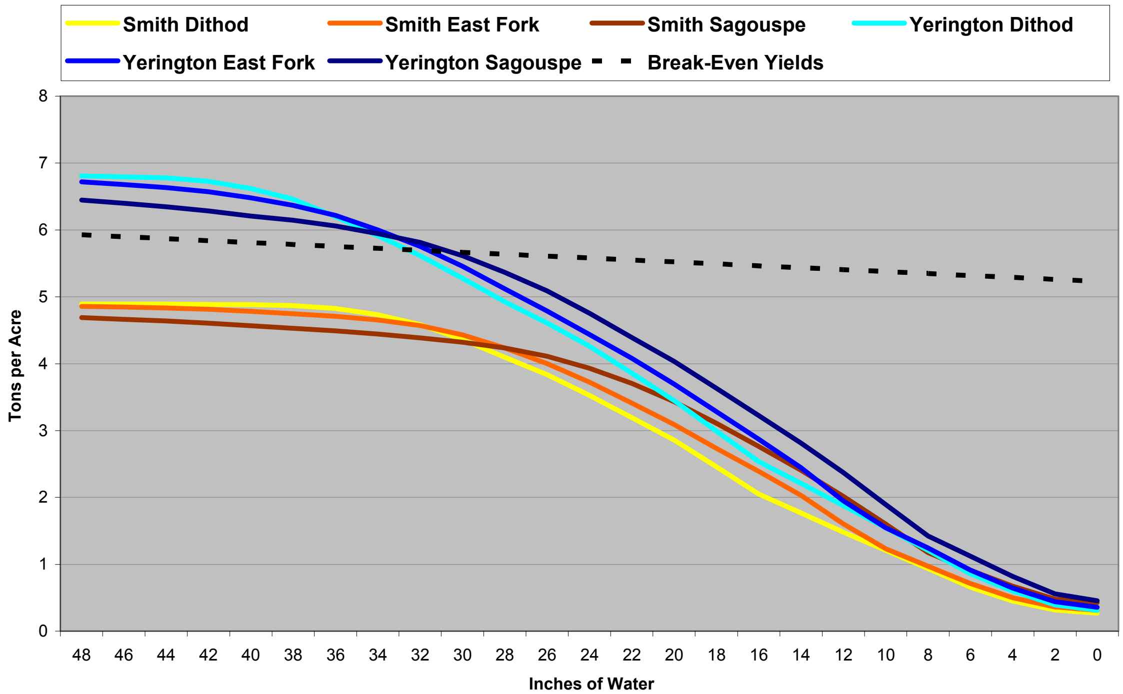

Figure 1. Alfalfa yields for all soil types and both locations under all irrigation regimes.

At $144.00 per ton, break-even yield was calculated at 5.93 tons/acre. Break even prices varied drastically between locations, producers in Smith need a per ton price of $177.34 to recoup expenses; producers in Yerington have a break-even price of $128.19 (Table 1).

Net returns were consistently negative in Smith at all irrigation levels; returns did not become consistently negative at Yerington until irrigation levels were below 30 inches, substantially reducing yields. At 48" of irrigation, Sagouspe soil was the least favorable with net returns of only $74.82, which increased to $114.03 for Eastfork and $126.86 per acre for alfalfa on Dithod soil in Yerington. The large difference in alfalfa yields between locations is most likely caused by the difference in elevation; the elevation at Smith is 5000', the elevation in Yerington is 4378'.

Table 1 Break-even prices for alternate watering strategies by location.*

Crop	Location		60%	80%	100%	120%	140%
			Percent of Typical Watering Strategy				
Alfalfa		Inches	28	38	48		
	Smith		$193.88	$176.58	$177.34		
	Yerington		$158.01	$131.65	$128.19		
Onions		Inches	16	22	28	34	40
	Smith		$457.94	$346.53	$319.74	$343.13	$444.78
	Yerington		$382.17	$289.24	$266.82	$286.35	$371.17
Lettuce		Inches	8	10	12	14	16
	Smith		$709.55	$596.88	$563.69	$558.91	$565.53
	Yerington		$688.27	$578.11	$549.12	$545.68	$550.91
Grapes		Inches	2		4		6
	Smith		$917.22		$572.47		$610.56
	Yerington		$945.76		$568.65		$593.60
Teff		Inches	22	28	36	42	48
	Smith		$632.74	$598.64	$571.37	$585.24	$593.96
	Yerington		$581.55	$551.69	$530.37	$549.24	$554.05
Barley		Inches	14	20	24	28	34
	Smith		$370.70	$298.00	$296.32	$303.48	$314.92
	Yerington		$340.89	$280.21	$278.31	$277.65	$281.24
Wildrye		Inches	8	10	12	14	16*
	Smith		$4.99	$3.39	$2.57	$1.95	$1.84
	Yerington		$3.76	$2.69	$2.13	$1.64	$1.59
Switchgrass		Inches	22	28	36	42	48
	Smith		$189.53	$186.34	$188.90	$195.71	$205.17
	Yerington		$172.17	$170.50	$170.07	$173.33	$177.85

*Optimal break-even for Wildrye is at 22" of irrigation ($1.54, $1.41)
All prices are per ton except for Wildrye which is per pound and are averaged over all soils

Onions

At 28” of irrigation, there was no difference between yields by soil type at either location; onion yields in Smith Valley were 31.56 tons/acre and yields in Yerington in the Mason Valley were 37.81 tons/acre (Figure 2).

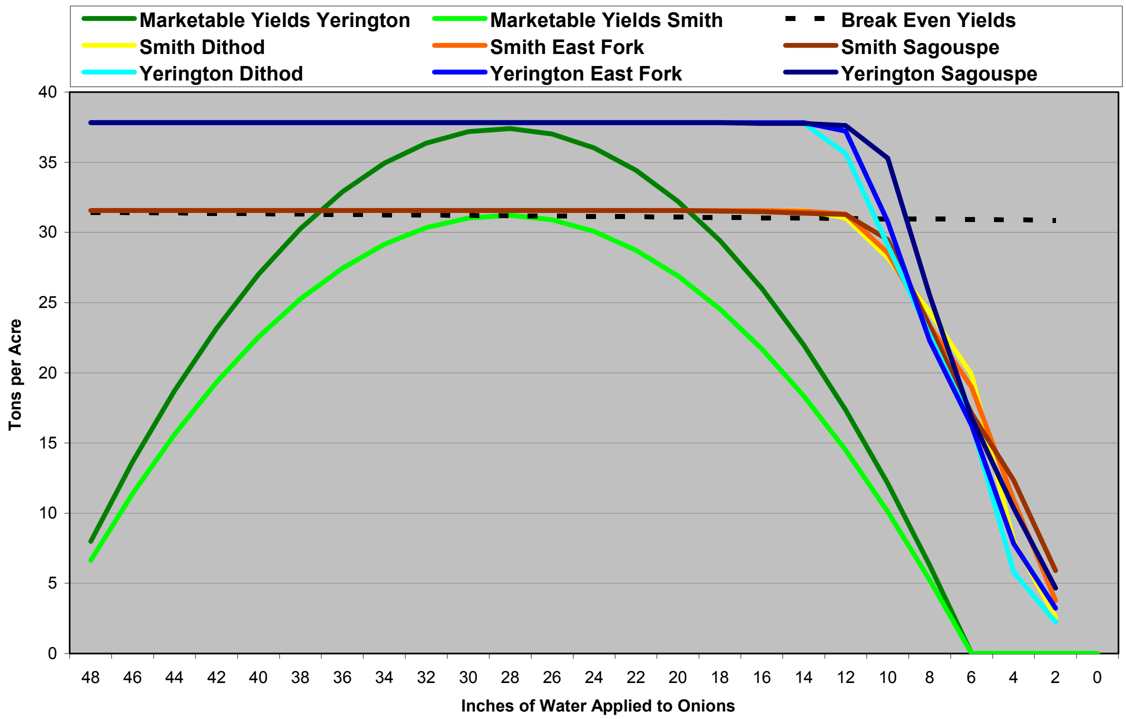

Figure 2. Onion yields for all soil types and both locations under all irrigation regimes.

Break-even yield was 31.18 tons/acre for pricing of $320.00 per ton. Break-even pricing was $52.92 higher in Smith at $319.74 compared with Yerington’s break-even price of $266.82 (Table 1). At this irrigation level, there was a difference between locations of close to $1980.00 in net returns; Smith’s net returns were $8.25 while Yerington had net returns of $1989.05 (Table 2).

Onion yields flat lined in the WinEPIC model between 48 and 12 inches of irrigation, which could erroneously cause the belief that water use could be increased or decreased with no impact on returns. However, because of quality issues, the window of marketable yields is much smaller and peaks at 28” of irrigation. This difference between actual and marketable yields for onions has been studied and documented (Henderson 2003). When irrigation is increased, the amount of onions that result in splits or doubles increases dramatically. Splits or doubles occur when a single bulb becomes two bulbs that are joined at the sides; producers purposely select varieties that grow the largest with the least amount of splits or doubles because they are unmarketable as fresh onions. The larger the onion, the higher price per pound: decreasing the amount of irrigation results in yields of numerous smaller onions with the same weight as a few large onions (20 small as compared with 5 jumbo) which reduces available returns.

Onions should not be grown on the same plot for more than two years, forcing producers to plant less profitable rotational crops. Onions appear to be the leader with regard to returns in Yerington and are slightly profitable in Smith, but have extremely high investment costs (Table 3).

Table 2. Comparison of net returns for all crops under optimal watering strategies with regard to yields.

	Alfalfa		Onions		Lettuce		Grapes	
	$144/ton		$320/ton		$700/ton		$825/ton	
Location & Soil Type	**Returns**	**Inches**	**Returns**	**Inches**	**Returns**	**Inches**	**Returns**	**Inches**
Smith Dithod	-$131.76	38	$8.25	28	$1,733.98	14	$739.22	4
Smith East Fork	-$147.93	42	$8.25	28	$1,733.98	14	$1,033.58	4
Smith Sagouspe	-$177.05	44	$8.25	28	$1,733.98	14	$1,843.07	4
Yerington Dithod	$130.92	44	$1,989.05	28	$1,942.53	14	$886.40	4
Yerington East Fork	$114.03	48	$1,989.05	28	$1,942.53	14	$1,143.97	4
Yerington Sagouspe	$74.82	48	$1,989.05	28	$1,942.53	14	$1,879.87	4

	Teff		Barley		Wildrye		Switchgrass	
	$760/ton		$360/ton		$2.50/pound		$66/ton	
Location & Soil Type	**Returns**	**Inches**	**Returns**	**Inches**	**Returns**	**Inches**	**Returns**	**Inches**
Smith Dithod	$179.59	34	$256.58	32	$561.66	24	-$506.09	22
Smith East Fork	$202.78	34	$253.87	22	$636.07	22	-$512.45	26
Smith Sagouspe	$192.79	36	$135.70	22	$433.67	18	-$521.38	20
Yerington Dithod	$231.81	36	$374.75	32	$659.49	22	-$469.62	20
Yerington East Fork	$254.62	36	$323.05	32	$799.98	22	-$482.27	18
Yerington Sagouspe	$270.07	36	$218.79	22	$527.33	18	-$497.43	18

Table 3. Investment costs for all crops on differing acreage.

Crop	**Alfalfa**	**Onions**	**Lettuce**	**Grapes**
Acreage	400	400	400	5
Capital Investment*	$818,041.00	$5,347,469.50	$2,876,196.00	$88,390.80
Principal & Interest Annual Payments**	$65,922.98	$430,933.33	$231,782.29	$7,123.10

Crop	**Teff**	**Barley**	**Wildrye**	**Switchgrass**
Acreage	60	240	200	200
Capital Investment*	$190,004.00	$905,870.00	$339,989.00	$204,476.00
Principal & Interest Annual Payments**	$15,311.74	$73,000.81	$27,398.49	$16,477.99

*excluding housing and land
**30 years, 7% interest

A 400 acre farm planted to onions would require a capital investment of over $5,000,000, yet that same 400 acre farm planted with alfalfa would require slightly over $800,000 in capital input. In addition to the large amount of equipment required to grow and process onions, a large labor force is needed from land preparation through shipping, requiring the associated bookkeeping and management skills and time.

Teff

At 36” of irrigation, production of teff seed in Smith averaged 1.01 tons/acre; Yerington results were similar, with an average of 1.09 tons/acre (Figure 3).

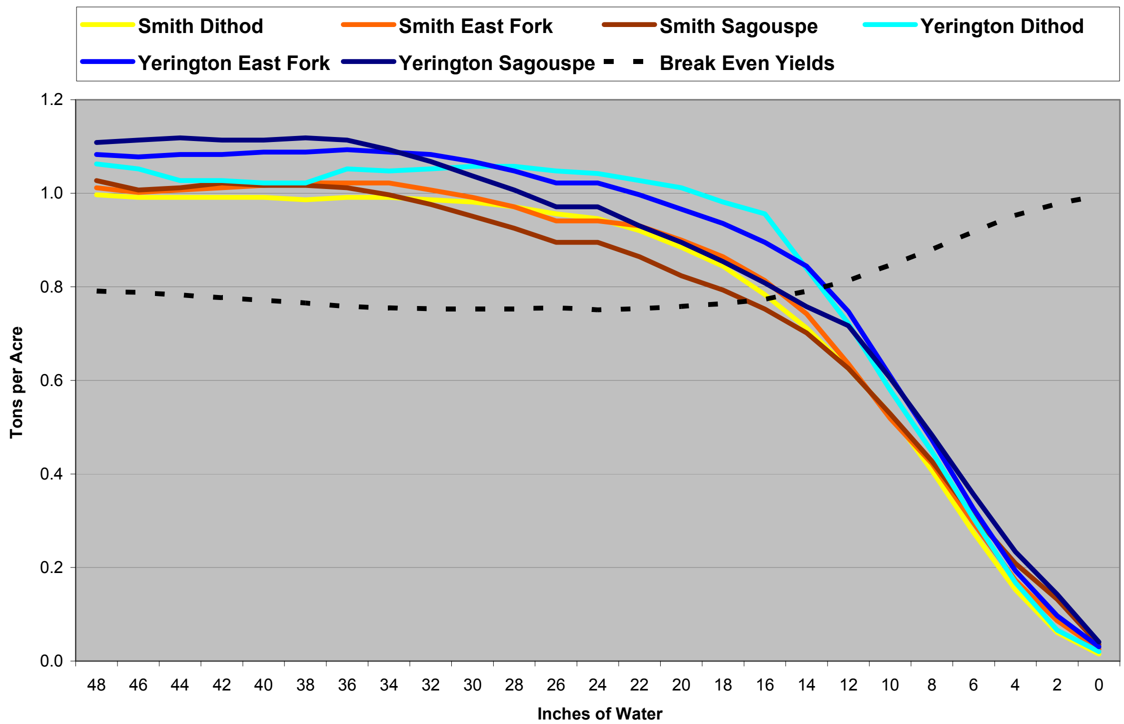

Figure 3. Teff seed yields for all soil types and both locations under all irrigation regimes.

When producers received $760.00 per ton for seed, 0.76 tons needed to be produced for a break-even yield. Break-even prices were similar in both locations, $571.37 in Smith and slightly lower in Yerington at $530.37 (Table 1). In Smith, the highest net returns were with Eastfork soil at $200.52 and in Yerington the soil type with the highest returns was Sagouspe, with returns of $270.07 per acre. Teff is a versatile crop that can be used for pasture, hay, or a silage crop in addition to seed production and can be used as an emergency forage crop because of its short growing season of three months from planting to harvest. It can meet the needs of a growing niche market for those who have celiac disease or are allergic to wheat because of its gluten-free qualities; the flour has high protein content and contains numerous other nutrients. There are two factors that offset the aforementioned benefits: the lion’s share of the market for teff seed is controlled by one buyer; additionally, at 36” of irrigation, the large amount of water teff consumes makes it less than desirable as an alternative crop for this study. Teff has lower capital investment costs than other crops under consideration because both planting and harvesting were contracted out at custom rates; the only equipment owned by the producer is a tractor, a pickup truck, and a four-wheeler (Table 3).

Great Basin wildrye

At 12" of irrigation, yields varied greatly between soils and locations. The lowest yield in Smith was on Dithod, 252.88 pounds/acre and the highest yielding soil was Sagouspe with yields of 393.37 pounds/acre. Yerington followed the same pattern with Dithod yielding the lowest poundage of 309.08 per acre; Sagouspe was again the preferred soil for wildrye with yields of 468.30 pounds/acre (Figure 4).

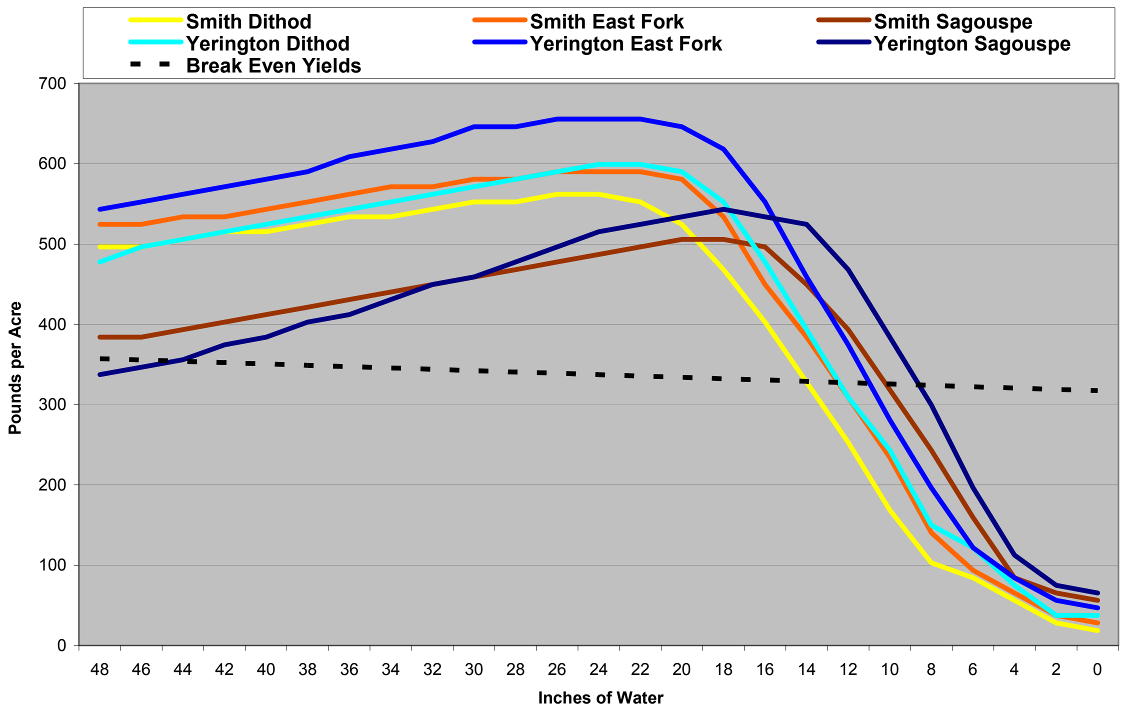

Figure 4. Great Basin wildrye seed yields for all soil types and both locations under all irrigation regimes.

At a price of $2.50 per pound for seed, break-even yield was 327.3 pounds of seed produced per acre. Prices and yields are reported in pounds and pounds/acre for this crop because that is the usual marketing practice. Break-even prices were $2.57 in Smith Valley and $2.13 in Mason Valley (Table 1). Net returns varied between a low of ($186.04) on Dithod soil in Smith to a high of $352.51 on Sagouspe soil in Yerington for the common irrigation strategy of applying one foot of water. The WinEPIC model predicts maximum production at higher levels of irrigation; returns are predicted to be as high as $799.98 per acre (Table 2).

Wildrye seed yield simulation by the WinEPIC model fell within parameters of 300-450 pounds per acre as reported by the literature for 12" of irrigation. Simulation with the model additionally showed overall maximum yields and maximum returns occurred at higher levels of irrigation from 18 to 26 inches depending on soil type (Figure 4, Table 2). A thorough review of the literature revealed no studies with Great Basin wildrye at any level of irrigation above 12". Brent L. Cornforth, the farm manager for the USDA Natural Resource Conservation Service Plant Materials Center at Aberdeen, Idaho, stated he believed "600 pounds per acre yields are possible" under certain conditions, but had no firsthand knowledge of anyone increasing irrigation levels beyond current standards. Further extensive production studies need to be conducted with this native crop to determine if larger yields are possible with additional irrigation because of its many uses: it is useful for winter grazing, provides habitat for numerous species of wildlife, and is a prime choice for reseeding after disturbances, useful for restoration following fire and for reclamation of mining lands. Great Basin wildrye has the lowest capital investment cost of any of the profitable crops, lower even than alfalfa's costs of $2045.10 per acre; wildrye requires a capital investment of only $1699.95 per acre (Table 3). If producers were able to grow Great Basin wildrye and benefit economically, it would also benefit ecosystems across Nevada.

Switchgrass

At 36" of irrigation, switchgrass yields averaged 4.33 and 4.81 tons/acre in Smith and Yerington respectively (Figure 5).

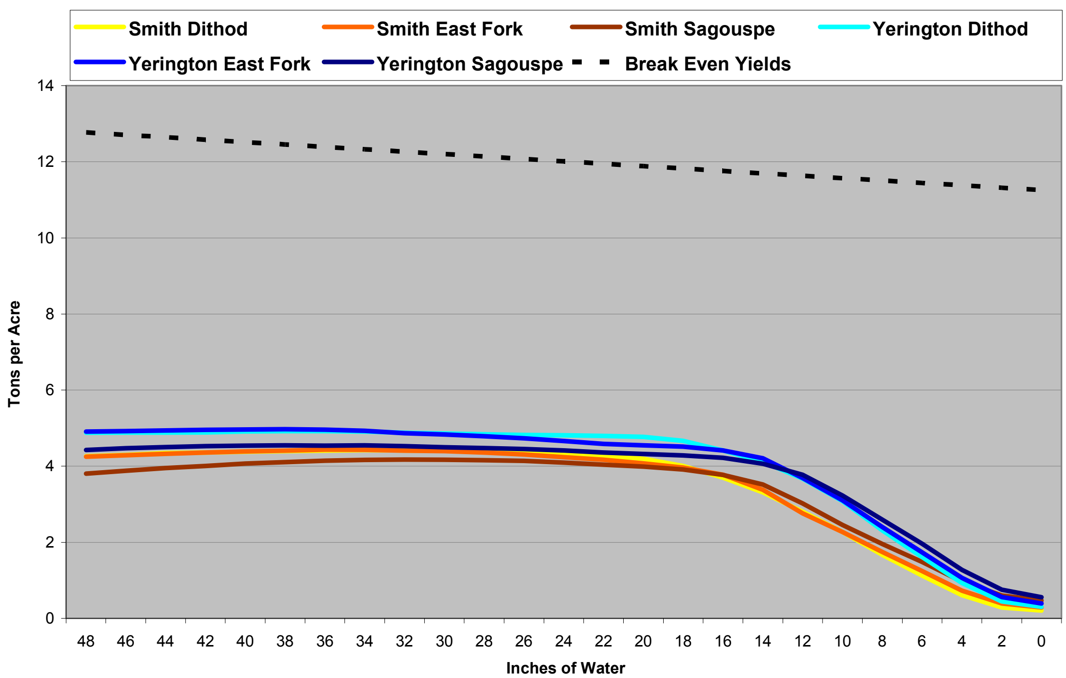

Figure 5. Switchgrass yields for all soil types and both locations under all irrigation regimes

Yields would have to be 12.39 tons/acre for producers to break even at pricing of $66.00 per ton. At current yields, prices would have to be $188.90 per ton in Smith and $170.07 in Yerington for producers to break-even (Table 1). Net returns were extremely negative on all soil types at both locations; the least amount of loss at Smith was on Dithod soil with net returns of ($506.09) with 22" of irrigation and at Yerington losses were minimized on Dithod soil with 20" of irrigation at returns of ($469.62).

Switchgrass came under consideration as an alternative crop because of the high demand for alternative fuel sources. Switchgrass contains a large amount of biomass and therefore would be used to produce cellulosic ethanol. This crop is a viable option in the eastern United States where it could be grown on marginal lands with no additional irrigation needed, using existing precipitation. Its high water requirements, current low pricing, and lack of processing facilities make it a poor choice for the prime agricultural land in the Walker Basin.

Two-row malt barley

At 24” of irrigation, malt barley yields on Dithod and Eastfork soils were almost identical in Smith at 3.37 and 3.36 tons/acre, dropping to 3.02 tons/acre on Sagouspe soil; results were similar in Yerington where malt barley yielded 3.58 and 3.55 tons/acre on Dithod and Eastfork soils and yields dropped to 3.25 tons/acre on Sagouspe soil (Figure 6).

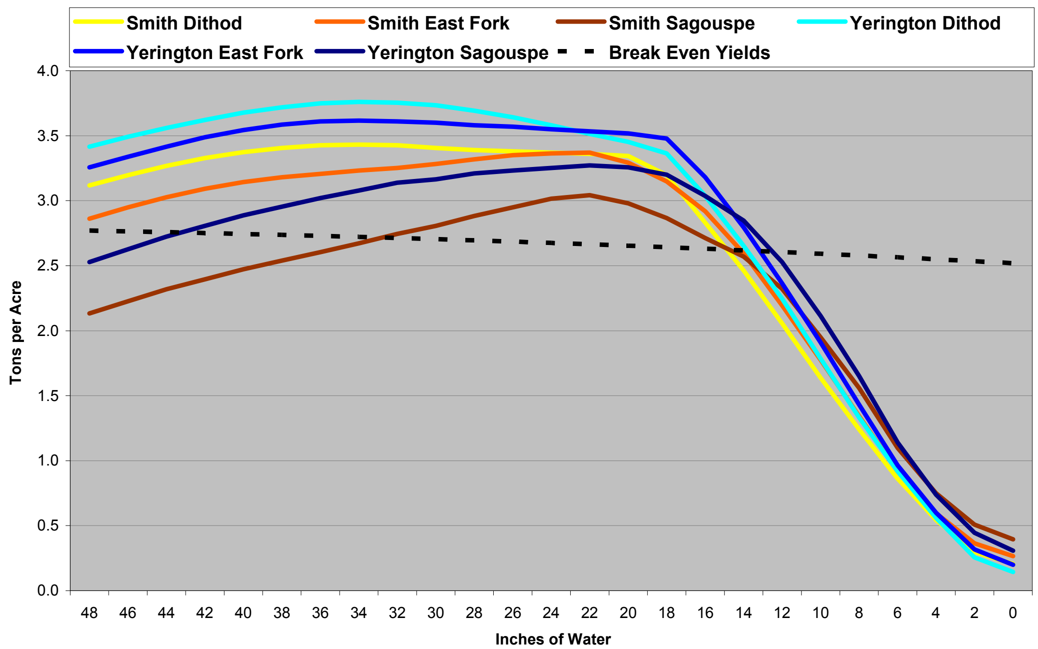

Figure 6. Two-row malt barley yields for all soil types and both locations under all irrigation regimes.

At $360.00 per ton, the break-even point for yield was 2.68 tons/acre. Break-even pricing averaged over yields from all soils was $296.32 in Smith and $278.31 in Yerington (Table 1). In both locations, net returns were highest on Dithod soil with returns of $250.04 for Smith and $325.75 for Yerington and lowest on Sagouspe soil with returns of $122.64 for Smith and $207.57 at Yerington. Two-row malt barley appears to have potential for yield and profit with the caveat that this crop should not be undertaken prior to contracting with a maltster. Brewers have very specific desires and requirements with regard to variety; strict standards exist for characteristics including protein, moisture, and foreign material levels, skinned and broken kernel limitations, sprout damage, and color and plumpness of kernel because of the effects of these characteristics on the brewing process. Malt barley was configured with center pivot irrigation to give an alternative to those producers who currently use center pivot irrigation; center pivot irrigation is also a good choice for those downstream users who do not receive the full amount of their allocated surface rights because of the systems' reliance on ground rather than surface water. If the costs of the center pivot systems are removed from the budget, making malt barley a flood irrigated crop, per acre capital investment drops to $2149.46, making it comparable with alfalfa's investment costs of $2045.10 per acre. Water-wise it is a good choice because it requires only half the irrigation used by alfalfa. With investigation into the availability of contracts, two-row malt barley could be a choice alternative crop.

<u>Leaf lettuce</u>

At 12" of irrigation, yields were extremely similar across soils and with regard to location; leaf lettuce yields averaged 12.17 tons/acre at Smith and 12.49 tons in the Mason Valley at Yerington (Figure 7).

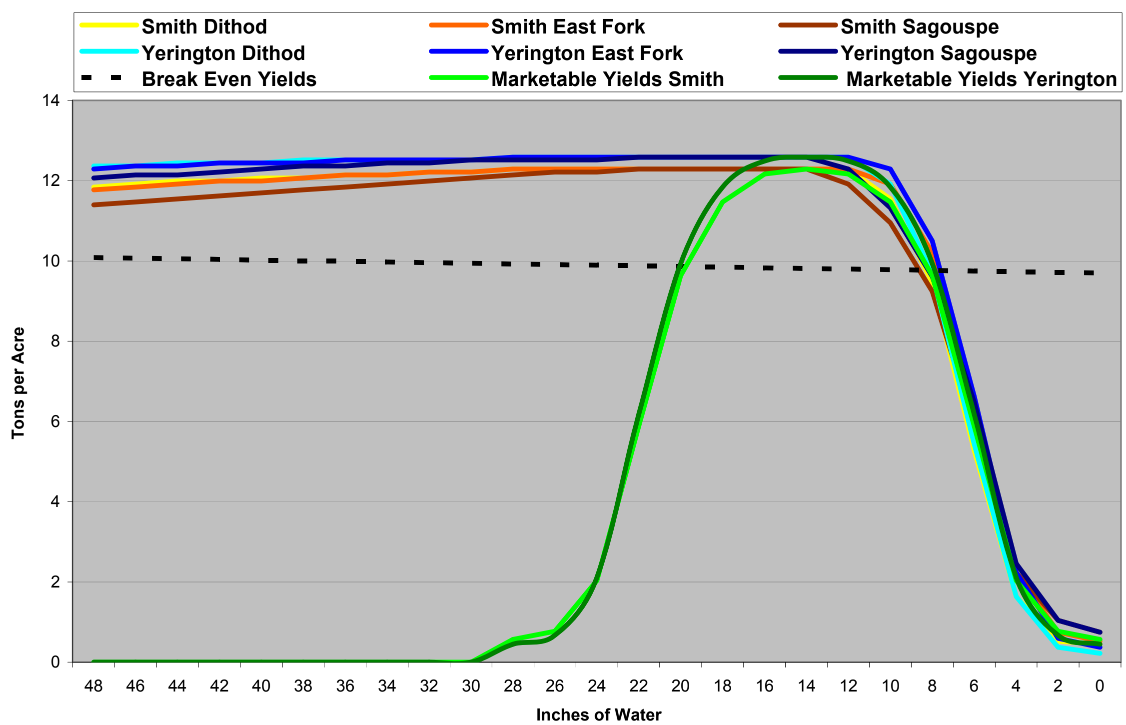

Figure 7. Leaf lettuce yields for all soil types and both locations under all irrigation regimes.

9.80 tons/acre of production is necessary to break-even with pricing of $700 per ton. Break-even prices at simulated production levels would be $563.69 in the Smith Valley and $549.12 in Yerington (Table 1). Net returns averaged over all soils were extremely high at both locations with producers in Smith receiving $1658.27 per acre and producers in Yerington netting $1884.19 per acre. Leaf lettuce commands high prices and uses minimal water. The literature suggests irrigation of 12" but this study found that leaf lettuce is at maximum production on all chosen soils in the Walker Basin with 14” of irrigation. WinEPIC predicts constant high yields at all irrigation above 12”, however marketable yields follow a bell shaped curve that crests at 14” of irrigation. Lettuce that receives too much water can become easily susceptible to fungal disease or rot at high levels of applied water; additionally, over-irrigation leaches nutrients below the active root zone (Hartz 1996). When the Mason Valley received unexpected rain early this summer, one of the producers growing leaf lettuce was forced to plow the crop under. Leaf lettuce is a high return crop, yet also requires a large capital investment; an upside to this necessary large capital investment is that the equipment needed for lettuce is much of the same equipment used for onions: both use set spot sprinklers, drip irrigation, and refrigeration equipment in addition to large amounts of labor. Both crops are planted on approximately April 15, lettuce is harvested on June 15 when it would need refrigeration until shipping; onions would not require refrigeration until they are harvested in late August or early September. Leaf lettuce and onions would make a good rotational combination; with lettuce using 12” of irrigation and onions using 36”, splitting the available four acre feet of irrigation between two plots, two acre feet would be available for potential sale or lease. For producers willing to incorporate hired labor into their farming practices and able to obtain funding for the necessary capital investment, leaf lettuce appears to be an optimal crop for the Walker River Basin, as it performs well in both Smith and Mason Valleys.

Wine grapes

At 4” of irrigation, yields were similar between locations, but varied widely between soil types. At this level of irrigation, Sagouspe was the preferred soil at both locations resulting in yields of 7.4 tons/acre in Smith and 7.45 tons/acre in Yerington; Dithod was the least preferred soil, yielding only 6.07 and 6.24 tons/acre (Figure 8).

When producers receive a price of $825.00 for wine grapes, break-even yield is 5.17 tons at 4” of irrigation. Break even prices averaged over all soils were almost equal between locations; the break-even price in Smith was $572.47, for Yerington the break-even price was slightly lower at $568.65 (Table 1). Net returns, like break even prices, were almost equal between locations with wine grapes planted to Sagouspe soils in Smith returning $1843.07 per acre and those planted in Yerington returning $1879.87 per acre to those producers. Wine grape yields increase with additional irrigation, but quantity alone is not the goal of producers; grapes, like onions and lettuce, differ between yield and marketable yields. The higher yields predicted by the WinEPIC model at higher levels of irrigation are not the main consideration; deficit irrigation improves the quality of the grapes. As opposed to table grapes, where bigger are better, wine grape producers purposely aim for smaller size grapes. Smaller size grapes have a larger surface to volume ratio which increases the amount of skin on the grapes; the skin contains the color and flavor producing ingredients. Increased numbers of small size yields that occur from reducing irrigation, while an undesirable trait in onion production, is a premium in grape production. Reduced irrigation is related to another important quality in wine grape production: alcohol content. As water levels are increased during the growing period, the alcohol level able to be obtained from the grapes in the fermentation process decreases because increasing irrigation adversely affects the amount of sugar in the harvested product. Grapes have the highest capital investment costs of any crop under consideration with per acre costs of over $17,000 (Table 3). They can be profitable however if the producer does all the maintenance labor, only hiring outside labor during harvest. Wine grapes, like two row malt barley, should be grown under contract as vintners are interested in certain varieties and should be consulted and contracted with prior to planting.

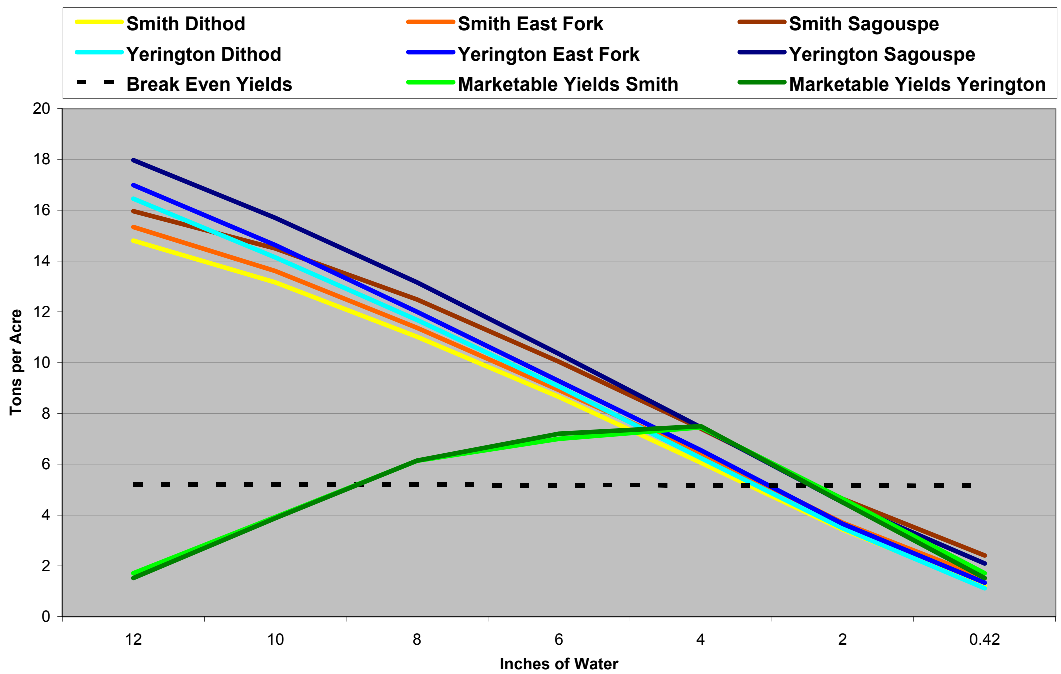

Figure 8. Wine grape yields for all soil types and both locations under all irrigation regimes

Forecast Analysis of Individual Crops

<u>Alfalfa</u>

Stochastic yields for alfalfa were multiplied by stochastic pricing drawn from a triangular distribution; after costs, net returns varied from a low of ($292.32) to a high of $702.23 per acre. Although historical pricing was available, it does not reflect the large increases in price that have recently occurred. For this reason a triangular pricing distribution was chosen with $144 per ton as the minimum (Curtis et al. various 2008), $177/ton as the midpoint, and current local reported pricing of $200/ton as the maximum (USDA-AMS July 2007b). The mean net return per acre was $165.90 with a standard deviation of $152.55.

<u>Onions</u>

Stochastic pricing for onion yields was calculated using a triangular distribution as there were only 10 years of available data and not the 20 required. The average of the last 10 years, or $288 per ton was used as the minimum; $320 per ton (Curtis et al. various 2008) was used as the median, and $364, the price obtained by projecting the linear trend of Nevada historical data to 2009 was used as the maximum. Net returns for onions varied widely with ($960.40) as the lowest, and $4550.17 the highest net returns per acre; mean returns were $1584.27 with a standard deviation of $841.64.

Teff

A fixed price was used for teff pricing (Curtis et al. various 2008). Even with a fixed price, the variation in yields led to negative returns in one hundred and eight of the one thousand iterations. Net returns per acre varied between ($289.87) and $558.15. The mean net return was determined to be $156.86 with a standard deviation at $126.78.

Great Basin wildrye

A triangular distribution was used to create stochastic pricing for wildrye; there was a large variance in returns from ($193.35) to $2495.20 as the low and high returns respectively. Average net return was $788.34 per acre with a standard deviation of $456.45. The input prices for the triangular distribution used with wildrye came from the conservative low used in enterprise budgets of one-third of retail at $2.50/ pound (Curtis et al. various 2008), a mid-point price of $5.00/pound, and the 2007 retail at $7.50 (Utah Seed 2007). Only two percent of the 1000 iterations resulted in negative returns. This risk analysis was conducted with 12" of irrigation, but higher yields are believed to be possible at higher irrigation levels; with higher yields this crop would be even more appealing.

Switchgrass

Fixed pricing was used for switchgrass and all returns were consistently negative; in the worst case returns had a low of ($687.89) and the best case returns were a per acre loss of ($317.11). Mean losses were ($534.84) with a standard deviation of $88.32. Switchgrass is a big loser in Northwestern Nevada. The fixed price used came from enterprise budgets where $66/ton was used (Curtis et al. various 2008), the price being paid for hay rather than the lower price of $40 to $50 that ethanol producers are currently paying for biomass. This crop may be economically viable in the eastern part of the United States where it is native but is not an economically feasible crop in the arid west.

Two-row malt barley

Two-row malt barley pricing was calculated by using a triangular distribution to generate stochastic prices. Minimum returns were ($409.90), maximum returns were $454.59. For malt barley, the standard deviation was larger than the mean, with a mean of ($22.49) and a standard deviation of $139.06. The poor results for this crop are a consequence of the pricing distribution. Current available pricing for two-row malt barley is based on cash prices at the grain elevator which are believed to be much lower than that paid for barley grown under contract. In several NASS reports in the malting barley column was the disclaimer "price estimates not published to avoid disclosure of individual firms". For the triangular distribution used for this analysis, the lowest cash price paid at grain elevators in Idaho (Idaho Barley Commission 2008) on July 2, 2008, $201.16/ton was used as the minimum price; $280.00/ton, the highest cash price paid at the same location on the same day was used as the mid-point price, and reported contract prices of $360.00/ton from the enterprise budgets was used as the maximum price (Curtis et al. various 2008). The large variation in returns for barley was certainly a product of the variation in input prices because yields had a small amount of variation: standard deviation was only .26 with a mean of 3.58.

Leaf lettuce

Pricing for leaf lettuce used historical data and a simple trend model to produce stochastic prices. This crop had the largest range of returns, from a low of ($1385.57) to a high of $4729.58. Net returns had a mean of $1515.56 and a standard deviation of $988.59. A simple regression trend model taking 10 years of historical pricing from NASS combined United States data was used to simulate price; the model was a good fit with significance for the constant of 0.000 and the trend variable significant at 0.04. Leaf lettuce is currently priced in enterprise budgets at $700.00/ton (Curtis et al. various 2008), so the 2009 predicted stochastic range of between $626.60/ton and $773.85 seemed reasonable. This crop did not do as well as expected in this analysis perhaps due to the wide range of variation in yields; yields varied between 9.4 and 12.5 tons to the acre.

Wine grapes

In this analysis grapes had the highest potential for loss with minimum possible net returns of only ($2866.07). Maximum returns were $2548.62. Mean net returns were $532.80 with a standard deviation of $1116.82. Price was forecast using a triangular distribution; the minimum price of $725.00/ton was taken from information from a local winery, the mid-point price of $825.00/ton was from enterprise budgets (Curtis et al. various 2008), and the high of $954.00/ton (USDA-NASS 2007b). Even though the mean yield was 6.26 tons per acre and median yield was 6.85 tons per acre, because the vineyard in the model did not reach maximum yields until approximately the tenth year of production, minimum yield was as low as 1.77 tons per acre. The extremely large variation in yield combined with projected high per acre costs of production at $4544.77 for 2009 made this crop one that should only be considered by those producers who are neutral to risk or who are risk loving. This fits with current area practices, as most wine grapes produced in the area are produced on 5 acres or less; this is not the only source of income for those producers.

Forecast Analysis of Crop Comparison

In scrutinizing the combined cumulative distribution function graph, switchgrass, barley, teff, and alfalfa had steep distribution slopes; wildrye was slightly less steep, with grapes, lettuce and onions having lower slopes; those crops with the least amount of variation of their net returns have the highest degree of slope (Figure 9).

Variation expresses the amount of deviation from a mean value or the range over which a value falls. Decision makers who are risk adverse prefer less variation: profits of $20 to $40 dollars are preferred to profits of $0 to $60, even though both scenarios have average profits of $30. This explains why producers in the Walker Basin are currently growing alfalfa: its cumulative distribution line has the steepest slope for any of the crops with mostly positive returns. Both lettuce and onions have mostly positive returns, but the wide variation in yields makes these crops less appealing. The steepness of the slope of the line for the distribution of switchgrass explains why, even though it is a consistent money loser, it is preferred, as also shown by the stochastic dominance tables, to either grapes, lettuce, or onions for those producers with even slight risk aversion (Table 4).

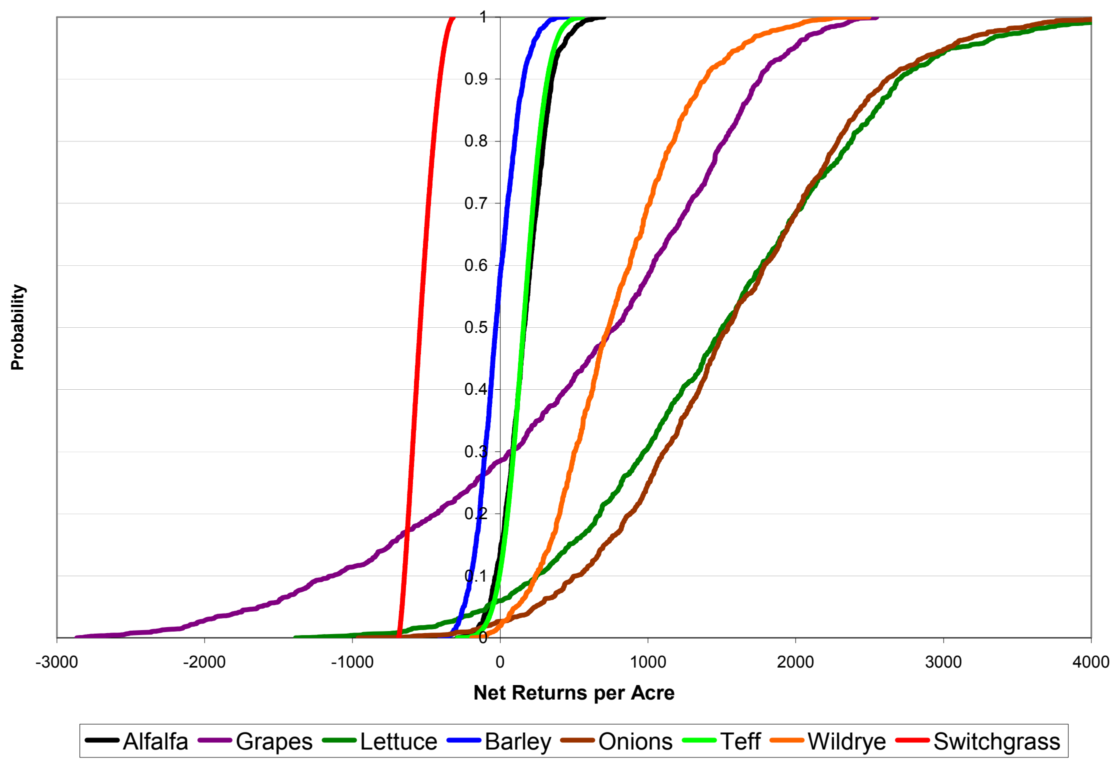

Figure 9. Combined comparative cumulative density function of net returns for all crops.

Table 4. Analysis of stochastic dominance with respect to a function (SDRF) at a risk aversion coefficient (RAC) of risk neutrality and at slight risk aversion

	Efficient Set Based on SDRF at Lower RAC	**0**		Efficient Set Based on SDRF at Upper RAC	**1**
	Name	Level of Preference		Name	Level of Preference
1	Onions	Most Preferred	1	Wildrye	Most Preferred
2	Lettuce	2nd Most Preferred	2	Teff	2nd Most Preferred
3	Wildrye	3rd Most Preferred	3	Alfalfa	3rd Most Preferred
4	Grapes	4th Most Preferred	4	Barley	4th Most Preferred
5	Alfalfa	5th Most Preferred	5	Switchgrass	5th Most Preferred
6	Teff	6th Most Preferred	6	Onions	6th Most Preferred
7	Barley	7th Most Preferred	7	Lettuce	7th Most Preferred
8	Switchgrass	Least Preferred	8	Grapes	Least Preferred

The stoplight chart uses values input by the user to determine the probability of an unfavorable, cautious, or favorable outcome to a chosen scenario using the metaphor of the red, yellow, or green coloration from a traffic signal to illustrate the data. Arbitrary inputs of no loss and profits of more than $250.00 per acre were chosen for analysis as these amounts seemed reasonable and comparable to producer's expectations. With an input low of $0.00 in returns and at least $250.00 in returns per acre as the desirable level, the stoplight chart predicted a more than 50% probability of a favorable outcome for grapes, lettuce, onions, and wildrye, when applied to SIMETAR results (Figure 10).

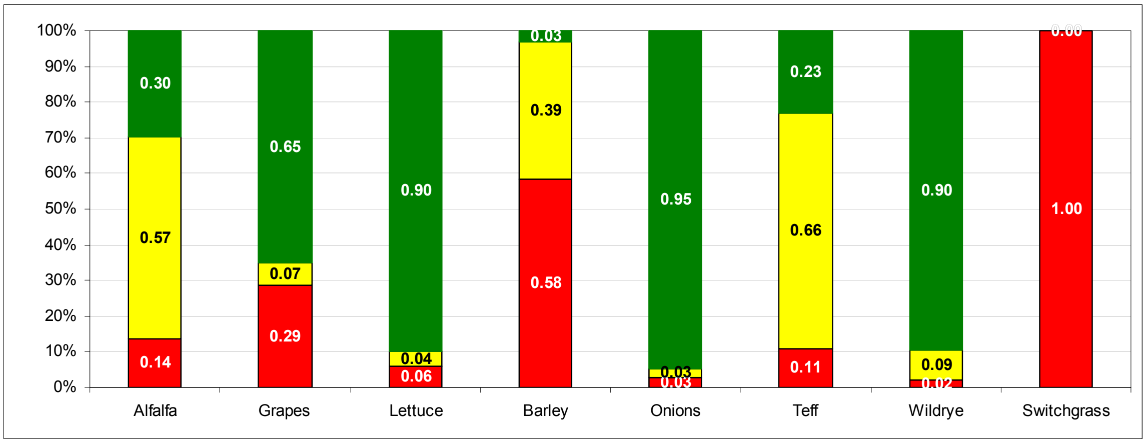

Figure 10. Probability of a favorable, cautious, or unfavorable result for returns greater than $250.00, but no less than $0.00

At these values, barley had a 58% chance of an unfavorable outcome and switchgrass had a 100% chance of an unfavorable outcome. Alfalfa had a 30% favorable rating and a 57% cautious rating; teff had a favorable probability of 23% with 66% probability of a cautious outcome.

SIMETAR allows the user to input different Risk Aversion Coefficients (RAC) to analyze decision maker's choices under any level of risk. Analyzing stochastic dominance for producers who were risk neutral at a Risk Aversion Coefficient (RAC) of 0 which implies risk neutrality, the preferred order of crops to plant is: onions, lettuce, wildrye, grapes, alfalfa, teff, barley, and switchgrass. When RAC level was raised to 1, that of a normal, or somewhat risk adverse producer, the preferred order changed to: wildrye, teff, alfalfa, barley, switchgrass, onions, lettuce and grapes (Table 4).

SIMETAR also graphs the level at which risk adverse decision makers choose or switch between crops. As shown, alfalfa became preferred to lettuce and preferred to onions at very small levels of risk aversion (Figure 11).

A risk adverse decision maker prefers a consistent small loss to fluctuating gains or losses. This preference for minimal variation in returns also explains why onions and lettuce drop behind wildrye, alfalfa, teff, and barley regardless of their higher profit potentials. At minimal amounts of risk aversion, grapes became the least preferred of any of the crops.

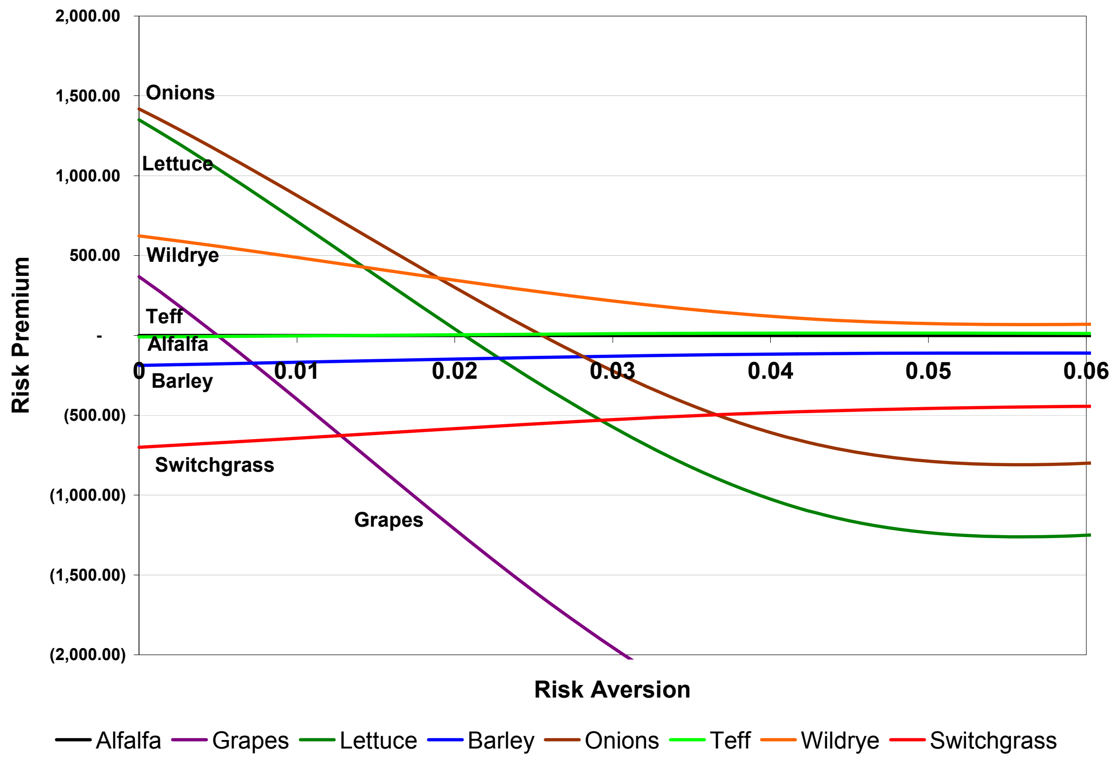

Figure 11. Risk aversion coefficient comparison between crops or SERF (Stochastic Efficiency with Respect to a Function) using a negative exponential weighted risk premium relative to alfalfa

CONCLUSIONS

The purpose of this study was to investigate the economic feasibility of low-water alternative crops for the Walker Basin region in order to reduce agricultural water use without causing economic damage to the producers in that region. Reducing agricultural water use is a necessary major component of the attempt to increase water levels in Walker Lake and avert further ecological degradation.

This study determined that there are alternative crops that could be economically feasible in Northwestern Nevada. For those producers able to obtain funding for capital investment who are willing to expand operations to include additional amounts of hired labor, growing onions and leaf lettuce under rotation would yield substantial returns for producers who are not averse to variations in returns. For those producers desiring to farm with no additional input to labor or who lack funding for capital, this study recommends further investigation into contractual availability of growing two row malt barley or Great Basin wildrye. All of the afore mentioned crops, either solely or in rotation, use 24” or less of irrigation, half of the necessary irrigation needed for alfalfa, enabling producers to potentially sell or lease some of their water if they so desire. Switchgrass is not recommended as being economically feasible at this time. Teff has potential for profit, yet is not as water conserving as other crops under consideration.

Wine grapes require a large outlay of capital investment and are labor intensive; they should not be attempted on a large scale by a first-time producer.

Field trials should be conducted in the region to determine if the high yields of Great Basin Wildrye seed that were predicted by our model are possible at higher irrigation levels than those of normal production practices.

Some of the limitations faced by this study were related to the model used. WinEPIC has no allowances for quality as evidenced by the results from simulation of onions and lettuce in the model. Additionally, WinEPIC does not allow for increased yields due to advances in technology or changes in yield from soil amendments other than nitrogen or phosphorus. Wine grape yields did not reach maximum yields until approximately year ten in the WinEPIC model, but local producers report full yields by the fourth year of production. Some of the limitations faced by this study were related to a lack of data. Simulated yields of Great Basin wildrye at higher levels of irrigation were unverifiable, and adequate historical pricing was not available for teff, switchgrass, Great Basin wildrye, two-row malt barley or wine grapes.

An immense limitation exists in regard to the application of the results of this study by producers: current Nevada water law. Nevada's current water law does not easily permit the sale of a portion of water rights; all the water rights for a given parcel are normally sold. Nevada law also hampers leasing water rights for an agreed amount of time; 'use it or lose it' is the law rule in Nevada. Both of these concepts are a large impediment to reducing agricultural water use in Northwestern Nevada. Compensation levels would need to be extraordinarily high to convince producers who are by nature risk adverse, to give up a steady source of almost guaranteed income from alfalfa production, for both them and for their descendants for generations to come.

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PROJECT H: FORMULATION AND IMPLEMENTATION OF ECONOMIC DEVELOPMENT STRATEGIES

ECONOMIC AND FISCAL IMPACTS AND ECONOMIC DEVELOPMENT STRATEGIES: CONSEQUENCES TO THE AGRICULTURAL ECONOMY IN THE WALKER BASIN

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The acquisition of water rights that have historically been used for agriculture in the Walker Basin, in order to increase the water flow into Walker Lake, could have a variety of economic and fiscal impacts in the subareas within the Walker Basin. This study examines four scenarios related to how those water rights are acquired, along with the resultant potential uses for the land following water rights acquisition, and estimates economic and fiscal impacts for those scenarios. Additionally, this study examines the potential economic impacts in the vicinity of Walker Lake based upon an assumption that sufficient water can flow into Walker Lake to save and restore the fish habitat. Finally, this project makes some recommendations regarding economic development efforts in Walker Basin that would be consistent with the desire of citizens in the communities and that might tend to offset any economic dislocations that could result from the acquisition of water rights.

EXECUTIVE SUMMARY

The Economic and Fiscal Impacts and Economic Development Strategies project is one of ten different projects examining various aspects associated with the acquisition of water and water rights in order to sustain Walker Lake, a terminal desert lake in western Nevada. A general description of the Walker Basin Project from the Walker Basin website (http://www.nevada.edu/walker/about/index.html) is as follows:

> The Walker Basin Project is a comprehensive, research-guided project to sustain the Basin's economy, ecosystem and lake. This federally funded project involves collaborative environmental and economic research conducted by researchers with the Desert Research Institute (DRI) and the University of Nevada, Reno. It also involves the acquisition of water and water rights from willing sellers under the coordination of the Nevada System of Higher Education. The research is exploring the best means by which to get additional water to the lake while maintaining the Basin's economy and ecosystem.

The Economic and Fiscal Impacts and Economic Development Strategies project also identifies a number of economic development opportunities that have the potential to directly or indirectly improve the quality and/or quantity of water that will reach Walker Lake by influencing decisions made by agricultural producers, and/or by leveraging alternative crop choices made by some of the agricultural producers, or finally by utilizing the river and lake resources "improved" by the project.

Most of the citizens living in the Hawthorne/Walker Lake sub-region view the project with a positive expectation that Walker Lake can be "saved", including preservation of the Lake as a fishery, migratory bird habitat, active recreational facility and scenic landmark. Many of the citizens in the sub-regions where water and water rights may be acquired (Mason Valley and Smith Valley, Nevada) view the project with trepidation, concerned that their agricultural-based economies, communities, cultural heritage and lifestyles may be changed forever, and are primarily focused on potential negative outcomes. The purpose of this study was to look at possible economic impacts in each of the above sub-regions, and in particular to look at a several potential outcomes under various scenarios in areas targeted for acquisition of water and water rights, and then to identify potential economic development opportunities that might help mitigate any potential negative impacts.

With the acquisition of water and water rights one thing is certain: change. Change often presents challenges and opportunities. This study validates this general observation by showing how different decisions made by those conveying water and water rights (primarily agricultural producers) and by those acquiring water and water rights in terms of their policies about how much water is "left with the land" can substantially alter the economic impacts of the project. In turn, the economic impacts will affect the fiscal impacts.

This study is relevant to many of the other high arid agricultural areas of Nevada, the western United States and the world. While these other areas may not be dealing with preservation of a terminal lake, the competing interests for limited water resources, often pitting agricultural uses against municipal and/or industrial uses, will create pressure on agricultural producers to sell their water rights. Decisions will be driven by the economic benefits to be derived from various uses of the water. Understanding that there is not a single "predetermined" negative outcome for the agricultural producers and the communities that support and depend on agriculture is an important lesson.

IMPLAN (IMpact Analysis for PLANning) was the input/output model used as the primary economic impact assessment tool. The fiscal impact analysis used the economic impact results and location-specific tax rates. Economic development strategies were based upon suggestions by local residents in a number of community meetings and the project objective of improving the quality and/or increasing the quantity of water that might reach Walker Lake.

The potential economic impacts varied by region. In the Hawthorne/Walker Lake sub-region, located within Mineral County, the impacts of a declining lake level and the increasing levels of salinity have caused a drop in fishing and other recreational use of the lake. This has resulted in an estimated loss of around 41 jobs and a net annual economic loss to the community of around $1.3 million. It is anticipated that this loss could be recovered with stabilization and some modest recovery of Walker Lake.

In the upstream areas of Mason Valley and Smith Valley, within Lyon County, the economic impact from the acquisition of water rights currently used for agricultural production could be negative or positive, depending upon whether the land is "returned" to desert or whether the amount of water acquired per acre leaves sufficient water for alternative crops. Which alternative crops are cultivated and the acreage involved in such production will substantially influence the economic impact.

The key question to be answered, simply put, was this: "What will be the economic impacts of acquiring water in Mason Valley and Smith Valley, destined for Walker Lake, in quantities sufficient for 50,000 acre feet annually to reach the Wabuska Gauge?" (The Wabuska Gauge is located at a point along the Walker River below Mason Valley.) The answer, unfortunately, is not as simple as the question. The answer depends upon what economic activity is "displaced" by the water rights acquisitions, and what happens with the proceeds received by those willing sellers. In terms of current agricultural water consumption, the primary crops in the region are alfalfa hay and grass hay.

The research team examined four different scenarios as to how water might be obtained for Walker Lake, along with estimates of the economic impacts that might be associated with each of these scenarios: scenario 1) land goes from agriculture (alfalfa rotations) to desert; scenario 2) existing crop rotations and farming practices are altered to achieve water savings; scenario 3) alternative crops that require less water are cultivated; and, scenario 4) other (non-agricultural) sources of water rights are procured. These scenarios were based, in part, upon information developed by other research teams working on the Walker Basin project.

Modification of existing agricultural practices and crop rotations (scenario 2) may be easier to implement than switching to alternative crops (scenario 3), while creating a much more favorable economic impact than removing land from agricultural production (scenario 1). The inducement to agricultural producers to modify their practices in order to conserve water would be the financial benefit of leasing “saved water”, assuming that any current legal and/or administrative obstacles can be overcome. The risks perceived by farmers may be substantially less than those associated with alternative crops. The farmers would be growing crops that they currently cultivate, with the same equipment, same buyers or market and similar risks. With the financial incentive to use less water (to use water more efficiently), additional water-saving measures are likely to be developed and adopted over time. For example, while farmers in the region currently may monitor soil moisture levels when growing onions, very few do so for alfalfa or grass hay, instead relying upon historical patterns of irrigation. The emphasis has always been on ensuring that the crops get enough water to produce good yields and not on water conservation because there has not been sufficient financial incentive to save water. A water leasing program might provide the needed incentive for farmers to implement scenario 2.

Using data from the crop budgets developed by Kynda Curtis et al in their Economic Analysis of Water Conservation Practices for Agricultural Producers in the Walker River Basin[1] and utilizing the IMPLAN input/output model, economic impacts in Mason Valley and Smith Valley associated with a number of crops were estimated. The alternative crops identified as being “viable” for cultivation in this sub-region (through other Walker Basin research projects) and having significant potential for water savings were teff (seed), baby leaf lettuce, two-row malt barley, great basin wild rye seed and wine grapes.

Teff seed: Teff is an annual grass native to the northern Ethiopian Highlands of northeastern Africa, and currently commercially grown in the U.S. in Idaho. Teff is one of the alternative crops being studied by Jay Davison, Elizabeth Leger and Erin K. Espeland[2]. Teff seed production requires approximately 2-3 acre feet of water per year, which would result in at least a 25% water savings compared to alfalfa while producing a net to the farmer slightly higher than alfalfa hay.

Baby leaf lettuce and spinach: Also generally known as “spring mix”, a number of varieties of baby leaf lettuce and spinach are currently grown in Mason Valley. By utilizing mechanical harvesting the labor expenditures for this crop have been reduced to less than 25% of that needed to cultivate this crop using manual harvesting. This increases the net profit to the farmer substantially while decreasing the reliance upon migrant labor. Spring mix requires one fourth of the irrigation water compared to alfalfa and grass hay, so holds great promise for water savings.

Two-row malt barley: Barley is an annual cereal grain, ranked fourth in the world in terms of quantity produced and area of cultivation. It is grown as a major source of animal feed with smaller amounts used for malting to be used in beer and ale production or sold in health food stores. Several varieties of two-row malt barley are grown in the western U.S. under dryland or irrigated conditions. Often the irrigated two row malt barley is grown under contract with maltsters, who pay a premium for high quality malting barley. Two-row malt barley should generate a net profit per acre to farmers approximately four times greater than the average net profit realized through rotations around alfalfa or grass hay and approximately twice that of the onion and alfalfa rotation while utilizing only two acre feet of irrigation water.

Great Basin wild rye seed: Great Basin wild rye is a grass native to the western U.S. and Canada. In addition to its potential for livestock grazing, it is used extensively for range rehabilitation following wildfires. Establishing wild rye helps to stabilize the ground against water and wind erosion while limiting the invasion of noxious weeds. Growing Great Basin wild rye seed should generate a net profit to farmers that is approximately half of the average profit that would be realized from a typical alfalfa or grass hay rotation while requiring only about one-third of the water.

Grapes: Grapes grown for wine production present an interesting prospect from a quick glance at the numbers. Grapes consume about one-third of an acre foot of water annually on drip irrigation, which is less than one-tenth of that typically required by alfalfa or grass hay, yet grapes also provide an estimated net profit per acre to farmers approaching three times the net produced by typical alfalfa and grass hay rotations. When the net profit from growing grapes is enhanced by the potential cash-flow benefit generated by the invested after-tax proceeds from the sale of excess water rights, the combined net benefit balloons to around eight times the average annual net profit generated by alfalfa and grass hay crop rotations. The economic impact to the region from grapes is also very attractive, at over eight times that generated through alfalfa and grass hay production.

The research team then constructed three examples to show how decisions relative to the four scenarios described above might affect economic impact (Figure 1). Assumptions were made about typical crop rotations, values that might be ascribed to water rights purchases and water leasing, tax rates on proceeds from the sale of water rights, rates of return on invested proceeds, and a number of other factors needed for the analysis.

In all three examples it was assumed that 14 percent of the water to be acquired would be from non-agricultural (geothermal) sources. This was based upon an option for geothermal water that has already been obtained. If the water quality from this source proves to be too poor for lake replenishment and cannot be improved sufficiently through some form of economically viable treatment, then the worst-case scenario would be amplified ay another 14% ($8.9 million annual loss). An important aspect of understanding and utilizing economic impact analysis is appreciating that the methodology is quite good at estimating the direction and the order of magnitude of likely impacts, but the projected impacts are not similar to more exact measurements that can occur "after the fact." Because the input/output models generate precise numbers as estimates of outcomes, some people conclude that these figures convey much greater precision than they actually do.

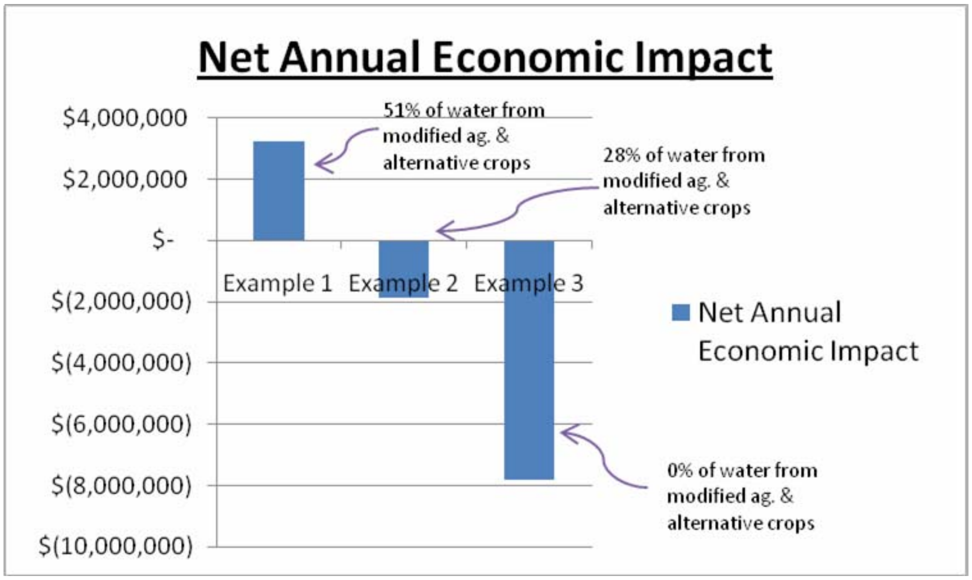


Figure 1. Net annual economic impact: comparisons of three example outcomes.

In the first example, the assumptions were that the balance of the water would be obtained by a combination of scenarios, with 35 percent of the water resulting from some agricultural land taken out of production, 10 percent of the water resulting from modified crop rotations and agricultural practices, and 41 percent of the water obtained through changes to alternative crops This example generated a projected net positive economic impact to the region of approximately $3 million annually (2007 dollars). For this sort of an outcome, it would probably be necessary for there to be programs initiated to assist farmers, create value-added processing and market development and thereby substantially reduce the perceived risk of switching to alternative crops. Such assistance might be in the form of a fund of $20-$25 million that could be a source of grants and low interest loans to farmers in the region. Such a fund, combined with agricultural technical assistance in how to best make the transition to alternative crops and business technical assistance, would certainly facilitate this sort of transition, which would preserve the agricultural character and the economic base of the region.

In the second example, the assumptions were that 58 percent of the water was obtained by taking some agricultural land out of production, 10 percent was obtained through changing crop rotations and agricultural practices, and only 18 percent was obtained through changes to alternative crops. This example generated a projected net negative economic impact to the region of approximately $1.9 million annually (2007 dollars).

In the third example the assumptions were that all of the water obtained from agricultural sources (86% of the total water obtained) would be from taking some agricultural land out of production. In this example, the projected annual economic impact was a negative $7.8 million (2007 dollars).

Clearly it makes more sense, from an economic impact perspective, to minimize the amount of agricultural land taken out of production and to maximize the amount of acreage that is switched from growing alfalfa to viable alternative crops.

Economic Development Recommendations

Specific economic development recommendations were made by the research team. Economic development is the process by which the economic, political and social well being of an area's inhabitants are improved. These recommendations were based upon comments made by citizens in community meetings that also generally met the objectives of either influencing decisions that might improve the quality and/or quantity of water reaching Walker Lake or that leveraged the improved river flows or lake condition.

These are preliminary recommendations that need to be vetted through community involvement. It is the intention of the Nevada Small Business Development Center to manage this vetting process and to work with local citizens, public officials, existing economic development entities and any other stakeholders who can be identified to initiate implementation of economic development strategies in and for these sub-areas.

<u>Mason Valley economic development strategies</u>

Targets: The suggested targets for economic development in Mason Valley include the following: a) value-added processing and market development related to the alternative crops of teff and two-row malt barley; b) agricultural research related to cultivation in arid high-elevation environments; c) alternative energy developments focused on geothermal and biodiesel production; and d) cleaning up the former Anaconda mine site. Each of these is selected for its potential link to the Walker Basin project.

Value-added processing and market development for teff and two-row malt barley both seem worthwhile of further investigation. Cultivation of both teff and two-row malt barley seem to have potential for reducing water consumption while generating positive economic impact within the region. It fits well with the Walker Basin project and is consistent with the preferences expressed by local citizens.

One dimension of market potential for teff may be related to celiac disease, an autoimmune digestive disease that interferes with absorption of nutrients from food that is triggered by the consumption of glutten which is found in wheat, barley and rye. It is estimated that roughly one in every 133 Americans has celiac disease but that 97% remain undiagnosed. Flours without glutten can be made from teff, rice, corn, soy, buckwheat and a few other products. Teff is purported to be an important health food for consumers to keep their bodies fit and to control weight. It is also marketed as a natural sports food which is consumed by East African runners.

Two-row malt barley is primarily used for brewing beer. Historically, breweries operated their own malting operations, but this has changed throughout most of the world because of the growth of a few larger commercial maltsters. With the growth of the brewpubs and micro-brewery business in the U.S., there may be an opportunity for a boutique custom malting operator to cater to the requirements of the small brewery operations. In addition to an end-market of home brewers, there are an increasing number of brewpubs and micro-breweries in the U.S. including at least 15 in Nevada. An initial investigation could include contacting these entities to see if they would have any interest in custom malts that might help them to differentiate their products and/or add different beer styles to their current offerings. If feasible, this would also fall in line with the trend to develop local supply relationships in order to reduce transportation costs and the carbon footprint associated with such products.

Agricultural research related to cultivation in arid high-elevation environments is another economic development target deserving further investigation. This economic development target has the potential for both increasing available water for Walker Lake and providing positive economic impact. It is consistent with the desires expressed by local citizens. Several trends tend to support this concept: increasing world population, increasing food costs, declining farm land, and climate change which seems to cause reduction in precipitation and availability of fresh water in many parts of the world.

Cultivation in some of the arid environments has led to desertification as a result of using farming practices that are not sustainable. Portions of rural Nevada provide ideal environments for testing alternative crops that can succeed under these arid conditions and also assess how modifications of farming practices can utilize irrigation water more efficiently. The existing physical environment, combined with expertise found within the University of Nevada, Reno's College of Agriculture, Biotechnology and Natural Resources and the Desert Research Institute, bring together factors ideally suited to help the United States develop the intellectual property needed to improve farming in these types of environments.

Alternative energy developments focused on geothermal and biodiesel production are two other potential targets for economic development that seem worthy of further investigation. The option to acquire geothermal water rights for the restoration of Walker Lake already points to linkage to this project. If geothermal power-plant effluent can provide some energy value, either in the form of generation of electricity or by providing a low-level heat source for commercial or industrial use, there would be a double benefit. One of the "negatives" of geothermal water is that it often contains large concentrations of dissolved minerals such as sodium, calcium, sulfate, chloride, fluoride or iron. However, there has been extensive research on the recovery of minerals and metals from geothermal fluids.[3] Depending upon the mineral content of the geothermal water in question, there might be some potential commercial benefit from extracting minerals and metals, and also improving the quality of this water source for Walker Lake, and this may be necessary for the water to be "acceptable" quality for the lake.

Production of biodiesel from algae may present one more "dual purpose" economic development possibility. Growing algae can be used to extract "contaminants" from water, thereby improving water quality and certain algae can also be a great feed stock for biodiesel. This may be applicable to treated effluent from local municipal wastewater treatment facilities. Depending upon the content of fertilizers in return flows into the Walker River from agricultural areas, there may be one additional source of water worthy of consideration for algae growth and biodiesel production.

Cleaning up the former Anaconda mine site has potential for positive economic impact, and might also have a relationship to the Walker Basin project. A widely-held perception is that the water in the old pit is contaminated, even though Lyon County has a test result (Sierra Environmental Monitoring – 2006) that shows the water passing drinking water standards. If, as part of any clean-up effort, minerals and metals could be removed from this water to improve its quality, and if any of this water could be made available for Walker Lake, it might provide one more source of non-agricultural water.

Smith Valley economic development strategies

Targets: The suggested targets for economic development in Smith Valley include: a) value-added processing and market development related to the cultivation of wine grapes, and perhaps to teff and two-row malt barley, b) agriculture-based tourism, and 3) recreational tourism focused on the Walker River.

It appears that Smith Valley may be more conducive to the cultivation of wine grapes than Mason Valley. If this proves to be true, as determined through monitoring of micro-climates within different parts of Smith Valley and if substantial acreage of grape cultivation is attractive to farmers, then the opportunity for another northern Nevada winery could be a real possibility. Smith Valley would provide an ideal setting for a winery.

Agriculture-tourism fits very well with a winery. Agricultural tourism could include farm or ranch-based bed-and-breakfast operations or dude ranch operations. Recreational tourism tied to the river could focus on recreational fishing or kayak/float activities, either within Smith Valley or perhaps in Wilson Canyon between Smith Valley and Mason Valley.

Hawthorne / Walker Lake economic development strategies

Targets: The suggested targets for economic development in the Hawthorne/ Walker Lake area related to the Walker Basin project include the following: a) lake-related developments such as boat ramps, improvements to camping and day-use areas, and renovation of the closed Cliff House motel and restaurant or construction of new motel and restaurant facilities; and b) development of geothermal alternative energy resources. The research team believes that Hawthorne's economy is primarily a military-based economy. Even if Walker Lake receives more water, the community should continue to pursue airport improvements, expansion of the ordnance and other explosives reprocessing, and contracting with federal agencies to support the military operations in the area, as well as developing home grown businesses. However, while these projects are viable economic development opportunities, they are not directly related to the Walker Basin mission of restoring Walker Lake and therefore are not included among the suggested targets.

Citizens and public officials working to enhance economic development in their communities need to understand what "advantages" their area offers, and their role in encouraging individuals to make investments that can utilize these advantages. Local citizens and officials can work to mitigate or eliminate different types of risks that would be perceived by potential investors and also create and/or promote their own competitive advantages. For example, public processes that tend to ensure communities will be receptive to certain types of development reduce one of the risks that might concern investors. Eliminating or reducing barriers to development might involve such things as land assemblage, expedited approval and permitting processes, development of key infrastructure related to transportation, communications, education, etc. Business risks might be mitigated through access to targeted capital pools through low interest loans and/or grants that either lower the cost of capital or extend repayment terms to improve early cash flow.

For local economic development efforts to maximize their success interested citizens and public officials should work to leverage existing available resources such as economic development entities, cooperative extension and business development entities that are part of state universities, and look for federal and state grant opportunities, particularly those targeted for rural communities. Additionally, they need a sufficiently funded lead individual or entity to be responsible for organization, communication and most importantly, relentless expenditure of energy into the economic development effort.

With all this, each community needs to develop a process for moving their local economic development efforts forward, some initial resources to fund the process, and eventually access to a larger resource pool to use as the catalyst for "making things happen".

To expedite successful economic development in each of the subareas of the Walker Basin, ideally some federal funding could be identified to assist economic development efforts in the basin. A small portion could be targeted for technical assistance and another small portion might be dedicated to research, with most of the funds being dedicated to a resource pool available for investment in needed infrastructure and for grants/loans to help mitigate development risks and to serve as a catalyst for new projects.

SECTION 1: BACKGROUND - ECONOMIC IMPACT ANALYSIS FOR THE WALKER BASIN

Economic impact analysis involves projecting changes in an economic system, often associated with some defined geographic region, which will result from certain actions and/or activities. Economists often utilize tools known as input/output models that are based upon historic relationships that exist in modern economies to make predictions about future economic impacts. Input/output models utilize existing data sets for the system (region) being analyzed and the industries that are likely to be affected, together with algorithms that have been developed that reflect how changes in one aspect of the economic system affect other aspects of the system.

Some Basic Concepts of Community Economics and Income and Employment Multipliers

A good description of how a regional economy functions was developed by Elizabeth Fadali and Thomas R. Harris[4], and with permission a portion is reprinted herein with some minor modification made by Ms. Fadali so that the description better fits this study.

Figure 2 illustrates the major flows of goods, services and dollars in any economy. The foundation of a community's economy is those businesses which sell some or all of their goods and services to buyers outside of the community. Such a business is a basic industry. The flow of products out of, and dollars into, a community are represented by the two arrows in the upper right portion of Figure 2. To produce these goods and services for "export" outside the community, the basic industry purchases inputs from outside of the community (upper left portion of Figure 2), labor from the residents or "households" of the community (left side of Figure 2), and inputs from service industries located within the community (right side of Figure 2). The flow of labor, goods, and services in the community is completed by households using their earnings to purchase goods and services from the community's service industries (bottom of Figure 2). It is evident from the interrelationships illustrated in Figure 2 that a change in any one segment of a community's economy will have reverberations throughout the entire economic system of the community.

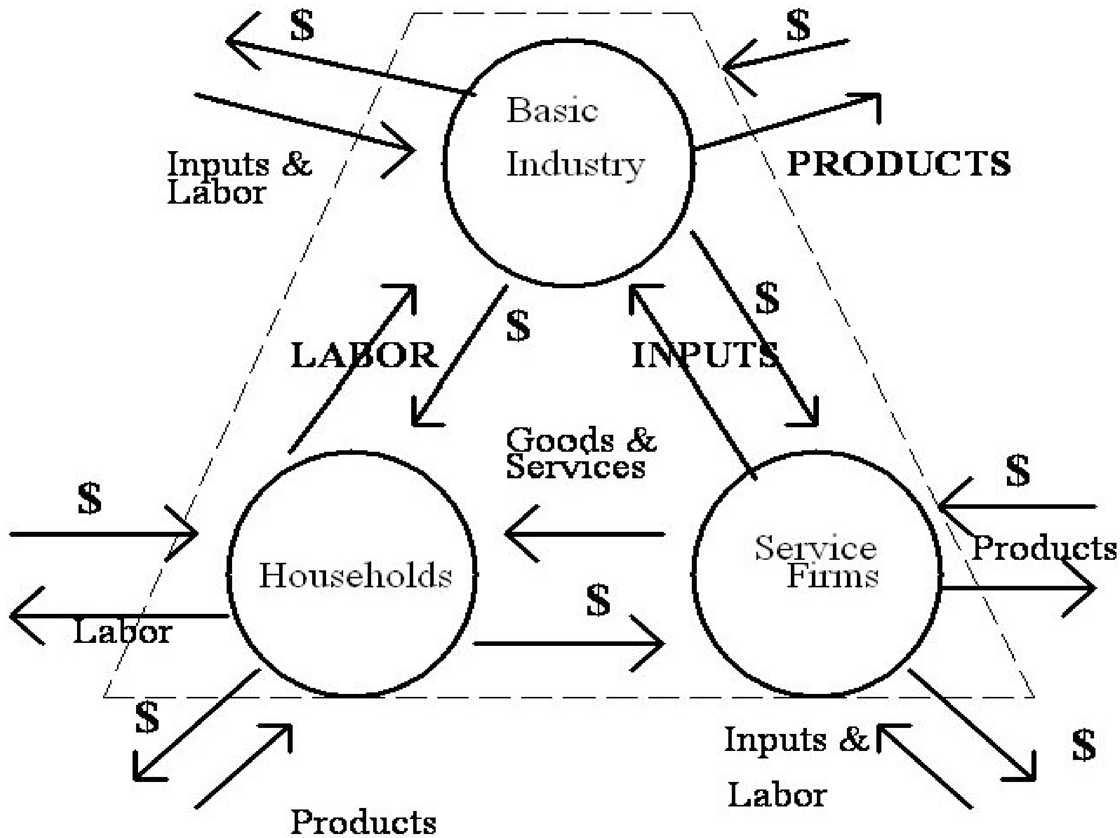


Figure 2. Overview of Community Economic System.

Consider, for instance, the Vegetable and Melon Sector which includes onion production, and its impacts on the local economy. The Vegetable and Melon Sector activities can be considered a basic industry as it draws dollars from outside the area when a crop such as onions is sold to buyers outside the region. These dollars are used to hire a people from the household sector such as laborers. Other local economic linkages are from the Vegetable and Melon Sector's purchasing goods from other sectors in the region. These include businesses such as wholesalers, utilities, trucking, retailers and so forth. As revenues increase in these businesses, they will hire additional people and buy more inputs from other businesses. Thus the change in the economic base works its way throughout the entire local economy.

The total impact of a change in the economy consists of direct, indirect and induced impacts. Direct impacts are changes in final demand within the local region which in this case is the Mason or Smith Valley region of Lyon County or Mineral County. Changes in final demand may be viewed as changes in total sales of goods or services for a given sector or sectors. For example, a direct impact could be a reduction of export sales in the vegetable and melon sector. Indirect impacts are the inter-industry effects that follow from the direct impacts to a sector. For example, a lettuce producer may decrease his fertilizer purchases if he believes sales of the lettuce will decrease. Induced impacts come from changes in household purchases due to changes in household income that arise from changes in the directly affected sector or sectors and the indirectly affected sectors. In this example if the vegetable farmer had to lay off a worker and the fertilizer salesman had to lay off a worker, then grocery stores, restaurants and other providers of consumer goods will have fewer sales.

An important aspect of understanding and utilizing economic impact analysis is appreciating that the methodology is quite good at estimating the direction and the order of magnitude of likely impacts, but the projected impacts are not similar to more exact measurements that can occur "after the fact." Because the input/output models generate precise numbers as estimates of outcomes, some people conclude that these figures convey much greater precision than they actually do.

If the question were posed to an individual farmer, "What will be the net profit from your farm operations next year?" some sort of reasonable estimate could probably be generated after some time and effort. But the estimate would likely begin with some qualifying statement such as "That depends upon the weather, the cost of fuel, the cost of electricity, the cost of fertilizer, and the market prices for agricultural products we are growing." Based upon assumptions about these issues, the estimate would likely be a rough estimate rather than something rounded to the nearest thousand dollars. The same general approach would likely be true if asking all the farmers and ranchers in Mason Valley and Smith Valley about combined profits from farming and ranching for the forthcoming year, but some of the risk related to individual crops and individual operations would be "smoothed out" by looking at a combined estimate. If the question were posed about average combined profits over the next ten years, some of the issues related to annual weather and market-force aberrations would tend to be less critical, but predictions further into the future would be tend to be less certain than the near future. The forecast would provide reasonable estimate as to direction (profit or loss) and approximate size of the profit or loss.

In much the same way, input/output models provide estimates that are dependent upon a number of assumptions made regarding the event being predicted, the nature and extent of linkages between industries and sectors of the economy, the "values" associated with costs and revenues, and any and all other factors explicitly or implicitly included in the models. In this context predictions made by input/output models are useful in anticipating how certain events and/or decisions are likely to compare against alternative events or decisions.

The focus of this report is economic impacts related to ranch or farm production and tourism. Economic impact studies attempt to measure and predict actual cash flow changes in a regional economy. Economic impacts occur when money changes hands.

Some environmental amenities such as clean air have value to people and their well-being but do not always involve direct market transactions. These benefits are sometimes called non-market benefits. Examples of such amenities affected by the Walker Basin project are enjoyment of the scenery at Walker Lake as well as enjoyment of the agricultural landscape created by irrigated green fields. Non-market benefits or costs may exist for increases or decreases in wildlife populations, lake levels and acreage that remains in agricultural production. Although these values are important, they are not the focus of this report.

Input/Output Model

The following sections present economic impact discussions for a) Mason Valley and Smith Valley, Nevada, b) Hawthorne, Nevada and c) Bridgeport California and Walker/Coleville, California, all related to the Walker Lake restoration project. For Mason Valley and Smith Valley analyses, the research team utilized an input/output model known as IMPLAN (IMpact Analysis for PLANning)[5]. This software is nationally recognized as a standard economic impact assessment tool, and is used extensively by regional economists. IMPLAN is based on input-output accounting of the flow of goods and services from producers to intermediate and final consumers. Economic impact models built using IMPLAN assess the economic relationships between producers and suppliers in the study area. The IMPLAN model was modified in order to better reflect regional conditions by using crop budgets that represent local practices (Curtis, this report). For Hawthorne, the research team utilized a study completed for the American Sportsfishing Association and revised in January 2008[6] (which was completed using IMPLAN), and arrived at predicted impacts by prorating figures provided within that study for the State of Nevada. An alternative estimate of economic impact analysis was completed for Mineral County utilizing IMPLAN for comparative purposes. For the portions of Mono county, California that are within the Walker Basin, no actual impacts are predicted at this time and there was no need to utilize an input/output model, but a discussion of potential impacts is included herein.

While the research team used 2006 IMPLAN, the figures were adjusted to 2007 dollars to match the crop budgets, which are all in 2007 dollars. All dollar figures are state in 2007 dollars. When dollar figures are developed for a time series, the impacts of inflation often mask underlying trends that would be apparent if amounts were state in "constant dollar" or "real dollars" as measured by purchasing power rather than in "nominal dollars". Since the values herein are state in 2007 dollars, this isn't an issue in this study.

Background Crop and Water-Source Information

The work completed in the G.I.S. Database Development: Water Rights and Distribution[7] and Demographics and Economics[8] resulted in Figures 3 through 6. Figure 3 and Figure 4 are maps indicating crop types in Mason Valley and Smith Valley. Figures 5 and 6 show water sources for these same areas by three categories: 1) ground (well) water only; 2) both ground water and surface water; and 3) surface water (natural flow decree water and storage water) only. The research team did not have access to the individual water right records. The research team based their analysis on the C-125 decree data.

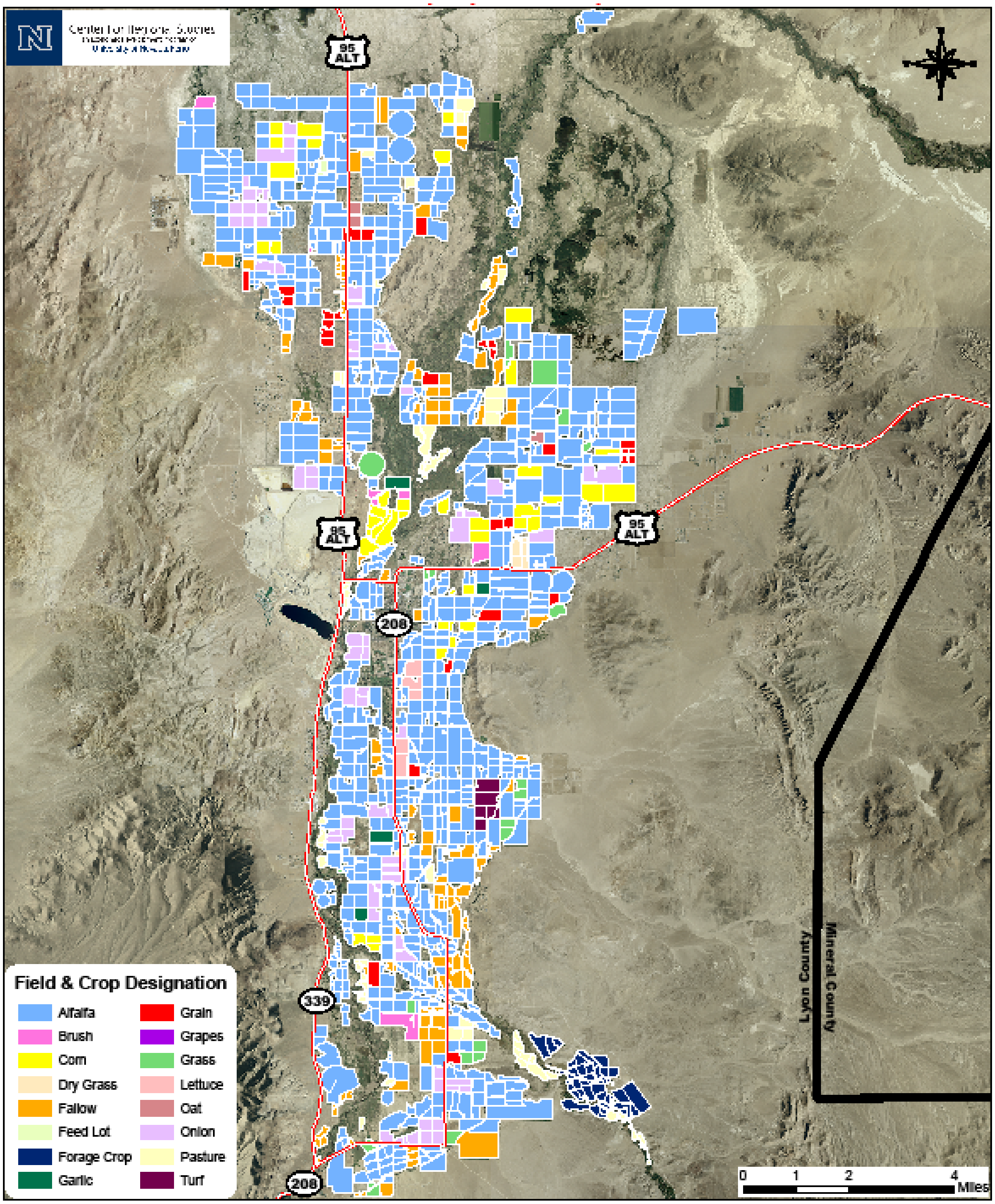


Figure 3. Crop and field designations – Mason Valley.

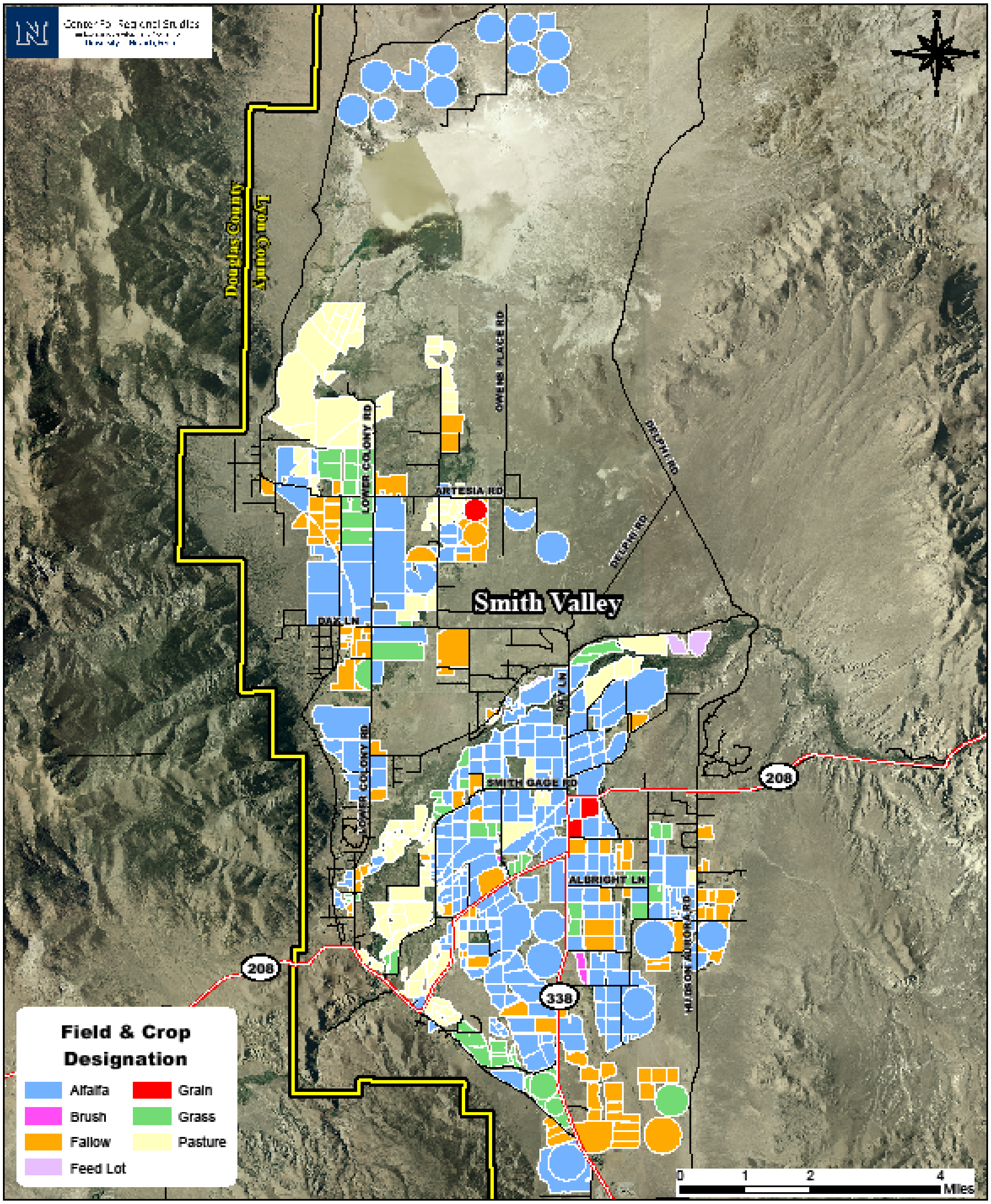


Figure 4. Crop and field designations – Smith Valley.

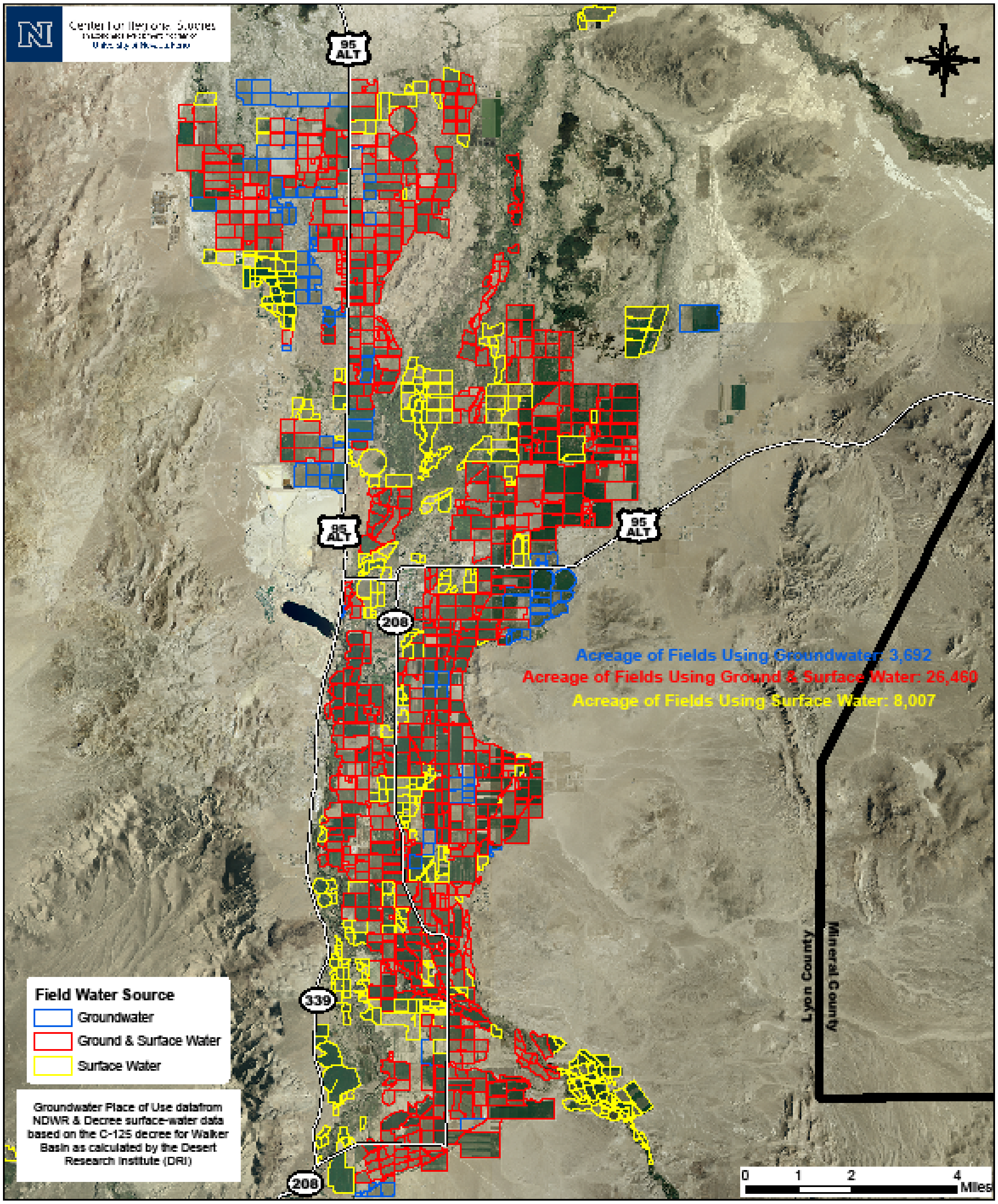


Figure 5. Field water sources – Mason Valley.

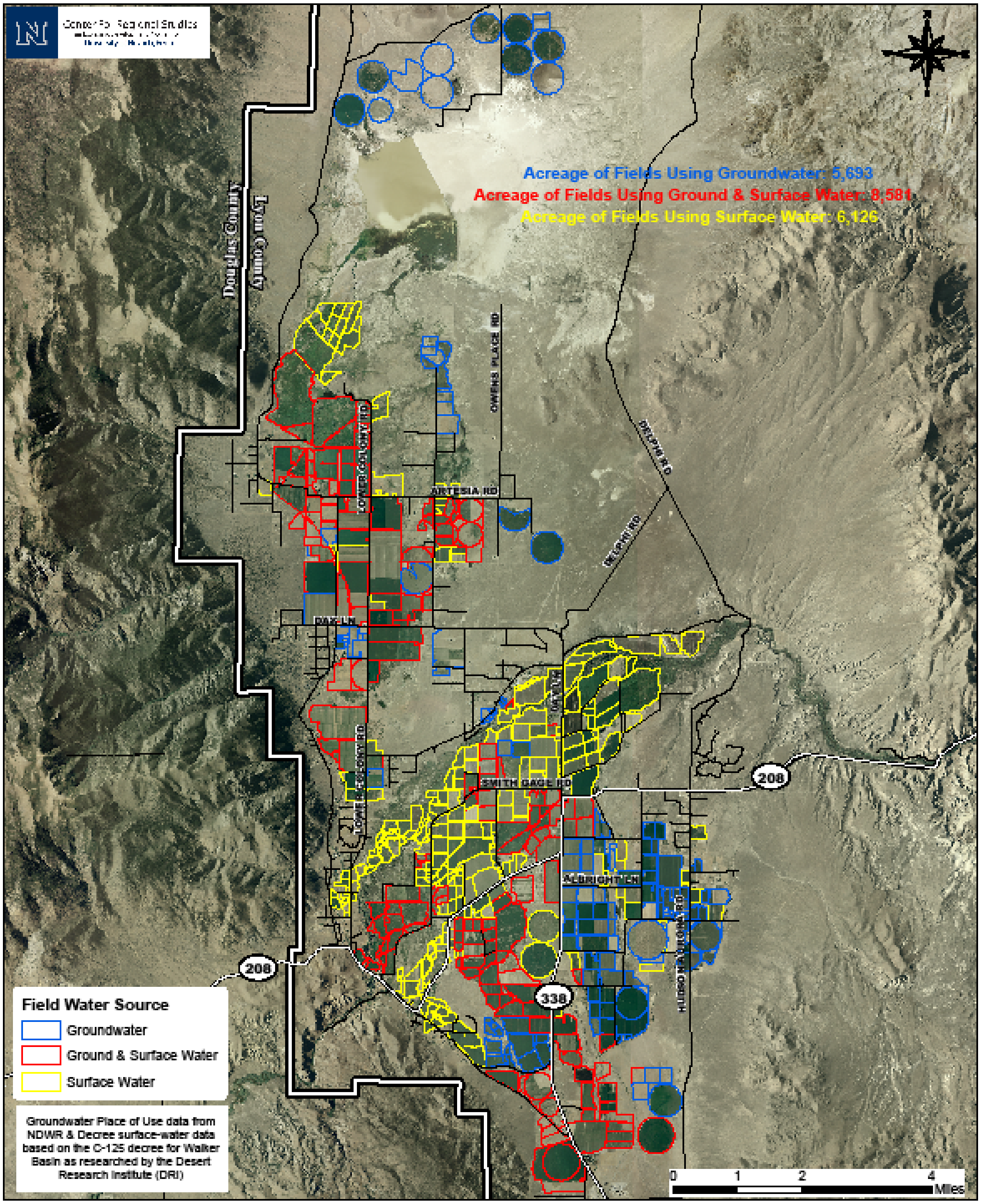


Figure 6. Field water sources – Smith Valley.

From the data in the crop maps and the water source maps we were able to derive a tabulation of types of crops by acreage and water source in Mason Valley and Smith Valley, as presented in Tables 1 and 2.

Table 1. Crop acreage totals and water sources for Mason Valley.

Mason Valley										
Field or Crop Type	Fields Using Ground Water	Acres	Fields Using Ground & Surface Water	Acres	Fields Using Surface Water	Acres	Total Number of Fields	%	Total Acres	%
Alfalfa	76	2,843.5	533	18,437.7	198	4,661.2	807	63.5%	25,942.3	68.0%
Brush	1	4.2	4	133.7	2	208.8	7	0.6%	346.7	0.9%
Corn			38	1,789.8	4	100.9	42	3.3%	1,890.7	5.0%
Dry Grass					4	107.2	4	0.3%	107.2	0.3%
Fallow	15	360.2	74	1,584.4	55	1,120.2	144	11.3%	3,064.9	8.0%
Feed Lot			5	31.1			5	0.4%	31.1	0.1%
Forage Crop			2	62.2	43	754.1	45	3.5%	816.3	2.1%
Garlic			3	140.8	1	71.8	4	0.3%	212.5	0.6%
Grain	4	82.7	20	574.3	7	184.2	31	2.4%	841.2	2.2%
Grapes			1	3.2	4	5.0	5	0.4%	8.2	0.0%
Grass	3	74.8	19	551.8	2	150.8	24	1.9%	777.4	2.0%
Lettuce			5	248.9			5	0.4%	248.9	0.7%
Oat			3	103.6			3	0.2%	103.6	0.3%
Onion	6	321.0	59	2,031.7	3	92.2	68	5.4%	2,444.9	6.4%
Pasture	2	5.8	34	508.8	34	549.1	70	5.5%	1,063.7	2.8%
Turf			6	257.5	1	2.0	7	0.6%	259.6	0.7%
Totals	**107**	**3,692.2**	**806**	**26,459.6**	**358**	**8,007.4**	**1,271**	**100.0%**	**38,159.2**	**100.0%**

Sources:
2007 & 2008 field mapping conducted on 2006 1-meter aerial photography (NAIPS).
2008 crop budgets developed by Cooperative Extension, University of Nevada.
Groundwater Place of Use data from NDWR and Decree surface-water data based on the C-125 decree for Walker Basin as calculated by the Desert Research Institute (DRI).

Table 2. Crop acreage totals and water sources for Smith Valley.

Field or Crop Type	Fields Using Ground Water	Acres	Fields Using Ground & Surface Water	Acres	Fields Using Surface Water	Acres	Total Number of Fields	%	Total Acres	%
Alfalfa	91	4,040.2	78	4,105.8	103	3,257.6	272	48.5%	11,403.6	55.9%
Brush			1	16.4	2	26.8	3	0.5%	43.2	0.2%
Fallow	36	1,024.0	42	1,545.3	33	742.2	111	19.8%	3,311.5	16.2%
Feed Lot					4	106.8	4	0.7%	106.8	0.5%
Grain			3	159.6			3	0.5%	159.6	0.8%
Grass	13	424.5	20	1,052.8	20	487.4	53	9.4%	1,964.7	9.6%
Pasture	12	204.0	41	1,701.2	62	1,505.4	115	20.5%	3,410.6	16.7%
Total	**152**	**5,692.7**	**185**	**8,581.0**	**224**	**6,126.2**	**561**	100.0%	**20,399.9**	100.0%

Sources:
2007 & 2008 field mapping conducted on 2006 1-meter aerial photography (NAIPS).
2008 crop budgets developed by Cooperative Extension, University of Nevada.
Groundwater Place of Use data from NDWR and Decree surface-water data based on the C-125 decree for Walker Basin as calculated by the Desert Research Institute (DRI).

These present “baseline conditions” from which we can make certain determinations and assumptions as set forth in this report. We realize that the crop maps present just one set of conditions and that crop changes, including those that are part of rotations, occur from year to year. None the less, the data provide us with a useful starting point for making comparisons relative to what may occur due to acquisition of water rights.

Using data from the crop budgets developed by Kynda Curtis et al the their Economic Analysis of Water Conservation Practices for Agricultural Producers in the Walker River Basin[9] and utilizing the IMPLAN input/output model, economic impacts in Mason Valley and Smith Valley associated with a number of crops were estimated, as presented in Table 3. The research team determined that the value added factors generated by IMPLAN were the most appropriate figures to use for estimating and comparing economic impacts, since this factor is much like a “gross regional product”, while the total output factors generated by IMPLAN are much like total sales adjusted for changes in inventory.

Table 3. Estimated annual economic impacts associated with one acre of various crops for the combined region of Mason Valley and Smith Valley, Nevada.

Alfalfa	Direct	Indirect	Induced	Total
Labor Income	$ 73	$ 61	$ 17	$ 151
Value Added	$ 476	$ 101	$ 40	$ 617
Employment	0.007	0.002	0.001	0.010
Onion	Direct	Indirect	Induced	Total
Labor Income	$ 1,983	$ 643	$ 343	$ 2,969
Value Added	$ 3,251	$ 1,296	$ 778	$ 5,324
Employment	0.054	0.016	0.011	0.080
Wild Rye for Seed	Direct	Indirect	Induced	Total
Labor Income	$ 150	$ 35	$ 24	$ 209
Value Added	$ 580	$ 64	$ 55	$ 699
Employment	0.005	0.001	0.001	0.007
Wine Grapes	Direct	Indirect	Induced	Total
Labor Income	$ 2,169	$ 209	$ 310	$ 2,688
Value Added	$ 4,067	$ 383	$ 703	$ 5,153
Employment	0.040	0.006	0.009	0.055
Switchgrass	Direct	Indirect	Induced	Total
Labor Income	$ 150	$ 112	$ 34	$ 296
Value Added	$ (2)	$ 143	$ 78	$ 219
Employment	0.005	0.006	0.001	0.012
Teff for Seed	Direct	Indirect	Induced	Total
Labor Income	$ 165	$ 150	$ 41	$ 356
Value Added	$ 443	$ 191	$ 93	$ 728
Employment	0.008	0.008	0.001	0.016
Teff for Hay	Direct	Indirect	Induced	Total
Labor Income	$ 165	$ 151	$ 41	$ 357
Value Added	$ 332	$ 184	$ 93	$ 609
Employment	0.008	0.008	0.001	0.017
Two Row Malt Barley	Direct	Indirect	Induced	Total
Labor Income	$125	$53	$23	$202
Value Added	$838	$121	$53	$1,011
Employment	0.005	0.001	0.001	0.007

From the data in the crop budgets and the economic impact estimates, Table 4 was developed, which summarizes per acre values associated with various crops, including net budget values to farmers, annual water use, and economic impact to the combined area of Mason Valley and Smith Valley. As with the prior table, these are general averages. Crop yields vary from field to field due to differences in soils, microclimates, irrigation practices and other factors, and there may be significant differences between Mason Valley and Smith Valley due to elevation differences and the impact on growing season.

Table 4. Crop net values to farmers, annual water use and economic impact.

		Representative	Per Acre Per Year			
		Farm / Plot	(To the farmer)	Annual	(To community)	
Crop		Size	Budget	Water Use	Economic	In Rotation
Code	Crops	(Acres)	Net Value	(Approx A.F.)	Impact	With
A	Alfalfa	402	$ 119.03	4	$ 617	C, D, E, F, G, H
B	Switchgrass	202	$ (393.11)	3	$ 219	
C	Teff seed	62	$ 148.06	3	$ 728	
D	Teff hay	62	$ 37.05	3	$ 609	
E	Baby leaf lettuce	402	$ 319.65	1	$ 6,629	
F	Onions	450	$ 478.37	3	$ 5,324	A, C, D, E, G, H
G	Two row malt barley	322	$ 399.83	2	$ 1,011	
H	Great basin wild rye (seed)	202	$ 49.49	1	$ 699	
I	Grapes (wine grapes)	5	$ 288.06	0.3	$ 5,153	
J	Great basin wild rye (desert)					
	Year 1		$ (306.00)	1		
	Years 2 forward		taxes	0	$ -	
	Crops for which a separate budget was not developed.					
K	Grass hay	Similar to alfalfa for benefit to farmers, water consumption, and economic impact.				
L	Small grain (hay)	Similar to teff hay.				
M	Baby leaf lettuce - mechanized	Similar to leaf lettuce, but more benefit to farmer and less economic impact due to mechanized harvesting. Net to farmer: $3,279/acre. Economic impact to region: $5,502/acre.				
N	Spinach	Similar to baby leaf lettuce				
O	Garlic	Similar to onions but less benefit to farmer, less water used and less economic impact.				
P	Corn	Similar to small grains / teff hay.				
Q	Pasture (grazing)	$125/acre net annual value to the farmer, and utilizes 4 A.F. of water/year. (Estimated benefit to farmer based upon grazing 1 AUM (cow and calf), rent of $25 per animal unit monthly (AUM) for 5 months). Econ. Impact $67/acre.				

For some of the crops presented in Table 4, the crops cannot be evaluated individually but consideration must be given to typical crop rotations. For example, in order to prevent disease, onions are typically not planted continuously in the same field. Typically after one or two years of onions, another crop is planted. Likewise, alfalfa is usually "rotated" out of fields after five to seven years to achieve highest production. Farmers typically try to maintain an alfalfa stand as long as it will produce strong yields to amortize the establishment cost over the longest period possible. In fields where the water source is lower priority natural flow decree without substantial storage water or supplemental ground water coverage, part of the normal rotation seems to be for fields to lay fallow occasionally. Therefore, analysis of these crops should to be done for the entire rotation, not simply for the individual crops. Presented in Table 5, 1.6 and 1.7 are three "typical" crop rotations.

One aspect of water rights is "duty". The duty of water operates as a limit on the amount of water that may be utilized on any field, and is designed to prevent waste. In Mason Valley and Smith Valley, the duty, or maximum application of irrigation water, varies from 3.2 acre feet (natural flow decree and storage) to 4.3 acre feet for some of the sandy areas up on the benches, to 4.0 acre feet for fields that have just well water. For simplicity in calculations, an average of 4 acre feet was used throughout this analysis.

Table 5. Typical alfalfa and fallow rotation with net budget, water use and economic impact per acre.

Rotation 1 - Alfalfa and Fallow		Budget	Water	Economic
Year	Crop	Net Value	Use	Impact
1	Alfalfa	$ 119	4	$ 617
2	Alfalfa	$ 119	4	$ 617
3	Alfalfa	$ 119	4	$ 617
4	Alfalfa	$ 119	4	$ 617
5	Alfalfa	$ 119	4	$ 617
6	Alfalfa	$ 119	4	$ 617
7	Fallow (14.3% of time)	$ -	0	$ -
	Totals	$ 714	24	$ 3,702
	Average year	$ 102.00	3.4	$ 529

Table 6. Typical alfalfa and small grain hay rotation with net budget, water use and economic impact per acre.

Rotation 2 - Alfalfa & Small Grain Hay		Budget	Water	Economic
Year	Crop	Net Value	Use	Impact
1	Alfalfa	$ 119	4	$ 617
2	Alfalfa	$ 119	4	$ 617
3	Alfalfa	$ 119	4	$ 617
4	Alfalfa	$ 119	4	$ 617
5	Alfalfa	$ 119	4	$ 617
6	Alfalfa	$ 119	4	$ 617
7	Small grain hay	$ 37	4	$ 609
	Totals	$ 751	28	$ 4,311
	Average year	$ 107.29	4.0	$ 616

Table 7. Typical onion and alfalfa rotation with net budget, water use and economic impact per acre.

Rotation 3 - Onion (2 years) & Alfalfa		Budget	Water	Economic
Year	Crop	Net Value	Use	Impact
1	Alfalfa	$ 119	4	$ 617
2	Alfalfa	$ 119	4	$ 617
3	Onions	$ 478	3	$ 5,324
4	Onions	$ 478	3	$ 5,324
5	Alfalfa	$ 119	4	$ 617
6	Alfalfa	$ 119	4	$ 617
7	Alfalfa	$ 119	4	$ 617
8	Alfalfa	$ 119	4	$ 617
	Totals	$ 1,670	30	$ 14,350
	Average year	$ 208.75	3.8	$ 1,794

Another aspect of this analysis that influences both agricultural production and water rights acquisition is the reliability of the water rights. From the standpoint of water rights acquisition, the reliability of water rights is related to the probability that the water will consistently make it to the Wabuska Gauge year after year. Perceived reliability will probably influence the value that will be paid for water rights, as well as the quantity of water rights that must be acquired in order to achieve the goal of 50,000 acre feet reaching the Wabuska Gauge annually. From the perspective of agricultural production, reliability of water rights is associated with the probability that water will be available throughout the growing season to irrigate crops. Farmers typically will not grow the high value/high investment crops in fields without primary groundwater or substantial coverage of most or all of the fields with supplemental ground water. For purposes of this analysis, the assumed levels of reliability associated with different sources of water are presented in Table 8.

Table 8. Estimated reliability of water rights.

Types of water rights:	Est. average reliability
Natural flow decree (depends upon priority - reliability range is larger)	40-50%
Storage water (Supplemental and New Lands)	70%
Primary groundwater	100%
Supplemental groundwater + natural flow decree	50%-100%

To project the economic impact associated with proceeds paid for water rights, a very useful piece of information would be what the value(s) will be paid for water rights. Since this is not known by this research team conducting the economic impact analysis, we will be making some assumptions about these values. To provide flexibility in adjusting those assumptions, economic impacts associated with water rights purchase or water lease have been calculated on a "standard" basis of impacts per $1,000 of acquisition price per acre foot and impacts per $100 of lease value per acre foot, and these values are presented in Table 9.

Table 9. Annual economic impact of proceeds from water rights per acre foot.

Impact per acre foot: Hypothetical Water Rights Sale Income. Sell water rights at $1000 per acre foot, invest money at 6% income per year, basis = $0 with capital gains tax 15%, savings plus federal income tax factor = 25%.				
	Direct	Indirect	Induced	Total
Labor Income	$ 5	$ 1	$ 1	$ 6
Value Added	$ 11	$ 1	$ 2	$ 14
Employment	$ 0	$ 0	$ 0	$ 0
Total Output	$ 17	$ 2	$ 2	$ 21
Impact per acre foot: Hypothetical Water Lease ($100 per acre foot), subject to assumed savings plus federal income tax factor = 25%				
	Direct	Indirect	Induced	Total
Labor Income	$ 9	$ 1	$ 1	$ 11
Value Added	$ 21	$ 2	$ 3	$ 26
Employment	0.0	0.0	0.0	0.0

For purposes of making comparisons, the proceeds from a sale of water rights are converted into an annualized cash flow by making an assumption that the proceeds will be taxed at a capital gains rate of 15 percent and the after-tax proceeds will be invested at an annual rate of return of six percent. This lease income and the cash stream from invested after-tax sale proceeds are both reduced by 25 percent to reflect impact of income taxes and savings on the disposable income stream. These standard values will need to be modified by the assumed purchase or lease values, and by assumptions about whether any of the proceeds are likely to be spent in the local economy. Those values will be set forth in the four scenarios presented below.

Utilizing the data presented herein and referenced in the other reports, it is now possible to look at some scenarios for how water rights might be acquired and what economic impacts might occur under these various scenarios.

SECTION 2: ECONOMIC IMPACT ANALYSES

The research team did not undertake economic impact analysis for the Shurz, Nevada area, nor did it hold community meetings in Shurz. No retail sales information is available from the Nevada Department of Taxation for businesses in Shurz. The Nevada Department of Employment Training and Rehabilitation shows 14 entities in Shurz that have covered employment: eight are tribal entities, two are federal entities, two are temporary – related to dam repair, and one is a local disposal company. With no plan for acquisition of water rights from the tribe, the research team did not envision there being any economic impact from this project.

Mason Valley and Smith Valley

Currently the acquisition of water rights is targeted in the Nevada portions of the Walker Basin, which essentially means Mason Valley and Smith Valley, two agricultural areas within Lyon County, Nevada. The key question to be answered, simply put, is this: "What will be the economic impacts of acquiring water rights in Mason Valley and Smith Valley, destined for Walker Lake, in quantities sufficient for 50,000 acre feet annually to reach the Wabuska Gauge?" The answer, unfortunately, is not as simple as the question. The answer depends upon what economic activity is "displaced" by the water rights acquisitions, and what happens with the proceeds received by those conveying water rights.

Presented below are four different scenarios as to how this could occur, along with estimates of the economic impacts that might be associated with each of these scenarios: scenario 1) land goes from agriculture to desert; scenario 2) existing crop rotations and farming practices are altered to achieve water savings; scenario 3) alternative crops that require less water are cultivated; and, scenario 4) other (non-agricultural) sources of water rights are procured. These scenarios are based, in part, upon information developed by other research teams working on the Walker Basin project.

Scenario 1 – Agricultural land taken out of production and goes from agriculture to desert

Under this scenario, there would potentially be two different areas of economic impacts: 1) the impacts resulting from changes in agricultural production (hereinafter referred to as the agricultural economic impacts, and; 2) the impacts resulting from the proceeds from the sale or water rights or lease of water to a party outside the regional economy (hereinafter referred to as the water rights proceeds impact). The economic impacts that have been projected are for the region comprised of Mason Valley and Smith Valley.

1. Agricultural economic impacts: When agricultural land is taken out of production, our economic impact scenario assumes that exports equal to the original amount of production are no longer sold. This is the direct impact. Indirect impacts are the reductions in expenditures for labor, materials, and profits to the farmer, all of which would have also resulted in other expenditures by households (induced impacts) through the local economy. If the land taken out of production had been producing crops as shown in Table 5 (Rotation 1), then the farmer would lose the net benefit from that field averaging $102 per acre per year, and the community would be losing the average total economic impact (direct, indirect and induced) of $529 per acre per year for every acre taken out of production, which is inclusive of the loss to the farmer. As indicated in Table 6 by Rotation 2, which represents a field primarily used to grow alfalfa with a rotation of small grain hay and no fallow years (which would be indicative of a water source with higher reliability), taking this field out of production would result in a loss of the net benefit from agricultural production averaging $107 per acre per year to the farmer, and a corresponding average negative economic impact of $616 per acre per year to the community. Rotation 3 in Table 7, which is one possible rotation that includes onions, indicates that taking this land out of production would result in an average net loss to the farmer in the amount of approximately $209 per acre per year, and an average negative economic impact to the region, inclusive of the loss to the farmer, of approximately $1,794 per acre per year. Since grass hay is relatively close to alfalfa hay in terms of net to the farmer and economic impact, these three rotations directly or indirectly represent about 80% of the agricultural land in Mason Valley and in Smith Valley based upon the crop acreages indicated in Tables 1 and 2.
2. Water rights proceeds impacts: The first step in estimating economic impacts related to the proceeds from the sale of water rights is to estimate what the price for water rights might be. While we don't know what the outcome of future negotiations might be, the research team found three pieces of public information that provide some indication of the possible value range, as shown in Table 10. Assuming that Table 9 provides figures "in the ballpark", it would appear that values could be around $2,900 per acre foot for water rights that have 100% reliability, with values adjusted downward somewhat proportionally for water rights that have lower reliability.

   Therefore, if a farmer had water rights that were natural flow decree without any storage water or supplemental ground water, these might have a value of $1,150 to $1,450 per acre foot, so based upon a duty of four acre feet, the farmer might expect a value of $4,600 to $5,800 per acre of land for water rights. Projecting the economic impact that might result from the proceeds paid for the water rights involves trying to predict human behavior. Will those selling water rights want to retain land on which they would have to pay property taxes (which would likely increase because they would lose the agricultural exemption) and which likely would have little economic benefit any time in the near future? Under these circumstances, a rational economic decision might be to sell the land along with the water rights. Therefore, the farmer might prefer a sale of the land and water rights, in which case the value might be more like $5,800 to $7,000 per acre.

The first question is would this sort of transaction pass the test of a rational economic decision? Assuming the farmer sold just the water rights with a 50 percent reliability value, receiving $5,800 per acre, and that the farmer paid capital gains taxes at a rate of 15%, leaving a net after tax amount of $4,930 per acre, and that this money could be invested at a rate of return of six percent per year, in effect the farmer would have an income from this investment that would equate to about $296 per acre of land taken out of production. This compares favorably to the net income produced from the three crop rotations shown in Tables 5, 6, and 7.

The next relevant question about human behavior is whether the seller will continue to reside in the region. If the seller conveys all of the water rights (and perhaps land as well), what is the likelihood the seller will relocate outside the region? If the seller relocates, the expectation that any of the proceeds or future income from investment of the proceeds will be expended in the region would be negligible. If the seller continues to reside in the region but is not engage in farming or some other business enterprise of equivalent scale, it is reasonable to assume that only a very small portion of the proceeds from the water rights or from investment of the water rights would be spent in the region. Therefore, under this scenario, the best case is that the investment income from the water rights sale proceeds will generate the small impacts indicated in Table 11, while the worst case is that there will be no economic impacts from the sale proceeds.

Table 10. Calculated value of water rights per acre foot to use in economic impact analysis.

From ranch sales					
Parcel	Acreage	Value/acre Raw Land	Sales Price	Computed Water Value	Assumed Reliability
12-011-12	313	$ 1,200	$ 4,000,000	$ 2,894.89	100%
12-191-23	201.8	$ 1,200	$ 1,779,061	$ 1,903.99	66%
From water lease:					
	Annual Rate per acre foot	Capitalization Rate		Computed Value	Assumed Reliability
Paiute water lease	$ 225	8.00%		$ 2,812.50	90-95%

Table 11. Agricultural land taken out of production and water rights sold.

Crop / Crop Rotation	Assumed Water Rights Reliability	Price Per Acre Foot[a]	Ag. Economic Impact[b]	Proceeds Economic Impact[c]	Combined Economic Impact
Rotation 1 - Alfalfa & fallow	40%	$ 1,160	$ (529)	$ 65	$ (464)
Rotation 1 - Alfalfa & fallow	50%	$ 1,450	$ (529)	$ 81	$ (448)
Rotation 1 - Alfalfa & fallow	60%	$ 1,740	$ (529)	$ 98	$ (431)
Rotation 2 - Alfalfa & small grain hay	70%	$ 2,030	$ (616)	$ 114	$ (502)
Rotation 2 - Alfalfa & small grain hay	80%	$ 2,320	$ (616)	$ 130	$ (486)
Rotation 2 - Alfalfa & small grain hay	100%	$ 2,900	$ (616)	$ 163	$ (453)
Rotation 3 - Onions & alfalfa	100%	$ 2,900	$ (1,794)	$ 163	$ (1,631)
Pasture	40%	$ 1,160	$ (67)	$ 65	$ (2)
Pasture	50%	$ 1,450	$ (67)	$ 81	$ 14
Pasture	60%	$ 1,740	$ (67)	$ 98	$ 31

[a] Price per acre foot calculated by multiplying estimated value of $2,900 per acre foot x assumed water rights reliability factor.

[b] Agriculture economic impact values for the crop rotations were taken from Tables 5, 6 and 7 and for pasture, from Table 4. Actual yields probably vary somewhat with different levels of water rights reliability.

[c] Water rights proceeds economic impacts were estimated by multiplying the price per acre foot x 4 acre feet per acre of land x the total value added component per $1,000 of water rights proceeds found in Table 9.

Other issues related to Scenario 1: There are some other important issues related to taking agricultural land out of production that are not included in the economic impact analysis. One of these is that the water should not initially be completely stripped from the land without reserving some water to be used for re-vegetation of the land with desert plants to prevent wind erosion and all the problems associated therewith. The cost of this has not been factored into this analysis. Minimally, some of the cost to establish great basin wild rye would be incurred, which has been estimated in excess of $306 per acre by extracting portions of one of the crop budgets developed by Kynda Curtis et al[10]. It is possible that up to half of this cost could be covered through a Conservation Reserve Program, which would also pay the farmer $14 to $15 per acre for a ten year period.

Another very significant issue is what happens to the share of the irrigation district's operation and maintenance (O&M) costs that were being paid by a farmer who sells water rights and the land is taken out of agricultural production? According to Ken Spooner, current manager of the Walker River Irrigation District (WRID), the O&M assessments for WRID, storage water, and independent assessment for ditch deliveries average around $25 per acre. Depending upon how and to whom this burden is shifted, there could be significant impacts not included in this analysis. If this burden becomes an ongoing liability of the purchaser there would probably be little economic impact to the region, but the acquisition cost for water rights would be substantially higher since it would necessarily include a provision for a permanent funding source to cover these recurring costs. This is the intent of a proposal being promoted by WRID for how to handle "vacant assessments." However, if termination of the use of water for agriculture also extinguished the appurtenant share of the irrigation district operating and maintenance budget, the cost burden would be shifted to other users and this would have significant economic impacts beyond those presented herein, and in the worst case might significantly impact the financial feasibility of other agricultural production dependent upon the irrigation district, storage waters and/or the ditch system.

Scenario 2 – Existing crop rotations and farming practices are altered to save water

Another approach to obtaining more water for Walker Lake rather than being used for agriculture would be to modify crop rotations and farming practices. Under current water law, there is no incentive for farmers to conserve water; in fact there is a disincentive due to the "use it or lose it" nature of beneficial use requirements. Making a rather significant assumption that this can be changed, this scenario examines the economic impacts that would result from altering farming practices for existing crops in order to save water, with the further assumption that water rights associated with the savings could be sold or leased. Some of these alterations are fairly straight forward. Presented below are three examples:

<u>Example 1: Modify Alfalfa and Fallow Rotation</u>

In looking at Rotation 1 in Table 5, it would be rather easy to increase the number of years the land is fallowed. For this example, the number of years fallow was increased to three, assuming that alfalfa stalks and roots could continue to prevent erosion for this period of time so long as livestock was kept off the field.

1. Agricultural economic impacts: Making this change in crop rotation would result in the reduced average net to the farmer as indicated in Table 12, Rotation 1A. The average net to the farmer per acre from agriculture would decrease from around the $102 value shown in Table 5 to approximately the $79 value shown in Table 12, or an order of magnitude of 20% decrease in the average net to the farmer from agriculture. At the same time, the economic impact from agriculture would decrease from an average of around $529 per acre to an average of approximately $411 per acre, again indicating a decrease on the order of magnitude of 20%.
2. Water rights proceeds impacts: If one assumes that this land has natural flow decree water rights with 50% reliability, then it would be reasonable to also assume that, on average, only 50% of the duty would arrive at the Wabuska Gauge. Therefore, the lease value would be approximately half of the lease rate suggested in Table 10, or $112.50 per acre foot per year. With a duty of 4 acre feet per acre, the net proceeds to the farmer at the 50% reliability rate would average $450 per acre per year under this example, as indicated in Table 12. In regard to lease fees for the water, since the farmer would remain in business and continue to reside in the region, there is a strong likelihood that some of the proceeds from the water leasing would continue to be spent within the region. The lease payments would, under these circumstances, have impacts similar to payments under a conservation reserve program (CRP). The projected economic impact from the water leasing proceeds is estimated at $117 per year during the years received.
3. Combined impacts: The combined average annual net to the farmer, projected at about $229 per acre under this scenario, compares very favorably with the average annual net indicated for Rotation 1 in Table 5 of $102 per acre. The

combined projected economic impact is somewhat less ($450 per acre vs. $529 per acre), indicating a 15 percent reduced impact on the regional (Mason Valley and Smith Valley) economy. Average water consumption would be projected to decrease by 0.7 acre feet per acre per year.

Table 12. Rotation 1A: modified alfalfa and fallow rotation with net budget, water use and economic impact per acre.

Year	Crop	Net Value	from W.R.	to Farmer	Use	Impact	W.R. Lease[b]	Impact
1	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
2	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
3	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
4	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
5	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
6	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
7	Fallow (33.3% of time)	$ -	$ 450	$ 450	0	$ -	$ 117	$ 117
8	Fallow	$ -	$ 450	$ 450	0	$ -	$ 117	$ 117
9	Fallow	$ -	$ 450	$ 450	0	$ -	$ 117	$ 117
	Totals	$ 714	$ 1,350	$ 2,064	24	$ 3,702	$ 351	$ 4,053
	Average year	$ 79	$ 150	$ 229	2.7	$ 411	$ 39	$ 450

[a]"Proceeds" from water rights assumes rotation 1A is grown in fields with natural flow decree water rights at 50% reliability, lease value $112.50/AF, multiplied times 4 AF.

[b]Economic impact calculated as follows: Lease value per AF x Number of AF leased x $26/$100 lease dollars received (from Table 9).

Example 2: modify alfalfa and small grain hay rotation

In looking at Rotation 2 presented in Table 6, it would be rather easy to increase the number of years that small grain hay is cultivated to three years resulting in a nine-year rotation.

1. Agricultural economic impacts: Making this change in crop rotation would result in the reduced average net to the farmer as indicated in Table 13, Rotation 2A. The average net to the farmer per acre from agriculture would decrease from around the $107 value shown in Table 6 to approximately the $92 value shown in Table 13, or an order of magnitude of 16% decrease in the average net to the farmer from agriculture. At the same time, the economic impact from agriculture would remain essentially the same ($614 per acre versus $616 per acre annually).

2. Water rights proceeds impacts: Within this example, the assumption is that the land has supplemental ground water, so the reliability is assumed to be 75%. In the third year of small grain hay, shortly after harvest the alfalfa seed would be drilled into the grain stubble and irrigation would begin in order to re-establish the alfalfa stand, requiring irrigation so no water savings are projected in this year. In the first two years of growing small grain hay there would be water savings of one acre foot per year, and with 75% reliability under this scenario, the farmer would receive $340 per year ($170 per acre foot) as indicated in Table 13. Again, because the continuation of the farming operations, it is reasonable to assume that the proceeds from the water rights leasing would generate local economic impact, estimated at $88 per year during years water-leasing proceeds were received.

3. Combined impacts: The combined average annual net to the farmer, projected at about $167 per acre under this scenario as shown in Table 13, compares very favorably with the average annual net indicated for Rotation 2 in Table 6 of $107 per acre. The combined projected economic impact is fairly close ($634 per acre vs. $616 per acre), indicating no significant change in impact on the regional (Mason Valley and Smith Valley) economy. Average water consumption would be projected to decrease by 0.4 acre feet per acre per year. The average net to the farmer, the economic impact and the water savings could all be improved by adding additional years of small grain hay to this modified rotation.

Table 13. Rotation 2A: modified alfalfa & small grain hay rotation with net budget, water use and economic impact per acre

2A - Alfalfa & Small Grain Hay		Budget	Proceeds[a]	Total Net	Water	Economic	Econ Impact	Total Econ
Year	Crop	Net Value	from W.R.	to Farmer	Use	Impact	W.R. Lease[b]	Impact
1	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
2	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
3	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
4	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
5	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
6	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
7	Small grain hay	$ 37	$ 338	$ 375	2	$ 609	$ 88	$ 697
8	Small grain hay	$ 37	$ 338	$ 375	2	$ 609	$ 88	$ 697
9	Small grain hay	$ 37	$ -	$ 37	4	$ 609	$ -	$ 609
	Totals	$ 825	$ 676	$ 1,501	32	$ 5,529	$ 176	$ 5,705
	Average year	$ 92	$ 75	$ 167	$ 4	$ 614	$ 20	$ 634

[a] "Proceeds" from water rights assumes rotation 2A is grown in fields with natural flow decree plus supplemental water rights at 75% reliability, lease value $168.75/AF, multiplied times 2 AF.

[b] Economic impact calculated as follows: Lease value per AF x Number of AF leased x $26/$100 lease dollars received (from Table 9).

Example 3: modify onion and alfalfa rotation

This example is based upon an alteration to Rotation 3 shown in Table 7 by cutting off irrigation to the alfalfa after the second cutting in years five, six and seven, as shown in Table 14 below.

According to the publication Intermountain Alfalfa Management[11], "Research and field experience throughout much of California have demonstrated that irrigation water can be withdrawn or reduced following the first cutting without significantly reducing stand density or yields the following year. Deficit irrigating forces alfalfa into a drought-induced dormancy. The stand usually recovers fully when it receives adequate water the next production season". This change in alfalfa cultivation is "speculative", and certainly warrants field study before it should be widely embraced.

The projected yield of 4.25 tons per acre is estimated based upon the observation that the first two cuts typically have substantially higher yields than the third and fourth cuts. Water consumption was based upon a typical irrigation schedule of three irrigations prior to the first cut, two irrigations prior to the second cut, two irrigations prior to the third cut and only one irrigation prior to the fourth cut. Several other expenses were allocated by the same percentage as the water. It was assumed that the aftermath grazing would be approximately the same, but this may not fit with the typical schedule of brining cattle in from high pasture in the Fall.

Combining the modified alfalfa cultivation plan with the onion/alfalfa rotation shown in Table 7 could result in the modified rotation shown in Table 15, with the impacts discussed below.

1. Agricultural economic impacts: Making this change in crop rotation would result in the reduced average net to the farmer as indicated in Table 15, Rotation 3A. The average net to the farmer per acre from agriculture would decrease from around the $209 value shown in Table 7 to approximately the $168 value shown in Table 15, or an order of magnitude of 20% decrease in the average net to the farmer from agriculture. At the same time, the economic impact from agriculture would decrease slightly from an average of around $1,794 per acre to an average of approximately $1,722 per acre.
2. Water rights proceeds impacts: Within this example, the assumption is that the land has primary ground water, so the reliability is assumed to be 100%. In this example, every other year of growing alfalfa there would be water savings of one and one-half acre feet per year, and with 100% reliability under this scenario, the farmer would receive $337 per year as indicated in Table 15. In the years onions are grown, there would be water available for lease in the amount of one acre foot per year, with the farmer receiving $225 per acre. Again, because the continuation of the farming operations, it is reasonable to assume that proceeds from the water leasing would generate local economic impact.
3. Combined impacts: The combined average annual net to the farmer, projected at about $350 per acre under this scenario as shown in Table 15, compares very favorably with the average annual net indicated for Rotation 3 in Table 7 of $209 per acre. The combined projected economic impact is fairly close ($1,770 per acre vs. $1,794 per acre), indicating no significant change in impact on the regional (Mason Valley and Smith Valley) economy. Average water consumption would be projected to decrease by an average of 0.6 acre feet per acre per year.

Table 14. Modified alfalfa budget for two cuts.

Alfalfa Budget Per Acre			
Gross Income	4 cuts	2 cuts	
Alfalfa Hay	$ 804.00	$ 569.50	4.25 tons @$134
Aftermath grazing	$ 90.00	$ 90.00	
Total Gross Income	$ 894.00	$ 659.50	
Operating Costs			
Rodent Control	$ 1.50	$ 1.50	
Insecticide	$ 30.00	$ 30.00	
Herbicide	$ 55.00	$ 55.00	
Fertilizer	$ 42.00	$ 42.00	
Irrigation	$ 111.00	$ 69.38	reduce water use by 37.5%
Operator Labor	$ 75.00	$ 75.00	owner has free time
Accounting & Legal	$ 5.00	$ 5.00	
Fuel & Lube	$ 70.90	$ 44.31	62.50%
Maintenance	$ 32.50	$ 32.50	
Utilities	$ 17.50	$ 10.94	62.50%
Miscellaneous	$ 5.00	$ 5.00	
Operating Capital Interest	$ 11.58	$ 11.58	
Total Operating Costs	$ 456.98	$ 382.21	
Income Above Operating Costs	$ 437.02	$ 277.29	
Ownership Costs			
Cash Overhead Costs:	$ 154.51	$ 154.51	
Noncash Overhead Costs:			
Buildings, Improvements & Equipment	$ 30.14	$ 30.14	
Machinery & Vehicles	$ 133.33	$ 83.33	62.50%
Total Noncash Overhead Costs	$ 163.47	$ 113.47	
Total Ownership Costs	$ 317.98	$ 267.98	
Total Costs	$ 774.96	$ 650.19	
Net Projected Returns	$ 119.04	$ 9.31	
Projected Water Savings	1.5	acre feet	
Source: Budget for 4 cuts - Curtis, Kynda R,, Mimako Kobayashi and Carol Bishop. "Northwestern Nevada Alfalfa Hay Establishment, Production Costs & Returns, 2008". UNCE Fact Sheet			

Table 15. Rotation 3A: modified onion & alfalfa rotation with net budget, water use and economic impact per acre.

Year	Crop	Net Value	from W.R.	to Farmer	Use	Impact	W.R. Lease[b]	Impact
1	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
2	Alfalfa - 2 cuts	$ 9	$ 338	$ 347	2.5	$ 425	$ 88	$ 513
3	Onions	$ 478	$ 225	$ 703	3	$ 5,324	$ 59	$ 5,383
4	Onions	$ 478	$ 225	$ 703	3	$ 5,324	$ 59	$ 5,383
5	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
6	Alfalfa - 2 cuts	$ 9	$ 338	$ 347	2.5	$ 425	$ 88	$ 513
7	Alfalfa	$ 119		$ 119	4	$ 617	$ -	$ 617
8	Alfalfa - 2 cuts	$ 9	$ 338	$ 347	2.5	$ 425	$ 88	$ 513
	Totals	$ 1,340	$ 1,464	$ 2,804	26	$ 13,774	$ 382	$ 14,156
	Average year	$ 168	$ 183	$ 351	3.2	$ 1,722	$ 48	$ 1,770

[a]"Proceeds" from water rights assumes rotation 3A is grown in fields with primary ground water rights at 100% reliability, lease value $225/AF, multiplied times usage less than 4AF.

[b]Economic impact calculated as follows: Lease value per AF x Number of AF leased x $26/$100 lease dollars received (from Table 9).

Other considerations related to Scenario 2: There are many other alternatives available. For example, one option is to harvest alfalfa a little earlier in its growth, thereby obtaining better quality hay while reducing water consumption. In many years, higher quality hay will command a higher price. As long as some portion of the farmers' lands stay in agricultural production, generating at least $5,000 revenues per year, the land continues to meet the minimum qualification for the property tax agricultural exemption. Additionally, under this scenario with the land remaining in agricultural production, the farmers would continue paying their share of irrigation district operating and maintenance expenses. Ideally, more research will be conducted on various crop rotation and farming practice alternatives in Mason Valley and Smith Valley, as well as on the impact of varying levels of irrigation on both production yields and crop quality for alfalfa and other crops, with the corresponding impacts on farm revenues and expenses.

Scenario 3 – Alternative crops that require less water are cultivated

A quick glance at Table 4 might lead one to believe that a simple solution to water conservation while preserving net benefit to farmers and economic impact to the region would be to switch from alfalfa and grass hay rotations to some of the alternative crops. In particular, teff seed, leaf lettuce, two row malt barley, and wine grapes all look promising.

Table 16 shows comparisons of the three crop rotations, initially shown in Tables 5, 6, and 7, with five alternative crops in terms of water consumption, net budget values and regional (Mason Valley and Smith Valley) economic impacts. An implicit assumption is that the farmers still reside in the region and spend a portion of the income stream from the water rights proceeds investment in the local economy. As before, IMPLAN was used to estimate the economic impacts.

There are some very relevant limitations, potential issues and special considerations that need to be discussed in regard to these alternative crops, as set forth below.

Table 16. Current "standard" crop rotations vs. alternative crops.

Crop / Crop Rotation	Assumed Water Rights Reliability	Avg. Water Use A.F. +/-	Per Acre Per Year: Net Benefit to Farmer: Budget Net Value	Net[a] From Invested W.R. Sale Proceeds	Total	Econ. Impact to Region: Farming Econ. Impact	Economic Impact[b] From Invested W.R. Proceeds	Total
Existing rotations								
Rotation 1 - Alfalfa & fallow	50%	3.4	$ 102	$ -	$ 102	$ 529	$ -	$ 529
Rotation 2 - Alfalfa & small grain hay	75%	4	$ 107	$ -	$ 107	$ 616	$ -	$ 616
Rotation 3 - Onions & alfalfa	100%	3.8	$ 209	$ -	$ 209	$ 1,794	$ -	$1,794
Alternative crops								
Teff seed	70%	3	$ 148	$ 104	$ 252	$ 728	$ 28	$ 756
Teff seed	100%	3	$ 148	$ 148	$ 296	$ 728	$ 41	$ 769
Baby leaf lettuce - mechanized	100%	1	$3,279	$ 444	$3,723	$ 5,502	$ 122	$5,624
Two row malt barley	70%	2	$ 400	$ 207	$ 607	$ 1,011	$ 57	$1,068
Two row malt barley	100%	2	$ 400	$ 207	$ 607	$ 1,011	$ 81	$1,092
Great basin wild rye (seed)	50%	1	$ 49	$ 222	$ 271	$ 699	$ 61	$ 760
Great basin wild rye (seed)	75%	1	$ 49	$ 333	$ 382	$ 699	$ 91	$ 790
Great basin wild rye (seed)	100%	1	$ 49	$ 444	$ 493	$ 699	$ 122	$ 821
Grapes (wine grapes)	100%	0.3	$ 288	$ 547	$ 835	$ 5,153	$ 150	$5,303

[a] "Net" assumes all proceeds subject to 15% capital gains tax rate without consideration of any original cost basis, with after-tax proceeds invested at 6% annual rate of return.

[b] Economic impact calculated as follows: Water rights value/AF x Number of AF sold x $14 value-added economic impact/$1,000 of sale proceeds (from Table 9).

<u>Teff seed</u>

Teff is an annual grass native to the northern Ethiopian Highlands of northeastern Africa, and currently commercially grown in the U.S. in Idaho. Teff is one of the alternative crops being studied by Jay Davison, Elizabeth Leger and Erin K. Espeland[12]. A teff budget was generated by Dr. Kynda Curtis et al[13] with the assistance of Jay Davison. Teff seed production requires approximately 3 acre feet of water per year, which would result in a 25% water savings compared to alfalfa, while producing a net to the farmer slightly higher than alfalfa hay. If the water rights (storage water with reliability estimated at 70%) could be sold at $2,030 per acre foot, the after tax net proceeds could be invested to generate an annual income stream equivalent to approximately $104 per acre. If water rights have a reliability factor of 100 percent, the water rights value would be approximately $2,900 per acre foot in this example, which would generate an income stream of $148 per acre annually. The combined net to the farmer would be on the order of $252 to $296 per acre per year, which would compare very favorably to growing alfalfa, while the combined economic impact to the region would be about 25 percent to 40 percent greater than that generated by growing alfalfa. There don't appear to be any technical problems related to the production of teff at this time. The key concern is related to the breadth of the market for teff seed. Currently, much of the market is in Ethiopia, Eritrea, India and Australia and to emigrants from these countries, with another market segment consisting of individuals who can't eat gluten.

<u>Baby leaf lettuce and spinach</u>

Also generally known as "spring mix", a number of varieties of baby leaf lettuce and spinach are currently grown in Mason Valley. By utilizing mechanical harvesting, the labor expenditures for this crop have been reduced to less than 25% of that needed to cultivate this crop using manual harvesting. This increases the net profit to the farmer substantially while decreasing the reliance upon migrant labor. Spring mix requires one fourth of the irrigation water compared to alfalfa and grass hay, so holds great promise for water savings. The mechanized harvesting requires very flat fields like those found throughout much of Mason Valley. As indicated in Table 16, the net profit per acre to the farmer from spring mix, with or without the enhanced benefit from selling unneeded water rights, is quite high relative to the three standard crop rotations, and the economic impacts are also substantially higher. Spring mix is relatively new to Mason Valley and has been grown back-to-back-to-back in the same fields since being introduced. There have not been any problems with disease or other agricultural issues related to this practice yet, but it might be unwise for farmers to lock into a “permanent” situation of having only one acre foot of water per year available by selling unneeded water rights until there has been a little more history with these spring mix crops. A key issue relative to expanding the production of spring mix would be the size of the market and whether a substantial increase in production would have a negative impact upon market price.

Two-row malt barley

Barley is an annual cereal grain, ranked fourth in the world in terms of quantity produced and area of cultivation. It is grown as a major source of animal feed with smaller amounts used for malting to be used in beer and ale production, or sold in health food stores. Several varieties of two-row malt barley are grown in the western U.S. under dryland or irrigated conditions. Often the irrigated two row malt barley is grown under contract with maltsters, who pay a premium for high quality malting barley. Two-row malt barley should generate a net per acre to farmers approximately four times greater than the average net realized through rotations around alfalfa or grass hay and approximately twice that of the onion and alfalfa rotation, while utilizing only two acre feet of irrigation water. As indicated in Table 16, for comparative purposes assumptions were made that two row malt barley would be grown in fields with storage water rights (70% reliability), and that water rights for 2 acre feet could be sold for $2,030 per acre foot, with after tax proceeds invested at 6% annual rate of return, generating a net annual income equivalent to $207 per acre. Combined with the net from the two row malt barley, the benefit to the farmer would be well in excess of six times the net benefit achieved from typical grass hay or alfalfa rotations, while the economic impact to the community would be approximately 70 percent greater. The key consideration would be to develop the market relationships with maltsters prior to planting two-row malt barley.

Great Basin wild rye seed

Great Basin wild rye is a grass native to the western U.S. and Canada. In addition to its potential for livestock grazing, it is used extensively for range rehabilitation following wildfires. Establishing wild rye helps to stabilize the ground against water and wind erosion while limiting the invasion of noxious weeds. Growing Great Basin wild rye seed should generate a net value to farmers that is approximately half of the average value that would be realized from a typical alfalfa or grass hay rotation, while requiring only about one-third of the water. Assuming that Great Basin wild rye seed would be grown in fields that have natural flow decree water rights, without any supplemental storage or ground water rights, leads to an assumed value of $1,450 per acre foot from the sale of unneeded water rights. Investing the net after tax proceeds at a 6% annual rate of return would generate an annual revenue flow to the farmer equivalent to $222 per acre, which is slightly more than double the average net that would be realized from a typical alfalfa or grass hay rotation, while also generating a larger (in excess of 40% larger) economic impact to the region. A key precondition to growing Great Basin wild rye would be to seek a contract or develop some other relationships to ensure that there would be a buyer at an acceptable price for the seed that is likely to be produced.

<u>Grapes</u>

Grapes grown for wine production present an interesting prospect from a quick glance at the numbers. Grapes consume about one-third of an acre foot of water annually on drip irrigation, which is less than one-tenth of that typically required by alfalfa or grass hay, yet grapes also provide an estimated net profit to farmers of $288 per acre after they reach full production which is approaching three times the net produced by typical alfalfa and grass hay rotations. With the net profit from growing grapes enhanced by the potential cash-flow benefit generated by the invested after-tax proceeds from the sale of excess water rights, the combined net benefit balloons to around eight times the average annual net generated by alfalfa and grass hay crop rotations. The economic impact to the region from grapes is also very attractive, at over eight times that generated through alfalfa and grass hay production.

However, the solution to the water issues in the Walker Basin is not a simple as having farmers with sufficient acreage simply switch from alfalfa and grass hay to grapes. There are some substantive issues related to growing grapes:

a) Climate/microclimate. The length of the growing season and the occasionally extremely cold winter weather (-5 to -20^{o} Fahrenheit) pose challenges to growing grapes in northern Nevada. Certain varietals have a much lower winterkill percentage during the incursions of arctic air, and their ability to survive and to produce fruit is enhanced by selecting locations with the appropriate microclimates. Typically hillsides provide the better protection against winter frost than valley floors near the rivers due to frost drainage and solar absorption on the hillsides. Additionally, the gravelly soils found on hillsides typically are more conducive to grapes. In Mason Valley most of the alfalfa stands are in the bottom of the valley, on flat ground. In this sense, Smith Valley may be better suited to grapes than Mason Valley. Before grapes are planted at any location, a small weather station should be installed to monitor the microclimate for a few years so that the data can be compared to other regions in Northern Nevada where grapes have been successfully cultivated.

b) Substantial investment required. The investment required to produce wine grapes is very large, ranging between $14,000 and $25,000 per acre. After planting, it takes three years for the vines to begin producing fruit, and in the third year production levels are not sufficient to offset costs and generate a profit. Maximum level of fruit production does not typically occur until year five. On the other hand, the vines typically continue producing at commercially viable levels for 35 years or more. Due to this large investment, a related investment must be in a well if one is not already available so that the vines do not die in periods of drought.

c) Market for wine grapes: In order to make certain that there will be a decent market for any grapes produced growers need an arrangement with a winery before the first vines are planted. The market for Nevada wine grapes is currently very limited. Tahoe Ridge Winery, the only commercial winery in northern Nevada, is expanding from a volume of 50,000 cases of wine annually to 100,000 cases (1.2 million bottles).[14] This expansion will require approximately 320 acres of vineyards, with sixty percent of these being in California (reflecting their blend of 60 percent California grapes and 40 percent Nevada grapes), which means that only 128 additional acres of grapes are needed in Nevada to fulfill their requirements. To create demand beyond this level, more wineries would be needed, which also requires substantial investment. The owners of Tahoe Ridge Winery estimate the current investment needed to build a new winery with an annual capacity of 100,000 cases would be $12-$14 million, plus the cost of market development which is substantial. It is also their opinion that more wineries in northern Nevada would be very good for their business.

Scenario 4 - Other (non-agricultural) sources of water rights are procured

Several non-agricultural sources of water rights have been mentioned in the community meetings held by the research team and by individual farmers subsequent to community meetings. One of these sources is geothermal water near Wabuska, with options apparently already procured from Homestretch Geothermal LLC and Homestretch Energy LLC. It appears that acquisition of these water rights would not displace any current economic activity, and so would not create any negative economic impacts. Since no economic activity is being displaced, it is possible that the value range will be less. Further, if the sellers have other ongoing commercial activities in the region, then it is entirely possible that there would be positive economic impact in the region resulting from the proceeds received by the sellers.

Mason Valley and Smith Valley Summary

The research team compared four scenarios for acquisition of water rights, with estimated benefit to farmers and economic impact as could be best determined for specific examples within each scenario. Table 17 provides a visual comparison of these scenarios.

There is a lot of useful information contained in Table 17. The research team again reminds readers that the specific numbers are not as "precise" as the impression created by the figures, but they should provide a useful indication of the direction and order of magnitude of certain actions. The dollar amounts all represent 2007 dollars.

Scenario 1: If agricultural land is taken out of production in order to acquire water rights for Walker Lake, with specific examples given in the top section of Table 17, the result is that for certain parcels essentially all of the water rights available and appurtenant to the land are acquired for the purpose of restoring Walker Lake. In general,

Table 17. Comparison of scenarios for acquiring water rights.

Water Acquisition Alternatives	Assumed Water Rights Reliability	Net Benefit[a] To Farmer Relative to Prior Crop Production	Net Economic Impact[b] to Region Relative to Prior Crop Production		Effective Water Rights Obtained Per Acre
Scenario 1. Take agricultural land out of production:					
(water rights are purchased)				per acre	
Rotation 1 - Alfalfa and fallow	40%	+2.3X	-88%	($464)	1.6
Rotation 1 - Alfalfa and fallow	50%	+2.9X	-85%	($448)	2
Rotation 1 - Alfalfa and fallow	60%	+3.5	-81%	($431)	2.4
Rotation 2 - Alfalfa and small grain hay	70%	+3.9X	-81%	($502)	2.8
Rotation 2 - Alfalfa and small grain hay	80%	+4.4X	-79%	($486)	3.2
Rotation 2 - Alfalfa and small grain hay	100%	+5.5X	-74%	($453)	4
Rotation 3 - Onions and alfalfa	100%	+2.8X	-91%	($1,631)	4
Pasture	40%	+1.9X	-3%	($2)	1.6
Pasture	50%	+2.4X	21%	14	2
Pasture	60%	+2.8X	46%	31	2.4
Scenario 2. Existing crop rotations & farming practices altered:					
(unused water rights are leased)					
Modify alfalfa & fallow rotation	50%	+2.2X	-15%	($79)	0.6
Modify alfalfa & small grain hay rotation	75%	+1.6X	+3%	+$18	0.2
Modify onion & alfalfa rotation	100%	+1.7X	-1%	-$24	0.4
Scenario 3. Alternative crops cultivated:					
(unused water rights are purchased)					
Teff seed (versus rotation 1)	70%	+2.5X	+43%	+$227	0.7
Teff seed (versus rotation 2)	100%	+2.8X	+25%	+$153	1
Baby leaf lettuce (versus rotation 3)	100%	+17.8X	+213%	+$3,830	3
Two row malt barley (versus rotation 2)	70%	+5.7X	+73%	+$452	1.4
Two row malt barley (versus rotation 2)	100%	+6.5X	+77%	+$476	2
Great Basin wild rye seed (versus rotation 1)	50%	+2.2X	+44%	+$231	1.5
Great Basin wild rye seed (versus rotation 2)	75%	+3.6X	+28%	+$174	2.2
Great Basin wild rye seed (versus rotation 2)	100%	+4.6X	+33%	+$205	3
Grapes (versus rotation 2)	100%	+7.8X	+760%	+$4,687	3.7
Scenario 4. Other (non-agricultural) sources of water procured:					
(water rights are purchased)					
Geothermal groundwater	100%	not	Unknown, but		N.A.

[a] Net benefit to farmer relative to prior crop production is computed by dividing the combined annual cash flow from any ongoing agricultural production plus invested water rights proceeds by the annual net from prior crop budget.

[b] Net economic impact computed from values in Tables 5, 6, 7, 11, 12, 13 and 15. The difference in economic impact to the region, as determined by applying the value-added factors to agricultural production and water rights proceeds, are compared, the net difference and direction of change is determined, and the percentage of change is calculated.

this is likely to involve fewer acres and fewer transactions than in the other scenarios. For every acre that has water rights in the 40 to 50 percent reliability category, the effective water obtained per acre will be 1.6 to 2.0 acre feet. More than likely, this acquisition would displace land used as pasture or for something similar to rotation 1, with either alfalfa or grass hay being alternated with occasional fallow. In general, this will be financially beneficial to the farmer. For land used as pasture, if our assumptions are right, the net economic impact on the region will be minimal if the farmers remain in the region and continue to spend some of the investment income locally. If the sellers move their primary residence to outside the region, the loss would be the amount of the full economic impact of approximately $67 per acre per year (see Table 4). If the land taken out of production is land being used for alfalfa or grass hay, the net economic impact will be negative in either case, ranging from a net loss of $448 to $464 per acre per year if the seller continues to reside in the region, up to approximately $529 per acre per year if the seller relocates outside the region.

If water rights are acquired in the 60-70 percent reliability range and the land is taken out of production, there is a high probability that the displaced crops would be similar to rotation 1 or 2, with alfalfa or grass hay in rotation with fallow or with small grain hay, although it could also be pasture. The effective water rights obtained would be 2.4 to 2.8 acre feet per acre, and the net financial benefit to the farmer would be more than sufficient to offset the loss of income from farming this ground. If the sellers continued to reside in the region, the net economic impact would be negligible for pasture, but would be substantial for alfalfa or grass hay rotations that were displaced, with the net loss ranging from $431 to $502 per acre per year. If the seller moved, the loss would again be the full economic impact of the displaced crop as shown in Tables 5 and 6.

If water rights are acquired in the 80-90 percent reliability range, the land is probably seldom or ever left fallow, so the displaced crops could be alfalfa or grass hay in something similar to rotation 2 or pasture. The effective water rights obtained should be in the range of 3.2 to 3.6 acre feet per acre. Once again, the net to the farmers would be more than sufficient to offset the lost net from agricultural production. The net economic impact to the region would be substantial as shown in Tables 6 and 17.

Land with 100% reliable water rights is typically used to grow alfalfa or grass hay in rotation with small grain hay in Smith Valley. In Mason Valley, in addition to these same crop rotations, the land might be used to cultivate onions in rotation with alfalfa, or for baby leaf lettuce / spinach, corn or garlic. The comparisons for alfalfa rotations with small grain hay and onions in rotation with alfalfa both show a substantial increase in net to the farmer through investment of the proceeds from a sale of water rights compared to the net from farming. Effective water rights obtained would be approximately 4 acre feet per acre. Both examples also indicate a substantial negative economic impact from the displacement of these crops. In the case of baby leaf lettuce and spinach, the net benefit to the farmer from invested proceeds from selling water rights would not be sufficient to equal the net obtained from cultivating these crops, so it would be unlikely to see land used for cultivation of lettuce and/or spinach coming out of production as the result of sale of water rights for the restoration of Walker Lake.

Generally, with the partial exception of pasture (where the seller continues to reside in the region), all of the examples in Scenario 1 that involve taking land out of agricultural production, have negative economic impact on the region.

Scenario 2: If existing crop rotations and farming practices can be altered to save water and the saved water can be leased, and if any current legal and/or administrative obstacles to doing this can be overcome, additional water can be acquired, but much greater acreage would need to be involved to achieve the same amount of water acquisition as in Scenario 1 or 3. The net financial benefits to farmers in Scenario 2 appear to be sufficient to induce some farmers to become engaged in these practices, at least on a trial basis, but the financial inducement is generally not as favorable as selling all the water rights and taking the land out of production. The economic impacts to the region range from slightly negative to slightly positive, which is substantially better than Scenario 1. The risk perceived by farmers relative to the Scenario 3, alternative crops, may be substantially less since the farmers would be growing the same crops that they currently cultivate, with the same equipment, same buyers or markets, and similar risks. With a financial incentive to use less water (to use water more efficiently), other water saving measures may be developed and adopted. For example, while farmers in the region currently may monitor soil moisture levels when growing onions, very few do so for alfalfa or grass hay, but instead rely on historical irrigation patterns that "work". The emphasis has been on ensuring the crops get enough water to produce good yields, but not on saving any excess water. Certainly more research in Mason Valley and Smith Valley on agricultural practices related to water consumption, crop quality and yield could be beneficial.

Scenario 3: Alternative crops appear to present some excellent potential in terms of water savings, improved net to farmers (including the financial benefit from water savings) that are in the same general range as in Scenario 1, with substantial contribution to the region in terms of economic impact. However, there definitely also appear to be limitations and risks associated with a number of factors: a) required levels of investment, b) new cultivation practices, c) new buyer relationships, d) unknowns about market absorption of the crops, and e) price volatility, in addition to other unstated risk factors associated with new crops. For each alternative crop, farmers may need assistance in overcoming some of these limitations and obstacles in order to be willing to make a change. Even with such assistance, the acreage that might be dedicated to these crops may be substantially limited: perhaps 200-400 acres of grapes in the region, maybe a few hundred acres of baby leaf lettuce and spinach, and perhaps a few thousand acres each of teff seed, two row malt barley and Great Basin wild rye. Even with these limitations, the combination of water savings and positive economic impact from alternative drops could provide an important aspect to the overall objectives of acquiring water for Walker Lake while minimizing negative impacts.

Scenario 4: The acquisition of other sources of water should be considered a top priority. This will have no negative economic impact, and perhaps positive economic impact. While only a portion of the acquisition target of 50,000 acre feet is likely to be from a source other than agricultural water rights, any contribution from this source will reduce the need to acquire water rights used for crop cultivation.

Conclusions – Consequences to the agricultural economy of Mason Valley and Smith Valley

These information, assumptions and procedures, taken together, provide us with a useful tool for estimating the economic impact to the region consisting of Mason Valley and Smith Valley that might result from the acquisition of sufficient water rights for an average of 50,000 acre feet, destined for Walker Lake, to reach the Wabuska Gauge annually. The research team constructed Tables 18, 19, and 20, which indicate three different examples of the overall economic impact in Mason Valley and Smith Valley. In Table 18, the assumptions were that only 7,500 acres are taken out of production, the modified crop rotations and agricultural practices include 15,200 acres, and around 12,500 acres under cultivation are switched to alternative crops. Under this set of assumptions, the net impact is projected to be a positive economic impact to the region, increasing the regional domestic product in excess of $3.2 million.

Table 18. Tool for predicting overall economic impact in Mason Valley and Smith Valley, example 1.

Water Acquisition Alternatives	Assumed Water Rights Reliability	Net Economic Impact to Region Relative to Prior Crop Production		Effective Water Rights Obtained Per Acre	Assumed Acres	Projected Impacts: Water Rights Obtained	Projected Impacts: Economic Impact
Scenario 1.a - Take agricultural land out of production: sellers continue to reside locally							
(water rights are purchased)			per acre				
Rotation 1 - Alfalfa and fallow	40%	-88%	($464)	1.6	500	800	($232,000)
Rotation 1 - Alfalfa and fallow	50%	-85%	($448)	2	500	1,000	($224,000)
Rotation 1 - Alfalfa and fallow	60%	-81%	($431)	2.4	0	0	$0
Rotation 2 - Alfalfa and small grain hay	70%	-81%	($502)	2.8	500	1,400	($251,000)
Rotation 2 - Alfalfa and small grain hay	80%	-79%	($486)	3.2	500	1,600	($243,000)
Rotation 2 - Alfalfa and small grain hay	100%	-74%	($453)	4	250	1,000	($113,250)
Rotation 3 - Onions and alfalfa	100%	-91%	($1,631)	4	0	0	$0
Pasture	40%	-3%	($2)	1.6	500	800	($1,000)
Pasture	50%	21%	14	2	500	1,000	$7,000
Pasture	60%	46%	31	2.4	500	1,200	$15,500
Subtotal Estimates for Scenario 1.a					3,750	8,800	$ (1,041,750)
Scenario 1.b - Take agricultural land out of production: sellers relocate outside region							
(water rights are purchased)			per acre				
Rotation 1 - Alfalfa and fallow	40%	-100%	($529)	1.6	500	800	($264,500)
Rotation 1 - Alfalfa and fallow	50%	-100%	($529)	2	500	1,000	($264,500)
Rotation 1 - Alfalfa and fallow	60%	-100%	($529)	2.4	0	0	$0
Rotation 2 - Alfalfa and small grain hay	70%	-100%	($616)	2.8	500	1,400	($308,000)
Rotation 2 - Alfalfa and small grain hay	80%	-100%	($616)	3.2	500	1,600	($308,000)
Rotation 2 - Alfalfa and small grain hay	100%	-100%	($616)	4	250	1,000	($154,000)
Rotation 3 - Onions and alfalfa	100%	-100%	($1,794)	4	0	0	$0
Pasture	40%	-100%	($67)	1.6	500	800	($33,500)
Pasture	50%	-100%	($67)	2	500	1,000	($33,500)
Pasture	60%	-100%	($67)	2.4	500	1,200	($33,500)
Subtotal Estimates for Scenario 1.b					3,750	8,800	$ (1,399,500)
Subtotal Estimates for Scenario 1.a+b					7,500	17,600	$ (2,441,250)
Scenario 2 - Existing crop rotations & farming practices altered:							
(unused water rights are leased)			per acre				
Modify alfalfa & fallow rotation	50%	-15%	($79)	0.6	5,000	3,000	($395,000)
Modify alfalfa & small grain hay rotatio	75%	+3%	+$18	0.2	10,000	2,000	$180,000
Modify onion & alfalfa rotation	100%	-1%	-$24	0.4	200	80	($4,800)
Subtotal Estimates for Scenario 2					15,200	5,080	$ (219,800)
Scenario 3 - Alternative crops cultivated:							
(unused water rights are purchased)			per acre				
Teff seed (versus rotation 1)	70%	+43%	+$227	0.7	2,000	1,400	$454,000
Teff seed (versus rotation 2)	100%	+25%	+$153	1	2,000	2,000	$306,000
Baby leaf lettuce (vs. rotation 3)	100%	+213%	+$3,830	3	250	750	$957,500
Two row malt barley (vs. rotation 2)	70%	+73%	$452	1.4	2,500	3,500	$1,130,000
Two row malt barley (vs. rotation 2)	100%	+77%	+$476	2	2,500	5,000	$1,190,000
Great Basin wild rye seed (vs. rotation 1	50%	+44%	+$231	1.5	1,000	1,500	$231,000
Great Basin wild rye seed (vs. rotation 2	75%	+28%	+$174	2.2	1,000	2,200	$174,000
Great Basin wild rye seed (vs. rotation 2	100%	+33%	+$205	3	1,000	3,000	$205,000
Grapes (vs. rotation 2)	100%	+760%	+$4,687	3.7	270	999	$1,265,490
Subtotal Estimates for Scenario 3					12,520	20,349	$ 5,912,990
Scenario 4 - Other (non-agricultural) sources of water procured:							
(water rights are purchased)							
Geothermal groundwater	100%	Unknown, but		N.A.		7,000	Unknown
Subtotal Estimates for Scenario 4						7,000	Unknown
Totals for Scenarios 1-4						50,029	$ 3,251,940

In Table 19, the assumptions were changed so that the agricultural land taken out of production was increased to around 11,750 acres, while 15,000 acres of land were involved in modified crop rotations and agricultural practices, and nearly 5,900 acres under cultivation were switched to alternative crops. Under this example, the net economic impact to the region was moderated to a projected loss of around $1.9 million to the regional domestic product.

Table 19. Tool for predicting overall economic impact in Mason Valley and Smith Valley, example 2.

Water Acquisition Alternatives	Assumed Water Rights Reliability	Net Economic Impact to Region Relative to Prior Crop Production		Effective Water Rights Obtained Per Acre	Assumed Acres	Projected Impacts: Water Rights Obtained	Projected Impacts: Economic Impact
Scenario 1.a - Take agricultural land out of production: sellers continue to reside locally							
(water rights are purchased)			per acre				
Rotation 1 - Alfalfa and fallow	40%	-88%	($464)	1.6	500	800	($232,000)
Rotation 1 - Alfalfa and fallow	50%	-85%	($448)	2	500	1,000	($224,000)
Rotation 1 - Alfalfa and fallow	60%	-81%	($431)	2.4	1,000	2,400	($431,000)
Rotation 2 - Alfalfa and small grain hay	70%	-81%	($502)	2.8	1,500	4,200	($753,000)
Rotation 2 - Alfalfa and small grain hay	80%	-79%	($486)	3.2	500	1,600	($243,000)
Rotation 2 - Alfalfa and small grain hay	100%	-74%	($453)	4	250	1,000	($113,250)
Rotation 3 - Onions and alfalfa	100%	-91%	($1,631)	4	125	500	($203,875)
Pasture	40%	-3%	($2)	1.6	500	800	($1,000)
Pasture	50%	21%	14	2	500	1,000	$7,000
Pasture	60%	46%	31	2.4	500	1,200	$15,500
Subtotal Estimates for Scenario 1.a					5,875	14,500	$ (2,178,625)
Scenario 1.b - Take agricultural land out of production: sellers relocate outside region							
(water rights are purchased)			per acre				
Rotation 1 - Alfalfa and fallow	40%	-100%	($529)	1.6	500	800	($264,500)
Rotation 1 - Alfalfa and fallow	50%	-100%	($529)	2	500	1,000	($264,500)
Rotation 1 - Alfalfa and fallow	60%	-100%	($529)	2.4	1,000	2,400	($529,000)
Rotation 2 - Alfalfa and small grain hay	70%	-100%	($616)	2.8	1,500	4,200	($924,000)
Rotation 2 - Alfalfa and small grain hay	80%	-100%	($616)	3.2	500	1,600	($308,000)
Rotation 2 - Alfalfa and small grain hay	100%	-100%	($616)	4	250	1,000	($154,000)
Rotation 3 - Onions and alfalfa	100%	-100%	($1,794)	4	125	500	($224,250)
Pasture	40%	-100%	($67)	1.6	500	800	($33,500)
Pasture	50%	-100%	($67)	2	500	1,000	($33,500)
Pasture	60%	-100%	($67)	2.4	500	1,200	($33,500)
Subtotal Estimates for Scenario 1.b					5,875	14,500	$ (2,768,750)
Subtotal Estimates for Scenario 1.a+b					11,750	29,000	$ (4,947,375)
Scenario 2 - Existing crop rotations & farming practices altered:							
(unused water rights are leased)			per acre				
Modify alfalfa & fallow rotation	50%	-15%	($79)	0.6	5,000	3,000	($395,000)
Modify alfalfa & small grain hay rotatio	75%	+3%	+$18	0.2	10,000	2,000	$180,000
Modify onion & alfalfa rotation	100%	-1%	-$24	0.4	0	0	$0
Subtotal Estimates for Scenario 2					15,000	5,000	$ (215,000)
Scenario 3 - Alternative crops cultivated:							
(unused water rights are purchased)			per acre				
Teff seed (versus rotation 1)	70%	+43%	+$227	0.7	1,000	700	$227,000
Teff seed (versus rotation 2)	100%	+25%	+$153	1	1,000	1,000	$153,000
Baby leaf lettuce (vs. rotation 3)	100%	+213%	+$3,830	3	250	750	$957,500
Two row malt barley (vs. rotation 2)	70%	+73%	$452	1.4	1,250	1,750	$565,000
Two row malt barley (vs. rotation 2)	100%	+77%	+$476	2	1,250	2,500	$595,000
Great Basin wild rye seed (vs. rotation 1	50%	+44%	+$231	1.5	500	750	$115,500
Great Basin wild rye seed (vs. rotation 2	75%	+28%	+$174	2.2	500	1,100	$87,000
Great Basin wild rye seed (vs. rotation 2	100%	+33%	+$205	3	0	0	$0
Grapes (vs. rotation 2)	100%	+760%	+$4,687	3.7	128	474	$599,936
Subtotal Estimates for Scenario 3					5,878	9,024	$ 3,299,936
Scenario 4 - Other (non-agricultural) sources of water procured:							
(water rights are purchased)							
Geothermal groundwater	100%	Unknown, but		N.A.		7,000	Unknown
Subtotal Estimates for Scenario 4						7,000	Unknown
Totals for Scenarios 1-4						50,024	$ (1,862,439)

In Table 20, the underlying assumptions are that the water rights acquired will consist of 7,000 acre feet annually from a geothermal source with the balance being acquired by taking approximately 17,400 acres of agricultural land out of production. The allocation of agricultural use was arbitrary and it was assumed that half of the sellers would continue to reside in the region while half would relocate outside the region. Under this example the net economic impact would be a loss of approximately $7.8 million of the local regional domestic product.

A comparison of these three examples, including estimated changes in employment and labor income associated with each example are shown in Table 21, with the net annual economic impact comparisons shown in Figure 1.

As can be seen from these examples, the economic impact to the region is highly dependent upon where and how the water rights are acquired and what happens to the land to which these water rights are appurtenant. For an outcome similar to that shown in Table 18, it would probably be necessary for there to be some programs initiated to assist farmers and substantially reduce the perceived risk of switching to alternative crops. Such assistance might be in the form of a fund of $20-$25 million that could be a source of grants and low interest loans to farmers in the region. This fund, combined with agricultural technical assistance in how to best make the transition to alternative crops and business technical assistance would certainly facilitate this sort of transition, which would preserve the agricultural character and the economic base of the region.

Table 20. Tool for predicting overall economic impact in Mason Valley and Smith Valley, example 3.

Water Acquisition Alternatives	Assumed Water Rights Reliability	Net Economic Impact to Region Relative to Prior Crop Production		Effective Water Rights Obtained Per Acre	Assumed Acres	Projected Impacts: Water Rights Obtained	Projected Impacts: Economic Impact
Scenario 1.a - Take agricultural land out of production: sellers continue to reside locally							
(water rights are purchased)			per acre				
Rotation 1 - Alfalfa and fallow	40%	-88%	($464)	1.6	1,000	1,600	($464,000)
Rotation 1 - Alfalfa and fallow	50%	-85%	($448)	2	1,000	2,000	($448,000)
Rotation 1 - Alfalfa and fallow	60%	-81%	($431)	2.4	2,000	4,800	($862,000)
Rotation 2 - Alfalfa and small grain hay	70%	-81%	($502)	2.8	2,000	5,600	($1,004,000)
Rotation 2 - Alfalfa and small grain hay	80%	-79%	($486)	3.2	1,000	3,200	($486,000)
Rotation 2 - Alfalfa and small grain hay	100%	-74%	($453)	4	500	2,000	($226,500)
Rotation 3 - Onions and alfalfa	100%	-91%	($1,631)	4	0	0	$0
Pasture	40%	-3%	($2)	1.6	500	800	($1,000)
Pasture	50%	21%	14	2	500	1,000	$7,000
Pasture	60%	46%	31	2.4	210	504	$6,510
Subtotal Estimates for Scenario 1.a					8,710	21,504	$ (3,477,990)
Scenario 1.b - Take agricultural land out of production: sellers relocate outside region							
(water rights are purchased)			per acre				
Rotation 1 - Alfalfa and fallow	40%	-100%	($529)	1.6	1,000	1,600	($529,000)
Rotation 1 - Alfalfa and fallow	50%	-100%	($529)	2	1,000	2,000	($529,000)
Rotation 1 - Alfalfa and fallow	60%	-100%	($529)	2.4	2,000	4,800	($1,058,000)
Rotation 2 - Alfalfa and small grain hay	70%	-100%	($616)	2.8	2,000	5,600	($1,232,000)
Rotation 2 - Alfalfa and small grain hay	80%	-100%	($616)	3.2	1,000	3,200	($616,000)
Rotation 2 - Alfalfa and small grain hay	100%	-100%	($616)	4	500	2,000	($308,000)
Rotation 3 - Onions and alfalfa	100%	-100%	($1,794)	4	0	0	$0
Pasture	40%	-100%	($67)	1.6	500	800	($33,500)
Pasture	50%	-100%	($67)	2	500	1,000	($33,500)
Pasture	60%	-100%	($67)	2.4	210	504	($14,070)
Subtotal Estimates for Scenario 1.b					8,710	21,504	$ (4,353,070)
Subtotal Estimates for Scenario 1.a+b					17,420	43,008	$ (7,831,060)
Scenario 2 - Existing crop rotations & farming practices altered:							
(unused water rights are leased)			per acre				
Modify alfalfa & fallow rotation	50%	-15%	($79)	0.6	0	0	$0
Modify alfalfa & small grain hay rotatio	75%	+3%	+$18	0.2	0	0	$0
Modify onion & alfalfa rotation	100%	-1%	-$24	0.4	0	0	$0
Subtotal Estimates for Scenario 2					0	0	$ -
Scenario 3 - Alternative crops cultivated:							
(unused water rights are purchased)			per acre				
Teff seed (versus rotation 1)	70%	+43%	+$227	0.7	0	0	$0
Teff seed (versus rotation 2)	100%	+25%	+$153	1	0	0	$0
Baby leaf lettuce (vs. rotation 3)	100%	+213%	+$3,830	3	0	0	$0
Two row malt barley (vs. rotation 2)	70%	+73%	$452	1.4	0	0	$0
Two row malt barley (vs. rotation 2)	100%	+77%	+$476	2	0	0	$0
Great Basin wild rye seed (vs. rotation 1	50%	+44%	+$231	1.5	0	0	$0
Great Basin wild rye seed (vs. rotation 2	75%	+28%	+$174	2.2	0	0	$0
Great Basin wild rye seed (vs. rotation 2	100%	+33%	+$205	3	0	0	$0
Grapes (vs. rotation 2)	100%	+760%	+$4,687	3.7	0	0	$0
Subtotal Estimates for Scenario 3					0	0	$ -
Scenario 4 - Other (non-agricultural) sources of water procured:							
(water rights are purchased)							
Geothermal groundwater	100%	Unknown, but		N.A.		7,000	Unknown
Subtotal Estimates for Scenario 4						7,000	Unknown
Totals for Scenarios 1-4						50,008	$ (7,831,060)

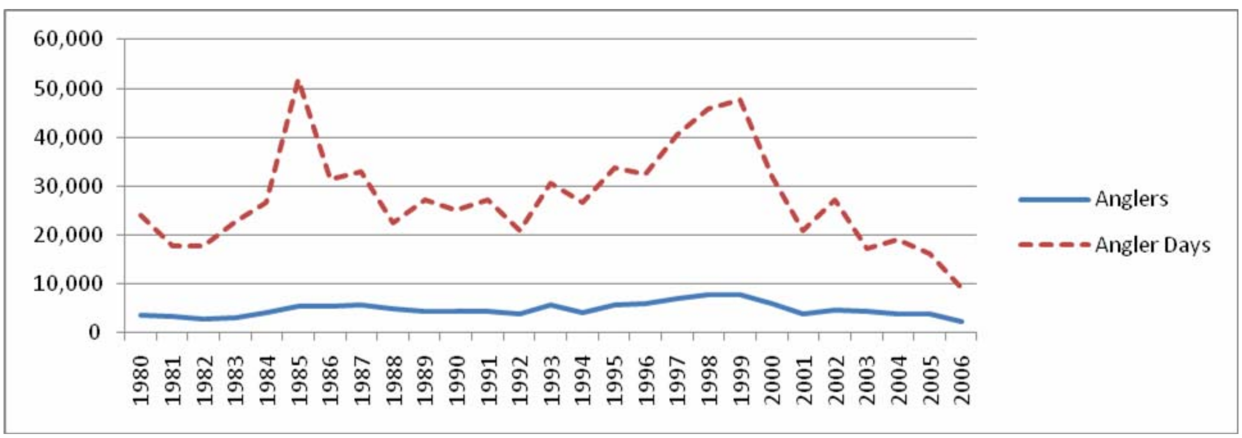
Table 21. Comparison of outcomes from three examples of economic impacts.

	Example 1	Example 2	Example 3
% Water from Modified Ag. & Alternative Crops	51%	28%	0%
Net Annual Economic Impact (2007 dollars)	$ 3,251,940	$ (1,862,439)	$ (7,831,060)
Estimated Change in Employment	59	3	-84
Estimated Change in Annual Labor Income	$ 1,707,830	$ 93,712	$ (2,444,712)

Hawthorne Area (Mineral County, Nevada)

Economic impact in the Hawthorne area related to the Walker Basin project would most likely occur as a result of a resurgence of the recreational fishing industry, plus some other outdoor recreation related to Walker Lake.

According to information provided by the Nevada Department of Wildlife[15], recreational fishing at Walker Lake had increased and decreased since 1980, with a consistent decline since the figures peaked in 1999, as shown in Figure 7. It is notable that the two large peaks in Figure 7 coincide with large inflows into Walker Lake and rising lake levels while the declines in 2000 to 2005 coincide with a period of small inflows and declining lake levels.



Source of data: Nevada Department of Wildlife

Figure 7. Number of anglers and angler days at Walker Lake.

Assuming that the Walker Basin project can arrest the decline in lake levels, and perhaps bring about an increase in lake level and improve the quality of the fishery and boat access to the lake, the question addressed by this research team is, "What would be the economic impact to Hawthorne and the immediate area?"

To determine an answer, the research team looked at an article based upon a recent study conducted for the American Sportfishing Association and funded by the Multistate Conservation Grant Program (Grant VA M-18-R), a program supported with funds from the Wildlife and Sportfish Restoration programs and jointly managed by the

Association of Fish and Wildlife Agencies and the U.S. Fish and Wildlife Service, 2007[16]. The article included the data set forth in Table 22 below.

Table 22. Economic impact of freshwater fishing in the United States and Nevada.

Category	Anglers	Angler Fishing Days	Estimated Retail Sales	Total Multiplier Effect	Multiplier	Jobs
United States Fresh Water Fishing - 2006	25,035,000	419,547,000	$31,182,648,546	$ 87,954,360,057	2.82	709,508
Nevada Fresh Water Fishing - 2006	142,000	1,526,000	$ 265,649,257	$ 403,704,775	1.52	3,045
Source: Sportfishing, an Economic Engine and Conservation Powerhouse in America, Tom Allen and Rob Southwick, American Sportfishing Association, Revised January 2008, [http://www.asafishing.org/asa/images/statistics/resources/SIA_2008.pdf]						

It is interesting to note the difference in the multipliers for the U.S. and Nevada. This results, essentially, from the "leakage" of expenditures in the respective geographic territories. When narrowing the region further to Hawthorne or Mineral County, the extent of leakages would be even greater. One way to get an appreciation of this is to examine the categories of retail expenditures in the U.S. from the Sportsfishing Economic Impact study, and examine which categories might possibly apply to the Hawthorne area, as set forth in Table 23.

Table 23. U.S. Angler expenditures by category and applicability to Hawthorne, Nevada.

U.S. Angler Expenditures by Category in 2006	(millions)	%	Probably Apply to Hawthorne
Travel Expenditures			
Food	$ 4,327	9.54%	*
Lodging	$ 1,975	4.36%	*
Airfare	$ 407	0.90%	
Public transportation	$ 117	0.26%	
Private transportation	$ 4,438	9.79%	
Boat fuel	$ 1,818	4.01%	
Guides	$ 832	1.84%	
Public land use fees	$ 177	0.39%	
Private land use	$ 144	0.32%	
Boat launching	$ 135	0.30%	
Boat mooring	$ 1,456	3.21%	
Equipment rental	$ 377	0.83%	
Bait (live, cut, prepared)	$ 1,183	2.61%	*
Ice	$ 378	0.83%	*
Heating & cooking fuel	$ 114	0.25%	
Subtotal	$ 17,878	39.43%	
Fishing Equipment (rods, reels, lines, lures, hooks, depth finders)	$ 5,271	11.63%	
Auxiliary Purchases (camping gear, binoculars, special clothing)	$ 969	2.14%	
Special Equipment (boats, trailers, trucks, RV's, cabins, etc.)	$ 16,808	37.07%	
Other Expenses (taxidermy, magazines, dues, licenses, land)	$ 4,410	9.73%	
Total Expenditures	$ 45,336	100.00%	17.34%

If an assumption is made that, as a result of the Walker Basin project, the number of angler days could be restored to the peak figures achieved in 1999, this would imply an increase of approximately 38,600 angler days over the 2006 figures. In comparison to all angler days in Nevada in 2006, this represents approximately two and one-half percent of the total for Nevada. One could assume, therefore, that the improvement in the Walker

Lake fishing activity could generate two and one-half percent of the total fishing-related retail sales projected for Nevada, or approximately $664,000, while creating 76 jobs. However, much of this benefit would occur outside the Hawthorne area, as people would likely be purchasing their boats, trucks, fishing equipment and even some of their food supplies outside the Hawthorne area. The best case scenario would be that perhaps 15 to 20 percent of the benefit would occur in the Hawthorne area, amounting to between $100,000 and$135,000 in retail sales and 10 to 15 jobs. Not all of this would contribute to local economic impact, since the component of the anglers composed of locals would not be bringing additional resources into the region, but would, at best, represent a redistribution of economic activity. To the extent that local anglers purchase equipment outside the region, it is highly possible there could be a net leakage of retail sales that would be in excess of the local retail sales generated by fishing.

An alternate estimate of economic impacts in Mineral County due to the Walker Basin project was calculated using data from a 1996 survey of 97 Walker Lake recreators and IMPLAN software.[17] As before, we assume that the Walker Basin project improves recreation at Walker Lake such that angler days increase by 38,600. Using the expenditure data from the survey, Walker Lake visitors spent an average of $30 per visitor day (updated to 2007 dollars). Using this number, local sales would increase by $1.15 million. About 13% of this expenditure was for lodging with the balance being spent in local retail sectors.[18] Assuming that 25% of the retail expenditures remain in the region leads to a calculated direct impact of approximately $150,000 in the lodging sector and $250,000 in the retail sector. The result of this direct impact on labor income, value added and employment is given in Table 24 below. The total impact of the increased angler visits would result in about 10 additional jobs and $327,000 in value added.

However, only about a third of the people interviewed for the survey said they were primarily there to fish. People who reported boating, picnicking or wildlife watching as their primary activity made up two thirds of the visitors. In other research reported in the 1996 study, all lake users were found to have a preference for higher water levels, so it is quite possible that all types of visitors would increase visits to Walker Lake if lake levels are higher. The second scenario in Table 24 assumes that there is an equal increase in visitor days for the two thirds of visitors who were non-anglers. If this were to be the case, total impacts of increased visits could result in an increase of as many as 31 jobs and about $980,000 in increased value added in Mineral County.

Table 24. Estimated annual economic impacts for increased recreation in Mineral County, Nevada.

Impacts from an increase of 38,600 angler days at $30 local expenditure per day				
	Direct	Indirect	Induced	Total
Labor Income	$129,093	$7,718	$42,072	$178,883
Value Added	$243,856	$13,404	$70,215	$327,475
Employment	8.8	0.4	1.1	10.2

Impacts from an increase of 115,800 visitor days at $30 local expenditure per day				
	Direct	Indirect	Induced	Total
Labor Income	$387,278	$23,154	$126,216	$536,649
Value Added	$731,568	$40,211	$210,646	$982,425
Employment	26.3	1.1	3.2	30.6

In a sense, these projected impacts represent the reversal of economic impacts already experienced in this area by the decline of Walker Lake and the associated increase in lake salinity. At the community meeting in Hawthorne, local residents represented that the communities of Hawthorne and Walker Lake had several businesses closed, including two shops selling fishing tackle, one boat repair facility, two gift shops in Walker Lake, and the Cliff House motel and restaurant. Additionally, there was no longer any local place to purchase a fishing license. These businesses probably represent around 30 lost jobs.

Additional economic benefits related to Walker Lake would certainly be possible, but not necessarily attributable to the Walker Basin project as projected economic impact. Lakeside resorts could be built, lake access could be enhanced, and other developments could occur, and in fact should be encouraged for the economic benefit of the region.

In summary, while the health of Walker Lake is important to Hawthorne, Nevada and the United States, the economic benefit to the Hawthorne area that would be directly attributable to the Walker Basin project is likely to be minimal in the near term.

Bridgeport and Walker/Coleville, (Mono County, California)

With the current focus of the Walker Basin project on acquiring water rights in Nevada only, the economic impacts in to agriculture in those portions of Walker Basin within Mono County, California that are directly attributable to the Walker Basin project are unlikely to be of any measurable magnitude. However, as the citizens of thee areas made clear in the community meetings held in Bridgeport and Walker, their primary private sector economic driver, in terms of employment, is tourism, and this is substantially tied to the recreational fishing on reservoirs, rivers and streams in the region. The concern voiced by these citizens was that the timing and amount of water releases from upstream storage, designated for Walker lake rather than for agricultural uses, could potentially impact the recreational fishing based tourism in their region, and this could have substantive negative economic impact in their communities. Until water rights are acquired and management practices are defined, it will be impossible to determine if there will be any such impacts. However, when management practices are being decided upon, consideration for the recreational fishing in those portions of Mono County within Walker Basin should be taken into consideration.

Additionally, should the geographic area of acquisition be expanded into California, or should the project involve any programs to change farming rotations and other agricultural practices, or to establish alternative crops in order to reduce water consumption for agricultural uses, then there could be economic impacts within the Bridgeport and Walker/Coleville areas.

SECTION 3: FISCAL IMPACT ANALYSIS

The fiscal impact of these proposals and various scenarios will describe the impacts of changes in water usage using the economic impacts described elsewhere in this report. As defined by Burchell and Listokin (1978), fiscal impact analysis is "a projection of the direct, current, public costs and revenues associated with residential or nonresidential growth to the local jurisdiction(s) in which this growth is taking place".[19] For purposes of this analysis, the relevant jurisdictions are a) Mason Valley and Smith Valley, located in Lyon County, Nevada and b) Hawthorne, located in Mineral County, Nevada all related to the Walker Lake restoration project.

Overview

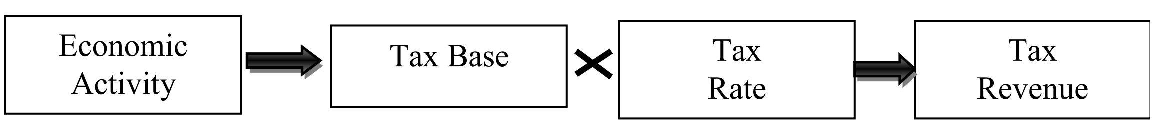
Projection of impacts on local government costs and revenues depend upon the economic impacts of a project. The economic impacts create changes in demand for government services which affect costs and also cause changes in local tax bases which in turn affect revenues.

Changes in demand for government services may arise from changes in a number of factors:

- total population
- demographic composition of population (e.g. age, employment status, income distribution).
- housing
- commercial activity
- infrastructure

Changes in any of these elements may change the need for local government to provide general or particular services. Costs associated with such changes may be estimated through either using current average costs or through detailed projections based upon expected service demand.

Changes in revenues reflect changes in taxable economic activity within the jurisdiction of local governments. As seen in the diagram below, changes in economic activity affect local tax bases which in turn affect local government revenues through taxation at the appropriate tax rate.



Because of the complexity of this causal chain, changes in each stage may or may not cause a change in net local government revenues. For example, a change in economic activity may not change the value of the legal tax base such as if purchases by a business are exempt from sales and use tax. A change in the tax base may not affect revenues as in the case of property tax limitations or guaranteed sales tax distributions. Thus, particular impacts must be estimated using specific economic impact projections and analysis of the local government revenue system for a particular entity. These will be described in more detail in the next section.

Ad Valorem and Sales Tax Revenues

Because of the geographic location of the proposal, the primary impacts will be felt on local governments in Lyon and Mineral County. While there are multiple levels of local government—special districts, towns, cities, county, and school district—given the particular location, the impacts will primarily relate to the county governments in the two counties.

In Nevada, county government revenues primarily rely upon three sources: ad valorem (property), sales and use taxes, and local fees.

The ad valorem tax is computed by multiplying the tax rate by the taxable assessed value. The average tax rate in 2007-2008 for Lyon County is $3.03 per $100 of assessed valuation. Thus, an acre of agricultural land valued at $214 would have a tax of $3.03 * (214/100) = $6.06, while an acre valued at $1.25 would have a tax of $0.04.

Ad Valorem (property) taxes are levied upon all real and personal property at a rate set by the relevant jurisdiction not to exceed $3.64 per $100 of assessed valuation. Assessed value depends upon the type of property and its use. The primary types of land in this particular project involve residential and agricultural land. Residential land is assessed at 35% of its appraised market value while any residential improvements are assessed at the estimated replacement costs less depreciation (based on a 50 year schedule). Agricultural land is assessed based on its use defined as, "Land devoted for at least three (3) consecutive years immediately preceding the assessment date to agricultural use or preparation for agricultural use and on which $5,000 gross income has been produced in an agricultural pursuit." (NRS 361A). The value of such land is based upon the capitalized earnings from the property rather than its market value.

Shown below in Table 25 is the table of Agricultural Land values published by the Nevada Department of Taxation.[20] As can be seen, the value of agricultural land ranges from $1.25 per acre for fourth class grazing to $214 per acre for intensive use land. Nearby residential land is valued at market value. For example in the Smith Valley Fire District, unimproved residential land was valued at an average $4,000 to $20,000 per acre.

Sales and use taxes are levied upon certain taxable sales and distributed by a formula to various state and local government entities. The tax base exempts certain products including groceries, agricultural implements, and intermediate goods. The tax rate varies by locality as shown in Table 26.

The taxes of most interest for this analysis are the Local School Support Tax (LSST), the Supplemental City County Relief Tax (SCCRT) and the Basic City-County Relief Tax (BCCRT). The LSST provides support for local school districts. However, total funding is determined by the state legislature and any difference between locally generated taxes and total funding is made up by the state. Therefore, increases or decreases in LSST have no net effect on local government. The SCCRT is part of the consolidated tax distribution. In the case of Lyon County and Mineral County, both are "guaranteed counties" whereby the amount of tax received from the state is determined by a formula based upon prior years' distributions and a growth factor reflecting inflation and population growth. For both counties, more revenue is guaranteed than is locally generated. Therefore, any changes in SCCRT derived from fluctuations in local sales will not affect the total amount of tax the locality receives. Finally, the BCCRT and local-option tax receipts are entirely subject to local economic conditions and may fluctuate accordingly. Together, these two taxes amount to approximately 0.75% of the value of taxable sales.

Table 25. Nevada Department of Taxation summary of land values.

Land Classification	ADOPTED 2009-2010	ADOPTED 2008-2009	ADOPTED 2007-2008	ADOPTED 2006-2007	ADOPTED 2005-2006	% Change 2005-06 2009-10	% Change 2008-09 2009-10	% Change 2007-08 2008-09	% Change 2006-07 2007-08	% Change 2005-06 2006-07
Intensive Use Land	$ 214.00	$ 179.00	$ 174.00	$ 166.00	$ 164.00	30.5%	19.6%	2.9%	4.8%	1.2%
Cultivated Land										
First Class Cultivated	$ 167.00	$ 140.00	$ 135.00	$ 129.00	$ 127.00	31.5%	19.3%	3.7%	4.7%	1.6%
Second Class Cultivated	130.00	109.00	105.00	100.00	99.00	31.3%	19.3%	3.8%	5.0%	1.0%
Third Class Cultivated	93.00	78.00	75.00	72.00	71.00	31.0%	19.2%	4.0%	4.2%	1.4%
Fourth Class Cultivated	65.00	54.00	53.00	50.00	49.00	32.7%	20.4%	1.9%	6.0%	2.0%
Native Meadow Land or Wild Hay Land										
First Class Meadow	$ 115.00	$ 91.00	$ 84.00	$ 81.00	$ 78.00	47.4%	26.4%	8.3%	3.7%	3.8%
Second Class Meadow	86.00	68.00	63.00	60.00	59.00	45.8%	26.5%	7.9%	5.0%	1.7%
Pasture Land										
First Class Pasture	$ 86.00	$ 115.00	$ 120.00	$ 96.00	$ 88.00	-2.3%	-25.2%	-4.2%	25.0%	9.1%
Second Class Pasture	67.00	88.00	92.00	74.00	68.00	-1.5%	-23.9%	-4.3%	24.3%	8.8%
Third Class Pasture	58.00	75.00	79.00	63.00	59.00	-1.7%	-22.7%	-5.1%	25.4%	6.8%
Fourth Class Pasture	24.00	35.00	37.00	28.00	25.00	-4.0%	-31.4%	-5.4%	32.1%	12.0%
Grazing Land										
First Class Grazing	$ 8.09	$ 6.32	$ 5.80	$ 4.30	$ 4.16	94.5%	28.0%	9.0%	34.9%	3.4%
Second Class Grazing	4.17	3.28	3.00	2.22	2.15	94.0%	27.1%	9.3%	35.1%	3.3%
Third Class Grazing	2.90	2.29	2.10	1.55	1.50	93.3%	26.6%	9.0%	35.5%	3.3%
Fourth Class Grazing	1.25	1.25	1.25	1.25	1.25	0.0%	0.0%	0.0%	0.0%	0.0%

Table 26. Nevada sales and use tax components.

Tax	Rate	Distribution
State Sales and Use	2.00%	State general fund
Local School Support Tax (LSST)	2.25%	Local school district (where sale was made)
Supplemental City-County Relief Tax (SCCR	1.75%	All local governments according to statutory formula
Basic City-County Relief Tax (BCCRT)	0.50%	County where the sale was made
Option	0-1.25%	To County where sale was made
Total	6.5-7.75%	

Local Government Revenues in Lyon and Mineral Counties

Lyon County:

As shown in Table 27, Lyon County's budgeted expenses for Fiscal Year 2007[21] totalled approximately $54 million dollars while revenues were significantly lower due to declining ending balance and previously accrued funds spent during 2007. The two primary revenues sources are ad valorem (property) accounting for 25% of total revenues and sales and consolidated taxes (42%). For purposes of analysis, these are the primary items affected by the proposed scenarios.

For Lyon County, total assessed value of property was $1,364 million of which $25 million was in agricultural land throughout the entire county as shown in Table 28

Table 27. Lyon County budget overview.

Category	(Millions)
Assessed Value	$ 1,364
Taxable Sales	$ 390
Total Expenditures	$ 54
Total Revenues	$ 43

Table 28. Assessed value of agricultural property in Lyon County.

Type	Acres	Value
Intensive	430	$ 70,419
Cultivated	8,945	$ 795,000
Meadow	1,197	$ 82,000
Pasture	13,729	$ 905,000
Grazing	79,833	$ 169,000
Total ag land	104,134	$ 2,021,419
Other Nonag		$ 8,000,000
Improvements		$ 15,000,000
Total		$ 25,021,419

Using the countywide average ad valorem tax rate of $3.03 per $100 of assessed value, agricultural land accounted for approximately $760,000 in ad valorem revenue for the county out of total revenues of approximately $28 million of total ad valorem revenues for all county, district, cities, and towns in Lyon County, or roughly 2.7%.

For Lyon County, in 2007, total taxable sales were $365 million, which represented a 15.2% decrease from the year prior. Total sales tax revenues for Lyon County only (not including school district or other entities within the county), were approximately $14 million.

Mineral County:

As shown in Table 29, Mineral County's budgeted expenses for Fiscal Year 2007[22] totalled approximately $10 million dollars while revenues were lower due to declining ending balance and previously accrued funds spent during 2007. The two primary revenues sources are ad valorem (property) accounting for 17% of total revenues and sales and consolidated taxes (45%). For purposes of analysis, these are the primary items affected by the proposed scenarios.

Table 29. Mineral County budget overview.

Category	(Millions)
Assessed Value	$ 105
Taxable Sales	$ 35
Total Expenditures	$ 10
Total Revenues	$ 9

For Mineral County, total assessed value of property was $105 million in 2005 of which $378,000 (0.36%) was in agricultural land throughout the entire county as shown in Table 30.

Table 30. Assessed value of all property in Mineral County.

Property Type	Acres	Value
Agricultural	15,000	$ 378,000
Other		$ 105,070,000
Total		$ 105,448,000

Mineral County's countywide average ad valorem tax rate was $3.66 per $100 of assessed value,which generates approximately $3.9 million annually in taxes, of which $1.7 million is collected for Mineral County's general fund.

For Mineral County, in 2007, total taxable sales were $35 million, which represented a 6.4% increase from the year prior. Increased military-related spending in Mineral County has boosted the economy. The total taxable sales rate in Mineral County is 6.75% which includes a 0.25% local option tax. Total sales tax revenues for the county were approximately $2 million in 2007.

Fiscal Impact Analysis

The impacts of the acquisition program have been evaluated under four different scenarios described in full above. These include:

Scenario 1 - Land goes from agriculture to desert. As noted above, under this scenario, there would potentially be two different areas of economic impacts: 1) the impacts resulting from changes in agricultural production (hereinafter referred to as the agricultural economic impacts, and; 2) the impacts resulting from the proceeds from the sale or lease of water rights to a party outside the regional economy (hereinafter referred to as the water rights proceeds impact).

Scenario 2 – Existing crop rotations and farming practices are altered to save water. Another approach to obtaining water for Walker Lake that is currently being used for agriculture would be to modify crop rotations and farming practices.

Scenario 3 – Alternative crops are cultivated that reduce water consumption.

Scenario 4 – Water rights from non-agricultural sources are procured**.** This would preserve total agricultural production while transferring water rights from other uses.

Lyon County fiscal impacts

Scenario 1 - Land goes from agriculture to desert. Scenario 1 is the only scenario which may change the tax bases for the county as agricultural land loses water rights and changes it use. The net effect of such changes in use depends upon the new use for the land. If the land is converted into non-agricultural use such as residential or commercial, it would lose its agricultural exemption and the assessed value of the land would likely increase from the current $1-200 per acre to approximately $4000 per acre. This would increase the total tax revenues from such land. On the other hand, if the land is left vacant and receives a valuation based upon use as "open space", then its value would likely remain approximately the same, although probably at the lower end of the range for agricultural land. This would likely result in a slight decrease in total ad valorem tax revenues. Since there are offsetting potential valuation changes, no estimate is possible for the net change in total ad valorem, although any change will likely be relatively minor given the small share (approximately 8%) of the county's total assessed value represented by agricultural land (Table 29).

Under scenario 1, there may be some changes in total retail sales. However, most of these sales will likely be exempt from sales taxation, such as agricultural implements, groceries, etc. Furthermore, with the exception of the local option tax of 0.25%, other taxes fall under the county's guaranteed status and thus even if total sales and use tax revenues decline, the county will not lose any of its distribution from the state which will increase its net subsidy to maintain the county's guaranteed revenues.

The primary effect on demand for local government services and the level of expenditures necessary depends upon changes in local population. As noted above, total employment will likely be quite small (maximum positive or negative impact less than 2%) resulting in negligible change in permanent population. Some changes may occur in temporary population associated with agricultural activities. However, since these workers (very few bring family members) are primarily housed on-site (according to John Snyder), there is limited net effect on local government services if there is a decrease.

Scenario 2-4: Under the remainder of the scenarios, while agricultural activity may change in composition, total economic activity and local tax bases, including property and sales, would not be substantially altered, therefore there would be no net fiscal impact on the county.

Mineral County fiscal impacts

Economic impact in the Hawthorne area related to the Walker Basin project would most likely occur as a result of a resurgence of the recreational fishing industry, plus some other outdoor recreation related to Walker Lake. One estimate, see above, is local sales would increase by $1.15 million. About 13% of this expenditure was for lodging with the balance being spent in local retail sectors.[23] Assuming that 25% of the retail expenditures remain in the region leads to a calculated direct impact of approximately $150,000 in the lodging sector and $250,000 in the retail sector. This would generate additional local sales and property. It is unknown what percent of such jobs would be filled by new immigrant population versus existing population, therefore, the total effect of such changes on local tax bases and demand for services is also unknown. While the additional retail sales from tourism would increase local tax revenues as indicated above, since the Mineral County is a guaranteed county and currently has total sales of approximately $35 million, this is a relatively minor amount.

SECTION 4: FORMULATION OF ECONOMIC DEVELOPMENT STRATEGIES

As indicated within the economic and fiscal impact section of this report, the actual impacts of the water rights acquisition in Mason Valley and Smith Valley will be dependent upon how and where water rights are acquired. One of the most critical issues will be the quantity of water rights that remain with the land, which will determine future agricultural production. This, in turn, will substantially determine the various possible scenarios of economic impacts in Mason Valley and Smith Valley.

The economic impact analysis provided a tool for predicting the direction and magnitude of economic and fiscal impacts. Actual economic and fiscal outcomes will be subject to decisions yet to be made. At the community meetings in all five of the subareas studied (Mason Valley, Smith Valley and Hawthorne in Nevada, and Bridgeport and Walker/Coleville in California) citizens indicated a desire for economic development that would complement their existing communities regardless of the actual impacts of the Walker Basin project in their particular areas. Economic development is the process by which the economic, political and social well being of an area's inhabitants are improved.

For the three subareas in Nevada, this study follows an economic development strategic planning process initiated by the Northern Nevada Development Authority (NNDA) and conducted by Angelou Economics in 2006 for a seven county area (Carson City, Churchill County, Douglas County, Lyon County, Mineral County, Pershing County and Storey County).[24] The research team desired to determine if there were any "conflicts" between our findings and the previous study. In addition to our careful reading of the NNDA/Angelou study, we met with Ron Weisinger, Executive Director of NNDA, and had a conversation with Shelley Hartmann, Executive Director of the Mineral County Economic Development Authority, about the results of our community meetings relative to their views of the NNDA/Angelou study. In short, they saw no conflicts, but rather found that our community meetings validated the prior study.

This does not mean, however, that the economic development strategies formulated for the Walker Basin subareas should exactly parallel those of the NNDA/Angelou study. While the geographic area of the NNDA/Angelou study includes Mason Valley, Smith Valley and the area around Hawthorne, the seven county area of the Angelou study is much larger than the three subareas that were the focus of this study and incorporate some areas where substantial industrial development is occurring and is welcome. The Walker Basin subareas in Nevada, as well as the two in California, have specific local characteristics and community "cultures" that will influence future economic development, in particular their strong desire to maintain their rural setting and way of life. Future economic development ultimately results from the decisions made by policymakers, individual entrepreneurs or corporate officers after consideration of issues such as "community acceptance", profit potential, risk and risk mitigation.

The following sections of this report present the results of the community meetings and provide a discussion of potential future economic development strategies including possibilities and processes.

Community Meetings: Citizens' Perceptions of Their Communities and Economic Development

For each community there is a brief presentation of the key words citizens offered to describe their communities, lifestyles and economies, suggestions made by the citizens of potential areas for economic development, and then a brief assessment by the research team of these suggestions for economic development.

Mason Valley, Nevada

Mason Valley has approximately 11,000 residents, with just over 3,000 residing in Yerington, the county seat of Lyon County. The valley and its economic base are described in detail in the G.I.S. database development project completed by Brian Bonnenfant, Brain Kaiser and Charles Morton that is a component of the Walker Basin project.[25]

<u>Citizens' comments</u>

The citizens at the community meetings in Yerington[26] described their community, lifestyle and local economy by suggesting the following key words and phrases: "agriculture, green, retired, safe, friendly, travel, recreation, wildlife, water, river, farming, lifestyle, peaceful, rural, old fashioned, organic, strong, united, stable, not for sale, and open space." They also listed a number of agriculture products in describing their area including the following: "alfalfa, onions, garlic, spinach, lettuce, dairy and livestock." They indicated that with economic development, they would like to preserve all of these aspects of their community and maintain Yerington as the County seat. Additionally they would like to preserve: "the quality of life, education system, the hospital, pride, community ethics and morals, common sense, good air quality, trust, viability, families and domestic water wells." They would like economic development to result in the following changes: "improved infrastructure, better healthcare, more jobs, reduced poverty, reduced substance abuse, and greater opportunities for young people."

The citizens expressed their concern that the acquisition of water rights in Mason Valley could result in the following problems: "government interference, misappropriated funds, slow growth, desertification, weeds, job loss, fallow ground, dirty air, no reclamation, loss of community pride, Yerington becoming a bedroom community, more traffic congestion, loss of desirability to potential residents, devalued property, lack of food production, loss of wildlife, higher cost of living, decreased agricultural production, increased crime rate, dependency, loss of political clout, more services, similar to a dust-bowl era, and less mining."

When asked which types of economic development they believed would be most attractive to the community, the citizens had many ideas. Suggestions for economic development included the following: "agriculture oriented businesses, more farmland, more dams on the river, renewable energy, airport/light aviation related industry, higher education facilities, better shopping, more complete medical facilities, high tech, better and/or more affordable internet services, and tourism including ag-tourism."

Agriculture related businesses was further expanded by mentioning: "alternative crops, bottling plant, possibly cheese production, more onion sheds, and agriculture-based value-added business based on food trends and health considerations." An agriculture-related educational facility for young people was mentioned, with discussion of a technical high school with intern programs for biological, mechanical and computer skills. The cross over between agriculture and renewable energy came up during the discussion of algae production that could be utilized to clean wastewater while producing biodiesel, perhaps using wastewater from the new Western Dairy milk processing facility. A general desire was for businesses that would create employment opportunities that would be attractive to young quality families. Finally, there was a desire to see something done with parts of the old Anaconda mine site so that it would be used for some useful purposes which would contribute to the local economy and that might include renewable energy (wind/solar), an industrial park, a bmx track (on the overburden disposal area), or processing the tailings for copper recovery. At the very least it would be desirable to grow some vegetation on the tailings, as was related by several residents as done on tailings in the vicinity of Ruth/Ely Nevada.

In light of the current water issues in the Walker Basin, more farmland and more dams on the river are quite unlikely. Cleanup of the old Anaconda mine site may be moving ahead, with Notice of Proposed Administrative Settlement[27] having been issued May 2008, and with the comment period scheduled to close on June 11, 2008. The 3,468 acre mine site is comprised of approximately half private land held in fee and the remaining land subject to management by the federal Bureau of Land Management. Through the proposed Administrative Order of Consent (AOC), Atlantic Richfield Company agreed to reimburse over $2.7 million for incurred response costs through May 2007 and to provide a technical assistance program for the community around the site. The site is presently undergoing a remedial investigation, and EPA anticipates resolving present and future response costs through subsequent agreements. Costs of future responses could be substantial and the process could continue over an extended period of time. Local residents expressed frustration at how long the EPA process is taking

Brief assessment of economic development suggestions

The economic development concepts suggested by the local residents fell into six major categories, with some overlap between them. These six industry categories are: agriculture related development, renewable energy, education facilities, aviation related developments, high tech businesses, and tourism. Some of the potential concepts for economic development may involve several of these categories.

Agriculture related development

Many of the residents attending our community meetings expressed a desire to see future economic development that is consistent with their existing agricultural-based rural economy. This not only "feels right" to the residents, but it follows good economic development practice. Economic development is often pathway-dependent, which is to say it is tied to what already exists in a community. This sort of development is more likely to occur and has a higher probability of success than development that is unrelated to past successes in a geographic area. This is the basis for industry clusters, a well-recognized concept in economic development.

Economic development tied to agriculture but not dependent upon increased acreage or substantially greater water consumption could occur in a number of ways, including but not limited to: alternative crops, value-added products and processes, agriculture research and development, agricultural education, and agriculture-tourism.

A portion of the Walker Basin research involves determining the viability and economic feasibility of alternative crops. Individual farmers and ranchers will need to decide which, if any, of these alternative crops make sense for them. Preliminary analysis indicates that several of these alternative crops could provide increased profitability to the farmers while also resulting in increased employment and other positive economic impacts to the community. However, due to the high levels of initial investment and perceived risk associated with alternative crops, some form of risk mitigation may be necessary in order to accelerate transition by farmers to some of these alternative crops.

Agriculture-related value-added products and processes seem to hold great potential. The new Western Dairy milk processing facility in Yerington is a recent example of an agriculture-related value-added high-technology processing facility benefitting the local economy. The facility required a $35 million capital investment and resulted in 24 new high-paying jobs for plant operations. The operators of Western Dairy have indicated that while they don't want to expand into cheese production, they would welcome such a facility nearby and would also be pleased to sell their byproducts as necessary raw materials for making cheese.

If wine grapes become one of the alternative crops of choice for some local farmers, one or more wineries might be viable locally. This would add direct secondary employment and create additional economic impact to the local economy. Growing grapes and making wine has evolved over the years and requires sophisticated technology. Thus some of the employment will include high-paying technician jobs. Additionally, wineries and cheese production facilities could provide tasting facilities and tours, thereby adding important components to an agriculture-tourism component of the local economy.

Renewable energy

Most of northern Nevada has an abundance of sunshine. Throughout the Great Basin the earth's crust is relatively thin, resulting in relatively easily accessible geothermal resources. Mason Valley seems to have substantial potential for both geothermal and solar energy development and projects related to both are reported to be under consideration. Additionally, some biomass possibilities may exist, perhaps including production of biodiesel and/or ethanol. Viability of these types of projects is likely to be dependent upon advances in technology. All of the renewable energy possibilities hold great potential for quality job creation and positive economic impact.

Aviation related development

Substantive economic development efforts based upon the airport would require an investment in improvements to the airport facilities. This process would likely begin with a review and update of the airport master plan including determination of what improvements are needed and potential funding sources. This process would involve substantial interaction with the Nevada Department of Transportation. Other communities in Lyon County are also seeking expansion of airport facilities and development of businesses around the airport includes Dayton, Fernley, and Silver Springs, so there may be competition for funding.

High tech entities

The term "high tech," when used in reference to economic development, could have a number of interpretations, and the local citizens did not elaborate on their intended meaning. It may simply mean businesses that provide employment opportunities that require advanced education and therefore also have higher wages. Some people, when using the term "high tech" mean cutting edge development in such fields as electronics, advanced computing or communications, new material science, biotechnology, or nanotechnology. Interestingly, advanced technology is being utilized in many traditionally "low tech" industries, so high tech could apply to almost any industry these days. Certainly high-tech can apply to agriculture, renewable energy and education.

Education

Under the current fiscal conditions, neither the State of Nevada nor the Lyon County School District would appear to have resources available for development of new educational facilities in Mason Valley in the near future. This does not, however, mean that educational facilities are out of the question; it simply means that non-traditional funding sources would be necessary to build and support educational facilities. If certain unique research and educational niches can be found, perhaps special funding sources can be identified. For example, some of the research work associated with the Walker Basin project deals with agriculture in an arid high-altitude environment. With current world food pressures, with such a high percentage of the world being arid, and with changing climate conditions, it would seem there might be a great need for research and training facilities along the same lines as some of the research included in the Walker Basin project. Perhaps the University of Nevada, Reno, and the Desert Research Institute could continue research in the very critical areas of best agricultural practices in arid high-altitude environments through continued projects and expanded facilities in Mason Valley and Smith Valley. With current budget limitations on resources from the State of Nevada, the most likely potential funding source is federal monies.

Tourism

Tourism related economic development could be in several forms: agriculture-tourism, either tied to product sectors like wine and cheese industries, and/or through dude ranch operations, recreation oriented tied to hunting, fishing, viewing wildlife, hiking and camping, and special events. These types of development would seem to be consistent with the desires expressed by the local citizens for maintenance of the rural agricultural character of this area.

Former Anaconda mine site

Cleaning up of the former Anaconda mine site may present some other interesting opportunities for combining research and education. The mine site contains uranium, thorium, and other hazardous substances, and water on the site may be contaminated with these materials. The University of Nevada, Reno has a Civil and Environmental Engineering program with expertise in dealing with some of these issues. Perhaps the cleanup efforts could include development and commercialization of new processes for cleaning up abandoned mine sites.

Smith Valley, Nevada

Smith Valley includes the communities of Smith and Wellington. The population of Smith Valley is approximately 2,000 (2007 population estimate). It is also within Lyon County. Smith Valley and its economic base are also described in detail in the G.I.S. database project that is a component of the Walker Basin project.[28]

<u>Citizens' comments</u>

The citizens, at the community meetings in Smith[29], described their community, lifestyle and local economy by suggesting key words. The following key words and phrases to describe the physical setting: "rural agricultural, few noxious weeds, scenic beauty, green, arid, dark skies, starry nights, pivots and sprinklers, beautiful public park and dirt roads". In describing the community and lifestyle, terms suggested included: "agricultural-based economy, small, clean, industrious, low population, friendly, independent, strong sense of community, horse friendly, wildlife friendly, redneck, small schools and classrooms, community support for schools, retired and tired, old farmers, few services, little business, no municipal water or sewer, lots of private property, lots of volunteerism, community pride, strong sense of home, sense of history and family, sense of sanctuary, sustainable, the last frontier, and positive energy in community." One phrase that seemed to sum up all aspects was "sense of sanctuary."

The Smith Valley citizens expressed concern that many favorable aspects of the community could be lost through the acquisition of water rights for Walker Lake, and that their valley could experience "desertification, decline in population and property values, closing of businesses and loss of jobs, changes in the viewscapes, loss of domestic wells", and a resulting "general decline in sense of community and volunteerism."

The types of economic development cited by local residents as being most attractive to the area included green (renewable) power plants, light clean industrial development, creating a village with a theme, tourism including agricultural-tourism and wildlife tourism, and more recreation such as a mountain biking system. Infrastructure that citizens felt would be helpful included a municipal water system and affordable housing. Changes in agriculture that the local residents thought could be beneficial included low-water use crops that were more profitable, and value-added agricultural products, perhaps based on food trends and health considerations. One hurdle identified by the residents related to this last suggestion was that the University of Nevada, Reno has no food-science department that is looking at such things as omega-3 crops like purslane, which is considered a weed by most farmers. The implication was that development of such expertise and programs at UNR could be beneficial to the region.

<u>Brief assessment of economic development suggestions</u>

Green (renewable) energy

One key question related to renewable energy in Smith Valley is whether this would be for meeting local energy needs or for "export". This is important because one of the critical factors for exporting renewable energy is the availability of existing infrastructure (i.e. transmission lines for electricity) or the cost of building new infrastructure for exporting this energy. For biofuels, there would need to be processing and transportation infrastructure.

Tourism

Tourism based on recreational activities, wildlife, and agriculture would seem to fit the desires expressed by local citizens for maintaining the characteristics of their valley. Creating a village with a theme might add the necessary infrastructure to obtain substantial economic benefit from an increased number of tourists. Since Smith Valley may be a good environment for wine grapes, there might be a good basis for developing tourism around a local winery.

Light clean industrial development

Of the suggestions from citizens, this may be the most difficult to implement and provide the poorest fit with the characteristics of the valley that local residents indicated they wished to maintain. There is no existing industrial base, no support services or facilities, and no industrial work force. Infrastructure for light industry is virtually non-existent.

Hawthorne / Walker Lake, Nevada

Hawthorne is a community of just under 3,000 people (estimated by the Nevada State Demographer for 2007), and is the county seat of Mineral County, Nevada. It is located about seven miles south of Walker Lake. The community of Walker Lake, with a population of approximately 300 people, is approximately 12 miles north of Hawthorne along the western shore of Walker Lake.

<u>Citizens' comments</u>

At a community meeting[30] local citizens described their community, lifestyle and local economy by suggesting the following key words and phrases: "patriotic, environmental, friendly, blue collar / middle class, outdoor recreation, hunting, fishing, rock hunting, challenging economy, things taken away, limited land and resources, three percent (3%) privately owned, limited water, low crime, hometown / old fashioned, sense of community, neighborly, and community unifies around common goals and causes." With any economic development that might occur, the community members indicated they would like to preserve all these aspects of their community except the challenging economy. Additionally, the citizens mentioned that they would like economic development to result in the following changes: "improved medical care, economic diversity, sustainable population levels, expanded and more diverse retail, more amenities, and more lake functions such as boat races." In general, they felt that an improved economy will improve everything else.

The citizens at the community meeting indicated that without more water flowing into Walker Lake, the lake would not be able to sustain fish. The lower lake levels and increased salinity have already resulted in reduced fish longevity, smaller fish, decline in the number of migratory birds, a decline in recreational use of the lake with a corresponding decrease in tourism dollars spent on fishing equipment and supplies, as well as decline in other related tourist expenditures. They indicated that the receding shoreline held up funding for recreational improvements at the lake. Additionally, they commented that the receding shoreline is increasing the dust hazard, which affects tourists, residents and the equipment at the military base. They reported an increase in respiratory illness resulting from the dust. They noted that the groundwater level at the community of Walker Lake is dropping, which affects domestic wells.

The citizens felt that the types of economic development that would best fit their community would be operations that were related to the lake, aviation, the military and/or renewable energy. They also had some enthusiasm for "home grown" businesses – business ventures developed by people who already reside in Hawthorne.

<u>Brief assessment of economic development suggestions</u>

Lake related development

Before lake related economic development is likely to occur, there will need to be some indication that the decline of Walker Lake and the resultant trend of increasing salinity can be or has been stopped and perhaps reversed. The risk associated with any investments will likely be too great until this has occurred. However, if the risk associated with the declining lake level can be mitigated, then the opportunity should certainly exist to re-establish lake-related businesses that were previously present in the communities of Hawthorne and Walker Lake. In the short run, economic development related to Walker Lake will be "on hold" waiting for the outcome of the efforts to save the lake.

Aviation related development

According to the citizen input, the Hawthorne Municipal Airport has "lots of room", great weather, and is used both for general aviation and the military. Master planning for the airport is currently underway. A security fence is being constructed, and a fire suppression system will be constructed in the near future, both of which are necessary for additional development to occur in and around the airport. A new fuel facility is going through the permitting process. The new fuel facility is particularly important to the Army Special Ops Command. Blackhawk helicopters currently must bring in fuel from Fallon. Other airport improvements that could greatly enhance the airport would include facilities upgrades (runway, aprons, etc.) to accommodate larger aircraft. Airport improvements could lead to additional hangars, and expansion of industry located at the airport. The executive director of the Mineral County Economic Development Authority reported there are some groups interested in providing hangars for general aviation access to the Mammoth recreation area, which is only 80 miles away by automobile.

Military related businesses

There is a substantial military presence in and near Hawthorne. The U.S. Army Ammunition Depot opened in Hawthorne in 1930, was later expanded to include the Naval Ammunition Depot, and in 1980 converted to a government-owned, contractor-operated facility. In addition to storing munitions, the facility also houses operations to demilitarize, renovate and recycle conventional ammunition. The Marine Corps operates a live-fire ordnance test facility which includes full instrument ranges with state-of-the-art radar tracking and audio/visual recording equipment. The U.S. Navy maintains a

Naval Undersea Warfare Center (NUWC) Division facility in Hawthorne that is part of the fleet testing and logistics operations. Part of the U.S. Navy presence in Hawthorne has involved recycling batteries which contain economically significant quantities of base and/or precious metals. Additionally, the U.S. Army conducts training near Hawthorne. U.S. Special Forces Soldiers rehearse reacting to ambush, dealing with improvised explosive devices (IEDs), advanced driving in rough terrain, pre-mission planning, diplomacy, heavy and light weapon training, medical treatment in the field and other skills needed in Afghanistan. The troops also become acclimated to high altitudes. Layered on top of all this, Special Operations Consulting – Security Management Group, a private security training firm, operates a training facility for private security forces in Hawthorne. Their High Desert Special Operations Center, with over 4,000 acres of varying terrain, is the largest most comprehensive security training facility west of the Mississippi.

Angelou Economics completed a study in October 2007 examining the Military Business & Resource Gap Analysis for the 7-County Northern Nevada Region.[31] Through interviews with base commanders, major defense contractors and community leaders, the study determined that military contracting in Mineral County grew from $33 million in 2001 to over $61 million in 2006. Further, the study identified six industry areas that had substantial potential for additional contracting opportunities in the Hawthorne area: 1) fabricated metal product manufacturing, 2) warehousing and storage, 3) professional, scientific and technical services, 4) administrative and support services, 5) waste management and remediation services, and 6) food services and drinking places.

Related to all of this, the Mineral County Economic Development Authority is targeting gun manufacturers from across the nation for relocation to Mineral County by offering a more receptive political and community environment to the gun manufacturing industry than is currently found in many states.

Renewable energy related businesses

Like much of Nevada, the Hawthorne area has plenty of sunshine and geothermal resources in the vicinity. Hawthorne has been considering the use of geothermal energy for over 30 years, ever since a geothermal well (owned by the County) was drilled a few miles out of town with temperatures around 210^{o} F. Historically, lack of a sufficient return on investment and/or inadequate financial resources to develop this geothermal resource for a district heating system have been insurmountable barriers for the community. The U.S. Navy is commencing two 4,000 foot geothermal wells following significant research and a shallow well. The contracts have been let and these wells were scheduled for completion in the summer of 2008. Since natural gas, typically the most economical fossil fuel, is not available in Hawthorne, renewable energy alternatives may prove to be quite viable.

Home-grown businesses

Two substantial advantages of home-grown businesses in communities are: 1) no relocation recruitment effort is required – the proprietors already reside in the community, and 2) business retention, avoiding the loss of businesses to other communities due to competitive economic factors is easier, as proprietors have already chosen to live in the community. The key element for home grown businesses to serve as an engine for economic development is that the businesses need to be in primary industries (import money, export goods or services) or must support primary industries in order for them to stimulate the rest of the local economy.

Shelley Hartmann, executive director of the Mineral County Economic Development Authority, expressed great enthusiasm for locally grown businesses. Hawthorne just completed its first NxLeveL entrepreneurship class, with 18 local residents graduating from the course. Four were owners of existing businesses who are now more focused on growing their businesses, and the other 14 were individuals interested in business start-ups. Most are looking at either selling to the government, or doing e-commerce, and will develop customers beyond the local residents. A grant proposal was recently submitted to the USDA to bring broadband services into the communities of Walker Lake and Mina which should benefit e-commerce in those communities. Ms. Hartmann expressed a desire to offer the NxLeveL training on a recurring basis and to provide additional resources to help support new and expanding businesses. Along these lines, the development authority has added a small business incubator within its facility.

Bridgeport, California

Bridgeport is the County seat of Mono County, California. The total 2007 population of Mono County was just over 14,000, with nearly 60 percent of that population residing in the town of Mammoth Lakes, which is outside the Walker Basin. The 2000 census indicated 794 people living in Bridgeport, with another 52 in Twin Lakes. The headwaters of the Walker River system are near Bridgeport, and the rugged mountains provide spectacular scenery.

<u>Citizens' comments</u>

Citizens of Bridgeport described their community, lifestyle and local economy by suggesting the following key words and phrases: "rural community, scenic value, closely knit, safe (can walk the town without fear), tourism (appeal to fishermen), seasonal, highly dependent on water, best fishing in the Eastern Sierra, agriculture and little development."[32]

With the understanding that water rights acquisition efforts are currently limited to Nevada, the concerns of the Bridgeport-area residents about the Walker Lake restoration project are essentially limited to how and when water would be transported, how this would affect the storage and river flows in their area, and how all of this could impact fishing and the scenic beauty of their area.

When discussing economic development, the residents of Bridgeport indicated they would like to find ways to bring in more tourism, particularly during the offseason. They would also like to attain a higher percentage of year-round residents. They indicated that a simplified system for camping reservations by the Forest Service would be beneficial, since some campers seem to have become discouraged by the current system. Also, they felt that the Forest Service created too much business competition with local businesses.

Potential improvements cited by local residents included having a rodeo, bringing in more good entertainment, and the addition of a visitors center to better support tourism by enticing people passing through on the highway to stop. The addition of winter tourism activities such as helicopter skiing or other sports was mentioned as something that would be favorable. Finally, ways to leverage the existing fly fishing activity, such as having fly rod manufacturing, was another idea mentioned for economic development.

Brief assessment of economic development suggestions

Tourism was the only area of economic development suggested by the local citizens. In light of their current economic base and infrastructure, this makes sense. One of the primary suggestions was to develop tourism in times of the year that would complement their current primary tourism season, which is the five months beginning in May and ending with September.

Walker/Coleville, California

Walker, Coleville and Topaz are in Mono County, California, and are located in Antelope Valley close to the Walker River. The Nevada/California state line cuts through the north end of Antelope Valley, also bisecting Topaz Lake, a reservoir on the Walker River. Walker and Coleville are about five miles apart, with Coleville to the north of Walker, and Topaz is approximately five miles north of Coleville. The 2000 census showed a combined population for Walker, Coleville and Topaz of just under 1,200 people.

Citizens' comments

The citizens, at the community meeting in Walker, described their community, lifestyle and local economy by suggesting the following key words and phrases: "depressed economy, easy relaxed lifestyle (if retired), rural, family and community oriented, greenbelt through center of valley, wildlife and fishing, night skies, largest portions of the local economy are from hay, cattle and tourism, lots of retirees, and small scale."[33]

Concerns about the Walker Lake restoration project are similar to those heard in Bridgeport, with the primary focus on how releases of water might affect Topaz Lake, thereby affecting tourism and the local economy. The local citizens were also concerned that water rights acquisitions might eventually be expanded into California, thereby affecting Antelope Valley.

For future economic development efforts, the residents expressed the need to maintain the small-scale nature of the community. Areas of economic development that would be compatible with the area include recreation, tourism (the main source of employment), cottage industries, home-based businesses, and small businesses. The residents stressed the need to protect agricultural interests and wildlife, and to preserve access to public lands. They indicated that public improvements along the river and main street improvements would enhance tourism.

Brief assessment of economic development suggestions

Tourism

Recreation-based tourism takes advantage of the natural setting in and around Antelope Valley, including the Walker River and Topaz Lake, and can leverage some of the existing tourism infrastructure (motels, cabins, camping sites, etc.).

Home-based and small business development

Cottage industries, home-based and small businesses would fit the “small scale” suggestion made by local residents, and would fit the character of the communities.

Economic Development Recommendations

Successful economic development is, ultimately, dependent upon individuals making investment decisions in a community. Those individuals consider the risks and returns associated with potential investments and then allocate their resources to those projects and locations that meet their criteria.

Certain locations offer competitive advantages for such investments relative to other locations. Historically, economic centers grew around communities that offered transportation infrastructure, beginning with seaports and intersections of “trade routes”, later including rail centers, road and highway intersections, and eventually airports. Other infrastructure became important as economies became more sophisticated. These included developments around industrial infrastructure, specialized labor and industry expertise, educational facilities, particularly those with advanced research and development capabilities that are an essential ingredient of the “expertise”, and access to capital that understands the local industries. These are the basis for industry clusters. Other drivers of economic development in certain localities, not previously mentioned, include natural resources, intellectual property and energy.

Citizens and public officials, working to enhance economic development in their communities, need to understand what “advantages” their area offers, and their role in encouraging individuals to make investments that can utilize these advantages. Local citizens and officials can work to mitigate or eliminate different types of risks that would be perceived by potential investors and also create and/or promote their own competitive advantages. For example, public processes that tend to ensure communities will be receptive to certain types of development reduce one of the risks that might concern investors. Eliminating or reducing barriers to development might involve such things as land assemblage, expedited approval and permitting processes, development of key infrastructure related to transportation, communications, education, etc. Business risks might be mitigated through access to targeted capital pools through low interest loans and/or grants that either lower the cost of capital or extend repayment terms to improve early cash flow.

For local economic development efforts to maximize their success, interested citizens and public officials should work to leverage existing available resources such as economic development entities, cooperative extension and business development entities that are part of state universities, and look for federal and state grant opportunities, particularly those targeted for rural communities. Additionally, they need a sufficiently funded lead individual or entity to be responsible for organization, communication and most importantly, relentless expenditure of energy into the economic development effort.

With all this, each community needs to develop a process for moving their local economic development efforts forward, some initial resources to fund the process, and eventually access to a larger resource pool to use as the catalyst for “making things happen”.

To expedite successful economic development in each of the subareas of the Walker Basin, ideally some federal funding could be identified to assist economic development efforts in the basin. A small portion could be targeted for technical assistance and another small portion might be dedicated to research, with most of the funds being dedicated to a resource pool available for investment in needed infrastructure and for grants/loans to help mitigate development risks and to serve as a catalyst for new projects.

Specific economic development recommendations made by the research team that are presented below are related to either a) economic impacts directly attributable to the historical decline of the water level of Walker Lake (those impacts that have already occurred in the Hawthorne area) or b) economic impacts that are likely to occur as a result of the acquisition of water rights in Mason Valley and Smith Valley, and that ideally will contribute to the quantity and quality of water flowing into Walker Lake. These impacts are, essentially, geographically limited to the three subareas in Nevada. The research team, therefore, has limited its specific recommendations to these subareas.

These should be considered as preliminary recommendations that need to be vetted through community involvement. It is the intention of the Nevada Small Business Development Center to manage this vetting process and to work with local citizens, public officials, existing economic development entities and any other stakeholders who can be identified to initiate implementation of economic development strategies in and for these sub-areas. This effort will continue, as a part of the Walker Basin project, through December 2008, at which time the current funding provided for this portion of the Walker Basin project comes to an end.

For each sub-region, the proposed economic development strategies set forth below includes three components: 1) targeted economic development projects/industries, 2) suggested public policy recommendations, and 3) identified potential resources. The targeted projects/industries are primarily those that are in some manner related to the overall Walker Basin project, as this approach has the potential of providing dual benefits of complementing the Walker Basin project and providing general economic benefits to the communities.

Mason Valley economic development strategies

1. Targets: The suggested targets for economic development in Mason Valley include the following: a) value-added processing and market development related to the alternative crops of teff and two-row malt barley; b) agricultural research related to cultivation in arid high-elevation environments; c) alternative energy developments focused on geothermal and biodiesel production; and d) cleaning up the former Anaconda mine site. Each of these is selected for its potential link to the Walker Basin project as described below.

   a) Value-added processing and market development for teff and two-row malt barley both seem worthy of further investigation. Cultivation of both teff and two-row malt barley seem to have potential for reducing water consumption while generating positive economic impact within the region. Value-added processing fits well with the Walker Basin project and is consistent with the preferences expressed by local citizens.

In regard to teff, one aspect of market potential may be related to celiac disease. It is an autoimmune digestive disease that interferes with absorption of nutrients from food and is triggered by the consumption of glutten, which is found in wheat, barley and rye. It is estimated that roughly one in every 133 Americans has celiac disease but that 97% remain undiagnosed. Flours without glutten can be made from teff, rice, corn, soy, buckwheat and a few other products. Teff is purported to be an important health food for consumers to keep their bodies fit and to control weight. It is also marketed as a natural sports food which is consumed by East African runners. Finally, there is at least one glutten-free beer made from teff.

Currently the nearest facility for processing teff seed into teff flour is located in Idaho. If teff is to become one of the alternative crops adopted by farmers in the Walker Basin, there may be a viable opportunity to develop facilities for not only processing the flour, but also for production of consumer products. It could become similar to or perhaps even larger than the manner in which Lattin Farms produces consumer products near Fallon.

Two-row malt barley is primarily used for brewing beer. Traditionally, breweries operated their own malting operations, but this has changed throughout most of the world because of the growth of a few larger commercial maltsters. The closest maltsters to Nevada are in Vancouver, Washington and Pocatello, Idaho. Both are owned and operated by Great Western Malting Co., which in turn is part of a larger entity that owns Bairds Malting in the UK, Barrett Burstin Malting in Australia, and Canada Malting in Canada. However, with the growth of the brewpubs and micro-brewery business in the U.S., there may be an opportunity for a boutique custom malting operator to cater to the requirements of the small brewery operations. The research team believes this opportunity is worth investigating. There is one small boutique maltster in Australia that has successfully competed against the large maltsters, which might serve as a source of information and a model.

In addition to an end-market of home brewers, there are an increasing number of brewpubs and micro-breweries in the U.S, including at least 15 in Nevada. An initial investigation could include contacting these entities to see if they would have any interest in custom malts that might help them to differentiate their products and/or add different beer styles to their current offerings. If feasible, this would also fall in line with the trend to develop local supply relationships in order to reduce transportation costs and the carbon footprint associated with such products.

b) Agricultural research related to cultivation in arid high-elevation environments is another economic development target deserving further investigation. This potential economic development target has the potential for both increasing available water for Walker Lake, and providing positive economic impact. It is consistent with the desires expressed by local citizens. Several trends tend to support this concept: increasing world population, increasing food costs, declining farm land, and climate change which seems to cause reduction in precipitation and availability of fresh water in many parts of the world. Cultivation in some of the arid environments has led to desertification as a result of using farming practices that are not sustainable.

Portions of rural Nevada provide ideal environments for testing alternative crops that can succeed under these arid conditions and also assess how modifications of farming practices can utilize irrigation water more efficiently. The existing physical environment, combined with expertise found within the University of Nevada, Reno's College of Agriculture, Biotechnology and Natural Resources and the Desert Research Institute, bring together factors ideally suited to help the United States develop the intellectual property needed to improve farming in these types of environments. Economic development efforts to leverage these circumstances and build upon the Alternative Agriculture and Vegetation Management research that is part of the current Walker Basin study have the potential to result in an ongoing research program and facilities located in Mason Valley and Smith Valley. This type of economic development could be quite significant for the region.

c) Alternative energy developments focused on geothermal and biodiesel production are two other potential targets for economic development that seem worthy of further investigation. The option to acquire geothermal water rights for the restoration of Walker Lake already points to the linkage to this project. If the geothermal water can provide some energy value, either in the form of generation of electricity or by providing a low-level heat source for some commercial or industrial use, there would be a double benefit. One of the "negatives" of the geothermal water source is that geothermal water often contains large concentrations of dissolved minerals such sodium, calcium, sulfate, chloride, or iron. However, there has been extensive research on the recovery of minerals and metals from geothermal fluids.[34] Depending upon the mineral content of the geothermal water in question, there might be some potential commercial benefit from extracting minerals and metals, and also improving the quality of this water source for Walker Lake. The trend of increasing prices for many commodities adds to the intrigue of this potential aspect of geothermal development. Dr. Amy Childress, in the College of Engineering at the University of Nevada, Reno has been conducting research on various methods of removing "contaminants" from brackish water which may present an opportunity for a related economic development possibility. This research project in Mason Valley could potentially improve the quality of the water destined for Walker Lake while creating new intellectual property in the field of mineral and metal recovery from geothermal fluids.

Production of biodiesel from algae may present one more "dual purpose" economic development possibility. Growing algae can be used to extract "contaminants" from water, thereby improving water quality and certain algae can also be a great feed stock for biodiesel. A manager from the new Western Dairy plant in Yerington mentioned this as a potential application to their waste stream. This may also be applicable to treated effluent from local municipal wastewater treatment facilities. Depending upon the content of fertilizers in return flows into the Walker River from agricultural areas, there may be one additional source of water worthy of consideration for algae growth and biodiesel production.

d) Cleaning up the former Anaconda mine site has potential for positive economic impact, and might also have a relationship to the Walker Basin project. A widely-held perception is that the water in the old pit is contaminated, even though Lyon County has a test result (Sierra Environmental Monitoring – 2006) that shows the water passing drinking water standards. A few wells in close proximity to the mine site have some water quality issues. If, as part of any clean-up effort, minerals and metals could be removed from this water to improve its quality, and if any of this water could be made available for Walker Lake, it might provide one more source of non-agricultural water. One of the Lyon County Commissioners indicated to the research team that in the days when the mine was operational, water was pumped from wells near the mine and this water flowed into Walker River and ultimately was part of the flow that made its way to Walker Lake. Lyon County has filed an application with the State Engineer for water rights in the pit. A Lyon County Commissioner indicated that the State Engineer wants more information about the source of the water in the pit before acting on this application.

2. Suggested public policy recommendations: The research team developed three public policy recommendations that would enhance the targeted economic development projects described above and relate to: a) acquisition of water rights; b) modification of water rights law; and c) identification of some of federal funding sources for these economic development efforts.

   a) When the acquisition team acquires water rights, there could be a policy to "balance" the acquisition so that some acreage is left with sufficient water rights to grow alternative crops (such as teff or two-row malt barley). This would enhance the potential for development of the value-added processing and market development mentioned above. At the same time, the value-added additional processing would tend to improve the market for these alternative crops grown by local farmers.

   b) Some aspects of water rights law may require modification in order to accomplish the above policy recommendation. From the standpoint of both economic impact and economic development, it would seem that there could be benefits from such modification of water rights law that would allow partial sale of water rights rather than an "all or none" approach.

   c) Identification of some federal funding for economic development projects seems to have merit, particularly when the recommended projects are related to the general intent of restoring Walker Lake. Specifically funding could be used for: 1) additional feasibility analysis of the recommended target developments and others that may be identified during the vetting process; 2) funding the projects through a combination of grants and loans; and 3) providing funding for technical assistance necessary for such projects to be implemented and successfully operated.

3. Potential resources: Federal sources of financial and technical assistance should be explored. Potential sources of financing for these types of projects could include the U.S. Department of Agriculture, U.S. Department of Energy, and the U.S. Environmental Protection Agency. Nevada resources could include the Nevada Commission on Economic Development, the Northern Nevada Development Authority, the Nevada Division of Environmental Protection, the Nevada State Office of Energy, and the University of Nevada, Reno including the College of Agriculture Biotechnology and Natural Resources, the College of Engineering and the College of Business.

<u>Smith Valley economic development strategies</u>

1. Targets: The suggested targets for economic development in Smith Valley include: a) value-added processing and market development related to the cultivation of wine grapes, and perhaps to teff and two-row malt barley, b) agriculture-based tourism, and 3) recreational tourism focused on the Walker River.

   a) Each of the alternative crops has the potential to divert substantially more water from agricultural uses into restoration of Walker Lake. It appears that Smith Valley may be more conducive to the cultivation of wine grapes than Mason Valley. If this proves to be true, as determined through monitoring of micro-climates within different parts of Smith Valley, and if substantial acreage of grape cultivation is attractive to farmers, then the opportunity for another winery could be a real possibility. Smith Valley would provide an ideal setting for a winery. Regarding teff and two-row malt barley, if these crops can be cultivated in Smith Valley with adequate yields to be profitable, then any value-added processing and market development could occur in either Mason Valley or Smith Valley. Either location should benefit the region.

   b) Agriculture-tourism fits very well with a winery. Agricultural tourism could include farm or ranch-based bed-and-breakfast operations or dude ranch operations.

   c) Recreational tourism tied to the river could focus on recreational fishing or kayak/float activities, either within Smith Valley or perhaps in Wilson Canyon between Smith Valley and Mason Valley.

2. Suggested public policy recommendations: Exactly the same policy recommendations are applicable for the Smith Valley economic development as were suggested for Mason Valley.

3. Potential resources: Federal sources of financial and technical assistance should be sought for the Smith Valley economic development projects. One federal source of funding for different aspects of these projects could be the U.S. Department of Agriculture. Nevada resources could include the Nevada Commission on Economic Development, the Northern Nevada Development Authority, and the University of Nevada, Reno including the College of Agriculture Biotechnology and Natural Resources and the College of Business.

Hawthorne / Walker Lake economic development strategies

1. Targets: The suggested targets for economic development in the Hawthorne/ Walker Lake area related to the Walker Basin project include the following: a) lake-related developments such as boat ramps, improvements to camping and day-use areas, and renovation of or construction of new motel and restaurant facilities; and b) development of geothermal alternative energy resources. The research team believes that Hawthorne's economy is primarily a military-based economy. Even if Walker Lake receives more water, the community should continue to pursue airport improvements, expansion of the ordnance and other explosives reprocessing, and contracting with federal agencies to support the military operations in the area, as well as developing home grown businesses. However, while these projects are viable economic development opportunities, they are not directly related to the Walker Basin mission of restoring Walker Lake and therefore are not included among the suggested targets.
2. Suggested public policy recommendations: If the level of Walker Lake can be stabilized and perhaps increased, the research team believes that some combination of federal and state policies should seek to encourage recreational use of the lake while protecting the environment for future generations.
3. Potential resources: Federal sources of financial and technical assistance should be sought for the Hawthorne economic development projects. Federal sources of financing for different aspects of these projects could include the U.S. Department of Defense, the U.S. Department of Agriculture, the U.S. Department of Energy, and the U.S. Department of Interior (U.S. Fish and Wildlife Service). Nevada resources could include the Nevada Commission on Economic Development, the Nevada Department of Conservation and Natural Resources, the Nevada Department of Wildlife, the Northern Nevada Development Authority, and the University of Nevada, Reno including the College of Agriculture Biotechnology and Natural Resources and the College of Business.

In fall 2008, the Nevada Small Business Development Center plans to hold meetings in the Mason Valley/Smith Valley and the Hawthorne/Walker Lake areas to vet these recommendations and seek additional citizen input. A final report will be generated in early 2009.

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PROJECT I: DEVELOPMENT OF A WATER RIGHTS GIS DATABASE

DEVELOPMENT OF A GIS DATABASE IN SUPPORT OF WATER RIGHT ACQUISITIONS IN THE WALKER BASIN

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CONTENTS

Appendices are included in digital format on a storage drive at the back of the report

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In support of water leasing and acquisitions, assessment of water distribution systems, and other spatial data requirements for the Walker Basin Project, a geographic information system (GIS) database of vector, raster and tabular data has been developed by Desert Research Institute (DRI) researchers. The GIS database development project was not a stand-alone effort, but rather a service task with the principal objective of acquiring, developing and analyzing the requisite spatial and tabular data needed to successfully support many of the projects that make up the Walker Basin Project. In particular, a majority of the GIS data development focused on providing data for the Decision Support Tool (DST) water flow modeling effort. The GIS database includes both surface and groundwater distribution networks and water rights. These data were used as inputs for a DST designed for use in the basin, providing spatial and tabular data to the supply, demand, and basin management components of the DST, as well as calibration data to assist in the validation of the models. The DST will provide a mechanism for conducting scenario analysis for potential withdrawals of water from the system due to acquisitions and/or leasing, and how much of these withdrawals will be available for increased water delivery to Walker Lake. In addition to data sets for the DST, a wide variety of other spatial data sets were developed and integrated into the GIS database in support of other Walker projects, as well as outside entities requesting spatial data (alternative agriculture and vegetation management; plant, soil and water interactions; health of Walker River and Lake; economic impacts and strategies; demographics and economic development; the United States Fish and Wildlife Service (USFWS) restoration project; Western Development and Storage, the acquisitions team; and Jones and Stokes, the Environmental Impact Statement (EIS) development team). DRI researchers constructed an extensive GIS database of the entire Walker Basin, with data sets from federal, state, and local agencies combined and integrated with derivative data sets developed at DRI. The result is a scalable collection of spatial data (i.e. geodatabases, shapefiles, rasters, and tables) representing a wide variety of spatial and temporal features as well as tabular information for the Walker Basin. The database could be used in the future by resource managers and researchers from agencies and private interests for investigating hydrologic, ecological and economical phenomena in the Walker Basin.

INTRODUCTION

In support of water acquisitions, water leasing, assessments of water distribution systems, and other spatial data requirements for the Walker Basin Project, Desert Research Institute (DRI) researchers have developed a geographic information system (GIS) database of vector, raster and tabular data. The GIS database project was a service task with the principal objective of acquiring, developing and analyzing the spatial and tabular data needed to successfully support the individual projects that make up the Walker Basin Project.

The acquisition of spatial data from federal, state, and local agencies has been an ongoing process since the beginning of the project in April 2007. Many of the data sets acquired have required extensive editing and modification, as well as quality assurance and quality control (QA/QC) checking to ensure consistency within the GIS database and with data and software used by other researchers in the Walker Basin Project.

A majority of the GIS development process focused on providing data for the Decision Support Tool (DST) water flow modeling effort. Derivative data sets were developed and customized so as to supply the proper inputs to the DST development process, including the supply side (PRMS model of Walker basin headwater areas), the demand side (groundwater MODFLOW models of Mason and Smith valleys), and the basin management system (surface water MODSIM models of Mason and Smith valleys). For a detailed description of the development of the DST, please see the related project report, "Development of a Decision Support Tool in Support of Water Right Acquisitions in the Walker River Basin" (Desert Research Institute, 2009).

In addition to data sets for the DST, a wide variety of other spatial data sets were developed and integrated into the GIS database in support of other projects in the Walker Basin Project, as well as outside entities requesting spatial data. Some of these projects include alternative agriculture and vegetation management; plant, soil and water interactions; health of Walker River and Lake; economic impacts and strategies; and demographics and economic development. In addition, components of the GIS database have been developed and shared with other entities associated with the Walker Basin Project, including the United States Fish and Wildlife Service (USFWS) Restoration project; Western Development and Storage, the acquisitions team; and Jones and Stokes, the Environmental Impact Statement (EIS) development team.

The completed GIS database provides a comprehensive geospatial database for the Walker Basin.

METHODS AND APPROACH

The GIS database development research efforts focused on three principal activities: 1) development of the GIS database structure, format, and working projection system; 2) data acquisition and database development; and 3) spatial data analysis. Most of the project involved the acquisition, and/or attempted acquisition, of various spatial data sets determined as necessary to satisfy the input requirements for the DST and data requests made by other projects within the Walker Basin Project. Many of the acquired data sets, however, have required additional processing and development in the database framework utilized by DRI, as well as QA/QC to ensure data accuracy and completeness. Data analysis of various components of the database has been required at times to provide needed derivative data in customized formats for both the DST modelers and other project users.

GIS Database Structure, Format, and Projection System

Based on existing GIS software resources at both DRI and University of Nevada, Reno (UNR), project researchers agreed to use Environmental Systems Research Institute (ESRI) ArcGIS version 9.2 (and later in the project, version 9.3) GIS software as the platform for collecting, developing, and analyzing Walker Basin spatial data. The ESRI native format shapefiles, multi-format rasters, personal geodatabases (based on the Microsoft ACCESS database structure) and dBASE IV and Excel tables were determined to provide the most efficient means for storing, manipulating, and analyzing the spatial data. A directory tree structure for folders, working directories and files was developed for managing the spatial data on DRI's servers and client computers. This same directory structure was translated to portable storage drives delivered to the sponsor (see description of the directory tree structure in Appendix 1). A standardized naming convention for files was established to provide easier access to the data and more efficient tracking of data development history. The Universal Transverse Mercator (UTM) coordinate system, based on the North American Datum (NAD), 1983 horizontal datum, was selected as the projection and datum system that all data would be translated into or reprojected to for inclusion in the GIS database.

Data Acquisition and Database Development

A significant amount of project time was devoted to the acquisition of spatial data from a number of federal, state, county, and local agencies as well as private firms. Data acquisition strategy focused on obtaining existing data sets to avoid duplication of effort. DRI then determined which data sets required in-house development, and built data sets and databases to satisfy these needs. Table 1 in Appendix 1 lists the data sets acquired and/or developed for the project. All of the data sets are ArcGIS compatible, i.e. capable of being viewed with either ArcGIS or ArcGIS Explorer. The GIS database has been copied to a USB storage drive, with attached Federal Geographic Data Committee (FGDC) standard metadata for each data set.

The following sections describe the various types of spatial data acquired and/or developed for the Walker Basin Project. For more details on each data set in the database, see Table A1 and the metadata for the data layers on the accompanying project USB storage drive.

Base layers

Data acquisition began with the collection and establishment of base-layer data for the approximately 10,191 km^2 (3,935 mi^2) Walker Basin area. These data sets included high-resolution image files acquired from several different sources, including the United States Department of Agriculture (USDA), United States Geological Survey (USGS), and private firms such as AirPhotoUSA. To sufficiently cover the entire Walker Basin watershed, USDA National Agriculture Imagery Program (NAIP) one-meter aerial photographic mosaics collected in 2005-2006 were combined for all four counties in the basin (Douglas, Lyon, and Mineral counties on the Nevada side; Mono County on the California side) then converted to Enhanced Compression Wavelet (ECW) format using Global Mapper version 9.2 image processing software. This image file format compressed the large mosaic using a lossy compression, greatly improving the efficiency of refreshing and utilizing the image data in both GIS and image processing software. Figure 1 shows the spatial extent of the Walker Basin study area, from the headwaters in the Sierra Nevada Mountains on the southwest side of the basin to Walker Lake and its associated sub watersheds on the east. The locations of Smith and Mason valleys are identified on the NAIP imagery (Figure 2), as these are two of the more important agricultural areas in the region and the focus of much of the GIS development work in this project.

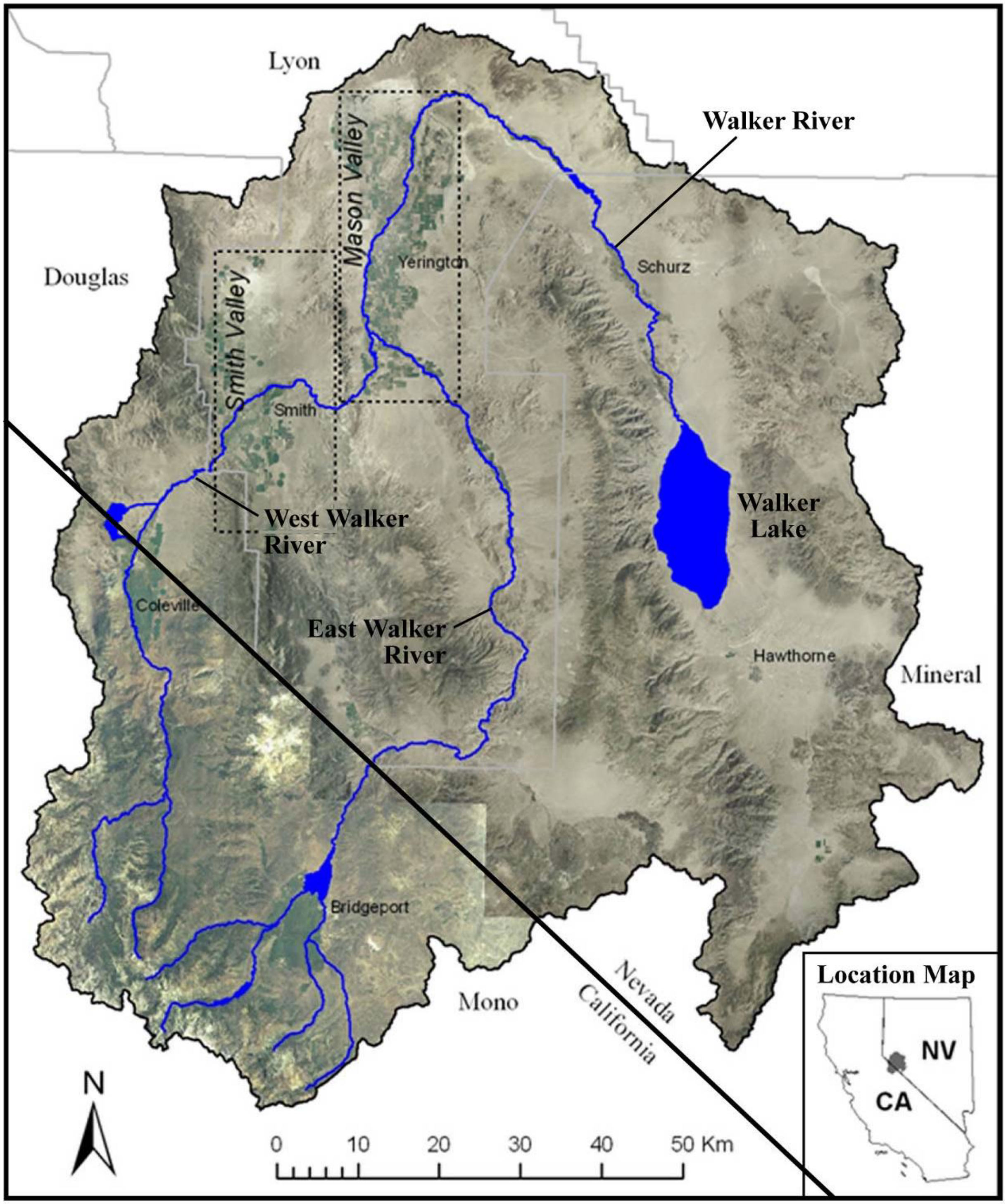

Figure 1. Walker River Basin. Hydrographic features are overlaid on a USDA NAIP natural color photo mosaic acquired in 2005-2006. Dashed boxes indicate the locations of Mason and Smith valleys.

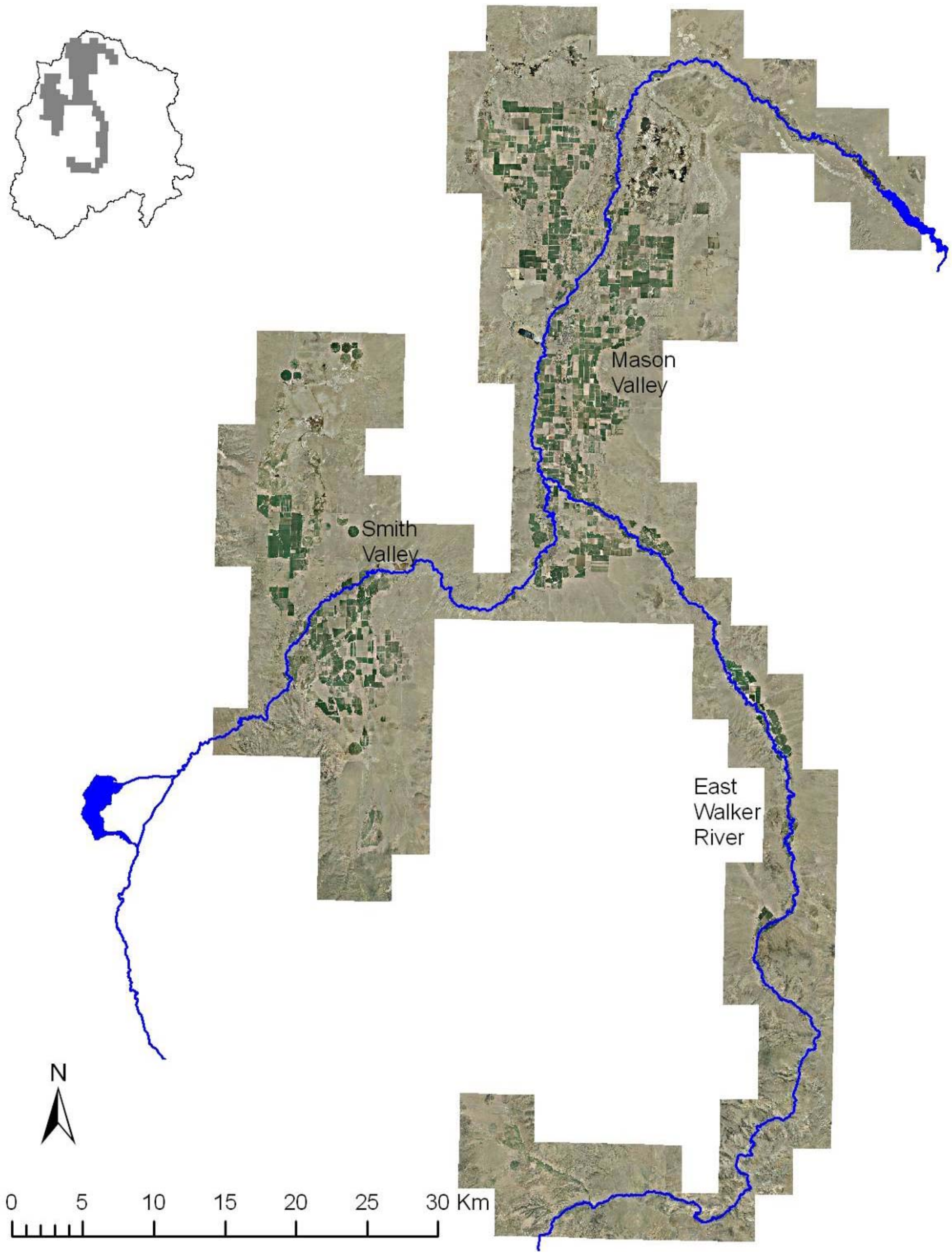

Figure 2. One-foot aerial photographic mosaic of Mason and Smith valleys, as well as the East Walker River corridor in Lyon County, NV.

One-foot natural color aerial photography for Lyon County, purchased by DRI from AirPhotoUSA was utilized as the principle base layer. This high-resolution mosaic, acquired in spring 2007, provided updated detail of anthropogenic and natural features (i.e., crop types, field boundaries, irrigation distribution networks, and diversion points) in Mason and Smith valleys and for portions of the East Walker River corridor (Figure 2). The one-foot aerial photography was complemented by six–inch-resolution aerial photography of the Yerington, Nevada area. The original AirPhotoUSA Tagged Image File (TIF) image files for both the one foot and six inch resolution aerial photography were mosaicked and converted to ECW format using GLOBAL MAPPER 9.2. Basic infrastructure data sets acquired in the first few months of the project and used as base data included updated parcel and road centerline data for all four counties in the Walker Basin. Figure 3 shows Lyon County parcel data for Mason and Smith valleys. Other infrastructure data collected included the Public Land Survey System (PLSS), land ownership, and roads data sets from the Bureau of Land Management geospatial data archive, and scanned, mosaicked 1:24000-scale USGS topographic maps, as well as administrative boundaries for counties and the Walker River Irrigation District (WRID). The boundary for the WRID was taken from the Proof of Beneficial Use (PBU) maps that were filed at NDWR by the district to support the certification of water right permits 5528, 25017, and 25813. The boundary is defined by aliquant section parts.

Agricultural/soils data

Agricultural field boundaries for Mason, Smith, Antelope, and Bridgeport valleys, as well as the East Walker River corridor, were obtained from the USDA Farm Service Agency (FSA). These data consisted of field boundaries digitized from aerial photography flown in the mid 1990s. The USDA FSA field boundaries required updating based on current aerial photography from 2005-2006 and 2007. The FSA fields were overlaid on the one-foot 2007 imagery for Mason, Smith, and East Walker valleys and the one-meter 2005-2006 imagery for Antelope and Bridgeport valleys, so that field boundaries could be edited, added, and/or deleted. Fields were digitized and/or edited based on the edges of irrigated vegetation, i.e., service roads, maintenance yards, and households were not included in the calculation of field areas. Once the field boundaries were updated, crop identification was performed for Mason and Smith valleys by researchers from UNR and DRI, based on analysis of the one-foot imagery, one-meter imagery, Goggle Earth, and field observations. Agricultural classes added to the field data attribute table consisted of 16 types of forage and row crops, as well as pasture, fallow fields, and feed lots.

The USDA Natural Resource Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) soils data for the entire Walker Basin was obtained by DRI and included in the GIS database.

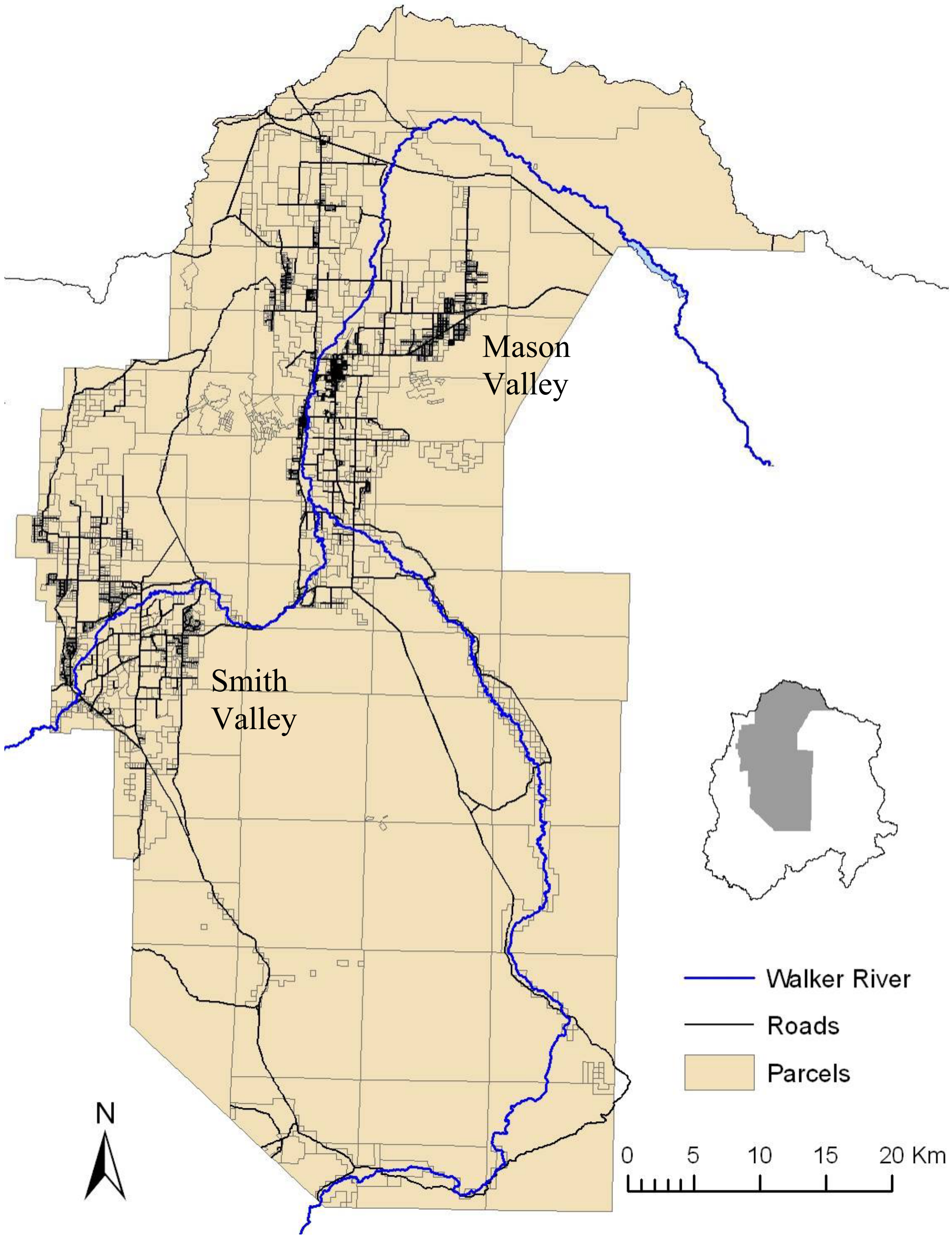

Figure 3. Lyon County parcel database features for Mason and Smith Valleys.

Digital Elevation Models (DEMs)

Light Imaging Detection and Ranging (LIDAR) data collected in November, 2007 by Fugro Horizons, Inc., was provided to DRI by the USFWS, Lahontan NFH Complex.. The one-meter cell horizontal resolution, 10- to 15-centimeter vertical resolution bare earth LIDAR data was collected over the principal corridors of the Walker River system. Fugro Horizons processed the bare earth data to create a very high resolution digital elevation model (DEM) of these areas in the Walker Basin. Figure 4 shows an example of the LIDAR-derived DEM model for the Wabuska Gage/Stanley Ranch area. These data were used by DRI to assist researchers in their efforts to identify and map the ditch and drain network systems in Mason and Smith valleys.

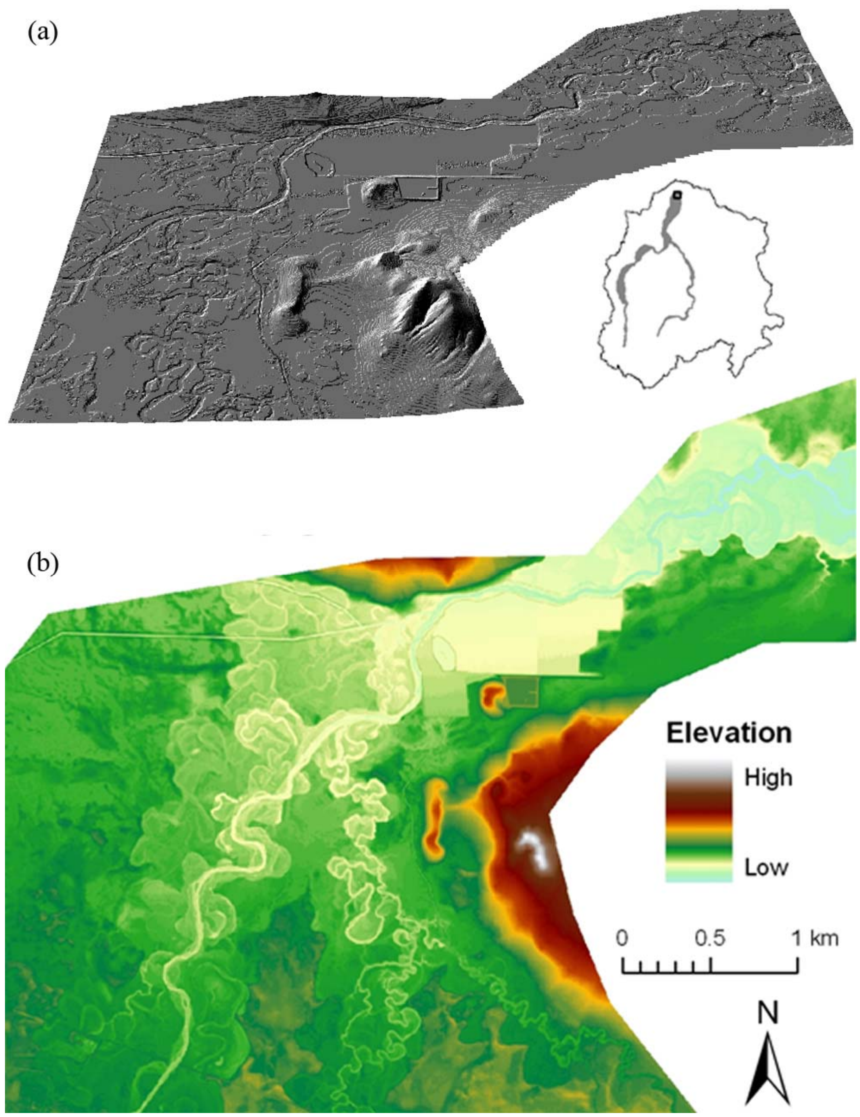

Figure 4. (a) LIDAR DEM-derived surface representation of the Wabuska Gage/Stanley Ranch area at the north end of Mason Valley. View angle from the southwest. (b) LIDAR DEM of the Wabuska Gage/Stanley Ranch area; color coded by elevation.

The main stem of the Walker River was located within the LIDAR imagery's spatial extent in Mason Valley and identified using hydrologic routines first described by Jenson and Domingue, 1988. The Walker River main stem provided the input into the groundwater modeling component of the DST by locating modeling units containing a stream cell.

The one-meter cell resolution LIDAR and 10-meter cell resolution USGS National Elevation Dataset (NED) DEM data were fused into contiguous elevation layers, one for Mason Valley, the other for Smith Valley. The creation of the one-meter cell resolution elevation model standardized all elevation data prior to resampling to the 100-meter cell groundwater modeling unit resolution used by the DST team. Groundwater analyses used the 100-meter cell resolution elevation data in two forms, both of which are described below.

The processes involved in the valley DEM preparation and secondary extraction of elevation data by groundwater modeling unit are best described as a series of steps. These steps are:

1. Resample the USGS 10-meter DEM to the one-meter resolution of the LIDAR data.
2. Merge the USGS 10-meter and one-meter LIDAR elevation data into a single valley wide elevation model with the LIDAR data overriding the resampled USGS data and creating a single-elevation layer. Operation performed in ArcGIS.
3. Fill all sink holes in the newly combined elevation layer, and compute the direction of flow and number of cells flowing through each cell within the modeled valley's extent.
4. Identify ravines and the Walker River by extracting cells with a large number of cells or upstream area flowing through each cell by setting a threshold of one square kilometer, selecting out those cells that meet or exceed the threshold and interactively extracting the Walker River using onscreen techniques.
5. Overlay the hydrologic model units identified as 100-meter-square grid cells used to conduct surface and groundwater modeling, identify the model units that intersect a DEM-delineated stream segment as identified in step 4 and numerically order each modeling unit from upstream to downstream.
6. Extract, from the newly created filled DEM in step 3, the minimum elevation and mean elevation of each model unit. The minimum elevation resulted from extracting the lowest one-meter-elevation cell located within the entire 100-meter square hydrologic modeling unit. The mean is the average of the 10,000 one-meter-elevation cells located within a modeling unit.

Figure 5 shows the derivative 100 m DEM for the Mason Valley modeling area. The raster DEM was then converted to a vector polygon shapefile. The final product of the above stepwise progression was a groundwater model unit vector layer (shapefile) with three separate attributes. The first attribute depicts whether a modeling unit contains the Walker River within it with the second and third attributes containing the minimum and mean elevation for each model unit.

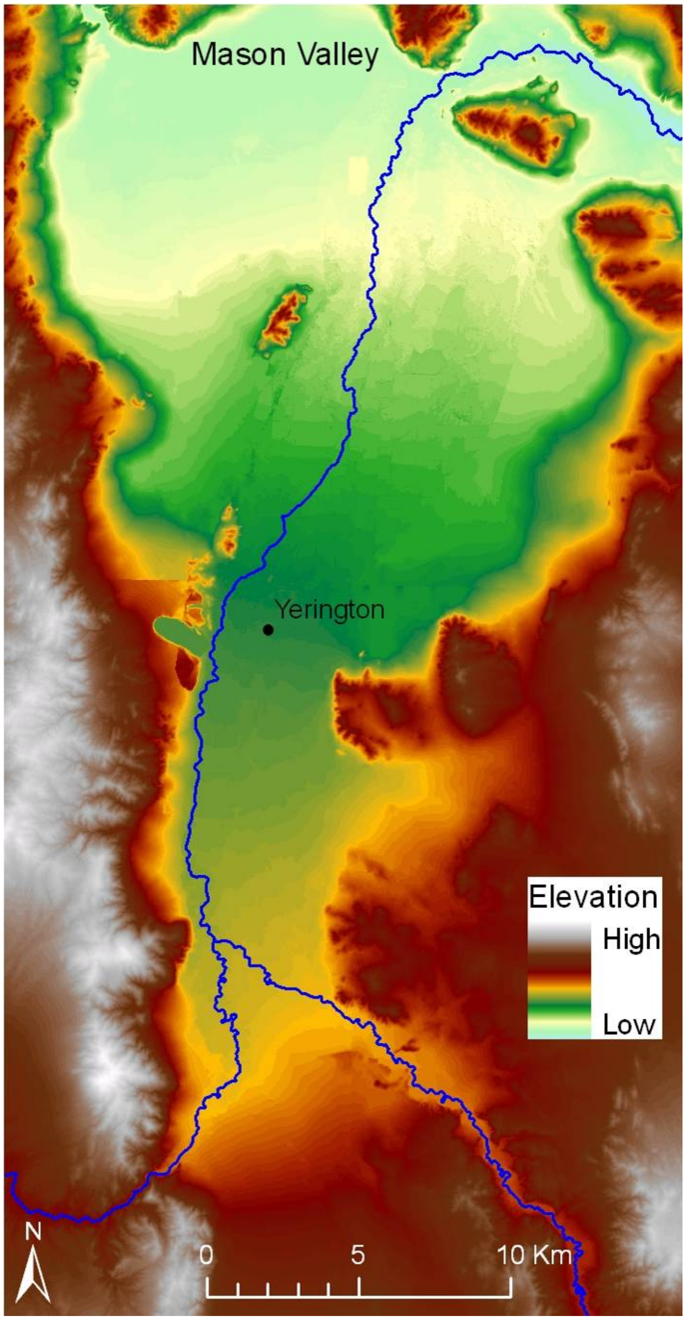

Figure 5. Fused LIDAR one-meter DEM data and USGS NED 10-meter DEM data for Mason Valley; color coded by elevation.

Surface water data

Acquisition and development of surface water data was one of the most time-consuming tasks of the entire GIS effort, as most of these data sets had to be digitized or manually entered into digital format.

The WRID assisted DRI researchers with the location and identification of major diversions off of the Walker River main stem, and west and east forks. Using real time differential global positioning system (GPS) and recreational GPS technology, head gates and weirs for over 25 river diversions (Figures, 6, 7, and 8) in Mason and Smith valleys. These locations were input into the GIS database using the one foot aerial photography as a base to correct for any GPS accuracy errors; most of the head gates and weirs were visible on the one foot aerial photography.

Figure 6. The Westside Canal diversion off of the West Fork of the Walker River – west side of Mason Valley, NV.

Figure 7. Mickey Fox diversion off of the East Walker River – Mason Valley, NV.

Figure 8. Measurement weir for the Mickey Fox diversion ditch – Mason Valley, NV.

The 2007 one-foot aerial photographic mosaic of Lyon County was used to develop the delivery and drainage system for irrigation in Mason and Smith valleys. Primary and secondary ditches, as well as primary and secondary drains were mapped for the two valleys using Manifold Systems GIS software. From- and To-node topology was used to show flow direction for both ditches and drains (Figure 9). Primary ditches were assigned names based on the original points of diversion off of the river system. Locations of primary ditches and drains were verified in the field in Mason and Smith valleys. Locations where ditches and drains were replaced with pipe or were routed underground were noted and appropriate adjustments to the line work in the GIS database were made. Ditch and drain line work were edited to ensure that all line segments representing ditches and drains properly snapped to the river centerlines for the east and west forks, and main stem of the Walker River system.

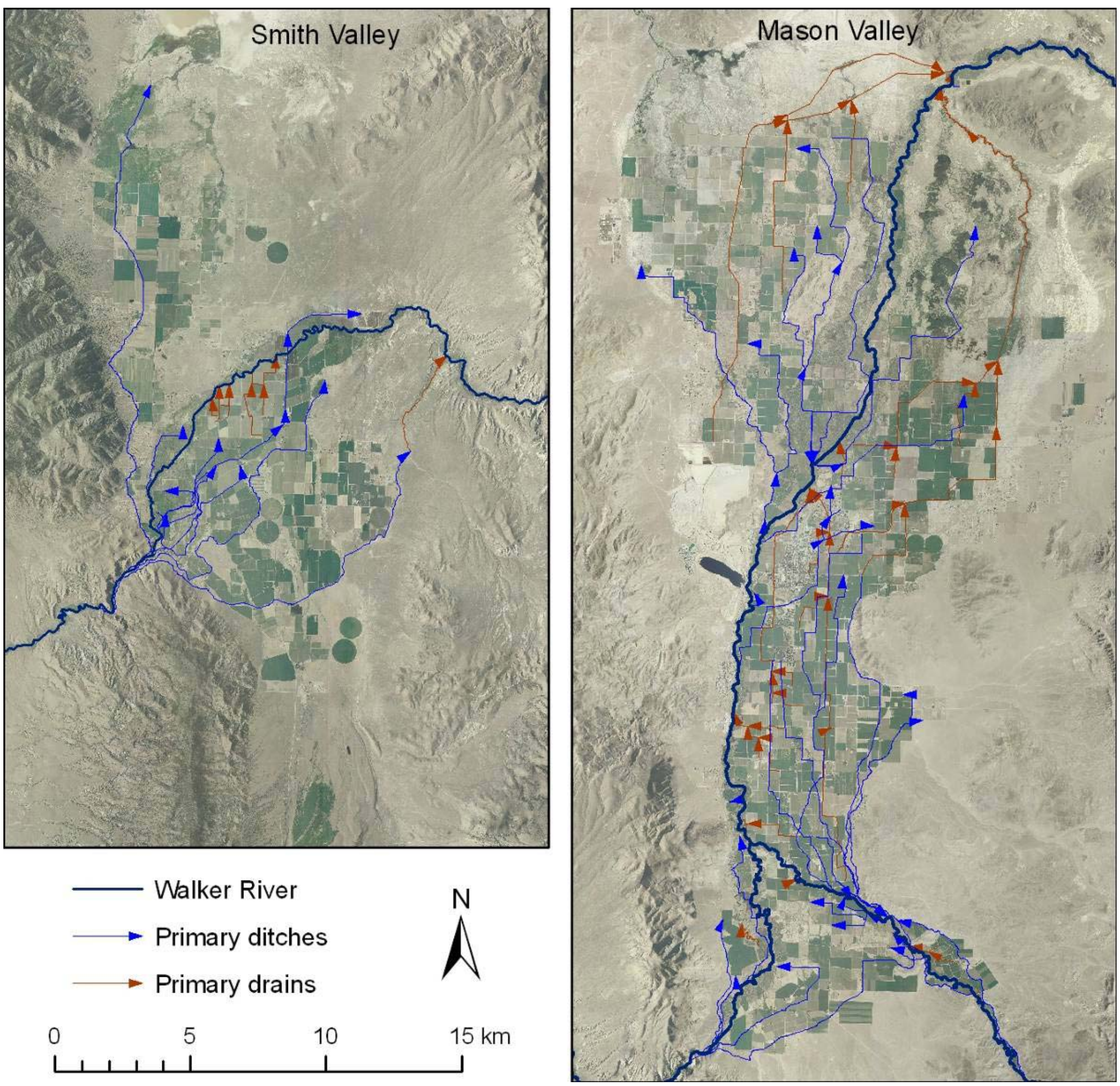

Figure 9. Diversion ditches and drains in Mason and Smith valleys with flow directions identified.

The U.S. Board of Water Commissioners Walker River Water Master provided both annual and daily diversion data for the time period 1996 to 2006, with an additional year of 2007 annual data. These diversion data were tabulated for the main points of diversion, irrigation season March 1 through October 31, for the following areas within the Walker Basin: Upper East Walker, East Walker, Antelope Valley, Smith Valley, and Mason Valley. Annual decree, storage, and permit (flood) diversion data were provided in acre feet for each diversion, subtotaled by each section. Permit data were not included for 1996 to 1998. The annual data were provided by the Water Master's office in hardcopy format, which DRI researchers entered into digital format. Table 1 lists the annual diversion data for 2007. Figure 10 shows the locations of the annual diversion sections within the Walker Basin.

Table 1. 2007 annual diversion data for the east and west forks, and main stem of the Walker River. Units in acre feet.

Ditch	Decree	Storage	Permit	Total
Antelope Valley:				
Carney	1,330.84	0.00	0.00	1,330.84
Main Canal	2,259.64	0.00	0.00	2,259.64
Hardy	601.90	0.00	0.00	601.90
Big Slough	26,539.66	0.00	0.00	26,539.66
West Goodnough	977.80	0.00	0.00	977.80
Powell	96.88	0.00	0.00	96.88
Harney	768.97	1.98	0.00	770.95
Alkali	1,230.35	0.00	0.00	1,230.35
Swauger	7,099.43	0.00	0.00	7,099.43
Rickey	1,074.84	0.00	0.00	1,074.84
Little Antelope	1,022.79	0.00	0.00	1,022.79
Section Total	43,003.11	1.98	0.00	43,005.09
East Walker:				
Baker Snyder	36.99	603.98	0.00	640.97
East Walker	4,326.26	5,868.32	0.00	10,194.58
Fox	4,528.95	1,611.84	0.00	6,140.79
Greenwood	1,731.91	1,445.76	0.00	3,177.67
Hall	296.09	1,497.39	0.00	1,793.48
High	0.00	805.07	0.00	805.07
Hilbun	171.61	485.99	0.00	657.60
Nelson	0.00	180.18	0.00	180.18
Mickey	2,358.04	680.63	0.00	3,038.67
Upper East Walker	2,128.18	657.00	0.00	2,785.18
Section Total	15,578.03	13,836.16	0.00	29,414.19

Table 1. 2007 annual diversion data for the east and west forks, and main stem of the Walker River. Units in acre feet (continued).

Ditch	Decree	Storage	Permit	Total
Main:				
Campbell	8,194.37	2,496.68	0.00	10,691.05
Dairy	171.45	0.00	0.00	171.45
Joggles	5,336.08	1,294.52	0.00	6,630.60
McLeod	571.98	0.00	0.00	571.98
Nichol Merritt	7,053.87	1,425.46	0.00	8,479.33
SAB	2,779.25	425.70	0.00	3,204.95
Sciarani	348.24	43.06	0.00	391.30
Spragg	2,003.01	1,205.34	0.00	3,208.35
West Hyland	4,893.53	1,444.59	0.00	6,338.12
Main River Pump	0.00	152.70	0.00	152.70
Section Total	31,351.78	8,488.06	0.00	39,839.84
Tunnel:				
D & GW	729.91	377.11	0.00	1,107.02
Kelly Alkali	1,426.87	195.37	0.00	1,622.23
Lee Sanders	225.62	17.82	0.00	243.44
Tunnel	2,925.31	2,312.32	0.00	5,237.63
West Side Canal	765.05	392.69	0.00	1,157.75
Nordyke Quail	432.31	72.88	0.00	505.20
Section Total	6,505.07	3,368.20	0.00	9,873.27
West Walker:				
Burbank	727.65	236.33	0.00	963.98
Colony	1,620.19	4,936.67	0.00	6,556.87
Gage Peterson	2,541.23	263.80	0.00	2,805.03
Plymouth	2,311.45	1,762.18	0.00	4,073.63
River Simpson	2,034.19	1,326.98	0.00	3,361.17
Saroni	828.17	3,482.90	0.00	4,311.07
West Walker	2,507.04	693.26	0.00	3,200.29
Lower Fulstone	525.14	46.19	0.00	571.33
Upper Fulstone	440.27	0.00	0.00	440.27
West Walker Pumps	100.78	36.99	0.00	137.77
	13,636.12	12,785.30	0.00	26,421.42
Section Total				
Grand Total	110,074.11	38,479.70	0.00	148,553.80

2007 Walker River Irrigation District - River readings from 03/01/2007 to 10/31/2007 (all figures are in acre feet). Figures are based on delivery records from River Riders.

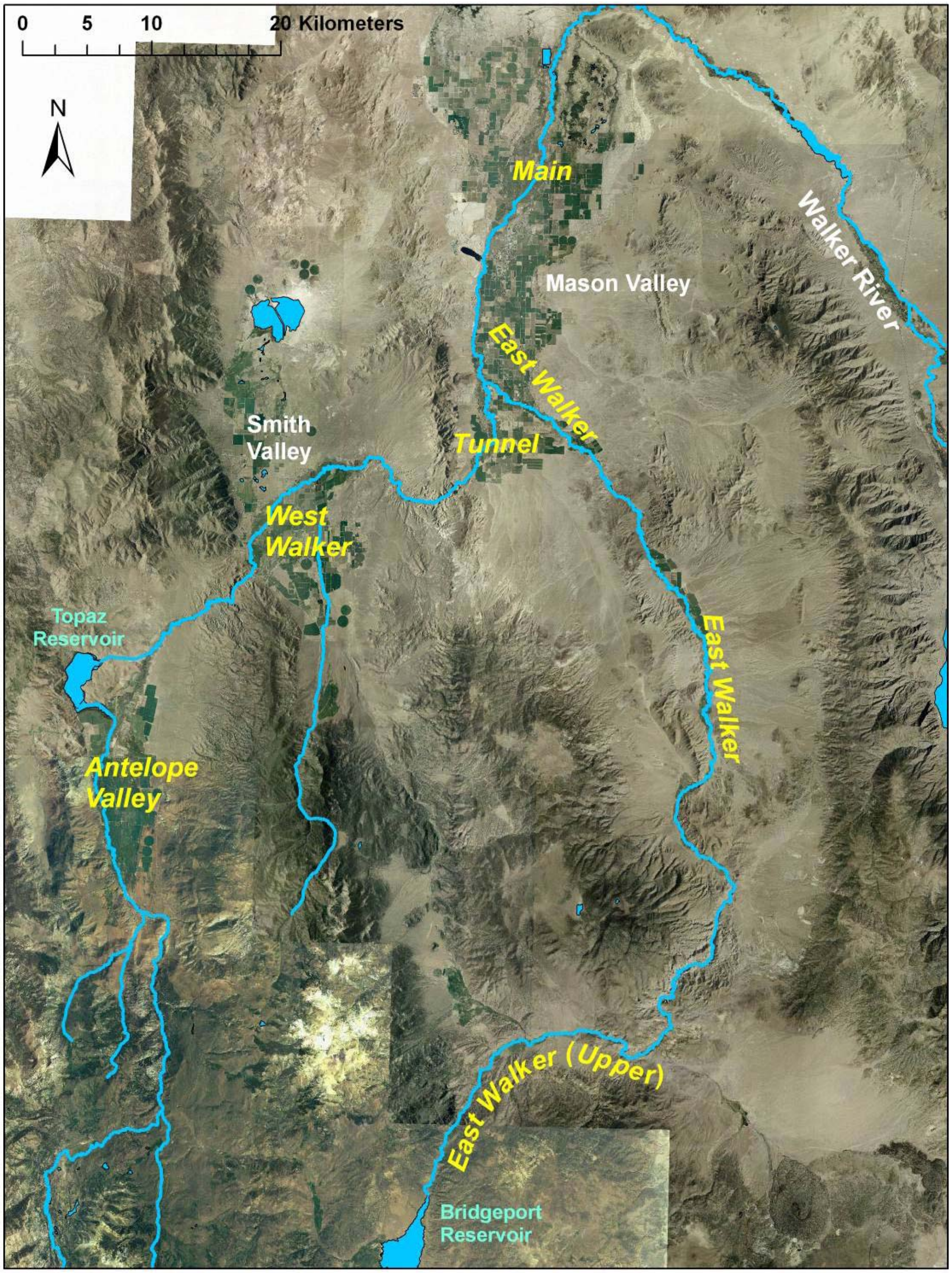

Figure 10. Locations of annual diversion sections (yellow) in the Walker Basin.

Daily diversion data for 1996 to 2006 (decree and storage only) were provided by the Water Master's office in hardcopy format, a single page or multiple pages for each day of delivered water, identified by diversion. Units were in cubic feet per second (cfs). The data were entered into digital format, with a diversion entry for each day. This created a data file with thousands of entries for each year. Extensive QA/QC was performed on the data to ensure that all dates in the irrigation season were covered, and that all diversion ditch names were consistent from year to year. In some cases, missing days were found; if these missing days could not be recovered at the Water Master's office then the flows for that day were interpolated based on the irrigation days on either side of it for the particular diversions made. Data were converted to a format where each field entry consisted of a ditch diversion name and each row represented a date between March 1 and October 31 for each water year. This conversion was done in Microsoft Excel using a macro conversion program written in Visual Basic For Application (VBA). Finally, all 11 years of daily diversion data were integrated together into one large array using the R programming language, where fields represented any and all diversion ditches that were used during the 11-year time series, and the rows indicated the 365 days of the calendar year.

To better understand the use and distribution of flood (permit, surplus, or excess) water in the water budget, and how these types of rights would effect the overall flow model, DRI used priority summary data from the period 1996 to 2006 to identify years when flood rights were distributed and the extent of flood-water distributions within the Basin during those years. Flood waters were released from1996 to 1999 and 2005 to 2006 (wet years). Release periods within the irrigation seasons varied depending on the availability of excess water, but most flood water was made available in the spring and summer. Flood data was combined with the tabular data from the annual diversion data set; this identified within-year release periods to estimate the distribution of flood waters throughout the respective irrigation seasons.

Historical monthly diversion data compiled for the time period 1930 to 1995 by the now defunct Nevada Division of Water Planning (NDWP) were obtained from Randy Pahl, a former employee of NDWP now with the Nevada Department of Environmental Protection (NDEP). These data, in Microsoft Excel format, contained monthly values of decree, storage, and flood diversions for March through October, 1930 to 1995, by diversion ditch. The spatial extent of these diversion data is the same as that for the annual and daily diversion data from the U.S. Water Master's office. The spreadsheets were used for both MODFLOW and MODSIM development.

Groundwater data

Upon project initiation, DRI formed a collaborative relationship with the Nevada Division of Water Resources (NDWR) to develop GIS data sets of groundwater usage Points of Diversion (PODs) and Places of Use (POUs) for irrigation purposes for the portion of the Walker Basin within the state of Nevada. At NDWR, DRI researchers began the task of digitizing permitted and certificated POD and POU irrigation groundwater data from scanned maps based on the PLSS system. The following tasks were performed to enter the data into the GIS:

1. A hydrographic abstract was performed for Mason and Smith valleys to find all current, active groundwater rights used (restricted to permitted irrigation water rights only).
2. Each groundwater right had a permit number and a map displaying the location/extent of the POU and POD.
3. Each groundwater right map was geo-referenced to a PLSS data layer; the POU and POD data were manually digitized based on the referenced map. NDWR used the BLM Geographic Coordinate Database (GCDB) for a PLSS grid because it is the most comprehensive and non-proprietary grid available.
4. Changes in location and amount of water allowed for each groundwater right were calculated; the base water rights were first identified, and then subsequent abrogation permits were applied.
5. The permit (link) table was populated with each permit number as well as its corresponding POU IDs (Poly_ID) and POD IDs (Site_ID).
6. The POU attribute table was populated with the amount of irrigated acres within a polygon, and supplemental information, including all associated polygons, and total supplemental acreage.
7. The POD attribute table was populated with a Site ID (Basin Number, Township, Range, Section Number, and divisions of the section), well level, and flow information for the late 1990s and early 2000s for monitoring wells in Mason and Smith valleys.

The POU and POD data are an ESRI personal geodatabase , with the permit table used to relate the POU attribute table to the POD attribute table. Figure 11 shows the location of both PODs and POUs in Mason and Smith valleys.

Other groundwater data obtained from NDWR included 62 monitoring wells (irrigation and municipal wells) for Mason and Smith valleys with water levels in meters and metered flow information in acre feet for the 1993 to 2007 and 1993 to 2003 time periods, respectively. DRI researchers, with NDWR assistance, also constructed a larger data set of 309 municipal and irrigation wells throughout the two valleys, which included the 62 monitoring wells described above. A number of the other wells in the set of 309 municipal and irrigation wells did not have water level or flow rate information.

Hydrologic Response Units (HRUs)

Due to litigation and privacy issues associated with individual water rights at the farm scale, a farm scale minimum mapping unit was established for the primary irrigation areas in the Walker River Basin.

With the assistance of History Mapping Services, spatial data sets and associated tables were compiled to identify sub-areas of irrigated lands by diversion ditch source, the water rights that are appurtenant to the irrigated lands as a group, and the historic water diversion by ditch. A data set was developed that aggregated all of the irrigated fields (derived from the agricultural field data sets) linked by a diversion ditch source. Each group of fields linked by a common ditch refers to a Hydrologic Response Unit (HRU).

The water right and historic water diversion data could then be compiled into associated attribute tables and applied to individual HRUs.

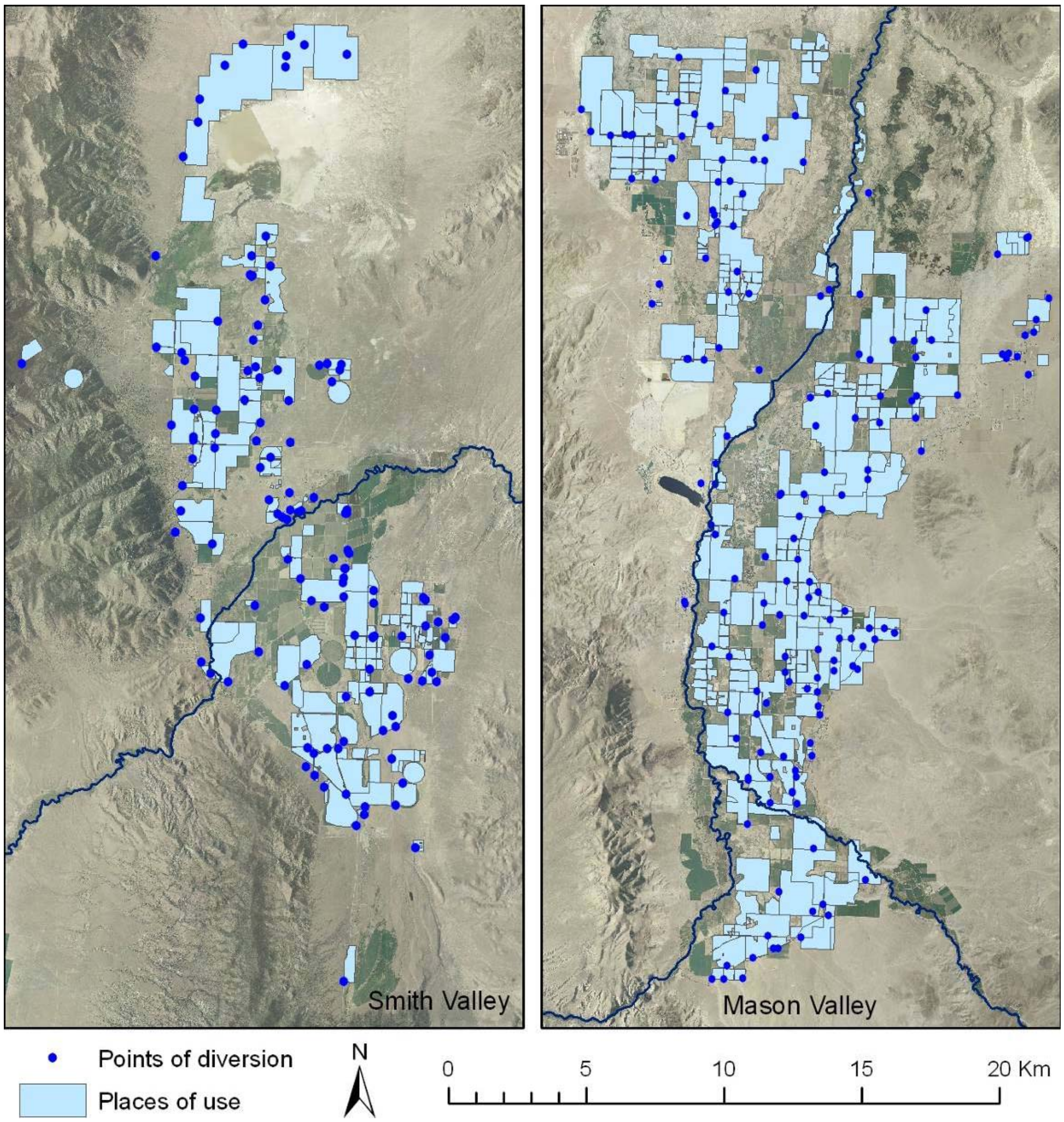

Figure 11. Groundwater Places of Use (POU) and Points of Diversion (POD) in Mason and Smith valleys.

The source for the HRU polygons are the digitized fields. The polygons were then attributed with Y/N categorical values for the following types of water rights:

- Decree C-125 water right claims
- Groundwater rights
- Storage (New Land and Supplemental) storage rights

- Drain water rights
- Miscellaneous non-decree water rights

The agricultural field boundaries and diversion ditch centerlines were overlaid on the 2007 one-foot aerial photography of Lyon County and the associations between fields and diversion ditches were established for sections of both Mason and Smith valleys and the East Walker River corridor. In many cases, surface diversions could be directly traced to individual fields. This method worked well in the northwest portion of Mason Valley where flood irrigation is still prevalent and the fields have a definite structure. In some areas, for example around the City of Yerington, many of the ditches had been diverted into underground pipes, leaving little evidence of their path on the high-resolution aerial photography. Four field inspections were conducted during the summers 2007 and 2008 to help with interpretation. In some cases, recorded subdivision and parcel maps from Lyon County were used to identify both underground and aboveground pipe routes.

The locations of the Decree C-125 surface water right claims by HRU were determined by using the data layer developed by History Mapping Services on the GCDB flat files (.scr and .dxf) PLSS base layer. There were often either extensive overlaps of claim areas, or much larger areas designated than actual irrigated acres. Water rights on the Nevada portion of the Walker River Basin were adjudicated using sections of the 1903 Nevada Revised Statutes (see explanation in Great Basin Land and Water [GBLW] Study, 2007, Appendix D) (Great Basin Land and Water, 2007). Instead of identifying specific areas of irrigation, the Walker River decree claims are described only by priority date, flow rate, number of acres irrigated, diverting ditch, and owner. A tabulation of all of the lands under the name of the decree claim owner, described by aliquant parts, were included. These tabulations often included parcels of land that were not irrigated at the time of the decree. To attach each decree water right claim to a specific set of irrigated fields, a reasonable estimate was made by comparing the 1997 NDWP Abstract database with the C-125 data (Pahl, 1999) and 2007 Lyon County parcel data set. The Abstract database provided information by claim number for individual owners; however, specific parcel numbers were not included. In most cases the parcels owned by the individual decree claim owners were identified, and the total water right was applied to the existing irrigated fields on the property.

For this project, it was assumed that the total groundwater permit is represented only by the irrigated fields on the designated POU, and not the entire POU. In Nevada water law, an applicant must first submit an application and map that describes the POD and POU to receive a water right. The NDWR reviews the application material, and if there are no problems with the application and water is available, and then a permit is issued to drill a well and construct the water supply system. A period of five years is typically allowed to develop the water and put it to ‘beneficial use’. At the end of five years, a Proof of Beneficial Use (PBU) map must be submitted, along with other documentation, for a water right certificate to be granted. If the applicant is unsure exactly where on the property that the fields will be placed, the application map is typically drawn showing the entire parcel. This creates a permit POU that is much larger than what the duty designates (e.g., 20 acres of water rights within a 100-acre parcel.). The discrepancy is resolved at the time that the PBU map is filed. Because of this situation, certificated water right POUs show fairly exact areas of appurtenance, but permit water right POUs can often cover large areas of non-irrigated lands.

Due to the lack of specific data on New Lands storage right areas, this field in the HRU attribute table was typically left blank unless there was compelling reason to assign it. If a field appeared to be receiving water from a ditch but did not have a decree water right or permit, it was assumed that the field was covered by an unidentified New Lands storage water right. As more specific data becomes accessible, it will be incorporated into later versions of the water flow model.

Based on discussions with WRID management, it was assumed that any land located within the boundaries of WRID is eligible to receive early season flood water under one or both of NDWR permits 5528 and 25017. Although a set of data layers was compiled from the PBU maps for these permits, the actual data were not included in the HRU descriptions. As previously described, flood data from annual diversion information were utilized by the modelers to better understand the contribution of flood water to the overall system budget.

In the northwest corner of Mason Valley towards the Adrian Valley drainage, and in the lower portion of the Colony Canal that drains into Artesia Lake in Smith Valley, are areas of drain water rights that were issued by NDWR in the mid-1950s. These water rights have been certificated, and exist outside of Decree C-125. In the NDWR Hydrographic Basin Abstracts, these permits are categorized as Other Surface Water rights (OSW).

A total of 44 HRUs were developed for Mason and Smith valleys, as well as the East Walker River corridor. This included HRUs for groundwater fed fields in Smith and Mason valleys, five river pumps found in both valleys, and an aggregation of fields found along the East Walker River corridor into two HRUs: East Fork and Upper East Fork. Figures 12 and 13 shows the spatial distribution of the HRUs in Mason and Smith valleys, respectively, with each HRU color coded by diversion ditch source. Table 2 shows a subsample of the HRU attribute table for the Campbell HRUs in Mason Valley, with data fields describing the spatial dimensions of the agricultural fields included in each HRU, the assigned diversion ditch, the crop type, and the type of water rights associated with each irrigated field in the associated HRU. A complete list of all HRUs in Mason and Smith valleys, and the East Walker River corridor, can be found in the attribute table for the HRU shapefile on the accompanying project USB storage drive.

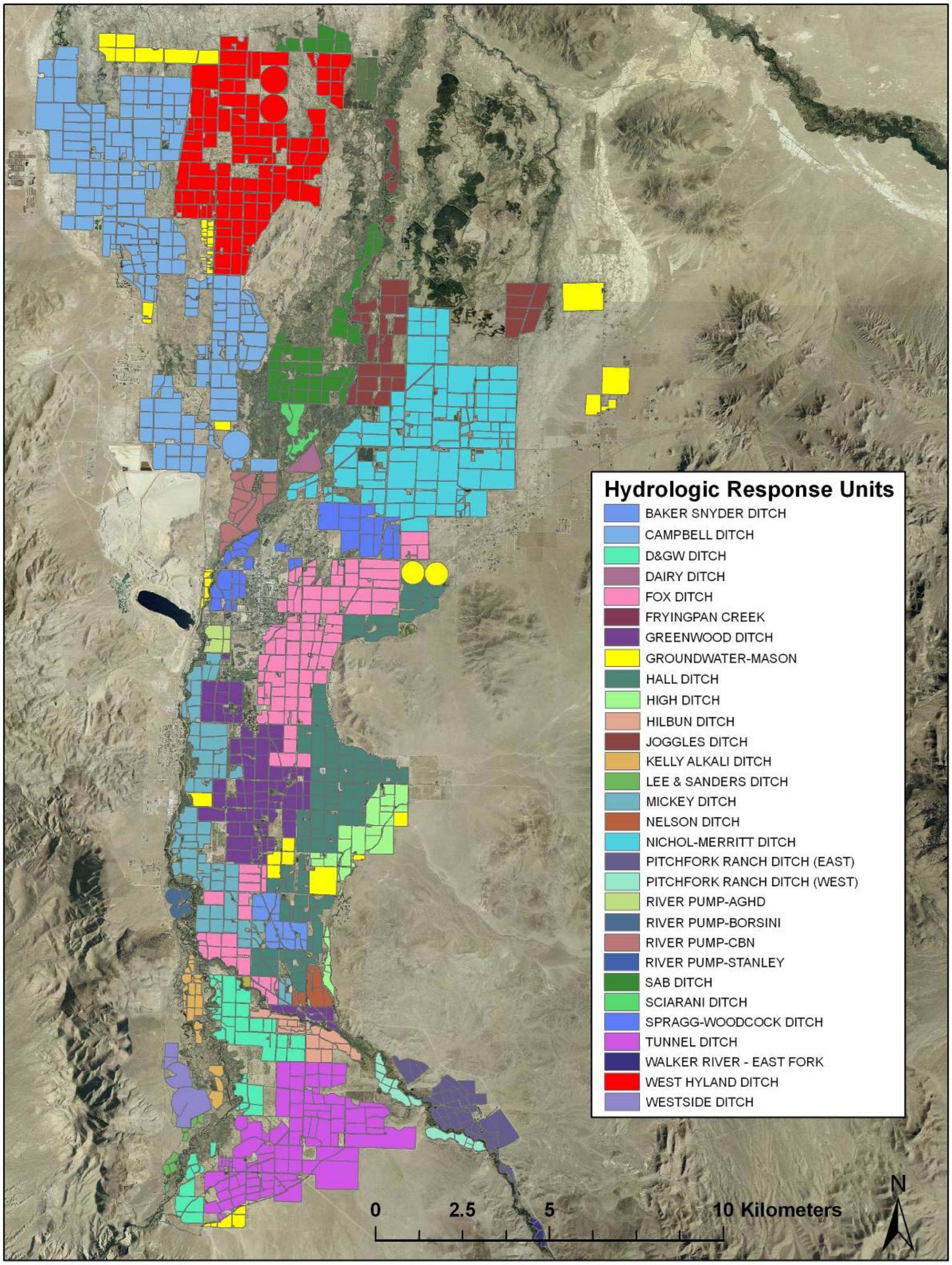

Figure 12. Distribution of Hydrologic Response Units (HRUs) in Mason Valley.

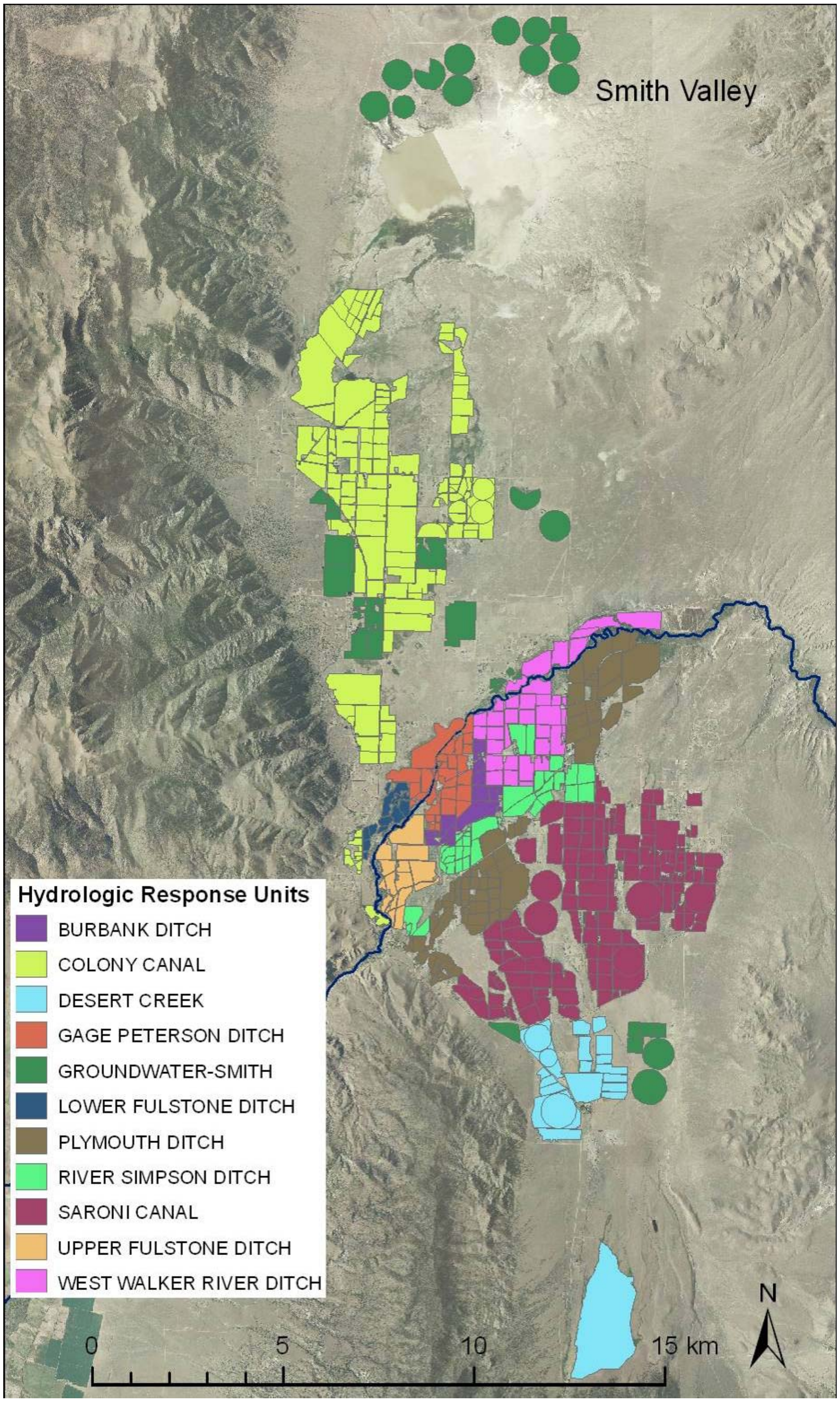

Figure 13. Distribution of Hydrologic Response Units (HRUs) in Smith Valley.

Table 2. Subsample of the HRU attribute table for the Campbell Ditch HRU in northwestern Mason Valley. Attributes include HRU name for each field, area in acres and hectares, crop type, and the type of water rights associated with each irrigated field in the HRU.

HRU/Ditch	Acres	Hectares	Perimeter (m)	Crop Type	Decree	Storage	Groundwater
Campbell Ditch	27.02	10.93	1664.23	Alfalfa	Y	Y	Y
Campbell Ditch	21.40	8.66	1202.98	Grass	N	Y	Y
Campbell Ditch	39.78	16.09	1583.67	Alfalfa	N	Y	N
Campbell Ditch	25.01	10.12	1356.72	Grain	N	Y	Y
Campbell Ditch	35.86	14.51	1520.97	Alfalfa	N	Y	N
Campbell Ditch	5.69	2.30	663.42	Alfalfa	N	Y	Y
Campbell Ditch	1.85	0.75	374.89	Alfalfa	N	Y	N
Campbell Ditch	33.12	13.40	1461.13	Corn	Y	Y	Y
Campbell Ditch	27.08	10.95	1305.02	Alfalfa	Y	Y	Y
Campbell Ditch	31.50	12.74	1416.85	Alfalfa	Y	Y	Y
Campbell Ditch	28.25	11.43	1420.58	Alfalfa	Y	Y	Y
Campbell Ditch	65.67	26.57	2185.48	Onion	N	Y	Y
Campbell Ditch	33.77	13.66	1484.22	Onion	N	Y	Y
Campbell Ditch	29.17	11.80	1362.40	Alfalfa	N	Y	Y
Campbell Ditch	35.27	14.27	1493.90	Alfalfa	N	Y	Y
Campbell Ditch	38.88	15.73	1575.10	Onion	N	Y	N
Campbell Ditch	35.74	14.46	1521.72	Onion	N	Y	N
Campbell Ditch	21.77	8.81	1222.96	Grain	N	Y	Y
Campbell Ditch	22.05	8.92	1188.79	Grain	N	Y	Y
Campbell Ditch	12.80	5.18	964.28	Grain	N	Y	Y
Campbell Ditch	9.73	3.93	865.79	Fallow	N	Y	Y
Campbell Ditch	3.61	1.46	479.99	Fallow	N	Y	Y
Campbell Ditch	38.28	15.49	1555.44	Corn	Y	Y	Y
Campbell Ditch	90.06	36.44	2482.38	Corn	Y	Y	Y
Campbell Ditch	15.69	6.35	1059.38	Fallow	N	Y	Y
Campbell Ditch	34.88	14.11	1491.28	Onion	N	Y	Y
Campbell Ditch	45.03	18.22	1695.94	Alfalfa	N	Y	Y
Campbell Ditch	35.63	14.42	1513.28	Alfalfa	N	Y	Y
Campbell Ditch	35.99	14.56	1528.96	Onion	N	Y	N

Decree – storage data

A series of data tables were developed to quantify the decree and storage rights for the Mason and Smith valley HRUs. The most current data available were from the 1997 database compiled by NDWP from actual records at the Walker River Water Master's office (Pahl, 1999). The data were primarily derived from an Abstract compiled by the Water Masters to track water rights for individual decree owners.

The Abstract table was extracted from the 1997 NDWP water right database and converted into a Microsoft Excel spreadsheet. In the Abstract table, each separate claim – priority date was given an individual entry. Each of these entries was re-named using an NDWR-compatible naming convention. (e.g., entry DWR-154_1895_01 stands for Decree Walker River – Claim 154 – priority date 1895 – parcel 01).

The entries for the Mason and Smith valleys and the East Fork claims up to the Bridgeport Reservoir were then copied onto a new worksheet. The fields for ditch, priority date, diversion rate (cubic feet per second [CFS]), and irrigated acres were arranged to set up the calculations for the annual volumes in acre feet (AF). A type of use field was added to specify that these were decree (DEC) water rights. An annual duty acre feet per acre (AC-FT/AC) field was added and decree claims were given either a high duty of 4.2768 AC-FT/AC for bench lands or a low duty of 3.2076 AC-FT/AC for bottom lands. Post-1906 water rights were assigned a constant duty of 2.6730 AC-FT/AC (1.00 CFS per hundred acres). The annual volumes were calculated by multiplying Irrigated Acres times the annual duty. The individual owners were then totaled by HRU (i.e., diversion ditch) and priority date. An effort was made to update the decree data with respect to subsequent water right transfers, particularly in relation to the various river pumps.

To derive supplemental storage water rights, the table compiled by Meyers (Meyers, 2001) for the days of storage allocation and associated duties was used. The annual duties used for the New Lands water rights were 1.5444 AC-FT/AC for the low duty areas, and 2.0592 AC-FT/AC for the high duty areas (GBLW, 2007). "Senior" pre-1874 decree water rights were not assigned storage rights. The decree water right claims that receive supplemental storage rights were copied and a storage suffix (STO) was added to the name. The appropriate duties were then assigned based on the base priority date and parent duty.

The totaled values were then copied to a final spreadsheet for conversion into a database table.. Table 3 provides a subsample of calculated volume data for the West Hyland Ditch HRU in northwestern Mason Valley. The total area of New Lands water rights by ditch was included at this stage (Meyers, 2001), and the associated volumes were calculated. New diversion rates were also calculated for both the decree and storage entries using the assigned annual duty.

Table 3. Decree/Storage data for the West Hyland ditch HRU in northwestern Mason Valley.

Type of Use	HRU/DITCH	Priority Date	Div Rate (CFS)	Irrigated Acres	Annual Duty (AC-FT/AC)	Annual Volume (AF)	Days of Diversion	Rate (CFS/AC)	Diversion Rate Calculated (CFS)
DEC	West Hyland Ditch	1873	3	250	3.2076	801.9000	245	0.012	3.000
DEC	West Hyland Ditch	1874	21.13	1761.19	3.2076	5649.1930	245	0.012	21.134
DEC	West Hyland Ditch	1877	0.86	72	3.2076	230.9472	245	0.012	0.864
DEC	West Hyland Ditch	1880	10.409	867.539	3.2076	2782.7181	245	0.012	10.410
DEC	West Hyland Ditch	1881	0.48	40	3.2076	128.3040	245	0.012	0.480
DEC	West Hyland Ditch	1887	0.78	65	3.2076	208.4940	245	0.012	0.780
DEC	West Hyland Ditch	1888	0.96	80	3.2076	256.6080	245	0.012	0.960
DEC	West Hyland Ditch	1891	1.656	138	3.2076	442.6488	245	0.012	1.656
DEC	West Hyland Ditch	1894	0.18	15	3.2076	48.1140	245	0.012	0.180
DEC	West Hyland Ditch	1896	1.1	92	3.2076	295.0992	245	0.012	1.104
DEC	West Hyland Ditch	1899	0.14	12	3.2076	38.4912	245	0.012	0.144
DEC	West Hyland Ditch	1900	1.68	140	3.2076	449.0640	245	0.012	1.680
DEC	West Hyland Ditch	1901	0.18	15	3.2076	48.1140	245	0.012	0.180
DEC	West Hyland Ditch	1904	0.31	26	3.2076	83.3976	245	0.012	0.312
DEC	West Hyland Ditch	1905	0.48	40	3.2076	128.3040	245	0.012	0.480
DEC	West Hyland Ditch	1906	0.24	20	0.8316	16.6320	245	0.012	0.240
STO	West Hyland Ditch	1874		1761.19	0.0950	167.3131	4	0.012	21.134
STO	West Hyland Ditch	1877		72	0.2614	18.8208	11	0.012	0.864
STO	West Hyland Ditch	1880		867.539	0.5940	515.3182	25	0.012	10.410
STO	West Hyland Ditch	1881		40	0.6415	25.6600	27	0.012	0.480
STO	West Hyland Ditch	1887		65	0.6890	44.7850	29	0.012	0.780
STO	West Hyland Ditch	1888		80	0.6890	55.1200	29	0.012	0.960
STO	West Hyland Ditch	1891		138	0.7366	101.6508	31	0.012	1.656
STO	West Hyland Ditch	1894		15	0.7603	11.4045	32	0.012	0.180
STO	West Hyland Ditch	1896		92	0.7603	69.9476	32	0.012	1.104
STO	West Hyland Ditch	1899		12	0.7841	9.4092	33	0.012	0.144
STO	West Hyland Ditch	1900		140	0.7841	109.7740	33	0.012	1.680
STO	West Hyland Ditch	1901		15	0.7841	11.7615	33	0.012	0.180
STO	West Hyland Ditch	1904		26	0.8078	21.0028	34	0.012	0.312
STO	West Hyland Ditch	1905		40	0.8078	32.3120	34	0.012	0.480
STO	West Hyland Ditch	NEWL		1,231	1.5444	1900.6159	65	0.012	14.768

Type of Use: DEC – Decree; STO - Storage

Landsat Thematic Mapper (TM) satellite imagery

USGS Landsat TM and Ehanced Thematic Mapper (ETM) satellite imagery from the 1980s, 1990s, and early 2000s, acquired for a previous project, were utilized in an attempt to quantify the amount of riparian vegetation in Smith and Mason valleys for various years dating back to 1986. Derivative riparian data sets were developed from six Landsat TM scenes spanning 16 years from 1986 to 2002, acquired at the height of the irrigation season in July and August for each scene (Desert Research Institute, 2006). Specific acquisition dates for the six scenes for Path 42, Row 33 were: August 30, 1986; July 29, 1992; August 7, 1995; August 31, 1998; July 27, 2000; and August 18, 2002. All scenes were acquired in precision corrected format, cubic convolution resampling, 28.5 meter cell size, with cloud cover less than 10%.

Two additional Landsat TM scenes were purchased for the year 2000, June 9 and September 15, to compliment the existing July 27, 2000 scene. These data were processed to produce a time series of irrigation acreage fluctuations in Mason and Smith valleys during a relatively dry year. The two new scenes were georectified to the July 27, 2000 scene using ITT VisionSystems ENVI version 4.4 image processing software. Figure 14 shows false color band composite of the three scenes for Mason Valley. The Root Mean Squared Error (RMSE) result of the rectification process was less than a pixel (28.5 meters), ensuring close spatial agreement between scenes. From the raw, rectified image data, derivative Normalized Difference Vegetation Index (NDVI) images were calculated for each of the three scenes using the following equation:

$$(NIR-Red)/(NIR+Red) \qquad (1)$$

where NIR = Landsat TM near-infrared channel 4; Red = Landsat TM red channel 3.

The NDVI is a ratio of shortwave infrared (near-infrared) and red reflectance that provides a convenient, rapid estimate of the amount and an indication of the health of vegetation in a remotely sensed image. The NDVI measurements minimize the effects of topography and atmosphere (Holben and Justice, 1981), require no prior knowledge of ground conditions, and are sensitive to the amount of photosynthetically active vegetation present (Tucker, 1979; Myneni *et al.*, 1992). There are minimal topographic effects in the agricultural areas of Mason Valley due to the flat terrain. Computationally, NDVI measures the deviation of a vegetated cell relative to a soil baseline (Huete and Tucker, 1991). Remotely sensed NDVI measurements have been used for a variety of agricultural applications as a means of monitoring irrigation water use and crop assessment (Olalla *et al.*, 2003; Rembold and Maselli, 2004).

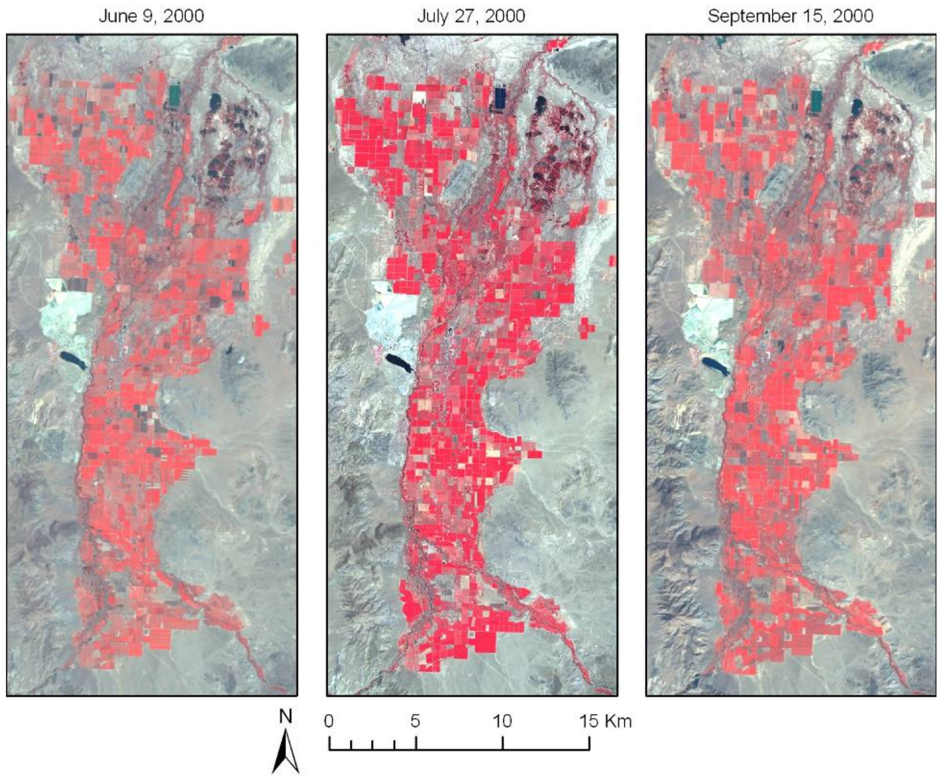

Figure 14. Landsat TM false-color composite scenes of Mason Valley for three dates in 2000: June 9, July 27, and September 15.

NDVI threshold analysis was then performed on each of the three NDVI images, identifying the optimum value of NDVI that indicated high biomass, for both irrigated lands and riparian/wetland vegetation, in Mason and Smith valleys. The threshold values were kept low enough to ensure that even partially irrigated fields and fields with new growth or row crops (if any), as well as fields recently cut, were captured in the NDVI thresholding process. A binary integer raster for each year of data was then created, with a value of 255 assigned to all NDVI cells above the threshold value, and a value of 0 assigned to all cells below the threshold.

Spatial Data Analysis

Two spatial analysis operations were performed using the GIS database additional derivative data sets. These analyses utilized the georeferenced data layers in the database to develop spatial queries of the relationships between the layers, then produced maps and tables to show these relationships.

<u>Analysis of irrigation source by field</u>

An analysis was conducted to determine the source , i.e., surface water, groundwater, or both, of irrigation water applied to fields in Smith and Mason valleys. The agricultural field data layer was intersected with both the groundwater POU from NDWR and the polygon file describing the geographic boundaries of the surface decree rights obtained from History Mapping Services. A new shapefile was created that contained attributes for 1,832 agricultural fields in Mason and Smith valleys, with an additional attribute field indicating the source of irrigation water. Figures 15 and 16 show the results of the irrigation water source inventory for each field in Mason and Smith valleys.

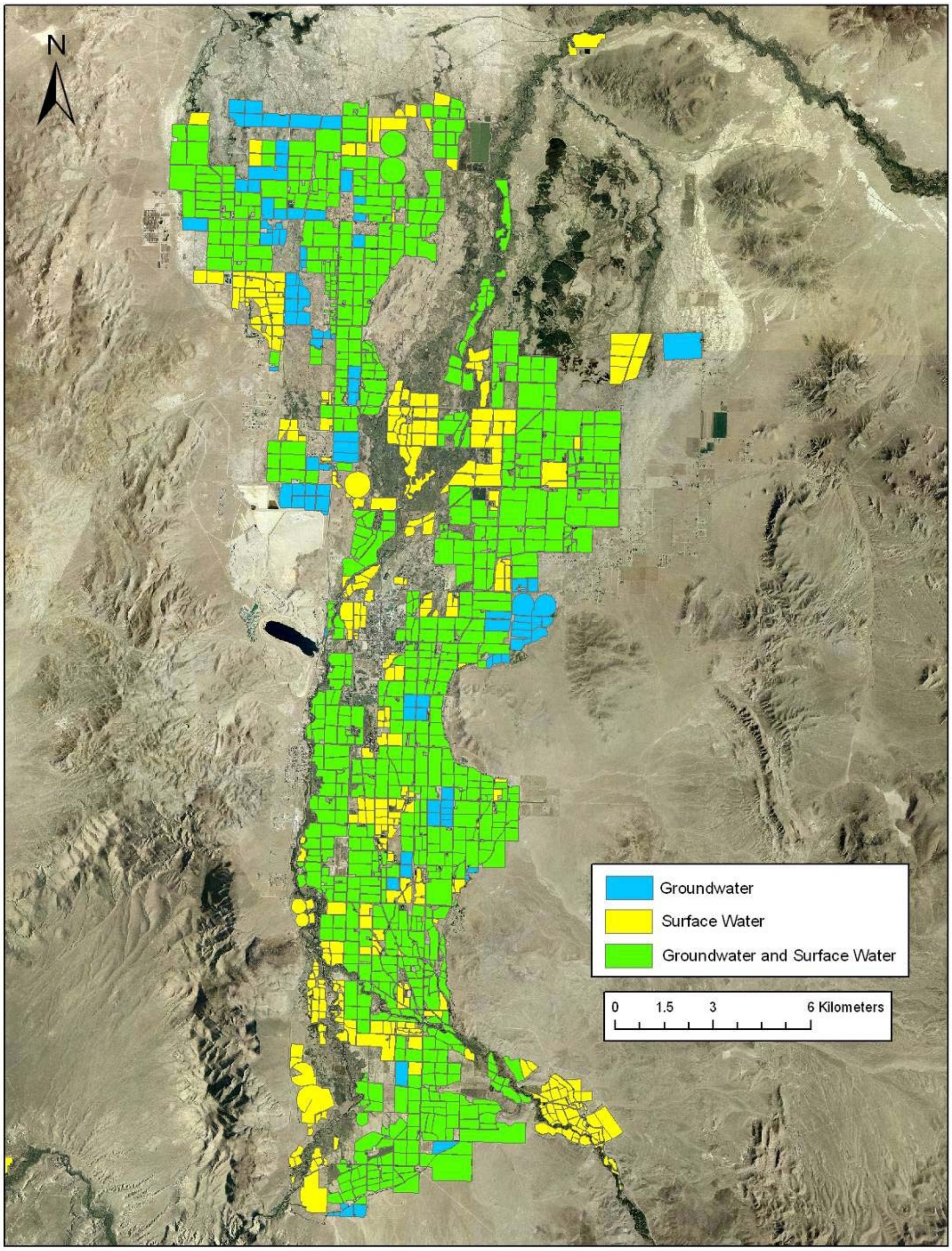

Figure 15. Water source inventory of agricultural fields in Mason Valley.

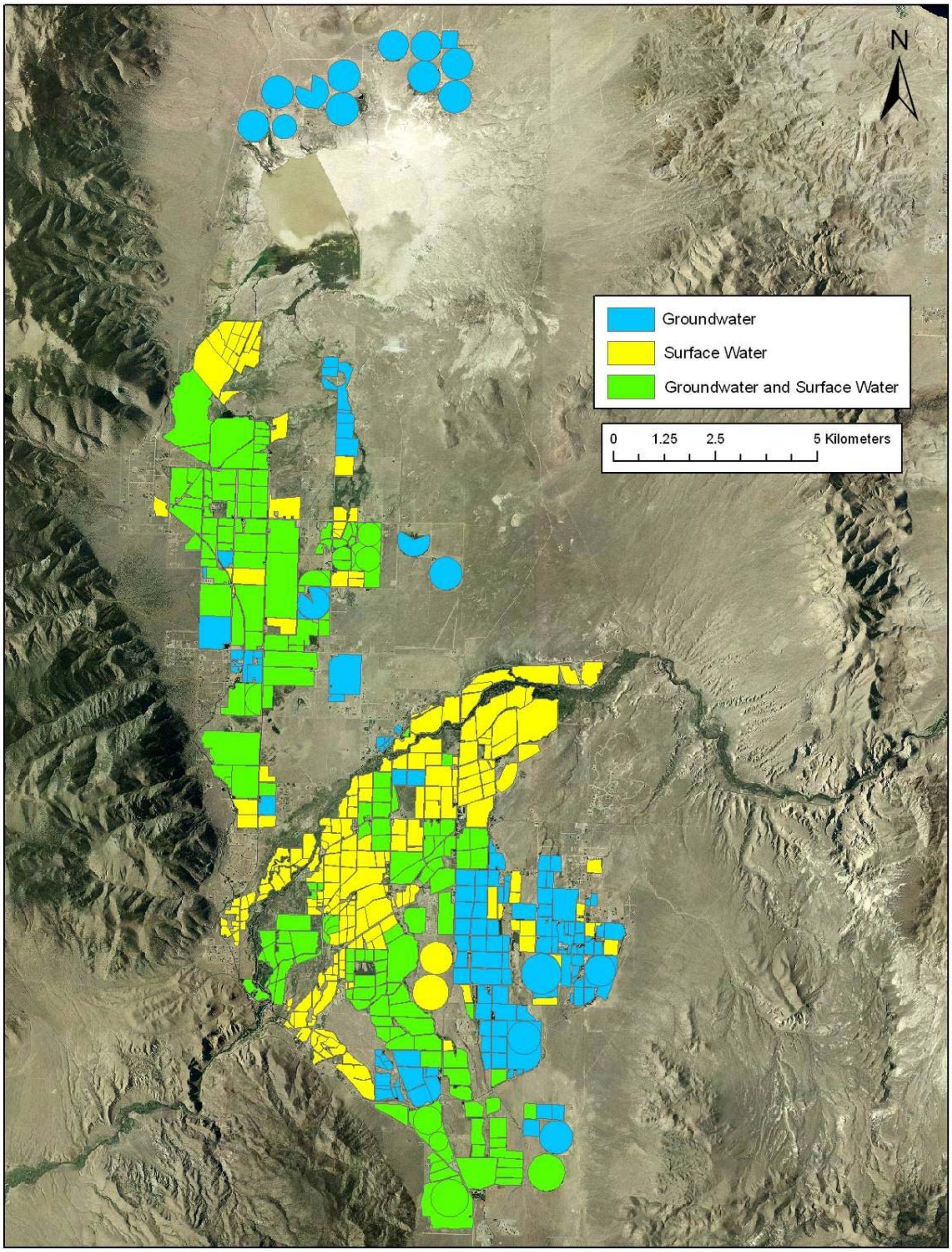

Figure 16. Water source inventory of agricultural fields in Smith Valley.

Analysis of irrigated acreage in 2000

The georectified Landsat TM NDVI derivative data sets were used to produce multiple snapshots of irrigated fields in Mason and Smith valleys during a relatively dry year, 2000 to observe intraseasonal fluctuations in irrigated acreage. The water balance of the agricultural fields (i.e. the evapotranspiration (ET) of crops) drives the water balance for the entire basin, including the river flows, so it was imperative, for the purposes of modeling the groundwater system, to understand how much of the crops were in production at any given time. An analysis of a dry year afforded the opportunity to better understand the relationship between crops and irrigation practices, versus a wet year when almost all agricultural fields would have been receiving water.

The HRU data were used as a mask that was applied in ENVI to the three dates of NDVI data, June 9, July 27, and September 15, 2000. By using the HRU data as a mask, riparian and non-irrigated vegetation outside the field boundaries were eliminated from the analysis, leaving only irrigated vegetation found within field and pasture boundaries (Figure 17). It should be noted that several irrigated fields can be seen in Figure 17 for Mason Valley that were not included in the NDVI analysis; these fields were not included because, while the 2000 Landsat image data indicate they were irrigated, the fields were not irrigated in the 2005 to 2007 time period, the acquisition dates of the aerial photography used to map the agricultural fields, and thus the HRUs. The derivative masked NDVI files in ENVI format were then converted to ESRI rasters (grids). Zonal Statistics were run using the Spatial Analyst extension in ArcGIS. In this function, the HRU polygons were treated as the zonal data set (areas of interest), with the diversion/ditch assignment (or groundwater designation) attribute field as the identifying zone. The respective NDVI values for each of the three NDVI data sets were designated the value rasters in the zonal statistics calculations. The resultant zonal statistics table contained the minimum, maximum, range, mean, standard deviation, sum, and area for the NDVI cell values by HRU. The area, in square meters, of NDVI values (irrigated vegetation) for each HRU in the table were then converted to acres in Excel. Table 4 shows the summarized irrigated agricultural areal results, by HRU, for the July 27, 2000, analysis.

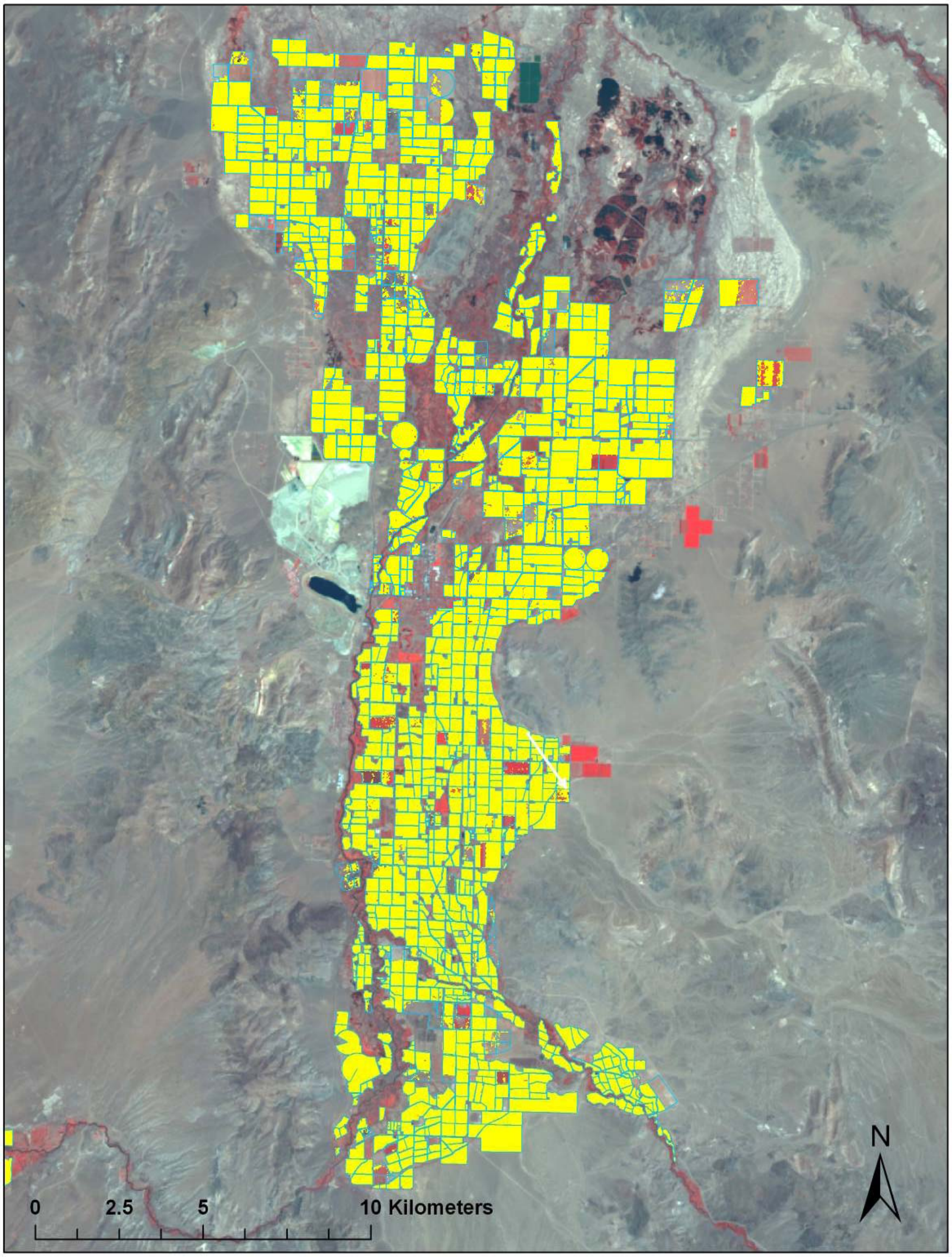

Figure 17. NDVI threshold results for Landsat TM data acquired July 27, 2000 over Mason Valley. Blue lines indicate HRU boundaries used to mask out riparian and non-irrigated vegetation found within fields and pastures. Yellow areas indicate NDVI response for irrigated vegetation within each HRU.

Table 4. Estimated irrigated acres for Mason and Smith valleys derived by HRU from Landsat TM satellite data acquired July 27, 2000. Area in square meters and acres.

Hydrologic Response Unit	Zone Code	Area (m^2)	Area (acres)
Colony Canal	1	20939800	5174
Groundwater	2	11821500	2921
Lower Fulstone Ditch	3	736711	182
Gage Peterson Ditch	4	1397070	345
River Simpson Ditch	5	3715230	918
Plymouth Ditch	6	8215910	2030
D&GW Ditch	7	3286360	812
High Ditch	8	2748650	679
Hilbun Ditch	9	1284980	317
Tunnel Ditch	10	11082300	2738
Sab Ditch	11	4520170	1116
Campbell Ditch	12	22134600	5469
West Hyland Ditch	13	13973100	3452
River Pump-CBN	14	1685420	416
Sciarant Ditch	15	673355	166
Fox Ditch	16	12922900	3193
Hall Ditch	17	10323700	2551
Greenwood Ditch	18	7679820	1897
Mickey Ditch	19	6273010	1550
Baker Snyder Ditch	20	1384070	342
River Pump-Borsini	21	148642	36
Kelly Alkali Ditch	22	1111160	274
Nelson Ditch	23	649800	160
River Pump-Warburton	24	60918	15
Westside Ditch	25	1506720	372
Lee & Sanders Ditch	26	302969	74
Pitchfork Ranch Ditch (West)	27	981198	242
Pitchfork Ranch Ditch (East)	28	2641440	652
Joggles Ditch	29	4362600	1078
Nichol-Merritt Ditch	30	18075000	4466
Spragg-Woodcock Ditch	31	3527600	871
River-Pump-Stanley	32	424807	104
West Walker River Ditch	33	5433950	1342
Saroni Canal	34	14802400	3657
Upper Fulstone Ditch	35	2176020	537
Desert Creek	36	6663700	1646
Burbank Ditch	37	1335340	329
River Pump AGHD	38	494660	122
Dairy Ditch	39	427244	105

DISCUSSION AND RECOMMENDATIONS

This section identifies which spatial data sets were used by specific projects within the larger Walker Basin Project, in order to provide some context as to how different projects used the spatial and tabular data developed for the GIS database. There is a description of the data storage and distribution mechanisms utilized, a discussion of some of the issues and challenges related to the data collection and development effort throughout the life of the project, and finally, some recommendations for maintenance of the database and potential future enhancements.

Spatial Data Uses by Project

Six of the original 10 projects that make up the larger Walker Basin Project requested spatial data developed for the GIS database (DST for water flow modeling; alternative agriculture and vegetation management; plant, soil and water interactions; health of Walker River and Lake; economic impacts and strategies; demographics and economic development). In addition, three other entities associated with the project (USFWS restoration project; Western Development and Storage, the acquisitions team; and Jones and Stokes, the EIS development team) utilized some data sets in the GIS database. Dissemination of data to these entities was limited to those data sets that fell within the data sharing guidelines specified in the data sharing protocol set up for the project by DRI and the University of Nevada, Reno (UNR), primarily public domain information. The following list summarizes these projects and associated Walker Basin Project entities and the specific data layers and tabular information from Table A1 that were used to support their efforts:

- DST water flow modeling
    - Supply side (PRMS) – lakes; USGS gaging stations; Walker Basin hydrological sub basins; Walker Basin hydrologic boundary; USGS major hydrologic features; NAIP air photo mosaic of Walker Basin; Walker Basin 10 meter DEM; Landsat TM satellite images; scanned 1:24k topographic maps of Walker Basin
    - Demand side (MODFLOW) – soils; groundwater POUs and PODs; surface diversions; ditches and drains; HRUs; rivers; USGS wells; NDWR monitoring wells; NDWR irrigation and municipal wells; USGS gaging stations; air photo mosaic of Lyon County; NAIP air photo mosaic of Walker Basin; 10 meter DEM; one meter LIDAR DEM; Landsat TM satellite images; irrigated lands grids for 2000; annual diversions; daily diversions; monthly diversions; zonal statistics for irrigated lands
    - Basin Management System (MODSIM) - groundwater POUs and PODs; surface diversions; C-125 decree; ditches and drains; fields supplied by river pumps; sumps; HRUs; lakes; rivers; USGS wells; NDWR monitoring wells; NDWR irrigation and municipal wells; USGS gaging stations; WRID boundary; Walker Basin hydrologic boundary; Lyon County parcels; PLSS system; Walker Basin air photo mosaic of Lyon County; six inch Yerington air photo mosaic; 1994 USGS DOQs; NAIP

air photo mosaic of Walker Basin; 10 meter DEM; one meter LIDAR DEM; Landsat TM satellite images; C-125 decree database; annual diversions; daily diversions; monthly diversions; decree and storage data

- Alternative agriculture and vegetation management
    - Agricultural fields with crop IDs; surface diversions; ditches and drains; Landsat TM satellite images; annual diversion data; daily diversion data; monthly diversion data
- Plant, soil and water interactions
    - Agricultural fields with crop IDs; surface diversions; ditches and drains; Landsat TM satellite images; annual diversion data; daily diversion data; monthly diversion data
- Health of Walker River and Lake
    - Walker Basin hydrographic boundary; surface diversions
- Economic impacts and strategies
    - Agricultural fields with crop IDs and water sources; Lyon County air photo mosaic; NAIP air photo mosaic of Walker Basin
- Demographics and Economic Development
    - Agricultural fields with crop IDs and water sources; Antelope Valley and Bridgeport Valley agricultural fields; surface diversions; Walker Basin hydrographic boundary; Mono County parcel data; Douglas County parcel data; PLSS data; Lyon County air photo mosaic; NAIP air photo mosaic of Walker Basin; 10 meter DEM of Walker Basin; one meter LIDAR DEM
- USFWS Restoration Project
    - Surface diversions; ditches and drains; one meter LIDAR DEM; Lyon County parcel data; Mono County parcel data; Mineral County parcel data; Douglas County parcel data
- Western Development and Storage
    - Ditches and drains; Lyon County parcel data; Douglas County parcel data; PLSS data; NAIP air photo mosaic of Walker Basin
- Jones and Stokes
    - Ditches and drains; Lyon County parcel data; Douglas County parcel data; PLSS data; NAIP air photo mosaic of Walker Basin

Data Storage and Distribution

The ArcGIS shapefiles, rasters, personal geodatabases, and associated tables (dBase IV, Microsoft Access and Excel) developed for this project were stored on a central internal server with a directory tree structure based on categories of data and a file-naming convention based on developer, content, and date of development (for example, TBM_ditchpods_081208 is a shapefile of main points of diversion along the river stems, developed by Tim B. Minor on August 12, 2008). This name convention made it easier for users to access pertinent data using either Microsoft Explorer tools, or ArcCatalog. Figure 1 in Appendix 1 illustrates the file system structure set up on the DRI server for storing the GIS database, the same file system used for the accompanying project USB storage drive.

All data sets were passed to project team members in either ArcGIS format (spatial data) or Microsoft Excel format (tables). Often, the development of the data sets required several iterations based on additional requests by the modelers and/or missing dates found in the data, requiring close collaboration between the GIS database development team and the modeling team. This was especially true with the daily diversion data, as the many thousands of lines of diversion data sometimes contained missing days and misspelled or variant spellings of ditch names. Several iterations of the HRU data files and the Decree-Storage descriptions were required as updated diversion or water rights information was provided by WRID, the Walker River Water Master, or History Mapping Services. As described above, several iterations of the ditch and drain network shapefiles were also required for integration with the NETWORK ANALYST and MODSIM software used by the DST team.

Data Acquisition/Data Development Issues and Limitations

The GIS database development team faced many challenges constructing a complete, concise, and accurate GIS database for the various projects within the Walker Basin Project. The following is a list of key data acquisition/data development issues experienced by the team during the course of the project:

- Relatively short time line of project for collecting data, and parallel nature of the various Walker Basin research project timelines, limited the collection of all data requested and/or required by various Walker Basin Projects.
- Restricted access to critical data related to water distribution systems and water rights required the DST modelers to re-adjust their original target modeling scale (farm scale) to a coarser scale (HRUs).
- Antiquated formats of some critical data sets (analog-only versions) required longer, more intense data entry effort than originally anticipated.
- Noticeable gaps in data sets compromised the accuracy of the GIS database.

Every attempt was made by the GIS database development team to acquire the most up-to-date, accurate spatial and tabular information for the Walker Basin Project. The GIS team attempted to collect these data as quickly as possible, but given the relatively short timeline of the overall Walker project and the parallel tracks of the GIS data collection and development effort and the other Walker Basin Projects, some of the final pieces of the database were not received and then passed on to these projects until very late in the project timeline.

Due to current water rights litigation issues in the Walker Basin, and the sensitive nature of individual surface water rights in the Walker Basin, DRI researchers were restricted in their attempts to acquire critical, detailed storage and decree water right data.

Desert Research Institute was only allowed access to a limit number of individual water cards for potential willing sellers in the Mason and Smith valleys areas. The lack of extensive, detailed decree and storage water right information for the study area meant that DRI was often making educated guesses at the distribution and delivery of surface water as it related to the HRUs and the decree-storage data. This included spatial location information on non-supplemental storage rights (New Lands storage rights). Supplemental storage rights (rights that are supplemental to decree rights and are based on priority dates) were calculated from the available decree water right totals. The main source of information for Decree C-125 data, as described in the Methods and Approach section, was the 1997 NDWP database tables compiled from historical Walker River Water Master files. These database tables were compiled before the current litigation issues forced restricted public access to WRID and Walker River Water Master's data. Although dated, the NDWP database contained the most comprehensive analysis of the Decree C-125 water rights available. This was considered to be a reasonable source of data, because the difficulty in transferring decree water rights usually limits the number of changes to the actual decree, and those few changes would be well documented through the permit files at NDWR.

Although DRI's access to detailed individual decree and storage rights data in the basin was restricted, the Institute did receive valuable information from both the Walker River Water Master, Jim Shaw, and WRID manager Ken Spooner, in the form of diversion data and diversion locations, respectively. These data proved absolutely essential in the development of the Walker Basin water flow model, and the efforts of both the Water Master's office and WRID are greatly appreciated.

Development of the annual and daily diversion data sets took much longer than originally anticipated because the data, as delivered to DRI, were in analog (hardcopy) format. This required a much longer, more intense commitment of human resources to properly enter the data into electronic format, all the while ensuring quality control of the resultant data sets and minimizing data entry errors. Data entry of diversion data was performed up until the last few weeks of the concurrent Walker Basin Projects.

Data gaps are a reality of any GIS database development effort, and this project was no different. DRI did not receive the available 2007 daily diversion data in time for the completion of the project, so this valuable year of diversion data was not included in the DST development effort. There were several missing daily diversions for the various years of data received, so the data values for these dates had to be interpolated based on surrounding days. Inconsistencies in the names of diversion ditches from year to year, and the omission of specific ditches, especially for the monthly diversion data for 1930 to 1995, created problems when attempting to identify consistent relationships between surface diversions and fields for the HRU data development effort. Although the one foot aerial photography of Lyon County afforded very detailed mapping of the ditches and drains, the replacement of ditches with underground pipes, as discussed above, required an estimation of where underground delivery systems moved water relative to open systems, and this probably led to some data gaps in the mapping of ditches and drains in Mason and Smith valleys.

The data acquisition and development issues described above impose some realistic limitations on the GIS database. Given the various scales of the data used to development the database, and some of the restrictions (legal or otherwise) of the data, the appropriate scale to utilize these data are at the HRU modeling unit, not the farm scale. Obviously the detailed parcel data made available by the various counties would allow for more detailed farm scale mapping and modeling, but not without sufficient, accurate water delivery and water rights information at that same scale. Until extensive field checking can be performed in the proposed Phase II Walker Basin Project (and more importantly, allowed by private land owners and water system administrators), the HRU, ditch and drain, and various water rights data described above should be used with the appropriate accuracy qualifications.

Recommendations

For maintenance of the Walker Basin GIS database, as well as future enhancements to the database, DRI recommends that all current shapefiles, rasters, tables and personal databases be integrated into file geodatabases to facilitate access across institutions and/or agencies. A file geodatabase data model is not limited by size, can be stored in a file system, and will allow concurrent editing of spatial features. A file geodatabase will also make it easier to transport the database between agencies, or members of the private sector who have an interest in the database and the means to view or analyze the data.

For future large, interdependent projects like the Walker Basin Project, it would be more advantageous if the GIS database development task was performed sequentially relative to other application projects.. The development of the GIS database coincident with the other research projects made it very difficult to provide the initial data layers in a timely manner, and then develop derivative data sets and subsequent analyses when requests were made for such products late in the project cycle. One thing that could aide this process is the establishment of collaborations and/or data sharing agreements with key agencies and institutions very early in the project, or even before the project begins.

CONCLUSIONS

Spatial and tabular GIS data for the Walker Basin were developed in support of the Walker Basin Project. A majority of these data sets were requested by and provided to the DST team, both as inputs to the various modeling components and as calibration data to validate the model results. The GIS database also supported several other projects in the Walker Basin Project, as well as restoration, acquisition, and environmental impact interests associated with the Basin project. The GIS development team constructed an extensive GIS database for Walker basin, with data sets from federal, state, and local agencies combined with derivative data sets developed at DRI. The result is a GIS database that spatially integrates surface water and groundwater distribution systems with surface water and groundwater rights, combining infrastructure and administrative data with enhanced high resolution aerial and satellite derived image data. The GIS database represents a comprehensive, spatially georeferenced data set of the Walker Basin. The database will be used in the proposed Phase II Walker Basin Project, specifically to support planned enhancements to the DST, which will include updating the GIS database with new, more accurate data. These enhancements will improve the DST's ability to conduct scenario analysis for potential withdrawals of water from the Walker River system via acquisitions and/or leasing agreements, as well as the ability to determine how much of these withdrawals will be available for increased water delivery to Walker Lake.

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APPENDIX A. WALKER BASIN GIS DATABASE: DATA LAYERS, FILE NAMES, FORMATS, SOURCES, SPATIAL EXTENTS, AND SCALES

The following table and figure describe the spatial data layers, tables and other data acquired, compiled or developed for the Walker Basin GIS database. Table A1 lists all of the data sets by data category, with a data description, an associated file name in the GIS database (on both the DRI server and the project USB flash drive), the data format (geodatabase, shapefile, coverage, raster, table), the source of the data, the spatial extent or area covered by the data, and the scale (representative fraction for vector data sets, cell resolution for raster data sets) of the data set. Figure A1 shows the file system set up on the DRI server for storing the GIS database, which is the same file system set up on the accompanying project USB flash drive.

Table A1. Spatial Data layers acquired, compiled, or developed for the Walker Basin GIS database development project.

Description	*Filename*	*Data Format*	*Source*	*Spatial Extent*	*Scale*
Agricultural Fields/Soils					
Mason Valley (MV) and Smith Valley (SV) fields with crop IDs and water sources	TBM_agfields_watersources_61808	Arc shapefile	DRI/U.S. Department of Agriculture (USDA)	Mason and Smith valleys	1:7920
Antelope Valley and Bridgeport Ag fields	TBM_ant_bridge_agfields_091108	Arc shapefile	DRI/USDA	Antelope Valley Bridgeport Valley	1:7920
Walker Basin Soil Survey Geographic (SUURGO) database	Soils directory (contains all SSURGO spatial and tabular data)	Arc shapefiles and layer files	USDA – Natural Resources Conservation Service (NRCS)	Walker Basin	1:24000
Hydrology/Groundwater					
MV and SV Groundwater Places of Use and Points of Diversion	JMS_walker_groundwater_02242009	Arc personal geodatabase	Nevada Division of Water Resources (NDWR)/DRI	Mason and Smith valleys	1:10000
MV and SV surface diversions	TBM_ditchpods_081208	Arc shapefile	DRI/Walker River Irrigation District (WRID)	Mason and Smith valleys	1:1000

Description	***Filename***	***Data Format***	***Source***	***Spatial Extent***	***Scale***
C-125 decree for Walker Basin	AES_C-125_01-11-08	Arc shapefile	History Mapping*	Walker Basin	1:24000
Flood rights for MV and SV	AES_flood_08-26-08	Arc shapefile	History Mapping	WRID	1:24000
MV and SV ditches and drains	TBM_ditches_primary_092608 TBM_drains_primary_092608	Arc shapefiles	DRI/History Mapping	Mason and Smith valleys	1:1000
MV and SV Hydrologic Response Units (HRUs)	AES_hru_12-02-08	Arc shapefile	History Mapping/DRI	WRID	1:7920
MV fields supplied by river pumps	AES_river-pumps_mason_06-23-08	Arc shapefile	History Mapping	Mason Valley	1:1000
MV and SV sumps	AES_sumps_08-14-08	Arc shapefile	History Mapping	Mason and Smith valleys	1:1000
Walker Basin lakes	TBM_lakes_082508	Arc shapefile	DRI/History Mapping	Walker Basin	1:100000
Walker River (main stem and forks)	TBM_wemriver_cl_080508	Arc shapefile	DRI/History Mapping	Mason and Smith valleys	1:1000
USGS wells	AES_usgswells_62807	Arc shapefile	History Mapping/U.S. Geological Survey (USGS)	northwestern Nevada	1:24000
NDWR monitoring wells	MDR_107_108_monitoredwells_020408	Arc shapefile	NDWR/DRI	Mason and Smith valleys	1:2000
NDWR irrigation and municipal wells	MDRgroundwater_well061307	Arc shapefile	NDWR/DRI	Mason and Smith valleys	1:2000
USGS gaging stations	USGS_gagingstations_092007	Arc shapefile	USGS	Walker Basin	1:100000
Walker Basin hydrological sub basins	USGS_250khucs_090607	Arc shapefile	USGS	Walker Basin	1:250000
WRID boundary	TBM_WRIDboundary_082508	Arc shapefile	History Mapping	WRID	1:2000
Walker Basin hydrologic boundary	TBM_walkerbasinboundary_053107	Arc shapefile	DRI/USGS	Walker Basin	1:250000

Description	*Filename*	*Data Format*	*Source*	*Spatial Extent*	*Scale*
Walker Basin major hydrologic features	USGS_100khydromajor_090607	Arc shapefile	USGS	Walker Basin	1:100000
Lyon County parcels, right-of-way, centerlines, lot lines, subdivisions	lyoncnty_parcelbasedata_041007	Arc personal geodatabase	Lyon County	Lyon County	1:1200
Mono County parcels	monocnty_parcels_121806	Arc shapefile	Mono County	Mono County	1:1200
Mineral County parcels	mineralcnty_parcels_082506	Arc shapefile	Mineral County	Mineral County	1:1200
Douglas County parcels	DC_parcels_100207	Arc shapefile	Douglas County	Douglas County	1:1200
Public Land Survey System	TBM_walkbasin_qq_053107 TBM_walkbasin_sections_053107 TBM_walkbasin_township_092007	Arc shapefiles	BLM/DRI	Walker Basin	1:100000
Land ownership	BLM_allnv_landowner_092007, BLM_allnv_landowner_092007.lyr	Arc shapefile and layer file	BLM	Nevada	1:100000
Reservation boundaries	AES_reservations_05-30-08	Arc shapefile	History Mapping	Walker Basin	1:1200
Image Data (rasters)					
Air photo mosaic of Lyon County - 2007	LC_one-foot_07	ERDAS ecw	AirPhotoUSA	southern Lyon County	one foot
Air photo mosaic of Yerington, NV - 2007	Yerington-NV-6IN-2007	Lizard Tech Mr. Sid	AirPhotoUSA	Yerington, NV	six inch
1994 black and white digital orthophotography quadrangles (DOQs)	AES_Mason_94DOQ_110207	ERDAS ecw	USGS/History Mapping	Mason Valley	one meter
NAIP air photo mosaic of Walker Basin (natural color)	TBM_NAIPwalkerbasin_utmz11_04080 8	ERDAS ecw	USDA/DRI	Walker Basin	one meter
10 meter Digital Elevation Model	walker_dem	Arc grid	USGS	Walker Basin	10 meter
One meter LIDAR DEM of river corridors in Walker Basin	gdintall	Arc grid	U.S. Fish and Wildlife Service (USFWS)/DRI	Walker Basin	one meter

Description	***Filename***	***Data Format***	***Source***	***Spatial Extent***	***Scale***
Fused one meter LIDAR DEM and 10 meter DEM of Mason Valley	lidar_fill_1m	Arc grid	DRI	Mason Valley	one meter
Landsat TM satellite image data for 2000	6-09-00, 7-27-00, 9-15-00	tif	USGS/DRI	Walker Basin, portions of Fallon area	28.5 meter
Irrigated lands for 2000 based on Landsat TM data	609hruirr, 727hruirr, 915hruirr	Arc grid	DRI	Mason and Smith valleys	28.5 meter
Scanned 1:24000 topographic map mosaic of Walker Basin	Walker-basin_24k_utm	ERDAS ecw	USGS/History Mapping	Walker Basin	2.4 meter
Tables and Documents					
1997 C-125 decree database	c125-97	Microsoft Access	Nevada Division of Water Planning (NDWP)**	Walker Basin	-
1997 C-125 decree description	walker decree	Adobe pdf	NDWP	Walker Basin	-
MV and SV annual diversions 1996-2007	MDR_1996-2007_annualdiversions_080108	Microsoft Excel	DRI/Water Master***	Walker Basin	-
MV and SV daily diversions 1996-2006	SM_DD_1996_converted_100108…. SM_DD_2006_converted_100708	Microsoft Excel	DRI/Water Master	Walker Basin	-
1930-1995 monthly diversion data	Antelope Diversions by type, East Walker Diversions by type, Mason Diversions by type, Smith Valley Diversions by type, Tunnel Section Diversions by type	Microsoft Excel	NDWP	Walker Basin	-
Decree and storage data	AES_decree_12-11-08	Microsoft Excel	History Mapping	Walker Basin	-
Zonal statistics tables for irrigated agriculture by HRU	60900_irrigacres_byHRU, 72700_irrigacres_byHRU, 91500_irrigacres_byHRU	Microsoft Excel	DRI	Mason and Smith valleys	-

*History Mapping Services, Virginia City, NV
**Nevada Division of Water Planning (NDWP). Documents and data originally developed by the now defunct Nevada Division of Water Planning
***The Walker River Federal Water Master. Chief Deputy Water Master, U.S. Board of Water Commissioners

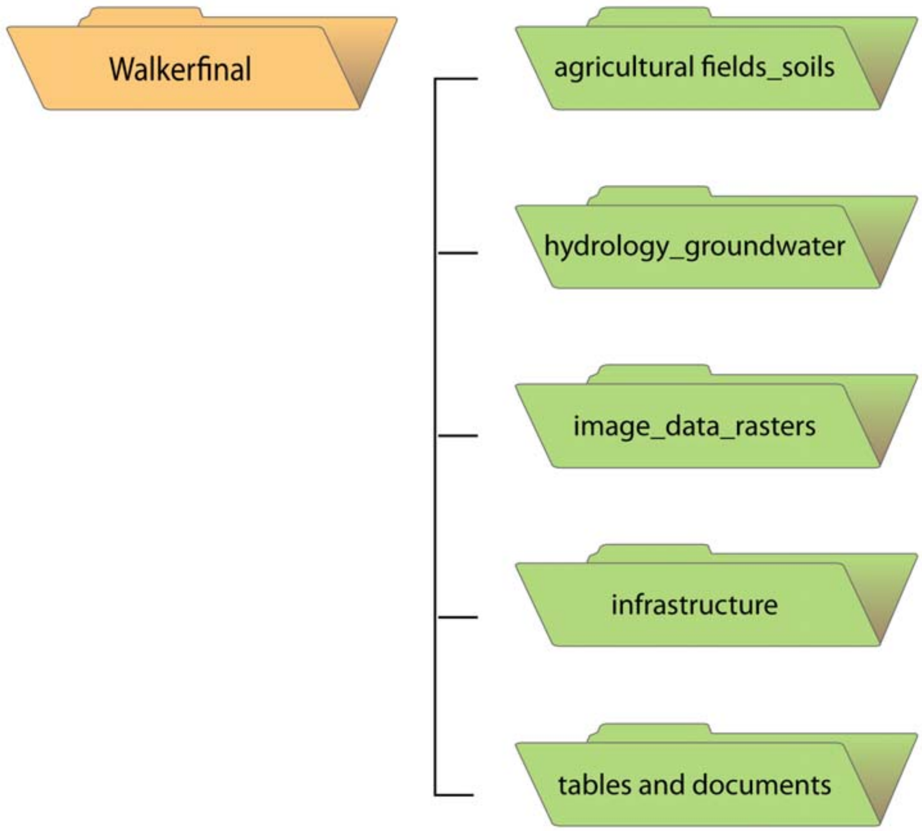

Figure A1. Walker Basin GIS database file system.

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PROJECT I: DEVELOPMENT OF A WATER RIGHTS GIS DATABASE

ECONOMIC AND DEMOGRAPHIC ANALYSIS OF THE WALKER BASIN

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Contents

List of Figures

ABSTRACT

In order to quantify any economic impact to the Walker Basin as the result of water right acquisitions, the current economic and demographic characteristics of the communities within the Walker Basin were developed and analyzed using local, state, and federal databases and geographic information systems software. The Walker Basin, covering portions of Douglas, Lyon, and Mineral Counties in Nevada and Mono County in California, is a collection of rural sub-hydrographic basins. Population is mainly concentrated in a handful of communities, mostly on the Nevada side in southern Lyon County and northern Mineral County. Although agriculture is a predominant and traditional industry in the Walker Basin, employment and industry totals indicate a diverse economy. Almost a quarter billion in taxable sales is generated in the Walker Basin, with the majority of sales generated from retail industries. Another $58 million in revenue is estimated to be generated from crop production in Mason and Smith Valleys (Lyon County) covering over 50,000 acres. Current and future residential and commercial construction activity is mostly targeted to populated areas and is consistent with the current economic conditions.

INTRODUCTION

Because the geographic extent of the Walker Basin covers portions of four counties in western Nevada and eastern California, and the fact that traditional sources of data are only available at the county and city level, the resulting Walker Basin economic and demographic datasets required extensive treatments and mapping. The most populated region of the Walker Basin, Lyon County, has experienced annual growth rates of up to 10.6% since the 2000 Census survey was performed, although the majority of the county's growth was located in areas to the north, outside the Basin. In order to update the selected 2000 Census demographic variables for the smallest geographic area, digital parcel bases, county assessor data, and federal income estimates were used to develop the current Census-block level information. Local economic indicators were identified and analyzed using confidential databases provided by state governments (Nevada only), local government databases, and field surveys. The following demographic and economic attributes are the key components in understanding the residential and economic conditions in the Walker Basin:

- Population estimates
- Age, race, sex estimates
- Occupation and education estimates
- Income estimates
- Household composition
- Housing unit types
- Housing unit ages
- Housing values
- Firms, employment, and payroll by type of industry

- Taxable sales by type of industry
- Crop yield and value estimates
- Residential construction activity
- Proposed commercial activity

METHODS AND APPROACH

Database acquisitioning was the first step in analyzing the socio-economics of the Walker Basin. Current, small-area demographic and economic information is very difficult to obtain, especially in rural areas of Nevada. Traditionally, due to cost benefits, socio-economic information is maintained and reported at the county and city level. In order to analyze non-traditional, irregular areas of geography, "raw" government databases that contain information by physical address or assessor parcel number are required. In order to obtain and develop small area data from the government databases two important requirements are needed. First, some government databases contain confidential information, and therefore, require agreements to obtain and use the sensitive data. The Center for Regional Studies at the University of Nevada, Reno has obtained confidentiality agreements with the Department of Employment and Department of Taxation in order to secure and use their databases. Second, in order to analyze small, irregular areas using the raw government records from the various databases, geographic information systems (GIS) software is required. The GIS allows the mapping and querying of the databases upon the "geocoding" of the address-specific information, or "joining" of the parcel-level property information (assessor data) to the digital parcel map base.

Upon the acquisition and mapping of the necessary databases, geographic regions were defined in order to analyze the socio-economic information down to the subregion level and for the entire Walker Basin. The defined subregions include the Walker Basin portions of Douglas, Lyon, Mineral, and Mono Counties with special attention given to the Smith and Mason Valleys within Lyon County, Nevada. The additional attention paid to the two valleys in Lyon County is due to the density of their population and industry.

Population

Population estimates are calculated by updating the 2000 Census block-level population with new residential units queried from county assessor data. Because it is difficult to collect digital parcel bases and county assessor data on the same given date, each dataset contains a different delivery date which effects the resulting date of the data for the entire basin. All county assessor databases were collected in 2007, but during different months. As a result, the demographic estimates do not have a specific date, but reflects the best possible snapshot of any given day in 2007.

Occupancy rates and average household sizes *by type of unit at the Census block-group level* are applied to each housing unit constructed since the 2000 Census survey (April 1, 2000) in order to develop current population from housing unit estimates. This method that calculates population, households, and housing units at the parcel level was developed by the Center for Regional Studies in the mid-1990's and is currently used to develop estimates in several counties.

Age, Race, and Sex

Upon calculating current population estimates, current age, race, and sex estimates are calculated by applying the 2000 Census block-level ratios to the current population within each Census block. This method assumes that the percentages of age, race, and sex in the year 2000 are the same in 2007. This method was chosen due to the prohibited costs and length of time required to generate "primary data" through household surveys.

Occupation and Education

Upon calculating current population estimates, current occupation and education estimates are calculated by first "modeling down" the Census block-group information from the Summary File 3 to the much smaller Census blocks using block to block-group ratios. The 2000 Census block-level ratios of occupation and education are then applied to the current population by age range within each Census block to derive the 2007 estimates. This method assumes that the percentages of occupation and education in the year 2000 are the same in 2007. This method was chosen due to the prohibited costs and length of time required to generate "primary data" through household surveys.

Income

The 2000 Census median household income, median family income, and per capita income at the Census block-group level are updated using 2000-2008 average annual growth rates of median family income reported by the Federal Financial Institutions Examination Council (FFIEC) using U.S. Department of Housing and Urban Development estimates at the Census tract level. As a result, the income estimates are for 2008.

Housing Units

Current housing unit estimates are calculated by adding the new residential units queried from county assessor data to the 2000 Census block-level housing unit counts.

Housing Values

Current housing values for the Douglas County portion are calculated from April 2007 county assessor sales files. Current housing values for Mason and Smith Valleys (Lyon County) are calculated from August 2008 county assessor sales files. Current housing values for the Mineral and Mono County portions are calculated using August 2008 real estate listing prices provided by the website www.zillow.com.

Firms, Employment, and Payroll

The current number of firms, number of employees, total payroll, and average wages by type of industry for Nevada are obtained from the Department of Employment, Training, and Rehabilitation (DETR) through confidentiality agreements. The 2nd quarter 2007 "covered employment" (ES-202) data includes only those entities that file for covered employment insurance, therefore, the data excludes most sole proprietors and all seasonal migrant labor. A combination of latitudes and longitudes (provided by DETR), city names within the DTER database, and geocoding of addresses using the GIS software are used to identify and extract the firm and employment counts and average wages for the specific communities and subregions in Douglas, Lyon, and Mineral Counties.

Current firm and employment counts and total payroll for the Mono County, California portion of the Walker Basin are obtained from the U.S. Census Bureau's 2006 "Zip Business Patterns". Zip code level statistics are used for California because the majority of commerce and employment in Mono County is located in Mammoth Lakes, an area not within the Walker Hydrographic Basin. The zip codes used in the analysis include 93517 (Bridgeport), 96107 (Coleville), and 96133 (Topaz).

Taxable Sales

The current estimate of taxable sales by type of industry is obtained from the Department of Taxation (Nevada only) through confidentiality agreements. Calendar year 2007 gross and taxable sales were verified and mapped for Lyon and Mineral Counties, and calendar year 2005 sales were used for the Douglas County portion due to the limited number of establishments (11).

Attempts were made to query business revenue amounts from the 2002 Economic Census (U.S. Census Bureau) for the Mono County portions of the basin using the three zip codes for that area. The total numbers of businesses by industry and sales receipts (revenue) are not provided by the Economic Census, due to the limited number of establishments. Too few establishments invoke disclosure clauses that prevent the release of the information for confidentiality reasons.

Crop Yield and Values

Crop types and estimated values are only provided for Mason and Smith Valleys due to cost-benefits and limited access to areas in order to conduct field verifications on the ground. Other sizeable crop locations include Antelope Valley in Douglas and Mono Counties (east and south of Topaz Lake), and areas within the Walker River Indian Reservation.

In order to calculate crop yields and values, each crop first required identification of crop type through field surveys and aerial photography. Although spring 2007 one-foot photography was available, the spring 2006 one-meter photography was used due to the difference between the conditions displayed on the ground. The 2006 aerial photography appears to show more fields in production, suggesting a winter and spring with higher amounts of precipitation than 2007.

Large-format maps of crops in Mason and Smith Valleys were generated and then verified through field surveys by John Snyder, an agricultural grower who resides in Mason Valley. The resulting fields and crops were then digitized into a digital map layer by the Desert Research Institute (DRI). Upon the creation of the digital boundaries, computer software calculated the acres for each field and crop.

The current values of each crop are provided by Cooperative Extension's (University of Nevada) crop budgets and John Snyder (agricultural grower in Mason Valley).

Residential Construction Activity

Current and proposed activity of residential construction is obtained from planning commission, city council, and county commissioner meeting minutes. The resulting meeting minutes are reported monthly and the research of residential projects by the Center for Regional Studies began in 2005 and will continue after the completion of the Walker Basin research.

Each residential development is tracked through the typical phases of the application process including tentative map application, final map application, planning commission approvals, city council and county commissioner approvals, and finally, the under-construction phase.

Upon the completion of each housing unit the county assessor data is then used to track land use, building size, ownership, and sales history. The county assessor data allows the calculations of absorption rates of new units and their median sales prices. Digital parcel basis are employed in combination with the assessor data in order to "clip" the information for inside the Walker Basin.

Proposed Commercial Activity

Current activity of proposed commercial construction is obtained from planning commission, city council, and county commissioner meeting minutes; building permits; and consultations with Sierra Pacific Power Company's Economic Development department. Building permits and meeting minutes are reported on a monthly basis and the research of proposed commercial projects by the Center for Regional Studies began January 2007 and will continue after the completion of the Walker Basin research.

Commercial activity attributes that are maintained, when and where available, include type of use, project name, applicant name, owner, location, status, and size and valuation of construction.

Upon the completion of the commercial construction, the research of building use, building size, ownership, and sales information is conducted using county assessor databases. Digital parcel basis are employed in combination with the assessor data in order to "clip" the information for inside the Walker Basin.

SUMMARY OF FINDINGS

Population

Walker Basin is not similar to other areas of Nevada that have experienced rapid rates of growth, adding only 1,228 persons since the year 2000 (Appendix 1). This population increase represents a growth rate of 1% per year, much slower than the rate of growth for the State of Nevada during the same period. Reasons for the low population increase may include the long distances to the amenities of large population centers, lack of secondary education facilities, and limited employment opportunities outside of agriculture.

Smith Valley's population growth rate of almost 5% between the years 2000 and 2007, its median home value of $475,000, and its large-lot properties may indicate that the growth in Smith Valley was driven by retirees and "second" home owners. The

Topaz Ranch Estates in Douglas County, between Smith Valley and US Highway 395, also experienced moderate growth between 2000 and 2007.

The population change between the years 2000 and 2007 was flat for the most populated region, Mason Valley, and the Mono County portion of the basin. The second most populated area, the Mineral County portion of the basin, is estimated to have lost population since the 2000 Census. Reasons for the population loss in Mineral County may be attributed to employment swings at the Hawthorne Army Ammunition Depot.

Age

The Walker Basin is home to an elderly population base. Although the areas of Douglas County, Mono County, and Smith Valley have high percentages of retirees and “empty nesters”, the Mineral County and Mason Valley areas contain more families with children. The diverse age groups between the communities in the Walker Basin reflect the overall difference in its demographics. Within the basin there are communities sought out for employment and services in order to raise families. And then there are areas like the Topaz Ranch Estates in Douglas County that draw mostly older householders without children.

Race

Unlike most rural areas in Nevada, the population in Walker Basin is diverse with spread-out concentrations of non-Hispanic white, pockets of Hispanics in agricultural areas, a relative high percent of blacks in the town of Hawthorne (Mineral County), and two American Indian reservations (Campbell Ranch and Walker River). The Hispanic population fluctuates in the areas of Mason and Smith Valleys where the migrant population spikes during planting and harvesting seasons, but the Hispanics also have a year-around presence in Mason and Smith Valleys. The relative high percent of blacks in Hawthorne may be a result of employment or military personnel at the Hawthorne Army Ammunition Depot.

Sex

Although the difference is not pronounced, all communities in the Walker Basin contain more men than women. A comparison with Census estimates for the State of Nevada shows that the ratio of men to women in Walker Basin does not vary from the norm. The somewhat moderate gap between the numbers of men and women in the Mono County portion of the basin may be explained by the U.S. Marine Corps’ Mountain Warfare Training Center in Pickle Meadows.

Occupation

Overall, the white-collar occupation in Walker Basin outnumbers the blue-collar occupations, followed by service and then sales occupations. The areas with large amounts of agriculture overcome the gap between white and blue-collar occupations, with the ratio almost one-to-one in Mason Valley and 14% more blue-collar than white-collar occupations in Smith Valley. It is an interesting fact that the high concentrations of blue-collar workers in Smith Valley live in an area with a median housing price of $475,000. This conflicting set of demographics, although, may be explained by high-paying blue-collar jobs (construction and agriculture), the rapid changes to the Smith

Valley demographics since the 2000 Census when the household survey of employment was conducted, or both.

All communities in the Walker Basin contain low amounts of sales occupations. The Mineral County portion of the basin, on the other hand, has a relatively high percent of service occupations. The high ratio of service occupations in Mineral County may be explained by U.S. Highway 95 that connects Reno with Las Vegas, Walker Lake, and the Hawthorne Army Ammunition Depot.

Education

Education statistics are not a strong attribute for the Walker Basin with low percentages, as compared to the State of Nevada, in all levels of education including high school graduation. Low levels of higher education diplomas are expected in rural areas with large amounts of agriculture: farming occupations do not require college degrees and distances to educational facilities damper educational opportunities in rural areas.

The Mono County portion of Walker Basin has the highest percent of educated individuals with only a little over 10% without a high-school diploma. Although the percent of those without a high-school diploma in Smith Valley is nearly one-in three, the valley ranks second, of all the areas in the basin, in the percent that obtained a bachelor's degree or higher out (after Mono County). Again, the data characterizes Smith Valley as a dichotomous community.

Income

Median household and family income levels in the Walker Basin are also lower than the State of Nevada levels by over $10,000. The level of income reflects the level of wages and the occupations that pay them. Rural areas in Nevada without mining occupations traditionally do not report incomes similar to those received in urban areas.

The ranches and "ranchettes" of Smith Valley point to higher incomes, with higher median household and per capita income than the State of Nevada. Smith Valley's per capita income is ranked 19 out of 71 "Census Designated Places" (CDP) in Nevada, according to the 2000 Census.

Although the income levels are not significantly high, the health of income in Walker Basin seems to be satisfactory. According to current government estimates of consumer price inflation and Census tract-level income, the rate of income growth between the years 2000 and 2008 in the Walker Basin has outpaced the rate of price inflation. The income in the basin, as a result, is estimated to be growing at a pace that leaves residual savings after the inflation of purchases is factored in.

Household Composition

The majority of households in the Walker Basin are family households, but, surprisingly, the majority of family households are households without children. Between one-in-two and one-in-three households contain a wife and husband, elderly siblings, or adult family members, but no children.

Smith Valley leads all other communities in Walker Basin with the percent of family households with children, and the Mineral County portion of the basin has the highest percent of family households with single parents.

Housing Unit Types

Almost every housing unit in the Walker Basin is either a single-family detached or a mobile/manufactured home, typical of the housing product in rural areas. The single-family product is much more dominant in the high-income area of Smith Valley, whereas the mobile/manufactured homes are more prevalent in the Douglas County portion of the basin. A relatively high percent of multi-family units are found in the Mineral County portion of the basin, possibly due to the Hawthorne Army Ammunition Depot. The various housing unit types between communities of the Walker Basin reflect the diversity of the basin's socio-economics.

Housing Unit Ages

The housing unit stock in the Walker Basin is aged (60% built before 1980), but significant amounts were built in Mason and Smith Valleys and the Douglas County portion of Walker Basin in the last seven years. Each of these regions built over 10% of their total housing stock between 2000 and 2007. Almost one-in-three Smith Valley homes were built in this period. Such rapid growth of rooftops can change the demographic and economic characteristics of a given area and are usually the cause of concern for planners and politicians.

Likewise, areas like the Mineral and Mono County portions of the Walker Basin with limited or no growth in new housing units can have adverse effects on a community. Zero population growth would be accepted by many, but the exclusion of new housing units puts pressure on the existing housing stock. Old housing stock can affect public works budgets, business recruitment, economic vitality, and overall quality of life.

Housing Values

Housing values in the Walker Basin, as one would expect, are determined by housing product, lot and house sizes, age of housing stock, and location, location, location. The region with the highest amount of positive factors, Smith Valley, has the highest median home value in the Walker Basin and is significantly higher than the region with the next highest median value (Mono County portion of the basin). Ironically, the median price of a home in Smith Valley can buy four homes priced at the median value for the Mineral County portion of the basin. Home values are another attribute that exposes the community diversity in the Walker Basin that can be separated by a single mountain range.

Firms and Employment

As one would expect, the number of business establishments and jobs are more prevalent where there are more rooftops. What one may not expect is that although the Walker Basin economy is heavily agrarian, the firm and employment totals indicate a diversified number of industries with large amount of employment in schools, hospitals, and restaurants.

Although agriculture dominates the landscape in Mason and Smith Valleys and portions of Mono and Douglas Counties, only one-in-thirteen employees hired by industries in the Walker Basin are employed in agriculture. The majority of jobs in the Walker Basin are in the service-type industries, with most of those employed in some sort of community service (education, health care, and social services). The lack of retail in the Walker Basin is evident by the fact that there are more employed in the management and administrative services sector (573 employees) than retail trade (399 employees) (Appendix 2).

The estimated payroll paid by industries that file for unemployment insurance in the Walker Basin is nearly $209 million per year. Consumer expenditure surveys conducted by the Bureau of Labor Statistics (U.S. Department of Labor) report that approximately two-thirds of total wages are spent on goods and services, thus the spending of this portion of the payroll contributes to the local economy. The remaining portions of employee wages are spent on taxes, pensions, insurance, and other items that do not contribute to the local economy.

It is important to note, although, that there is traditionally a sizeable amount of sole-proprietor industries (those without employees) in rural areas. A significant amount of these sole-proprietors do not file for unemployment insurance with the State, and, therefore, are excluded from monthly surveys that report industry employment and payroll. According to the latest estimates (2006) from the Bureau of Economic Analyses (U.S. Department of Commerce), 26% of all jobs in Lyon County are within sole-proprietor industries.

The sole proprietors do not generate payroll, but certainly contribute to local area expenditures with their business earnings. The earnings paid to seasonal labor is not reported or is accessible, therefore, a small portion of agricultural payroll is missing from this analysis.

Taxable Sales

The sector generating the highest gross sales and the second highest taxable sales in the Walker Basin is wholesale trade, collecting almost a third of the total pie (Appendix 5). As a comparison, wholesale trade represented only 9% of the taxable sales reported for the 2007-2008 fiscal year in the State of Nevada. Although Mason Valley generates the most sales in wholesale trade, Smith Valley and the Mineral County portion of the basin also report significant sales in wholesale trade. The concentration of wholesale trade industry seems to be supported by the rural nature of the Walker Basin. Wholesale businesses do not require retail storefronts and can be operated out of a residence.

Another third of the total sales pie was collected by supermarkets, markets, convenience stores, and gas stations (combined). Over $60 million is collected by local markets and gas stations, but it is understood that many more millions of dollars in food and gas purchases “leak” outside of the Walker Basin to areas anchored with large retailers and shopping centers. Supermarkets, markets, convenience stores, and gas stations generate the highest sales in the Mineral County portion of the basin. Although manufacturing generated the third highest gross sales in Walker Basin, all retail-type entities combined generate over half of all sales and almost two-thirds of the taxable sales.

It should be noted that Douglas, Lyon, and Mineral Counties are “tax guaranteed” counties where the State of Nevada guarantees a specific amount of revenues back to the cities and counties using a formula applied to the State’s total taxable sales. As a result, tax-guaranteed counties are not dependent on the amount of taxable sales generated within their borders in order to meet their service needs. The tax-guarantee agreement is particularly important for large, rural counties that lack a solid economic base to support their overhead. High-growth counties like Lyon County, on the other hand, need to constantly compare their sales tax collection with the amount guaranteed by the State. When the amount of sales taxes generated in the county exceeds the amount guaranteed by the State, the guaranteed county will be on the losing end of sales tax revenue.

Crop Yield and Values

Crops that generate revenue cover 28% of all land in Mason and Smith Valleys and are estimated to generate almost $60 million in revenues to the local farmers (Appendix 10). Although the revenues and land assemblage are significant, the $58 million in estimated revenues generated in 2007 is less than both the total sales ($224 million) and total payroll ($209 million) reported by the Walker Basin businesses in 2007. If the approximate estimates of crop values outside of Mason and Smith Valleys (but within the Walker Basin) are added to the valleys' total, the grand total of 2007 crop revenue in Walker basin may be somewhere near $60 million.

Alfalfa is, by far, the most dominant crop in both the amount of acres and the amount of revenue. Significant impacts to the alfalfa fields would have immediate effects on the agriculture industry as a whole in Mason and Smith Valleys due to the shear size of its production.

Turf, lettuce, grapes, onions, and garlic are estimated to be the most valuable crops on a per acre basis, but they only represents 6% of all crop acres in Mason and Smith Valleys. Factors such as crop rotation, climate, soils, and water availability limit the amount and locations of where crops are planted, thus recommendations on increasing specific crop acreage is outside the scope of this analysis.

Residential Construction Activity

The overall trend of single-family and mobile/manufactured home construction is on the increase since 1990. Due to the drastic drop in local home sales, combined with the economic contractions felt across the nation, the number of new homes constructed in 2007 tied for the lowest number (51) since 1990 when there were 49 units built in Mason and Smith Valleys (Appendices 11 and 12). The year 2007 mirrored the period between 1999 and 2002 when an average of 64 homes were built per year. The 74 multi-family units built in 1998 prevented that year from joining the years of limited housing construction.

A total of 624 units, including a 142 unit mobile-home park, are currently approved for construction in the Mason and Smith Valleys (Appendix 13). A total of 1,614 units have obtained tentative maps, but still need building permits before they construct. Another 566 units have begun the approval process, but lack the initial approvals for tentative maps.

Using the average construction rate of 90 units per year as calculated from the historical activity between 1990 and 2007, nearly seven years will be needed to fully construct the units with final approvals, an additional 18 years will be needed to construct the units with tentative map approvals, and another six years will be needed to construct the number of units just beginning the approval process. At a rate of 90 units per year, it will take 31 years to absorb every unit currently with approvals or seeking approvals in Mason and Smith Valleys.

Future rate of housing construction in the Mason and Smith Valleys is uncertain due to a variety of factors. The main obstacles to a recovery in home construction include continual foreclosures of existing homes, difficulty in obtaining financing for construction and home purchases, the remoteness of the Walker Basin, and the increase in fuel prices. The last two factors have the most significant impact on retirees. A 2006 survey of new home buyers in Washoe and Lyon Counties reports that 35% of new single-family home buyers that were from outside the area are retirees. Another important factor that can lead to a spike in home purchases and home construction is new industry moving to the area, providing employment opportunities.

Similar sources of information in Douglas, Mineral, and Mono Counties are reporting no activity for future residential developments in their portions of the Walker Basin.

Proposed Commercial Activity

Future commercial activity is very limited and confined to minor commercial construction projects in Mason and Smith Valleys. The town of Hawthorne in Mineral County has the most potential for development due to the federal Base Re-Alignment Commission's (BRAC) plan of shrinking the Hawthorne Army Ammunition Depot. As part of the plan, a redevelopment district is planned for areas of the Base that will be eventually abandoned.

The significant commercial activities that are proposed for Hawthorne have potential due to the needs of the region. The proposed modular-housing construction company should be well situated where it can build and deliver manufactured housing to those rural areas in Nevada and western California where finding and recruiting general contractors is very difficult due to the various logistics concerning employees and construction materials. Areas in Nevada with cyclical mining activity experience particular difficulties with answering housing needs during spikes in mining activity.

The other potential commercial activity that may have implications on rural areas, including the Walker Basin, is exploration, production, and manufacturing of renewable energy sources (solar, wind, and geothermal). The U.S. Navy, the military branch responsible for geothermal energy exploration and production, is currently studying the feasibility of geothermal exploration on the Hawthorne Army Ammunition Depot.

Attempts at calculating the amount of commercial and industrial construction per year in the more populated areas of the Walker Basin were unsuccessful due to the lack of data availability. Ten-year averages of the square feet of commercial and industrial construction is an important indicator for calculating the amount of commercial construction per new household or employee added to the given area. The amount of construction per new household or employee can determine if project sizes are feasible, or otherwise guide healthy commercial construction activity.

RESULTS

Population

The Walker Basin contains 18,999 persons spread over 3,934 square miles according to 2007 estimates (Appendix 1). The resulting 4.8 persons per square mile is in stark contrast to the urban setting of the City of Las Vegas with 5,210 per square mile and the City of Reno with 3,192 persons per square mile. The community with the most population in the Walker Basin is Mason Valley, Nevada. Mason Valley, home of the Lyon County seat in Yerington, contains 8,583 persons as of 2007, or 45% of all residents in the basin (Figure 1). At 183 square miles, Mason Valley contains 47 persons per square mile.

Other communities in the basin are sparsely populated and, therefore, are aggregated into larger regions for reporting purposes. The Mineral County, Nevada portion of the basin (Hawthorne, Schurz, and Walker Lake) is the next most populated region in the basin with 4,128 persons, or 22% of the basin's population. The Mono County, California portion within the basin (home to the Topaz, Coleville, Walker, and Bridgeport communities) contains 2,290 persons, the Douglas County, Nevada portion (Topaz Ranch Estates and Antelope Valley) contains 2,158, and Smith Valley, Nevada (Smith and Wellington – Lyon County) contains 1,840.

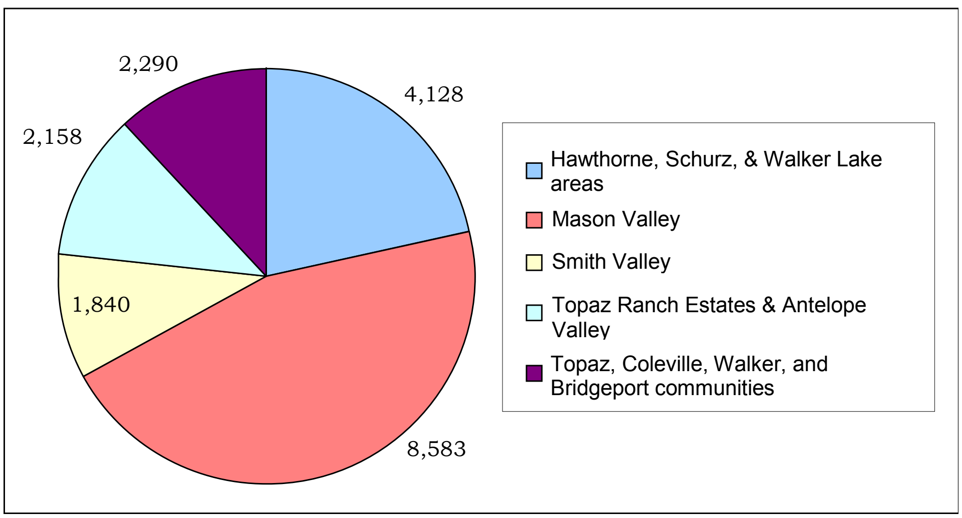


Figure 1. Walker Basin 2007 population estimates by community.

The region that experienced the highest rate of growth between 2000 and 2007 is Smith Valley. Smith Valley grew by 44% between the years 2000 (1,277 persons) and 2007 (1,840 persons) at a rate of 4.8% per year. During the same period, Lyon County grew at a rate of 6.6% per year and the State of Nevada grew at a rate of 4.3%. The Douglas County region of the basin (mainly the Topaz Ranch Estates) expanded at the next highest annual rate (2.31%), growing from 1,808 to 2,158 persons. Mason Valley, the most populated region of the basin, only added 913 persons between 2000 and 2007, with an annual population growth rate of 1.46% for that period. The Mineral County portion of the basin decreased in population by 656 persons between 2000 and 2007, losing population at a rate of 1.89% per year.

Within the California portion of the basin, the population growth rate of 0.36% per year that existed between the years 1990 and 2000 is estimated to be the growth rate between the years 2000 and 2007. Thus, the population in the Mono County portion of the Walker Basin is estimated to have added only 79 persons since the 2000 Census.

Age

Over 60% of the population in the Walker Basin is 35 and older with a median age of 42.1 (Appendix 1) compared to the median ages of 35.0 and 36.7 in the urban counties of Clark and Washoe, respectively. The Douglas County portion of the basin contains the oldest median age at 48.9 and the Mono County portion of the basin contains the youngest median age at 39.4, reflecting two communities side by side but almost ten years apart in median age of population. The median ages of Mason Valley, Smith Valley, and the Mineral County portion are 41.4, 42.4, and 41.3 respectively. Analyzing age brackets, the 45 to 49 year olds contain the highest population in the Mono County portion (7.2%), Smith Valley (10.6%), and the entire Walker Basin (7.2%) (Figure 2). In the Douglas County portion of the basin, the highest percent of population are 70 to 74 years of age (9.7%), and in Mason Valley and the Mineral County portion the highest percent are 10 to 14 years of age (7.1% and 7.9%, respectively). The Walker Basin concentration of diverse age groups from region to region reflects distinct demographics that are sometimes separated by a single mountain range or a small stretch of highway.

Although the Walker Basin is evenly distributed between the old (21% are 65 and older) and young (24% are 17 and younger), the Douglas County portion is much more concentrated with the elderly (29% are 65 and older) while Mason Valley and the Mineral County portion of the basin are more concentrated with young people (26% and 25%, respectively, are less than 18 years of age). For the State of Nevada, only 11% of the population is 65 and older and 25% are under 18 years of age, according to the 2006 American Community Survey (U.S. Census Bureau). Consequently, the Walker Basin population, although containing similar percentages of children in relation to Nevada, is heavily concentrated by an aging population.

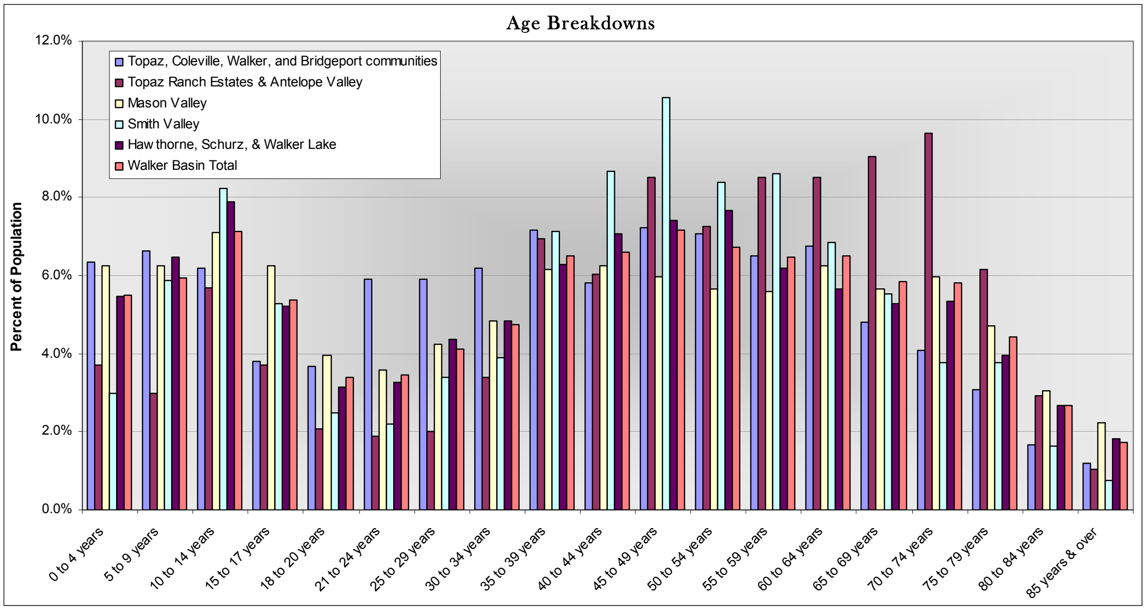


Figure 2. Walker Basin 2007 age estimates by community.

Race

The Walker Basin is estimated to be 76% white (non-Hispanic), 15% Hispanic, and 7% American Indian (Appendix 1 and Figure 3). The relative high number of American Indians is the result of the Campbell Indian Reservation north of Yerington and the Walker River Indian Reservation north of Walker Lake. Over 16% of Mineral County portion's population is American Indian. Areas heavily dependent on agriculture contain the largest amount of Hispanics with 20% in Smith Valley and 19% in Mason Valley. The largest concentration of African Americans (5%) is within the Mineral County portion of the basin, more specifically the town of Hawthorne. The 2000 Census totals for Nevada, the latest year that reports non-Hispanics by race, show percentages of 65% white, 7% black, 1% American Indian, and 20% Hispanic (the balance includes Asians, "mixed-race" and "others"). The Walker Basin, as a result, predominantly consists of whites with pockets of Hispanics in agricultural areas, Native Americans on Indian reservations, and a relatively high percent of blacks in the town of Hawthorne (Mineral County).

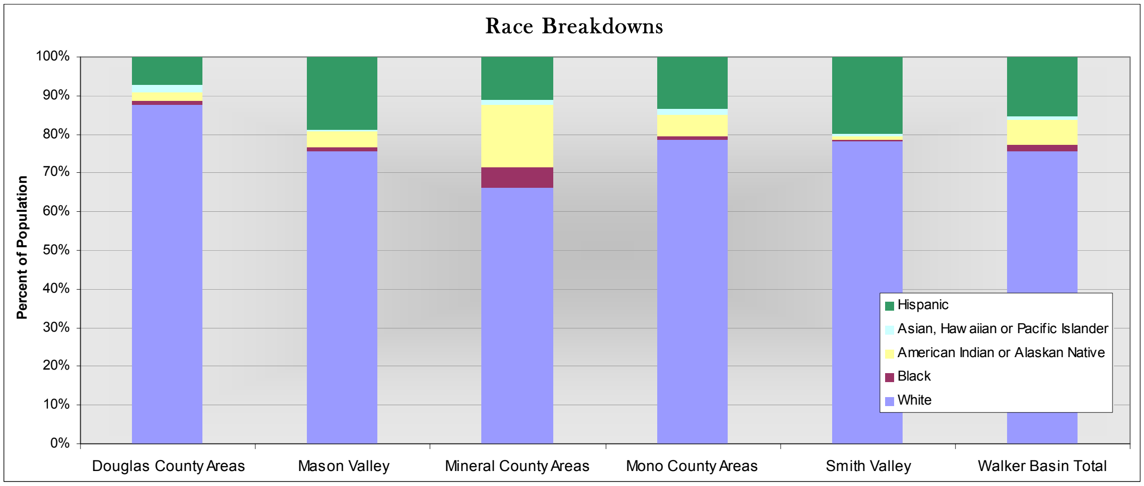


Figure 3. Walker Basin 2007 race estimates by community.

Sex

The male population is larger than the female population in the Walker Basin (51.5% v. 48.5%) and all regions within the basin (Appendix 1 and Figure 4). The male population is also slightly larger in the urban counties of Clark and Washoe. The Mineral County portion of the basin contains the least difference between the sexes with only 12 females less than males. The largest difference is in the Mono County portion with 6.6% less females, for a total of 152 females. At the State of Nevada level, the ratio of sexes is 51% male and 49% female, according to the 2006 American Community Survey (U.S. Census Bureau). In relation to the State of Nevada, there is only a half percent difference between the ratios of sexes in Walker Basin.

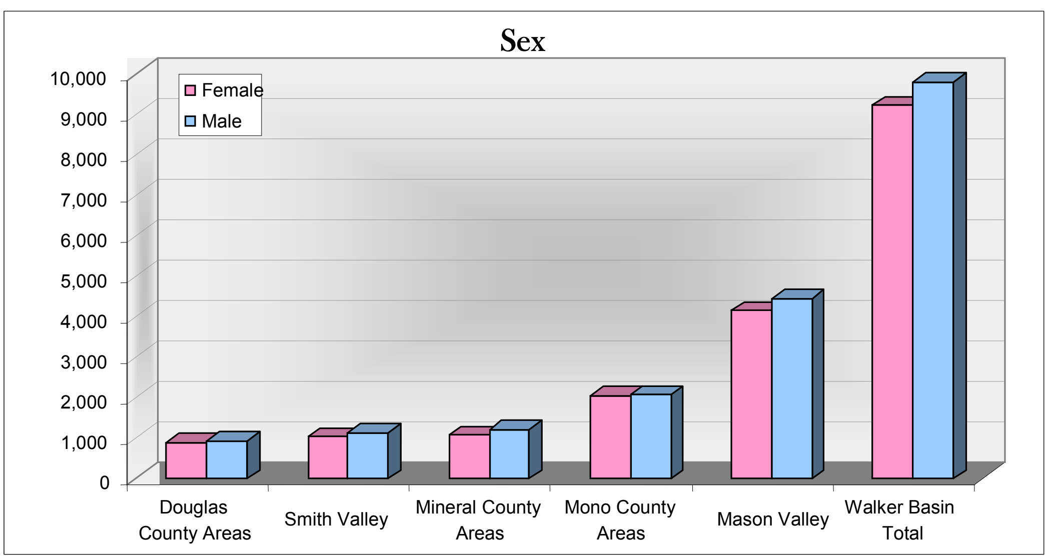


Figure 4. Walker Basin 2007 gender estimates by community.

Occupation

A slim majority of those that reside in the Walker Basin (40%) are occupied by white-collar industries that include management, business and finance, technology, engineering, science, legal, media, health care, and office related careers (Appendix 1 and Figure 5). Another 35% of residents over 15 years of age are employed in blue-collar occupations including farming, forestry, fisheries, construction, transportation, and manufacturing. Service occupations employ 16% and sales occupations employ only 9% of the labor force in Walker Basin. In the State of Nevada, 41% are employed in white-collar occupations, 27% in blue-collar, 19% in services, and 12% in sales, according to the 2000 Census.

The region with the highest percentage of white-collar employment is the Mono County portion (49%) with Smith Valley reporting the lowest (32%). Alternatively, Smith Valley reports the highest percentage of blue-collar employment (46%) with the Mono County portion reporting only 28%. Only the Mineral County portion of the basin reports more of a share in service jobs (20%) than the State of Nevada, which is dependent on the accommodation and food-service industry. Smith Valley reports the smallest percentage of service jobs (10%), but the highest percentage of sales occupations (13%) out of all the regions in the basin. The percent of sales jobs is less than 10% for all the other regions in the Walker Basin.

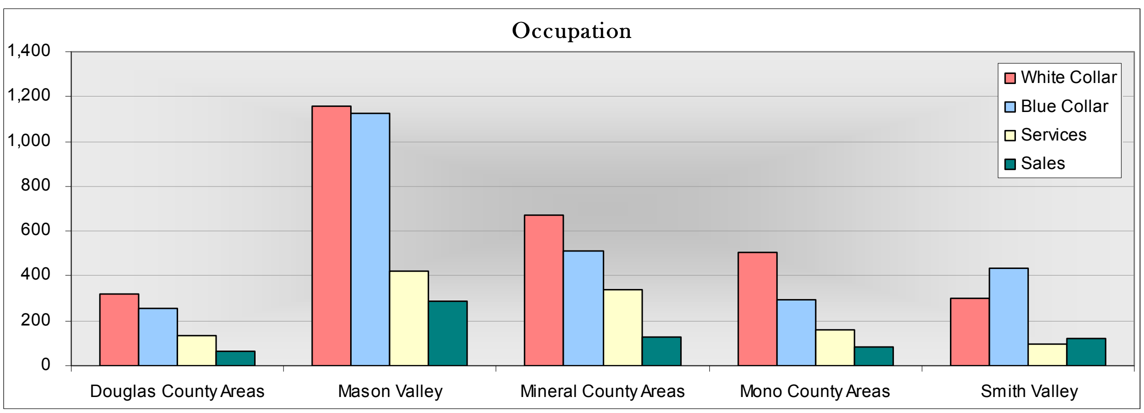


Figure 5. Walker Basin 2007 occupation estimates by community.

It is important to note that occupational employment is different from industrial employment totals. Any given industry may employ multiple occupations. The Macy's Department Store, for example, is a retail industry, but it employs truck drivers, custodians, clerks, accountants, sales reps, etc. For employment by industry totals, see the "firms and employment by type of industry" section below.

Education

Almost 78% of residences 25 years and older in the Walker Basin have obtained a high school diploma or higher, compared to 82% in Clark County, 86% in Washoe County, and 83% in the State of Nevada (2007 American Community Survey, U.S. Census Bureau). While, over one in five (22%) have not received a high school diploma, which is 5% higher than Nevada as a whole (17%) Within the basin, 28% have taken college courses, but did not obtain a secondary degree (compared to 24% in Nevada). Of those that earned some type of college degree, 5% received an associates degree (7% in Nevada), 9% received a bachelor's degree (14% in Nevada), and 5% received a professional or graduate degree (7% in Nevada). Over one in ten (12%) of those 25 and older in the basin have obtained a four-year degree, compared to one in five (21%) in Nevada and over one in four in the U.S. (27%).

The Walker Basin region with the highest percent of persons age 25 and older without a high school diploma is Smith Valley (31%) (Appendix 1 and Figure 6). The region with the lowest percent is the Mono County portion (13%), resulting in an 18% difference between the two regions. The region with the highest percent of those with a four-year degree or higher is the Mono County portion (18%), and the region with the lowest percent is the Douglas County portion (7%). The ratio of post-graduate degrees is also the greatest in the Mono County portion (6.8%), with only 0.4% of persons 25 and older obtaining a post-graduate degree in the Douglas County portion.

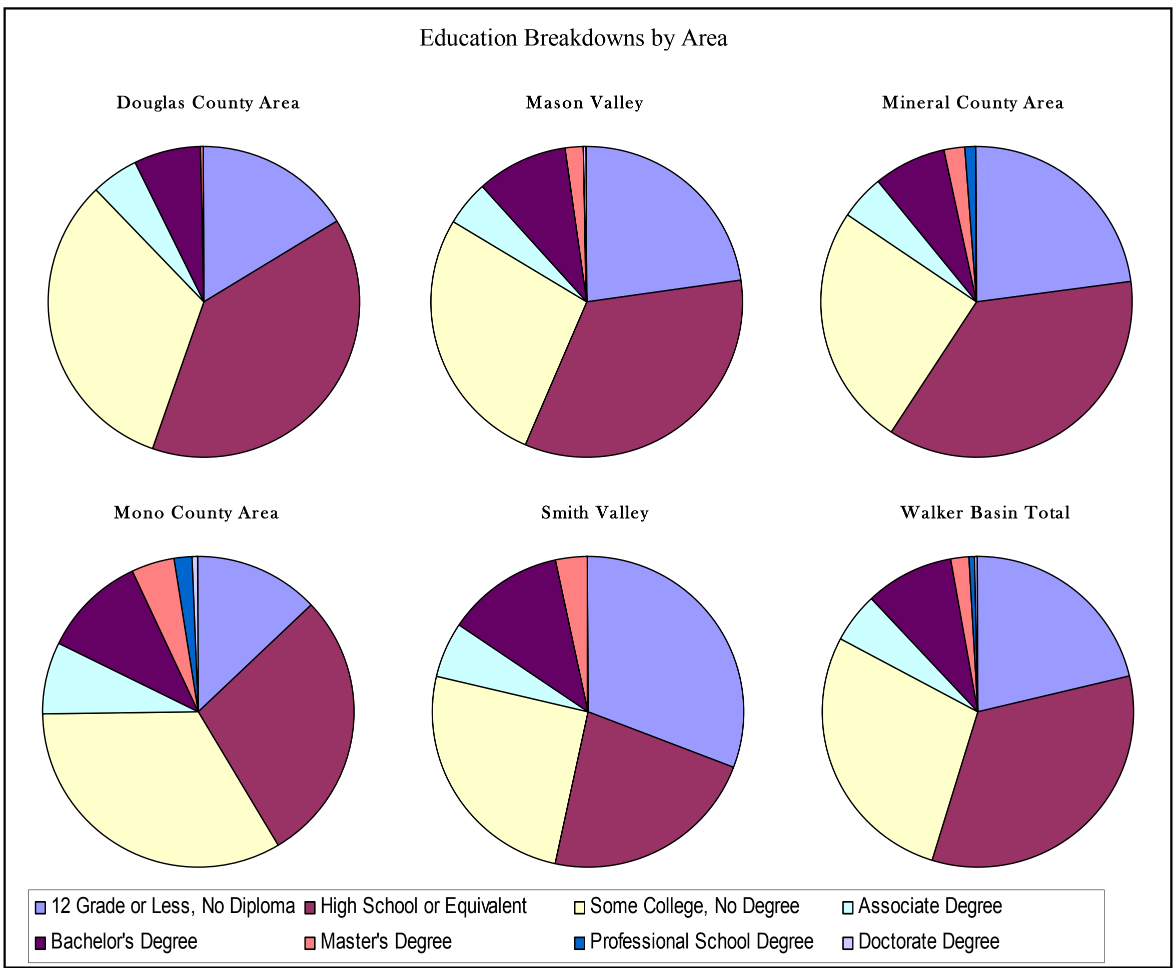


Figure 6. Walker Basin 2007 educational attainment estimates by community.

Income

The current (2007) median household income estimate for the Walker Basin is $44,485, compared to $55,996 in Clark County, $54,343 in Washoe County, and $55,062 in Nevada. The median family income estimate for the basin is $51,002, compared to $62,842 for Nevada. On a per person basis (per capita income), the estimate for the basin ($23,703) is $4,000 less than for all persons in Nevada ($27,729).

The Walker Basin region with the highest household, family, and per capita income is Smith Valley ($59,794, $61,944, and $27,827, respectively) (Appendix 1 and Figure 7). The region with the lowest household and family income is the Douglas County portion of the basin ($41,008 and $46,776, respectively). The Mineral County portion is estimated to have the lowest per capita income at $21,417).

The 2008 median family income estimates calculated by the Housing and Urban Development (HUD) at the Census tract-level reports that the income for the Walker Basin has grown 3.04% per year between 2000 and 2008. The consumer price index for the west urban geography (smallest region reported by U.S. Bureau of Labor Statistics) reports that inflation has grown at a rate of 2.98% per year for the same period (through June 2008).

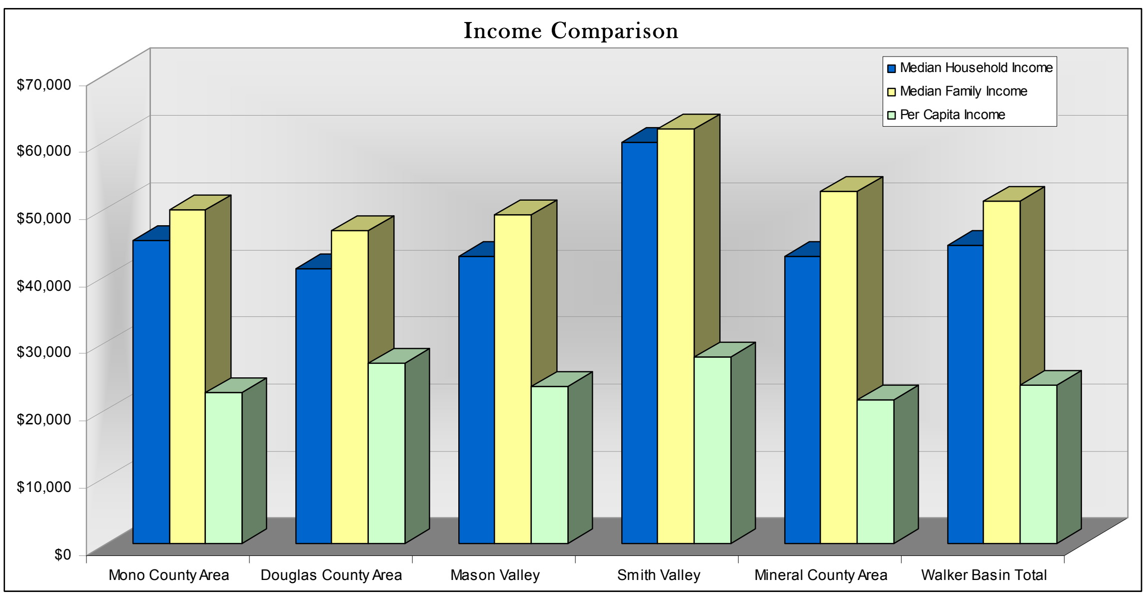


Figure 7. Walker Basin 2007 income estimates by community.

Household Composition

Over one in four households (26%) in the Walker Basin contains only one person, similar to all households in Nevada (27%; 2007 U.S. Census Bureau data). Almost 70% of households in the basin are filled by families, whereas the ratio of family households is 66% in Nevada. Over 27% of all households in the basin contain children under 18 years of age. The ratio of households with children rises to 31% at the State of Nevada level.

The Mineral County portion of the Walker Basin contains the highest percent of one-person households (27%), and Smith Valley contains the smallest percent (18%) (Appendix 1 and Figure 8). Conversely, Smith Valley has the highest share of family households (77%), and the Mineral County portion contains the lowest share (67%). In keeping with the family values, Smith Valley leads the basin in the percent of households with children under 18 (31%). Only 18% of the households in the Douglas County portion of the basin, on the other hand, contain children. Almost half (49%) of the households in the Douglas County portion are home to married couples without children.

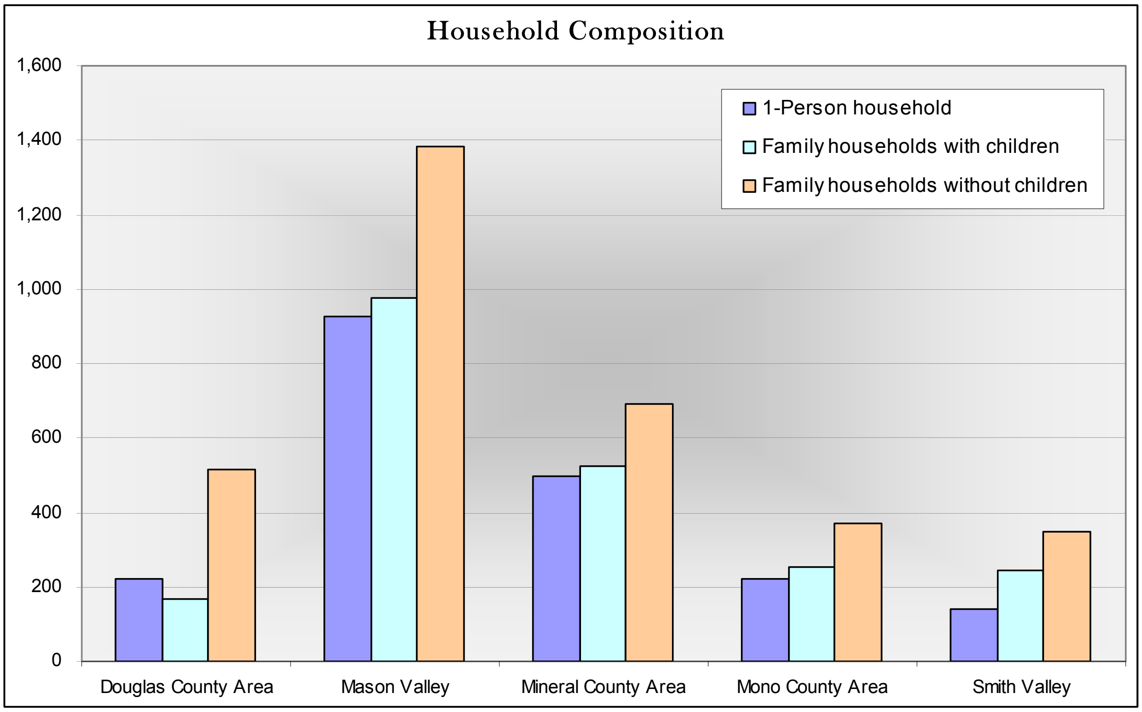


Figure 8. Walker Basin 2007 household composition estimates by community.

Housing Unit Types

The Walker Basin residential unit count was nearly 10,000 (9,826) for 2007. The majority of the units were detached single-family units (60%). The second largest housing unit type in the basin is mobile and manufactured homes (29%). Multi-family units only account for 8% of all units in the basin, and the remaining 3% are attached single-family units. According to 2007 U.S. Census Bureau statistics, the housing stock in Nevada is primarily detached single-family (58%) and multi-family (31%) units. Only one out of fifteen units in Nevada (7%) is a mobile or manufactured home.

The percent of detached single-family homes is the highest in Smith Valley (82%), whereas the Douglas County portion of the basin contains almost twice as many mobile/manufactured units (61%) than detached single-family units (35%) (Appendix 1 and Figure 9). Only 12% of all units in Smith Valley are mobile/manufactured units, the lowest percent in the basin. The Mineral County portion contains the highest share of multi-family units (11%) compared to all other regions in the Walker Basin. Smith Valley contains only seven multi-family units (1%).

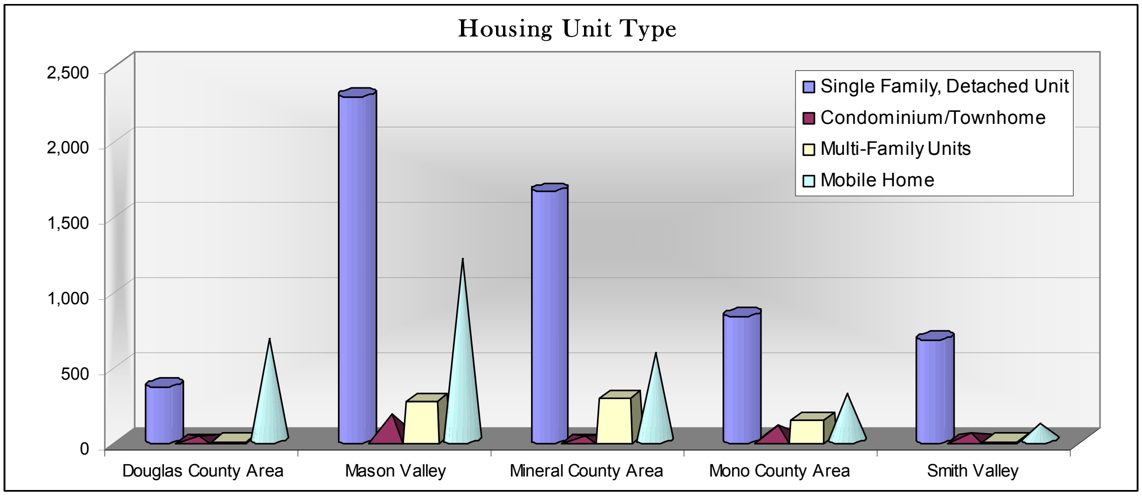


Figure 9. Walker Basin 2007 housing type estimates by community.

Housing Unit Ages

The average age of a housing unit in the Walker Basin is 38 years (built in 1970), compared to the average age of 16 years (built in 1992) for all homes in Nevada (2007 American Community Survey, U.S. Census Bureau). Three out of five (60%) housing units in the basin were built before 1980 (29% in Nevada). Almost 40% of all housing units in the basin were built before 1970 (14% in Nevada), and over 13% were built before 1950 (3% in Nevada). Only 9% of all housing units in the basin were built since the year 2000, compared to nearly one out of four (23%) in Nevada.

Areas with high ratios of aged housing stock are the Mono and Mineral County portions of the Walker Basin, with Mason Valley close behind (Appendix 1 and Figure 10). One out of two homes (50%) in Mono County, 48% in Mineral County, and 40% in Mason Valley were built before 1970. Every region in the basin, excluding the Douglas County portion, contains a high ratio of units built before 1950 (14% to 16%). Significant percentages of units built since the year 2000 occurred in Smith Valley (32%), the Douglas County portion (14%), and Mason Valley (11%).

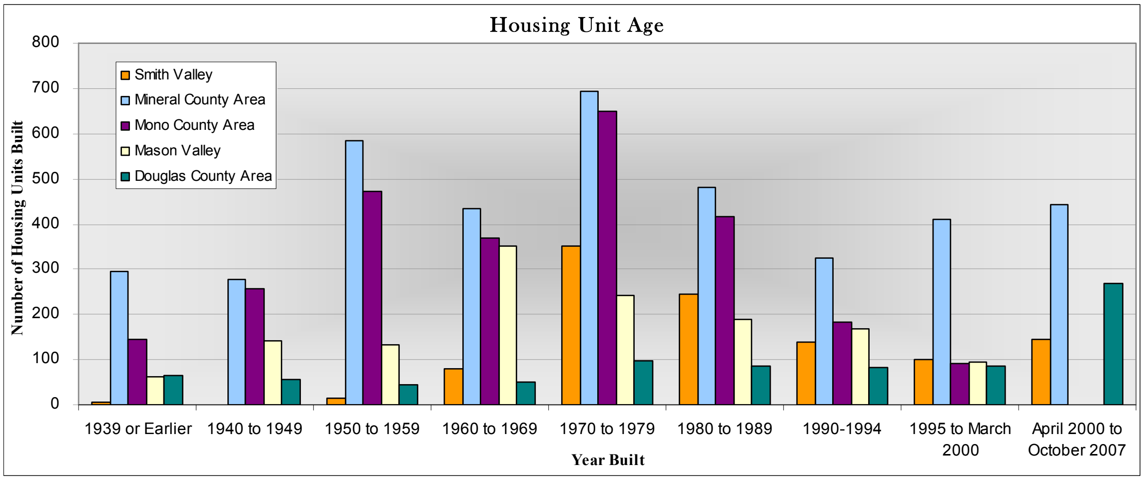


Figure 10. Walker Basin 2007 housing age estimates by community.

Housing Values

The median price of a single-family home in the Walker Basin is $228,854, and the average price is $246,816. According to the 2007 American Community Survey, the median value of owner-occupied homes in Nevada is $302,600, $307,300 in Clark County, and $346,900 in Washoe County. The median price per square foot of single-family units in the Walker Basin is $144.60, and the average price per square foot is $151.02.

The area with the highest housing prices is Smith Valley, with a median price of nearly half a million dollars ($475,000) and a median price per square foot of $203.70 (Appendix 1 and Figure 11). The area with the highest single-family affordability (lowest housing prices) is the Mineral County portion of the basin, with a median price of $118,500 and median price per square foot of $87.15. Ironically, the area with the highest price per square foot value is the Mono County portion of the basin, with a price per square foot of $212.30. The difference between the highest total value (Smith Valley) and highest value per square foot (Mono County) is the result of the size of the structure. Mono County contains a large amount of vacation homes with smaller footprints, whereas Smith Valley contains ranch-type properties with large lots, and subsequently, large home footprints.

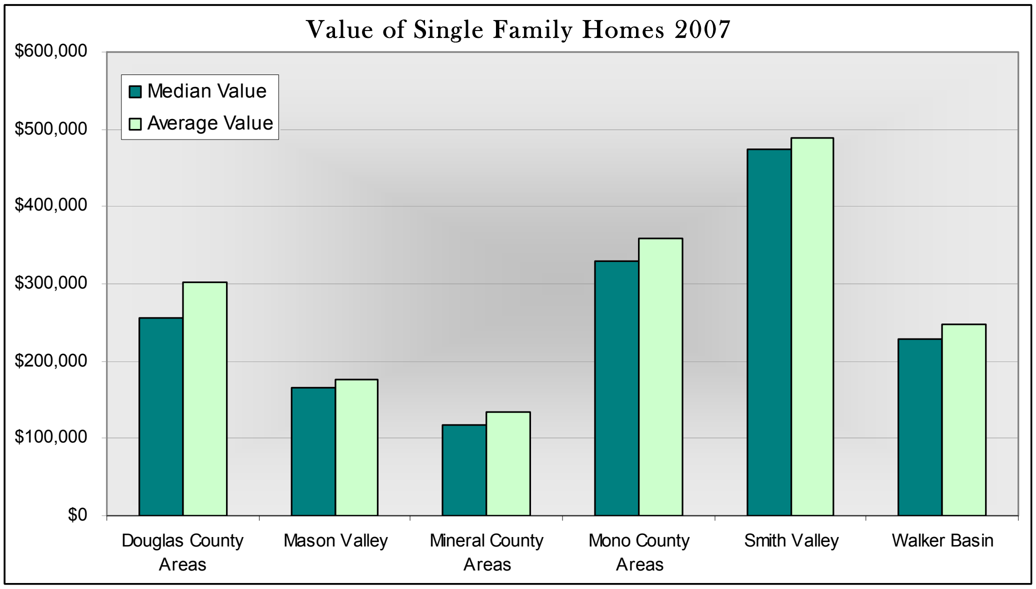


Figure 11. Walker Basin 2007 home value estimates by community.

Firms, Employment, and Payroll

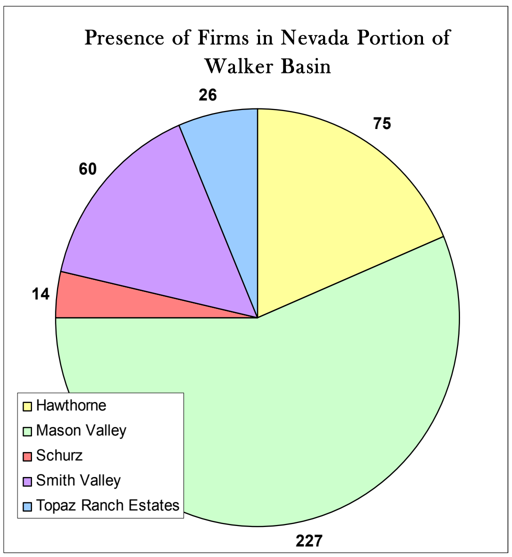
The Walker Hydrographic Basin contains 456 establishments (including government) that employ 6,477 persons, according to 2007 (Nevada) and 2006 (California) employment reports from the Department of Employment, Training, and Rehabilitation (DETR) and U.S. Census Bureau. The majority of industries in the Walker Basin are located in Mason Valley (227 firms), followed by the Mineral County portion of the basin (89 firms), Smith Valley (60 firms), the Mono County portion (54 firms), and the Douglas County portion (26 firms) (Figure 12). Of the 89 firms in the Mineral County portion of the basin, 75 are located in Hawthorne and 14 are located in Schurz on the Walker River Indian Reservation.

The Nevada portion of the Walker Basin contains a diverse mix of industries with construction (14.7% of all firms in NV), retail trade (12.7%), educational/health/social services (10.7%), entertainment/accommodation/food services (9.7%), agriculture/forestry (9.5%), and finance/insurance/real estate (9.2%) generating two out of every three establishments (Appendix 2). For Mason Valley, location of almost half of the total firms in the entire basin, the retail trade sector ranks first in the number of establishments (15.0%), followed by construction (14.1%) and finance/insurance/real estate (11.5%). The three sectors combined represent more than 40% of all firms in Mason Valley.

The Mono County portion of the Basin contains mostly accommodation and food service industries (53.7% of all industries in the portion) with a supporting amount of retail (16.7%). Combined, the accommodation, food services, and retail industries comprise over 70% of all establishments on the California side of the basin (Appendix 3).

For employment, Mason Valley and the town of Hawthorne contain almost 6,000 of the 6,317 total employees on the Nevada side (Figure 12), with the California side reporting only 160 employees. Excluding seasonal migrant labor, the educational/health/social services sector employs 36% (2,273) of all employees working in the Nevada portion of the Walker Basin. The next largest employers on the Nevada side are government (829 employees), entertainment/accommodation/food services (660), management and administrative services (573), and agriculture and forestry (485). The above top five industries on the Nevada side employ over 76% of total employed persons.

Employees in Mason Valley alone represent over 64% of the total employment in the Walker Basin. The majority of those employed in Mason Valley are located within the educational/health/social services sector (44.2%), followed by government (15.6%) and agriculture and forestry (9.5%). Again, the employment data lacks seasonal migrant labor totals.



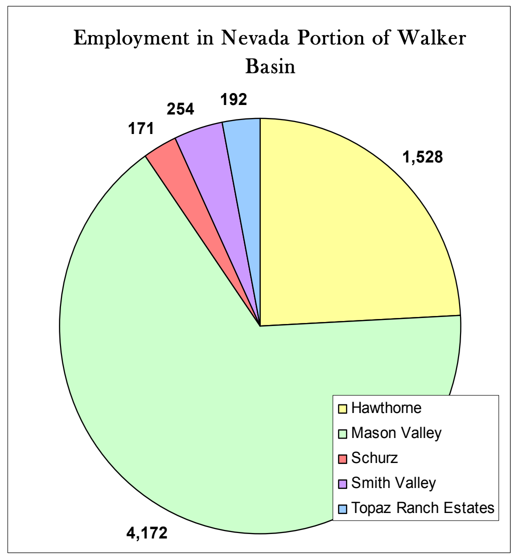


Figure 12. Walker Basin 2007 firm and employment estimates for Nevada communities.

Employment on the California side mimics the establishment counts with the majority of employment located in the accommodation and food services and retail trade sectors. Exact employment totals are not available by sector due to reporting limitations in the U.S. Census data ("ZIP Business Patterns"). The numbers of establishments by employment size range are reported by the U.S. Census Bureau instead (Appendix 3).

The total payroll estimated for the Nevada side of the Basin is $204.3 million based on second quarter 2007 payroll totals (multiplied by four to estimate annual). The average hourly wage on the Nevada side is $15.55 based on the second quarter payrolls and employees reported by entity. The highest hourly wage on the Nevada side is in the community of Schurz ($18.99), followed by Hawthorne ($15.74), Mason Valley ($15.61), Smith Valley ($14.68), and Douglas County portion ($10.79).

The finance, insurance, and real estate sector in Smith Valley (4 firms and 13 employees) pays the highest wage in the Nevada portion of the basin ($41.13 per hour) followed by the transportation and utilities entities in Mason Valley (10 firms and 89 employees = $34.89 per hour) and professional services in Smith Valley (4 firms and 5 employees = $30.55). The lowest wage earners in the Nevada portion of the basin are employed in the entertainment, accommodation, and food services sector ($8.64 per hour) which is the fourth largest sector in terms of total establishments and third in terms of total employment.

The total annual payroll reported for the California side is $4.5 million, only 2.2% of the total payroll estimated for the Nevada portion of the Basin. Hourly wage estimates are not available for the California side.

Lacking from the industrial employment and payroll estimates are the majority of "sole proprietors", those that do not hire employees or file for unemployment insurance. The establishments that file for unemployment insurance are the source of the employment and payroll surveys conducted by Department of Employment, Training, and Rehabilitation. The government source of sole-proprietor employment, Bureau of Economic Analyses (BEA - U.S. Department of Commerce), although, does not provide estimates below the county geographic level. The most current estimates (2006) for Lyon County report that 26% of all employment is found in the sole-proprietor sector (Appendix 4). If the 26% factor of sole-proprietors is applied to the total employment in the Walker Basin, another 2,225 "occupations" may exist in Walker Basin. The term, occupation, is used because sole-proprietors tend to hold secondary jobs, thus sole-proprietors are often found within the employee totals for other sectors. It was also assumed that the majority of sole proprietors would be employed by the agricultural sector, but the 2006 BEA estimates for Lyon County show that only 320 sole proprietors (1% of total employees) were involved in farm employment. The majority of the sole proprietors in Lyon County had occupations in non-farm industries.

Taxable Sales

The most current estimates report that a total of $225 million in gross sales and $67.5 million in taxable sales were generated by Nevada businesses in the Walker Basin (Appendix 5). The data for the Nevada portion of the Walker Basin covers 328 entities that reported taxable sales in the calendar year of 2007 for Lyon and Mineral Counties, and 2005 for Douglas County. The majority of entities are concentrated in Mason Valley (58%), while the remaining locations are in the Mineral County portion of the basin (26%), Smith Valley (13%), and the Douglas County portion (3%) (Figure 13). Limited reporting sites in the Mono County portion of the Walker Basin prevents the release of 2002 Economic Census revenue information for the small communities. Therefore, sales receipt data for the California portion of the basin are not available.

There were 29 wholesale trade businesses in the Walker Basin, amounting to 9% of the total – the highest percentage of all industries. This industry also had the largest amount of total gross sales with $72.4 million in 2007, which was nearly one-third of all sales in the area. Wholesale trade businesses averaged nearly $2.5 million in gross sales per location. Total *taxable* sales for this industry slipped in just behind supermarkets and convenience stores with $12.2 million, averaging $421,000 per location.

As a combined industry, supermarkets, markets, convenience stores, and gas stations accounted for 6% of all establishments in the Walker Basin that reported taxable sales. Gross sales for this industry totaled more than $64 million, or nearly 30% of the total gross sales for the basin. Gross sales averaged $3.4 million in sales per location, the most of any other industry. The supermarket/convenience store industry also led the other industries in the Walker Basin in total *taxable* sales in 2007 with $12.6 million. The average taxable sales per location were over $665,000.

Manufacturing was identified to be another significant industry based on revenue in the Walker Basin. The 6% of the businesses classified as "manufacturers" reported total gross sales of $12.9 million in 2007, averaging over $680,000 per location. The manufacturing sector's taxable sales totaled more than $4.3 million, or $229,000 per location.

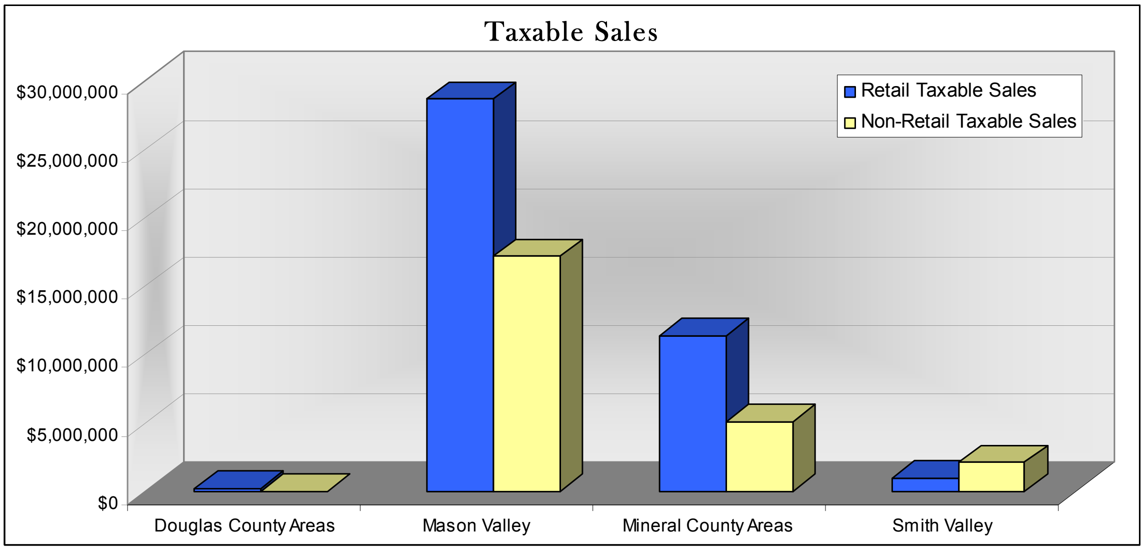


Figure 13. Walker Basin 2007 taxable sales estimates for Nevada communities.

Mason Valley

In 2007, there were 191 businesses that reported taxable sales in Mason Valley – 103 were retail and 88 were non-retail (Appendix 6). All sectors generated over $167 million in gross sales and almost $46 million in taxable sales.

Within just Mason Valley, wholesale trade ranked the highest in terms of locations (9%), gross sales (33% of the total), and taxable sales (18% of the total). Wholesale trade businesses averaged $3.2 million in gross sales per location in 2007 with total gross sales of $55.2 million. Taxable sales totaled $8.3 million, or $488,000 per location.

Supermarkets, markets, convenience stores, and gas stations' sales accounted for 24% of the area's total gross sales ($40 million) and averaged over $5 million per location. The industry's total taxable sales were $7.8 million (17% of the total) and averaged $975,700 per location. Eight of the nineteen locations for this industry were in Mason Valley.

Thirteen of the nineteen manufacturers in the Walker Basin are located in Mason Valley, and the 13 entities represent 7% of all reporting entities in the valley. With total gross sales of over $12.6 million in 2007, manufacturers in Mason Valley had the third highest sales in the area. On average, manufacturers' gross sales per location were $967,000 and their taxable sales per location averaged $312,000. Revenues from manufacturing accounted for 8% of the total revenue generated from all entities in the valley, and 9% of all taxable sales.

Used auto dealers accounted for 9% of the area's total taxable sales, and paint, glass, and hardware stores represented another 6% of the total taxable revenues. Neither had many locations – only 3 used auto dealers and 4 hardware stores – but both industries posted significant sales for the area with a combined total of over $12 million in gross sales, of which $6.7 million is taxable.

Smith Valley

A total of 41 (13%) of the Walker Basin's 328 businesses that reported taxable revenue were located in Smith Valley, grossing $11.4 million in sales (Appendix 7).

The six wholesale trade businesses (15% of all entities in Smith Valley) accounted for 67% of all sales ($7.6 million) and 40% of the taxable sales ($1.2 million) for the area. Each wholesale trade location averaged $1.3 million in gross sales – a mark far surpassing all other industries in Smith Valley.

Supermarkets, markets, convenience stores, and gas stations, with four locations (10% of all entities in Smith Valley), were a distant second in total revenue, with $621,000 (5% of total sales). The industry generated $297,000 in taxable revenue (10% of Smith Valley total).

The construction industry (one reporting entity) generated the third highest revenue, with over a half-million dollars in gross sales (5% of total revenue in Smith Valley) and $254,000 in taxable sales (12% of total).

Two drinking establishments generated over $500,000 in gross sales and $240,000 in taxable sales.

Mineral County Portion of the Basin

Over one quarter of all businesses that reported taxable sales in the Walker Basin were located in the Mineral County portion, and their total revenues represent 20% of all revenues generated in Walker Basin (Appendix 8).

Wholesale trade businesses accounted for $9.5 million (21%) of the area's total gross sales and $2.7 million (16%) of the area's taxable sales. There were 6 locations of wholesale trade businesses in the Hawthorne/Schurz area, each averaging $1.5 million in gross sales and nearly $450,000 in taxable sales.

Supermarkets, markets, convenience stores, and gas stations had the largest amount of sales ($23.4 million). This industry accounted for over *half* of all sales, reflecting the lack of other industries in the area with substantial sales revenues. Businesses in this industry had 7 locations in the Hawthorne/Schurz area and had average gross sales of $3.3 million per location and average taxable sales of $648,000 per store.

The arts, entertainment, and recreation industry generated over $2 million in gross sales in 2007 at two locations. A total of seven drinking establishments generated $1.2 million, and two liquor stores generated almost $1 million in gross sales.

Douglas County Portion of the Basin

Because of its rural nature with slightly over 1,000 residences spread over 220 square miles (one residence per five square miles), the Douglas County portion of the basin lacks businesses that offer commodities or services. In 2005, only toys and hobbies, drinking establishment, gift and souvenir shop, catalog and mail order, direct selling, miscellaneous retail, and photographic studio industries reported revenues (Appendix 9). The 11 reporting entities generated total gross sales of $242,000 (0.1% of the basin's total), and $203,000 in taxable sales (0.3% of the basin's total).

Crop Yield and Values

The areas in Walker Basin with the highest amount of crop production, Mason and Smith Valleys, produced 51,655 acres of crops of value in 2007 (Appendix 10). The 14 different crop types grown in 2007 are estimated to be valued at $58.6 million (2007 dollars). A total of 1,832 fields were mapped and surveyed in both valleys. The overall value per acre is $1,125 ($58.6M/51,655) in southern Lyon County, but the value per acre for each crop type deviates between $90 and $16,553.

Alfalfa is the dominant crop in southern Lyon County, covering 37,346 acres, or 72% of all crops grown in 2007. The estimated value of alfalfa ($35 million) represents 60% of the total value generated by all crops in Mason and Smith Valleys. Although the crop size ranks fourth (2,445 acres, or 5%), onions have the second highest total production value ($13.4 million) representing 23% of the total value grown in the two valleys. The second largest "crop" acres mapped in southern Lyon County is pasture, with 4,474 acres, or 9% of the total crops combined. The value of pastures, although, is minimal, estimated at $403,000 (0.7% of total value).

Mason Valley contained the most acres of crops of value (34,717) in 2007, with an estimated production value of $45.3 million (2007 dollars). Alfalfa is the predominant crop in Mason Valley, with almost 26,000 acres (68% of the total field acres in the valley) spread over 807 fields (Figure 14). The estimated value of the alfalfa crop in 2007 is $24.3 million, or 54% of the total estimated crop value in Mason Valley. Onion is the second largest crop with 2,445 acres (7% of all fields) and an estimated value of $13.4 million (30% of total crop value in Mason Valley). Corn is the third largest crop acreage with value at 1,891 acres (5% of all fields) with an estimated value of $170,000. In 2007, the third most valued crop grown in Mason Valley is turf, with an estimated value of $4.3 million (10% of Mason total) harvested from 260 acres. Turf is estimated to have the highest value per acre ($16,553) out of all the crops grown in Mason and Smith Valleys. Another 3,443 acres on 156 fields were mapped in Mason Valley, but the feed lots, brush, and fallow are not considered as revenue generating crops.

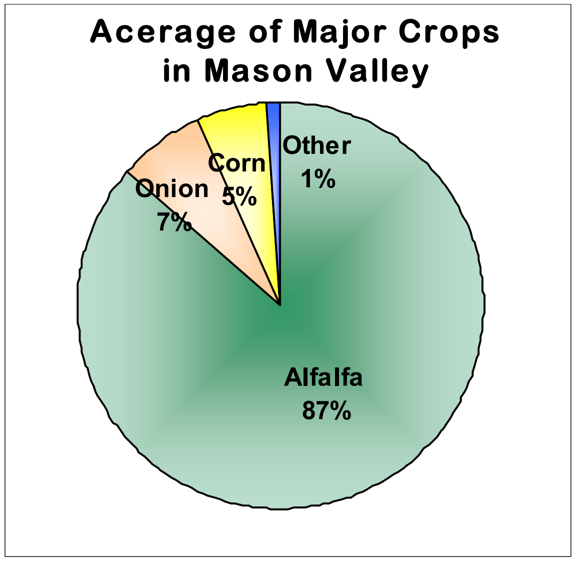


Figure 14. 2007 Mason Valley crop types by acreage.

Smith Valley contains 16,939 acres of crops of value on 443 fields with a total estimated value of $12.8 million (2007 dollars). Alfalfa is also the predominant crop in Smith Valley with 11,404 acres (67% of valued crop acreage in the valley) grown in 2007 for an estimated value of $10.7 million (83% of the total value estimated for the valley) (Figure 15). Pastures represent the second highest amount of crop acreage (3,411), covering 20% of the valued crop acres in Smith Valley. The value of the pastures, although, are not significant. The total value of the pastures is estimated to total $307,000, or just 2% of the valley's total value. The third largest crop in size is grass with 1,965 acres, or 12% of the valley's total crop acreage of value. The 2007 value of grass is estimated to be $1.8 million, the second highest value in the valley. The value of grass represents 14% of the total crop value in Smith Valley. Grain is the remaining crop of value that was mapped in Smith Valley, with 160 acres on 3 fields and a value of $16,000. As with Mason Valley, another 3,461 acres of feed lots, brush, and fallow were mapped in Smith Valley on 118 fields, but lack commodity value.

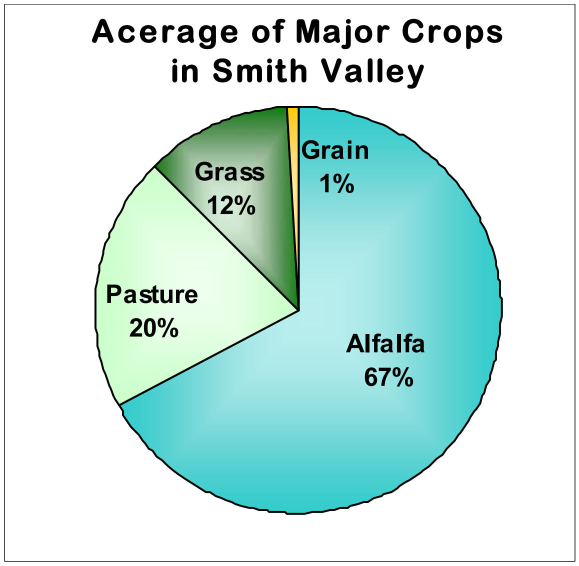


Figure 15. 2007 Smith Valley crop types by acreage.

Assuming that the non-mapped crops in Douglas, Mineral, and Mono Counties are predominantly alfalfa ($936 per acre) and pasture ($90 per acre), rough crop revenue estimates can be gauged by applying an arbitrary amount of $500 per acre (based on the current values of alfalfa and pasture) to the total acreage of agricultural land-use that is maintained by the county assessor departments. Antelope Valley, which overlaps Douglas and Mono Counties, contains almost 20,000 acres of agricultural land-use. Applying the almost 20,000 acres to $500 per acre calculates a possible $10 million in crop values per year. The stretch of Walker River that extends from Wabuska in northern Mason Valley through the Walker River Indian Reservation to Walker Lake contains only 30 acres of agriculture land use, resulting in minimal crop revenue.

Applying arbitrary crop values per acre to agriculture land-use acreage, although, does not provide revenues with high confidence. There are a variety of factors that can input error into the method. The exact crop types and resulting value per acre are not known, areas of agriculture on Indian reservations are not captured by the county assessor data, and only a portion of agriculture land use acreage is put into crop production. As a result, without field mapping and verification supported by aerial photography, the total crop size in areas outside Mason and Smith Valleys are roughly estimated at a couple thousand acres with a value of a couple of million dollars.

Residential Construction Activity

Historical and current housing construction activity in the Walker Basin is concentrated in the Mason and Smith Valleys in Lyon County. All other regions in the basin have not experienced significant housing construction, and, therefore, the discussion of housing construction will be limited to the Mason and Smith Valleys.

Smith Valley

Between 1990 and 2007, over 90% of the new residential units constructed in Smith Valley have been *single-family detached* (SFD) units, with an average of 22 new SFD units constructed each year (Appendix 11). An average of 31 SFD units were built between 2000 and 2007, but 2002-2005 were particularly robust years for single-family construction in Smith Valley – these four years averaged 41 new SFD units each year. Building began to slow in 2006 when only 28 SFD units were constructed, followed by only 10 SFD units in 2007 (Figure 16). In total, there have been 400 new SFD units constructed between 1990 and 2007, and 244 units between 2000 and 2007.

Single-family attached (SFA) units have not historically been a factor in Smith Valley, and no new SFA units were constructed in the area between 1990 and 2007. Mobile-home/manufactured units account for the remaining 9% of new housing units constructed between 1990 and 2007, averaging two new units per year. Currently, there are only four new projects planned for Smith Valley (Appendix 13).

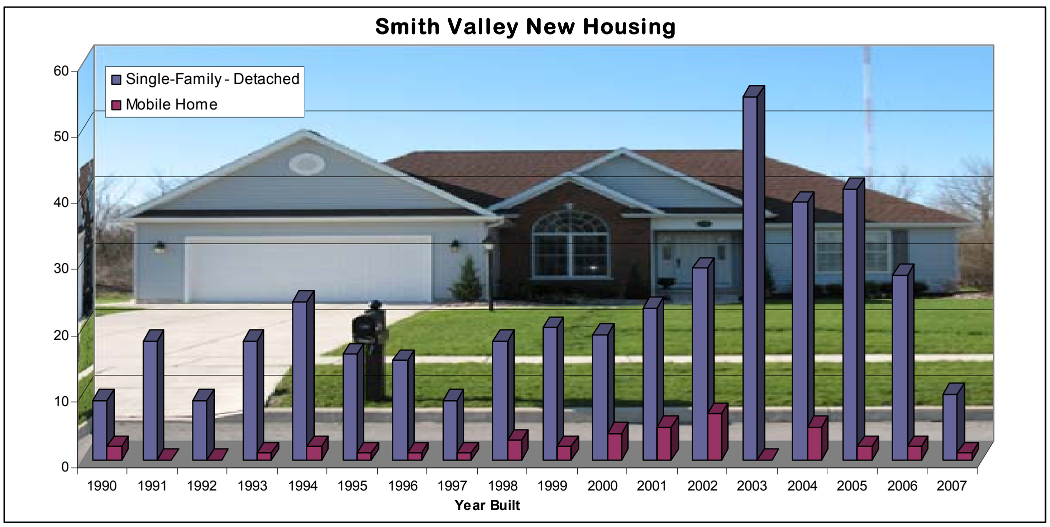


Figure 16. Smith Valley housing construction by year and type.

Mason Valley

Over 1,100 new residential units have been constructed in Mason Valley between 1990 and 2007, averaging 66 new units per year (Appendix 12). Between the years 2000 and 2007, 444 residential units were built, averaging 56 units per year. Of the total units built between 1990 and 2007, 49% of those are SFD units and another 40% are mobile/manufactured homes (Figure 17).

For the single-family detached (SFD) product, an average of 32 units was built each year in Mason Valley between 1990 and 2007 for a total of 583 units. With the exception of 1998 through 2002, construction of this type of unit was relatively stable over the last twenty years. Between the years 2000 and 2007, 231 SFD units were constructed for an average of 29 units per year. The slow period of home construction between 1998 and 2002 (averaging 17 SFD units per year) returned in 2007 when only 14 new single-family detached units were constructed (Figure 17).

Like Smith Valley, single-family *attached* (SFA) units are not very common and only 35 SFA units were constructed between 1990 and 2007. Manufactured and mobile homes, however, were the second most common type of housing product added to Mason Valley between 1990 and 2007 after SFD units. Mason Valley added, on average, 26 manufactured or mobile home units each year between 1990 and 2007 for a total of 468 new units of this type. Between the years 2000 and 2007, 201 manufactured/mobile homes were added for an average of 25 units per year. The addition of manufactured and mobile units has been remarkably stable over the years, with no real highs or lows in the data.

While multi-family units made up 8% of the total new units constructed between 1990 and 2007, nearly all of the multi-family units were built in 1998 with two projects in Yerington – a 32 unit apartment complex and a 42 unit assisted living facility. Most other years experienced zero or very little multi-family building activity.

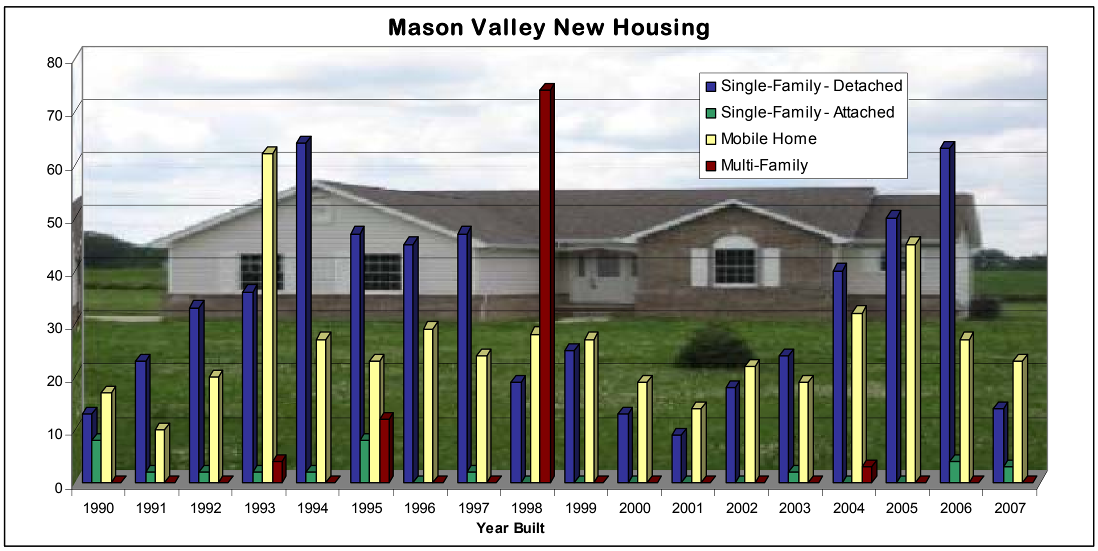


Figure 17. Mason Valley housing construction by year and type.

There are five approved subdivisions with Tentative Maps in Mason Valley outside the City of Yerington, but given the state of the economy in 2007, none of the developers involved have moved forward with their construction plans. The five planned projects in the unincorporated area of Mason Valley are *Rebecca Ranch Subdivision* (63 units), *Diamond Hot Springs* (54 units), *Walker River Subdivision* (32 units), *Grant View Subdivision* (7 units), and *Bates Estates* (6 units) for a total of 162 units (Appendix 12).

The latest residential project that has begun the approval process in the unincorporated area of Mason Valley is the *Perry Subdivision* that is proposing 11 single-family lots on 26 acres. The tentative map request is on the County Commissioners' agenda for September of 2008.

The City of Yerington has 13 subdivisions planned; two are under construction, two have Final Maps approved to begin construction, six have approved Tentative Maps, and three are undergoing Feasibility Studies in the pre-tentative map phase.

The *Arrowleaf North* community, complete with a golf course, has 200 units approved for construction. Of these 200 units, 10 were built in 2006 and two were built in 2007 with sizes ranging from 1,600 square feet to 2,400 square feet. As of the end of 2007, 12 units were sold and occupied.

Quail Meadows, by Midtown Ventures, is the only other "active" subdivision in the City of Yerington, though only one home was constructed and sold in 2007. This subdivision is approved for a total of 72 units and the first ten units were built and sold in 2006. Sizes of the homes in this subdivision range from 1,600 square feet to 1,800 square feet. With a sales absorption rate of less than one per month and an additional 61 approved units remaining, it may take years to completely absorb Quail Meadows.

The two subdivisions in the City of Yerington with Final Maps but that have yet to begin construction are *Copper Point,* with 27 units planned, and *Pony Express Mobile Park,* with 142 mobile home units planned. No additional information is available at this time with respect to the developers' plans to bring these approved units to market.

There are six subdivisions accounting for over 1,600 single-family units approved on Tentative Maps planned for the City of Yerington. The largest residential project is *Grand View Estates* (765 units), followed by the *Walker River Country Club* (503 units), *Arrowleaf South* (132 units), *Saddle Horn* (109 units), *Cherry Blossom* (64 units), and the *Silver Sage Subdivision* (41 units).

The three projects in the City of Yerington currently under the "feasibility study" status (pre-tentative map phase) include the *Rio Vista Subdivision* (60 units), the *River Meadows Subdivision* (136 units), and the *Rose Creek Estates* (346 units).

While the total number of sales in Mason Valley far outnumbered the sales in the Smith Valley area, the median sales prices were far less as a result of the smaller average lot size. There were 72 sales of single-family detached homes in 2007 (new and existing), carrying a median sales price of $166,000 (Appendix 1). Another 23 manufactured or mobile homes were sold in 2007 with a median price of $123,500, and three duplexes sold for a median price of $150,000 (for entire structure). Two multi-family projects sold as well, both containing 3-4 units, with a median price of $215,000.

Proposed Commercial Activity

Knowledge of future commercial projects in the Walker Basin is limited to the Lyon and Mineral County portions. Currently, there are two commercial buildings under construction in Mason Valley, and one approved and one proposed project in Smith Valley (Appendix 14). Three proposed commercial projects were identified in Hawthorne (Mineral County).

A commercial building valued at $517,000 is currently under construction near the Campbell Ranch (Yerington Indian Reservation) in Mason Valley. Another industrial building valued at $385,000 is under construction at the Desert Pearl Farms in Mason Valley.

In Smith Valley a breeder's kennel has been approved, and a Catholic church is proposing to expand their facility to include additional classrooms, storage, and public assembly space for a total of 1,164 square feet.

In Hawthorne, two commercial projects are currently under consideration, one located on the U.S. Department of Defense's Hawthorne Army Ammunition Depot and one located off the base. The off-base project proposes a modular-housing construction operation consisting of 150 employees on 40 acres. The owners are reportedly looking for investors to finance the start-up. The project targeted for the military base entails ammunition recycling and remediation, consisting of 10-15 employees and a 20,000 square foot facility. This on-base proposal is the continuation of the U.S. Department of Defense's Base Realignment and Commission (BRAC) study recommendations. In addition to future BRAC proposals, there are also preliminary discussions for the possible geothermal energy production by the U.S. Navy, targeted for the Hawthorne Army Ammunition Depot's vast amount of property.

The much-hyped project slated for Hawthorne, the Peninsula Flooring manufacturing and distribution facilities and thousands of associated housing units for the employees has been terminated. The status of the associated proposal of a redevelopment district by the unincorporated town of Hawthorne that was to facilitate the Peninsula Flooring project continues to be dependant on future base recommendations from BRAC.

Zero commercial projects have been proposed for the portions of Douglas and Mono Counties in the Walker Basin.

Attempts were made to calculate the amount of commercial and industrial construction (square feet) per year in the regions with the most population (Lyon and Mineral County), but it was determined that the county assessors do not record or maintain the size of commercial and industrial structures. The square feet of commercial and industrial improvements are recorded and maintained by the county assessors in Clark (Las Vegas) and Washoe (Reno) Counties, however.

Appendix 1: Geodemographic Analysis - Walker Basin Subregions

WALKER HYDROGRAPHIC BASIN - DOUGLAS, LYON, AND MINERAL COUNTIES, NEVADA & MONO COUNTY, CALIFORNIA

2007 Estimates

	Mono County, CA		Douglas County		Lyon County				Mineral County		Grand Total	
	Topaz to Bridgeport		Topaz Ranch Estates		Mason Valley		Smith Valley		Hawthorne/Schurz		Walker Basin	
POPULATION & HOUSEHOLDS												
2007 POPULATION	2,290		2,158		8,583		1,840		4,128		18,999	
2000 CENSUS POPULATION	2,233		1,808		7,670		1,277		4,784		17,772	
1990 CENSUS POPULATION	2,154		1,158		5,835		904		5,964		16,014	
2000-2007 PERCENT INCREASE	3.67%		19.40%		11.90%		44.08%		-13.71%		7.53%	
2000-2007 AVERAGE ANNUAL GROWTH RATE	0.36%		2.31%		1.46%		4.83%		-1.89%		1.04%	
AREA OF ANALYSIS (SQUARE MILES)	883.8		220.4		183.3		109.0		1,579.6		3,934.2	
PERSONS PER SQUARE MILE	2.6		9.8		46.8		16.9		2.6		4.8	
2007 HOUSEHOLDS	880		958		3,446		770		1,811		7,865	
AVERAGE HOUSEHOLD SIZE	2.60		2.25		2.49		2.39		2.28		2.42	
2007 FAMILIES	623		682		2,288		543		1,219		5,355	
AVERAGE FAMILY SIZE	2.83		2.57		2.96		2.92		2.59		2.81	
NUMBER OF HOUSING UNITS BY TENURE												
OCCUPIED HOUSING UNITS	880	**63.8%**	958	**88.9%**	3,446	**87.4%**	770	**91.8%**	1,811	**70.0%**	7,864	**80.0%**
OWNER-OCCUPIED UNITS	525	**38.0%**	681	**63.2%**	2,437	**61.8%**	572	**68.2%**	1,309	**50.6%**	5,523	**56.2%**
RENTER-OCCUPIED UNITS	355	**25.7%**	277	**25.7%**	1,009	**25.6%**	198	**23.6%**	502	**19.4%**	2,341	**23.8%**
VACANT HOUSING UNITS	500	**36.2%**	120	**11.1%**	498	**12.6%**	68	**8.2%**	776	**30.0%**	1,962	**20.0%**
TOTAL HOUSING UNITS	1,380	**100.0%**	1,078	**100.0%**	3,944	**100.0%**	838	**100.0%**	2,587	**100.0%**	9,826	**100.0%**
NUMBER OF PERSONS BY RACE												
SINGLE-RACE NON-HISPANIC:												
WHITE	1,796	**78.4%**	1,889	**87.5%**	6,493	**75.7%**	1,442	**78.4%**	2,730	**66.1%**	14,349	**75.5%**
BLACK	28	**1.2%**	22	**1.0%**	75	**0.9%**	5	**0.3%**	215	**5.2%**	345	**1.8%**
AMERICAN INDIAN OR ALASKAN NATIVE	128	**5.6%**	48	**2.2%**	364	**4.2%**	19	**1.1%**	675	**16.4%**	1,236	**6.5%**
ASIAN, HAWAIIAN, OR PACIFIC ISLANDER	31	**1.3%**	43	**2.0%**	28	**0.3%**	7	**0.4%**	51	**1.2%**	159	**0.8%**
HISPANIC	308	**13.4%**	157	**7.3%**	1,622	**18.9%**	367	**20.0%**	456	**11.0%**	2,911	**15.3%**
NUMBER OF PERSONS BY SEX												
FEMALE	1,069	**46.7%**	1,033	**47.9%**	4,149	**48.3%**	898	**48.8%**	2,058	**49.9%**	9,208	**48.5%**
MALE	1,221	**53.3%**	1,126	**52.1%**	4,436	**51.7%**	942	**51.2%**	2,070	**50.1%**	9,792	**51.5%**
NUMBER OF PERSONS BY AGE												
0 TO 4 YEARS	146	**6.4%**	80	**3.7%**	537	**6.3%**	55	**3.0%**	225	**5.5%**	1,042	**5.5%**
5 TO 9 YEARS	152	**6.6%**	64	**3.0%**	536	**6.2%**	108	**5.9%**	267	**6.5%**	1,126	**5.9%**
10 TO 14 YEARS	142	**6.2%**	123	**5.7%**	610	**7.1%**	151	**8.2%**	326	**7.9%**	1,353	**7.1%**
15 TO 17 YEARS	87	**3.8%**	80	**3.7%**	538	**6.3%**	97	**5.3%**	216	**5.2%**	1,018	**5.4%**
18 TO 20 YEARS	84	**3.7%**	45	**2.1%**	341	**4.0%**	46	**2.5%**	129	**3.1%**	645	**3.4%**
21 TO 24 YEARS	135	**5.9%**	40	**1.9%**	308	**3.6%**	40	**2.2%**	135	**3.3%**	659	**3.5%**
25 TO 29 YEARS	135	**5.9%**	43	**2.0%**	363	**4.2%**	63	**3.4%**	180	**4.4%**	784	**4.1%**
30 TO 34 YEARS	142	**6.2%**	73	**3.4%**	415	**4.8%**	72	**3.9%**	200	**4.8%**	901	**4.7%**
35 TO 39 YEARS	164	**7.2%**	150	**6.9%**	530	**6.2%**	131	**7.1%**	259	**6.3%**	1,233	**6.5%**
40 TO 44 YEARS	133	**5.8%**	130	**6.0%**	537	**6.3%**	160	**8.7%**	292	**7.1%**	1,252	**6.6%**
45 TO 49 YEARS	165	**7.2%**	184	**8.5%**	511	**6.0%**	194	**10.6%**	306	**7.4%**	1,360	**7.2%**
50 TO 54 YEARS	162	**7.1%**	157	**7.3%**	485	**5.7%**	154	**8.4%**	317	**7.7%**	1,275	**6.7%**
55 TO 59 YEARS	149	**6.5%**	184	**8.5%**	481	**5.6%**	159	**8.6%**	255	**6.2%**	1,227	**6.5%**
60 TO 64 YEARS	155	**6.8%**	183	**8.5%**	536	**6.2%**	126	**6.8%**	233	**5.6%**	1,233	**6.5%**
65 TO 69 YEARS	110	**4.8%**	195	**9.0%**	486	**5.7%**	101	**5.5%**	218	**5.3%**	1,111	**5.8%**
70 TO 74 YEARS	93	**4.1%**	208	**9.7%**	513	**6.0%**	70	**3.8%**	220	**5.3%**	1,105	**5.8%**
75 TO 79 YEARS	71	**3.1%**	133	**6.1%**	403	**4.7%**	69	**3.8%**	164	**4.0%**	840	**4.4%**
80 TO 84 YEARS	38	**1.7%**	63	**2.9%**	263	**3.1%**	30	**1.6%**	110	**2.7%**	505	**2.7%**
85 YEARS & OVER	28	**1.2%**	22	**1.0%**	191	**2.2%**	14	**0.8%**	75	**1.8%**	330	**1.7%**
MEDIAN AGE	**39.4**		**48.9**		**41.4**		**42.4**		**41.3**		**42.1**	

Appendix 1: Geodemographic Analysis - Walker Basin Subregions

WALKER HYDROGRAPHIC BASIN - DOUGLAS, LYON, AND MINERAL COUNTIES, NEVADA & MONO COUNTY, CALIFORNIA

2007 Estimates

	Mono County, CA		Douglas County		Lyon County				Mineral County		Grand Total	
	Topaz to Bridgeport		Topaz Ranch Estates		Mason Valley		Smith Valley		Hawthorne/Schurz		Walker Basin	
NUMBER OF HOUSEHOLDS BY SIZE, TYPE, & PRESENCE OF CHILDREN												
1-PERSON HOUSEHOLD:	224	**25.4%**	220	**22.9%**	926	**26.9%**	141	**18.3%**	496	**27.4%**	2,007	**25.5%**
MALE HOUSEHOLDER	120	**13.7%**	128	**13.3%**	444	**12.9%**	74	**9.6%**	248	**13.7%**	1,014	**12.9%**
FEMALE HOUSEHOLDER	103	**11.7%**	92	**9.6%**	482	**14.0%**	67	**8.7%**	248	**13.7%**	993	**12.6%**
2 OR MORE PERSON HOUSEHOLD:	656	**74.6%**	738	**77.1%**	2,520	**73.1%**	629	**81.7%**	1,315	**72.6%**	5,858	**74.5%**
FAMILY HOUSEHOLDS:	622	**70.7%**	682	**71.2%**	2,358	**68.4%**	591	**76.7%**	1,219	**67.3%**	5,471	**69.6%**
MARRIED-COUPLE FAMILY:	514	**58.4%**	578	**60.3%**	1,897	**55.0%**	543	**70.5%**	873	**48.2%**	4,404	**56.0%**
WITH OWN CHILDREN UNDER 18 YEARS	181	**20.6%**	108	**11.3%**	687	**19.9%**	218	**28.3%**	306	**16.9%**	1,500	**19.1%**
NO OWN CHILDREN UNDER 18 YEARS	333	**37.8%**	469	**49.0%**	1,210	**35.1%**	325	**42.2%**	567	**31.3%**	2,903	**36.9%**
OTHER FAMILY:	108	**12.3%**	104	**10.9%**	461	**13.4%**	48	**6.2%**	346	**19.1%**	1,068	**13.6%**
MALE HOUSEHOLDER, NO WIFE PRESENT:	26	**3.0%**	50	**5.2%**	171	**5.0%**	23	**3.0%**	122	**6.8%**	393	**5.0%**
WITH OWN CHILDREN UNDER 18 YEARS	16	**1.8%**	28	**2.9%**	104	**3.0%**	13	**1.6%**	78	**4.3%**	238	**3.0%**
NO OWN CHILDREN UNDER 18 YEARS	10	**1.1%**	22	**2.3%**	67	**1.9%**	11	**1.4%**	45	**2.5%**	155	**2.0%**
FEMALE HHOLDER, NO HUSBAND PRESENT:	82	**9.3%**	54	**5.6%**	291	**8.4%**	24	**3.2%**	224	**12.4%**	675	**8.6%**
WITH OWN CHILDREN UNDER 18 YEARS	54	**6.2%**	32	**3.3%**	184	**5.3%**	11	**1.4%**	143	**7.9%**	424	**5.4%**
NO OWN CHILDREN UNDER 18 YEARS	28	**3.2%**	22	**2.3%**	107	**3.1%**	13	**1.7%**	81	**4.5%**	251	**3.2%**
NONFAMILY HOUSEHOLDS:	34	**3.9%**	56	**5.9%**	162	**4.7%**	39	**5.0%**	96	**5.3%**	387	**4.9%**
MALE HOUSEHOLDER	21	**2.4%**	33	**3.4%**	107	**3.1%**	23	**3.1%**	64	**3.5%**	248	**3.2%**
FEMALE HOUSEHOLDER	13	**1.5%**	24	**2.5%**	55	**1.6%**	15	**2.0%**	32	**1.8%**	139	**1.8%**
TOTAL HOUSEHOLDS	880	**100.0%**	958	**100.0%**	3,446	**100.0%**	770	**100.0%**	1,811	**100.0%**	7,865	**100.0%**
NUMBER OF PERSONS 25 YEARS & OVER BY EDUCATIONAL ATTAINMENT												
12 GRADE OR LESS, NO DIPLOMA	201	**13.0%**	282	**16.4%**	1,209	**22.7%**	383	**30.9%**	654	**23.1%**	2,728	**21.5%**
HIGH SCHOOL OR EQUIVALENT	439	**28.4%**	670	**38.8%**	1,798	**33.7%**	280	**22.6%**	1,024	**36.2%**	4,211	**33.2%**
SOME COLLEGE, NO DEGREE	516	**33.4%**	561	**32.5%**	1,449	**27.1%**	311	**25.1%**	716	**25.3%**	3,552	**28.0%**
ASSOCIATE DEGREE	114	**7.4%**	87	**5.0%**	262	**4.9%**	71	**5.8%**	134	**4.7%**	668	**5.3%**
BACHELOR'S DEGREE	171	**11.1%**	119	**6.9%**	497	**9.3%**	151	**12.2%**	212	**7.5%**	1,150	**9.1%**
MASTER'S DEGREE	68	**4.4%**	7	**0.4%**	102	**1.9%**	43	**3.5%**	57	**2.0%**	277	**2.2%**
PROFESSIONAL SCHOOL DEGREE	30	**1.9%**	0	**0.0%**	10	**0.2%**	0	**0.0%**	32	**1.1%**	73	**0.6%**
DOCTORATE DEGREE	8	**0.5%**	0	**0.0%**	11	**0.2%**	0	**0.0%**	1	**0.0%**	19	**0.2%**
TOTAL PERSONS 25 YEARS & OVER	1,547	**100.0%**	1,726	**100.0%**	5,338	**100.0%**	1,239	**100.0%**	2,830	**100.0%**	12,679	**100.0%**
NUMBER OF PERSONS 16 YEARS & OVER BY CIVILIAN EMPLOYMENT OCCUPATION												
WHITE COLLAR[1]	504	**48.5%**	322	**41.5%**	1,156	**38.6%**	302	**31.6%**	673	**40.6%**	2,957	**39.9%**
BLUE COLLAR[2]	295	**28.4%**	255	**32.9%**	1,123	**37.5%**	437	**45.7%**	514	**31.1%**	2,625	**35.4%**
SERVICES[3]	159	**15.3%**	136	**17.5%**	424	**14.2%**	95	**10.0%**	340	**20.5%**	1,154	**15.6%**
SALES	81	**7.8%**	63	**8.2%**	289	**9.7%**	121	**12.6%**	129	**7.8%**	683	**9.2%**
TOTAL EMPLOYED CIVILIAN POPULATION 16 YEARS & OVER	1,039	**100.0%**	776	**100.0%**	2,993	**100.0%**	956	**100.0%**	1,657	**100.0%**	7,420	**100.0%**
NUMBER OF HOUSEHOLDS BY HOUSEHOLD INCOME												
LESS THAN $14,999			92	**9.7%**	516	**15.4%**	80	**11.3%**	365	**20.1%**	1,052	**15.4%**
$15,000 TO $24,999			91	**9.5%**	488	**14.6%**	84	**11.9%**	239	**13.2%**	902	**13.2%**
$25,000 TO $34,999			168	**17.5%**	557	**16.6%**	84	**11.9%**	241	**13.3%**	1,050	**15.4%**
$35,000 TO $49,999			160	**16.7%**	671	**20.1%**	94	**13.3%**	308	**17.0%**	1,233	**18.1%**
$50,000 TO $74,999			169	**17.6%**	556	**16.6%**	148	**20.9%**	353	**19.5%**	1,225	**18.0%**
$75,000 TO $99,999			100	**10.5%**	267	**8.0%**	104	**14.7%**	182	**10.1%**	653	**9.6%**
$100,000 TO $149,999			101	**10.5%**	140	**4.2%**	57	**8.1%**	85	**4.7%**	383	**5.6%**
$150,000 OR MORE			76	**7.9%**	150	**4.5%**	57	**8.0%**	31	**1.7%**	314	**4.6%**
TOTAL HOUSEHOLDS			958	**100.0%**	3,344	**100.0%**	708	**100.0%**	1,811	**100.0%**	6,821	**100.0%**
MEDIAN HOUSEHOLD INCOME	$45,313		$41,008		$42,925		$59,794		$42,818		$44,485	
MEDIAN FAMILY INCOME	$49,757		$46,776		$49,160		$61,944		$52,584		$51,002	
PER CAPITA INCOME	$22,505		$26,950		$23,421		$27,827		$21,417		$23,703	

Appendix 1: Geodemographic Analysis - Walker Basin Subregions

WALKER HYDROGRAPHIC BASIN - DOUGLAS, LYON, AND MINERAL COUNTIES, NEVADA & MONO COUNTY, CALIFORNIA

2007 Estimates

	Mono County, CA		Douglas County		Lyon County				Mineral County		Grand Total	
	Topaz to Bridgeport		Topaz Ranch Estates		Mason Valley		Smith Valley		Hawthorne/Schurz		Walker Basin	
NUMBER OF HOUSING UNITS BY TOTAL UNITS IN STRUCTURE												
SINGLE FAMILY, DETACHED UNIT	840	**60.8%**	377	**35.0%**	2,303	**58.4%**	686	**81.9%**	1,673	**64.7%**	5,879	**59.8%**
CONDOMINIUM/TOWNHOME	88	**6.4%**	16	**1.5%**	167	**4.2%**	41	**4.9%**	14	**0.6%**	326	**3.3%**
MULTI-FAMILY UNITS	149	**10.8%**	10	**0.9%**	278	**7.0%**	7	**0.8%**	296	**11.4%**	739	**7.5%**
MOBILE HOME	304	**22.0%**	662	**61.4%**	1,196	**30.3%**	104	**12.4%**	572	**22.1%**	2,838	**28.9%**
TOTAL HOUSING UNITS	1,380	**100.0%**	1,078	**100.0%**	3,944	**100.0%**	838	**100.0%**	2,587	**100.0%**	9,826	**100.0%**
NUMBER OF HOUSING UNITS BY YEAR STRUCTURE BUILT												
BUILT APRIL 2000 TO OCTOBER 2007	0	**0.0%**	145	**13.4%**	444	**11.3%**	270	**32.2%**	1	**0.0%**	860	**8.7%**
BUILT 1995 TO MARCH 2000	96	**6.9%**	100	**9.3%**	410	**10.4%**	86	**10.3%**	91	**3.5%**	782	**8.0%**
BUILT 1990 TO 1994	168	**12.2%**	137	**12.8%**	325	**8.2%**	83	**9.9%**	184	**7.1%**	897	**9.1%**
BUILT 1980 TO 1989	189	**13.7%**	245	**22.7%**	481	**12.2%**	87	**10.4%**	416	**16.1%**	1,418	**14.4%**
BUILT 1970 TO 1979	242	**17.6%**	351	**32.5%**	693	**17.6%**	98	**11.7%**	651	**25.2%**	2,035	**20.7%**
BUILT 1960 TO 1969	350	**25.4%**	80	**7.4%**	434	**11.0%**	49	**5.8%**	368	**14.2%**	1,280	**13.0%**
BUILT 1950 TO 1959	133	**9.6%**	15	**1.3%**	585	**14.8%**	44	**5.3%**	472	**18.3%**	1,249	**12.7%**
BUILT 1940 TO 1949	142	**10.3%**	0	**0.0%**	277	**7.0%**	56	**6.7%**	258	**10.0%**	733	**7.5%**
BUILT 1939 OR EARLIER	61	**4.4%**	6	**0.6%**	295	**7.5%**	65	**7.8%**	146	**5.6%**	573	**5.8%**
TOTAL HOUSING UNITS	1,380	**100.0%**	1,078	**100.0%**	3,944	**100.0%**	838	**100.0%**	2,587	**100.0%**	9,826	**100.0%**
AVERAGE YEAR STRUCTURE BUILT	1973		1984		1972		1984		1964		1970	
NUMBER OF SINGLE FAMILY HOMES BY REPORTED SALES PRICE [4]												
$ TO $100,000	0	**0.0%**	0	**0.0%**	10	**13.9%**	0	**0.0%**	4	**33.3%**	14	**10.6%**
$100,000 TO $149,999	1	**4.3%**	1	**8.3%**	17	**23.6%**	0	**0.0%**	5	**41.7%**	24	**18.2%**
$150,000 TO $199,999	2	**8.7%**	3	**25.0%**	22	**30.6%**	0	**0.0%**	0	**0.0%**	27	**20.5%**
$200,000 TO $249,999	1	**4.3%**	2	**16.7%**	12	**16.7%**	0	**0.0%**	2	**16.7%**	17	**12.9%**
$250,000 TO $299,999	3	**13.0%**	2	**16.7%**	4	**5.6%**	1	**7.7%**	1	**8.3%**	11	**8.3%**
$300,000 TO $399,999	11	**47.8%**	1	**8.3%**	7	**9.7%**	3	**23.1%**	0	**0.0%**	22	**16.7%**
$400,000 TO $499,999	2	**8.7%**	1	**8.3%**	0	**0.0%**	4	**30.8%**	0	**0.0%**	7	**5.3%**
$500,000 TO $749,999	3	**13.0%**	2	**16.7%**	0	**0.0%**	4	**30.8%**	0	**0.0%**	9	**6.8%**
$750,000 TO $999,999	0	**0.0%**	0	**0.0%**	0	**0.0%**	1	**7.7%**	0	**0.0%**	1	**0.8%**
$1,000,000 OR MORE	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**	0	**0.0%**
TOTAL SINGLE FAMILY HOMES WITH REPORTED SALES	23	**100.0%**	12	**100.0%**	72	**100.0%**	13	**100.0%**	12	**100.0%**	132	**100.0%**
MEDIAN VALUE FOR SINGLE FAMILY HOMES (2007)	$329,500		$256,770		$166,000		$475,000		$118,500		$228,854	
AVERAGE VALUE FOR SINGLE FAMILY HOMES (2007)	$358,975		$302,037		$176,650		$489,169		$135,067		$246,816	
MEDIAN VALUE PER SQUARE FOOT (2007)	$212.30		$165.50		$118.40		$203.70		$87.15		$144.60	
AVERAGE VALUE PER SQUARE FOOT (2007)	$227.08		$179.22		$118.90		$221.00		$93.90		$151.02	

FOOTNOTES:

[1]White Collar occupations include management occupations; business and financial operations; computer and mathematical occupations; architecture, engineering, drafting, and mapping occupations; life, physical, and social science occupations; legal occupations; education, training, and library occupations; arts, design, media, entertainment, and sports occupations; healthcare practitioners, technical staff, and healthcare support occupations; and office and administrative support occupations.

[2]Blue Collar occupations include farmers and farm managers; building and grounds cleaning and maintenance; farming, fishing, and forestry occupations; construction, extractions, and maintenance occupations; production occupations; and transportation and material moving occupations.

[3]Service occupations include community and social service occupations, protective service occupations, food preparers and servers, and personal care and personal service occupations.

[4]Includes all single-family and manufactured homes within the county assessor databases. Includes transactions that occurred within the previous 12 months from the data of the assessor's sales file. Values do not include mobile homes or condominiums.

Sources:

2007 Douglas, Lyon, & Mineral County Assessor's data
2000 Census Summary File 1 block level data & Summary File 3 block-group level data
Nevada State Demographer
Bureau of Economic Analyses, U.S. Department of Commerce

Appendix 2 - Firms, Employment & Wages by Industry

Walker Basin - Nevada Portion

2nd Quarter 2007 Averages

	LYON COUNTY		MINERAL COUNTY		DOUGLAS COUNTY	Walker Basin - Nevada Portion Only
Summary	*Mason Valley*	*Smith Valley*	*Hawthorne*	*Schurz*	*Topaz Ranch Estates*	
Total Firms	**227**	**60**	**75**	**14**	**26**	**402**
Total Employment	**4,172**	**254**	**1,528**	**171**	**192**	**6,317**
Average Wage*	**$15.61**	**$14.68**	**$15.74**	**$18.99**	**$10.79**	**$15.55**
Total Annual Payroll**	**$135,467,616**	**$7,765,284**	**$50,023,260**	**$6,753,420**	**$4,310,400**	**$204,319,980**

Firms by Industry

Industry	Mason Valley		Smith Valley		Hawthorne		Schurz		Topaz Ranch Estates		Walker Basin - Nevada Portion Only	
Agriculture & Forestry	24	**10.6%**	13	**21.7%**	1	**1.3%**					38	**9.5%**
Construction	32	**14.1%**	12	**20.0%**	4	**5.3%**	3	**21.4%**	8	**30.8%**	59	**14.7%**
Educational, Health, & Social Services	21	**9.3%**	4	**6.7%**	10	**13.3%**	5	**35.7%**	3	**11.5%**	43	**10.7%**
Entertainment, Accommodation, & Food Services	17	**7.5%**	4	**6.7%**	14	**18.7%**			4	**15.4%**	39	**9.7%**
Finance, Insur., & Real Estate	26	**11.5%**	4	**6.7%**	6	**8.0%**	1	**7.1%**			37	**9.2%**
Government	9	**4.0%**			6	**8.0%**	1	**7.1%**			16	**4.0%**
Information	4	**1.8%**			2	**2.7%**					6	**1.5%**
Management & Admin. Services	8	**3.5%**	2	**3.3%**	4	**5.3%**	1	**7.1%**			15	**3.7%**
Manufacturing	6	**2.6%**	2	**3.3%**	1	**1.3%**					9	**2.2%**
Mining	2	**0.9%**			2	**2.7%**					4	**1.0%**
Other Services	8	**3.5%**	1	**1.7%**	2	**2.7%**			1	**3.8%**	12	**3.0%**
Professional Services	17	**7.5%**	4	**6.7%**	5	**6.7%**			3	**11.5%**	29	**7.2%**
Retail Trade	34	**15.0%**	1	**1.7%**	10	**13.3%**	1	**7.1%**	5	**19.2%**	51	**12.7%**
Transportation & Utilities	10	**4.4%**	7	**11.7%**	5	**6.7%**	2	**14.3%**	2	**7.7%**	26	**6.5%**
Wholesale Trade	9	**4.0%**	6	**10.0%**	3	**4.0%**					18	**4.5%**

Employment by Industry

Industry	Mason Valley		Smith Valley		Hawthorne		Schurz		Topaz Ranch Estates		Walker Basin - Nevada Portion Only	
Agriculture & Forestry	397	**9.5%**	85	**33.5%**	1-4	**d**					485	**7.7%**
Construction	197	**4.7%**	33	**13.0%**	19	**1.2%**	41	**24.0%**	21	**10.9%**	311	**4.9%**
Educational, Health, & Social Services	1,846	**44.2%**	14	**5.5%**	336	**22.0%**	59	**34.5%**	18	**9.4%**	2,273	**36.0%**
Entertainment, Accommodation, & Food Services	269	**6.4%**	24	**9.4%**	265	**17.3%**			102	**53.1%**	660	**10.4%**
Finance, Insur., & Real Estate	112	**2.7%**	13	**5.1%**	40	**2.6%**	5-9	**d**			172	**2.7%**
Government	651	**15.6%**			146	**9.6%**	20-49	**d**			829	**13.1%**
Information	17	**0.4%**			10-19	**d**					28	**0.4%**
Management & Admin. Services	34	**0.8%**	5-9	**d**	529	**34.6%**	1-4	**d**			573	**9.1%**
Manufacturing	113	**2.7%**	20-49	**d**	1-4	**d**					139	**2.2%**
Mining	10-19	**d**			5-9	**d**					22	**0.3%**
Other Services	41	**1.0%**	1-4	**d**	5-9	**d**			1-4	**d**	49	**0.8%**
Professional Services	72	**1.7%**	5	**2.0%**	25	**1.6%**			7	**3.6%**	109	**1.7%**
Retail Trade	245	**5.9%**	1-4	**d**	108	**7.1%**	10-19	**d**	27	**14.1%**	399	**6.3%**
Transportation & Utilities	89	**2.1%**	18	**7.1%**	16	**1.0%**	10-19	**d**	10-19	**d**	152	**2.4%**
Wholesale Trade	75	**1.8%**	25	**9.8%**	16	**1.0%**					116	**1.8%**

*Average Wage by Industry**

Industry	Mason Valley	Smith Valley	Hawthorne	Schurz	Topaz Ranch Estates	Walker Basin - Nevada Portion Only
Agriculture & Forestry	$14.83	$11.82	d			$14.29
Construction	$14.95	$19.61	$11.12	$27.69	$12.67	$16.81
Educational, Health, & Social Services	$16.34	$25.32	$16.67	$20.80	$26.33	$16.63
Entertainment, Accommodation, & Food Services	$8.86	$6.94	$8.05		$9.52	$8.64
Finance, Insur., & Real Estate	$13.01	$41.13	$11.19	d		$14.17
Government	$16.70		$13.60	d		$16.12
Information	$16.50		d			$18.44
Management & Admin. Services	$15.18	d	$21.04	d		$20.55
Manufacturing	$18.40	d	d			$18.15
Mining	d		d			$28.75
Other Services	$8.28	d	d		d	$9.06
Professional Services	$16.30	$30.55	$18.14		$14.81	$16.85
Retail Trade	$12.64	d	$11.61	d	$8.94	$11.84
Transportation & Utilities	$34.89	$15.60	$27.28	d	d	$28.13
Wholesale Trade	$15.17	$15.94	$22.62			$15.77

d - Disclosure limitations. The values are not reported in order to protect the information of individual businesses.

*Many employees work less than or more than 40 hours per week. The above wage estimates are calculated by dividing the 2nd Quarter 2007 payroll by the number of employees and 520 hours (13 weeks by 40 hours). Thus, the average wage estimates may not represent the actual wage received by the employee per hour.

**The Total Annual Payroll is calculated by multiplying the 2nd Quarter 2007 payroll by four (the number of quarters in a year).

***Wages for service workers may include tips.

Source: Department of Employment, Training, & Rehabilitation (DETR) for specific use by Center for Regional Studies

Based on entity reporting; excludes entities not filing for covered employment insurance (sole proprietors) and seasonal migrant workers.

Appendix 3 - Establishments & Employees by Industry & Size

Walker Basin - California Portion

2006

ZIP Code 93517 - Bridgeport, California

Number of establishments: 37
Number of employees: 116
Annual Payroll: $3,224,000

	Total Estabs	%	Number of Establishments by Employment-size class			
			'1-4'	'5-9'	'10-19'	'20-49'
Total	37	**100.0%**	29	6	1	1
Construction	1	**2.7%**	1	0	0	0
Manufacturing	1	**2.7%**	1	0	0	0
Retail trade	5	**13.5%**	4	1	0	0
Information	1	**2.7%**	1	0	0	0
Real estate & rental & leasing	1	**2.7%**	0	0	1	0
Professional, scientific & technical services	1	**2.7%**	0	1	0	0
Health care and social assistance	1	**2.7%**	1	0	0	0
Arts, entertainment & recreation	1	**2.7%**	1	0	0	0
Accommodation & food services	24	**64.9%**	19	4	0	1
Other services (except public administration)	1	**2.7%**	1	0	0	0

ZIP Code 96107 - Coleville, California

Number of establishments: 15
Number of employees: 44
Annual Payroll: $1,290,000

	Total Estabs	%	Number of Establishments by Employment-size class			
			'1-4'	'5-9'	'10-19'	'20-49'
Total	15	**100.0%**	10	5	0	0
Construction	2	**13.3%**	2	0	0	0
Retail trade	3	**20.0%**	1	2	0	0
Transportation & warehousing	1	**6.7%**	1	0	0	0
Information	1	**6.7%**	1	0	0	0
Real estate & rental & leasing	1	**6.7%**	0	1	0	0
Professional, scientific & technical services	1	**6.7%**	1	0	0	0
Health care and social assistance	1	**6.7%**	0	1	0	0
Accommodation & food services	5	**33.3%**	4	1	0	0

ZIP Code 96133 - Topaz, California

Number of establishments: 2
Number of employees: 0
Annual Payroll: $0

	Total Estabs	%	Number of Establishments by Employment-size class			
			'1-4'	'5-9'	'10-19'	'20-49'
Total	2	**100.0%**	1	1	0	0
Utilities	1	**50.0%**	0	1	0	0
Retail trade	1	**50.0%**	1	0	0	0

Walker Basin Total (California Portion Only)

Number of establishments: 54
Number of employees: 160
Annual Payroll: $4,514,000

	Total Estabs	%	Number of Establishments by Employment-size class			
			'1-4'	'5-9'	'10-19'	'20-49'
Total	54	**100.0%**	40	12	1	1
Construction	3	**5.6%**	3	0	0	0
Manufacturing	1	**1.9%**	1	0	0	0
Utilities	1	**1.9%**	0	1	0	0
Retail trade	9	**16.7%**	6	3	0	0
Transportation & warehousing	1	**1.9%**	1	0	0	0
Information	2	**3.7%**	2	0	0	0
Real estate & rental & leasing	2	**3.7%**	0	1	1	0
Professional, scientific & technical services	2	**3.7%**	1	1	0	0
Health care and social assistance	2	**3.7%**	1	1	0	0
Arts, entertainment & recreation	1	**1.9%**	1	0	0	0
Accommodation & food services	29	**53.7%**	23	5	0	1
Other services (except public administration)	1	**1.9%**	1	0	0	0

Source: 2006 ZIP Business Patterns, U.S. Census Bureau, U.S. Department of Commerce

Appendix 4: 1990-2006 Employment by Industry

Lyon County, Nevada

Standard Industrial Classification (SIC) Breakdowns

Employment Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total full-time and part-time employment	7,829	8,001	8,152	8,839	9,516	10,170	10,623	11,330	12,025	13,020	14,377
Wage and salary employment	5,805	5,839	6,001	6,433	6,961	7,416	7,693	8,127	8,697	9,565	10,773
Proprietors employment	2,024	2,162	2,151	2,406	2,555	2,754	2,930	3,203	3,328	3,455	3,604
Farm proprietors employment	292	292	298	361	351	333	324	319	324	322	323
Nonfarm proprietors employment	1,732	1,870	1,853	2,045	2,204	2,421	2,606	2,884	3,004	3,133	3,281
Farm employment	629	540	538	619	643	567	634	717	698	704	718
Nonfarm employment	7,200	7,461	7,614	8,220	8,873	9,603	9,989	10,613	11,327	12,316	13,659
Private employment	6,209	6,354	6,424	6,998	7,573	8,260	8,586	9,128	9,790	10,721	11,963
Agricultural services, forestry, & fishing	146	155	162	195	229	235	236	276	283	311	320
Mining	193	186	215	193	190	225	261	223	202	160	207
Transportation and public utilities	395	350	379	438	409	399	407	412	402	486	459
Construction	669	677	694	783	900	885	997	1,070	1,155	1,286	1,339
Manufacturing	1,289	1,279	1,249	1,350	1,517	1,734	1,623	1,590	1,704	1,659	1,825
Wholesale trade	174	170	216	260	247	253	264	394	572	582	736
Retail trade	1,079	1,147	1,163	1,253	1,348	1,537	1,629	1,640	1,582	2,084	2,431
Finance, insurance, and real estate	415	408	407	432	428	532	605	762	863	859	965
Services	1,849	1,982	1,939	2,094	2,305	2,460	2,564	2,761	3,027	3,294	3,681
Government and government enterprises	991	1,107	1,190	1,222	1,300	1,343	1,403	1,485	1,537	1,595	1,696
Federal, civilian	53	44	46	43	46	47	51	52	57	61	83
Military	63	62	65	61	59	55	64	63	62	62	66
State and local	875	1,001	1,079	1,118	1,195	1,241	1,288	1,370	1,418	1,472	1,547
State government	63	66	78	71	66	69	72	75	78	(D)	(D)
Local government	812	935	1,001	1,047	1,129	1,172	1,216	1,295	1,340	(D)	(D)

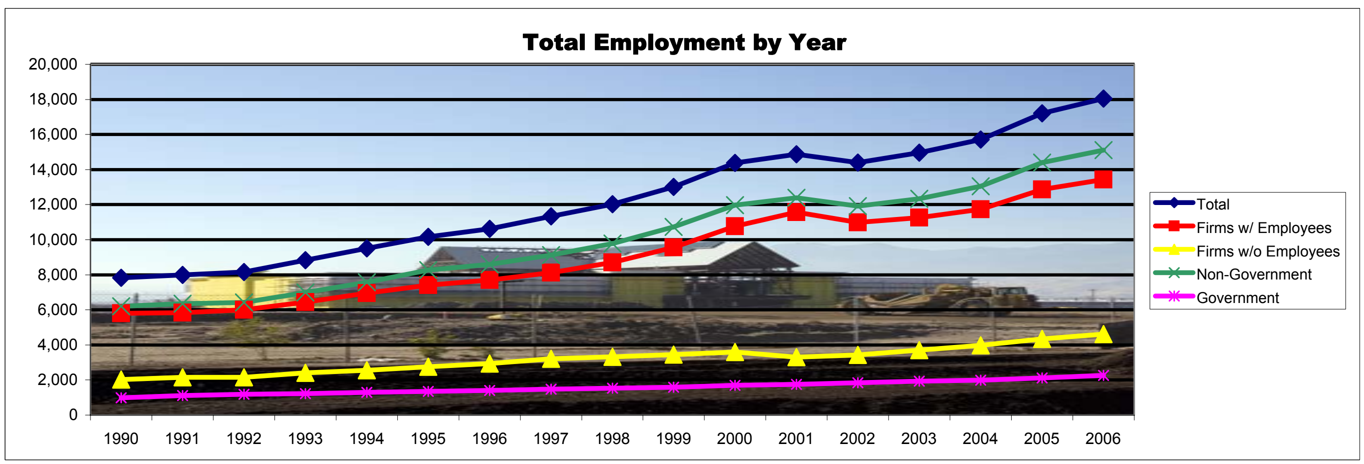
North American Industrial Classification (NAICS) Breakdowns

Employment Category	2001	2002	2003	2004	2005	2006
Total employment	14,868	14,404	14,965	15,714	17,209	18,048
Wage and salary employment	11,567	10,980	11,261	11,735	12,858	13,434
Proprietors employment	3,301	3,424	3,704	3,979	4,351	4,614
Farm proprietors employment	326	327	319	318	321	320
Nonfarm proprietors employment	2,975	3,097	3,385	3,661	4,030	4,294
Farm employment	716	636	701	673	682	666
Nonfarm employment	14,152	13,768	14,264	15,041	16,527	17,382
Private employment	12,392	11,921	12,335	13,053	14,405	15,112
Forestry, fishing, & related activities	156	198	210	221	214	209
Mining	166	146	225	215	177	182
Utilities	77	75	70	71	72	71
Construction	1,356	1,356	1,435	1,690	2,038	2,007
Manufacturing	2,143	2,184	2,289	2,441	2,606	2,533
Wholesale trade	709	658	553	643	697	725
Retail trade	2,171	2,098	2,072	1,919	2,052	2,212
Transportation and warehousing	335	349	317	299	340	415
Information	54	56	60	63	62	65
Finance and insurance	230	275	284	274	327	345
Real estate and rental and leasing	548	608	725	834	947	1,066
Professional and technical services	(D)	(D)	(D)	647	697	733
Management of companies and enterprises	(D)	(D)	(D)	27	26	53
Administrative and waste services	1,102	466	551	645	684	686
Educational services	(D)	(D)	(D)	(D)	84	92
Health care and social assistance	(D)	(D)	(D)	(D)	822	849
Arts, entertainment, and recreation	673	722	720	775	941	1,103
Accommodation and food services	460	538	629	669	762	839
Other services, except public administration	906	852	796	772	857	927
Government and government enterprises	1,760	1,847	1,929	1,988	2,122	2,270
Federal, civilian	71	73	73	68	71	74
Military	71	75	81	86	95	105
State and local	1,618	1,699	1,775	1,834	1,956	2,091
State government	(D)	(D)	(D)	(D)	84	96
Local government	(D)	(D)	(D)	(D)	1,872	1,995

1990-2006 Average Annual Growth Rates

Total full-time and part-time employment	**5.36%**
Wage and salary employment	**5.38%**
Private employment	**5.72%**
Government and government enterprises	**5.32%**
Proprietors employment	**5.29%**

Note: Due to the conversion from the SIC to NAICS industrial classification system as a result of the NAFTA Agreement, trending the private employment industries between 2000 & 2001 is not possible for all sectors.



Source: Bureau of Economic Analysis, U.S. Department of Commerce
http://www.bea.gov/regional/reis/CA25fn.cfm
http://www.bea.gov/regional/reis/CA25Nfn.cfm

Appendix 5 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Walker River Basin - Nevada Portion

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Retail Industries	Locations	Total Revenue	Average Revenue	Total Taxable Sales	Average Taxable Sales
Home Improvement & Department Stores					
Home Improvement & Building Materials	3	$ 891,962	$ 297,321	$ 571,370	$ 190,457
Paint, Glass, & Hardware	6	$ 6,070,764	$ 1,011,794	$ 3,683,841	$ 613,974
Nurseries, Lawn, & Garden Supplies	3	$ 453,113	$ 151,038	$ 442,013	$ 147,338
Major Department Stores	1	$750k-$1m	$750k-$1m	$750k-$1m	$750k-$1m
Variety & General Merchandise	9	$ 1,536,358	$ 170,706	$ 1,287,076	$ 143,008
Food - At Home					
Supermarkets, Markets, & Convenience Stores Gas Stations	19	$ 64,185,577	$ 3,378,188	$ 12,639,332	$ 665,228
Candy, Bakeries, & Miscellaneous Food Stores	3	$ 27,428	$ 9,143	$ 26,737	$ 8,912
Liquor Stores	2	$ 916,088	$ 458,044	$ 690,630	$ 345,315
Drug Stores & Pharmacies	1	$1-$5 million	$1-$5 million	$250k-$500k	$250k-$500k
Food - Away from Home					
Restaurants & other Eating Establishments	21	$ 4,516,559	$ 215,074	$ 4,503,670	$ 214,460
Drinking Establishments	17	$ 3,567,323	$ 209,843	$ 3,283,146	$ 193,126
Casino, Casino Hotel					
Motorized Equipment					
New & Used Auto Dealers	2	$ 3,160,806	$ 1,580,403	$ 1,814,677	$ 907,339
Used Auto Dealers	3	$ 7,416,538	$ 2,472,179	$ 4,253,418	$ 1,417,806
Auto Supply Stores	5	$ 1,375,333	$ 275,067	$ 933,372	$ 186,674
Boat, Motorcycle, RV, & Misc. Dealers	1	$1-$5 million	$1-$5 million	$1-$5 million	$1-$5 million
Apparel					
Women's Apparel & Accessories					
Men's, Children, & Family Apparel	3	$ 138,313	$ 46,104	$ 137,726	$ 45,909
Miscellaneous Apparel & Accessories	6	$ 65,125	$ 10,854	$ 14,966	$ 2,494
Shoe Stores					
Home Furnishings					
Furniture Stores	1	$750k-$1m	$750k-$1m	$250k-$500k	$250k-$500k
Floors, Drapery, & Upholstery	2	$ 88,741	$ 44,371	$ 84,030	$ 42,015
Household Appliances & Electronics	4	$ 267,359	$ 66,840	$ 248,016	$ 62,004
Miscellaneous Home Furnishings	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Household & Personal Goods					
Computers & Software	2	$ 9,820	$ 4,910	$ 9,744	$ 4,872
Videos, Music, & Musical Instruments	1	$100k-$250k	$100k-$250k	$25k-$100k	$25k-$100k
Book Stores	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Used Merchandise & Pawnshops	6	$ 98,520	$ 16,420	$ 80,844	$ 13,474
Jewelry Stores	4	$ 283,191	$ 70,798	$ 113,409	$ 28,352
Sporting Goods	3	$ 185,376	$ 61,792	$ 137,677	$ 45,892
Hobbies, Toys, & Crafts	2	$ 4,541	$ 2,271	$ 956	$ 478
Office Supply Stores	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Gifts, Novelty, & Souvenirs	8	$ 250,733	$ 31,342	$ 198,920	$ 24,865
Florists	4	$ 237,708	$ 59,427	$ 222,948	$ 55,737
Tobacco Stores					
Miscellaneous Retail					
Miscellaneous Retail	30	$ 1,565,032	$ 52,168	$ 802,711	$ 26,757
Manufactured Homes					
Other non-classified Retail Establishments					
Non-store Retailers					
Non-store Retailers	18	$ 18,246,286	$ 1,013,683	$ 1,387,502	$ 77,083
RETAIL TOTAL (includes actual sales displayed as ranges):	**193**	**$ 122,678,632**	**$ 635,641**	**$ 41,334,789**	**$ 214,170**

Appendix 5 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Walker River Basin - Nevada Portion

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Non-Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Agriculture, Forestry, Fishing and Hunting	8	$ 1,653,820	$ 206,728	$ 104,311	$ 13,039
Mining	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Utilities	1	$100k-$250k	$100k-$250k	$100k-$250k	$100k-$250k
Construction	6	$ 2,701,953	$ 450,326	$ 546,896	$ 91,149
Manufacturing	19	$ 12,931,638	$ 680,613	$ 4,356,673	$ 229,299
Wholesale Trade	29	$ 72,384,445	$ 2,496,015	$ 12,214,709	$ 421,197
Transportation and Warehousing	2	$ 49,344	$ 24,672	$ 49,344	$ 24,672
Information	5	$ 238,087	$ 47,617	$ 125,260	$ 25,052
Finance and Insurance	2	$ 19,125	$ 9,563	$ 19,125	$ 9,563
Real Estate and Rental and Leasing	10	$ 2,116,527	$ 211,653	$ 676,250	$ 67,625
Professional, Scientific, and Technical Services	9	$ 487,405	$ 54,156	$ 428,387	$ 47,599
Management of Companies and Enterprises	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Administrative and Support and Waste	6	$ 243,589	$ 40,598	$ 85,301	$ 14,217
Educational Services	8	$ 38,664	$ 4,833	$ 38,472	$ 4,809
Health Care and Social Assistance	2	$ 284,351	$ 142,176	$ 19,437	$ 9,719
Arts, Entertainment, and Recreation	4	$ 4,668,965	$ 1,167,241	$ 4,613,456	$ 1,153,364
Other Accommodation and Food Serv (other than those listed in Retail)					
Other Services (except Public Administration)	20	$ 2,940,678	$ 147,034	$ 879,941	$ 43,997
Public Administration					
Non-classified Establishments	2	$ 348,010	$ 174,005	$ 14,817	$ 7,409
NON-RETAIL TOTAL (includes actual sales displayed as ranges):	**135**	**$ 101,342,874**	**$ 750,688**	**$ 24,401,623**	**$ 180,753**
GRAND TOTAL (Retail & Non-Retail Industries):	**328**	**$ 224,021,506**	**$ 682,992**	**$ 65,736,412**	**$ 200,416**

Sales are reported by business entities at the county level. Retail sales for business entities with more than one location in a given county are calculated by dividing the total sales by the number of locations under the same ownership.

'Non-store Retailers' include mobile home dealers, food caterers, catalogue & mail order houses, merchandising machine operators, direct selling organizations, fuel oil and natural gas dealers, news dealers, & newsstands.

'Non-classified Establishments' include entities not classified by the Department of Taxation according to the North American Industrial Classification System (NAICS)

Appendix 6 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Mason Valley - Lyon County, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Home Improvement & Department Stores					
Home Improvement & Building Materials	2	$ 700,448	$ 350,224	$ 395,903	$ 197,952
Paint, Glass, & Hardware	4	$ 4,711,935	$ 1,177,984	$ 2,507,452	$ 626,863
Nurseries, Lawn, & Garden Supplies	2	$ 289,715	$ 144,857	$ 278,615	$ 139,307
Major Department Stores	1	$750k-$1m	$750k-$1m	$750k-$1m	$750k-$1m
Variety & General Merchandise	6	$ 1,068,293	$ 178,049	$ 891,637	$ 148,606
Food - At Home					
Supermarkets, Markets, & Convenience Stores Gas Stations	8	$ 40,102,095	$ 5,012,762	$ 7,806,178	$ 975,772
Candy, Bakeries, & Miscellaneous Food Stores	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Liquor Stores					
Drug Stores & Pharmacies	1	$1-$5 million	$1-$5 million	$250k-$500k	$250k-$500k
Food - Away from Home					
Restaurants & other Eating Establishments	11	$ 2,655,724	$ 241,429	$ 2,650,530	$ 240,957
Drinking Establishments	7	$ 1,794,608	$ 256,373	$ 1,548,827	$ 221,261
Casino, Casino Hotel					
Motorized Equipment					
New & Used Auto Dealers	1	$1-$5 million	$1-$5 million	$1-$5 million	$1-$5 million
Used Auto Dealers	3	$ 7,416,538	$ 2,472,179	$ 4,253,418	$ 1,417,806
Auto Supply Stores	4	$ 1,325,088	$ 331,272	$ 897,588	$ 224,397
Boat, Motorcycle, RV, & Misc. Dealers	1	$1-$5 million	$1-$5 million	$1-$5 million	$1-$5 million
Apparel					
Women's Apparel & Accessories					
Men's, Children, & Family Apparel	3	$ 138,313	$ 46,104	$ 137,726	$ 45,909
Miscellaneous Apparel & Accessories	3	$ 26,081	$ 8,694	$ 8,591	$ 2,864
Shoe Stores					
Home Furnishings					
Furniture Stores	1	$750k-$1m	$750k-$1m	$250k-$500k	$250k-$500k
Floors, Drapery, & Upholstery	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Household Appliances & Electronics	3	$ 232,697	$ 77,566	$ 213,354	$ 71,118
Miscellaneous Home Furnishings	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Household & Personal Goods					
Computers & Software	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Videos, Music, & Musical Instruments					
Book Stores					
Used Merchandise & Pawnshops	3	$ 20,464	$ 6,821	$ 19,862	$ 6,621
Jewelry Stores	2	$ 281,977	$ 140,989	$ 112,220	$ 56,110
Sporting Goods	2	$ 137,021	$ 68,510	$ 131,557	$ 65,779
Hobbies, Toys, & Crafts	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Office Supply Stores	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Gifts, Novelty, & Souvenirs	2	$ 234,929	$ 117,464	$ 183,116	$ 91,558
Florists	2	$ 144,887	$ 72,443	$ 144,189	$ 72,095
Tobacco Stores					
Miscellaneous Retail					
Miscellaneous Retail	13	$ 949,730	$ 73,056	$ 274,055	$ 21,081
Manufactured Homes					
Other non-classified Retail Establishments					
Non-store Retailers					
Non-store Retailers	12	$ 16,192,573	$ 1,349,381	$ 856,757	$ 71,396
RETAIL TOTAL (includes actual sales displayed as ranges)	**103**	**$ 88,389,774**	**$ 858,153**	**$ 28,734,807**	**$ 278,979**

Appendix 6 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Mason Valley - Lyon County, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Non-Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Agriculture, Forestry, Fishing and Hunting	4	$ 1,076,647	$ 269,162	$ 485	$ 121
Mining					
Utilities	1	$100k-$250k	$100k-$250k	$100k-$250k	$100k-$250k
Construction	4	$ 2,100,490	$ 525,123	$ 137,409	$ 34,352
Manufacturing	13	$ 12,571,960	$ 967,074	$ 4,060,162	$ 312,320
Wholesale Trade	17	$ 55,217,126	$ 3,248,066	$ 8,294,237	$ 487,896
Transportation and Warehousing	2	$ 49,344	$ 24,672	$ 49,344	$ 24,672
Information	4	$ 237,976	$ 59,494	$ 125,149	$ 31,287
Finance and Insurance	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Real Estate and Rental and Leasing	10	$ 2,116,527	$ 211,653	$ 676,250	$ 67,625
Professional, Scientific, and Technical Services	6	$ 456,362	$ 76,060	$ 412,118	$ 68,686
Management of Companies and Enterprises					
Administrative and Support and Waste	5	$ 17,243	$ 3,449	$ 12,447	$ 2,489
Educational Services	4	$ 15,073	$ 3,768	$ 15,073	$ 3,768
Health Care and Social Assistance	2	$ 284,351	$ 142,175	$ 19,437	$ 9,718
Arts, Entertainment, and Recreation	2	$ 2,557,272	$ 1,278,636	$ 2,552,616	$ 1,276,308
Other Accommodation and Food Serv (other than those listed in Retail)					
Other Services (except Public Administration)	12	$ 1,499,283	$ 124,940	$ 623,674	$ 51,973
Public Administration					
Non-classified Establishments	1	$250k-$500k	$250k-$500k	$ -	$ -
NON-RETAIL TOTAL (includes actual sales displayed as ranges):	**88**	**$ 78,759,794**	**$ 894,998**	**$ 17,207,296**	**$ 195,537**
GRAND TOTAL (Retail & Non-Retail Industries):	**191**	**$ 167,149,568**	**$ 875,129**	**$ 45,942,103**	**$ 240,535**

Sales are reported by business entities at the county level. Retail sales for business entities with more than one location in a given county are calculated by dividing the total sales by the number of locations under the same ownership.

'Non-store Retailers' include mobile home dealers, food caterers, catalogue & mail order houses, merchandising machine operators, direct selling organizations, fuel oil and natural gas dealers, news dealers, & newsstands.

'Non-classified Establishments' include entities not classified by the Department of Taxation according to the North American Industrial Classification System (NAICS)

Appendix 7 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Smith Valley - Lyon County, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Home Improvement & Department Stores					
Home Improvement & Building Materials					
Paint, Glass, & Hardware					
Nurseries, Lawn, & Garden Supplies	1	$100k-$250k	$100k-$250k	$100k-$250k	$100k-$250k
Major Department Stores					
Variety & General Merchandise					
Food - At Home					
Supermarkets, Markets, & Convenience Stores Gas Stations	4	$ 621,113	$ 155,278	$ 296,753	$ 74,188
Candy, Bakeries, & Miscellaneous Food Stores					
Liquor Stores					
Drug Stores & Pharmacies					
Food - Away from Home					
Restaurants & other Eating Establishments					
Drinking Establishments	2	$ 500,475	$ 250,238	$ 479,009	$ 239,504
Casino, Casino Hotel					
Motorized Equipment					
New & Used Auto Dealers					
Used Auto Dealers					
Auto Supply Stores					
Boat, Motorcycle, RV, & Misc. Dealers					
Apparel					
Women's Apparel & Accessories					
Men's, Children, & Family Apparel					
Miscellaneous Apparel & Accessories	2	$ 37,219	$ 18,610	$ 4,550	$ 2,275
Shoe Stores					
Home Furnishings					
Furniture Stores					
Floors, Drapery, & Upholstery					
Household Appliances & Electronics					
Miscellaneous Home Furnishings					
Household & Personal Goods					
Computers & Software					
Videos, Music, & Musical Instruments					
Book Stores					
Used Merchandise & Pawnshops	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Jewelry Stores	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Sporting Goods					
Hobbies, Toys, & Crafts					
Office Supply Stores					
Gifts, Novelty, & Souvenirs	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Florists					
Tobacco Stores					
Miscellaneous Retail					
Miscellaneous Retail	2	$ 25,799	$ 12,899	$ 24,059	$ 12,029
Manufactured Homes					
Other non-classified Retail Establishments					
Non-store Retailers					
Non-store Retailers	3	$ 859	$ 286	$ 859	$ 286
RETAIL TOTAL (includes actual sales displayed as ranges):	**17**	**$ 1,354,475**	**$ 79,675**	**$ 974,215**	**$ 57,307**

Appendix 7 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Smith Valley - Lyon County, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Non-Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Agriculture, Forestry, Fishing and Hunting	3	$ 544,903	$ 181,634	$ 71,556	$ 23,852
Mining					
Utilities					
Construction	1	$500k-$750k	$500k-$750k	$250k-$500k	$250k-$500k
Manufacturing	4	$ 357,945	$ 89,486	$ 296,121	$ 74,030
Wholesale Trade	6	$ 7,634,317	$ 1,272,386	$ 1,226,560	$ 204,427
Transportation and Warehousing					
Information	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Finance and Insurance					
Real Estate and Rental and Leasing					
Professional, Scientific, and Technical Services					
Management of Companies and Enterprises	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Administrative and Support and Waste	1	$100k-$250k	$100k-$250k	$25k-$100k	$25k-$100k
Educational Services	2	$ 7,655	$ 3,827	$ 7,655	$ 3,827
Health Care and Social Assistance					
Arts, Entertainment, and Recreation					
Other Accommodation and Food Serv (other than those listed in Retail)					
Other Services (except Public Administration)	4	$ 743,404	$ 185,851	$ 73,158	$ 18,289
Public Administration					
Non-classified Establishments	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
NON-RETAIL TOTAL (includes actual sales displayed as ranges):	**24**	**$ 10,048,116**	**$ 418,672**	**$ 2,117,801**	**$ 88,242**
GRAND TOTAL (Retail & Non-Retail Industries):	**41**	**$ 11,402,591**	**$ 278,112**	**$ 3,092,016**	**$ 75,415**

Sales are reported by business entities at the county level. Retail sales for business entities with more than one location in a given county are calculated by dividing the total sales by the number of locations under the same ownership.

'Non-store Retailers' include mobile home dealers, food caterers, catalogue & mail order houses, merchandising machine operators, direct selling organizations, fuel oil and natural gas dealers, news dealers, & newsstands.

'Non-classified Establishments' include entities not classified by the Department of Taxation according to the North American Industrial Classification System (NAICS)

Appendix 8 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Hawthorn, Schurz, & Walker Lake - Mineral County, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Home Improvement & Department Stores					
Home Improvement & Building Materials	1	$100k-$250k	$100k-$250k	$100k-$250k	$100k-$250k
Paint, Glass, & Hardware	2	$ 1,358,829	$ 679,414	$ 1,176,389	$ 588,194
Nurseries, Lawn, & Garden Supplies					
Major Department Stores					
Variety & General Merchandise	3	$ 468,065	$ 156,022	$ 395,439	$ 131,813
Food - At Home					
Supermarkets, Markets, & Convenience Stores Gas Stations	7	$ 23,462,369	$ 3,351,767	$ 4,536,401	$ 648,057
Candy, Bakeries, & Miscellaneous Food Stores	2	$ 21,454	$ 10,727	$ 20,763	$ 10,381
Liquor Stores	2	$ 916,088	$ 458,044	$ 690,630	$ 345,315
Drug Stores & Pharmacies					
Food - Away from Home					
Restaurants & other Eating Establishments	10	$ 1,860,835	$ 186,083	$ 1,853,140	$ 185,314
Drinking Establishments	7	$ 1,243,664	$ 177,666	$ 1,228,745	$ 175,535
Casino, Casino Hotel					
Motorized Equipment					
New & Used Auto Dealers	1	$100k-$250k	$100k-$250k	$100k-$250k	$100k-$250k
Used Auto Dealers					
Auto Supply Stores	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Boat, Motorcycle, RV, & Misc. Dealers					
Apparel					
Women's Apparel & Accessories					
Men's, Children, & Family Apparel					
Miscellaneous Apparel & Accessories	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Shoe Stores					
Home Furnishings					
Furniture Stores					
Floors, Drapery, & Upholstery	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Household Appliances & Electronics	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Miscellaneous Home Furnishings					
Household & Personal Goods					
Computers & Software	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Videos, Music, & Musical Instruments	1	$100k-$250k	$100k-$250k	$25k-$100k	$25k-$100k
Book Stores	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Used Merchandise & Pawnshops	2	$ 77,034	$ 38,517	$ 59,960	$ 29,980
Jewelry Stores	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Sporting Goods	1	$25k-$100k	$25k-$100k	$0k-$25k	$0k-$25k
Hobbies, Toys, & Crafts					
Office Supply Stores					
Gifts, Novelty, & Souvenirs	4	$ 12,226	$ 3,056	$ 12,226	$ 3,056
Florists	2	$ 92,821	$ 46,410	$ 78,759	$ 39,380
Tobacco Stores					
Miscellaneous Retail					
Miscellaneous Retail	7	$ 389,868	$ 55,695	$ 328,334	$ 46,905
Manufactured Homes					
Other non-classified Retail Establishments					
Non-store Retailers					
Non-store Retailers	3	$ 2,052,854	$ 684,285	$ 529,886	$ 176,629
RETAIL TOTAL (includes actual sales displayed as ranges):	**62**	**$ 32,705,945**	**$ 527,515**	**$ 11,422,712**	**$ 184,237**

Appendix 8 - 2007 Retail & Non-Retail Revenues & Taxable Sales

Hawthorn, Schurz, & Walker Lake - Mineral County, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Non-Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Agriculture, Forestry, Fishing and Hunting	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Mining	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Utilities					
Construction	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Manufacturing	2	$ 1,733	$ 867	$ 390	$ 195
Wholesale Trade	6	$ 9,533,002	$ 1,588,834	$ 2,693,912	$ 448,985
Transportation and Warehousing					
Information					
Finance and Insurance	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Real Estate and Rental and Leasing					
Professional, Scientific, and Technical Services	3	$ 31,043	$ 10,348	$ 16,269	$ 5,423
Management of Companies and Enterprises					
Administrative and Support and Waste					
Educational Services	2	$ 15,936	$ 7,968	$ 15,744	$ 7,872
Health Care and Social Assistance					
Arts, Entertainment, and Recreation	2	$ 2,111,693	$ 1,055,846	$ 2,060,840	$ 1,030,420
Other Accommodation and Food Serv (other than those listed in Retail)					
Other Services (except Public Administration)	4	$ 697,991	$ 174,498	$ 183,109	$ 45,777
Public Administration					
Non-classified Establishments					
NON-RETAIL TOTAL (includes actual sales displayed as ranges):	**23**	**$ 12,534,964**	**$ 544,998**	**$ 5,076,526**	**$ 220,719**
GRAND TOTAL (Retail & Non-Retail Industries):	**85**	**$ 45,240,909**	**$ 532,246**	**$ 16,499,238**	**$ 194,109**

Sales are reported by business entities at the county level. Retail sales for business entities with more than one location in a given county are calculated by dividing the total sales by the number of locations under the same ownership.

'Non-store Retailers' include mobile home dealers, food caterers, catalogue & mail order houses, merchandising machine operators, direct selling organizations, fuel oil and natural gas dealers, news dealers, & newsstands.

'Non-classified Establishments' include entities not classified by the Department of Taxation according to the North American Industrial Classification System (NAICS)

Appendix 9 - 2005 Retail & Non-Retail Revenues & Taxable Sales

Douglas County Portion of Walker Basin, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Home Improvement & Department Stores					
Home Improvement & Building Materials					
Paint, Glass, & Hardware					
Nurseries, Lawn, & Garden Supplies					
Major Department Stores					
Variety & General Merchandise					
Food - At Home					
Supermarkets, Markets, & Convenience Stores Gas Stations					
Candy, Bakeries, & Miscellaneous Food Stores					
Liquor Stores					
Drug Stores & Pharmacies					
Food - Away from Home					
Restaurants & other Eating Establishments					
Drinking Establishments	1	$25k-$100k	$25k-$100k	$25k-$100k	$25k-$100k
Casino, Casino Hotel					
Motorized Equipment					
New & Used Auto Dealers					
Used Auto Dealers					
Auto Supply Stores					
Boat, Motorcycle, RV, & Misc. Dealers					
Apparel					
Women's Apparel & Accessories					
Men's, Children, & Family Apparel					
Miscellaneous Apparel & Accessories					
Shoe Stores					
Home Furnishings					
Furniture Stores					
Floors, Drapery, & Upholstery					
Household Appliances & Electronics					
Miscellaneous Home Furnishings					
Household & Personal Goods					
Computers & Software					
Videos, Music, & Musical Instruments					
Book Stores					
Used Merchandise & Pawnshops					
Jewelry Stores					
Sporting Goods					
Hobbies, Toys, & Crafts	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Office Supply Stores					
Gifts, Novelty, & Souvenirs	1	$0k-$25k	$0k-$25k	$0k-$25k	$0k-$25k
Florists					
Tobacco Stores					
Miscellaneous Retail					
Miscellaneous Retail	8	$ 199,635	$ 24,954	$ 176,263	$ 22,033
Manufactured Homes					
Other non-classified Retail Establishments					
Non-store Retailers					
Non-store Retailers					
RETAIL TOTAL (includes actual sales displayed as ranges):	**11**	**$ 228,438**	**$ 20,767**	**$ 203,055**	**$ 18,460**

Appendix 9 - 2005 Retail & Non-Retail Revenues & Taxable Sales

Douglas County Portion of Walker Basin, Nevada

(Source: Nevada Department of Taxation for specific use by Center For Regional Studies, University of Nevada, Reno)

Non-Retail Industries	*Locations*	*Total Revenue*	*Average Revenue*	*Total Taxable Sales*	*Average Taxable Sales*
Agriculture, Forestry, Fishing and Hunting					
Mining					
Utilities					
Construction					
Manufacturing					
Wholesale Trade					
Transportation and Warehousing					
Information					
Finance and Insurance					
Real Estate and Rental and Leasing					
Professional, Scientific, and Technical Services					
Management of Companies and Enterprises					
Administrative and Support and Waste					
Educational Services					
Health Care and Social Assistance					
Arts, Entertainment, and Recreation					
Other Accommodation and Food Serv (other than those listed in Retail)					
Other Services (except Public Administration)					
Public Administration					
Non-classified Establishments					
NON-RETAIL TOTAL (includes actual sales displayed as ranges):	**0**				
GRAND TOTAL (Retail & Non-Retail Industries):	**11**	**$ 228,438**	**$ 20,767**	**$ 203,055**	**$ 18,460**

Sales are reported by business entities at the county level. Retail sales for business entities with more than one location in a given county are calculated by dividing the total sales by the number of locations under the same ownership.

'Non-store Retailers' include mobile home dealers, food caterers, catalogue & mail order houses, merchandising machine operators, direct selling organizations, fuel oil and natural gas dealers, news dealers, & newsstands.

'Non-classified Establishments' include entities not classified by the Department of Taxation according to the North American Industrial Classification System (NAICS)

Appendix 10 - Agricultural Field Summary

Mason & Smith Valleys - Lyon County, Nevada

Mason Valley

Field or Crop Type	Fields Using Groundwater	Acres	Fields Using Ground & Surface Water	Acres	Fields Using Surface Water	Acres	Total Number of Fields	%	Total Acres	%	Estimated Value Per Acre	Total Estimated Value
Alfalfa	76	2,843.5	533	18,437.7	198	4,661.2	807	63.5%	25,942.3	68.0%	$936	$24,282,037
Brush	1	4.2	4	133.7	2	208.8	7	0.6%	346.7	0.9%	No Value	
Corn[1]			38	1,789.8	4	100.9	42	3.3%	1,890.7	5.0%	$90	$170,160
Dry Grass[1]					4	107.2	4	0.3%	107.2	0.3%	$90	$9,652
Fallow	15	360.2	74	1,584.4	55	1,120.2	144	11.3%	3,064.9	8.0%	No Value	
Feed Lot			5	31.1			5	0.4%	31.1	0.1%	No Value	
Forage Crop[1]			2	62.2	43	754.1	45	3.5%	816.3	2.1%	$90	$73,463
Garlic[2]			3	140.8	1	71.8	4	0.3%	212.5	0.6%	$1,150	$244,416
Grain[3]	4	82.7	20	574.3	7	184.2	31	2.4%	841.2	2.2%	$100	$84,122
Grapes			1	3.2	4	5.0	5	0.4%	8.2	0.0%	$5,330	$43,535
Grass[4]	3	74.8	19	551.8	2	150.8	24	1.9%	777.4	2.0%	$936	$727,675
Lettuce			5	248.9			5	0.4%	248.9	0.7%	$7,000	$1,742,592
Oat[5]			3	103.6			3	0.2%	103.6	0.3%	$468	$48,478
Onion[6]	6	321.0	59	2,031.7	3	92.2	68	5.4%	2,444.9	6.4%	$5,500	$13,446,873
Pasture[1]	2	5.8	34	508.8	34	549.1	70	5.5%	1,063.7	2.8%	$90	$95,732
Turf[7]			6	257.5	1	2.0	7	0.6%	259.6	0.7%	$16,553	$4,296,761
Totals	**107**	**3,692.2**	**806**	**26,459.6**	**358**	**8,007.4**	**1,271**	**100.0%**	**38,159.2**	**100.0%**		**$45,265,495**

Smith Valley

Field or Crop Type	Fields Using Groundwater	Acres	Fields Using Ground & Surface Water	Acres	Fields Using Surface Water	Acres	Total Number of Fields	%	Total Acres	%	Estimated Value Per Acre	Total Estimated Value
Alfalfa	91	4,040.2	78	4,105.8	103	3,257.6	272	48.5%	11,403.6	55.9%	$936	$10,673,801
Brush			1	16.4	2	26.8	3	0.5%	43.2	0.2%	No Value	
Fallow	36	1,024.0	42	1,545.3	33	742.2	111	19.8%	3,311.5	16.2%	No Value	
Feed Lot					4	106.8	4	0.7%	106.8	0.5%	No Value	
Grain[3]			3	159.6			3	0.5%	159.6	0.8%	$100	$15,959
Grass[4]	13	424.5	20	1,052.8	20	487.4	53	9.4%	1,964.7	9.6%	$936	$1,838,955
Pasture[1]	12	204.0	41	1,701.2	62	1,505.4	115	20.5%	3,410.6	16.7%	$90	$306,950
Total	**152**	**5,692.7**	**185**	**8,581.0**	**224**	**6,126.2**	**561**	**100.0%**	**20,399.9**	**100.0%**		**$12,835,666**

Grand Total	**259**	**9,384.9**	**991**	**35,040.6**	**582**	**14,133.6**	**1,832**		**58,559.1**			**$58,101,161**

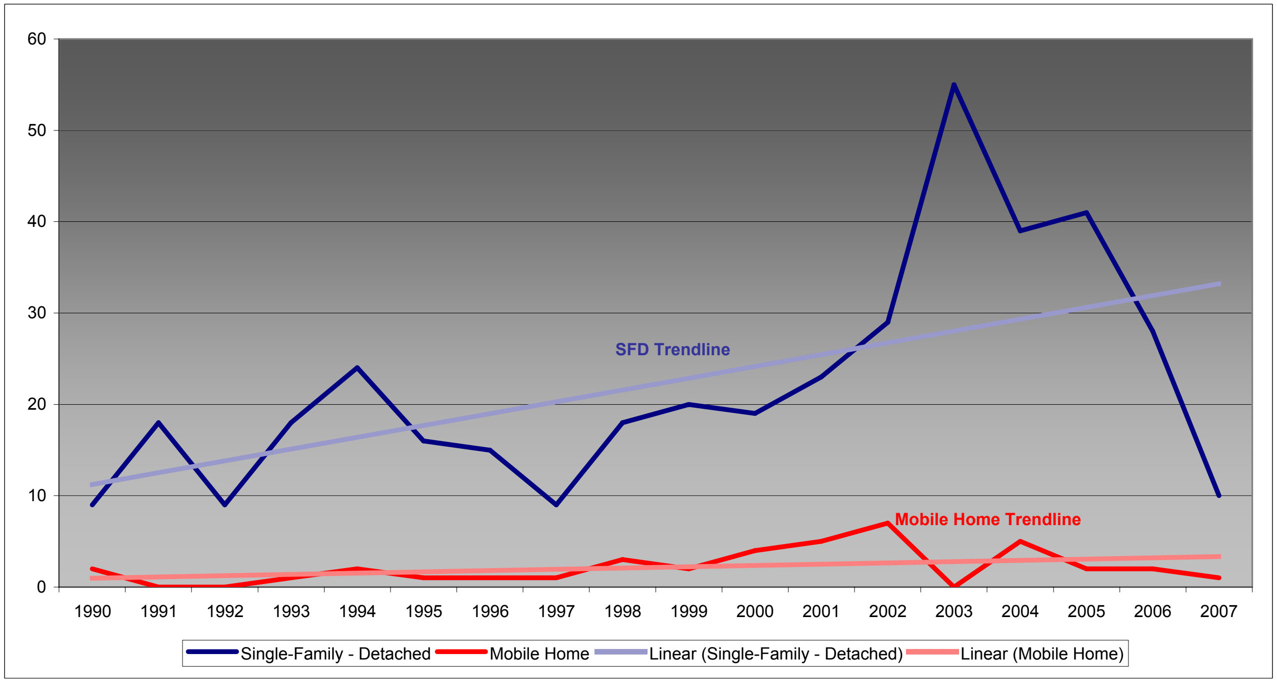
1. Crop budgets are not available for corn, dry grass, forage crop, & pasture. As a result, the value per acre of alfalfa hay "aftermath grazing" is used.
2. Approximate values for garlic obtained from John Snyder (8 tons per acre @ $0.22 per pound).
3. Crop budget for grain is not available. Grain values are assumed to be similar to oat crops.
4. Crop budget for grass is not available. Grass values are assumed to be similar to alfalfa.
5. Approximate values for oats obtained from John Snyder.
6. Crop budget for onions based on CABNR estimates of $6,000 per acre for red & white onions and $4,050 for yellow onions. Onion types grown in Mason Valley is estimated to be 80-85% white and red onions.
7. Crop budget (retail) for turf obtained from Western Turf (Reno, NV).

Sources:
2007 & 2008 field mapping conducted on 2006 1-meter aerial photography (NAIPS).
2008 crop budgets developed by CABNR/UNCE, University of Nevada, Reno.
Groundwater Place of Use data from NDWR and Decree surface-water data based on the C-125 decree for Walker Basin as calculated by the Desert Research Institute (DRI).

Appendix 11 - Residential Units by Type & Year Built

Smith Valley - Lyon County, Nevada

Calendar Year	Single-Family - Detached	Single-Family - Attached	Mobile Home	Multi-Family	Total
1990	**9**	0	**2**	0	**11**
1991	**18**	0	**0**	0	**18**
1992	**9**	0	**0**	0	**9**
1993	**18**	0	**1**	0	**19**
1994	**24**	0	**2**	0	**26**
1995	**16**	0	**1**	0	**17**
1996	**15**	0	**1**	0	**16**
1997	**9**	0	**1**	0	**10**
1998	**18**	0	**3**	0	**21**
1999	**20**	0	**2**	0	**22**
2000	**19**	0	**4**	0	**23**
2001	**23**	0	**5**	0	**28**
2002	**29**	0	**7**	0	**36**
2003	**55**	0	**0**	0	**55**
2004	**39**	0	**5**	0	**44**
2005	**41**	0	**2**	0	**43**
2006	**28**	0	**2**	0	**30**
2007	**10**	0	**1**	0	**11**
TOTAL	**400**	**0**	**39**	**0**	**439**
%	**91.1%**	0.0%	**8.9%**	0.0%	**100.0%**
1990-1999 Avg Per Year	**15.6**		**1.3**		**16.9**
2000-2007 Avg Per Year	**30.5**		**3.3**		**33.8**
1990-2007 Avg Per Year	**22.2**		**2.2**		**24.4**

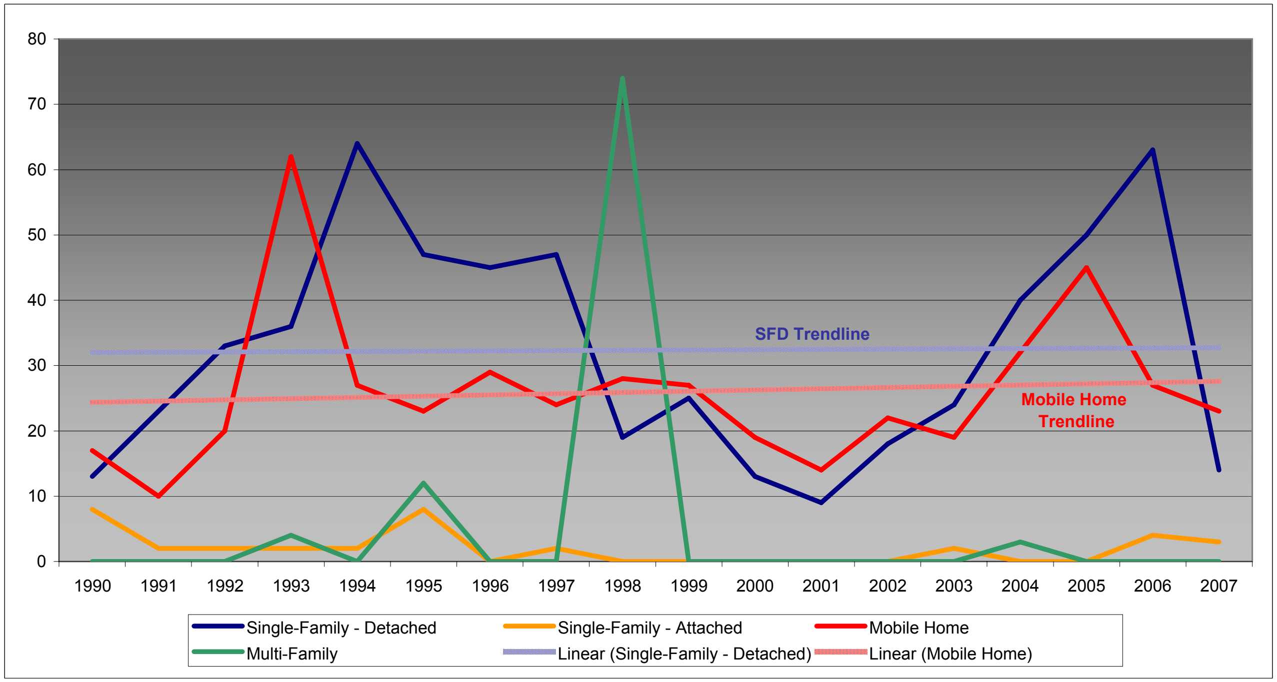


Source: Lyon County Assessor's Data

Appendix 12 - Residential Units by Type & Year Built

Mason Valley - Lyon County, Nevada

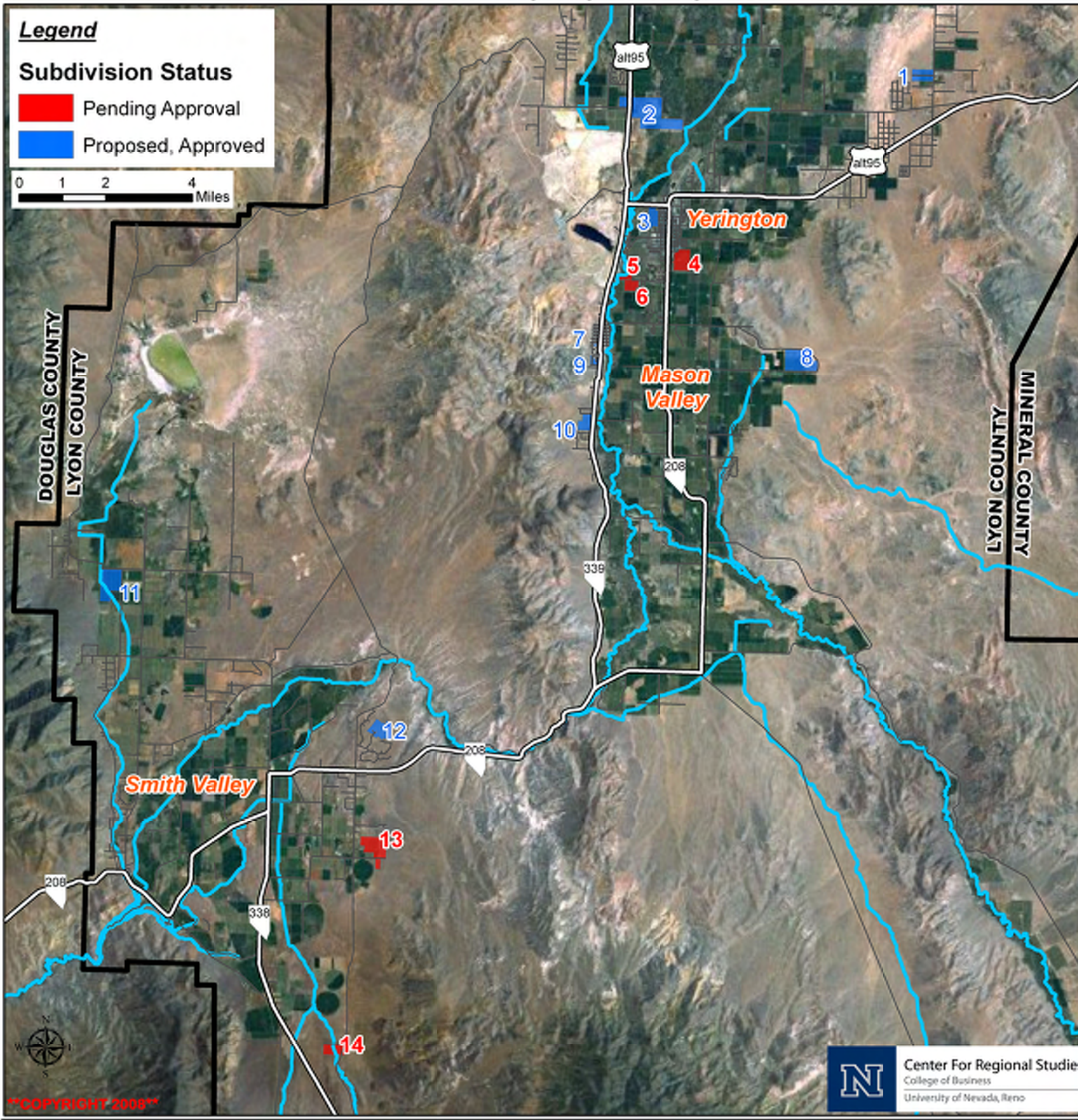
Calendar Year	Single-Family - Detached	Single-Family - Attached	Mobile Home	Multi-Family	Total
1990	13	8	17	0	38
1991	23	2	10	0	35
1992	33	2	20	0	55
1993	36	2	62	4	104
1994	64	2	27	0	93
1995	47	8	23	12	90
1996	45	0	29	0	74
1997	47	2	24	0	73
1998	19	0	28	74	121
1999	25	0	27	0	52
2000	13	0	19	0	32
2001	9	0	14	0	23
2002	18	0	22	0	40
2003	24	2	19	0	45
2004	40	0	32	3	75
2005	50	0	45	0	95
2006	63	4	27	0	94
2007	14	3	23	0	40
TOTAL	583	35	468	93	1,179
%	49.4%	3.0%	39.7%	7.9%	100.0%
1990-1999 Avg Per Year	35.2	2.6	26.7	9.0	73.5
2000-2007 Avg Per Year	28.9	1.1	25.1	0.4	55.5
1990-2007 Avg Per Year	32.4	1.9	26.0	5.2	65.5



Source: Lyon County Assessor's Data

Appendix 13 - Proposed and Pending Residential Subdivisions (September 2007)

Smith and Mason Valleys - Lyon County, Nevada



Annual Unit Absorption and Population Increase by Subdivision

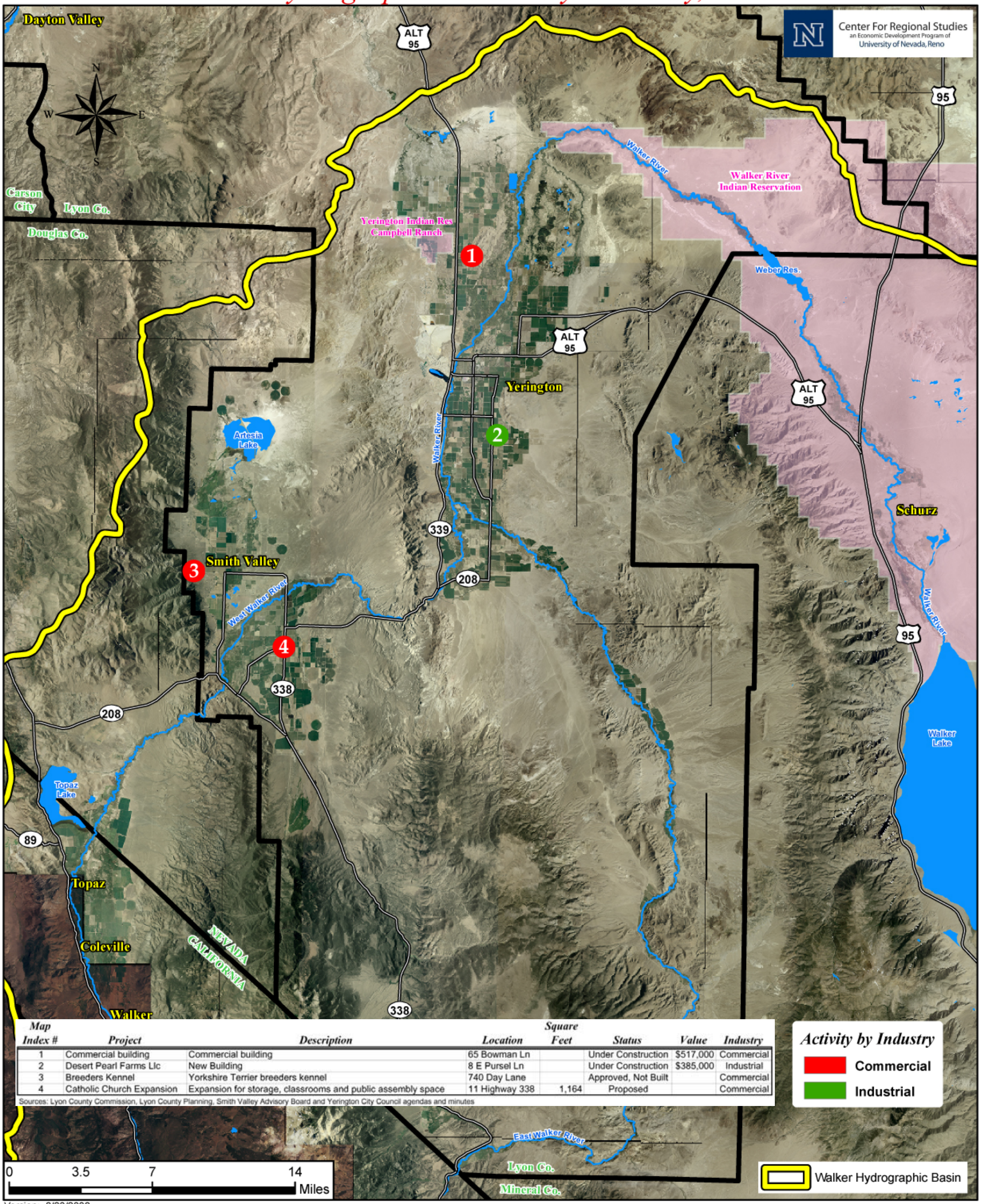
Proposed-Approved Subdivisions are shown in blue text, Subdivisions Pending Approval are shown in red text

City	Index	Project Name	Project Location	Status	Unabsorbed Units Left	Est. Annual Absorption	Est. Occupancy Rate	Est. Household Size	Units Year 1: 2008	Units Year 2: 2009	Units Year 3: 2010	Units Year 4: 2011	Units Year 5: 2012	Units Year 6: 2013	Population Year 1: 2008	Population Year 2: 2009	Population Year 3: 2010	Population Year 4: 2011	Population Year 5: 2012	Population Year 6: 2013
									Annual # of UNITS Absorbed by Subdivision						Annual POPULATION Increase by Subdivision					
Yerington	1	Silver Sage Subdivision	51 Bybee Ln	Tentative Maps	41	4	0.89	2.3			4	4	4	4	-	-	8	8	8	8
Yerington	2	Grand View Estates/Yerington Ventures	Luzier Ln/Alt95	Tentative Maps	768	4	0.89	2.3			4	4	4	4	-	-	8	8	8	8
Yerington	3	Walker River Country Club	South of Goldfield Ave	Tentative Maps	569	4	0.89	2.3			4	4	4	4	-	-	8	8	8	8
Yerington	4	Rose Creek Estates	SR208/Haynes Dr	Feasibility Report	346	4	0.89	2.3				4	4	4	-	-	-	8	8	8
Yerington	5	Rio Vista Subdiv.	Rio Vista Dr	Feasibility Report	60	4	0.89	2.3				4	4	4	-	-	-	8	8	8
Yerington	6	River Meadows Subdiv	Rio Vista Dr	Feasibility Report	132	4	0.89	2.3				4	4	4	-	-	-	8	8	8
Mason Valley	7	Bates Estates	Second South St	Tentative Maps	6	4	0.91	2.6			4	2	-	-	-	-	9	5	-	-
Mason Valley	8	Grand View Subdivision	41 E Pursell Ln	Tentative Maps	7	4	0.91	2.6			4	3	-	-	-	-	9	7	-	-
Mason Valley	9	Walker River Subdiv.	off Osterstone Ave	Tentative Maps	32	4	0.91	2.6			4	4	4	4	-	-	9	9	9	9
Mason Valley	10	Rebecca Ranch Subdiv	Rebecca Rd/Hwy 339	Tentative Maps	63	4	0.91	2.6			4	4	4	4	-	-	9	9	9	9
Smith Valley	11	Pinion Ranch Estates	Lower Colony Rd	Tentative Maps	40	4	0.91	2.6			4	4	4	4	-	-	9	9	9	9
Smith Valley	12	Sierra Desert View Est	off Desert View Dr	Tentative Maps	5	4	0.91	2.6			4	1	-	-	-	-	9	2	-	-
Smith Valley	13	Sovereign Enterprises	Grantview Dr/Hudson Aurora	Feasibility Report	9	4	0.91	2.6				4	4	1	-	-	-	9	9	2
Smith Valley	14	O'Banion Parcel	Great Basin Trl/SR338	Feasibility Report	4	4	0.91	2.6				4	-	-	-	-	-	9	-	-
				TOTALS:	2,013				-	-	36	50	40	37	-	-	80	109	86	79

Appendix 14

Proposed Commercial Activity - 2nd Quarter 2008

Walker Hydrographic Basin -- Lyon County, Nevada



Map Index #	Project	Description	Location	Square Feet	Status	Value	Industry
1	Commercial building	Commercial building	65 Bowman Ln		Under Construction	$517,000	Commercial
2	Desert Pearl Farms Llc	New Building	8 E Pursel Ln		Under Construction	$385,000	Industrial
3	Breeders Kennel	Yorkshire Terrier breeders kennel	740 Day Lane		Approved, Not Built		Commercial
4	Catholic Church Expansion	Expansion for storage, classrooms and public assembly space	11 Highway 338	1,164	Proposed		Commercial

Sources: Lyon County Commission, Lyon County Planning, Smith Valley Advisory Board and Yerington City Council agendas and minutes

Version: 8/20/2008

PROJECT J: WILD HORSE AND BURRO MARKETING STUDY PURSUANT TO H.R. 2419, P.L. 109-103, SECTION 208

BLM WILD HORSE AND BURRO POLICY: AUCTION DESIGN AND HORSE PARK FEASIBILITY STUDY

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In legislation passed in 1971, Congress declared that "wild free-roaming horses and burros are living symbols of the historic and pioneer spirit of the West; that they contribute to the diversity of life forms within the Nation and enrich the lives of the American people." And further that it "is the policy of Congress that wild free-roaming horses and burros shall be protected from capture, branding, harassment, or death; and to accomplish this they are to be considered in the area where presently found, as an integral part of the natural system of the public lands" (US Code 2006).[1]

While there is little dispute about both the historic and symbolic nature of the free-roaming animals, the extent to which the wild horses and burros are an 'integral part of the natural system of the public lands,' has been a matter for debate and a focus of policy discussion. Despite the Congressional declaration there are concerns that, collectively with private livestock and native grazing animals, excessive numbers will contribute to rangeland degradation. This concern is heightened as evidence is gathered that confirms that the degradation can facilitate the spread of invasive plant species, changing wildfire cycles and stressing native ecosystems (Whisenant 1990).

The policy issues are particularly relevant for Nevada where about half of the 33,000 animals on federal public lands are to be found. These animals represent only a portion of the population of interest since a similar number, about 30,000 nationally, have been removed from the range in order to address the economic and ecological concerns noted above. Although the overall costs of maintaining the horses in captivity has increased, budget allocations for the BLM horse management program has fallen.[2] At the same time the rate of adoptions of horses in captivity by private citizens has fallen from 10,225 in 1998 to 4,732 in 2007.

Since the adoption of wild horses by members of the public plays an important role in the overall management policy, a research team in the Department of Resource Economics at the University of Nevada, Reno investigated several aspects of wild horse adoption, with a particular focus on how auctions have been used to distribute the animals. Previous work by Harris et al. (2005) included surveys of potential adopters which determined values they place on different characteristics of the horses. The authors discovered that there is significant heterogeneity in preferences. This chapter extends the original study, by (i) examining adopter preferences directly from horse auction data, (ii) conducting experimental research on auction design that focuses on the price impact of the preference heterogeneity issue, and (iii) using the original survey data in combination with other information to simulate potential revenues of a national wild horse and burro adoption center in Nevada.

This chapter is structured as follows: Section II presents a brief overview of the field auctions, while Section III discusses the experiments in auction design. This section begins by introducing the methodology of 'design economics' before presenting preliminary results from the study. Section IV presents the results of the stochastic revenue simulation study of the potential national wild horse and burro adoption center and Section V is a conclusion section.

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[1] Public law 92-195; the Wild Free-Roaming Horses and Burros Act of 1971. Additional background on the legislative and regulatory regimes are in Appendix 1.

[2] We refer to 'horses' as a shorthand for 'horse and burros' throughout the document unless otherwise noted.

WILD HORSE AND BURRO AUCTION MARKETS

Field auctions for wild horses are conducted both on site where the horses are housed and over the internet. This section reviews the data from each auction type. The data sets were provided by the BLM Western Regional office and BLM Eastern States office. Data from the Western Regional office contains the full bidding history of U.S Internet Wild Horse and Burro auctions between 2006 and 2008 in which 525 animals were sold. The recorded data includes characteristics of the animals that include age, color, gender, type, as well as the winning bid, and the number of bids for the adopted animals. The second data set contains similar variables from the in-person adoptions for the period from between 1997 to 2008 and contains a total of 26817 observations. The tables and the discussion below restrict attention to on-site data from 2006-2008 in order to make the most relevant comparison to the internet data.

There are some differences between the datasets. For example, the internet technology allows collection of data on the number of bidders for each adoption event and specific actions that include bid revisions. This data is not available for the onsite adoptions. The dataset for the onsite adoptions does contain data on the level of training of the horses; information that is omitted from the internet auctions.

Table 1 indicates that the group of internet bidders were more conservative than their counterparts onsite at the expositions as evidenced by the lower mean bid. Further, the value of the standard deviation is much lower for the internet auctions, 110 as compared to 329, demonstrating an element of consistency in the bids across bidders relative to the onsite auctions. Regression analyses that control for the characteristics of the horses for sale provide additional information on bidder motivation. Table 2 presents the range of characteristics among the horses as they relate to color and type.

Table 1. Live auction data, 2006-2008.

Auction Type	Number	Mean	Std. Dev.	Min	Max
Internet	2308	198.27	110.10	125	1095
Onsite	4791	230.25	328.58	125	7800

Table 2. Characteristics - color and type.

Color	Color Grouping	Code
bscb	bay, sorrel, chestnut, brown	*1*
bb	blue roan, blue	*2*
rrs	red, red roan, strawberry roan	*3*
dbg	dun, buckskin, grulla	*4*
wcp	white, cremello, palomino	*5*
ppg	pink, pinto, gray	*6*
black	Black	*7*
appaloosa	Appaloosa	*8*
O9ther	Other	*9*

Table 3. Characteristics - color and type (continued).

Type	Type Definition	
Colt	age less than 4, male, horse	*1*
Filly	age less than 4, female, horse	*2*
Gelding	gelding, horse or burro	*3*
Mare	age 4 or greater, female, horse	*4*
Jack	male, burro	*5*
Jenny	female, burro	*6*
Stud	age 4 or greater, male, horse	*7*
Others	Others	*8*

The analysis on characteristics showed that "*bscb" (*bay, sorrel, chestnut, and brown), "*wcp" (*white, cremello, and palomino), and "*dbg"* (dun, buckskin, and grulla) are the most popular color groups among the bidders. Further the level of training of the horse, only found in onsite datasets, had a critical impact on bidder valuations, with 'well-trained' horses receiving bids up to 75% greater than the untrained. Table 3 lists the proportion of trained horses in the on-site auction data, around 15.24% of the animals are trained among the animals between 2006 and 2008; the figure is much higher than the 7.23% among observations between 1998 and 2008, indicating a tendency to increase training. Given the revenue consequences, further analysis of the returns to training is warranted.

Table 3. Impact of training of wild horses.

Training	Observations	Percent	Bids	
			Mean	*Std. Dev*
TRAINED	730	15.24	$421	489.61
UNTRAINED	4061	84.76	$195	276.72

From Figure 1, "Gelding" and "Others" are the two favorite types in Onsite Adoption with the highest average bid amount, while the preferences are more evenly distributed among Internet-based adopters in terms of horse types. Regarding the color groups shown in Figure 2[3], *"dbg"* (dun, buckskin, and grulla) is the favorite group among onsite bidders followed by *"wcp"* (white, cremello,and palomino) , and for Internet bidders, *"bb"* (blue roan, and blue) and *"wcp"*(white, cremello,and palomino) yields the highest average bids. Overall, *"wcp"* (white, cremello, and palomino) color group exhibits attractiveness across two types of adoptions.

As mentioned above, number of bids information is only found in Internet Adoption data (see Table 4); "Gelding" ranks the highest among all type. Noticeably, comparing to the result shown by Figure 1, where "Gelding" did not generate the highest average bid amount, ongoing research is being undertaken to understand this result.

Further research is being conducted by using more sophisticated models to determine which of the bidding formats are more effective in eliciting the maximum willingness to pay for the animals.

[3] For Internet Adoption, "Other" color group has no observation.

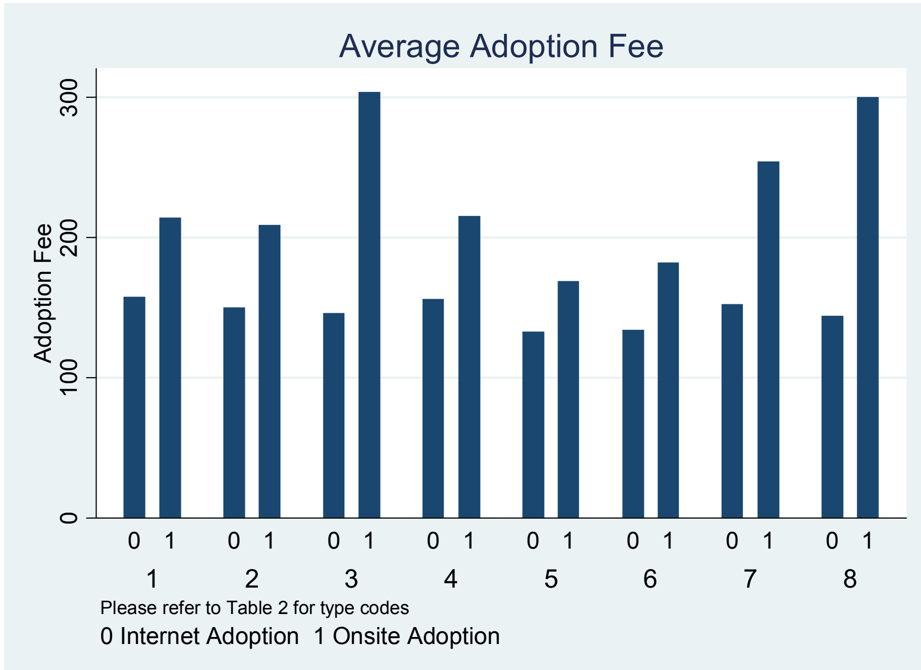

Figure 1. Average adoption fee between internet and onsite adoption over the type groups.

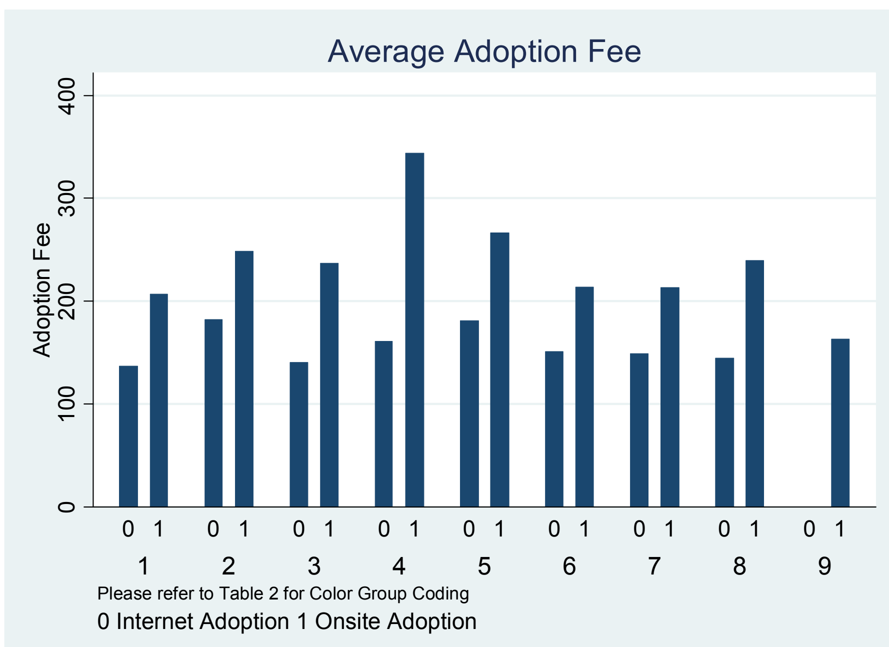

Figure 2. Average adoption fee between internet and onsite adoption over the color groups.

Table 4. Number of bids received by each type in Internet Adoptions.

Type	Type Definition	Number of Bids
Colt	age less than 4, male, horse	*359*
Filly	age less than 4, female, horse	*578*
Gelding	gelding, horse or burro	*723*
Mare	age 4 or greater, female, horse	*284*
Jack	male, burro	*74*
Jenny	female, burro	*79*
Stud	age 4 or greater, male, horse	*178*
Others	Others	*33*

AUCTION MARKET EXPERIMENTS

Design Economics

Auctions markets are an important method for allocating a wide variety of goods and services that include art, financial instruments, houses and horses. Because of their prevalence, a great deal of effort has been devoted to the theoretical study of auctions and this work has been recognized as one of the successful research programs in modern economic theory.

Auctions, like other market institutions, arise naturally as a result of the human propensity to "truck, barter, and exchange" (Smith 2007). However, there are also often intentional elements in market institutions either when creating them de novo or when placing constraints on the behavior of participants existing markets. Often, the intentional elements result from a regulatory process that is influenced by legislative, administrative, and judicial actors.[4] Perhaps surprisingly, only recently have economists begun to play a key role in the process of intentional market design. We believe that the value added by the economics profession is due largely to the development and refinement of experimental methods.

As in other sciences, experimental methods allow researchers to implement controlled changes in whatever phenomenon is under study and therefore to identify causal relationships. The usefulness of experimental methods in economics has been widely recognized by the profession as a whole as evidenced by the award of the Nobel Prize to Vernon Smith and Daniel Kahneman, two early contributors to the field.

Smith's fundamental contribution was to demonstrate that small changes in market institutions can have a large impact on economic efficiency. By announcing prices of transactions to traders in a double auction market, Smith showed prices move quickly to an efficient outcome, in contrast to an earlier study that had found similar markets without these characteristics were inefficient (Chamberlain 1948).[5]

Interestingly, Smith found that equilibrium is achieved in his double auction markets even though conditions that economic theory suggests are important, such as a large number of traders and price-taking behavior are absent. This result stresses the importance of the

[4] This discussion draws on Roth (2002).

[5] Kahneman's work at the intersection of psychology and economics has also had an enormous impact on the field but with less direct relevance to market design (see e.g. Kahneman 2003).

experimental approach for market design issues, and also the possibility for experimental results to spur advances in economic theory.[6]

Experimental methods are being used with increasing frequency to develop markets in areas as diverse as government auctions of electromagnetic spectrum, tax and tariff design, tradable pollution permits, water management in drought conditions, as well as in online commercial auctions and electricity markets. The flurry of activity in this area has led to the creation of the subfield of "design economics" (Roth 2002), which is thriving due to the high benefit/cost ratio associated with these efforts.

Experiments offer the benefit of being transparent and replicable, thus fostering informed debate about what are often contentious policy decisions. They are also relatively low in cost when compared to pilots conducted in field settings. Relative to pilot projects they reduce the possibility that the public will be exposed to policies with unanticipated negative consequences that can be costly to reverse. In brief, market design informed by experimental methods has an important role to play in the development and implementation of economic policy.

Wild Horse Auction Design Research

The market design effort to inform policy for wild horse adoption focuses on two alternative auction market structures; a sequential (SEQ) or good-by-good auction, and a right-to-choose (RTC) auction. In the SEQ each good is offered sequentially and the highest bidder purchases the good. In the RTC the highest bidder wins the right to choose from among the goods that are available at the time of that particular auction. The choice of market structures is motivated by the evidence of preference heterogeneity from both the survey data and the existing auction markets. Given the diversity of characteristics preferred by different adopters, it is often the case that there will be relatively little competition for a particular animal. Theoretical work and preliminary laboratory experiments suggest that the RTC can 'thicken markets' by creating competition across goods that are evaluated independently of each other in the SEQ setting. The experimental approach is straightforward. We sell sets of identical goods to subjects who are randomly allocated to the RTC and SEQ institutions. Ceteris paribus, differences in bidding behavior and auction revenues are therefore attributable to the different institutions.[7]

Theoretical research has shown that for risk-neutral bidders, revenue is equivalent in the two auctions, but that the RTC auction will outperform SEQ when bidders are risk-averse and subjects have heterogeneous preferences (Burgeut 2007). Intuitively, the possibility that one's preferred good will be chosen early makes the value of the later auctions less certain. Risk-averse buyers therefore are willing to pay a premium to secure their favored good in an early round.

---

[6] Smith and his colleagues also went on to make fundamental contributions to the field of applied market design with seminal studies in areas such as airline deregulation, and electricity and natural gas markets (Rassenti, Smith and Bullfinch 1982, McCabe, Rassenti and Smith 1991, Rassenti, Smith and McCabe 1994).

[7] We collect some additional information on characteristics of the bidders that include a measure of their attitudes to risk and demographics such as age, income and education. This allows a more careful analysis of the data when there are some differences in the subject pool across the two auction institutions.

The existing evidence on the performance of the RTC relative to the SEQ is from laboratory experiments using induced values and the results are generally supportive of the theory (Goeree, Plott, and Wooders 2004; Eliaz, Offerman, and Schotter 2005).8 Since we are interested in learning about the performance of the RTC institution in a setting similar to that of the BLM auction, we introduce real goods that are similar in value to the horses rather than the abstract 'goods' used in the laboratory studies. However, since we are recruiting bidders from the general public, rather than offering horses for sale, we use a variety of goods that we believe members of the general public will have an interest in.

In summary, and in contrast to the analysis of live auction data, experimental controls are used to insure that the effect of the auction institution is cleanly observed. The controls include the random allocation of subjects to the RTC and SEQ institutions, and the collection of additional information on risk attitudes which are known to have an impact on bidding behavior. Participants also complete a short survey that includes demographic and personality questions that will provide further controls in the analysis. The research therefore is a hybrid 'field experiment' that incorporates the most relevant elements of traditional field studies in economics with appropriate experimental controls (Harrison and List 2004).

Auction Design

In each auction session three goods were sold in three separate bidding processes. The goods included (i) hiking equipment, (ii) an Apple iPod and speaker system, and (iii) high quality wines. Each bundle has a retail value of approximately $250. Experimental sessions were conducted that varied the auction type (RTC vs. SEQ) and the information provided about the goods (high/low information). The study therefore consisted of a 2x2 factorial design with sessions allocated across the treatments as shown in Table 5.

Table 5. Experimental design.

	Information Condition	
Auction Type	Low	High
Right to Choose	8 sessions	12 sessions
Sequential	8 sessions	12 sessions

Each session contained either 5 or 6 bidders. In the SEQ treatments all goods were sold to the highest bidder at the second highest bid value. Similarly, in the RTC treatments the right-to-choose was sold to the highest bidder at the second highest bid value. Full instructions for both auction institutions are in Appendix B. In addition to the auction each session included a risk elicitation exercise based on the design of Holt and Laury (2002) and a short survey. These materials are also included in Appendix B.

Experimental Results

Figure 3 presents results from the risk elicitation protocol which yields evidence of risk aversion among bidders in both auction institutions. In addition Table 6 provides evidence from

[8] With induced values, subjects are assigned a value for an abstract good (Smith 1976). If they are successful in purchasing the 'good' at a price below the assigned value, the difference between their value and the purchase price is their profit. This methodology creates salient incentives for participants, though the abstract nature of the good raises concerns regarding the transferability of results to the policy domain.

the survey of diverse preference orderings over the goods. Under these conditions, the theory developed by Burguet predicts that the RTC will raise more revenue than the SEQ. However, we observe the opposite, revenues in the SEQ treatment are slightly higher on average, although the difference is not statistically significant, and so we fail to reject the null hypothesis of no difference in revenues across the two institutions. Table 7 presents the figures for total revenues as well as revenues in each phase for the RTC auctions.

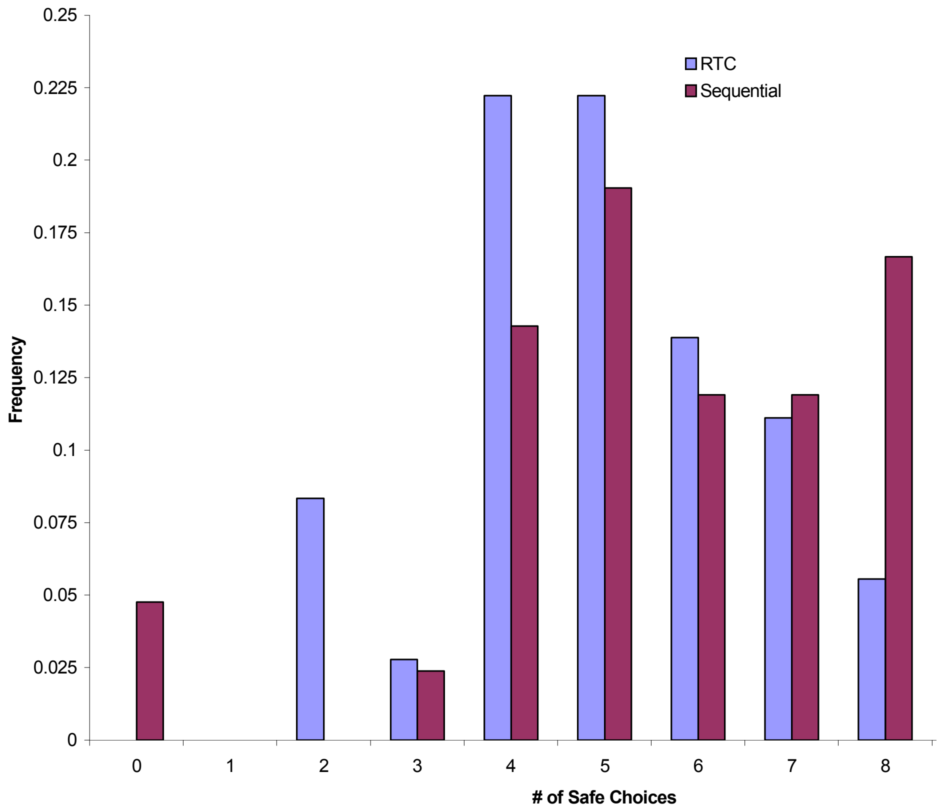

Figure 3. Distribution of safe choices in risk experiment.

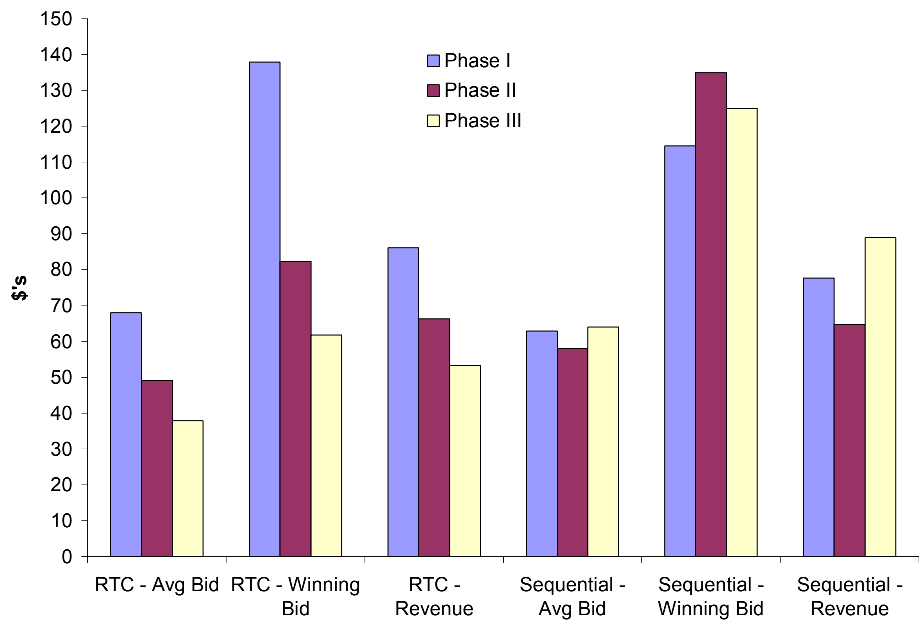

Figure 4. Observed bids and revenues by auction phase.

Table 6. Auction item preferences.

Auction Type	Good	Most Preferred Item	2nd Most Preferred Item	Least Preferred Item
Right to Choose	Wine Package	10	19	13
	Hiking Equipment	6	14	22
	iPod	26	9	7
Sequential	Wine Package	15	9	11
	Hiking Equipment	6	14	15
	iPod	14	12	9

Table 7. Auction revenues.

	Phase 1	Phase 2	Phase 3	Total
RTC	86.13 (17.2)	66.25 (24.2)	53.13 (15.3)	205.5 (48.8)
Sequential	NA	NA	NA	231.33 (86.3)

Note – revenue in dollars

Although the RTC does not result in increased revenues, the pattern of bids and revenues provides evidence that the subjects do understand the institution. As expected, revenues decline across phases, and bids are non-decreasing from phase-to-phase for those bidders whose preferred good remains available. What is surprising is that risk attitudes are associated with lower bids rather than higher bids as predicted by theory (Burguet 2007). Evidence for this result is found in Table 8 which presents models of individual bidding behavior. The *risk posture* variable is categorical from 1 to 10 with a higher number indicating more risk aversion. Note that the coefficients on *risk posture* for the SEQ models (3 and 4) are not significantly different from zero, as expected.[9] In the RTC models (1 and 2) however the coefficients are negative and significantly different than zero.

Table 8. Random effects estimates - Individual auction bids.

	Model 1 – RTC	Model 2 – RTC	Model 1 – Sequential	Model 2 - Sequential
Model Constant	34.09**	20.25	23.79	-12.14
	(14.43)	(13.34)	(18.19)	(23.37)
IQ Proxy	8.08**	5.67**	5.39	1.51
	(3.79)	(2.55)	(4.42)	(5.23)
Risk Posture	-3.47**	-3.24**	-0.18	3.33
	(1.71)	(1.19)	(2.50)	(2.88)
Above Average Wealth	16.76**	12.55**	9.71	10.91
	(8.31)	(5.60)	(10.24)	(12.25)
Most Preferred Good	31.33**	5.90	61.99**	79.21**
	(6.86)	(5.87)	(9.30)	(12.48)
2nd Most Preferred Good	14.77*	11.95**	19.89**	26.92**
	(7.90)	(5.79)	(9.30)	(10.89)
Lagged Revenue		0.31**		0.25
		(0.12)		(0.16)
# of Observations	126	84	105	70
Log Likelihood	-612.15	-372.91	-543.05	-361.66

Understanding the result on risk is critical to determining the suitability of the RTC auction format for wild horse adoption, and more generally for understanding where this institution may be usefully applied in the field. Our results suggest that both additional experimental treatments and extensions to the existing theory are needed. The theoretical framework assumes that each bidder has a known private value for the good and also knows the distribution of values among the other bidders. It is frequently true, however, that bids can be motivated by both private and common values, for example, when market price and resale opportunities enter into bidder calculations. Alternatively, individual uncertainty either about their own value, if they lack experience with a particular item, or about others values could affect bidding behavior. In the latter case, we would expect individuals may behave strategically in order to learn about other's values during a session.

Evidence on the importance of learning in our data is found in model 2 of Table 8 which models bidding behavior in the RTC. In this model, the lagged revenue is included as an explanatory variable and is found to have an important effect on bids. This suggests that individuals are learning from others bids in early phases of the RTC auction, forgoing potential profits in order to gain information on others values.

In the high information treatments detailed descriptions from the manufacturers, consumers and from independent reviewers are provided to the bidders to help resolve value uncertainty. Bidding in these treatments does differ from the low information treatments;

[9] In the sequential auction treatments the second-price institution means that bidding true value is a dominant strategy, unaffected by risk posture.

however, the impact does not vary across the auction formats. To investigate the common value and strategic learning alternatives further research using a combination of laboratory and field experimental protocols is proposed.

The laboratory sessions are useful because it is possible to eliminate any common-value motivations and also systematically vary the amount of information bidders have about others' values. In the field setting, a simple change to the protocol, not announcing the price at which the good is sold will diminish the ability of bidders to learn about values of others. With this change in protocol only the winner will gain specific information on prices (since the price is set by the second highest bidder), and losing bidders will not learn more than that there bid was not the highest. We hypothesize that eliminating the possibility of learning about others values will move to bidding more consistent with the existing theoretical predictions.

REVENUE SIMULATION STUDY

This section reports the results from a stochastic simulation study based on the survey responses in Harris et al. (2005). One of the goals of Harris et al. (2005) is to estimate the value of characteristics of wild horses offered at BLM horse auctions, that is, to identify which horses are most attractive and most likely to be purchased. The study shows that larger size, younger age, quiet, and less expensive are the common desirable wild horse characteristics using the probit econometric model.

This section utilizes the econometric estimation result in Harris et al. (2005). The estimation result is reported in Table 9 which is the respondents at the Reno wild horse and burro exposition (Harris et al., 2005).

Table 9. Probit estimation result in Harris et al. (2005).

Variable	Estimated Coefficients
constant	-0.57593
Size	0.04959
$Size^2$	-0.00017
Expense	-0.00064
Under 2	0.31935
2-6 years	0.27518
7 to 10	0.18527
Sorrel	-0.32584
Bay	-0.34574
Palomino	-0.19866
Gray	-0.38383
Gentle	-0.13269
Quiet	0.27706

The probit model was employed to derive the probability of a horse being adopted given different horse characteristics. The stochastic simulation model will derive different probabilities of horse adoption in order to complete a stochastic simulation.

The simulation is performed for identifying the potential distribution of revenues from a supply of horses given the preferences for horse characteristics among potential bidders in Nevada. First, the random horses are generated, that is, generate values of horse characteristics and expense. All of the wild horses' characteristics are assumed to be independent. Second, probability P_i is calculated using the estimated coefficients in Table 9. Third purchase decision is made with P_i, which is assumed to follow Bernoulli distribution which is binary decisions, purchase or not. The higher P_i value implies the larger chance to be purchased. The simulation is conducted on a sample of 2,000 horses and total revenues are calculated for the entire group. The simulation is iterated 100 times to generate a distribution of revenues.

Revenue is defined as the sum of adopted horses times the average price for a horse. The simulation results are presented in the table below which shows that on average, 718 of the 2,000 horses are sold for an average price of $506 (Table 10).

Table 10. Simulation results (2000 Horses).

	Total Revenue (dollars)	Number of horses sold (horses)	Average horse price (dollars)
Average	363,560	718	506
StDev	11,646	21	9

Figure 5 shows the distribution of revenue from possible wild horse auctions. From Table 10, the most likely (median) revenue for a wild horse was $362,020 with minimum revenue of $335,229 and maximum revenue of $406,276. These stochastic revenue estimates can be contrasted to operating and capital cost of a potential national wild horse and burro adoption center. Finally, a distribution of annual net returns from this proposed faculty can be developed. From distribution of net returns, policymakers can estimate potential net revenues in best, most likely, and worst times. This distribution of potential net returns would assist risk adverse decision makers in developing strategies for the construction and operation of a national wild horse and burro interpretive center.

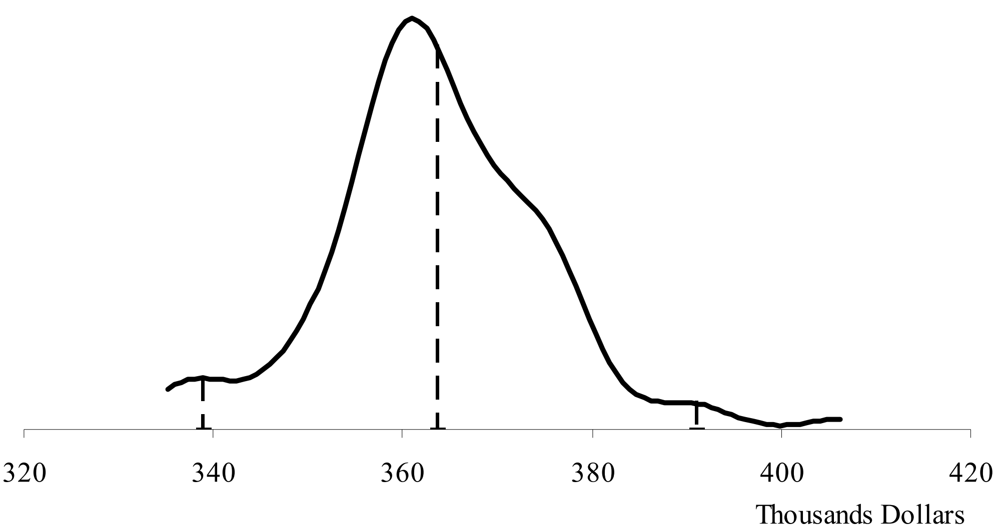

Figure 5. PDF approximation of total revenue.

CONCLUSION

Wild horse and burro policy is currently driven by several goals that include the mitigation of damage to rangeland, the commitment to humane treatment of the animals, and the control of regulatory costs. Placing animals with private owners and raising revenue from the distribution of the horses complements all these goals.

This study has investigated post studies to derive characteristics of wild horses that could increase rates of adoption. This study has also investigated alternative auction strategies that potentially could increase adoption rates of wild horses. Lastly, the study has employed stochastic simulation procedures to provide wild horse adoption decision makers with a range of potential revenues for wild horse adoptions. This range of revenues combined with capital and operation cost estimates of a potential wild horse and burro interpretive center would provide decision makers with information as to potential distribution of net returns. From the distribution of net returns, decision makers could decide on construction and operation of a national wild horse and burro interpretive center in a risk adverse vantage.

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APPENDIX 1: LEGISLATION RELATING TO WILD HORSES[10]

The Wild Horse Annie Act

During the 1950s in Nevada, Velma B. Johnston, later known as Wild Horse Annie, became aware of the ruthless and indiscriminate manner in which wild horses were being gathered from the rangelands. Ranchers, hunters and "mustangers" played a major role in harvesting wild horses for commercial purposes.

Wild Horse Annie led a grass roots campaign, involving mostly school children, which outraged the public and ultimately got them fully engaged in the issue. Newspapers published articles about the exploitation of wild horses and burros and as noted in a July 15, 1959, Associated Press article, "Seldom has an issue touched such a responsive chord."

In January 1959, Nevada Congressman Walter Baring introduced a bill prohibiting the use of motorized vehicles to hunt wild horses and burros on all public lands. The House of Representatives unanimously passed the bill which became known as the "Wild Horse Annie Act." The bill became Public Law 86-234 on Sept. 8, 1959, however, it did not include Annie's recommendation that Congress initiate a program to protect, manage and control wild horses and burros. Public interest and concern continued to mount, and with it came the realization that federal management, protection, and control of wild horses and burros was essential.

The 1971 Act - Public Law 92-195 Wild Free-Roaming Horses and Burros Act

By 1971, the population of wild horses had diminished drastically due to the encroachment of man and the mustangers elimination of them.

In response to public outcry, members of both the Senate and the House introduced a billed in the ninety-second Congress to provide for the necessary management, protection and control of the wild horses and burros. The Senate unanimously passed the bill on June 19, 1971. After making some revisions and adding a few amendments, the House also passed the bill by unanimous vote. Former President Richard M. Nixon signed the bill into law on December 15, 1971. The new law became Public Law 92-195, The Wild Free-Roaming Horses and Burros Act of 1971.

The Wild Free-Roaming Horses and Burros Act were later amended by the Federal Land Policy and Management Act and the Public Rangelands Improvement Act. Public Law 94-579, the Federal Land Policy and Management Act, dated Oct. 21, 1976, allowed for the Secretaries of the Interior and Agriculture to use or contract for the use of helicopters and motorized vehicles for the purpose of the management of wild horses and burros on public lands.

Public Law 95-514, the Public Rangelands Improvement Act of 1978, established and reaffirmed:

(i) the need for inventory and identification of current public rangeland conditions (monitoring);

(ii) the management, maintenance and improvement of the condition of public rangelands to productively support all rangeland values;

(iii) continuance of the law protecting wild free-roaming horses and burros from capture, branding, harassment or death, while at the same time facilitating the removal and disposal of

[10] This information retrieved from www.blm.gov.

excess wild free-roaming horses and burros which pose a threat to themselves and their habitat and;

(iv) the transfer of title after one year to individuals who had adopted wild horses and burros removed from public rangelands, provided the animals had received proper and humane care and treatment during that year.

APPENDIX 2: EXPERIMENTAL PROTOCOLS

<u>Experimental Instructions</u> [Right-to-Choose Auction]

Welcome to Jonesie's Auctions. You have the opportunity today to bid in an auction where we will be selling the three bundles of goods displayed on the table in front of you. We will provide you an opportunity to examine each of the items before the bidding begins. We ask that you do not talk with any of the other participants during the session. If you have a question at any time during the session, please raise your hand and a monitor will come to your seat and answer it in private.

Description of the available goods

Good 1: I-Pod and Speakers

- 2 GB iPod Nano with 500 song capacity
- JBL On Stage Micro portable music dock for I-Pod

Good 2: Hiking Equipment and Backpack

- REI Ridgeline backpack
- REI Hiker First Aid Kit
- Katadyn Hiker Microfilter

Good 3: Riedel Wine Glasses and Wine

- Set of 4 Riedel Chardonnay Glasses
- One bottle of 2006 Laird Family Estate Carneros Chardonnay
- Set of 4 Riedel Pinot Noir Glasses
- One bottle of DuNah Vineyards Russian River Valley Pinot Noir
- Set of 4 Riedel Cabernet/Merlot Glasses
- One bottle of 2004 Chappallet Napa Valley Cabernet Sauvignon

There are five bidders in this auction which will consist of three phases. Rather than sell the goods one by one, we will sell 'rights to choose' one by one. If in any phase you win one of the rights to choose, you will be able to choose which of the goods remaining at that time you want. To be more precise, in each phase a 'right to choose' is sold to the highest bidder. In the first phase, all five bidders will submit a bid for the first right to choose. The highest of these five bidders wins the first right to choose and selects the good that he or she prefers. At the end of the first phase, every bidder will be informed whether they won the first right to choose and which good was selected by the winning bidder.

Once the winning bidder from the first phase has selected their preferred item, the second phase starts. In the second phase all bidders will submit a new bid for the second right to choose. The highest of these bids wins the second right to choose and selects the good that he or she prefers from amongst the two remaining items. At the end of the second phase, every bidder will be informed whether they won the second right to choose and which good was selected by the winning bidder. In the third and final phase, all bidders will submit a new bid for the remaining item. The highest bidder in the third phase will win the final item.

***Auction Rules*:**

In each phase, you are asked to submit a bid indicating the maximum amount you are willing to pay to acquire the particular good being sold. Bids may be submitted in intervals as fine as one cent although there is no restriction on the amounts that you can bid. If you do not place a bid, it will be counted as a bid of zero dollars. Once I have received bids from all five bidders, I will order them from highest to lowest to determine the winner in that phase. The price that the winner in each phase pays depends on the bids of the other participants in the market. To be precise, in each phase the individual that submits the highest bid will be awarded the item for a price equal to the second highest bid submitted for that phase. If you do not submit the highest bid, you will not win the item in that phase and will not be asked to pay anything.

If two (or more) individuals submit the same high bid, then one of these bidders will be randomly selected and awarded the good for that phase. In such an instance, the winner pays a price equal to their own bid amount.

Example: If the bids in the first phase are ranked highest to lowest as follows:

$A (bid from bidder A)
$D (bid from bidder D)
$E (bid from bidder E)
$B (bid from bidder B)
$C (bid from bidder C)

Bidder A would win the first item and pay a price equal the amount of the bid submitted by bidder D.

The bidding process would then be repeated with everyone submitting a bid for the second item being sold. If the bids in the second phase are ranked highest to lowest as follows:

$E (bid from bidder E)
$C (bid from bidder C)
$F (bid from bidder F)
$B (bid from bidder B)
$A (bid from bidder A)

Bidder E would win the second good and would pay a price equal the amount of the bid submitted by bidder C. The bidding process would be repeated one final time with bidders submitting a bid for the final good.

Example: Before you submit your actual bids, I would like you to work through an example. Consider an auction where the following bids were submitted in the first phase of the auction if the good being sold is the I-Pod and Speakers. We want you to determine who will win the auction and how much they will pay to obtain the I-Pod and Speakers

Bidder 1's First Bid = 1103¥

Bidder 2’s First Bid = 850¥

Bidder 3’s First Bid =1200¥

Bidder 4’s First Bid = 250¥

Bidder 5’s First Bid = 475¥

Take the two highest bids and order them from highest to lowest:

Highest Bid _______________ 2^{nd} Highest Bid ________________

Now, determine which bidder has won the I-Pod and Speakers and the amount that he or she will have to pay. Fill in those numbers here.

Winning Bidder ____________ Amount Paid __________________

To assure that you understand how this auction mechanism operates, I will check your work after you complete this example. Please raise you hand once you have completed the example.

Final Transaction:

The winners in each phase will be required to pay me (cash or check) for the items that they have won at the end of the session. Once I have received payment, the respective item will be awarded to the winning bidder.

I understand that you may not have anticipated the need to bring cash or your checkbook with you for this experiment. In the case that you do not have the necessary cash (or a check) to pay for the items, we will provide you with a stamped envelope in which to mail the payment. Upon receipt of your cash or check, I will send you the items that you won. All postage will be paid by Jonesie’s Auctions for items mailed to the winners.

Note that while this is a real auction for the items displayed on the table in front of you, I plan to use data on the bids in this auction for economic research. I guarantee to sell all three of the items to the winners of this five-bidder auction, whatever the final auction prices turn out to be. Your bids represent binding commitments to purchase the items you win at the prices specified by the auction outcomes.

Good luck – we now invite you to spend a few minutes examining the goods on the table at the front of the room. Once you have examined the items, please return to your seats. Once everyone has been seated, we will ask you to write your bid for the first phase on the sheet provided.

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APPENDIX 1. Responses to Peer Reviews

Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin

What follows are the authors responses, in italics, to peer reviewer comments. To assist the peer review process we provided the reviewers with a series of questions, listed below.

Questions for peer review:

In addition to any general comments please address the following questions.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation?

2. Is the paper clear, well organized and concise?

3. Are the methods appropriate, current, and described in sufficient detail?

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct?

5. Are all tables and figures necessary, clearly labeled, and readily interpretable?

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper?

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted?

8. Can the paper be published with:
   - i. Minor revisions
   - ii. Moderate revisions
   - iii. Major revisions
   - iv. Too flawed to be published, even with major revisions

Contents

Past Elevation and Ecosystems of Walker Provide a Context for Future Management Decisions

Neither reviewer was aware that this chapter served as an introductory chapter to 300+ pages of specific research projects on Walker River and Walker Lake I responded to their comments accordingly.

Response to Reviewer 1

The manuscript presents results from a comprehensive, integrated ecology research project for the Walker River and Walker Lake that is based on process-oriented modern sampling and a review of existing literature providing abundant paleo-data. Walker Lake faced extreme variations in lake level and thus changes in water volume and salinity during its 30,000 year-long history. This paper reviews the effects of these drastic changes on ecosystems and I find this a novel and very important approach. Interestingly, the author comes to the conclusion that the Walker River is the key to species survival in Walker Lake. I also find especially important that the papers stresses the consequences and feedbacks of human impact on the lake level caused by ground water pumping because this complexity and large-scale changes often are under-estimated.

This paper is an important and innovative contribution to aquatic ecology because it combines paleo-data with management aspects of a lake-river system that should be published. I would suggest, however, that minor to moderate revisions are made and will provide a few more detailed comments below. I am aware that some of the questions arising to me may result from not knowing the entire volume or misunderstandings. Partly my suggestions derive from curiosity because I find this paper so interesting, and I would like to learn more about this topic.

1.Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? Yes.

2. Is the paper clear, well organized and concise? In general yes. I do miss, however, a brief overview of the main aspects controlling the climate in the region, a map with all sites discussed in the text, especially from the sites discussed in the section "Drought conditions at Walker Lake". Also, it would be helpful to have all sampling sites presented on a map. The climate scenario for each salinity state should be clearly emphasized. Maybe there could be a statement at the end of each salinity state as it is been done for the "Fresh waters" section?

Added brief paragraph on Walker Lake (Hawthorne) climate.

Added a figure (new Fig. 1) with map of Lake Lahontan high stands and localities mentioned in text. For those localities outside of the map borders, I described locations in text.

Climate scenarios for each salinity state are included.

3) Are the methods appropriate, current, and described in sufficient detail? This contribution does not contain a specific method section. Is there a separate chapter that describes the methods in more detail?

This chapter does not have a methods section. Methods sections are included for each project in subsequent chapters.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? In the 2nd paragraph (page 1) the author states that "recommendations for…. Monitoring plan statistically tracking the….. are provided" I have difficulties identifying a monitoring plan that statistically tracks the environmental condition. Maybe this could be made clearer and emphasized?

The sentence referring to the monitoring plan is deleted.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? Table 1.2 does not present any ostracode species for "this study" although it is indicated in the text (page 8, 3rd paragraph) that *L. ceriotuberosa* is the only abundant ostracode living in the lake today.

Ostracode analysis was not part of the current study. Reference (Bradbury et al. 1989) added in text for clarification that it was that study that noted the ostracode species was living in the lake today.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? Yes.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? It is stated that the focus of this paper is to present the composition of ecosystems during times of different salinities states on page 4 (2nd paragraph) and also on page 6 (3rd paragraph), maybe this could be reduced to one statement?

Although the timing of past phases of low and high salinities is apparently not of specific interest and thus not provided in detail, I think the paper would profit from giving the reader a general idea when phases of extremely high and low salinities occurred, even if there is dating insecurity. For example, can a more specific timing be given in the section "High salinity alkaline waters" (page 7, 3rd paragraph) for "at least twice" and "at time"? Also, page 8 (2nd paragraph) "the same core depth": Is here a more specific information about the age of the core depth possible? And, page 8 (bottom line), which "two time periods"? Giving approximate ages would also provide more consistency for the entire paper, because ages are given in the very detailed discussion in the section "Drought conditions at Walker Lake".

In the section "Historic change in taxa" I miss information on, for example, ostracodes and chironomids. Please make sure that all taxa are discussed.

Paragraphs combined.

Time periods included where appropriate. Clarified text describing that radiocarbon dating of cores is problematic and dating errors exist. As stated above, ostracodes are not part of current study. Chironomids are discussed in subsequent chapter, I believe.

8) Can the paper be published? The paper should be published with minor to moderate revisions.

<u>Response to Reviewer 2</u>

1. Unfortunately I did not find this chapter very informative on the relation of lake volume and/or river discharge to the ecology of either system. The simple fact is that if you want to restore Walker Lake to a more pristine (early historical condition) you have to 1: increase the discharge of the Walker River at the lake mouth, and (2) decrease the flux of irrigation return (which adds nutrients such as N and P to the lake). Again the simple fact is that the lake has transited from a system that overturns once a year in January, mixing to the bottom to one that can now chaotically mix during the summer as the thermocline reaches the bottom. The latter state causes the lake to be eutrophic because nutrients can be mixed throughout the lake more than once a year. In addition, the ratio of the volume of the epilimnion (where living organic matter is created) to the hypolimnion (where dead organic matter collects) has greatly increased with time. This means that more organic matter is being concentrated over the ever decreasing lake bottom area. Such an increase in the density of organic matter causes the system to become anaerobic and anaerobic bacteria to dominate. This type of bacteria is only about 10% as efficient as aerobic bacteria in breaking down organic matter and returning it to the lake as DIC. Thus the systems spirals to a higher eutrophic state and the bottom waters of the lake become depleted in oxygen. With respect to fish, they need cool water and oxygen. If the cool deep waters become depleted in oxygen the fish cannot find a place to live and go belly up, etc. etc.

I agree with statement. No changes to text necessary. The reviewer clearly thought that this chapter was a stand-alone chapter when he reviewed it.

2. Generally I see this report as a cataloging without criticism of past work on the lake, most of which has little bearing on the evolution of the lake's ecology. The section on the chemical evolution of Walker Lake is not up to snuff. First if you are going to simulate the chemical evolution of the lake, you need to state what chemical model you are employing; i.e., Phreeque, EQ3, etc. Secondly, all these models are equilibrium models; i.e., calcite will precipitate when its IAP (saturation state) is reached. Great Basin lakes are not, I repeat not, equilibrium systems. The lake may exceed its saturation state with respect to a mineral by several orders of magnitude. The demonstration of this problem is that monohydrocalcite (which is not stable under any earth conditions) has precipitated from Walker Lake during the historical period when equilibrium concepts suggest that calcite or aragonite should have precipitated. In any case, forget the classification scheme shown on Fig. 1.1. Again the point to be made is that both carbonate and calcium (NOT CALCITE!!!) are discharged to the lake. At some point some form of calcium carbonate begins to precipitate (and that point will be quickly reached after the lake begins to form) and because the molar concentration of Ca in the river is much less than the molar concentration of carbonate/bicarbonate, a Rayleigh

fractionation process will deplete the Ca to very small levels. There will remain some Ca in solution because it is complexed to other chemical species. An equilibrium or non-equilibrium model would have told you that non-complexed Ca should have been at very low levels for the last several thousand years.

Chapter is general overview. Criticism and analysis of published literature could be included on the timing of high or low lake stands or climate or diversion controls on lake levels, but as stated in text, this is not the direction or intent of this chapter.

Chemical evolution discussion is meant to be a general discussion of snapshots in time of the lake geochemistry, not a detailed geochemical model of lake solutes. I included a sentence stating that this is a general overview and this simplified scenario does not account for non-equilibrium processes, species of calcium precipitated, or calcium complexed to other chemical species.

Reviewed text for misuse of word "calcite" and replaced with carbonate and calcium where appropriate. Agree with last part of paragraph 2 and my text is consistent with reviewer's statement.

Added reference in text to Leach and Benson study regarding pollution.

We don't know what the chemistry of the Lahontan high stand was, but there is a pretty good indication based on ostracode and mollusk (my research) modern and paleo studies that it was fresh.

3. Projects on the Walker River may have been few but the program run by Leach and Benson measured the chemistry of the river at numerous sites during both the high flow and low flow periods and demonstrated the problem with irrigation return as a pollutant.

Added statement in text which includes evaporation and humidity at lake in addition to temperature as part of climate influence.

4. We do not know what the chemistry of the highstand Lake Lahontan was like. It could have very well been quite saline. The volume of the lake is not a balance between Sierran snowpack and temperature over the lake. River discharge is a function of the snow pack, but evaporation at the lake surface is not a simple function of temperature; in fact, evaporation is mostly a function of humidity of the air over the lake which is dependent on T. Because cloudiness in the historical period is small during the warm season, rates of lake evaporation tend to be relatively constant (+/- 15%) in an annual sense. For this reason, I would suggest that the evaporation rate during the Holocene has been relatively invariant. Again dilution is the solution to pollution (read lake salinity). Salinity is almost a perfectly inverse function of lake volume. The amount of TDS added to the lake annually is tiny. The only other major contributor is the flux of salts from a brine some 10s of meters below the center bottom of the lake.

Agree with author. This is discussed in the Thomas report.

5. The discussion of the taxa in the lake is horribly incomplete. There is just no data for most of the time frame discussed except for data on cods and diatoms and that data is

completely flawed from the long core taken from the lake. Only the Livingstone cores have produced good data and the interpretations from the types of diatoms and ostracodes are not based on ecological knowledge of the critters; they are based on analogies where the critters have been previously noted. For example is critter A was previously found in a saline pond, the former workers would posit finding it in Walker implies Walker was saline. Maybe, maybe not!

Taxa discussion is incomplete because it is based on what is known about prehistoric and historic taxa. Current taxa are discussed in subsequent chapters. Flawed core record is discussed in text, which is why dates greater than ~5,000 years ago are not specified. Ecological knowledge of critters is based on modern data from greater than 600 localities throughout the U.S., not analog studies.

6. With regard to river diversion, while one has to acknowledge the possibility, I am yet to be convinced of the fact and the timing of such.

The timing of river diversion is referenced to specific published studies. These studies report different time periods for diversion to Adrian Valley. I make the point that the exact timing of diversion (or cause of low lake levels) is not as important to this chapter as is the effect of low lake levels on taxa.

7. The author should point out how much water has been consumed by irrigation practices and she should also calculate how long it would take given various increases in river discharge to bring the lake back up to whatever level (read salinity) is desired. One cannot simply say that lake productivity has increased when confronted with increasing stored organic matter over time in the lake's sediment. It is reasonable to suspect this to be true but the amount of residual OM is a function of production-respiration.

A calculation of irrigation water consumed or increased river flow for a specified lake level are not pertinent to this chapter. Sentence on lake productivity is deleted.

8. One should not swallow stump data in lakes whole. If the stumps in Tenaya represent a change in climate, then that change is about 90% drier than today. If the stumps in the West Walker represent as Stine suggests a complete cessation of flow, then the snowpack in the Sierra was essentially zero for many decades. Something is wrong with this picture!! For example, Pyramid would have fallen several tens of meters and I doubt the cui ui would still be with us.

There is a problem with the tree stump data. The point in the paper is that there were substantial droughts in the past and future droughts will affect Walker Lake taxa.

9. The author should discuss Sierran tree-ring data and also the Mono Lake climate modeling study carried out by Nick Graham and Malcolm Hughes which pointed out that runoff during the middle-12th and late-13th centuries was decreased by about 30%. Also Benson has shown that discharge to Pyramid Lake (which implies Walker Lake also was decreased by ~30% between 8 and 3 cal ka.

Added reference to Graham et al.

PROJECT A: INSTREAM AND LAKE AQUATIC HEALTH

Lake Aquatic Health

<u>Response to Reviewer 1</u>

General Comments:

In general, the report read very well and was structured appropriately. The main objectives were succinctly developed in the Executive Summary and the subsequent individual segments were organized, complete, and relatively capable of being viewed as stand alone documents. Some of the information was very repetitive, but this was unavoidable given the need to provide appropriate context for each segment of the report.

This was a consequence of our desire to provide a limnological overview at the beginning, followed by subsequent chapters with expanded detail and further discussion.

The report provides useful information regarding the current limnological conditions of Walker Lake and the potential threats of a continued water level decline. The developed database appears to be appropriate and sufficiently documented for the stated goals. The ecological model development appears appropriate and model results are somewhat similar to the provided observations in the lake. However, I disagree with the assertion that the model was validated given the information provided and I am concerned that future applications of the model may leave managers with inappropriate conclusions, primarily regarding implications for the biological community (see Arhonditsis and Brett 2004).

We agree overall with the reviewer's sentiments that the current status of the model should be clarified to indicate its current level of development. We have added caveats throughout the chapter to indicate the current model status and the need for further refinement before the model is suitable to inform management decisions. The support for model development for this project was very limited in terms of budget and also in terms of time, due to reliance on field data collected through other tasks.

The reviewer's comments were very helpful for improving the current report and also for supporting arguments for future refinement of the model.

The algal & zooplankton community focus of the Food Web section was well placed for compatibility with the stated primary goals of the report. The information provided on the fish community in Walker Lake was very limited and provides little utility for future understanding of how water quality changes will influence fish population dynamics.

Although the developed model was not fully corroborated and the fish community was given short shift, the report adequately addresses the stated primary goals. Ecological model development and corroboration is a difficult and time consuming process, rarely complete to the satisfaction of any reviewer. After minor revision, this manuscript will be suitable for publication as a report. I have inserted a few general concerns into the review format provided and some specific comments will follow those concerns.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? Yes, the paper is cohesive and very easy to read. I see no compelling reasons to adjust the structure or format of the document.

Agreed. We feel a major reedit or reorganization of the material is not necessary at this time.

For the most part, the conclusions appear to support the data. However, as stated previously, the provided data was insufficient to support the conclusion regarding corroboration of the model. The authors appropriately held data in reserve for model corroboration, but the actual corroboration analysis was deficient (e.g. see Haefner 1996). The authors state that “The temporal patterns were **very similar** to those reported by Horne.”

The wording of this section was adjusted to more accurately reflect the model performance. An additional paragraph was also added to this (limnology) section of the report describing limitations in the current version of the model and the need for model refinement before using the model to inform management.

But similarity is not sufficient and temporal similarity is a very broad scale from which to make a comparison. One graph illustrating the simulated vs. observed results and a simple statistical correlation analysis would provide the minimum support necessary for referring to the model as “corroborated” and it would probably still be more appropriate to refer to the model as consistent with observations rather then corroborated.

We agree, and our wording in the text has been adjusted to reflect this distinction.

2. Is the paper clear, well organized and concise? Yes.

3. Are the methods appropriate, current, and described in sufficient detail? For the most part the methods are appropriate, current and adequately described. I feel the model goes beyond its capabilities and its utility is overstated. However, large scale ecological models are traditionally deficient (Arhonditsis and Brett 2004) and with a discussion of the appropriate caveats this model should be acceptable for publication as a report.

The utility of the model was restated and caveats were inserted throughout the chapter.

Many of the figure heads for the graphs lacked appropriate detail and the method used to interpolate between points was not provided (with exception of the food web section). However, these minor issues are easily addressed.

We have added more detail to the figure heads for many graphs and, where relevant, have indicated the interpolation methods used.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? In addition to my previous concerns regarding model corroboration I also did not feel the model adequately reflected the vertical extent of the dissolved oxygen profiles as suggested (page 84, figure 5). I would be troubled if this model was used to assess the amount of suitable habitat available for zooplankton or fishes during the summer. It appears the model under estimates the amount of available DO in the water column around the thermocline (pg 84 fig 5., figs 15-17 compared to pg 26 fig 9; similarly suggest lower than observed DO values between 5 &15 meters during the summer). The thermocline is an important area of the lake for biotic organisms, primarily mobile ones. Given the data available, I don't think the model can, nor needs to be recalibrated to address this apparent DO bias at the thermocline as long as the documentation addresses the issue. Similarly, I would have liked to see more cautious language used regarding the model and its utility.

Same as above, we have emphasized the model's limitations, especially related to DO dynamics which are in great need of further refinement (with subsequent funding).

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? No. Most figures have inadequate figure headings for interpretation of the graphs. Each figure head should provide sufficient information for each graph to be interpreted in the absence of the text. Some of the figures have axis errors. These will be identified below in the specific comments.

Again, we have added detail to the figure heads for most graphs and, where relevant, have indicated the interpolation methods used. Axis errors have been corrected.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? Overall the references appear sufficient. I would like to see more development of the model corroboration section and this would probably require the inclusion of appropriate references regarding some of the assumptions taken.

We appreciate the references provided by the reviewer and we have requested reprints. We will expand this section in future drafts as time allows.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? Yes. All of the parts are appropriate in length and content.

We agree, despite some repetition in text and content between chapters.

8. Can the paper be published? With minor revisions.

Most comments and minor revisions have been incorporated as indicated herein.

Some specific comments: (suggested changes are underlined)

Pg. ii, Line 8, Because so many organizations …

Fixed

Pg. ii, Line 10. …users might ask.

Fixed

Pg. 8 Lines 6-8. Hanging sentence that could be joined with the previous paragraph.

Done

Pg. 9. Many single sentence paragraphs. Consider grouping a few together.

Done

Pg. 21. Figure 4. Nice graph, but could include the method used to interpolate between data points? Linear interpolation?

Done

Pg 22. Line 2. Move Figure 6 to the end of the sentence in parenthesis.

Unclear what the reviewer meant by this comment. There didn't seem to be a sentence in parenthesis from this section.

Pg 22. Figure 5. The secchi depths would be easier to use if the water depths were inverted similar to previous graphs.

This figure was revised to reflect the useful comments of these reviewers.

Pg. 26. Figure 9. The scale in the legend could use a few more reference numbers. Again, what method of interpolation was used?

Interpolation method has been provided in the chart caption. Legend scale is equivalent to Figures 4 and 11, which seemed to be OK, so we didn't make any changes to Figure 9.

Pg. 43. Fig 20, 21. Is the y-axis correct? Very useful graphs with nice contours, legends, and scale.

The y-axes have been corrected in Figures 20, 21 and 22.

Pg. 57. Line 8. …page XX for…

This has been corrected.

Pg. 57. Line 15 …were the most current available.

This has been corrected.

Pg. 77. Figure 1. The text is unreadable in many places.

Fixed

Pg 108. Line 9. mesh size of net?

we have modified the sentence as follows;

Next, vertically integrated zooplankton tows from near the bottom to the surface were collected using a 50-cm-diameter zooplankton net with 80-micron mesh

Pg 112. Line 4-5. inappropriate carriage return.

Fixed

Pg. 123. Line 7. These the profiles showed…

Fixed

Pg. 123. Line 9. The DO values in the evening…

Fixed

Pg 124. Line 3. …and respiration rates…

Fixed

Pg. 125. Line 17. …uses in the this category of…

Fixed

Pg. 129. Line 8. …strategies could affected during…

Fixed

Pg 134. Line 4. …of the lake from way from…

Fixed

Pg. 137. last line. …the fifth power, divided…

Fixed

Pg. 142. Figure 4. Title needs adjusting.

Fixed

Pg 146. Line 5. The lowest and highest values are identical.

Fixed

Pg 146. Line 8. little variation but an increase in winter (November).

Fixed

Pg. 147. Figure 8. No replication? Error bars?

No replication was placed on this graph since the data was generated from 1 primary location. It is common to determine zooplankton densities by counting subsamples from the same field sample. Placing error bars around these means would be considered pseudoreplication.

Pg. 149. Figure 11. Label axis.

Fixed

Pg 150. Line 12. Please provide the sample size. Note that Fulton's K condition factor is most appropriate for comparisons within a system not among systems. Wr relative weight is a more appropriate condition index for among system comparisons (Kruse and Hubert 1997), or use the slope and intercept method (Cone 1989).

This is correct however since very little if any information is available for cutthroat trout from other ecosystems with the same parameters for comparison we used the Fulton's K for comparison. We correct our manuscript by noting these comparisons are not always accurate and interpretation should be conducted with caution.

Pg. 152. Line 3. …are highly patchy in ….

Fixed

Pg. 152. Line 11. …tui chub morphotype is slightly more

Fixed

References:

Arhonditsis G.B. and M.T. Brett. 2004. Evaluation of the current state of mechanistic aquatic biogeochemical modeling. Marine Ecology Progress Series. 271:13-26.

Cone, R. S. 1989. The Need to Reconsider the Use of Condition Indexes in Fishery Science. T. Am. Fish. Soc. **118**(5): 510-514.

Haefner, J.W. 1996. Modeling Biological Systems; Principles and applications. Chapman and Hall. New York, NY. USA.

Kruse C.G., and W.A. Hubert. 1997. Proposed standard weight (Ws) equation for interior cutthroat trout. North American Journal of Fisheries Management. 17: 784-790.

Response to Reviewer 2

Summary

The DRI/UNR team did a very nice job in expanding and focusing the limnological study of Walker Lake. They added a number of activities that were lacking from previous work and overall took a very professional approach. As the salinity of Walker Lake continues to increase large ecological changes are only matter of time. If there are to be serious consideration to new management actions, this limnological information is essential.

In addition to the standard limnological parameters that would be part of most limnological surveys, the DRI/UNR team also included interesting sections related to bacterial function groups, food web dynamics, data management, dissolved oxygen budgets and simulation modeling.

Before stating my general and specific comments there are two points to be made. First, the authors recommend that additional monitoring field work be done in support of this project. I agree and want to point out that even though a model was calibrated for this study, its use seemed to be most appropriate to develop preliminary ideas for management and generate hypotheses. I would have to speak with the authors, but it appears as though the model needs more work before it is used to guide the details of an extensive restoration effect. As noted elsewhere in this review, the authors should be commended for carrying out the initial develop of this model, it will have significant utility down the road.

We completely agree with the reviewer regarding the utility of the current version of the model. We have adjusted the wording throughout the report and added several caveats to make it clear that the model is still in the early stages of development and that much refinement is necessary before it can be used to guide management decisions. We would like to point out that the modeling task was a small component of the overall project scope and also that it was developed under severe time constraints due to reliance on data from other tasks.

We have attempted to address the reviewer's questions and comments below. However, many of these helpful thoughts cannot be properly addressed without a much more detailed investigation and further model refinement. We greatly appreciate the thoughtful review and we hope to address all of these issues through future work.

Second, the presentation of some very good information is somewhat awkward in the sense that the text is written as a series of individual manuscripts with not enough integration. There is considerable over-lap in information presented and it would be very useful to tie it together in a more comprehensive manner.

Reviewer 1 noted that this was unavoidable given the need to provide appropriate context for each segment of the report. Although we agree that it would be useful to eliminate some of these redundancies, at this time it would require an effort beyond the funding currently available for this portion of the project.

Note: I found it very difficult to review this large a document using the questions for peer review supplied by the Academy. I hope this does not cause any trouble and that what I provide below will be sufficient.

General Comments on all Chapters

1. There was significant overlap between the various sections, with some of the same data presented as many as three times. While the report was not difficult to read and follow, and the writing for each section was clear, the document as a whole lacked a progressive flow through the material. It would benefit from a more complete effort to integrate all the material.

The same as above. Repetition was a consequence of our desire to provide a limnological overview at the beginning, followed by subsequent chapters that would provide more detail and further discussion. We agree it would be useful to fully integrate all of the material for a more progressive flow, but that effort is impractical at this time.

2. I did not see a discussion related to the possible impacts of TDS-related toxicity to sensitive life stages of resident fish. Have bioassays been performed such as those done in Pyramid Lake?

In the discuss we added sentence that points out the physiological impacts of salinity levels.

3. There have been no recent comprehensive limnological surveys of Walker Lake – therefore this activity was needed for management decisions. I also appreciated the attempt to begin modeling to (1) help inform information and data gaps and (2) develop working (initial) hypotheses about how the lake will respond to changes in water supply.

We appreciate this acknowledgement of the utility of the current model.

4. In light of comment #3 above, can the authors state the appropriateness of their model for policy decisions. Does the model need more development or can it be used now to make decisions regarding the development of additional sources of water for Walker Lake.

We have added text to address this issue at several places throughout the report. The reviewer is correct to point out the limitations of the current model in guiding decisions.

5. Specific citations should be made to direct reader to location of other data bases used.

In Table 1 and in the database methods section we reference a new Appendix in the Walker Lake Database User Manual that provides sources and contact info for the data entered into this database.

6. Document should provide a review of historic data vis-à-vis QA/QC, methods used and ultimately the reliability of past data.

This refers to the collection of detailed QA/QC information from historic agency sampling programs that were not part of this project. That would be an effort well beyond the limited scope and funding provided for the database development task.

7. What QA/QC guidelines were followed for the DRI/UNR sampling. This is not provided in the first chapter on the contemporary limnology. If it appears elsewhere, please make a notation.

Standard QA/QC procedures for sampling and analysis by DRI and UNR have been indicated and cited within the text. Additional information is available in subsequent chapters where sampling methods and results are discussed in greater detail.

8. Document lacked literature citations in many sections and there was little reference to other saline terminal lake. Given the large literature available from nearby Pyramid Lake and Mono Lake, there are sources of out side information that need to be incorporated.

This project was developed to provide an assessment of the current Walker Lake limnological conditions for modeling purposes and to provide a reference against which changes resulting from future water rights acquisitions and delivery could be evaluated. It was not intended to be a comparative study of saline lakes in the region. However, when this material is developed for publication in a peer-reviewed journal, we anticipate adding references to work on other saline terminal lakes.

9. Team did a nice job to develop and manage the database.

We appreciate the recognition that considerable effort went into developing the Walker Lake database and populating it with as much information as possible from agency monitoring programs as well as from the shorter term studies implemented as part of this project.

10. In the opening chapter on contemporary limnology, there is very little discussion in the Results/Discussion section. This is in part due to the fact that latter 'chapters' cover topics with more specificity; however, this is part of comment #1 (above) – a more complete job to integrate the 'chapters' will improve the presentation of material.

The same as above. While we agree it would be useful to fully integrate all of the material for a more progressive flow, that effort would exceed the funding available at this time. The intent of this chapter was to provide a limnological overview at the beginning, followed by subsequent chapters with further detail and more discussion.

11. The modeling results should be removed from the contemporary limnology chapter. There is a full chapter dedicated to the modeling study. Since not enough information can be given in the contemporary limnology chapter it unnecessarily detracts from the modeling effort. i.e. the reader is left with too many questions after reading the first chapter and must wait for the modeling chapter. At the least, please refer to the fact that more information is given in the later chapter on modeling.

This comment is really best addressed by the UNR/DRI management. The modeling description was initially intended to be part of the contemporary limnology section because it was only a small subset of the lake ecology component and it was intended to support the development of the monitoring plan. The modeling chapter was originally intended to be an *appendix to provide details for curious readers about the model's development, input data, etc. It was later "upgraded" to a chapter but can just as easily be "downgraded" or dropped.*

We have added text at the beginning of the modeling results sections to indicate that more detailed information is provided in a subsequent chapter on the model.

12. The chapter on Contemporary Limnology ends with this sentence "Ultimately, the Walker Lake ecological model will help to optimize future water deliveries in terms of lake benefits, which is critical for developing sound management strategies." I was not clear on whether the authors believe that the model is currently ready to contribute to management decisions/policy or whether they consider it a good beginning but that more needs to be done.

We consider the model to be a "good beginning" and the wording has been adjusted.

13. More discussion comparing the DRI/UNR sampling results to previous data would be useful. I understand that there is not always a good historical database, but when possible it would be useful.

14. Recommendations for the enhanced/continued monitoring program should be expressed in terms of specific needs, based on model results, management questions and general limnological standards of protocol.

Many of the monitoring recommendations provided were based on model results and sensitivity analysis, as well as from management questions related to limnological conditions and water quality trends. No change made.

15. I see this entire report as the starting point for further considerations of management approaches.

Agreed and noted in the conclusions.

16. This report highlights the need for a science and monitoring plan to support targeted research.

Agreed and noted in the conclusions.

Specific Comments

Contemporary Limnology of Walker Lake, Nevada

1. There should be a table early on in the document that provides information of lake characteristics such as, maximum and mean depth, volume, bottom area, etc.

These characteristics keep changing as the lake level drops. The USGS has conducted a bathymetric survey, but the data have not been entered into a GIS database, so constructing these relationships would be difficult at this time. There is a chart from the USGS shown in the modeling chapter (Stone et al.) which illustrates the relationship between different Walker Lake volumes and surface area. (We had thought to do a similar one which shows the relationship between depth and volume, but did not have time after incorporating all other suggested changes to the document.)

2. Table 1 should be expanded (perhaps as an Appendix) to give more information on the specifics of the monitoring program and data availability.

Table 1 is intended to provide a short summary of the monitoring programs and data available in the Walker Lake database. The caption has been revised to reflect this, and we reference appendices (A and F) in the database User Manual that contains additional information as suggested by the reviewer.

3. Page 9 – Were the additional profiles at WL3 taken primarily for salinity profiles?

Text was revised to clarify that DO and temperature profiles were also collected at this site.

4. Page 12 – It would be helpful to state what was the minimum size limit for plankton cell size that was observable.

Done.

5. Page 13 – Paragraph on microbial approach could be expanded and more literature citations would be helpful.

Expanded this paragraph slightly and added some references. The two paragraphs following this one now also serve to better define the microbial approach.

6. Page 13 – Last paragraph – the cultivation-based approaches tell you what is there and more specifically what will grow in the test. They do not account for actual environmental conditions nor do they speak to the importance of these functional groups to the lake's microbial ecology. I believe the authors used these tests in an appropriate manner, i.e. they gave a first understanding of what might be there. This information can be used in the future to better understand their role(s).

This isn't really a request for changes, but rather a comment supporting our use of the cultivation techniques.

7. First chapter on contemporary limnology should at least give a brief over view of the food web work by Chandra at al.

We reference the food web chapter in our contemporary limnology discussion, but the UNR/DRI project management team had decided early on that these would be treated as separate chapters without any attempt at integration or overview. No change made.

8. Explain why 1-D approach to WQ modeling was justified in Walker Lake. I don't disagree, but it should be justified more in the document.

A 1-D approach was selected for this study because a more advanced 2-D or 3-D approach was not feasible with the resources allocated for the modeling effort. However, we feel the 1-D model was appropriate for investigating general trends in lake limnology and that with further refinement it can provide helpful guidance to management decisions. The 1-D model will also allow for long-term (i.e. 30 year) simulations after specific flow scenarios are developed. Long-term simulations are not feasible with more advanced hydrodynamic models.

Finally, we chose CAEYDM for this project because it can easily be coupled with a 3D hydrodynamic model should additional resources become available.

9. Page 20 – Second paragraph in Results/Discussion is more appropriate in Methods section.

Done

10. Page 20 – Figure 4 does not contain DO data as indicated in text.

Text has been revised to correctly indicate temperature in Figure 4 and DO in Figure 9.

11. Page 21-21 – Figure 5 does not present annual Secchi depths; the x-axis on Figure 5 (time) should distinguish the relative times, i.e. each full 12 month period should be represented by the same distance on the axis; in Figure 5 why were only two dates selected for representation?

This Figure was revised to reflect the useful comments of these reviewers

12. Page 23 – For the general reader it would be useful to explain why the samples have a similar ionic character regardless of when it is sampled.

The lake has very high TDS, is generally well mixed, and seasonal thermal stratification does not significantly change the major-ion chemistry. That is, the proportions of the major ions do not change with time or temperature. Note, however, this is not the case for dissolved oxygen, nutrients concentrations, and algal populations, all of which are affected by limnological processes such as thermal stratification. Change made to text.

Also, is the increased in TDS in December part of a seasonal affect or does it relate to long-term increases.

Walker Lake and Pyramid Lake are terminal lakes. As such, river water flowing into the lake carries dissolved constituents to the lake, and evaporation removes water from the lake but leaves the dissolved constituents behind. Thus, all terminal lakes have increasing TDS (and salinity and specific conductance) over time. Change made to text.

What are toxic levels of TDS for the fish in Walker Lake?

There is not a specific value of TDS that is "toxic" to fish in Walker Lake. Rather, TDS is one of many factors that affect fish health in the lake. For example, if the Tui chub, an important food source for Lahontan Cuthroat Trout in Walker Lake, cannot reproduce in the lake because of say insufficient dissolved oxygen, the number of LTC in Walker Lake may decline. It is important to note though, that higher levels of TDS correlate with decreases in LTC numbers, for example "It is obvious that as TDS has risen, both non-acclimated and acclimated LCT survival has diminished." (http://www.leg.state.nv.us/73rd/Interim/Studies/Treasures/exhibits/19140H-1.pdf).

No change made.

As noted above, Pyramid Lake and others have seen a similar increase in salinity as seen in Figure 8 – references to this being a more wide-spread phenomenon would be useful.

See response to comment 2b (above) about TDS in December

13. Page 25 – Would groundwater inflow only be expected during the period April-July?

Ground water would flow into the lake year round; however, during the April through early July time frame, increased ground water flow would occur because of annual spring time snow melt and runoff. Thus, it should be easier to identify increased ground-water input to the lake during this time period. Change made to text.

14. Page 27 – Explain why there was such a difference in October. Do these monthly values represent a depth-weight mean of the water column?

We added a few sentences of text to better explain Figure 10 and the features/differences observed in this chart.

15. Page 27-28 – There is no discussion of the relationship between DO and nutrients nor of N:P ratios.

Our focus was on developing the Walker Lake database and model. We provided an overview of dissolved oxygen and nutrient dynamics in this context, but did not have time to more fully develop the discussion to infer relationships between dissolved oxygen and nutrient concentrations or nutrient ratios. No change made.

16. Page 30; Figure 12 – Chlorophyll sampling in the spring needs to be intensified to capture the onset of the spring bloom.

Recommendations for long-term monitoring now include more frequent sampling in early spring to capture the onset, distribution and dynamics of phytoplankton blooms.

17. Page 34-38 – The presentation on bacteria is significantly more detailed that the discussion for anything else in this chapter.

This was necessary to convey the findings in this chapter (since no separate treatment follows). Information was condensed as much as possible without detracting from results (note that comment #5, above, had requested additional information).

18. Page 39 – With regard to the concept of metal-drive respiration, how speculative is it at this point (conceptual or demonstrated. What would have to be done to show its importance in Walker lake and what are ecological consequences. Citations from the literature would be particularly helpful here.

Metal-driven respiration has been demonstrated in other systems. To understand whether it is important to Walker Lake would require measurements of metal cycling rates in isolates and in-situ. This is now noted in the text.

19. Page 40 – the comment that "overall, the activity of alkaliphilic iron-reducing bacteria in Walker Lake, a group that was not even known to exist prior to our study, may be of benefit to fish" needs further details and explanation.

This process has been better described in the text. We have also focused on the net effect to organic carbon and oxygen consumption, directly, rather than on subsequent potential benefits to fish. (Also see our response to comment #21, below.)

20. Page 42 – A series of questions about the model (a) how was 'new flow' added to lake in the model (as surface flow that could stratify, full mixed with lake water, etc.),

All new flow was added via the Walker River using the river's current geometry. This has been noted in the text.

(b) since the dissolved oxygen results are critical to this investigation, it would be useful to know more about the mechanistic features of the DO component of the model,

We have added a reference to the CAEDYM science manual, which provides a complete description of the DO component of this model.

(c) how would the area of the bottom (m^2) that is both oxygenated and de-oxygenated change as a result of new water addition (important if benthic food production is important as stated),

The 1-D model cannot explicitly determine the portion of the lake bottom that is oxygenated or deoxygenated. This information could be inferred by comparing the model's forecast for the elevation of anoxic conditions with the lake bed area above and below that elevation. Such an analysis was beyond the scope of the modeling effort but could be addressed in the future. However, we would suggest further model refinement before going through the trouble.

(d) what are ecological ramifications to the rather rapid change in salinity predicted with new water added (15 to 11 mg/L) or with no water added (15 to 21 mg/L), and

The hypothetical high and low flow scenarios tested in the study were at the extreme ends of the observed flow record and such drastic shifts are not expected to occur with new water acquisitions, so we did not include a discussion of ecological effects resulting from these scenarios.

(e) how confident are the authors that the modeled increase in density stratification is feasible and not just a by-product of the 1-D model.

The density stratification only occurred under an extremely high flow condition and the simulated density stratification was quite weak. It is possible that a more sophisticated 3D simulation may yield different results. However, these results suggest that some density stratification could occur under such an extreme condition, and this is reasonable based on similar conditions in other systems. This has been noted in the text for clarification.

21. Page 50 – This page includes a comment on the possible beginning of hypereutrophy while earlier there was discussion of metals-drive oligotrophy. Are these states related?

Nutrient driven eutrophy and metal-driven oligotrophy are different process that produce opposite effects on the same condition (trophic state). Each could work to offset the net effect in one direction or the other. While the potential for metal-driven oligotrophy is raised, we do not have the data to support it. It would be interesting if the proposed high rates of metal *cycling were helping to keep lake eutrophication in check (relative to lake trophic condition without metal cycling), but that is purely speculative at this point.*

User Manual: Walker Database Version 1

22. As noted above, an Appendix with a more detailed summary of data availability would be useful. What data were not included in the DRI/UNR effort?

We added Appendix A to the Walker Lake Database User Manual that provides sources and contact info for the data entered into this database. We also added Appendix F to show what data were collected by which organizations on specific sampling dates from 2000 through 2008.

23. Are the methodologies used for the various historic and current data sets available?

Methods used by the Walker Lake sampling program in this project were discussed in the document. The methods used by historic data collection efforts were not available in our data compilations and would likely take considerable effort to collect and verify. This would be a topic to develop if the Walker Lake Database is to receive future support for continued updates, quality assurance, distribution and use.

Ecological Model for Walker Lake, Nevada

(note a number of specific questions regarding the ecological model were presented above since the model was first presented in the chapter on contemporary limnology)

24. Page 77 – Graph of bottom area versus lake elevation would be useful for discussions related to benthic food webs.

We agree this would be an interesting addition and we will try to create a figure for future drafts. Figure 1 partially addresses this concept but to develop a true relationship between bottom area and lake elevation would require a GIS analysis using the 3D bathymetric data collected by the USGS and that would require additional resources.

25. It would be helpful to have a table for the modeling parameters, variable and initial input data that was used in this modeling effort.

Hundreds of modeling parameters and variables are required for the DYRESM-CAEDYM model and references to the modeling documentation, which include tables for this information, have been added. Default values were used for nearly all model parameters. Descriptions of all data sources, including boundary conditions, initial conditions, and calibration data can be found in the text.

26. Page 81 – Explain why calibration/validation was only done for surface elevation, dissolved oxygen and temperature. I understand these are three very important forms of model output for the questions being asked, but given the argument that biology plays such and important role with regard to dissolved oxygen, biological parameters for photosynthesis and respiration and especially bacterial metabolism would appear to be very important for DO.

We agree that the calibration could be improved through additional parameters, however, DO, temp, and water elevation were the only consistent observations available to us during the calibration period. Additional data describing algal and microbial communities have since become available and could be used to improve the model calibration through future work.

27. Page 83 – The statement is made that CAEDYM requires little to no calibration and that there was reasonable agreement between simulated and measured DO. Please quantify what is meant be reasonable – the middle depths in Figure 5 suggest a 2 ppm difference. This might not be ecologically meaningful, but an explanation would help. Was Figure 5 a typical example? While the CAEDYM authors may claim little need for DO calibration, were they dealing with system so strongly influenced by microbial physiology.

We have expanded the text in this area. As alluded to by the reviewer, the statement regarding little to no calibration is that of the CAEDYM developers. It was not possible to move beyond a qualitative description of model performance to a quantitative calibration metric, such as root-mean-square error or a Nash-Sutcliff coefficient, because the simulation results and observed data are not available at commensurate elevations. Thus, a visual comparison of the general trends was used.

There are a host of reasons that could contribute to discrepancies between modeled and observed data including simplified representations of algal, microbial, and zooplankton communities in addition to the lack of fish component within the model or the lack of a meteorological monitoring station on the lake.

28. Page 84 – Good to show the agreement between the modeled output and the results of Horne et al. (1994).

This is difficult to complete because only a small portion of Horne's raw data is available to us. The model was parameterized based on the figures provided by Horne and the descriptions within the body of the text. Likewise, the evaluation of model performance was made by comparing simulated results with the overall observations reported by Horne (i.e. temperature and DO patterns over time). Such information does not readily lend itself to a direct graphical comparison, unlike the results from temperature and DO profiles collected by the DRI and UNR teams and reported numerically as a function of depth.

29. For the model sensitivity analysis what is the consequence of running this test for one year only. Might the model show increased/decreased sensitivity to varying parameters over time?

Due to time and funding constraints we could only run the full sensitivity test for one year. However, in future work we would like to run extended simulations for those parameters that showed a high degree of sensitivity.

30. Page 85 – In the model analysis, it appeared as though only a few parameters demonstrated any degree of significant sensitivity (e.g. air temperature, solar radiation, wind speed). Does this find have implications for the role that biological processes have in Walker Lake and their influence on DO? Does this imply that DO is physically driven?

We don't feel that this conclusion can be drawn from the sensitivity analysis alone given the relatively crude nature of the model at this point. However, the reviewer's questions are excellent examples of hypotheses that can be generated based on current model results which can be tested through future research or further model refinement.

31. Page 92 – First paragraph. Even though a very wide range of values for bottom sediment nutrient conditions were used in the model no noticeable change in DO profiles were observed. At the same time the model did reveal some near-bed changes in nutrient levels. Discuss how this might affect lake microbial ecology, vis-à-vis in-lake DO profiles and concentrations.

It is difficult to speculate on this aspect because at this point we know next to nothing about nutrients or microbial communities associated with the lake bed sediments. Thus, even though the model didn't show great sensitivity to the sediment nutrient concentrations, it is critical that data be collected on this aspect.

32. Page 102 – Were the recommendations for model improvement based on the sensitivity analysis. What guided the formulation of these recommendations? The reason I ask this is that a number of the recommended monitoring parameters did not show up as being critical in the sensitivity analysis.

The sensitivity analysis was used to guide the recommendations but other issues were also taken into account. For example, the model showed a low level of sensitivity to sediment nutrients. However, no data is currently available for this parameter and thus our understanding of the lake's limnology and the overall model setup would be improved by having real data for sediment nutrients.

33. Does the depth of insertion for freshwater affect mixing and therefore lake profiles? For example will a density difference between the saline water in the lake and new freshwater result in a density stratification? Explain the quantitative connection between expanded microbial/bacterial monitoring and improving model performance.

The depth of insertion should make a difference and this would make for an interesting point for additional sensitivity analyses. It was assumed that all additional freshwater will be delivered from the Walker River and the elevation and streambed angle were set as the existing conditions for the river. The elevation should be adjusted dynamically if the simulated lake level rises substantially.

34. Expand discussion of model results and ramifications to fish.

Due to the limitations of the current incarnation of the model, as mentioned by the reviewer above, along with the hypothetical nature of the flow scenarios, we hesitate to speculate on ramifications of model projections on fish. Ultimately, a refined model could provide information regarding available fish habitat during the summer DO and temperature "squeeze".

35. Discuss pros and cons of modeling out only over a 5-year period.

A brief description of this has been included. A much longer simulation period is desirable (i.e. 20 to 30 years), but resources for this initial modeling effort, along with substantial *uncertainty attributed to the simplicity of the current model and lack of specific flow scenarios, do not justify longer simulations at this point in time.*

Walker Lake: Hypolimnetic Oxygen Deficit Assessment and Associated Limnological Factors

36. Page 108 – If lake was 28 m deep, why sample only to 22.5 m.

We have modified the text to indicate the depth at the reference site WL3 and have also learned through reviewing the bathymetry document that the 28 meter maximum depth from this document was actually measured in 2005 (Lopes and Smith 2007).

37. Page 113 – Define values of DO associated with hypoxia.

We have defined the DO values associated with hypoxia in the text (comment 37. Page 113) and added a reference where this is defined;

38. Page 115 – Explain why HOD was calculated in the bottom 8 meters of the lake and not higher. Is this determined by depth of hypolimnion in each year?

This was the top of the hypolimnion. To mitigate confusion, we have expanded the text to include a definition of HOD and how it is calculated;

39. Page 115-116 – I don't know if there is a simple answer, but does the conclusion that HOD represents the very minimum estimate of net productivity affect conclusions regarding what it would take to increase DO as a result of biological changes. The statement implies that you could get as severe a DO depletion even if net productivity were to be significantly reduced. Can this be discussed further?

I am just a little confused on the matter that if lake productivity is sufficient to drive and create extensive anoxia and HOD is a large under-estimate of net productivity, why would there appear to be a relationship between oxygen deficit and lake level. Would it be useful to calculate HOD per unit volume and see how that changes with time. It is not that I necessarily doubt the conclusions, I bring this up because DO is such an important aspect of all this work, a more detailed discussion would be useful to the reader especially if policy decisions will emerge from this work.

The calculation of HOD per unit volume could be useful, but the simple matter is the ratio of the hypolimnion volume (and thus the content to oxidize organic matter) to the lake's productivity is the ratio that drives the total oxidation deficit. However, when primary productivity is much greater than hypolimnion oxygen, the oxygen is consumed and then other oxidants come into play in order to degrade the reduced organics (e.g. sulfate, nitrate, iron, etc.). Thus, we feel that for the most part, the text adequately covers the topic. We agree that DO is an important aspect of this work. We have added text and split the second paragraph in the section to address the concerns raised.

40. The influence of morphometric scaling based on the relative size of the epilimnion and hypolimnion results from varying lake elevation can be very important as the authors indicate. Can the model be used to test some of the hypotheses generated in this chapter?

Data generated by the model could be used to investigate morphometric scaling hypotheses. However, the limitations of the 1D hydrodynamic model must be kept in mind and further validation of the model would be desirable before such testing is conducted.

41. Page 119 – It is stated that "Thus- the relative contribution of production in littoral zones may be on the increase as the lake level continues to decline." The report would benefit from an explanation of the ecological affects of this and how it relates to the fishery in Walker Lake.

We have determined that it is unclear from the literature whether or not this would in turn lead to an increase or decrease in the productivity, so have removed the comment "Thus- the relative contribution of production in littoral zones may be on the increase as the lake level continues to decline." from the document.

42. Page 120-124 – The measurement of primary productivity using the 14C method (as used here) has been successfully applied in Pyramid Lake, Mono Lake and nearby Lake Tahoe. Was this technique used to measure in situ rates of productivity on a regular basis.

We have included further explanation in the text and included two more references included in the text.

43. Page 124 – Sorry if I missed it, but was the model used to evaluate the risk of Walker Lake becoming polymictic?

Determining whether there is a risk of the lake becoming polymictic was not a specific objective of the model. Rather the model was used to evaluate general changes in the lake's limnology under different flow scenarios. Upon further refinement, the model could be used to investigate the probability of various mixing patterns developing under a range of flow scenarios.

44. Page 125 – While I agree that the Nodularia blooms will likely remain, it would benefit the report if the authors could more fully support the statement on page 125 that "All observations, data and analysis indicates that large nuisance blooms and deepwater hypoxia will continue or increase in occurrence and magnitude".

This is a general statement that is meant to convey that as long as the positive internal loading is maintained, the large phosphate will remain an issue and cyanobacterial blooms will be expected to continue. We have added the following reference to the text.

Whitton, B. A. and M. Potts. [eds.]. 2000. The ecology of cyanobacteria: their diversity in time and space. Kluwer Academic Publishers.

45. Page 125 – Discussions regarding nutrient/biomass removal are premature in light of the findings presented in the report. I see this entire report as the starting point for further considerations of management approaches.

Yes, we agree that this is as starting point and we discuss some approaches that could be taken in the future based on our observations. We discuss nutrient/biomass removal and deep water oxygenation as possible management approaches.

The Contemporary Ecology and Food Web Energetics of Walker Lake

46. Page 133 – Please state the concentration where salinity becomes adverse to fish.

In the discuss we added sentence that points out the physiological impacts of salinity levels.

47. Page 133 – Last sentence before Methods – what about bottom production; earlier it is stated that it largely supports the contemporary fishery.

Fixed

48. Page 135 – Please explain more about the 2003 and 2004 phytoplankton data that appears in Figures 5 and 6. Where did this come from and how does it relate to the current DRI/UNR findings. There appears to be a significant difference in the timing of Nodularia between the two time periods. Is this correct? Were the 17-station synoptic samplings done in 2003-04?

These statements are correct and have been corrected in the text. For example we have placed in the statement, "This data was obtained prior to the initiation of this research project via one of the authors in this chapter."

49. Page 136 – Define edible phytoplankton.

Fixed

50. Page 138 – If this report is to be read by non-technical readers, a brief overview of the stable isotopic methodology would be helpful. If not most technical readers will understand.

51. Page 147 – Figure 8 needs dates in the caption.

Fixed

52. Page 150 – What levels of freshwater need to be added for the other fish species to exist in Walker Lake.

This point was not addressed due to the lack relevant scientific or published literature

53. Page 151 – the statement is made that, "A continuous monitoring program by the state of Nevada's Department of Wildlife suggests limited recruitment of young of the year tui chub due to increasing saline condition and low freshwater flows entering the lake (Solberger personal communication)." If this document is to be used for policy decisions, this statement should be supported and presented in more detail.

This point was not addressed due to the lack relevant scientific or published literature

54. Reference to Chandra et al. (2008) is missing from citations.

Added

Instream Aquatic Health

Response to USFWS comments

Editorial changes and clarifications were made throughout the document as suggested by reviewer. The more extensive comments and the subsequent responses are list below.

1) page 74: Are epidendric sites still representative of the sandy reaches? I understand the issue with sampling sand sections, but downstream of the confluence is dominantly a sand system, so how do samples represent the sandy reaches?

We agree that the epidendric assemblages do not represent the periphyton communities as a whole in the lower reaches due to the dominance of sandy habitat. The epidendric samples do represent the richest targeted habitat that was available at these lower sites. The initial evaluation of epissammic periphyton assemblages showed that the sand-associated assemblages were largely dominated by a few taxa (Amphora, Achnanthes) that are specialized in attaching to sand grains. The dominance of these taxa was likely attributed to the physical environment (i.e. constantly shifting sand) and not entirely to water chemistry. The comparison of the RTHs is the approach most commonly used to compare habitats across differing environmental regimes and seemed to be the most appropriate for the aims of this longitudinal assessment.

2) page 76: There is some mention of the impact of irrigation on flows etc. but there is no discussion of how agricultural practices may be impacting the sampling results. Are TKN and Phosphorus associated with fertilizers?

Nitrate and ammonium are typically the forms of nitrogen that increase in agriculturally impacted streams. However, the increase in TKN could be due to the organic load from filamentous algae consistently growing to eutrophic levels at select sites (EWB, EWA, WA). Increasing concentrations of phosphorus in Great Basin streams have largely been attributed to watershed geology (e.g. increased volcanic ash deposits), although fertilizer inputs may also increase these measured concentrations in the Walker River. The largest apparent point sources of phosphorus appear to be coming from the reservoirs (Bridgeport and Weber).

3) page 76: The Walker River Paiute Tribe has been fallowing during both sampling seasons in conjunction with work being completed on Weber Dam, both impact flows at the SHRZ sampling site.

We are not sure what the reviewer is requesting. Drawing any direct connections between tribal activities above WA and the periphyton data at the time of collection would seem to be highly speculative based on the current study.

4) page 76: The lack of any sort of recommendations based off the results seem odd. Aren't there target periphyton populations for a "healthy" system?-this information will be valuable for monitoring future water acquistions and restoration activities.

We have indicated that select sites have eutrophic levels of algal accrual based on the measured standing stocks (i.e. biomass). A "target periphyton population" with regard to community composition is beyond the scope of the current work as no predictive model *(observed/expected) was constructed. However, generally a decrease in eutrophic taxa would indicate improved conditions as well as an increase in sensitive taxa (e.g. Cymbella). Moreover, good practices necessitate maintaining low-levels of biomass relative to flows and temperature. Data suggest some reaches are at high/moderate risk of having low dissolved oxygen at night. Exactly which reaches are presently affected cannot be determined from the present study.*

5) page 76: If you are going to keep using the Truckee as a reference for comparing results you should clearly state the differences between the two systems, specifically regarding flow management and anthropogenic activity. Questions could be raised on the validity of comparing these systems.

The Truckee is not being used as a "reference" system in our discussion. It is referred to for comparison as it is the only eastern Sierra river that there are adequate studies of periphyton dynamics. The Truckee basin is largely impacted by urban and municipal land uses (Truckee, CA and Reno/Sparks, NV) while the Walker basin is mostly developed for agricultural uses. The Truckee is tightly regulated to maintain fairly constant flows throughout the year while the Walker resembles a more natural hydrograph. However, the consistent base-flow for the Truckee below Reno/Sparks is largely driven by the discharge of wastewater effluent. The above description of flow and land-use differences were added to the text within the methods section regarding the selection of algal-based metrics.

6) page 76: Graphs used throughout the text (beginning Fig.3) could be potentially confusing. Just make sure it is clear to the reader what the graph is showing.

We have made adjustments to graphs symbolism that should help clarify the locations of the sampling points with regard to the east fork, west fork and main-stem. The changes should help clarify the trends observed and subsequently reported in the text. Also the nomenclature for sites has been changed throughout to be consistent with the other reports.

<u>Response to Reviewer 2</u>

General comments: As this review questionnaire is laid out, it appears that this is supposed to be a manuscript for publication rather than a project report? To me, it reads like a project report. To be submitted as a publication it needs more substance in introduction to pertinent literature and formulation of hypotheses or expectations based on concepts of longitudinal zonation or patch dynamics theory, other current concepts regarding organization of stream communities.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? There IS a story here, but it is not quite yet in a cohesive form. Among other things, the data analyses/presentations would benefit from being placed in the context of a reference condition comparison. Now this might not be feasible, but other streams of similar size and physiography in the region might be contrasted (lower Carson, upper, middle and lower Truckee), and examined in terms of the Lahontan Region IBI that I have produced, or the other sites on the West Walker that I have sampled (report available online at Calif State Water Resource Control Board). No reference is made to these other data sets, or to those collected on the lower Truckee by EPA. There is a great deal of data here and excess detail in data presentation that all show a gradient from upstream to downstream. This seems a foregone conclusion, so what is the significance? How is this related to impairment vs zonation or patch structure? Seems to me that the most important and interesting observation is that sites degraded in summer and fall conditions have the potential for communities of higher integrity during spring. Protecting water quality by maintaining higher flows (lower temps) thus appears to be one of the management implications of this study to loss of biological integrity. In fact it might be possible to use the higher flow conditions as a reference of sorts and measure the relative seasonal departures among sites as a means of scoring the extent of impairment from site to site.

Reference condition was not discussed because the focus of this work was to determine relationships between benthic macroinvertebrate community structure and discharge. The text was modified to clarify this focus, and to address issues regarding other BMI data sets in the Walker Basin. Most of the work conducted by this reviewer has been at high elevations, which is largely irrelevant to work conducted by this study because of cold temperatures, low nutrient content, and a more natural hydrograph than in the lower Walker Basin. Reference to work recently conducted by Tetra Tech working for NDEP to establish an IBI for the Truckee, Carson, and Walker Rivers was added to the report. This work found that Walker River benthic communities show that the river is in 'fair' condition.

2. Is the paper clear, well organized and concise? Again, this is in more of a report format so needs more organization along the lines of a scientific publication.

Yes, this is a report and substantial changes (including shortening the length) are required before it is submitted for publication.

3. Are the methods appropriate, current, and described in sufficient detail?

Another issue is comparability of sampling methods, and the approaches outlined here do not match any standard method in use in the region, so may not be applicable in any case to other regional data. That said, the methods used were repeatable and sampled an impressive diversity of fauna from differing habitat types and with great seasonal resolution over a 2-year time span. As a baseline then, this is a rich data set for contrasts within itself and for a restricted application to this watershed. The very short reach-lengths described for the physical habitat surveys may not be an appropriate geomorphic representation of habitat, but they do serve the purpose of correlation with the biota. One problem with this though may be that since the sample quadrats for inverts were pooled, the habitat data (depth and current) related other than as a composite mean? This will cause loss of resolution with microhabitat associations. Taxa counts of 300 are fine, but sources since Vinson and Hawkins (1996) have concluded that 500 is a better representation of diversity for a fixed-count sample. How samples were normalized (resampling routine?) to 300m is not explained. Community metrics need reference to more primary literature that has evaluated metric sensitivity.

Data accumulated during this project were intended to address the question, 'How will Walker River benthic communities respond to increased flow?' Data that were compiled can be analyzed in a number of ways (including those that are traditionally used for bioassessment), and we elected to conduct analyses that revealed information that indicated specific environmental elements that influence BMI communities, including many that are relevant to effects of changes in discharge. Habitat metrics (depth and current velocity) were a composite mean, which is appropriate for data analysis that was conducted and the purpose *of this study. Yes, these methods are not appropriate to determine microhabitat use…this is not an intent of this study.*

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? The analyses are appropriate to the data set (CCA etc), but are repetitive and need condensing. The descriptive community metrics could be presenting in a table rather than graphs, and thereby include more metrics than presented. The ordinations are confusing and also excessive. Finding a way to summarize this information will be crucial to developing a publishable manuscript.

Many comments by this reviewer focused on redundancy in data analysis and in figures. These comments would be appropriate if this report was being prepared as manuscript for publication, but we believe they have little relevance for a report, which should provide greater detail that can support management interpretation. Comments to shorten and focus information will be incorporated when the report is shortened for ms submission. The level of detail in the report in context of graphs vs. tables showing results from the multivariate analyses is typical for presentations in the peer reviewed literature.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? See above comments. The tables contain many mis-spellings of taxa names. Why is the table not taxonomically organized? It is difficult to follow. Isoperla is a stonefly, not a mayfly.

These issues have been resolved.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? The report does need more context to relevant literature on physical and spatial patterns of community organization. Since the RCC of Vannote, there has been much published on the topic of longitudinal pattern and templates.

Reviewer comments are correct but this report the discussion was minimally broadened to include discussion of other ideas regarding biotic changes along the river continuum. This will be fully developed when the report is revised for publication.

7) Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? As above, the data need condensing and the text needs expanding and revision to be placed into a broader context than just this river basin.

See the above response to comment no. 4.

8. Can the paper be published?: But is this a report or a manuscript?? With major revisions

We concur and will revise appropriately when it is submitted.

PROJECT E: DEVELOPMENT OF RECOMMENDATIONS TO MAXIMIZE WATER CONVEYANCE AND MINIMIZE DEGRADATION OF WATER QUALITY IN WALKER LAKE DUE TO EROSION, SEDIMENT TRANSPORT, AND SALT DELIVERY

Historic Erosion and Sediment Delivery to Walker Lake from Lake-level Lowering: Implications for the Lower Walker River and Walker Lake under Increased Flows

Response to Reviewer 1

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? Aside from a few items in the results section, the story here is very clear, the conclusions are well supported by the data and results.

2. Is the paper clear, well organized and concise? There is logical organization to the paper. Its flows well through introductory material, contains pertinent background. There are some awkward paragraphs in the results when describing geomorphic change over time.

3. Are the methods appropriate, current, and described in sufficient detail? The methods are well applied. There is a nice use of combined historic information, geomorphic field work, GIS, and numerical modeling with current software.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? The sediment transport model seems appropriate and applied within its design use. The assumptions (clear-water boundary conditions at the top, fluctuating lake elevation at the bottom) are realistic. Sediment characteristics are well described and applied in the model.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? Tables and figures are appropriate. Table 4 is a bit much, that could be an appendix, or available upon request. Maybe it would be more useful to condense the table into mean values for a station. Figure 8 doesn't provide much information, and figure 23 is almost too dark to see the feature that is the focal point. Also there should be a flow orientation on all figures.

We have kept Table 4 in manuscript, but maybe the publisher will have us put it in an appendix?

Although figure 8 may not provide that much information, we kept it in for completeness. Maybe the next editing round will suggest that we remove it.

Figure 23 is the best picture of the siphon that I have, so kept it in.

Flow is from North to South in all figures and is clearly stated in text.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? There could be some additional references regarding bed armoring processes, or bed re-organization over time for a flood event. These would be useful in presenting the results of sediment transport modeling.

Removed the discussion of bed armoring, so nullifies this comment.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? The length is fine, the results could be streamlined.

8. Can the paper be published? The paper can be published with moderate revision.

Response to Reviewer 2

Abstract is good overall. I was left wondering about results such as total volume of erosion, average annual loads, etc. Can these numbers be easily included here?

Added appropriate numbers to abstract.

Introduction is very good. Here are a few notes:

-2nd paragraph under Hydrology heading justifies using Wabuska gage for proxy of flow below Weber. This is probably fine for large flow events, and total annual volumes, but daily data during low flow could be substantially different.

Added appropriate text to reflect this idea.

-3rd paragraph under Hydrology heading refers to "undisturbed" hydrology in the early 1900's. It should be noted that irrigation diversion was well-developed at that point, though not having the same effect as storage facilities, the diversions would have a cumulative downstream effect.

Added appropriate text to reflect this idea.

-The message derived from the 3rd and 4th paragraphs under the Hydrology heading is somewhat unclear. The 3rd talks about natural attenuation of flood peaks and decreasing peak magnitude downstream, and the 4th talks about presumed anthropogenic no flow periods. The message should be clear that the natural attenuation would not necessarily decrease annual volumetric contributions to Walker Lake, while human consumption would.

Added appropriate text to reflect these ideas.

Methods are clear and appropriate, here are a few questions:

-How is on the ground resolution of aerial photography determined?

Added scales of photos used, which allows readers to calculate the scales themselves, if they would like.

-Are there any estimates for how much horizontal error is associated with digitizing polygons on these photos? Does that produce compound errors in mass calculations?

We did not do a formal error calculation, but I suspect that these estimates are within a factor of two, similar to error estimates derived for shoreline erosion quantities from Lake Tahoe in Adams and Minor (2002).

-There are statements regarding issues of how to define the channel. No statement of how this was resolved.

Added appropriate text to rectify this omission.

-More detail could be provided on estimating thickness of eroded area. Was an average thickness used over the area producing a rectangular volume? If so how realistic is this geometry, what might the error be in mass calculation?

Added appropriate text to rectify this omission.

Results are clear and concise in general:

-The erosion chronology starts to get confusing at about the 5th or 6th paragraph. Timing and magnitude are harder to determine.

Added appropriate text to try to make it less confusing.

-The last 4 paragraphs of the erosion history would benefit from more discussion of the total masses transported during the timeframes in discussion. From what I understand 1.02 MT eroded between 1997 and 2005. Later, we find that 936,000 MT eroded during the 2006 runoff period alone. 1997 was a big year, why did 2006 move so much, what are implications for process?

Beefed up the discussion a bit to include quantitative estimates and implications for geomorphic process.

-Some sediment transport results seem counter-intuitive to me. The lower river seems like an area where fine grain and erodible material in the bed and banks presents an unlimited source of sand and silt to the channel. Transport under these conditions would be limited by capacity. However, a statement is made that the results show a supply limitation, does this seem realistic?

Supply-limited reaches do occur along the lower Walker River, as evidenced by ancient lake beds outcropping in the bed of the river. Therefore, tried to clarify the language a bit.

-In the 3rd paragraph under the Sediment Transport Modeling heading, a discussion of bed armoring begins. The bed is said to scour and armor, thereby reducing transport. Classic investigations of bed armoring have been carried out in gravel bed streams where large particles armor the bed, shielding smaller material at depth. Are there any studies that can be referenced for this phenomenon occurring in sand? Beside resistant clay lenses, I would imagine the potential scour depth to be considerable in this system, and the ability of sand grains to "armor" the bed to be minimal. A further doubt arises when the change in grain size is mentioned, with a finer distribution occurring through time. This implies that larger particles are removed from the bed, and smaller material begins to create an armor layer? A few good references for bed armoring, and supply vs capacity limited transport in sand systems would be helpful here.

We removed discussion of bed armoring and offered alternative explanation.

-There is no comparison of total loads estimated through modeling with those estimated through geomorphology. How do they compare? This is important. It is mentioned again in the 5th paragraph of the conclusions without stating any numbers.

We have added text that compares the estimates derived from aerial photograph analysis and from sediment transport modeling.

-The last paragraph in the results section seems to refer to an important concept in fluvial geomorphology called the "effective discharge", this could be stated clearly and referenced.

We agree and have stated the concept clearly and referenced it properly.

I hope this is beneficial to the authors, and that the article receives acceptance and publication. It is well-written, insightful, and timely in a period of increased human water use, and decreased water supply.

Evaluation of the Potential for Erosion and Sediment Transport in the Upper Walker River and Associated Impacts on Water Quality

Response to Reviewer 1

I have reviewed the report "Development of Techniques to Predict Erosion and Sediment Transport in the Upper Walker River and Associated Impacts on Water Quality" and offer you the following comments.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? The paper is good reference and background for decision making in moving forward with plans in the Upper Walker River

2. Is the paper clear, well organized and concise? The paper is sufficiently organized but lacks some clarity with an abundance of data and results with less explanation and insightful analysis of the data. The title indicates "Development of Techniques" but the conclusions mention little of any new techniques.

The title has been modified to "Evaluation of the Potential for Erosion and Sediment Transport in the Upper Walker River and Associated Impacts on Water Quality". Completion of the project resulted in: 1) a compilation of detailed river cross section data from field surveying; 2) the development of a HEC-RAS model for the upper Walker River; and 3) a set of water quality data for various reaches of the upper Walker River.

3. Are the methods appropriate, current, and described in sufficient detail? All lab methods are well documented and very well performed.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? The use of the HEC-RAS model lacks sufficient background support for its use (e.g., no mention of Manning's roughness coefficients and how they were selected). There is no calibration and verification of the setup, while significant use is made of the output. Velocities and depths would vary with the roughness coefficient and no rationalization is made. Model predictions are sometimes referred to as data, and they are not.

When model is used to simulate various flow rates it is not made clear if this is steady-state or unsteady; and if unsteady what type of pulse is used to produce the peak flows mentioned. A 1-hr peak flow, 1-day or 1-week or more would produce different results.

The HEC-RAS model was run for steady-state conditions. Some text describing how the model was calibrated by adjusting values for Manning's n and a comparison of water depths measured in the field to water depths predicted by the HEC-RAS model has been added.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? Some tables include highlighting that is not specified. At least one table has scientific notation of values where decimal numbers of higher multiples would be clearer (e.g., 4.7E5 acre-ft versus 47 thousand acre-ft (taf)).

The significance of highlighted data in tables is indicated at the bottom of those tables. Scientific notation has been incorporated where appropriate.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? The following issues with the references are noted:

(Adams, year?) year not given and not included in references
(Parker, 2005) in text but not in references
Text says Niell (1967) but references list Neill (1968)
Bathurst (1985) in text but not in references
Dickman (1990) in text but not in references
Limerinos (1970) in text but not in references
Thein (1993) in text but not in references
(Thomas et al., 2007) in text but not in references
Brownlie, W.R. (1981) is listed twice. Need to distinguish with a and b.
Brunner, G.W. (2008) in references but not in text
Dyhouse *et al*., 2003 in references but not in text
Hicks F.E. and Peacock T. (2005) in references but not in text
Hoggan, D.H. (1997) in references but not in text
DeVries *et al*., 2003 in references but not in text
Murat, A.H. (2006) in references but not in text
Myers, T. (1997) in references but not in text
Rantz, S.E., (1982) in references but not in text
Sharpe et al., 2008 in references but not in text
Stacy, M.L. (2001) in references but not in text
Taylor, T. (1996) in references but not in text

The references have been updated accordingly.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? I don't consider this a paper as much as I do a report. The report needs to contain more substantiation of the HEC-RAS calibration and verification to support any conclusions on velocities or flooding.

The text has been modified to provide more details related to the calibration of the HEC-RAS model.

8. Can the paper be published? It needs only moderate revisions to be published.

I have made numerous minor changes in text as far as grammar and word usage is concerned and will forward the printed copy with mark ups to your attention.

<u>Response to Reviewer 2</u>

This manuscript illustrated the work conducted on Upper Walker River to address the channel stability problem for concerned reaches. The author collected topographic data, sediment and water quality samples on the east, west branches and the combined reach of Upper Walker River, developed a HEC-RAS model to investigate the river hydraulics and conducted laboratory experiment to study the critical shear stress. Abundant data are generated from the study. The approaches are generally in the right directions though some specific treatments are questionable. The description for all tasks conducted in the project, the methods, results and conclusions are generally clear, but details were missed for some key aspects. Some approaches are apparently not consist in different sections and should be justified in detail.

Specific comments:

1. The description of the survey data is not clear in terms of quality and methodology. The horizontal resolution (points per cross section) and vertical accuracy are not provided. Did the measurement cover the under water topography (bathymetry)? Or the under water topo does not affect the flow simulation? This should be addressed.

The field surveying data was collected using state-of-the-art GPS surveying instrumentation. Pertinent details regarding the horizontal and vertical resolution of the coordinates collected while measuring the river cross sections has been included in the text. At each cross section, coordinates were collected at intervals of approximately 2 to 5 feet across the river channel. Coordinates of the channel bottom were collected by placing the bottom of the rover on the channel bottom. Coordinates were also collected at the edge of the water surface on both sides of the channel. This enabled the actual depths of water at each point in the channel cross section to be determined.

2. The slopes of the channels are not illustrated, which is a key feature of stream topography.

Profiles of the river sections have been included in the revised version of the document.

3. Where were sediment samples collected at each cross section? On the bank or in the bed? Under the water or besides the water? What were the sampling depths? Was there an armoring layer found?

Sediment samples were collected from the center of the main channel at each sampling location. The surface of the bed sediment was collected to bed depths of approximately 4 to 6 inches. There was no armoring at the selected sampling locations.

4. Page 15: "…placing the flow sensor at 1/3 of the depth of flow from the water surface…". This is not the common place to set the sensor. It should be 0.4 depth from the bottom. Why was this setting used?

The proper methodology was used in the field when channel cross section data was collected. The text has been modified accordingly.

5. Page 17: "Adams, year?" should be corrected.

6. Page 21: What is the mechanism of PCX? What is background particle count measurements? What is the PCX reading to determine the incipient condition? More details should be provided.

The HACH PCX is a particle monitoring device that is often used to monitor the quality of filter effluent during drinking water treatment. The instrument extremely sensitive and is able to detect minute variations in concentrations of particles. A sample stream of about 100 mL/min passes through the sensor within the instrument. The blockage of light caused by particles in the sample stream is monitored. The instrument is also able to quantify the sizes of various particles in the sample stream. This instrument was used during the flume studies in order to detect the onset of incipient particle motion indicative of the critical hydrodynamic conditions. The water used during the flume studies was collected at the same time that the sediment samples were collected. Prior to the start of each flume experiment, the water was circulated within the flume in order to monitor the "background" particles present in the water. With the initiation of sediment erosion and transport, the particle counts correspondingly increased. The data obtained from the PCX is reported in terms of "normalized particle counts". It is representative of the relative concentration of particles present in the sample stream.

7. Page 23 table 2.7: reference for using d60/d10 as the uniformity coefficient

A reference has been included in the text. The uniformity coefficient is indicative of how well-sorted (poorly-graded) or poorly-sorted (well-graded) a sample of sediment is. A poorly-sorted (well-graded) sample has a flatter, broader grain size distribution curve since a larger variety of particle sizes are present. A well-sorted (poorly-graded) sample has a much steeper, narrower grain size distribution curve indicating that most are the particles are about the same size.

8. Page 26: the second sentence in the last paragraph should be revised.

The text has been modified.

9. Page 29 section 3.2: Is the method of incipient sediment size applicable for non-uniform sediment? Is the hiding and exposing effect considered? Page 30: Why not use different Shields parameter for each particle size class, which should be more accurate?

The intent of the analysis and discussion related to the incipient motion of sediment was to use a variety of accepted methods to quantify the potential of the sediments collected at various locations along the upper Walker River to be transported under a range of anticipated flow conditions. The various methods were chosen following a review of techniques presented in current literature related to sediment transport. Parker (2008) summarized the findings of Buffington and Montgomery (1997) who reviewed eight decades of incipient motion data, with a special emphasis on gravel-bed rivers. They concluded that the data generally followed the overall shape of the Shields diagram and the modified Shields diagram using the critical Shields parameter proposed by Brownlie (1981). Observations by

Neill and Yalin (1969) and Gessler (1970) indicated that values for initiation of motion of coarse materials determined using the original Shields diagram were too high. Garcia (2008) and Parker (2008) suggested that the expression proposed by Brownlie (1981) should be divided by 2 to define a lower boundary on the modified Shields diagram that is more consistent with observed data from Buffington and Montgomery (1997) for streams having d_{50} greater that 1 mm. The resulting values were found to be more relevant for engineering applications (Garcia, 2008). In a similar but smaller overview of methods for predicting incipient motion in sand bed streams, Marsh et al. (2004) also considered the Shields diagram as one of the best methods after comparing it along with three other methods (Garcia, 2008). In summary, Garcia (2008) indicated that there is sufficient evidence to conclude that the Shields diagram is quite useful for field application.

Whether one method is judged to be more or less appropriate than another, the resulting analyses consistently indicated that the sediments found in the upper Walker River would be expected to be actively transported under most of the anticipated flow conditions. This was consistent with what was observed in the field at each of the locations where sediment samples were collected. Even at relatively low flow conditions, active sediment transport was visually observed. Particles were being transported along the surface of the sediment beds.

10. Page 31: "…observed that the incipient sediment particle size suddenly decreased when the flow increased from 25 cfs to 50 cfs." The reason should be discussed.

The reason for the observed decrease in incipient sediment particle size as the flow increased has been discussed in the text. Figures showing the characteristics of the channel at 25 cfs and 50 cfs have been included to support the discussion.

11. Page 32 figure 3.6: It is a surprise that ~50 mm particles can be moved under 25 cfs flow. From table 2.7, all sampled sediment particles should be smaller than 50 mm. That means the channel is not stable even under very low flows. How could this happen?

The results obtained confirmed what was observed in the field at each of the locations where sediment samples were collected. Even at relatively low flow conditions, active sediment transport was visually observed. Particles were being transported along the surface of the sediment beds.

12. Page 35: Why was the Brownlie formula was used here rather than the constant 0.047 (page 30)? Another value of 0.03 was used in page 40. Is it for riprap? If so, provide the reference. The methodology seems inconsistent through the report. Needs justification.

The issues related to this comment have been addressed in response to Comment 9 above. The text in the relevant sections has been modified accordingly.

13. Page 42 table 3.10: Are the highlighted records the critical velocities? What is the criteria to determine the value? What is the normalized particle count?

The highlighted rows in these tables are indicative of the critical velocities corresponding to the initiation of particle motion during the flume experiments. As described in Response to Comment 7 above, the HACH PCX was a particle monitor used to detect changes in particle concentrations during the flume experiments. The data obtained from the PCX is reported in *terms of "normalized particle counts". It is representative of the relative concentration of particles present in the sample stream.*

14. Page 48-50: Why was Keulegan's formula used to calculate the shear stress rather than using $\tau = \gamma$ RS? S can be determined with the flume slope for uniform flow.

Determining the stability of the bed and banks of a natural alluvial channel depends on the definition of the threshold of sediment movement. Sturm (2001) discussed the threshold condition in terms of both a critical shear stress τ_{bc} and a critical velocity V_c. The critical velocities for six sediment samples from the upper Walker River were determined by performing the flume experiments. The Keulegan equation presented in Sturm (2001) was used as a means of determining a value of the critical Shields parameter τ^*_c based on the observed critical velocity V_c for each sediment sample. The Keulegan equation is given by the expression:

$$V_c = 5.75\left(\sqrt{\tau_c^*(\gamma_s - 1)gd_{50}}\right)\log\left[\frac{12.2R}{k_s}\right]$$

Once a value of the critical Shields parameter τ^*_c was determined, the critical bed shear stress τ_{bc} was calculated using the expression:

$$\tau_c^* = \frac{\tau_{bc}}{\rho gRD}$$

This enabled a unique value of the critical Shields parameter to be used for each sediment sample. This concern was raised earlier in Comment 9.

The relevant text has been modified accordingly.

15. Page 53: "In Figure 3.11, … Since all the data lay above the curve in modified Shields diagram, this indicated that all of the sediments will be actively transported under the existing flow conditions in the upper Walker River." Figure 3.11 shows the comparison of critical shear stress (shields parameter) resulted from 3 method (one experiment and two theoretical). It is not a comparison of a critical condition and an actual condition (either measured or calculated). How can it show the sediment can be transported or not? Figure 3.9 had the same issue.

The applicability of the Shields diagram as an acceptable method for predicting incipient sediment motion was addressed above in response to Comment 9. The fundamental framework of the original Shields diagram as well as the modified Shields diagram (now Figures 3.11 and 3.12 in the revised text) can be used to predict the susceptibility of a sediment to be transported. If a sediment has characteristics which fell above the solid line in these figures, then active sediment transport is anticipated.

16. I expect the flume experimental results can provide some correction on the critical shear stress prediction based on some derived regression equation. The results generated critical velocity data. But no new equation (for critical velocity as a function of sediment size and flow parameters, mainly the hydraulic radius) developed. Same as critical shear stress, critical velocity

will change with flow condition. Table 3.19 used the flume derived critical velocity directly to the field. This is not correct. If the authors want to use this method, either they can develop an empirical equation based on flume data, or they can use some existing equations, but not apply the flume results directly.

The response to this comment is related to Comment 14 above. The authors agree that the some data collected during the flume experiments was inappropriately compared directly to field data. The purpose of the flume experiments was to determine a value of the critical velocity V_c *for each sediment sample. Then, the Keulegan equation was used to determine a value of the critical Shields parameter* τ^*_c *for each sediment sample based on the observed critical velocity* V_c *during the flume experiments along with the physical properties of the sediment. Then, the critical bed shear stress* τ_{bc} *for each sediment sample was calculated. Thus, the development of a separate empirical equation to relate the results of the flume experiments to observed field data is not necessary in this case. A similar concern was addressed in response to Comment 15 above.*

The text has been modified accordingly.

17. I don't understand why the authors want to use two different methods (shear stress and velocity) to study the channel stability. They did not do any comparison between them, nor make recommendation for one over the other.

The concern raised by this comment has been addressed above in response to Comments 9 and 14.

18. The authors did not discuss the possible sediment source. If majority of movable sediment comes from bank erosion, the strategy of applying riprap on stream bed will not work, and installing settling basins will not solve the fundamental problem.

The sources of sediment in the watershed are largely the result of natural processes such as erosion during surface runoff and weathering of minerals. There is very little development within the watershed relative to its overall size. Much of the sediment is introduced into the river channel during seasonal runoff events (i.e., spring runoff) and during periodic intense thunderstorms in the summer months.

Other researchers are currently investigating the quantities of sediment yielded within various portions of the watershed.

Lining the river channel with rip rap is not considered to be an economically practical solution. Settling basins have been suggested simply as a means of capturing some of the sediment in the lower reaches of the river. Clearly, settling basins will not mitigate the source of the sediments.

19. All equations should be numbered.

All equations have been numbered.

20. Reference Parker (2005) is missing.

The references have been updated accordingly.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? It is clear that all tasks aimed to the same goal. But some work did not show enough power to support the intension. See specific comments.

2. Is the paper clear, well organized and concise? Generally it is.

3. Are the methods appropriate, current, and described in sufficient detail? Generally the designed framework is good, but some specific methods are not correct. And some details need to be supplied. See specific comments.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? Yes.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? Possibly.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? Some references are missing.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? The length is fine.

8. Can the paper be published? The current version can not be published. I cannot make decision before reading a new version with major revisions.

PROJECT F: DEVELOPMENT OF A DECISION SUPPORT TOOL IN SUPPORT OF WATER RIGHT ACQUISITIONS IN THE WALKER RIVER BASIN

Development of a Decision Support Tool in Support of Water Right Acquisitions in the Walker River basin

We appreciate the comments provided by the two reviewers and believe that their comments have resulted in significant improvements to our final report. Below, we have provided a detailed response to each of the comments made by each reviewer:

Response to Reviewer 1

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? Yes, the report presents a cohesive story. Would be good to have an Executive Summary

This report is actually a "chapter" in a much larger report that will contain an executive summary for the entire report. Based on this comment and comment #3 made by Reviewer #2 (see below), we have added a section called Purpose and Scope beginning on page 10, after the Introduction section.

2. Is the paper clear, well organized and concise? The tense is not always consistent throughout the document.

We have made changes throughout the document with respect to the tense.

3. Are the methods appropriate, current, and described in sufficient detail? Not clear how the PRMS model was linked to the ModFlow model. The schematic shows them being linked and the title of the chapter also suggests that they are linked.

Based on this comment and comments #6 and #8 made by Reviewer #2 (see below), we have modified the text and one of the figures (please see response to comments #6 and #8 by Reviewer #2, below).

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? No statistical analysis was provided with the model output, so the evaluation of model accuracy was not permitted. Just a vision representation of the model results.

We did not propose to perform a statistical analysis of the model output in our scope of work; rather, we proposed to evaluate the model in terms of visual and objective measures. The primary purpose of the project was to develop the DST. Further analysis of the model results, improvements to the model, and scenario-based applications are planned in Phase II.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? Very good figures and tables.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? Page 11: Would be good to include references that support the background climate information for the area.

Unfortunately, we could not find a relevant paper to reference to climate information. Our comments in this section are based on our own interpretation of observed meteorological data and our understanding of the hydrologic processes in the study area.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? OK

8. Can the paper be published? With minor revisions

<u>Response to Reviewer 2</u>

1. pg 1 title – "Decision Support Tool" is a very generic name. I think you need a better name for the software which gives a feel for what this actually does. "Water Right Acquisition Support" or something.

We decided not to modify the name of the software product since "Decision Support Tool" or "DST" is what we proposed in our scope of work and have promoted to all of the stakeholders over the life of entire duration of the project. We feel that changing the name of the product at this point would add much more confusion than leaving alone.

2..pg 2 TOC – I was confused (for a while) about all of these subsections with the same name (i.e. "Conclusions", "Purpose and Scope", etc.). Figure out how to make the subsection headings more distinctive

Titles of the subsections were modified to include the name of the model discussed within the section, e.g. PRMS Conclusions.

3. pg 8 para 1 – There is a "Purpose and Scope" sub section for each of the modeling sections describing the purpose of each model, but no "Purpose of this Document" section. Maybe the intended audience of this paper knows the purpose, but it took me awhile to figure out that this is a project status report. I think this document would be well served to have a "Purpose of this Document" paragraph at the end of the Introduction, or maybe a subsection after the Intro and before the "Site Description."

In response to this comment, we added a section called Purpose and Scope beginning on page 10, after the Introduction section that refers to the document as a whole. Purpose and Scope section titles in each of the modeling sections were removed for clarity.

4. pg 8 para 2 ln 1 – This sentence is what the whole paper is about. I went past this the first time I read this. I think you need add something more about "proposed water rights acquisitions" and "what evaluate the effectiveness" means.

See the above text of the new Purpose and Scope section in response to comment (3), which also addresses this comment.

5. pg 9 ln 1 – "University of Nevada's Desert Terminal Lakes Program" I have no idea what this is. Either list some of the specific goals or provide a Reference. Maybe list some of these out and move this up to the front of the paragraph to go with the first sentence.

This is a valid point made by the reviewer based on his or her review of this "Chapter" alone. This "Chapter" is, however, a small part of a much larger report that will include an introduction that clearly explains the Desert Terminal Lakes Program and how this work fits within the program. We don't think it would be appropriate to repeat this information in our Chapter.

6. pg 9 para 1 ln 1 – "Four models are combined to create the DST." This is confusing. In this paragraph, I see "First", "Second", and "Finally" That seems like three. Is the fourth SWL? or a repeat application of MODSIM? Also, the first level headers in the TOC indicate that there are three models.

We made the following changes. The original text "Four models are combined to create the DST." was modified to read "Three models are combined to create the DST."

7. pg 9 para 1 – I believe this is the first mention of PRMS, MODFLOW, and MODSIM. Add the citations for these models here.

Based on this comment we made the following changes.

The original text, with the modification from the previous comment (6) included,

"Three models are combined to create the DST. First, a physically based hydrologic model (PRMS) of the headwater supply areas is developed. This model is not directly linked to the others, but will be instrumental in future scenarios that may involve potential climate change. Second, groundwater flow models (MODFLOW) are developed for Smith and Mason valleys, the primary agricultural areas in the Walker River basin. The groundwater models focus on agricultural demand areas and groundwater-surface water interaction in the river corridor. Finally, a streamflow routing and reservoir operations model (MODSIM) is developed for the entire basin."

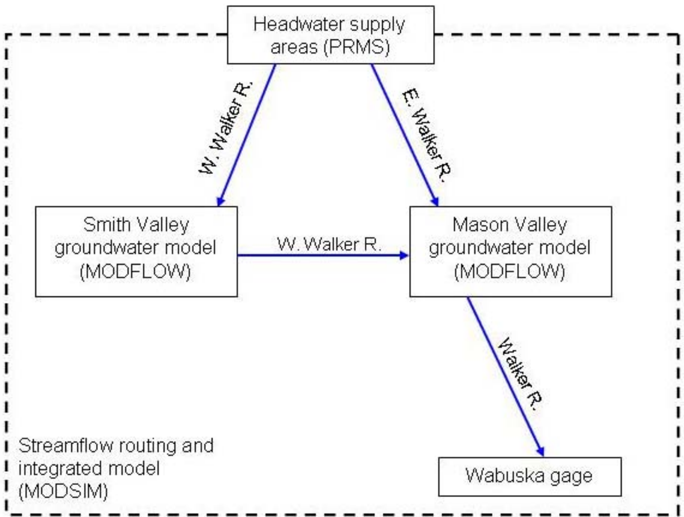
was modified to read

"Three models are combined to create the DST. First, a physically based hydrologic model (PRMS; Leavesley et al., 1983) of the headwater supply areas is developed. This model is not directly linked to the others, but will be instrumental in future scenarios that may involve potential climate change. Second, groundwater flow models (MODFLOW; Harbaugh et al., 2000) are developed for Smith and Mason valleys, the primary agricultural areas in the Walker River basin. The groundwater models focus on agricultural demand areas and groundwater-surface water interaction in the river corridor. Finally, a streamflow routing and reservoir operations model (MODSIM; Labadie and Larson, 2007) is developed for the entire basin."

8. pg 10 fig 1 – Figure 1 is confusing. Is this supposed to be a schematic diagram of water flow in the Walker River Basin? Or is it how information flows between the models? I guess it's both.

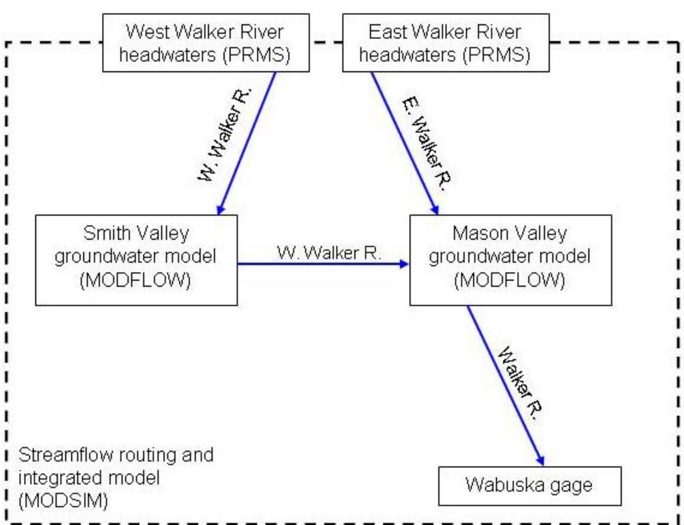
I think if you have two MODFLOW boxes you should have two PRMS boxes. Does the dashed box indicate that the whole basin is simulated by MODSIM? I don’t think that is the case.

The original figure and caption



“Figure 1. Conceptualization of the DST. PRMS models the headwater supply areas. MODFLOW simulates agricultural demand areas in Smith and Mason valleys. MODSIM controls streamflow routing throughout the basin. Output from the MODFLOW models is used in the MODSIM model.”

were modified as shown below.



“Figure 1. Conceptualization of the DST. The exchange of information between models follows the flow of water through the basin. PRMS models the headwater supply areas. MODFLOW simulates agricultural demand areas in Smith and Mason valleys. MODSIM

controls streamflow routing and reservoir operations from the headwaters to the Wabuska gage. Output from the MODFLOW models is used in the MODSIM model."

9. pg 10 ln 1 – Where is Twin Lakes or the West Walker River gage in figure 2? Either add them to the map, delete them from the text, or indicate that they are not shown on the map.

We have made the following changes to the document.

The original text

"Twin Lakes and Bridgeport Reservoir (42,450 acre-feet, 52 million m^3, of storage) on the East Walker River, and Topaz Lake (59,400 acre-feet, 73 million m^3, of storage) on the West Walker River provide storage and control downstream flow (Sharpe et al., 2007). From the West Walker River gage at Coleville, CA (USGS gage 10296500), the river flows northeast through Antelope Valley and Smith Valley and then into southern Mason Valley."

was modified to read

"Bridgeport Reservoir (42,450 acre-feet, 52 million m^3, of storage) on the East Walker River, and Topaz Lake (59,400 acre-feet, 73 million m^3, of storage) on the West Walker River provide storage and control downstream flow (Sharpe et al., 2007). From Coleville, CA (near USGS gage 10296500, not shown in Figure 2), the river flows northeast through Antelope Valley and Smith Valley and then into southern Mason Valley."

10. pg 10 last para – I did not verify any of these climate statistics

The climate statistics on page 10 were verified.

11. pg 12 para 1 – In the paragraph that starts "The U.S. Geological Survey's (USGS) Precipitation-Runoff Modeling System (PRMS) watershed model. . ." Add numbers to parallel the description of the approach from the previous paragraph.

The following changes were made.

The original text

"The U.S. Geological Survey's (USGS) Precipitation-Runoff Modeling System (PRMS) watershed model will be used to model the headwater supply areas. … MODSIM will be used to dynamically simulate reservoir operations and river systems within the basin. … Agricultural demand areas will be simulated using MODFLOW. … MODSIM will again be used to link the different models into one, integrated DST accessible to planners and managers."

was modified to read

"The U.S. Geological Survey's (USGS) Precipitation-Runoff Modeling System (PRMS) watershed model will be used to model the headwater supply areas (1). … MODSIM will be used to dynamically simulate reservoir operations and river systems within the basin (2). … Agricultural demand areas will be simulated using MODFLOW (3). … MODSIM will again

be used to link the different models into one, integrated DST accessible to planners and managers (4).”

12. pg 14 ln 7 – Is this were the acronym “EWR” defined?

The acronyms were defined in Table 1; however, based on the reviewer’s comment (14) we replaced subbasin acronyms in the text with the subbasin name.

13. pg 14 – Subheading “Model description”. Change this to “PRMS Description”

The subheading was changed as suggested by the reviewer. See response to comment (2).

14. pg. 16 last para – There is a problem with the consistency of the use of the acronyms that you are using to name the sub basins. Sometimes these are called "West Walker headwaters" sometimes called “WWR basin.” Are these names referring to different geographic areas or modeled areas? I would prefer that you not use the acronyms for the subbasins as I find them distracting.

Based on this comment from the reviewer, we removed all subbasin acronyms from the next and replaced them with the appropriate subbasin name.

15. pg. 17 fig. 4 – I did not verify the values presented in figure 4.

The values presented in Figure 4 were verified.

16. pg. 17 para 1 – Generally, PRISM works pretty well for what you are doing here, but sometimes it goes very wrong. It could be that PRISM is not very representative of the "bad PRMS basins" you plot below.

We have experienced some issues when using PRISM for this purpose in previous modeling projects, however, we have found that, in general, the use of PRISM has proven to be much more representative of the spatial and temporal distributions of precipitation and temperature in this area than any other approach we have tested. In phase II of this project, we plan to look at a variety of other issues related to snow water equivalent and the associated PRMS parameterization that may result in poor fits in the “bad” basins.

17. pg. 18 table2 – good.

We agree and made no changes to Table 2.

18. pg. 25 para 1 – PRMS and other snowmelt models have troubles in this region of the Sierra Nevada because winter daily temperatures are often near freezing. This makes it difficult to determine the form (rain or snow) of the precipitation. Small errors in HRU temperature can cause big problems in model performance.

Based on current efforts in the Truckee, Carson, and Walker basins with a similar approach that includes additional information on a variety of snow pack variables (from SNODAS) we are finding that the issue may be related to the parameterization of the snow related parameters rather than issues related to the temperature. Unfortunately, our findings are still in draft form and could not be included in this modeling effort. We do plan to incorporate *our findings into the Walker DST modeling effort in Phase II to, hopefully, improve the performance of PRMS in all of the study basins.*

19. pg. 27 fig. 17 – Something appears to be wrong with the amount of precip in the EWHW and EWR subbasins (and some others). These models could be improved by checking the annual water balances and adjusting the simulated precipitation down. A table of annual water balance table for each subbasin, including volume of precip, et, measured and simulated streamflow would be very helpful in showing the strengths and limitations of these PRMS models.

We did use the annual water balance information in our calibration process for each of the study basins. Unfortunately, in this case the annual water balance information does not provide enough information to accurately determine why the PRMS models are still underperforming in some cases. Again, believe that the issues are related to the parameterization of the PRMS snow related parameters (see response to comments #16 and #18 above) and will be revisited in Phase II of this project.

20. pg. 34 para 1 – I did not verify these numbers.

The values on page 34 were verified.

21. pg. 36 para 1 – I did not verify these numbers.

The values on page 34 were verified.

22. pgs. 42-43 – I did not verify the numbers in tables 4 or 5.

The values in Tables 4 and 5 were verified.

23. pg. 47 – Get rid of the subheading "Conceptual model"

The subheading was removed from the MODFLOW section. See response to comment (2).

24. pg. 49 para 2 – Is the SWL something that DRI personnel wrote? This either needs to be cited, documented fully, or dropped from this report. Does the input to SWL come from PRMS? Or somewhere else?

The SWL is simply our term for the set of FORTRAN programs developed at DRI to implement the surface and groundwater models. The SWL codes are custom codes that were developed at DRI and currently have no documentation. We believe that the purpose and functionality of the SWL codes are well described in the report and have chosen to keep the term "SWL" in the text of the report.

25. pg. 50 – "Model development" subheading should be "MODFLOW model development.

The subheading was changed to MODFLOW model development. See response to comment (2).

26. pg. 55 – Does figure 27 need a citation?

This figure was made by DRI personnel with data available from the USGS. The paragraph referencing the figure reads: "Rating curves for width and depth as a function of river flow *are developed using USGS measurements spanning years 1947 to 2007 at Hudson, Strosnider, and Wabuska gages (Figure 27)."*

27. pg. 56 para 1 – Is this paragraph describing MODFLOW or MODSIM input? If it's for MODFLOW are you recharging the cells in the HRUs?

This paragraph is providing background information on the available data for use in MODFLOW and, later, in MODSIM – there is no mention in the paragraph of either model since it is merely background on the available information.

28. pg. 62 fig 31 – Does figure 31 need a citation?

This figure was made by DRI personnel from data available in the GIS database referenced in the report. We do not believe that this figure requires a citation.

29. pg. 67-68 – I did not verify the results in tables 11 and 12.

The results in Tables 11 and 12 were verified.

30. pg. 71 para 2 – I don't think you need the acronym SNN

The acronym SNN was never used within the document, and was removed from page 71 as suggested.

31. pg. 72 – "Model evaluation" subheading should be "MODFLOW model evaluation

The subheading was changed to MODFLOW model evaluation. See response to comment (2).

32. pgs. 72-85 – These MODFLOW model evaluation sections look good, however, I did not verify any of this.

We reviewed and verified the MODFLOW model evaluation sections.

33. pg. 89 – "Conclusions" subheading should be "MODFLOW Conclusions." It's not clear what this is the conclusion of.

The subheading was changed to MODFLOW Conclusions. See response to comment (2).

34. pgs. 92-132 – This MODSIM section is beyond my technical expertise.

Understood. We did hire the developers of MODSIM to help us in the development, implementation, and review of the MODSIM applications described in this report.

35. pg. 95 ln 2 – The word "cost" needs to be defined here

Cost is a very common term used when describing the optimization of a dynamic simulation model. It is similar in concept to an objective measure used with models like PRMS during an optimization procedure – the objective measure is minimized (or maximized) through parameter value adjustment until a "best fit" is realized.

36. pg. 96 para 2 – “provided an unprecedented conjunctive surface and groundwater modeling system.” Should be “provided an unprecedented conjunctive surface- and ground-water modeling system.”

We agree with the reviewer’s intent, but disagree with the implementation. Because we used groundwater throughout the document rather than ground-water, we made the following changes.

The original text on page 96

“Direct coupling between MODFLOW river cells and MODSIM links using a custom module provided an unprecedented conjunctive surface and groundwater modeling system.”

was modified to read

“Direct coupling between MODFLOW river cells and MODSIM links using a custom module provided an unprecedented conjunctive surface water and groundwater modeling system.”

37. pg. 96 para 2 ln 1 – is there a reference for “the standard MODSIM-DSS Graphical User Interface (GUI)”

The original text on page 96

“MODSIM networks can be developed manually in the standard MODSIM-DSS Graphical User Interface (GUI), or in an ArcMap extension called Geo-MODSIM (Triana and Labadie, 2007).”

was modified by adding the necessary reference

“MODSIM networks can be developed manually in the standard MODSIM-DSS Graphical User Interface (GUI) (Labadie and Larson, 2007), or in an ArcMap extension called Geo-MODSIM (Triana and Labadie, 2007).”

38. pg. 97 para 1 last ln – “GUI interface” is redundant.

The original text on page 97

“Although the base model was developed in Geo-MODSIM, subsequent model development, calibration, and simulation involved only the standard GUI interface.”

was modified to read

“Although the base model was developed in Geo-MODSIM, subsequent model development, calibration, and simulation involved only the standard MODSIM GUI.”

39. pg 118 para 2 – The plots look good, but aren't you setting the model output to be the measured values? I probably don't understand the significance of what you are doing here. Are you saying that the plots would not match exactly if there were shortages and because there weren't any simulated shortages, the model works? This has to be explained somehow so that

readers that are not familiar with MODSIM will understand the significance. Maybe your target audience understands this already.

Unfortunately, the calibration and implementation of the MOSIM software is a very complicated process and is generally difficult to describe to those not familiar with dynamic simulation modeling approaches. We struggled with the level of detail we should provide in the report on the calibration and implementation of the MODSIM model. On one hand we would like to make the description as simple as possible so that those unfamiliar with dynamic simulation modeling can understand the general approach, while at the same time providing enough information for those familiar with dynamic simulation modeling to be satisfied that the approach is correct. We believe that the referenced text is both appropriate and necessary for those familiar to dynamic simulation modeling and is probably difficult to understand for those not familiar. As a result, we chose not to modify the text in this case.

40. pgs. 130 and 132 – It is strange to have two "Conclusions" sections in a row.

The section named Conclusions and Model Limitations was renamed DST Summary and Limitations to clarify that it refers to the DST and report as a whole.

41. pg. 132 para 2 – "…all play a role in the Walker River system and the DST." Should be something like "…all play a role in the Walker River system and are simulated by DST."

The original text on page 132

"Climate, streamflow, upstream storage areas, irrigation practices, crop and non-agricultural ET, groundwater-surface water exchange in the river corridor, groundwater pumping and recharge, and all known existing water rights (decree, storage, and flood) all play a role in the Walker River system and the DST."

was modified to read

"Climate, streamflow, upstream storage areas, irrigation practices, crop and non-agricultural ET, groundwater-surface water exchange in the river corridor, groundwater pumping and recharge, and all known existing water rights (decree, storage, and flood) all play a role in the Walker River system and are simulated by the DST."

42. pg 133. ln 3 – Justify this statement by adding tables showing how the annual water balance is represented. See comment 19.

Please refer to our responses to comments #19, #18, and #16 above. We don't think that our statement would be justified by the suggested annual water balance information and therefore chose not to include it in the report.

43. pg 133. para 1 – "Understanding the limits of the groundwater models is..." either cut or rewrite this sentence.

The original text on page 133

"Understanding the limits of the groundwater models is an important part of their implementation. The groundwater models are limited by include the non-unique solutions,

poor representation of water levels away from the river corridor in Smith Valley, and the significance of the simulated groundwater-surface water interaction given the unknown associated errors."

was modified to read

"The groundwater models are limited by their non-unique solutions, poor representation of water levels in parts of Smith Valley, and the unknown errors associated with the simulated groundwater-surface water interaction."

44. pg. 140 – Check the use of citation: Western Regional Climate Center (WRCC), 2008a.

This citation is used in the caption for Table 6 on page 45:

Table 6. Modeled monthly ET for phreatophytes, and riparian and wetland vegetation. Rates taken from (Maurer et al., 2005; Maurer and Berger, 2006) and adjusted using monthly average precipitation in Yerington, Nevada (Mason Valley), and Smith 6N and Wellington Stations (Smith Valley) (WRCC, 2008a).pg. 140 – Missing date of report: Wilson, J.D. and R.L. Naff.

45. pg. 140 – Missing date of report: Wilson, J.D. and R.L. Naff.

The date was added to the citation on page 140, which now reads:

"Wilson, J.D. and R.L. Naff, 2004. MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model – GMG Linear Equation Solver Package Documentation. U.S. Geological Survey Water-Resources Open-File Report 2004-1261."

PROJECT G: ECONOMIC ANALYSIS OF WATER CONSERVATION PRACTICES FOR AGRICULTURAL PRODUCERS

Economic Analysis of Water Conservation Practices for Agricultural Producers in the Walker River Basin

Response to Reviewer 1

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? The paper does a fair job of telling a cohesive story, although there were several sections that included apparently extraneous information. There were also some significant omissions. For example, the authors avoided addressing NV water law, quality impacts of changes in watering regimes, and the impact of incentive payments or water rights payments on cropping decisions. These appear to be critically important. The conclusions are not fully supported by the data or by references. Throughout the report, critical statements are not supported or explained in sufficient detail. This hinders the likelihood of another researcher being able to replicate the results or apply the same methodology.

Several sections were condensed to delete extra information. It was not the objective of this study to investigate water rights sales or water use incentive schemes, only the potential economic feasibility of lower water use crops (as compared to alfalfa). At this time all pertinent references and other statements are cited as needed. 0If another researched wished to replicate the results we would furnish our WinEPIC data base (agronomic and economic data for each crop) and they would be able to replicate the results.

2. Is the paper clear, well organized and concise? The paper is well written, concise and given the amount of information it is also well organized.

3. Are the methods appropriate, current, and described in sufficient detail? The methods appear appropriate, but not sufficiently described. See the attached notes.

We have responded to the reviewers attached notes.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? Model summary statistics were not provided, which made it difficult to evaluate the strength of the models or validity of assumptions. Otherwise, the analyses were largely correct (except for the discussion regarding risk).

The WinEPIC model is not a statistical model which evaluates data, but rather generates likely outcomes regarding crop yields for up to 100 years. Hence, there are no "model" summary statists to report. All model outcomes are reported in the graphs and tables presented in the report. All agronomic and economic data assumptions were verified through the use of enterprise budgets, extension personnel, interviews with farmers, and university soil and plant scientists.)

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? The tables have a great potential to help tell a very interesting story. Unfortunately, they are difficult to read in black and white and in some cases lack appropriate labeling.

The report needs to be reproduced in color. Line markers were used to replace the colored lines, but it made the graphs more difficult to read.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? Several assertions of fact are not supported. Otherwise, pertinent references appear to be cited.

At this time all pertinent references and other statements are cited as needed.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? The report is appropriate length for a technical report. The literature review should be condensed; a section should be added that addresses the sale of water rights (e.g., what price per acre foot have farmers been getting?).

The literature review was condensed. It was not the objective of this study to investigate water rights sales, only the potential economic feasibility of lower water use crops (as compared to alfalfa). Hence, we have not discussed water rights sales.

8) Can the paper be published? With major revisions

Specific comments:

1. I would have liked to see the paper estimate how much water was conserved as a result of planting the alternative crops, and/or under different assumptions about irrigation methods. The results on the crops are interesting, but the connection to water was lost shortly after the introduction.

By providing the amount of water used by each crop, producers can estimate the amount they would be able to conserve. This amount varies between producers, not all plant the same crops. Our task was not to determine the total amount of water savings, but the feasibility of alternative crops.

2. Pg. 3, 2nd para: The report describes the Walker Basin Project as a water rights purchasing program and indicates that completely halting irrigation would lead to a devastating loss to crop cover (resulting in dust bowl conditions). This suggests that adoption of alternative crops will result in residual water rights that can be sold via the project. However, on pg. 54, the authors state that Nevada law precludes partial sale of water rights. This should be addressed sooner in the report to avoid misleading the reader.

The report was created under the premise of the possibility of partial sale or lease of water rights in the future due to potential changes in Nevada water law. Although producers are allocated 4 acre feet of water per acre, during drought years most do not receive their full allocation, making this report helpful in determining if an alternative crop should be planted.

3. Pg. 4, 2nd para: Need a more full explanation of "local experts were consulted about experimental crops…" What methods were used, how many experts, was their broad consensus or disagreement?

Changed "local experts" to "local university and extension faculty".

4. Pg. 5, 1st para: It is indicated that WinEPIC has been calibrated for northern NV. Please provide a citation, and discuss the skill of the model (particularly when stating that the model can provide forecasts for 150 years).

The calibration of the model was determined by the models' creators at a workshop at Texas A&M, it was not a literature- based adjustment. The skill of the model is discussed at length under Data and Methods – Model Choice.

5. Pg. 5: consider bolding the section title "Related Literature." As-is, it looks like a typo.

Done

6. Pg. 6: the literature on water pricing (thru pg. 7) seems out of place here. The focus of the report is on alternative crops, not policy changes, and certainly not pricing of water.

Pg 6, 2nd paragraph through pg 9, 2nd paragraph has been removed from the report.

7. Pg. 7, 1st para, 2nd sentence: I would argue that the stated goal of water policy has little to do with the social costs. Instead, it is meant to bring prices closer to the long-run marginal cost (typically they are set at the SRMC) (e.g., Olmstead and Stavins 2007).

Pg 6, 2nd paragraph through pg 9, 2nd paragraph has been removed from the report.

8. Pg. 7, 1st para, 4th sentence: Please provide a citation for the statements about taxes and spot water markets.

Pg 6, 2nd paragraph through pg 9, 2nd paragraph has been removed from the report.

9. Pg. 9, last para: Please indicate how these criteria were determined. Did the expert panel define this list?

These criteria were determined by the authors. For clarification, changed "In order for an alternative crop to be economically feasible" to "In order for an alternative crop to be considered economically feasible by this study".

10. Pg. 15, 2nd para: The discussion of no-till seems misplaced, unless the results contemplate income from carbon credits or farm bill programs that is generated by adoption of no-till.

No-till is an important practice with regard to soil moisture retention, and affects the amount of water needed by the crop. Please refer to new version of report, page 13 first paragraph.

11. No-till is mentioned as being "incorporated… for all crops under consideration," but I did not see mention of no-till in the results. No-till is known to provide better long-run soil water storage for crop use, but probably does not increase water runoff to streams. If anything, no-till stabilizes production yields, but provides less water to streams. Either way, there should be some literature backing up this assertion.

This section has numerous references to the literature.

12. Pg. 17, 1st para: Please provide the page number for the quoted material. Also, move the period from "consumed." to after the parentheses.

Corrected

13. Pg. 17, 2nd para: there is an additional space in "…; Center 2006) ."

Corrected

14. Pg. 17, 3rd para, 2nd sentence: Please remove either "TAMU" or "Texas A&M University"; also, there is an unnecessary opening parenthesis before Teaxs A&M.

Corrected

15. Pg. 18, 2nd para, last sentence: please spell-out SSURGO as "Soil Survey Geographic".

Corrected

16. Pg. 19, 1st para, 2nd sentence: extraneous space following the coordinates for Smith Valley.

Corrected

17. Pg. 19, 2nd para, last sentence: Please indicate any citations and assumptions that support the alterations that were made to the crop profiles in WinEPIC.

These alterations were made by the agronomist at Blackland Research Center.

18. Pg. 20, 2nd para, 3rd sentence: Please provide additional description of how producer panels were used. How many producers per crop, etc?

The amount of producers varied by crop. Particulars were not disclosed for confidentiality reasons.

19. Pg. 21 – 22: Please provide justification (citation or personal communication) for the assumptions made on irrigation type, amount of water used, and length of rotations.

Assumptions were based on common production practices as stated in the first sentence of the paragraph.

20. Pg. 23, 2nd para: Please provide more description of how the model was validated. How much skill did the model possess? Exactly how close were the Lyon County yields to Churchill County?

Corrected

21. Pg. 25, equation 3: Please provide citations that support the use of normal and beta distributions for those crops. Also, if there are any summary statistics for the curves, please report those.

The distributions were determined by the data

22. Pg. 26, 1st para: Please report the alpha and beta parameters for the beta distributions. Someone wanting to replicate the results would need those.

Corrected

23. Pg. 26, equation 6: For the triangular distribution, which were the known, and which were the assumed values?

The known values were the minimum, midpoint and maximum values; the assumed values were those generated by the simulation.

24. Pg. 28: The graph is difficult to read in black & white. Consider including line markers. Ditto for all graphs in the report.

The report needs to be reproduced in color. Line markers were used to replace the colored lines, but it made the graphs more difficult to read.

25. Pg. 29: Please include the price per ton assumptions in the chart. Also, please consider comparing actual price per ton (at current or recent historic levels) to simulated break-even prices.

There are no prices per ton assumptions in this chart. Actual pricing levels are discussed for each crop in their respective sections.

26. Pg. 29: Please convert wildrye to price per ton, or explain why wildrye is only reported in price per pound.

Explanation is given under the wildrye section on page 33 of the newest version.

27. Pg. 29: Please explain why alfalfa and grapes are missing output for certain watering strategies.

Irrigation application was done in 2" increments.

28. Pg. 31: Output for onion yields appears to be very sensitive to yield curve assumptions. The authors should address whether the output has a relevant range (e.g., from 22 – 34 inches).

Yield curves were not assumed, they were generated by the WinEPIC model.

29. Pg. 33, Table 3: Please spell-out "P&I" and please provide a citation that justifies using a 7% rate.

P&I Corrected. The 7% rate was the same as the rate used in the enterprise budgets as suggested by the producer panels.

30. Pg. 33, 2nd para: Any difference in capital investment could be addressed by a program or policy change. Perhaps this should be addressed (at least superficially) in the discussion section.

This is beyond the scope of this report.

31. Pg. 34: Please provide a brief discussion of what assumptions you made that could significantly disrupt your results. How robust are the results?

In the previous version, page 34 discusses teff. I am unclear as to the pertinent page number for assumptions of results.

32. Pg. 40: I would like to see a section that addresses what changes in costs (perhaps due to a support program) would make less-thirsty crops economically preferred. In the last part of the 1st paragraph, the authors hint at this with a discussion of the relative costs of flood and center pivot irrigation for barley and alfalfa. [This is another way of determining what the water rights must sell for to achieve changes in crop and/or new technology adoption]

This is beyond the scope of this report.

33. Pg. 48: For wine grapes, it is unclear how the results were calculated with regard to maturing vines. Also, should an agritourism component be included?

The results were calculated using average yields over the lifecycle of the vines. This study focused on income from production.

34. Pg. 49, Figure 9: Please label the x-axis. I assume it is showing price per acre.

Corrected

35. Pg. 50, 1st para, last sentence. I disagree with the authors' characterization of how the steepness of the curves in Fig. 9 translate to one crop being preferred to another. It really depends on the level of risk aversion. Likewise, the statement "risk averse producers would rather lose $300 yearly than make a profit of $300 one year, losing $900 the next year" is not accurate. A more accurate description of a risk averse farmer would be one that would rather have $49 than a 50% chance at $100. Also, a citation is needed here.

Corrected – The last sentence has been removed.

36. Pg. 53, 3rd para: Could WinEPIC not account for quality changes with a weighting procedure?

The model does not have this capability at this time.

37. Pg. 54: The statement about NV water law (as stated) undercuts the significance of the report. I would like to see the authors address this.

The report was created under the premise of the possibility of partial sale or lease of water rights in the future due to potential changes in Nevada water law. Although producers are allocated 4 acre feet of water per acre, during drought years most do not receive their full allocation, making this report helpful in determining if an alternative crop should be planted.

38. Water rights, if sold, would supplement income. Should the sale of water rights be factored into the break-even price calculations?

There are too many unknowns regarding the price that would be received for water rights and amounts received by each individual producer.

Response to Reviewer 2

1.Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? Yes, for the most part.

2. Is the paper clear, well organized and concise? The manuscript is very long and for the most part is easy to follow but is not organized in a standard research paper format, i.e., problem statement/review of literature, objectives, data and methods, results and discussion, and conclusions/ recommendations. The manuscript would have a much stronger focus and be easier to follow if it were organized like a standard research paper with appropriate subheadings in each major section. In addition, there is a lot of text that simply doesn't add to what the authors are trying to do. For example, on page 24 in the first paragraph: "Although data can be input in either English or metric units, all output data…" The reader does not need to know about this because it adds nothing to the study and thus all extraneous statements like this should be eliminated from the manuscript. Removing such language would shorten the manuscript and make the analysis much more concise.

The report was formatted to the requirements of the Walker Basin Project. Superfluous text corrected – Numerous paragraphs have been removed from the last version, i.e. the last paragraph of page 6 through second paragraph of page 9; these do not appear in the newest version.

3. Are the methods appropriate, current, and described in sufficient detail? Methods used to calculate the costs of production appear to be reasonable for the most part. The authors, however, should make sure that they follow the standards out lined in the AAEA Costs and Returns handbook. I am not sure how the authors handled establishment cost for perennial crops in their simulation of net revenues. It seems to me that it would be appropriate to amortize establishment costs over the life of the investment and add the annuity value to the annual operating costs. The crop budgets don't indicate that the authors have done this.

Calculations were used for the formatting from UC Davis enterprise budgets. Establishment costs have been amortized over the life of the investment for perennial crops. (See UNCE special publications SP-08-06 through SP-08-14)
http://www.unce.unr.edu/publications/search/

It is a not necessary step and bad procedure to first simulate yields using the daily time step simulation model and then simulate them again in Excel using Simitar. Use the simulated yields from EPIC directly in the calculation of crop net revenues. All of the discussion of methods on pages 25 and 26 is superfluous and do not add to the analysis and may in fact add bias to the analysis in that you are making assumptions about the distribution of yields when you don't need to make the assumptions, i.e., normal or beta distributed yields.

The yields were not simulated again in Simitar, only the amount of variation in yields between years. It was necessary to determine the distribution of the residuals of the yields in order to create stochastic yield variables.

I don't understand the discussion of irrigation strategies on pages 21 through page 23. Different amount of irrigation are applied to each crop but absolutely no documentation is provided to justify the set of irrigation and other production practices chosen. This certainly needs to be documented. Then, on page 24 in the analysis section, the authors indicate that they simulate yields for each crop in increments of two inches up to 48 inches. Why discuss the different amounts of irrigation for each crop unless they are tied to a current recommendation.

> *As stated on page 18 of the newest version, "Irrigation amounts followed producer or research recommendations for the initial simulations". A range of irrigation levels were used to determine potential yields under all levels of available irrigation. In some cases, recommended levels were not optimum as seen with Great Basin wildrye on page 33.*

4. If statistical models are used, are model assumptions, inputs, and statistical design, and analysis? See my comments in question 3

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? Yes.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by data in this paper? No. See my comments in question 3

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? See my comments in question 3.

8. Can this paper be published? With major revisions.

PROJECT H: FORMULATION AND IMPLEMENTATION OF ECONOMIC DEVELOPMENT STRATEGIES

Economic and Fiscal Impacts and Economic Development Strategies: Consequences to the Agricultural Economy in the Walker Basin

Response to Reviewer 1

General comments

I am not sure as to the general purpose of the study. If this is intended as a reference document that will be the foundation piece for other reports you can ignore most of my suggestions regarding format changes. Format and readability are less important for a reference document. If however, the document will be circulated to a wide audience I think format changes would be useful.

I would make the following recommendation regarding general format:

1. Needs an executive summary. The abstract is useful but it does not state a summary of the findings. The general declarative sentence stating the purpose of this report is not offered until page 10.

Added executive summary

2. The table of contents needs to be revised. Chapters may not be necessary and could be renamed as sections. I think the long list of figures and tables could be removed. Also, the page listings may not be necessary for all the subsections. This assumes that the format is not mandated by an RFP.

Table of contents revised. Chapters were renamed as sections. List of tables and figures was retained, as the authors felt it was beneficial. Some of the subsection details in the table of contents was eliminated.

3. Needs a conclusion with an overview of policy recommendations.

Conclusions included in the executive summary

4. Add a section about the authors. In my experience these types of reports benefit from a small blurb about the authors. Users of these studies need to know the technical credibility of the authors.

Information about the authors has been included.

5. The most useful section is Chapter 3. This is the section where the public deliberation and policy prescriptions are presented. This should be emphasized in the executive summary.

An executive summary was added that emphasizes content from the former Chapter 3.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? The paper does tell a comprehensive (perhaps not cohesive) story. The analysis for the various locations are clearly designated and well supported by the analysis.

Chapters one and two need to be more integrated. It is a little confusing to see analysis for Mason Valley and Smith Valley in the first chapter then see tax impacts for Lyon County and Smith County. The introductory paragraph to chapter two does delineate the regions but it may be useful to include a map or footnotes on the fiscal impacts. This may not be necessary for someone who is familiar with the region.

> *Comments have been added so that it is clear that Mason Valley and Smith Valley are parts of Lyon County, while Hawthorne and Walker Lake are in Mineral County.The report's technical competence is clearly in line with a document of this type. The methods are appropriate and properly applied.*

2. Is the paper clear, well organized and concise? It is organized to extract specific data easily but overall the format makes it a difficult read.

> *The addition of an executive summary and the reformatting of the document should mitigate the "difficult read" observation.*

3. Are the methods appropriate, current, and described in sufficient detail?The methods are appropriate and described in sufficient detail. It would be useful to describe the direct, indirect, and induced impacts in more detail. In my experience most people don't know the difference between the impacts. Also, on page 18 the sentence that states the output from "IMPLAN are much like total sales" may be misleading. IMPLAN generates an output amount of output which may constitute sales or changes in inventory. It appears that the fiscal impact sere not estimated using the IMPLAN package. It may be useful to add a line or footnote saying that.

> *Language has been added and revised to address these comments. It was very clear to the other reviewer that IMPLAN was not used for the fiscal imapct analysis. The authors felt this is quite straightforsard.*

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? The statistics presented are in line with what one would expect in such a report. The underlying assumptions of the input-output methodology are appropriate and the application of the IMPLAN model appears correct.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? The tables and figures are clearly labeled and interpretable. The maps are very useful for a project like this. It may be useful to increase the size of the legends to make them more readable. The assessed value in tables 2.3 and 2.4 do not appear to reconcile the way tables 2.5 and 2.6 reconcile.

> *The smallest legend was removed, as the information was reduncant with the tables that immediately follow the maps. The tables include different information. Changing the title of table 2.4 (now table 3.4) helps to explain the difference between the two sets of tables.*

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? References appear appropriate.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? The length is appropriate. Depending on how the document is to be used, the material in chapter three should be highlighted. That is the useful portion of the report.

8. Can the paper be published? I would accept this paper with moderate formatting revisions. I do not think any of the actual analysis needs to be revised.

<u>Response to Reviewer 2</u>

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? The paper does tell a cohesive story. Four scenarios are presented concerning possible economic and fiscal impacts on the Walker Basin. The scenarios are well-defined and clearly stated. The conclusions are supported by the data. The limitations of the study are addressed directly and are unavoidable. Overall, this is a solid report. I do have several suggestions concerning mainly the organization of the paper that might improve readability.

2. Is the paper clear, well organized and concise? Generally, the paper is well written and well organized. I have the following suggestions.

First, an introduction (in addition to the abstract) describing the nature of the problem and the analysis that will be presented would be a helpful addition to the paper. An introduction of this type would be particularly useful to someone who might read the study a decade or so from now. As currently presented, the main body of the text begins with a description of economic impact analysis with no preliminaries.

Added executive summary

Second, Chapter 1 (Economic Impact) is far too long (60 pages) for most readers. Without much additional work, this chapter could be split into two separate chapters that would be much easier to follow. The first of the new chapters could contain the general introductory material on impact analysis and describe the four basic scenarios. The second 'new chapter' could then present the results of the impact analysis.

Done (and renamed as sections 1 and 2)

3. Are the methods appropriate, current and described in sufficient detail? The short answer is yes. More detailed comments follow. There are essentially four methods used in the report: (a) an analysis of current agricultural production and cropping patterns in the region, (b) the economic impact of the four scenarios analysis using IMPLAN, (c) the fiscal impact analysis using the impact results and location specific tax rates, and (d) the community survey approach that formed the basis of the economic development section.

The analysis of agricultural production and cropping patterns in the region is detailed, thorough and essential for the economic impact analysis that follows. This analysis in combination with general economic and demographic information about the region is, of course, the basis for the four scenarios developed in the study. The detail clearly and convincingly indicates that the Walker Basin is not a single homogeneous region and that the economic and fiscal impacts are likely to be different in different sub-regions. The authors have been careful to explain that water use, profitability, crop yields, and other critical variables presented are averages subject to considerable variation from farm to farm and by region.

The use of the IMPLAN software to evaluate the economic impacts of the four scenarios is an appropriate state-of-the-art approach. I use IMPLAN on a regular basis to conduct economic impact studies and the selection of this model should generate no controversy among professional economists. There are few alternatives and input-output model based multipliers contained in IMPLAN are both reasonably conservative and widely used. The explanation of the model is straight-forward and well done in the report. I have only two IMPLAN-related suggestions. First, a paragraph (no more) should be added that explains real versus nominal dollar values. The IMPLAN structural matrices are for a particular year. The most recent version is 2006 and dollar values of both inputs and outputs are in 2006 dollars. Since the water rights changes could occur over a period of several years, the fact that the results are in constant (2006?) dollars should be explained.

Explanation added.

Second, as explained (nicely) with Table 1.3, most economic impact studies attempt to estimate impacts in terms of value added, employment and labor income. Many readers of the study are likely to want to see the employment and labor income impacts. In the four basic scenarios, only value added (direct, indirect and induced) is presented in the tables (e.g., Tables 1.18 through 1.20). Why not have an additional table or two showing the employment and labor income impacts –as is done in the case of anglers and recreational use (Table 1.23)?

Added.

The method used to evaluate the fiscal impacts is to apply the appropriate tax rates to the impact results under the four scenarios. This is an appropriate method and far better than the generic tax rates built into IMPLAN. Again, I would stress that these are constant dollar estimates.

The authors felt that the fiscal impact analysis was fairly clear in indicating dollar values being based on fiscal 2007 budgets.

The economic development analysis in Chapter 3 is based primarily on surveys of local residents in a series of community meetings. This is an appropriate method to use for local economic development issues. A clear and largely unchallenged lesson from numerous local economic development studies is that the chances of success in the development arena are directly proportional to community involvement. I have only one suggestion to strengthen this approach: specifically, a discussion of the definition of economic development. This is a concept that can mean many things to different people.

A brief definition of economic development (one sentence) was added into the executive summary and the body of the report.

4. IF statistics or models are used are model assumptions, inputs, the statistical design, and analyses appropriate and correct? Please see the responses to question 3. This is not a statistical study in the usual sense of that phrase.

5. Are all tables and figures necessary, clearly labeled and readily interpretable? The tables and figures are necessary. The figures –especially the maps add clarity and ease of understanding to the material in the text. I suggested (above) a couple of additional tables containing employment and labor income impacts of the four basic scenarios. The tables are clearly labeled and relatively easy to interpret. Tables 1.18 through 1.20 probably contain too much data for most readers, but I do not have a good suggestion on how to change these.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? The references are pertinent. No additional references seem necessary.

7. Can the paper be published (minor, moderate or major revisions) or is it too flawed to be published even with major revisions? This paper can be published with minor revisions. I strongly recommend an introduction, splitting chapter 1 into two separate chapters, and including some discussion of real versus nominal values in the impacts section.

These comments were all addressed

PROJECT I: DEVELOPMENT OF A WATER RIGHTS GIS DATABASE

Development of a GIS Database in Support of Water Right Acquisition in the Walker Basin

Response to Reviewer 1

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation?

1. Take the majority of information from the methods section and create metadata for each dataset collected for the project and create an appendix of metadata (which is looks like you have done already).

An excellent suggestion. As part of our report, we have developed metadata for each of the data sets described in the original Table 1 (which is now in an Appendix at the back of the report). In addition, we will be providing a USB flash drive containing the database (with FGDC metadata) to BOR when we turn in the final report.

2. Keep the report short and refer to the metadata for further discussion of methods.

We will move Table 1 to an appendix (Appendix A) at the end of the report (now called Table A1). We will reference the metadata attached to the data sets in the ***Data Acquisition and database development*** *section.*

3. Focus should be content of the GIS, how it was used throughout the larger project, lessons learned and recommendation for maintenance or future enhancements. For the content of the GIS describe the spatial extent, scale of datasets and uses of the data in the larger project. Much of this could be handled in the first table that lists all of the datasets. I would recommend adding a column for spatial extent and scale of the data. In addition I would add which components of the project as a whole used the data i.e. specifically which datasets provided inputs to MODSIM and MODFLOW, which datasets contributed to the EIS etc.

Good idea. We have added three columns to Table A1 in the new appendix, one for spatial extent, one for spatial scale, and one for the actual file name of the data set on the accompanying USB flash drive so that it can be cross referenced with the table. We have added a subheading under the ***Discussion*** *section called* ***Spatial data uses by project****, that summarizes which projects within the Walker Basin project utilized the specific data described in the* ***Data Acquisition and database development*** *section and listed in Table A1.*

4. Make a graphic or flow diagram that illustrates the steps that were taken to obtain the data, basic processing steps and the final result.

We feel that the major revisions we've made to the report, i.e. more detailed descriptions of the database and its purpose and content, restructuring of the original Table 1 (now a table in Appendix A, the addition of the appendix, the development of the database on an accompanying flash drive, and a summary of which projects and groups are using the various data sets, have adequately addressed some of the identified shortcomings. We feel that the *addition of flow diagrams will only repeat what is now described in the text, and will only lengthen an already long report.*

5. Depending on how it ends up fitting together you might include some summary information for each study area from the GIS i.e. how many ditches, POUs etc.

We don't feel that enumerating the number of ditches, POUs, etc. in the text will provide any additional information that can't already be extracted from the attribute tables of the data layers that will now be readily available on the project flash drive that will accompany the report.

6. The data storage and distribution section could also be included or included as an appendix.

We have moved the file system figure to Appendix A and modified the discussion of the data storage and distribution issues in the Discussion section.

7. You begin to describe some of the lessons learned in the data acquisition / data development issues section but I think it could be more focused. A table or bulleted list of issues followed by the more detailed discussion of them may make it easier to follow. You could include a section on the limitations of some of the datasets.

We have added a set of bullets to the Data Acquisition/data development issues and limitations subsection that highlight some of the key issues. We have also added more detail to the discussion of these issues. We added a paragraph describing some of the limitations of the data.

8. Include recommendation to the agency for maintenance of the GIS and maybe some future enhancements. Do you have recommendations for the agency if they were to undertake this type of GIS project in another location? Where are the gaps in the available data? What datasets would be the highest priority to create in the future for supporting future analysis or enhancements to the models?

We have added a recommendation subsection to the Discussion section.

9. An alternative report

We will follow the reviewers above recommendations for a funding agency report, as that is our current reporting requirement to BOR.

2. Is the paper clear, well organized and concise?

1 .The paper was not clear, well organized or concise.

We are hoping that the above described responses, based on the reviewer's recommendations, will provide a clearer, more concise final report to BOR. We have modified and reformatted some of the sections to provide a more concise report.

3. Are the methods appropriate, current and described in sufficient detail?

1. I am concerned with the mixing of scales of data sources and no discussion about the impact on the hydrologic model. Resampling the 10 meter DEM data to 1 meter and combining it with

1 meter LIDAR data does not follow good practices. Convention is not to increase or decrease the scale of a dataset by more then 2.5 times.

We have clarified the text so the reviewer may fully understand how and why the resampling occurred and inserted a reference for hydrologic modeling using DEMs.

The reviewer is correct in their statement that analysis should not be done using a fused 1m and 10m DEM at the finer resolution; however, the only analysis we did using 1m data was to identify the Walker River main stem and this did not use any of the resampled 10m data to accomplish this task.

The resampling of the data was done to allow us to fuse the data sets together in preparation to resampling to the higher 100m pixel resolution required for analysis within the hydrologic modeling efforts. Data may be fused at any resolution, it is the analysis that may be impacted by the fusion efforts. Thus, we resampled up beyond the minimum 10 pixel resolution.

The Landsat information was used to generate different datasets and all information is scaled up to the 100m hydrologic modeling unit resolution, thus, again there is no downscaling of the Landsat information only upscaling of the final product.

It should be noted that there are multiple papers which do imagery classification at a different resolution than the DEMs which are used to discriminate further. As a matter of fact, manuscript authors have used elevation as an ancillary dataset to further refine land cover, precipitation, wildlife habitat and many other types of classifications. The assertion that all data has to be at the same pixel resolution for differing attribute information is incorrect and a quick look through PERS at many land use/land cover classification manuscripts will void any argument against this. The reviewer is correct that for a similar attribute (i.e. elevation) downscaling may and has been shown to result in "strange" data outcomes (i.e. striping). This noted many authors have stated that often this has more to do with the resampling algorithm than the actual resolution of the information. Regardless it is still an effect and we did not downscale any data that was used in a final analysis. We just downscaled to allow for fusing of data prior to upscaling.

2. I have not kept up on the Landsat interpretation literature but there may be other equations that are better then NVDI.

In previous DRI projects involving Landsat TM analyses of the Walker basin, researchers have experimented with the use of other, newer satellite-based vegetation indices such as SAVI and MSAVI. The results with these soil-adjusted vegetation indices were not as promising as with the NDVI, so a decision was made to use NDVI for this project.

3. On page 36 it would help if you describe the topography of the study area to support the assertion that the effects of topography on the NVDI values are minimal, assuming the area is flat.

We have added a description of the topography found in Mason Valley to the Landsat TM section (Mason Valley is flat).

4. It would also be helpful to have an accuracy assessment for the Landsat interpreted data.

An accurate assessment of the Landsat interpreted data would have been difficult given that the time period of the analysis was the year 2000. Accuracy assessment of sample sites within the current irrigated fields would have been difficult given the limited access to private property and the relatively short time frame of the project.

5. Page 40 – I think you conducted a zonal sum to calculate the area of irrigated lands within each HRU but it is unclear which of the zonal statistics was used. The description of this process needs to be rewritten.

We have rewritten this section to clearly state that the ArcGIS Spatial Analyst Zonal Statistics function was used to ***summarize*** *the number of acres of irrigated land (based on NDVI values) per HRU.*

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct?

1. See comments under # 3 on resampling data and NVDI.

Addressed above and changes made to final report.

5. Are all tables and figure necessary, clearly labeled, and readily interpretable?

1. Label the rivers and lake

Done.

2. The state boundary line and the county boundary lines should be different line types.

Done.

3. What are the study area boundaries? Figure 1 – has two dashed boxes, are these the study areas? If they are the boundaries should be included on Figure 2 and 3. If they are study area boundaries are the study areas for the entire project or just the hydrologic modeling component?

The study area is the entire Walker Basin. Smith and Mason valleys were identified in Figure 1 because of their significance as prominent agricultural regions and because they are the focus of much of the GIS development work due to importance in the DST development process and other Walker Basin projects. We have identified them on Figures 2 and 3.

4. The location map should be labeled as a location map. I am finding in my own work that as strange as it may seem not everyone recognizes those as location maps.

Done

5. Figure 4 – not having the same orientation on both the surface and elevation maps makes it difficult to read. Either have two figures or have the same orientation for both the surface and the elevation. Alternatively draping the elevation over the hillshade can also be an effective method for illustrating the data. I am not sure where figure 3 and 4 are referenced in the text.

We have adjusted the orientation of the hillshade in Figure 4 to match that of the elevation map. Figure 3 is referenced on page 5; Figure 4 is referenced on page 10.

6. Recommend including hydrologic boundaries of the watersheds to the maps. If this is supporting hydrologic modeling then an indicator of the boundaries of the model should be included.

Figures indicating the hydrologic boundaries for the various DST model domains are included in the DST modeling final report; we did not duplicate them here.

7. Figure 15: The title is not clear. I am guessing that the yellow polygons are the HRU's but I am not sure how it illustrates the NDVI results.

This figure is now Figure 17. We have modified the figure caption to better explain that the yellow areas indicate the irrigated acreage found within the HRU boundaries for the Landsat scene acquired 7/27/00.

8. Table 1: I would add the scale of the original data, the extent of the data and indicate which projects used GIS data i.e. hydrologic modeling, EIS etc.

We have addressed this issue and our response is described above under Section 1.

9. Table 2: it would be nice to have the different areas illustrated on a map. Antelope Valley, East Walker etc.

We have added Figure 10, the locations of the annual diversion sections identified in Table 2 (now Table 1).

10. Table 3: unless your data is accurate to the 6^{th} decimal place I would reduce the number of decimal places. Define what the different Crop type values are as footnote to the table.

We have reduced the number of decimal places in the table. We spelled out the crop type names (values) in the table.

11. Table 4 – in a footnote define the Type of Use code.

Done.

12. Table 5 – same comment as table 3.

Done.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper?

1. Look for some more recent citations on NVDI analysis for identification of irrigated lands, wetlands and riparian areas.

We added several references on the use of NDVI in the assessment of irrigated lands.

2. Need to have references to support the manipulations of the elevation datasets. Look specifically for literature supporting hydrologic modeling and DEM creation.

We added a reference for hydrologic modeling using DEMs.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted?

1. The length will depend on what the focus of the report ends up being.

We have tried to keep the length of the report down by putting all of the data and metadata on a DVD to accompany the report.

8. Can the paper be published with:

1. To be published in a book or journal it would need to have an entirely different focus.

If we publish these results in a peer-reviewed journal or book, we will be integrating these results with those from the DST modeling report, condensing the material dramatically, and emphasizing the development of the spatial data specific to the model development process.

2. It can be published as a report to an agency with major revisions.

We hope that the major revisions we have made and the modifications and reformatting we have done to the document will be sufficient for the BOR report.

Response to Reviewer 2

1. Better describe why the database was built and how it would be used.

Addressed this comment in the Introduction section.

2. Grammatical changes to page 1.

Done.

3. Continued text on page 10.

Text was not continued in draft because of size of Figure 4.

4. Why list Permit data in Table 2 when all zeros?

The annual diversion data received from the Federal Water Master contained decree, storage, AND permit (flood) diversion data for the years 1996 to 2006. The example we show in the report, 2007, did not have any permit (flood) diversions because it was a relatively dry year.

5. What about domestic/municipal wells? Weren't they needed for groundwater model?

Both municipal wells and irrigation wells were included in the groundwater modeling process. We have modified the text in the document to reflect the use of both well types. NDWR did not have flow rates available for domestic wells in Mason and Smith valleys, and domestic well pumping was not thought to have a significant impact on the groundwater system in both valleys.

6. On page 35, spell out GBLW.

Acronym GBLW is identified and spelled out on page 27.

7. Why was it important to observe fluctuations in irrigated acreage for a relatively dry year, 2000?

We have added a discussion of the significance of the dry year analysis to the section Analysis of irrigated acreage in 2000.

8. Delete zeros and reduce significant digits in Table 5.

Done.

Economic and Demographic Analysis of the Walker Basin

<u>Response to Reviewer 1</u>

1. **Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation?** The paper explains how demographic and economic estimates are made for a subregion economy. As such, the paper does not fulfill the role of analysis that is suggested in the title. Rather the work is the estimation of stylized facts that one would need to do analysis. The interpretation is anecdotal. There are no hypotheses or theoretical frameworks guiding the paper. One is struck by the redundancy of the results and the conclusions, suggesting that a rewrite to tightening things up is called for.

The authors completely disagree that the "interpretation is anecdotal" and that "the paper does not fulfill the role of analysis". The objective of the Demographic & Economic Analysis of the Walker Basin (data acquisitioning, treatments, mapping, reporting, and interpretations) was clearly stated during the proposal, planning, development, and draft report stages. The context of the term "analysis" used in the title is the presentation of the results of this process, and, therefore, should not trigger a complete rewrite in order to meet academic definitions involving "hypotheses or theoretical frameworks".

2. Is the paper clear, well organized and concise? As noted above the paper drags with repetition. I would have thought with the use of GIS methods that some descriptive graphs might be useful in describing what the author(s) want to say. Rather than repetitively presenting facts in sentences, table would go a long way in making this work easier to read and understand. There are a number of style issues that would improve the text–every where one sees "in order to" the simple "to" works better. An editor would be of help here. As such, this are areas that needs addressing so as to help the reader. The text is a good draft from the writer(s) perspective, but there is awkwardness and extensive repetition for the reader.

The reviewer was provided with a preliminary draft that completely lacked graphs, tables, and maps. Since the preliminary draft was provided to the reviewer, graphs have been imbedded within the narrative and 20 pages of maps and tables have been added. A review of the "style issues" has been performed and adjustments made.

The development and discussion of subregion data to further the understanding of demographics and economics in Walker Basin and its communities was the stated goal throughout the project. Translating the resulting data into narratives was just as torturous, *we are sure, as the reviewer having to read the narrative, but the intent was not to entertain. Explanation of the GIS methods is a good topic, but not integral to the intended results and would have lengthened the already extensive paper.*

3. Are the methods appropriate, current, and described in sufficient detail? The paper falls into the class of work that covers facts of use–what many call stylized facts. Obviously, the approach falls short of a full discussion on water, either the work needs to be formulated on a narrower focus on demographic and economic facts for undertaking an analysis of water issues, using the Walker Basin, as an example or linkage to water added, thereby adding to the focus and direction of the paper.

RESPONSE: The stated objective of Demographic & Economic Analysis of the Walker Basin was to benchmark the various demographic and economic indicators in the Basin and communities within the Basin without their correlation to water use. There are several tasks within the overall Walker Basin Report that addresses the issues of water in the Basin. Tying the demographic and economic activity to water use is an excellent proposal and will be discussed for future research if needed.

The reviewer completely misses the mark regarding the methods used to develop the analysis. One cannot simply obtain the information used in the analysis from websites or local governments. Because of the multiple sub-county and unincorporated areas in the Basin that span four counties and two states, the core information is extremely difficult to obtain and develop into meaningful data. The methods used and documented allowed the development of current demographic and economic information for communities in the Basin that have never been analyzed in such detail. The "stylized facts" (the narrative) are a result of difficult and complex processes to cull the information from various databases and package into reports.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? The uses descriptive statistics; there are no models. As a result, the analysis stays at a fundamental level. I would not want to suggest that an elaborate modeling structure is called for, that is not where the paper is going. This focus depends on the framework of the editor and publishers.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? I suggest that tables are called for– it would be a help to the reader. Also, with tables and GIS graphs and figures, the author(s) should not repetitively keep the text, resulting in further redundancy.

The reviewer was provided with a preliminary draft that completely lacked graphs, tables, and maps. Since the preliminary draft was provided to the reviewer, graphs have been imbedded within the narrative and 20 pages of maps and tables have been added.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? No bibliography is attached, though references are made to data sources in the text.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? I recommend condensing. The results and the conclusions are highly repetitive.

RESPONSE: We agree that the discussion of the various demographic and economic indicators is a boring read, but a necessary process to report on the complete set of attributes. We fail to see where we repeat the conclusions for a specific attribute. Moreover, this reviewer's request to condense conflicts with the requests from the second reviewer stated below.

8. Can the paper be published? With major revisions

Response to Reviewer 2

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? The paper provides a concise overview of current and historical demographic and economic trends for the "Walker Basin" region. It was highly useful to show these trends at both the regional level and at the county-local level. Useful comparisons to state-wide activity also provided additional insight into how these demographic and economic trends within the "Walker Basin" region compare to state-wide behavior.

For the most part, the conclusions that the authors arrive to are supported by the data presented. The interpretation is clear and concise, especially when compared to state-wide trends. However, state-wide comparison was not used in all sections. Additional comparison with state-wide trends may provide additional insight and support for the author's conclusions and interpretations. Additional comparison to national demographic and economic trends might also provide further support for the conclusions made by the authors.

The draft was reviewed for areas where comparisons to statewide trends can be added. In some cases statewide comparisons were added. We resist the request for comparisons to nationwide trends to keep the document concise and not overly worded, as suggested by the first reviewer.

2. Is the paper clear, well organized and concise? The authors have written a fairly clear, well organized and concise paper. Demographic and economic trends for the "Walker Basin" region are presented for the following: population; age, race and sex; occupation and education; income; housing units; housing values; firms, employment and payroll; taxable sales; crop yields and value; residential construction activity; and proposed commercial activity.

When the authors present data for the various categories listed above, quantitative and statistical analysis is presented in a way that is clearly understandable and directly related to estimating and illustrating current and historical demographic and economic trends for the "Walker Basin" region. When data is presented on sub-areas of the "Walker Basin" region, the authors use a consistent and concise approach which makes comprehension easy.

In-terms of organization of the paper itself, the "Conclusion" section should be moved to the beginning of the paper between the "Methods and Approach" section and the "Results" section. I would also recommend that the "Conclusion" section be renamed to something like "Summary of Findings" or just "Findings". This reorganization may help make the paper easier to understand as well as more "reader-friendly" – especially for policy makers that are not interested in reading through the entire document before getting to the author's own conclusions and results.

The "conclusion" section was moved above the "results" section and renamed to "summary of findings", as suggested.

3. Are the methods appropriate, current, and described in sufficient detail? Given that the authors are only presenting demographic and economic trend analysis, there is no need for overly-complicated statistical and/or econometric analysis. The level of quantitative and statistical analysis presented is sufficient to support the conclusions and interpretations made by the authors. The methods used are appropriate and are very common across similar studies and the authors have described these methods and approaches in sufficient enough detail.

Thank you for supporting our position against the first reviewer's take on the methods used.

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? As mentioned previously in my response to Question 3, the authors are merely presenting demographic and economic current and historical trend analysis for the "Walker Basin" region. This level of analysis does not require complex model building found in higher-level statistical and/or econometric analysis. The approach used by the authors within the study is appropriate and correct for the type of analysis being used.

However, the authors could expand upon their demographic and economic trend analysis by presenting results of a location-quotient and/or input-output analysis to show potential growth industries across the "Walker Basin" region. Location-quotient and input-output analysis is common in this type of analysis and would be most useful in the "Firms & Employment" section located on Page 10. The use of location-quotient and input-output analysis would help strengthen the conclusions and interpretations already made by the authors. If the authors choose to add location-quotient and/or input-output analysis, state-wide and nation-wide comparisons would be useful.

Another useful point of comparison would be to compare the various trends presented throughout the paper to the largest population centers in Nevada, including the Reno-Sparks-Washoe County area and the Las Vegas metropolitan area. Although much of this comparison is already indirectly captured by presenting state-wide comparison trends, comparing current and historical demographic and economic trends in the "Walker Basin" region to similar data sets for Nevada's two largest urbanized centers would help make clearer the differences between rural and urban communities. On several occasions, the authors assert the conclusion that the rural nature of the "Walker Basin" region helps define and explain some of the trends. It would be useful to have an "urban comparison" in order to support the conclusion that the rural nature of the "Walker Basin" region helps to define current and historical demographic and economic trends.

The location-quotients are an excellent suggestion that will be explored for future research. A input-output analysis was conducted within the "Economic & Fiscal Impacts and Economic Development Strategies" section of the Walker Basin Report.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? There are no tables or figures in the study. The authors have chosen to use a narrative to present all of their data. This might be a potential draw back of the study as much of the data in the narrative presentation may be easier to understand if presented in table and/or figure form.

In the "Results" section of the paper, much of the data presented could have been presented in table form. I would recommend that the authors consider developing simple tables to more clearly present the study's quantitative findings. For example, the following table could be developed for the "Population" sub-section:

Population for "Walker Basin" Region

Area	Total Population 2007	Percentage of Total 2007	Persons per Square Mile
"Walker Basin" Region	18,999	100.0%	5
Mason Valley	8,583	45.0%	47
Mineral County (Hawthorne, Schurz, Walker River)	4,128	22.0%	
Ect.	Ect.	Ect.	Ect.

Although I have not finished this table, similar tables could have been developed for the entire "Results" section without any change to the narrative component. The narrative component is important in helping provide insight into various trends and in helping to provide explanations in the trends. However, similar tables to the one example I have presented above would provide the reader with a more "user-friendly" way to view the data and how various sub-region demographic and economic trends compare to region-wide, state-wide, and even national-wide trends. Sub-region vs. region vs. state vs. national trend comparisons are made easier through the use of data tables.

Bar charts and line charts would also be useful, especially in the "Residential Construction Activity" sub-section of the study to show year-to-year changes in construction activity. Similar sub-region vs. region vs. state vs. national trend comparisons in residential construction activity could also easily be communicated using bar charts, line charts, and tables. The narrative is useful in helping explain these trends but is less useful in helping to simply present the data itself.

I would also recommend that the authors include maps when appropriate. The authors refer (several times) to various mapping techniques – especially for crop yield production and value. The inclusion of maps provides helpful visual references to the reader and would add to the clarity of the narrative presentation already provided in the study.

The reviewer was provided with a preliminary draft that completely lacked graphs, tables, and maps. Since the preliminary draft was provided to the reviewer, graphs have been imbedded within the narrative and 20 pages of maps and tables have been added.

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? The authors have provided significant and appropriate citations and references for all data collected and analyzed throughout the study. Superior citation and referencing was made in the "Methods & Approach" section. No changes are necessary.

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted?The length of the report is appropriate. The authors have successfully been able to communicate a large amount of data and material in a concise manner without either understating or overstating the conclusions.

As already mentioned, I recommend that the "Conclusion" section be moved to the top of the report between the "Methods and Approach" section and the "Results" section. This should not alter the length in any way.

The addition of possible charts, tables, figures, and/or maps, would lengthen the report as it currently is but should not lengthen it too much.

The "conclusion" section was moved as suggested and a significant amount of graphs, tables, and maps were added.

8. Can the paper be published? The document, as it is currently, could be published as is without any revisions, changes, and/or alterations. Even without the suggested changes to the "Conclusion" section that I have suggested, or even without the addition of strategically placed charts, tables, figures, and/or maps, the document, as is, is perfectly acceptable and meets contemporary standards for high-quality scholarly and practitioner work.

GENERAL COMMENTS:

After reviewing the report, "Demographic & Economic Analysis of the Walker Basin", I congratulate the authors on a job well done. The authors have clearly used exhaustive means to detail the various demographic and economic characteristics of the "Walker Basin" region. I was particularly impressed with the ability of the authors to provide such detailed quantitative analysis on a wide array of various socio-demographic and economic characteristics and provide those characteristics and trends over a significant number of years.

The report on various demographic and economic trends for the "Walker Basin" region will undoubtedly serve as a critical first step in developing concise and consistent economic development policy for the entire region.

PROJECT J. WILD HORSE AND BURROW MARKETING STUDY PURSUANT TO H.R. 2419, P.L. 109-103, SECTION 208

BLM Wild Horse and Burro Policy: Auction Design and Horse Park Feasibility Study

Response to Reviewer 1

The following review does not provide an exhaustive list of comments. Somecomments overlap between sections. The following comments provided are fromboth a policy maker and researcher perspective. Given the seriousness of the flaws of the experimental design used to address the issue before the researchers, I find that this research is not publishable either as part of a comprehensive feasibility study or as an unrelated research article.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? The body of the work between the introduction and conclusion does nothing to link the two.

The purpose of the paper was to present studies that potentially could improve wild horse adoption by the federal government, estimate characteristics of wild horses to enhance adoption, and develop an approach to introduce risk in estimating returns from horse adoptions. These three objectives successfully completed provide information that could enhance wild horse adoption that is currently unavailable.

• Given the title of the paper, the three extensions of previous work and the conclusions, I am not sure what story the authors are trying to tell. There seems to be a problem statement embedded in the introduction related to the reduction in adoptions and [that] a "…research team…investigated several aspects of wild horse adoption, with a particular focus on how auctions have been used to distribute the animals.". This problem statement is again noted in the conclusions "Placing animals…raising revenue…" The main conclusion of the study states that "This study has investigated auctions which might increase adoptions of wild horses…while simultaneously increasing revenues from adoptions…

The primary objective of this paper is to present results of three investigations of wild horse adoptions which could enhance adoption rates. The paper also provides a range of potential revenues from a targeted auction of wild horses. This provides readers with not only a most likely revenue scenario which is really a 50% chance of revenues but revenues from a worst and best case scenario. The reader is given a range of possible revenues which provides the reader with a risk assessment of revenue generation from adoption of wild horses.

• The main conclusion is not supported by the data in any fashion. No meaningful analysis of the actual auction data was conducted. Actual auction designs are neither defined nor controlled for in the experimental design. Therefore, the policy maker has not learned if what she is doing is flawed, and if so, what she can do about it.

This comment raises several points which we will address in order. First the reviewer indicates that the main conclusion is not supported by the data in any fashion. We view this statement as false. We have provided extensive evidence from our experimental auctions that *suggests contrary to existing theory, the optimal way to auction multiple heterogeneous goods to risk adverse bidders is via sequential rather than right to choose auctions.*

Next the reviewer correctly notes that no meaningful analysis of the actual auction data was conducted. While we would have preferred to incorporate the actual auction data into our analysis, the data provided by BLM is insufficient to carry out any meaningful analysis – at least with regards to the "on site" auctions. Importantly, the data provided by BLM for the "on site" data does not contain any information regarding the number of bidders that participated in the auctions. Lacking such information, we are unaware of any empirical approach that could be used to back out the underlying distribution of values for the auctioned horses. Although one could attempt to use a reduced form approach that examines the correlation between a particular auction format and revenues, we would not know what to make of such information in the absence of data on the number of bidders as both variables influence observed bids. Thus, even if one found a correlation between auction formats and revenues in the BLM data, it is impossible to determine whether this reflects differences in bidding behavior directly related to changes in the auction format or differences in the number of bids submitted in the corresponding auction – particularly if the number of bidders who participate is correlated with auction formats.

Finally, the reviewer claims that actual auction designs are neither defined nor controlled for in the experimental design. We could not disagree with this comment more and believe that this and many similar statements made throughout this review demonstrate a fundamental flaw in the reviewer's understanding of auction theory. It is true that we employ a sealed-bid, second price auction in our experiment and that this is only one of several formats used by the BLM to organize horse sales. Yet under very standard conditions, these various auction formats are outcome equivalent. In fact, all one needs to show equivalence of the sealed-bid, second price auction and an ascending English auction is that bidder's values are independent (IPV) draws from a common underlying distribution. Importantly, this IPV assumption is the foundation upon which the theory for right-to-choose auctions is built.

• Authors state "Since we are interested in learning about…RTC in a setting similar to that of the BLM auction…". However, the design of the experiments is in no way comparable to BLM auctions. Definitions of BLM auctions are not provided.

Again, we could not disagree with this reviewer more strongly. From the perspective of theory, there are a number of key features of an auction market that dictate whether RTC auctions should outperform equivalent good-by-good auctions. The first is that the auctioneer wants to sell heterogeneous goods. The second is that the goods are not perfect substitutes, i.e., we are not selling two of the exact same good. Third, it must be the case that buyers have a potential heterogeneous preference ordering over the goods – i.e., you and I may prefer different goods. And finally, although it is not necessary, much of the RTC literature focuses on cases where the underlying distribution of values for the different goods is similar. That is, we want goods that are of similar value.

Previous work by several of the PIs has shown that these latter three conditions hold for wild horses. Importantly, this work shows that individuals view different horses as substitutes but have a distinct ordering over these types and recognize that such values differ across the *population of potential horse buyers. Hence, we are confident that the BLM horse auctions satisfy the key features of the models upon which we build our experiment. Further, the goods that we selected to use in our auction also satisfy these properties. Hence we see a direct analog between our setting and BLM horse auctions.*

• The apparent focus of the research is on three extensions to other peoples' work (i), (ii) and (iii) which has little to do with the 'mandate' of the project:

Unclear as to what the reviewer is referring. The experimental field auctions are novel and directly related to the substance of the project. The live auction data has not been previously analyzed. The revenue simulation builds on earlier work conducted in the department.

• (i) Preferences are evidenced by prices paid for adoption and are split out by horse characteristics and auction type. Horse characteristic groupings are not justified. In total, no discussion over seller preferences for auction type was addressed.

Live auction data: The characteristics were in the original dataset as well as discussion of aggregation and seller preferences.

• (ii) and (iii) Will be discussed later.

2) Is the paper clear, well organized and concise?

• I was forced to dig through the experiment instructions to complete my understanding of the mechanism design and aspects of the experimental auctions.

• I was forced to call BLM officials for a description of their auctions.

This research was to investigate alternative auctioning procedures that could be adopted by BLM. This was not a study of current BLM auction practices.

3) Are the methods appropriate, current, and described in sufficient detail?

• I would agree that using experimental markets to better understand heterogeneous preferences impacts on revenue generation; given appropriate auction mechanism designs is an appropriate method.

• The mechanism design of the experiment does not follow the sole auction theory paper cited, Burguet (2007). Most notably, Burguet's bidding agents are unit demand constrained, the items for sale are heterogeneous and the auction mechanism is an oral ascending second-price auction and information is private. In the experimental design, bidders are not constrained in purchases, the items for sale are not even in the same product market, and the auction mechanism is a sealed-bid second-price auction. Revenue equivalence of the oral ascending and the authors sealed bid auction are questionable given the discrepancies between the two auction mechanisms, products offered, etc. As such, it was not surprising that the results were 'contrary' to the theory.

We again could not disagree with the reviewer more. In both Burguet's (2007) paper and in earlier working paper versions of this article, he discusses how the results of his model readily generalize to situations where bidders are not unit demand constrained. Moreover, although Burguet focuses much of his discussion on the sale of distinct condos with a given *complex, this does not mean that his theory only holds if the goods sold are from the same product market. The key in Burguet's, or any similar model, is that the goods being sold are not perfect substitutes. That is, each bidder must value one good more than the others and know that there is some probability with which other bidders also most prefer (highly value) this same good. This is clearly the case in our experiment and is easily borne out if one examines the data from our sequential auctions (for which the equilibrium bidding strategy is to bid your value). For all three goods in these auctions, the distribution of bids from those agents who indicate that the item was their most preferred stochastically dominates that generated from agents who indicate that the respective item was their second most preferred which stochastically dominates that generated from agents who indicate that the respective item was their least preferred.*

• To address preferences and auction mechanism design, I would begin reviewing the sequential auction literature. In this line of literature it has been found that the order of heterogeneous items offered for sale can significantly impact seller revenue. Given the three *distinct* products auctioned, the order the items were sold must be controlled for in the experiment. If the auction design gets back on track of sequential sales of one heterogeneous product (horses), this line of literature may provide some enlightening experimental work.

The order the goods were sold in the sequential treatments was randomized so this issue should not have an impact on a comparison between the two auction types.

• Special attention needs to be made about the information provided sellers in horse auctions and maintained in the experiment. For the exception of horse owners who desire a 'wild horse' in their back yard which is a private value auction, all other horse owners face a common value auction. They must purchase the item before they know its true value (and costs). Therefore, I would focus on the sequential common value auction literature.

Bidders have preferences for types that are observable in advance.

• I noticed some confusion by the authors as far as the difference between common values and correlated values. When 'uninformed' bidders rely on signals from the bidding of 'informed' bidders in order to determine their own valuation, I would look to the literature which focuses on 'correlated values'. In common value auctions, bidders know the distribution of signals. As such, bidders incorporate drop out bid information of rivals to form a conservative reservation bid designed to address the adverse selection of holding the highest private signal. Bydoing so they bidder mitigates the 'winner's curse'.

We agree that correlated values are potentially important in this setting.

4) If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct?

• The authors note that they are conducting a 2X2 factorial experiment (table 5). However the statistical models reported do not maintain the design of the experiment (table 8). For instance, the random effects model controls for auction type, but not information.

The second draft is revised to include the informational sessions which were underway at the time of the first draft. We do not find a treatment effect and therefore pool the data. The substance of the findings is unaffected.

• Sequential auctions in general and the experimental auctions also have a time series component, apparently not addressed in the analysis.

The time-series aspect is collinear with pref in the RTC auction and is therefore addressed in the regression. We find no evidence of an effect over time for the performance of SEQ treatments. As noted previously we randomize the good sequence in the SEQ treatment.

• The authors point out that there may be learning across auction sessions, and is not explicitly controlled for in the statistical procedures. The lagged revenue variable is not justifiably incorporated into all bidders reaction functions as only the winner realizes the surplus. Also, given that three *distinct* products are sold, I am not sure how anyone could learn anything from the previous bid, unless it was rival budget constraints or preferences of rivals for unrelated goods.

We find that the lagged revenue variable has an impact on subsequent bids, despite the reviewer's uncertainty of the cause. We also find this behavior interesting and deserving of further study.

• Authors' definition of measure of risk proxy, IQ proxy and supporting literature for said definitions are absent.

Added to revised version

• (iii) When using someone else's output table, a detailed description of the model and output is still warranted. For instance, are the estimated coefficients latent variable impacts or are they actually the marginal impacts on probabilities? Significance of each variable? The assumption that the horse characteristics in the model are independent, particularly size and age, gentle and quiet is not justifiable. Also, the issue of endogeneity of expense was not addressed, which I assume came from auction data where expense is the dependent variable. However, expense was not defined, so I have nothing to go on.

The model description for the table is in the text and the appendix. Expenses are also defined in the text.

5) Are all tables and figures necessary, clearly labeled, and readily interpretable?

• Table 2 would benefit by including the frequency of each category. Also, it would be nice to have some justification for the delineation between categories. Also, I am curious to know what the 'other' category is related to the sex and type of animals.

These points are addressed in the text as with the regression results.

• Given the comments I had regarding actual auction design, Table 3 would benefit from breaking out the trained and untrained categories to auction type.

Table 3 comments are addressed in the paper.

• Some of the interpretation problems the authors found with 'gelding' is that this category is not broken out by training, age and or burro vs. horse.

References have been added as requested and needed in the text. This response belongs below…

6) Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper?

• Literature review is basically non-existent.

References have been added as needed in the text.

• There are likely no direct theoretical references as the experimental design is such a hybrid.

7) Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted?

• Justifying experimental procedures to addresses policy issues is not supported by the fact that Smith won a Nobel. The other justifications are appropriate.

The reference to Smith does not state what the reviewer claims.

• (iii) I am not convinced that the projected revenue section adds anything to the paper.

We disagree with the reviewer. Policy makers who have interest in a possible wild horse and burro national interpretative center would be interested in possible revenues. However a most likely revenues scenario is a 50% solution. It is only under average conditions. What would be of interest to policy makers is the potential range in revenues so they can have an idea of potential revenues under the worst and best conditions. Knowing the range on revenues provides risk averse decision maker information to make policy decisions.

8) Can the paper be published with:

As a policy maker, this research tells me nothing and runs the risk of policy makers not believing in the value of experimental economics. As a researcher, the methods are flawed, hypotheses unclear and supported evidence significantly lacking. As such, I conclude that this article is *too flawed to be published even with major revisions.* The authors need to clearly identify the problem, stay on track and not run experiments for experimentation's sake. In general, the paper seems to be a status report rather than a final product as on more than one occasion 'more work [experiments] is needed' without explanation about what that work [experiments] would entail. From what I learned with a few phone conversations, there are numerous auction formats contained in the field auction data already collected. At no time are the two 'generalized' actual auction types described in the paper, nor how buyer preferences play a role in the observed price differentials between the actual formats. For instance, the Federal Government uses several auction mechanisms, 'onsite' auctions are English, sealed-bid and silent while 'internet' are strictly a silent auction. Finally, I learned that many of the horses are simply adopted by paying the $125 adoption fee, which is the seller's reservation price with no competitive bid taken. This makes me wonder about the 'Live Auction Data' presented.

As noted in previous replies, we believe the reviewer's discussion of the experiments reflect important misunderstandings.

The author's should not overlook the 'gold' mine of natural experiments over various auction designs within their natural data. I would suggest analyzing the natural data first. Issues such as adoptees being capacity constrained by virtue of qualifications for adoption and no clear title upon purchase may undermine the value of any auction design. After fully understanding the natural data, I would then design alternative auction mechanisms to test if there is any revenue improvement. The issue of adoption per se is a marketing issue. For instance, to increase adoption rates, the BLM would benefit from targeting a consumer market. I suspect most consumers want to ride and 'bond' with their horse. Your data already suggest that consumers are willing to pay more for broke and gentle horses, which are apparently in short supply. A feasibility study of training horses may be in order, if it hasn't already.

As noted in previous replies, we believe the reviewer's discussion of the experiments reflect important misunderstandings.Responses to Reviewer 1

<u>Response to Reviewer 2</u>

General comments

Page 4. Without knowing anything about the horse auction market, the bids make perfect sense to me. I would expect the internet bids to be slightly smaller, since they do not have the ability to see the horses they are bidding on up-close (an opportunity I assume live bidders have). Further, the higher variance for live bids makes sense, since presumably the bidders are skillful, and will place much higher bids for "better" horses, and lower bids for "inferior" horses. (Quotes used since I have no idea what makes for a good horse other than what I read in your paper.)

This is a helpful discussion.

Page 10: Font size changed.

All font size in the paper is of the same size.

Page 10: I don't think Kahneman won for being an experimentalist. His contributions were to issues related to experiments, but he was awarded the prize more for his work in economics and psychology.

Reference to Kahneman has been modified.

Page 12: Were bids placed for all 3 items simultaneously in the SEQ auction?

Auction design questions/issues:

How could you tell which was the preferred item in the sequential auction? Was this just what people told you? Or, were you going by the highest bids? If you were going by the highest bids – did you vary the order that you auctioned off the three products? That could make a difference – as one might expect slightly lower bids.

The order the goods were sold in the sequential treatment was randomized across sessions. Preferences were elicited in survey conducted after the auction was completed.

What does the total bid represent in the sequential auction (table 7)? Is that the mean across all three products? Is that the sum of the bids for the 3 products?

These are the total revenues, averaged over each auction session.

Is the sum of the bids for the three products theoretically equivalent to bidding on each product individually? I would assume it is not. For instance, if I thought the IPOD was worth $80, and the other two items were worth $20, if the IPOD was available during all three rounds of bidding, the sum of my bids would be $240. However, in the sequential, it would only be $120.

Conditional on the good remaining available, bids should not diminish over the phases.

Can you list the sample size in your tables? (E.g., for table six, just put (N=?) after "preferences")

The counts in table 6 do represent the sample size. We have modified to make more clear.

Conclusion:

This is pretty skimpy. Can you discuss your findings and/or make policy recommendation? Saying you investigated auctions.

The conclusion section was expanded as desired.

In addition to any general comments please address the following questions.

1. Does the paper tell a cohesive story? Are the conclusions supported by the data and their interpretation? The story is not too cohesive. It has some interesting results, but I really have no idea what is the better method the end. I think the authors should tell a better story (is one of these auctions preferable or why?).

The paper conclusions were expanded and the text was changed to make parts of the paper more cohesive.

2. Is the paper clear, well organized and concise? As far as being clear, I think it would help to have a "in this paper, we do XYZ" sentence. Through the introduction, there seems to be about a sentence and a half on what you are doing in the paper (investigating aspects of horse adoption…). More details might help the reader follow your paper more clearly.

In the beginning of the paper, the text was changed to provide an overview of the objectives of the paper. This should add cohesion to the paper.

3. Are the methods appropriate, current, and described in sufficient detail? I had some confusion over the auction methods and results that I noted in my general comments.

Responded to the general comments

4. If statistics or models are used, are model assumptions, inputs, the statistical design, and analyses appropriate and correct? They seem appropriate.

5. Are all tables and figures necessary, clearly labeled, and readily interpretable? Yes

6. Are all (and only) pertinent references cited? Are they provided for all assertions of fact not supported by the data in this paper? Yes

7. Is the length appropriate? Should any parts of the paper be expanded, condensed, combined, or deleted? Length is appropriate.

8. Can the paper be published? With major revisions (to conclusion, introduction, and auction design)

APPENDIX 2: Responses to Bureau of Reclamation Reviews

Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin

Project B, "Alternative Agriculture and Vegetation Management in the Walker Basin" and Project C, "Plant, Soil and Water Interactions" presented preliminary data in their respective reports, which were therefore not submitted for peer review.

There were no additional reviewer comments or suggestions for Project E, "Development of Recommendations to Maximize Water Conveyance and Minimize Degradation of Water Quality in Walker Lake due to Erosion, Sediment Transport and Salt Delivery."

Project A: Contemporary Limnology of Walker Lake, Nevada

Pg. 4 (PDF Page 16). A detailed baseline dataset cannot be derived from a 1-2 yr study. The hydrology of temperate terminal lakes is highly variable and both years of this study were fairly low runoff. The long-term (30 yr) dataset from Mono Lake shows just how variable the productivity of a terminal lake may be. Furthermore, defining a specific condition as baseline has important policy and legal implications (e.g. Why not consider Cooper and Koch's work of the 1970s baseline conditions?). Long-term monitoring of a suite of limnological parameters at Walker Lake is an important part of restoration efforts and studies in the 70s, 90s, and current NDOW monitoring are integral to this.

> We struck the term “baseline” from our text. However, it is worth mentioning here that the database included historic data from all other sources that we were able to collect (therefore not just representing the 1-2 DRI/UNR study, as suggested by reviewer).

Pg. 4 (PDF Page 16). Caption should include time of year. Also elevation is better shown as a continuous line plot.

> Lake levels in Figure 1 represent the annual mean of monthly measurements. This information has been added to the caption and the chart has been changed to a continuous line plot, as recommended.

Pg. 5 (PDF Page 17). It is not true that prior to anthropogenic desiccation, TDS was near the upper limits for LCT and tui chub.

> Revised sentence to remove reference to upper limits of acceptable salinity and pH for freshwater fish such as trout and chubs, as recommended by reviewer.

Pg. 5 (PDF Page 17). Although Beutel assumes the hypolimnion "historically" did not go anoxic, he provides no evidence of this except by comparison to Pyramid. Many productive temperate lakes, saline and fresh, experience hypolimnetic anoxia. It is clear from Cooper's 70s studies that Walker was experiencing hypolimnetic anoxia nearly 40 years ago and it is not known how much earlier and at what lake volume this began to occur. The "health of the fisheries" was much higher even during Cooper's study period with anoxic hypolimnions. The work "historically" should be carefully quantified throughout these reports to prevent misleading the reader.

> Revised text to indicate that Beutel et al. have suggested from their studies that historically the lake did not become anaerobic.

Pg. 5 (PDF Page 17). "stronger summer stratification" needs a reference. Also, "increased solute load" needs a reference. Is there data that shows "solute load", which usually refers to inputs from streams, has increased.

> Removed text on stronger summer stratification etc.

Pg. 6 (PDF Page 18). There are a great many basic research questions that could be pursued at Walker Lake and we can assume that Walker Lake harbors unique and interesting microbial communities. However, the basic microbial processes are well-known (even for salt lakes) and the authors have not provided compelling arguments as to how basic research on microbial *processes in Walker Lake will provide useful management information or even monitoring data to assess the "health" of the lake.*

This comment on the microbial work is the usual argument about basic research: how can it contribute to developing useful management information? Since the lower trophic and microbial/microalgal community structure of Walker Lake was previously uncharacterized, some preliminary work was needed. Subsequently, as developed in the updated narrative of this chapter, there are substantial reasons to believe that microbial processes are relevant to understanding lake ecological functions and predicting change, which is important for developing good management strategies.

Pg. 8 (PDF Page 20). These six stations are a subset of our 10 stations which are being monitored monthly. It duplicates a portion of ongoing work that was already being conducted by NDEP, NDOW, and WLFIT. Note they only sampled twice in 2008. It is difficult to see how their program provided higher spatial and temporal resolution.

Added suggested text to indicate that the five DRI/UNR monitoring sites were a subset of those maintained by NDEP, NDOW and WLFIT.

Pg. 11 (PDF Page 23). As there are so many authors cited here, there are many potential method or variations of methods being employed. I would like the methods to be clearly specified.

Methods were cited in the text, and authors can be contacted for further information.

Pg. 13 (PDF Page 25). A compelling rationale for this research and its relevance to management and policy has not been established. None of the results presented here change this assessment and incorporation of this work into long-term monitoring would seem highly inappropriate based on the needs of the restoration efforts. This is not to say that it isn't interesting 'basic' science.

There seems to be principled opposition to the microbiological study done as part of this report. We disagree. This was essential baseline research into the role that microorganisms play in controlling the lake's redox and nutrient chemistry. Evidence was found for multiple effects, several of which could have direct impacts on fish (e.g. the detection of an anaerobic process for sulfide removal). As the lake level continues to decline, our window for developing an understanding of how major biogeochemical cycles currently operate is slipping away. It would be regrettable if we had no information concerning how the major nutrient and biogeochemical cycles of this lake functioned prior to further change or the loss of its major fisheries. The study was not funded to develop management strategies based on these findings, rather simply to determine whether microorganisms could be relevant to biogeochemical processes in Walker L (and the answer was yes).

Pg. 18 (PDF Page 30). While no long-term met data exist at the lake, USGS did have a met station in the lake during a year-long evaporation study. As the calibration of the model in *several cases was done with only a year's data it would seem highly appropriate to use the USGS data. At least a comparison should be made between their data and the data collected at Hawthorne.*

We completely agree that such a comparison would be very valuable. We indeed requested and received this data from the USGS during model development. Because the met data did not overlap with the present limnological study, and because it the data was only available for one year (with several gaps due to instrument malfunctions) we decided not to use the data in the original model setup. However, returning to this data to further evaluate model performance would be an excellent next step if additional resources become available.

We would like to make it abundantly clear to the reviewer that resources allocated to model development were a fraction of the overall project and in our opinion were at about 10% of the level that necessary to thoroughly test, validate, and implement the model for decision making. The text on which the reviewer made is comments was unfortunately slightly outdated, and we have made efforts throughout to clarify that this is a preliminary effort and we consider it to be a "good start" at this point in its development.

Pg. 18 (PDF Page 30). I don't think doubling the shear coefficient is a minor adjustment. DYRESM was designed to have fixed parameters. I do not know if doubling this parameter (see below) iswithin the range that the designer's intended. This should be discussed further

I struck the word “minor” from the sentence, “By making minor adjustments….”

Pg. 18 (PDF Page 30). "parameters" usually mean the model coefficients. "State variables" or just "variables" refers to the modeled and observed data against which the model is calibrated.

As suggested, changed word from “parameters” to “variables.”

Pg. 19 (PDF Page 31). As the main "health" criteria of the lake should be based on the LCT population it is not clear that the model has the capability to perform "impact assessments". There is no validation for any of the phytoplankton, zooplankton, and fish components of CAEDYM.

Reviewer correctly indicates there is no validation for the phytoplankton, zooplankton or fish components of CAEDYM. Funding was sufficient to develop the hydrodynamic DYRESM portion more fully than the ecological CAEDYM portion of the coupled DYRESM-CAEDYM model. [Thus our recommendation for continued model development during Phase 2 of the Walker Basin Project.]

Pg. 22 (PDF Page 34). As this is strong counter-evidence to the hypothesized increased internal loading and decreasing "health" associated with "successional processes", it is remarkable that the authors do not comment further.

It may be “remarkable” that we did not comment on the significance of increased clarity seen in the long-term data, but we did not feel there was enough information available to speculate as to the potential mechanisms. We have revised Figure 5 to better show this relationship and added a regression line for the trend. We also indicate that this trend could just be the result of a greater frequency of measurements in recent years.

Pg 24 (PDF Page 36). The pairs of TDS and EC shown here display quite high errors for measurements taken in the lab. Higher TDS -- lower EC, not possible. It is not clear how TDS was measured.

I don't understand reviewer comment here (we don't have any TDS values greater than the EC values), with TDS determined at the EPA and State certified DRI Water Analysis Laboratory (EPA 160.1, SM 2540C).

Pg. 34 (PDF Page 46). Nothing in this section provides compelling support that it could provide useful information to management or restoration monitoring. I say this even though I find this work scientifically interesting and have myself been part of a large team of microbiologists studying similar processes and communities in Mono Lake. However, there we were funded by NSF to conduct basic research into microbial processes.

Again, the reviewer appears to believe that if information does not have direct management implications, it should not be included. We disagree, and feel that the microbiology results presented from Walker L. are relevant on a fundamental basis, and may prove to be relevant to management in the future.

Pg. 40 (PDF Page 52). A number of water budgets have been done for Walker Lake based on partially gaged runoff, precipitation, and lake elevation changes. The DYRESM run employed the 11,000 ac-ft groundwater estimated by Thomas (1995). At what depth was this assumed to be input to the lake? The surface elevation agreement between observed and predicted during 2007 implies that DYRESM is accurately modeling evaporation. What was the calculated evaporation during this year? How does that compare to USGS's estimates and the prior estimates used in the previous water budgets? A much better validation would be to simulate multiple years. It would be a simple matter to simulate 10 or 20 years for which the same met data and river discharge data are available. This is particularly important if you are going to make predictions over 5-yr periods.

Because no specific data were available on depth of river input to the lake, we distributed this input along the vertical profile.

We agree that a long-term comparison of 5 years or more would be very valuable and should be conducted in the future. The biggest limitation here is the spotty meteorological data in the region. We considered using a weather generator or data from the North American Regional Reanalysis to perform such a simulation, but resources did not allow that in the first stage of the study. We did rely heavily on the USGS ET report as a "reality check" for the model results, but we did not perform any type of direct comparison because their study was limited to one year, and it was not a year we have simulated, yet. Our ET rates varied from about 80 mm in January to about 200 mm in July.

Pg. 42 (PDF Page 54). In general, I do not believe the model has been adequately validated to place any confidence in its use (see comments in other chapter). Much more effort should have been devoted to validation. For instance, can the model capture any of the observed variation in *the 2003-2007 dissolved oxygen profiles. There was significant variation over this period. There should be some objective criteria developed to examine model performance. One of the most basic is that it explains more of the seasonal and inter-year variation than the simple seasonal multi-year means of dissolved oxygen concentrations. 2003-2007 provide a good data set, but the 90s and 70s would also provide additional validation.*

Sure, as mentioned above, we completely agree that the model requires additional validation before it can be used with confidence to inform management. Again, this was a very modestly funded task and we consider the model to be a good start on a tool that can inform management.

Pg. 42 (PDF Page 54). It appears that under the model, the high-flow condition results in an increase in the hypolimnion which would be worse for the Lake. This concept may benefit from additional discussion.

The reviewer suggests that high-flow condition in the model shows an increase in the hypolimnion, which would be detrimental to the lake. This is not apparent to us. The elevation of the reduced temperature region increases slightly under the high flow condition, but its thickness as a proportion of the total lake depth decreases slightly. The region of depressed DO concentrations decreases. These trends need further investigation, first to assess the model's performance in representing mixing and stratification mechanisms and then second to evaluate the implications for the lake.

Pg. 47 (PDF Page 59). The use of pH, nutrients, carbon, chla, and zooplankton for model calibration is not well-documented, if at all in this or other chapters.

As to the first comment on this page, these lake parameters were not used for model calibration but rather for model parameterization. For example, pH and nutrient concentrations are specified as initial conditions and boundary conditions, as discussed in this chapter and the model addendum. Chl-a and zooplankton data were used to set certain model characteristics, such as which predefined model groups to use (as described in the model addendum), and the initial conditions for these groups. These parameters should be used to further calibrate and validate the model in the future. However, this was not possible during this stage of model development for two reasons. First, as mentioned previously, limited resources did not allow us to develop the ecological component of the model to an advanced stage. Second, due to the compressed time scale of this project, most of the ecological data were not provided to us until the very tail-end of the project period.

Pg. 47 (PDF Page 59). This is true of all lakes and is well-known.

The second comment simply notes that some of our general observations on microbially-driven processes is true of lakes in general. We agree, which is why we recommend these should be further studied at Walker, since there are important differences in the rates and microbial taxa involved.

Pg. 47 (PDF Page 59). What is proposed here is a great deal of work to develop a complex model of detailed microbial processes of carbon and nitrogen cycling. This does not seem appropriate to the management issues at hand.

As to the third comment on this page, our recommendation is that greater effort is needed to represent phytoplankton blooms, since they are both important and transitory, so may not be captured by the regular monthly sampling program. We still feel that this is a reasonable observation.

Pg. 48 (PDF Page 60). The lake turns over in autumn and sampling during any of late autumn through late winter provide suitable information on lake-wide conditions. Current NDOW monitoring is scheduled monthly from Jan-November. This is more than adequate.

We have revised the paragraph on sampling during the period of maximum mixing to represent our intended message that sampling does not need to occur each month during this period, but at a regularly scheduled time each year when the mixing is likely to be deepest (perhaps January).

Pg. 48 (PDF Page 60). "Despite" makes no sense here. Mono Lake at 98,000 mg/l salinity is still holomictic in winter and stratifies in summer.

No change to first sentence of conclusion is needed, as the reviewer simply notes that Mono Lake remains holomicitic at a higher salinity than Walker Lake.

Pg. 50 (PDF Page 62). How understanding microbial processes contribute to developing sound management strategies is unclear.

Added the following text to make management implications more clear (referencing second comment on this page).

"Since microbial and microalgal biogeochemistry controls many of the factors that define ecosystem function and potential, ranging from availability of limiting nutrients (N), to toxin production (H_2S, NH_3) and trophic status, it is evident that understanding these processes could be essential for developing sound management strategies and predicting effects as the lake conditions change."

Pg. 50 (PDF Page 62). There is NO evidence provided that the Walker Lake ecological model (the coupled DYRESM/CAEDYM) can be used to optimize water deliveries in terms of lake benefits. The most likely factors involved in optimizing water deliveries will deal with LCT in-stream movements and possibly tui chub recruitment. Beyond that, there is no evidence that anything other than the total volume of water deliveries is important.

Added the phrase, "… with continued development …." to improve clarity.

We don't feel the need here to argue that improved understanding of lake processes and the development of tools that allow us to predict the response of such processes to changed boundary conditions (including volume, timing and quality of water inflow) will lead to improved management decisions. However, there's no doubt this tool needs further refinement before it can fulfill that role. The model was selected because of its flexibility and ability to incorporate a wide range of lake characteristics -- including fish. It also could provide projected environmental conditions to drive more complicated food web or ecological community models. Once again, we see this tool as a good start and it could be used to inform water delivery and acquisition decisions in the future.

Pg 64 (PDF Page 76). I think it a waste of time to include Walker-related documents in an ACCESS relationship database. There are any number of much more efficient and widely used bibliographic software programs that are much better suited for this purpose. Very few people will use this feature. Resources would be much better utilized to develop a Walker Lake bibliography in EndNote, Reference Manager, Zotero or another software package.

Reviewer suggests that EndNote or similar bibliographic software would be better suited for compiling Walker related documents than the Walker Database (developed in MS Access). This may be true, but we were working with Access and added the bibliography as an extra; we were not funded to develop a bibliographic database.

Walker Lake and River Database Chapter. Revised

Project A: Ecological Model for Walker Lake, Nevada

A common theme throughout all reviews of the Walker Lake model has been that the model has several shortcomings and was not thoroughly tested. We agree. The reality of the situation is that this task was originally cut from the project, and then added back in on a very meager budget. Working nights and weekends, we produced a model that we consider to be a very good start and it seems to be capturing the lakes physical processes fairly well. A more sophisticated model would capture the processes better. Additional resources would have allowed us to test it more thoroughly. Also, standard model performance metrics such as RMS, Nash-Sutcliffe, etc. do not lend themselves well to applications with both temporal and spatial variability. For example, there's not a single gaging station (or better yet, multiple stations) for which we can compare a modeled and observed parameter throughout the simulation – expect for lake depth. Instead, sporadic observations are available to which we can compare results and use professional judgment to ascertain model performance. Sharing every instance of these comparisons is not feasible in this situation. Further, due to the compressed time-scale of this project, much of the observed data was not available to us until very late in the project. However, we agree that a more thorough and systematic model evaluation should be completed before the model should be used to evaluate future water management scenarios with any certainty. We do concede, however, that our original document painted an overly rosy perspective of the model. We have added extensive caveats to the text in subsequent drafts. However, the number and versions of drafts have caused some confusion as they have been circulated to various reviewers.

Page 74: I would argue that none of these objectives were met. Much more realistic objectives should have been set.

Objectives were updated based on re-scoped and re-budgeted model.

Page 74:How was the model customized? A clear description should be provided. A complete list of parameter noting which ones were changed and where they were obtained should be included. This is normal practice in deploying a model.

Text was added to describe parameterization.

Page 75: There is little confidence that the model can forecast ecological responses to specific Walker River flow scenarios. This has clearly not been established.

Emphasis to preliminary nature of the model was added throughout.

Page 78: WLM is not previously defined except as a station ID in a table.

Defined.

Page 78: previous?

Former?

Page 82: Parameters describing the physical mixing processes in DYRESM were designed to calibration free. Doubling the shear production efficiency does not seem to be a minor modification. This may illustrate an inability of DYRESM to model internal mixing processes, the inadequacy of the 1-D approximation for Walker Lake, inadequate wind field data, or something else. A full explanation of this parameter and how it has been varied in other studies using DYRESM is warranted. CWR should be consulted on this modification.

Accounting for shear production efficiency in a single coefficient is a limitation of a one-dimensional model. It is normal practice to “tweak” these coefficients in order to achieve a pattern of vertical mixing that is consistent with observed data. Adjustment of a default parameter of this nature by a factor of two is not unusual. Yeates and Imberger (2003) describe the complexities of internal mixing and the limitations of parameterizing these processes in order to reach feasible solutions. The values used in other DYRESM applications are not typically stated.

Page 82: Displaying a single temperature profile is completely inadequate to convincingly demonstrate the adequacy of the physical mixing processes in DYRESM. An objective measure of performance must be developed and analyzed for both seasonal and varying conditions observed in different years. Furthermore, there is great danger in relying on this simple "chi-by-eye" procedure and assuming this validates the model. Press et al, recognized experts in the field, say it best:

"The important message we want to deliver is that fitting of parameters is not the end-all of parameter estimation. To be genuinely useful, a fitting procedure should provide (i) parameters, (ii) error estimates on the parameters, and (iii) a statistical measure of goodness-of-fit. When the third item suggests that the model is an unlikely match to the data, then items (i) and (ii) are probably worthless. Unfortunately, many practitioners of parameter estimation never proceed beyond item (i). They deem a fit acceptable if a graph of data and model “looks good.” This approach is known as chi-by-eye. Luckily, its practitioners get what they deserve."

Emphasis to preliminary nature of the model was added throughout. Interesting the reviewer did not suggest an appropriate goodness-of-fit measure. Of course, traditional measures such as RMS and Nash-Sutcliffe are difficult to apply in this context and the budget did not allow for a systematic calibration effort. Further, observing how well the model is capturing phenomena such as stratification and de-stratification with sporadic observed data is nearly impossible with standard metrics. However, a fuller investigation into model performance should be conducted if future resources allow.

Page 82: This is not a measure of the ability to describe physical processes in the lake. It is a measure of its calculation of evaporation. The model's estimate of evaporation for different years and conditions should be explicitly presented and compared to other estimates.

Funny, we thought evaporation was a physical process.

Page 83: Same comment as for temperature applies. Also note that the agreement is rather poor and that a different date is shown than that for temperature. It is absolutely necessary to show the entire seasonal predictions and observed data from multiple years to have any confidence in the model. Until that is done, no prediction or scenario runs are even warranted.

Showing entire seasonal temperature profiles is not feasible in a summary report. As stated in the report, these were "typical" results.

Page 86: Objective measures of performance are needed.

Such as? Again, a detailed model analysis was not feasible with the given resources and objective measures, or metrics, are not easily defined.

Page 87: Please explain the mechanism of this counter-intuitive result. Heat exchange due to differences in air temperature occur in the very surface layers. Increased heating of the uppermost surface layer would normally increase vertical thermal stratification and decreased the depth of the mixed layer. The opposite pertains to cooler air temperatures.

Not necessarily. The depth of the mixed layer obviously depends on a host of complex interacting processes. This is, however, an interesting observation that deserves a closer look. Unfortunately, teasing out how the model is arriving at specific surface layer depths is not straightforward and cannot be conducted at this point in the project.

Page 92: Here the authors note that the model is entirely insensitive to order of magnitude changes in nutrient content of the lake-bed sediments. Yet, in an earlier section they contend that it is important to determine the nutrient characteristics of the sediments more accurately. Like many of their recommendations this seems based more on personal preferences than objective reasoning. However, I would add that I do not think the sensitivity analysis included an appropriate metric of performance and I also think multi-year simulations would be more appropriate for analyzing the sensitivity of sediment characteristics.

Good point on the multi-year simulations. However, in spite of the model's "apparent" insensitivity to a range of boundary conditions, we currently have no information on lake sediments. As described in the report, the boundary was thus estimated based on sediments from other systems. This complete lack of data would make this a data gap by any metric that you choose.

Page 92: As above, the authors note that the model predictions are insensitive to large variations order of magnitude) in nutrients loads from river inflows, yet they state it is important to greatly increase monitoring of river nutrient loads.

As the reviewer correctly notes in the comment above, extended simulations would likely have shown a response to changed nutrient loads and this should be looked at in the future. As with lake sediments, this data is almost non-existent and thus should be augmented for more realistic estimates of nutrient loads. However, the extent of such monitoring should be weighed with other project needs.

Page 95: Without an objective measure or presentation of this data, the reader is left in the dark and has to accept all this on faith. A table is certainly appropriate and a list of all parameters used is imperative! Note the vertical mixing coefficient was doubled to get an approximate temperature fit to the Aug 28, 2007 profile.

The only parameters that were changed from default conditions were specifically noted in the text. The model depends on dozens of parameters and a table would be redundant. The vertical mixing coefficient was changed as noted throughout all simulations, not just for the one profile that was included in the report (see notes above).

Page 95: I do not believe the model has been adequately analyzed and validated to have any confidence in scenario analysis. Also, note that the most important "health" metrics of the lake (LCT, tui chub, nuisance algal blooms) are not even considered in the validation. What are the phytoplankton, zooplankton and fish predictions of the model? How do these compare to observed values? Does the model have any utility in assessing these indicators of lake health?

The model was selected because of its flexibility and ability to incorporate a wide range of lake characteristics -- including fish. It also could provide projected environmental conditions to drive more complicated food web or ecological community models. Including such complexity was way beyond the resources available for this task. The model could be further developed to inform such questions. However, forecasting algal blooms and fish populations is a very complex task with a high degree of uncertainty.

Project A: Walker Lake: Hypolimnetic Oxygen Deficit Assessment and Associated Limnological Factors

We thank the reviewers for their comments and input related to the Walker Lake Hypolimnetic Oxygen Deficit Assessment and Associated Limnological Factors section of the Walker Basin Task 6 Final Report. In the responses that follow, we address each reviewer's specific comments related to this section of the report and detail responses to the comments that require changes to this section of the document. However, other groups need to provide information for other sections and general comments, and we presume that these concerns are being addressed by other authors.

Page 108; Note NDEP has been collecting water chemistry on a much more regular basis. Also much of this work unnecessarily duplicated ongoing monitoring by NDOW which began in 2002 and has continued through present, and a more intensive design implemented by the WLFIT that began in 2007.

Noted. Some duplication is beneficial for the added value of projects. Full disclosure of available data and open channels of communication regarding plans allow for more focused studies.

Page 116; It is interesting that the areal HOD has decreased over this period. This implies that the productivity is declining. This deserves special comment.

The total oxygen content of the lake's hypolimnion has declined. Therefore, if the total oxygen content of the lake's hypolimnion is consumed, this could lead to a decline in HOD but not necessarily be accompanied by a decline in primary productivity. Therefore, one cannot assume that the scaling is due to a decline in productivity at this time.

Page 117; It is unlikely that the internal loading scales directly to surface area as this ignores the well known transport of organic matter to the deeper portion of the lake resuspension and settling. Simple morphometric ratios must be used with caution.

We agree that the ratios must be used with caution, but feel this is an appropriate use of these ratios.

Page 119; It is almost certain that the relative contribution of the littoral zone is increasing with decreasing depth. This is a well known function for almost all lakes. More integration with the existing limnological literature would be helpful here.

It is unclear from the literature whether or not this would in turn lead to an increase or decrease in the productivity, so have removed the comment "Thus- the relative contribution of production in littoral zones may be on the increase as the lake level continues to decline." from the document.

Page 126; Although seasonal de-oxygenation of the hypolimnion is almost assured well into the future, it is not true that all data indicate they will increase or that Walker Lake is in the midst of a successional phenomena towards hypereutrophy. How does increasing Secchi depths and decreasing areal HOD support these statements.

We would like to point out that the driving force behind the positive feedback loop discussed is the abundance of available phosphorus, which is discussed in the previous paragraph. This is a general statement that is meant to convey that as long as the positive internal loading is maintained, the phosphate will remain an issue and cyanobacterial blooms will be expected to continue. It is indeed interesting that Secchi depths did reach these values in early and late 2007. However, minimum Secchi depths of less than < 2 m are still consistent with hypereutrophy. We have added the following reference to the text.

Whitton, B. A. and M. Potts. [eds.]. 2000. The ecology of cyanobacteria: their diversity in time and space. Kluwer Academic Publishers.

References

Lopes, T. J., and J. L. Smith. 2007. Bathymetry of Walker Lake, West-Central Nevada: U.S. Geological Survey Scientific Investigations Report 2007-5012.

Project A: The Contemporary Ecology and Food Web Energetics of Walker Lake

1) All editing comments were noted and changed in the manuscript.

2) The authors have made numerous requests since November to receive reports and documentation from the reviewers that support existing efforts or strains of fishes introduced into the lake. The BOR liason has not received responses from the reviewers for these reports. Thus, no additional changes were made to the final document but can be incorporated later after the authors are allowed to determine if they are appropriate for citation.

3) Specific comments and responses are provided below.

Page 132 The 12.4 g/l in Beutel refers to 1996. It is misleading to cite this when talking about 2005. Please cite dates along with any salinity measurements.

Agreed and the text has been changed to reflect increasing salinity

Page 133: Some or all of these numbers are wrong, but I can't tell without a date being given. In general dates should accompany statements like these as the lake has changed markedly.

Agreed and the changes have been made accordingly.

P134: What about the phytobenthos? Filamentous algae is extensive in the lake and epilithic diatoms are also present and important as food resources to grazers.

Agreed however we did not measure benthic periphyton or plant production and thus this was not introduced as a topic in the paper.

P137: In reference to the equation, Isn't it the weight in grams x 105 divided by length cubed? Not the wt raised to the 5th power.

This has been corrected but it should be noted that we used the same equation as described above but presented a different mathematical version. In any case, we have correct the equation and just provided the original reference for this equation that is standard in fisheries textbooks.

P139: Please explicitly state how data were corrected for baseline variation.

This has been corrected.

P140: Many of the figures in this Part of task 1 appear multiple times though various "chapters" (or reports). It is not clear why it was organized this way and it is somewhat confusing.

The figures are repeated throughout the chapters to give context to each chapter. Since this chapter was dealing with contemporary food web structure and the lower food web is very important for fisheries production it was included here as well as the other chapters.

The spatial variability portion of this chapter appears to be work done by L. Newton in 2003-2004. Please document the use of N. crassa instead of N. spumigena or N. spumigene var. crassa. I understand that this genera is undergoing revision, but it should be clear to the reader that all the studies from the 70s, 90s and current are talking about the same species.

This has been corrected.

P 146: Is data in this figure from the 2003-04 study or from the 2007 study?

We are more explicit in the text in regards to these numbers in the paragraph.

Numbers shown here do not agree with the text for both Moina and Leptodiamtomus. And the numbers for all species do not match Figure 8.

This has been corrected.

P149: "Benthic invertebrates are represented by a single combined measure of C & N isotopes and this almost certainly misrepresents trophic positions among the group of inverts in the lake that are known to represent predators, grazers, and detritovores, and mixed consumers."

The reviewer is correct however does not understand the utility of the isotopes. Benthic invertebrate signatures typically do not represent discrete trophic levels either 1) due to their differential metabolism for processing isotopes or 2) invertebrate taxonomists inadvertently misidentify the true feeding nature of these organisms which likely receive their energy from a variety of sources. Until this debate is resolved the authors continue to utilize and interpret the isotope data with the best available scientific literature available and have followed methods similar to other studies.

Potentially the most interesting finding is the fact that LCT are almost exactly a trophic level (15N of 3.1) higher than chub, and chub exactly one trophic level higher (3.2) than benthic inverts. This suggests LCT are dependent on chub. This is at odds with recent stomach analyses. What is the explanation for this apparent discrepancy?

This is not at odds with the stomach data. The utility of the isotope data is that it integrates signals over time and avoids the traditional issues with stomach collections where the fish has digested stomach matter and it is misidentified. Our understanding is that LCT are not necessarily caught during all seasons in the lake and the sample size for stomachs analysis may be low. Thus, we believe the isotope data is more accurate than the stomach data reflects.

The conclusion that chub are dependent on benthic inverts should be tempered by the fact that no YOY chub were analyzed and it is generally thought that the younger age classes would be most dependent on zooplankton. This was well-documented in Koch et al (1979). If it is no longer true than this is a significant change in the plankton dynamics.

While no YOY chub were analyzed, age class 2+ or greater were analyzed. Based on the authors experiences at Pyramid and Eagle lake LCT utilize non YOY chub as forage and will eat non YOY chubs. This information combined with the isotopic nitrogen signal suggests the chubs are feed on a mix of chub and plankton.

Project A: Major-ion and trace-element chemistry of Walker River and Walker Lake, Nevada.

All comments made by the late 2009 reviewer were redundant with earlier comments. No changes were made in the final report.

Project A: Walker River Periphyton

Page 27: Previous sentence talked about the east fork and Mason Valley - what part of the river are you talking about here- only the lower portion?

Edited text to; "Standing stocks of algal biomass were present at levels often considered to signify eutrophic conditions (greater than 5 to 15 µg chl *a*/cm^2) in the sites along the East Walker and into Mason Valley. Overall, the river had high abundances of siltation-tolerant diatom taxa, with the most notable abundances (exceeding 60%) at the lower sites."

Page 29: Interesting. It might be worth noting that diversion out takes throughout the Walker River Basin can act as fish barriers, decreasing the utility of fish as an indicator species. In addition to fish barriers, localized stocking can skew fish data.

We feel that this topic is better left to discussion in the fish data.

Page 30: Management for what? Is this referring to future water management based on water acquisitions? Land management?

Many management applications could be evaluated using periphyton. We feel that a list of specific river management schemes could confuse the reader or infer artificial limits to the use of periphyton dynamics.

Page 30: Is this baseline evaluation clearly and succinctly written up somewhere? This will be a very helpful tool to measure benefits of water acquisitions, impacts of restoration projects, etc.

Does the reviewer feel this should be done in the introduction?

Page 31: Are these different locations than the previous Chapter or just different nomenclature? Also GPS locations would be helpful.

We updated the map and all of the graphs to use the same site nomenclature throughout th document. Specifically related to the site map, we added UTM coordinates to the border of the map so site locations could be determined and updated the site abbreviations.

Page 32: Does not match map. FLSTN or FLST - FLST is used throughout the document. It would be helpful to date the photos.

We updated the nomenclature in this chapter to the latest revision.

Page 33: Confusing. SHRZ is on the main stem not the West Fork. A point graph with each sampling location labeled may be more helpful. This causes problems throughout the discussion. It would be clearer if sampling points on the main stem were called such. Or just clearly explain this figure - could not find a description of figure 3 in the text.

We agree with the reviewer and updated all of the graphs with a similar layout to include a different shade and symbol for the main stem, rather than plotting both forks on the same point for the main stem.

Page 33: Should this habitat be briefly explained or is it common knowledge?

Text was edited to clarify; " Sampling of the richest targeted habitat (RTH), i.e. the in-stream habitat type that supports the taxonomically richest assemblage of organisms within a sampling reach at each sampling location, helped in identifying differences in periphyton communities in relation to water quality."

Page 35: Was FSW collected from each sampling location?

Text was edited to clarify; "Filtered stream water (FSW), collected the day of sampling at each site and filtered through a 47-mm Whatman GF/F filter with approximately 180 mm Hg vacuum, was used as the transporting medium (solvent) for the periphyton that was scraped from the cobble."

Page 39: Why the last decade? USGS measurements go back significantly further and samples were only collected in '07 and '08.

A recent historical context was helpful in understanding how the sampling years compare with recent flow regimes.

Page 42: Explain that the last two years have been drought conditions.

Edited text to include; "Due to drought conditions the discharge during this study (2007 to 2008) was typically 40 to 60 percent lower all along the river than the means for the last decade."

Page 46: This paragraph is unclear. Variation in water and land management make it very difficult to compare the Truckee and Walker systems. Is this taken into account anywhere in the text?

See response to second to last comment from page 76. The text was also edited as follows; "The ratio of TN to TP (Figure A.7.9) ranged between 5 and 25 (mol:mol), averaged 12.64, and tended to decrease from upstream to downstream. The ratio did not appear to display as evident or as strong a gradient as has been documented in the Truckee River (Green and Fritsen 2006). However, it should be noted that the sampling sites in the Walker basin did not extend to the higher elevations in the Sierra Nevada as did that particular study of nutrient balance within the Truckee River."

Page 49: Is this related to work on the Weber Reservoir and flow releases?

We do not feel there is adequate information to show a relationship to the aforementioned activities.

Page 51: The whole river system or only the EF was in eutrophic conditions?

Edited text for clarification; "In combination with the high nutrient concentrations measured in the East Walker at the EWB site, it is apparent that the stream system was in a eutrophic condition at select sites. Such eutrophic conditions may lead to large oxygen fluctuations and high export or loading of organic matter to downstream locations, especially during summer (Dodds and Gudder 1992). Despite the high biomass (Figure A.7.11) and nutrient concentrations in some locations, portions of the river exhibited more meso- or even oligotrophic characteristics. For instance, the West Walker that exhibits both low biomass (Figures A.7.11 and A.7.12) and low nutrient concentrations (and more unrestricted/regulated water discharges) appeared to be in a condition that could be considered oligotrophic (based on TP being less than 0.8 µM and benthic chl *a* being less than 2 µg chl *a*/cm^2; Dodds *et al.* 1998)."

Page 51: Because flows associated with irrigation and agricultural use are higher in the summer?

Through the downstream movement of formerly attached algae that becomes detached as water temperatures reach levels beyond tolerance.

Page 59: The SHRZ site was likely being impacted by tribal fallowing associated with construction on Weber Dam, thus altering the timing of flows in the lower reach.

Text was edited for clarity.

Page 59: Associated with low water years?

We do not have adequate information to make this association.

Page 61: Again, it is important to point out the Truckee and Walker are managed differently and have very different anthropogenic influences.

See second to the last response which is a response to a comment on page 76 and also the response to the comment from page 46.

Page 68: What defines "good" water quality?

Added clarification in text; "A high proportion of these genera usually correlate with "good" water quality (i.e. low concentrations of phosphorus, nitrogen, and chloride) (Wang *et al*. 2005)."

Page 72: Are certain agricultural processes increasing the nutrient supply?

Yes.

Page 72: The proper name is the "Mason Valley Wildlife Management Area (MVWMA)."

Text updated with current revision of nomenclature.

Page 74: Are epidendric sites still representative of the sandy reaches? I understand the issue with sampling sand sections, but downstream of the confluence is dominantly a sand system, so how do samples represent the sandy reaches?

We agree that the epidendric assemblages do not represent the periphyton communities as a whole in the lower reaches due to the dominance of sandy habitat. The epidendric samples do represent the richest targeted habitat that was available at these lower sites. The initial evaluation of epissammic periphyton assemblages showed that the sand-associated assemblages were largely dominated by a few taxa (*Amphora*, *Achnanthes*) that are specialized in attaching to sand grains. The dominance of these taxa was likely attributed to the physical environment (i.e. constantly shifting sand) and not entirely to water chemistry. The comparison of the RTHs is the approach most commonly used to compare habitats across differing environmental regimes and seemed to be the most appropriate for the aims of this longitudinal assessment.

Page 75: Can target periphyton populations be established off these data?

Alone, these data could not be used for this purpose, but could after being integrated with a program such as EMAP protocols.

Page 76: This chapter still needs a good editing. Lots of minor typos and sentence structure issues. This chapter seems to have a fair amount of detailed information, but the discussion/conclusion is missing some important points.

-There is some mention of the impact of irrigation on flows etc., but there is no discussion of how agricultural practices may be impacting the sampling results. Are TKN and Phosphorus associated with fertilizers?

Nitrate and ammonium are typically the forms of nitrogen that increase in agriculturally impacted streams. However, the increase in TKN could be due to the organic load from filamentous algae consistently growing to eutrophic levels at select sites (EWB, EWA, WA). Increasing concentrations of phosphorus in Great Basin streams have largely been attributed to watershed geology (e.g. increased volcanic ash deposits), although fertilizer inputs may also increase these measured concentrations in the Walker River. The largest apparent point sources of phosphorus appear to be coming from the reservoirs (Bridgeport and Weber).

-The Walker River Paiute Tribe has been fallowing during both sampling seasons in conjunction with work being completed on Weber Dam, both impact flows at the SHRZ sampling site.

We are not sure what the reviewer is requesting. Drawing any direct connections between tribal activities above WA and the periphyton data at the time of collection would seem to be highly speculative based on the current study.

-The lack of any sort of recommendations based off the results seem odd. Aren't there target periphyton populations for a "healthy" system? - this information will be valuable for monitoring future water acquisitions and restoration activities.

We have indicated that select sites have eutrophic levels of algal accrual based on the measured standing stocks (i.e. biomass). A "target periphyton population" with regard to community composition is beyond the scope of the current work as no predictive model (observed/expected) was constructed. However, generally a decrease in eutrophic taxa would indicate improved conditions as well as an increase in sensitive taxa (e.g. *Cymbella*). Moreover, good practices necessitate maintaining low-levels of biomass relative to flows and temperature. Data suggest some reaches are at high/moderate risk of having low dissolved oxygen at night. Exactly which reaches are presently affected cannot be determined from the present study.

-If you are going to keep using the Truckee as a reference for comparing results you should clearly state the differences between the two systems, specifically regarding flow management and anthropogenic activity. Questions could be raised on the validity of comparing these two systems.

The Truckee is not being used as a "reference" system in our discussion. It is referred to for comparison as it is the only eastern Sierra river that there are adequate studies of periphyton dynamics. The Truckee basin is largely impacted by urban and municipal land uses (Truckee, CA and Reno/Sparks, NV) while the Walker basin is mostly developed for agricultural uses. The Truckee is tightly regulated to maintain fairly constant flows throughout the year while the Walker resembles a more natural hydrograph. However, the consistent base-flow for the Truckee below Reno/Sparks is largely driven by the discharge of wastewater effluent. *The above description of flow and land-use differences were added to the text within the methods section regarding the selection of algal-based metrics.*

-The graphs used throughout the text (beginning on Fig. 3) could be potentially confusing. Just make sure it is clear to the reader what the graph is showing - I did not see Fig 3 discussed in text.

We have made adjustments to graphs symbolism that should help clarify the locations of the sampling points with regard to the east fork, west fork and main-stem. The changes should help clarify the trends observed and subsequently reported in the text. Also the nomenclature for sites has been changed throughout to be consistent with the other reports.

Project A: Relationships between Aquatic Environments and Walker River Benthic Macroinvertebrate Communities, Nevada and California

A paragraph was added to generally describe how humans have altered physico-chemical characteristics of the Walker River, and that information provided by this study provides insight into the influence of some of these alterations on benthic macroinvertebrate communities. This study could only examine a limited number of human influences, but it provides guidance for future work and the some of the best ecological information ever compiled on an eastern Sierra river system.

Page 78: Previous sentence discussed downstream sites. This sentence is unclear. Is it still referring to downstream sites?

Sentence was not changed. The 'previous sentence' describes environmental conditions observed in Mason Valley and below, and the following sentence describes changes that were observed along the stream gradient toward the Sierra Nevada.

Page 79: Unclear sentence.

Sentence revised as suggested.

Page 79: Which values?

Sentence revised to include 'tolerance values'.

Page 82: lowering lake level?

Sentence revised as suggested.

Page 83: Why is this under methods?

Section deleted, but information moved into the Introduction.

Page 83: There are some minor storage reservoirs in the headwaters.

Sentence revised as suggested.

Page 83: This may be more closely related to peak flows associated with calling for irrigation water. Because water is being stored in the reservoirs.

Sentence revised to note the influence of irrigation storage and releases on river discharge. But, in reference to runoff occurring during May and June, the reviewer observed that this may be attributed to irrigator calls for water. This may be true, but peak springtime runoff following the natural hydrograph also occurs during this period. The same is true for the period November through February. Yes, storage occurs during this period but this is also the typical low flow period following the natural hydrograph. A statement was inserted referring to flows being affected by water management.

Page 109: This is the first time in all the chapters that there has been any discussion of agricultural land use potentially influencing results. Similar to the other chapters the lack of any sort of significant discussion to current land and water management activities is disappointing. There must be some recommendations and conclusions based on these results......or even future BMI values that would indicate improved river conditions.

Reviewer comments not addressed. While interests of the review are an important goal of ecological work in the river, but we believe that data collected over two years of drought provide for a relatively weak assessment of the effects of human activity on river life. We hope that future studies will include years with average and above average annual precipitation so that a gradient of differences between these conditions a drought can be analyzed. Management recommendations were not included because these were never a proposed part of this study.

Project A: Spatial and temporal variability in elemental composition and stoichiometry of benthic macroinvertebrate communities in the Walker River, Nevada and California.

Page 127: Diversions are primarily for agricultural use.

Corrected as suggested.

Page 128. Awkward.

Sentence restructured.

Page 128. Awkward.

Sentence restructured.

Page 129: Does this paper discuss impacts of agricultural influences on C, N, and P levels? Yes. Agricultural influences on C, N and P levels due to both fertilizer runoff into the river as well as reduction in flow due to diversions.

Page 129: specifically?

Corrected as suggested.

Page 129: They (?) being the headwaters?

This sentence no longer exists in the chapter as this has been covered in previous chapters.

Page 129: at the confluence.

Same as response to Comment 6.

Page 132: Is this influenced by irrigation and agriculture?

It is mainly due to higher flow in winter and smaller flow mixed with agricultural runoff containing fertilizers in spring and summer. The sentence was revised to reflect this information.

Page 132: Is this directly correlated to certain agricultural practices? It is not clear if this is directly correlated to certain agricultural practices.

We did not look at details of agricultural practices.

Page 144: Cite historical information.

Citation inserted.

Page 145: This is the first time that fertilizers, livestock, non-point source solution have been mentioned in any detail.....isn't this impacting results in all the other studies.

This information is discussed in Chapter A.8, river environments and benthic macroinvertebrates.

Project A: Fishes of Walker River: Present composition and basic ecology

Page 153: This leaves out key information regarding fish species in the river. There is no mention of the stocking programs by NDOW, which influence species composition. There is no mention of the various barriers to fish movement.

These comments were addressed by discussing barriers to fish migration in the river. It was not our intention in this project to discuss the stock and catch of fishes in the river. Thus, this information was not included in the chapter. This information can be obtained from the Walker Basin Working group, the USFWS and NDOW who stock the river with game fish.

Page 153: If all samples were collected at the same location, they should all have the same name. Two of the 6 papers have different sampling location nomenclature.

Report changed to correct this.

Page 153: Opening sentence needs to discuss sampling methodology, seems very choppy and confusing.

This has been corrected by providing a broader introductory paragraph.

Project D: Science, Politics, and Water Policy: Resolving Conflict in the Walker River Basin

GENERAL

As noted in more detail below, this report contains many undocumented quotes, claims, and/or assertions attributed to both named and anonymous sources; each should be specifically referenced, re-stated as the author's opinion, or dropped. The analysis in Chapters 1 and 4 focuses primarily on the research aspects of the Walker Basin Project (involving a commitment of not more than 20% of available funds), and far too little on its more ambitious, and controversial, water acquisition component (involving a commitment of not less than 80% of available funds). Additional discussion of the evolving acquisition effort would be valuable, which as of this writing includes 11 separate option and purchase agreements between the University and willing sellers with a composite negotiated value (subject to many contingencies) of more than $90 million; completion of a Draft Environmental Impact Statement (EIS) on the acquisition program by the U.S. Bureau of Reclamation, which includes discussion of their decision to complete a Final EIS but not a Record of Decision on the program; and legislation pending (see next comment) that will, if it becomes law, substantially re-structure and build upon the Project's fee acquisition and research efforts to-date, end the University's direct involvement with the acquisition program, and launch a 3-year demonstration water leasing program (and additional fee acquisitions) as part of a more comprehensive effort. Finally, as the above comments make clear, the most important parts of this report are already out-of-date. No doubt it was always going to be difficult to produce an historical account of the Walker Basin Project so soon after its inception, however in light of recent and pending events – above all the anticipated enactment of into law of federal legislation (as well as companion actions already taken by the University of Nevada's Board of Regents) that would lead to the University's assignment of its acquisition-related rights, interests, and obligations to the National Fish and Wildlife Foundation before the end of 2009 – it would seem most appropriate to revise and update this report to focus on what can now be seen as "phase 1" of a longer-term restoration effort.

I wish to thank the reviewer for taking time out of what must be a very busy schedule to review this project. The comments and recommendations are appreciated. I address the reviewer's concerns below.

The reviewer notes that the manuscript is outdated where acquisitions are concerned. I agree. Had the manuscript been reviewed closer to the time of submission (March 2009), it would have been up to date to that point in time. Given that nearly nine moths have passed since that time, several important events have occurred which should be included in the manuscript. The reviewer specifically notes that 11 options to purchase water have been negotiated at a value of approximately $90 million; a draft EIS on the acquisition program has been completed by the US Bureau of Reclamation; and legislative efforts are pending that, if they become law, would (a) substantially restructure and build upon the project's fee acquisition and research efforts to-date; (b) end the university's direct involvement with the acquisitions program; (c) launch a three-year demonstration water leasing program (and additional fee acquisitions); and (d) lead to the university's assignment of its acquisition-related rights, interests and obligations to the national fish and wildlife federation before the end of 2009. These points are all well-made and all are now mentioned in chapter four. I also provide more information about the current status of these items. Jim Richardson, who is part of the acquisitions effort, notes as well that it is possible that most or even none of these options will ever be exercised, and that if they are, that process will take at least four or five years. There is also the possibility that the leasing program itself will render some the purchase options moot—and the possibility, as well, of technological advancements that will do the same thing (i.e., desalinization technology, which is currently under development by Amy Childress and Scott Tyler at University of Nevada, Reno). I will reference an article that appeared on this in the Nevada News "Suarez develops new solar distillation pond methods," by Mike Wolterbeek.

The reviewer's second main general point is that this report "contains many undocumented quotes, claims and/or assertions [that are] attributed to both named and anonymous sources." This comment puzzles me. If a claim or quote is "attributed," then how does that translate into "undocumented"? I did, however, delete the material that was referenced to anonymous. That having been said, I went through the manuscript carefully to see where more documentation needed to occur. I found a few and put in a citation, as appropriate. I should note here, however, that an editor and reviewer of these chapters, whom I hired on my own, noted that the manuscript was "over referenced". For additional citation issues, I relied on the points the reviewer made in this regard in the "specific comments" section. All of the "specific comments" are discussed in the following pages.

Finally, the reviewer notes that chapters one and four focus "primarily on the research aspects of the Walker Basin Project (involving a commitment of not more than 20% of available funds), and far too little on its more ambitious, and controversial, water acquisition component (involving a commitment of not less than 80% of available funds)." First of all, the fact that 80% of the funds were dedicated to purchases is irrelevant. I do not plan to devote anywhere near 80% of the book to acquisitions. Further, the options are private transactions that should not be made public at this time (even if I had access to detailed information about them, which I do not). All that can be said is that 11 options exist. The book is about the bigger picture, of which the acquisitions program is but a small part. Second, chapter one devotes only one paragraph to a discussion of Walker research. Chapter four is dedicated entirely to Walker research—and it was designed to do just that.

It might be useful here to note the outline of the book. Chapter one provides a general background for the project, including a discussion of the negotiated settlement of water issues relating to the Newlands project and the Carson and Truckee Rivers. I include that discussion as a transition into the Walker Project because the strategies undertaken to resolve the walker issues are very different from those undertaken for the Carson/Truckee.

The reviewer in several places asks that I provide more detail on the negotiated settlement. I wrote an entire book about that topic and am only providing a brief overview in this manuscript. The idea is not to delve into the specifics, but to set up a contrast between that and Walker.

Chapter two covers western settlement in general and settlement of Nevada in particular. It includes a discussion of early explorers and settlers, reclamation, Anglo/Indian contact, and various other influences on Nevada (gold and silver, the Mormons, etc.). It ends on Nevada becoming a state. This is all by way of historical background.

Chapter three, when finished, will provide background on the development of agriculture and ranching in the state of Nevada, including the development of Mason and Smith valleys and the creation of the walker river irrigation district—it will end by covering the disputes over water in those valleys, and the legislation that was passed that resulted in efforts to save Walker Lake, which in turn led to the Walker Basin Project itself.

Chapter four focuses specifically on the Walker Basin Project.

Chapter five will cover whatever has happened with the project and the acquisitions process at the time that the chapter is written. It was and is my understanding that the timeline for this book stretches through 2011.

A final chapter will be devoted to a summary and conclusions. It will include, likely, a discussion of the increasing use of "civic science" (which is what my field calls research like that conducted for the Walker Basin Project).

Re the reviewer's specific comments

P3, 1st paragraph: if defined as the "land of interior drainage" the Great Basin includes most of Nevada (not just "most of northern Nevada") and at best very small portion of western Wyoming (?)

This description is taken directly from an expert. I do not understand the reviewer's problem with this description. It appears the reviewer is not clear either, as he ends his comment with a question mark.

P3, 2nd paragraph: the last sentence -- "To make matters worse, all of the rivers in Nevada are over-allocated" -- seems out of place, value-laden, and ill-defined (at least at this point)

Agreed. Deleted offending sentence.

P3, 3rd paragraph: if defined as the "land of interior drainage" (see 1st paragraph above) then the headwaters of the Truckee, Carson, and Walker Rivers in California do not lie outside the Great Basin

Deleted "outside the Great Basin."

P3, last sentence: "since completion of Derby Dam in 1905, more than half (and sometimes all) of the flows of the Truckee River have been diverted to Lahontan Reservoir" – this statistic seems dated, and at a minimum should include reference to the specific period of record to which it applies; ditto the use of that water "to support irrigated agriculture" (only) at the end of that sentence on P4

Provided more detail. Specifically: the Truckee River historically terminated in Pyramid Lake, but since completion of derby dam in 1905, an average of 250,000 acres-feet-year (a-f-y) was diverted, through 1968, from the Truckee river to Churchill county, where it has been used, along with Carson river water, to support irrigated agriculture in the area (Horton, 1996:1-7). According to Joe Gremban, president of the Sierra Pacific Power Company in the late 1980s, the diversion took, at time, all of the water in the Truckee River at Derby Dam, leaving nothing to flow to Pyramid Lake.

P4, 1st full paragraph: again, dated and without particulars (and more generally, much has happened over the past 2 decades to affect the diversion and use of waters of the Truckee and Carson Rivers into and below Lahontan Reservoir)

I do not see how this is "dated." A "significant" portion of the Walker River is captured and stored for use in Smith and Mason valleys to support agriculture. How much depends on a number of factors: how much water is requested by individual farmers, how much water is stored in the reservoirs, whether it is a wet or dry year, etc. I used the word significant, because it is significant enough to have seriously impacted Walker Lake. This information is taken directly from an expert's take on it. I do not dispute this expert. Similar descriptions are reported by others.

P4, 2nd full paragraph: Smith and Mason Valleys in Nevada

Agreed. It should be Mason and Smith Valleys in Lyon County, Nevada. I added Nevada.

P4, same paragraph: "the volume of each has been greatly diminished" – as above, a few specific details would be helpful

Again, this is language taken from an expert. The volume of each fork of Walker is "greatly diminished." How much diminished they are, again, depends on a number of variables.

P4, last paragraph: tribal governments are an important 4th level, esp. in the context of this Paper

Reviewer wants me to mention specifically the tribes as one of the competitive users of Walker River water. I do not mention the others specifically (that comes later) either. I refer to a generic set of users. It is not appropriate at this place to specify all of the competing users for walker river water.

P5, first full paragraph: the first major extractive use of water in the West was for mining; prior to that Native peoples relied on the same waters in situ for much of their livelihoods, sustenance, and cultural identity

Agreed. Added that prior to Anglo use of these waters, the Native Americans depended on that water for sustenance and as a source of cultural identity.

P5, last paragraph: does "the three river systems" mean the Truckee, Carson, and Walker? (This becomes clear only later in the paragraph, which begins with discussion of Lake Tahoe only)

Cannot find reference to "three river systems" in this paragraph. Did find it on page eight and included mention of the three in parentheses.

P6, 2nd to last paragraph: Appendix A is referenced, however there is no appendix

Appendix A is indeed referenced. The reviewer notes that it was not included. Either you did not give it to him with the other chapters or I did not give it to you. I will make sure to include both appendices when I return the revised chapters to you.

P6, last paragraph: The statement "There were just too many issues left unresolved by the compact for it to be ratified" should, at a minimum, be preceded by a qualifier (e.g., "As discussed in the next section, …")

Added "as discussed below," per reviewer's suggestion.

P7, 2nd paragraph: It is not at all clear that, as quoted, Article I (Purposes) of the Compact has any particular "bias" built into it

Clarified how the appropriation doctrine has bias built into it, which was reflected in the 1968 compact in its description of the purposes of that compact.

P7, 3rd paragraph: "The west is the fastest growing and the most urbanized region in the United States" – most urbanized?? – at a minimum, footnote 7 should be expanded to include references that help to define and support these statements

Yes, the West is the fastest growing region in the United States according to not only this source, but many others. Changed "most urbanized" to "is becoming increasingly urbanized."

P7, 3rd paragraph: suggest "…greater value being placed on the western environment in general and on water dependent environmental resources in particular."

Substituted his suggested language.

P7, 4th paragraph: this paragraph jumps very quickly from questions about the use of water for irrigated agriculture (with little discussion of irrigated agriculture's dominant role in the development and use of western water) to the recognition of non-consumptive uses of water as beneficial – how did this happen??

Added "which had consumed the lion's share of western water supplies for decades."

P8: P8, 1st paragraph: why did Pyramid Lake matter to Interior? (i.e., no discussion of the Pyramid Lake Paiute Tribe, it's ancestral interests in the Lake, the fact that it's modern, Reservation entirely surrounds the Lake, Interior's crucial if sometimes conflicted role as a Tribal trustee, etc.)

Added that Pyramid Lake had by that time been receiving recognition as a national treasure that should be protected; it was also home to two endangered species (the Pyramid Lake cutthroat trout and the cui-ui).

PP 8-9: while interesting, the several pages devoted to the Native American rights movement and the early environmental movement seems both incomplete and out-of-place here

Agreed that the discussion of the Indian rights movement should not be in here as it adds little value and is a distraction. I deleted it.

P9, last paragraph: "Two of northern Nevada's lakes…" -- most of this paragraph includes background information that should have come much earlier

I disagree. The discussion of the environmental problems faced by these lakes as a consequence of the Newlands project follows a general discussion of the importance of the environmental movement in changing western water policy. I went from the general to the specific example. I saw no opportunity to get to this level of detail earlier in the chapter. Left as is.

P9, 2nd paragraph: Stillwater National Wildlife Refuge is mentioned here for the first time but not well described – where is it? How had it been "greatly affected by the Newlands Project?" etc.

I developed and inserted language that does both.

P10, 1st paragraph: "by 1966 the level of Pyramid Lake had dropped by 80 feet" – from what date?

1882. Added.

P10, 2nd paragraph: "by 1966 the Walker Lake level dropped by 108 feet; as of 2007 it had dropped by 145 feet" – again, from what date? (also the first two sentences in this paragraph should go at the end of the prior paragraph; everything thereafter is really focused on the Truckee-Carson system)

There is not enough room in this chapter for this discussion. Indeed, as previously noted, I have written a book on the negotiated settlement; two complete chapters are devoted to these details. These are not needed here, in my view. Instead, I have included a summary of the provisions of that settlement.

P10, 3rd paragraph: Senator Reid's efforts were clearly very important, however there is no discussion as to why the Walker Basin was "dropped" from the efforts that led to enactment of PL 101-618 (this comes later, on p11, but should be moved up or at least referenced in advance), nor mention of the importance of the 1989 Preliminary Settlement Agreement between the Pyramid Lake Paiute Tribe and Westpac Utilities (i.e., the "nucleus" for a new, legislated version of the Truckee-Carson portion of the compact), nor of the role of local and national environmental/conservation groups in developing an innovative approach for protecting and restoring the Stillwater NWR and other downstream wetlands concurrent with protecting and restoring Pyramid Lake (i.e., voluntary water acquisitions, which gained important support and prominence at the national level, and which in many ways set the stage for what is now being pursued in the Walker Basin)

Ditto a recommended inclusion of all of the elements (the Preliminary Settlement Agreement and TROA, among others) that led to the passage of Public Law. 101-618. That is the topic of a different book. I am giving an overview of the provisions of that settlement, and briefly describing how it came into being, by way of contrast to how the Walker Project came about.

P11, line 1: the Settlement Act ended decades of litigation among most of the parties involved in the underlying disputes (to their great relief, especially the federal government?)

Done.

P11, 1st paragraph: there are several references in this paragraph (and one in the following) to things that "Senator Reid believed" – is this all based on the author's interview with the Senator as finally referenced at the end of the 2nd paragraph (i.e., Reid, 2008)? That interview (or the proper source) should be cited each time.

> Line one: changed "among the parties" to "among most of the parties;" deleted the part about "to their great relief." First paragraph: inserted reference/citation to Senator Reid.

P11, 1st paragraph, line 12: "In addition, the federal government had a major presence in Churchill County" (and maybe explain how/why Churchill County matters in the Truckee-Carson context, and briefly what that major federal presence included, esp. in contrast to the situation in the Walker Basin)

> I deleted reference to federal presence in Churchill County.

P11, last paragraph and P12, 1st paragraph: these both seem completely out of place

> I deleted extraneous paragraphs, as recommended.

P12, 2nd paragraph: suggest a new heading here (e.g., On to the Walker?) – also as noted above, the water acquisition program at Stillwater (and now similar efforts elsewhere) has helped to set the stage for what is currently being pursued in terms of a large-scale, federally-funded effort to acquire water from willing sellers in order to protect and restore at-risk aquatic resources in the Walker River Basin – clearly the concurrent focus on (and funding for) associated research at the University of Nevada is an important and perhaps unique part of this effort, however at this point it remains to be seen whether and to what extent that research will result in a "science driven" acquisition program or whether the program will, perhaps more accurately, be informed by the results of that research over time (as well as shaped by politics and many other factors as it evolves)

> I inserted a new heading (On to the Walker River), as recommended. Inserted requested language in footnote 21

P12, 3rd paragraph: given litigation ongoing in the Truckee-Carson system it does not see appropriate to say that the water wars have "essentially ended" without at least a little more explanation; and as above, it would be best to link Senator Reid's goals (even if presumptively correct) to specific statements or other citable sources

> I deleted references to water wars, per recommendation.

P12, last paragraph: having finally turned back to the Walker, the paper now heads back to an examination of "major influences that shaped the creation and development of the state of Nevada"? (This definitely feels like filler; and this reviewer will now jump directly to Chapter 4, which seems more like the heart of the matter…)

> Reviewer notes a problem with chapter two and does not therefore review it. The contents of chapter two were part of the proposal. Lay readers (and that will be the eventual target audience) need to understand the development of the state of Nevada vis a vis its water resources and other influences in order to understand present-day water politics. Chapter two also sets up chapter three, which in turn

sets up chapter four. Some of the stakeholders seemed keen on having a history of Nevada and the development of Mason and Smith Valleys covered here. I did review chapter two again, checking for the kinds of problems the reviewer identified in the first chapter, and made the appropriate (in my view) changes.

Chapter Four

P31, paragraph 1: can't tell from this description where the two forks cross into NV

Included sentences noting where the east and west forks of walker cross the state line into Nevada.

P31, 2nd paragraph: is Lyon Co still "one of the fastest growing counties in the nation"? And in the last sentence, the Tribe and Mineral County are also interested in the preservation of Walker Lake

Yes, Lyon County is still one of the fastest growing counties in the nation.

P31, 3rd paragraph and P32, 1st paragraph: maybe good to break this up? Suggest "support" rather than "contain" a freshwater fishery; suggest putting "normal" (water years) in quotes, there really is no such thing; also upstream barriers (including major storage reservoirs, diversion dams, lack of passage and screening facilities, etc.) have contributed to the demise of the Walker Lake ecosystem and its fishery; current TDS levels are greater than 17,000 mg/l (vs. 13,000 mg/l here); important to note that laboratory studies show 16,000 mg/l as a 100% mortality threshold for LCT, however the Lake contains microenvironments that are spring-fed, etc. so those are all that's buying time at this point (and pretty sure tui chub, the LCT's principal food source, are also struggling to survive)

Changed "contains" to "supports," changed normal to "normal," noted the upstream barriers, changed 13,000 to 17,000, noted that the lake contains microenvironments that are spring-fed, which helps buy time for the trout and the lake. I had already noted the problems the tui chub were having.

P32, 2nd paragraph: this should refer back to Chapter 1, no need to repeat things here

Deleted paragraph, as recommended.

P32, 3rd paragraph: federal presence involves more than "advocacy" on behalf of the Walker River (and Yerington) Paiute Tribes, it's a federal trust obligation involving DOI through BIA and DOJ at least; also the Army Depot in Hawthorne is a factor, as are BLM-owned lands surrounding much of Walker Lake and Forest Service-owned lands upstream; and pretty sure the "interest in maintaining trout fisheries with non-indigenous hatchery stocks" is a state, not federal, interest; the figure of 110,850 acres represents the basin wide total for lands with surface water rights (decree plus storage), not lands in production (i.e., comparable to the 80,000 acres of water righted land reported to lie within WRID boundaries, including Smith Valley, Mason Valley, and the East Walker in NV)

I added to the description of the federal government's presence in Walker Basin, as recommended. I also noted in a footnote that the number reported represented the basin-wide total for lands with surface water rights.

P33, 3rd full paragraph: this report on the evolution of PL 107-171 paints only a partial view, and suffers (as above) from numerous undocumented claims ("This stipulation was intended to address opposition articulated by agricultural interests…; According to an anonymous source…; Senator Reid was determined…")

Deleted reference to Reid's thinking. Deleted material that came from an anonymous source.

P33, last line: PL 108-7 did not appropriate any funds, it simply allocated funds previously appropriated under section 2507 of PL 107-171 (this may seem like a small point but when it comes to federal outlays it can make a big difference)

Changed appropriated to allocated.

P34, 1st paragraph: Section 207 of PL 108-7 did not lift the original prohibition under PL 107-171 against purchase or lease of water rights, and so did not "pave the way for a water rights acquisitions [sic] program in the Walker Basin" (that did not occur until the enactment of PL 109-103 in Nov 2005)

Deleted sentence about paving the way for a water rights acquisition program, per recommendation.

P34, 2nd and 3rd paragraphs: these details are mostly extraneous to what eventually occurred under PL 109-103, with one exception: the "outsourced public education and 6 outreach initiative" led to the first public proposal to acquire water rights from a specific potential willing seller, who eventually became the first person to sign an option and purchase agreement as part of the University's Walker Basin Project

Deleted extraneous paragraphs and noted that the outsources public education initiative led to the first proposal to acquire water rights from a specific willing seller, who eventually became the first person to sign an option and purchase agreement as part of the university's Walker Basin Project.

P34, 4th paragraph: this should have a new section header (i.e., no longer a precursor to PL 109-103); technically, this Act was the Energy and Water Development Appropriations Act of 2006, and the directive was to provide not more than $70m "to the University of Nevada" (i.e., not just UNR)

Added a section header, per recommendation. Reviewer insists that the funds were appropriated to NSHE, not UNR. He goes on in the next recommendation to indicate that the funds were allocated to the University of Nevada under the direction of NSHE. He seems to be confusing the University of Nevada (which he notes is the language used in the legislation) with NSHE. Final note here: all of the legislation refers to UNR, not NSHE. I double checked and have that legislation on my computer.

P35: rather than simply listing what the legislation provides it would be helpful to explain what each of these programs involves and how, if at all, the various funding authorizations are, or could be, tied together

> Noted that Reclamation essentially entered into a master agreement to obligate the $70 and that funds would be released based on individual task orders. Changed section 28 to 208. I also removed the sentence that says that the horse and burro program was added at the request of Senator Ensign. Instead I said that it was added at the request of some of locals and the Nevada congressional delegation.

P35, 3rd paragraph: section 208, not section 28; also the "collaborative effort" involves the University of Nevada, Reno (UNR) and the Desert Research Institute (DRI) under the direction of the Nevada System of Higher Education (collectively, the University of Nevada, per the legislation); also good to explain the significance of/reasons for vesting oversight with a "Walker Basin Working Group" vs. an "Executive Steering Committee" as noted at the end of footnote 69

> DRI and UNR do not "collectively" form the University of Nevada. The legislation refers to the University of Nevada. The decision to vest oversight with a Walker Basin Working Group was made by at the system level, working with the PR people at UNR and DRI. I do not see the need to explain it to the reader. There was an Executive Steering Committee at the system level—and this is discussed in the document, separately from the Working Group.

P35, 4th paragraph and P36, 1st paragraph: here, and in most of what follows, the focus seems to be on the authorization of funding for research while saying very little about the authorization of funding "to acquire land, water appurtenant to land, and related interests in the Walker River Basin, Nevada" – the latter, of course, is by far the most controversial when it comes to the University's "deep, historic ties to Nevada agricultural interests," and most at odds with the previous prohibition on the purchase or lease of water rights moreover, while it may well be the case that "the policy goal of this appropriation [as interpreted by the University?] is to deliver water to Walker Lake," the legislation does not say that directly…so what is the back story that allows the reader to understand this assertion? How and why was the decision made to pursue a "virtual" research center and a "water only" options program, when it appears that the legislation anticipated a physical research center and pursuit of acquisitions involving land, water, and related interests that would be "most beneficial" not only to "environmental restoration" but to the establishment and operation of such a center? (These interpretations may or may not be accurate or complete, however these and other formational elements of the Walker Basin Project should at the very least be discussed.)

> Reviewer suggests that the policy goal of the legislation is not necessarily to deliver water to the lake, but that was merely UNR's or NSHR's interpretation. I disagree. So would Mary Conelly and Senator Reid. Mary even has buttons that says as much. Also wants me to focus more on the acquisitions program. That is not the purpose of this chapter. That program is briefly described, as are the other components of the Walker Basin Project. More detail will be provided later in the manuscript, in a section that will deal exclusively with this topic. This is not the appropriate place for an in-depth discussion of that topic.

P36, 2nd paragraph: this paragraph should be deleted -- it is a very long reach to suggest that the federal government (beyond the provision of federal earmark funding) is seriously interested in resolving this conflict, particularly as federal agencies step away from taking responsibility for the evolving acquisition program (e.g., the Bureau of Reclamation's recent decision not to issue a Record of Decision for the water acquisition program EIS) -- the rest of the paragraph seems, at best, aspirational and at worst, pre-mature and self-serving

Deleted, per reviewer's recommendation.

P36-41 (under Walker Basin Project): suggest breaking this out into (a) the research program and associated outreach efforts (which is the primary focus of what follows); and (b) the acquisition program (which is only mentioned in four places – i.e., that 80 percent of the funds were budgeted by the University for such purposes (p36); that an anticipated timeline for the acquisition process was developed as part of the initial planning process (p36); that Western Development and Storage was selected to coordinate the acquisition process (p37); followed by a somewhat-tortured one-paragraph description of the acquisition process (p40), which as of July 2009 included 11 recorded option and purchase agreements at a composite negotiated value (subject to appraisal, confirmation of title, and other due diligence) of more than $90 million

I have done that. He also suggested adding to the discussion of acquisitions, specifically noting the changes that have occurred since Mmarch 2008. I have done that.

P26, 2nd paragraph under Walker Basin Project: again, what are "the policy directives found in the legislation and appropriations"?

This language appears earlier in the document and clearly spells out the policy directives: "Section 208 directs the Secretary of Interior (under the provisions of section 2507 of the Farm Bill of 2002) to provide not more than $70 million to the University of Nevada, Reno to accomplish the following goals:

(A) to acquire from willing sellers land, water appurtenant to the land, and related interests in the Walker River Basin, Nevada; and (B) to establish and administer an agricultural and natural resources center, the mission of which shall be to undertake research, restoration, and educational activities in the Walker River Basin relating to—(i) innovative agricultural water conservation; (ii) cooperative programs for environmental restoration; (iii) fish and wildlife habitat restoration; and (iv) wild horse and burro research and adoption marketing [sec. 208 (a)].

P36, last paragraph: how is it known that "a Wild Horse and Burro Marketing Study was included…[a]t the request of Senator John Ensign"? Also, like Appendix A, Appendix B is referenced but not included

Deleted reference to Senator Ensign, per recommendation.

P37, last paragraph: the various "public claims" should be referenced

Public claims (comments and opposition) are referenced now.

P37, footnote 73: same footnote as #69 (except for reference to its previous life as an Executive Steering Committee at end)

Deleted, as it appeared earlier and was redundant.

P38, 2nd paragraph: "Such criticism began to wane"?? Perhaps so, for a brief period, but that does not reflect the tenor of most comments received during public hearings on the Draft EIS conducted by the Bureau of Reclamation during the summer of 2009, nor the tone of most of the articles authored by Mr. Sanford for the Mason Valley News throughout the course of 2009 (though this analysis seems to end with articles and interviews conducted in March 2008 and, as noted, focuses primarily on the research end of the Walker Basin Project through about that time)

I stand by my assertion that criticism of the researchers and the project began to wane as the community began to interact with the researchers and a sense of trust began to develop. I cited several articles that indicated the same thing. I did add a footnote that noted that opposition was loud and clear at the public hearing Reclamation held on the draft EIS in the summer of 2009, per reviewer's request.

P39, first paragraph: the points made here relating back to PL 101-618, including footnote 74, need further explanation and discussion (and, as elsewhere, reference to actual conversations, new articles, whatever)

Deleted reference to negotiated settlement.

P39, 2nd paragraph: What project? What study outline? What policy goal established by Congress? Where has the water flow model been used?

See earlier description of the project and policy directives, above. I do not see why the reviewer keeps referring to this when it has been so clearly spelled out, with direct quotes from the legislation itself. The models referred to in this document, at the time of this writing, were being developed and tested. I did not say any of these had been "used" for the project.

P39, 3rd paragraph: questions concerning the future use and management of lands from which appurtenant water rights are acquired and transferred are likely to be very important to the long-term success of the acquisition program and deserve far more attention than the brief discussion here

This will be covered in greater detail in a subsequent revision of this manuscript, when more information about that program is available and when options are converted to acquisitions.

P39, 4th paragraph: what are the University's "longstanding commitments" in the Walker River Basin?

I dealt with this by deleting the reference to "longstanding commitments" and including the following language instead (in chapter four): The federal government's physical presence in the Walker Basin is threefold. The U.S. Geological Survey (USGA) has several gaging stations by which it measures instream flows in the Walker River. There is an Army Depot in Hawthorne.

And the Bureau of Land Management (BLM) owns the land surrounding much of Walker Lake. It has a legal presence as well, because of its trust obligations to the Walker Lake Paiute Tribe, on whose behalf the federal government advocates.

P40, 1st paragraph: this paragraph begins with reference to incentives for agricultural water conservation under Nevada water law (which part? what incentives?) and ends with a statement, now stale, that "all of these research projects [relating to agricultural water conservation?] are well underway, with report deadlines scheduled for December 2008" – what is the point of this discussion?

This statement was not stale at the time of submission. It will, of course, be updated in the final version, as will any other parts of this manuscript that needs updating.

P40, 2nd paragraph: how can the acquisition portion of the Walker Basin Project be "science driven" (see comment for P12, 2nd paragraph, above) while acquisitions are being pursued "in parallel with the research project"? The Nevada State Engineer (rather than State of Nevada water engineer), and eventually the federal District Court (for water rights adjudicated under the Walker River Decree), must consider and either reject or approve, with or without conditions, applications submitted in proper form to change the place, manner, and/or purpose of use of water rights now appurtenant to lands in Nevada following acquisition of title (or with the cooperation of the owner) – the U.S. Bureau of Reclamation has no role in that process, rather it oversees (as lead federal agency) the NEPA (EIS) process (which has nothing to do with the Environmental Protection Agency), except that Reclamation has recently decided that, because it has no programmatic discretion or control over the expenditure of funds, it will complete a Final EIS but will not issue a Record of Decision for the proposed project (i.e., what is described in the Draft EIS as the University's Acquisition Program) – finally, as noted, federal legislation pending (as of early October 2009), as well as companion actions already undertaken by the University of Nevada Board of Regents, would allow the National Fish and Wildlife Foundation to accept assignment of the University's rights, interests, and obligations under the Walker Basin Project, and would provide additional funding to the Foundation to develop and implement a more comprehensive restoration program going forward

I did a search and found no such phrase (science-driven). Yes, additional things need to happen and some have since (the time of this writing) happened. These will be included in the revision.

P40, 3rd paragraph: most of this discussion seems like background information that could/should be presented earlier; quotes are also included but not referenced, as elsewhere throughout this document; and it is unclear how the Walker Tribe's claims to Walker River water would be sanctioned by P.L. 101-618, which of course pertained to the waters of the Truckee and Carson Rivers (so, at a minimum, additional explanation is needed)

I found no such discussion in the manuscript. I must have dealt with this concern when I first responded to the reviewer's comments, but did not make note of it in my reply.

P41, 1st paragraph: this entire paragraph discusses potential settlement legislation "slated for introduction in late 2009" but that is not how things have evolved (and that alone would 9 make for an interesting story, including how and whether more recent/current events might help to shape a comprehensive settlement going forward)

Appears to be convoluted and redundant; deleted.

P41, Conclusion: again, what are "the public policy goals stated in the legislation?" It is not the case that "purchase and title transfer [will be] contingent upon it being shown…that water can be delivered to Walker Lake" – that may well be a subject for examination by the Nevada State Engineer and/or the federal District Court as part of the water rights change approval process, but it has nothing to do with most of the options now pending that the University has negotiated with willing sellers; and yes, the project – and this description of its birth and evolution – are definitely in "midstream" at best (or, as suggested in the General comments above, at the end of the first phase of a longer term effort)

Conclusion: he strongly believes the purpose of the legislation and the project is not necessarily to deliver water to the lake. I respectfully disagree. So would Conelly, Reid and Dickens.

Thanks to the reader for helpful comments and suggestions.

PROJECT F: Development of a Decision Support Tool in Support of Water Right Acquisitions in the Walker River Basin

Page 13: PRISM over-estimates average annual precipitation in the Walker River basin by about 20 percent. See Lopes and Medina (2007). How does this affect model results?

We agree that PRISM estimates of the precipitation in the Walker River basin (as well as many other areas) may tend to be greater than those observed at some ground-based observation points. We do not actually use the PRISM estimates as input to our models, rather we use the PRISM long-term average monthly values over each 4km grid as a means to distribute actual daily observations to other locations in the watersheds that don't have actual ground-based observations. This is a common hydrologic modeling approach that has been shown through a variety of other studies to be more accurate than the development of regressions among point observations sites for spatial distribution of precipitation.

Page 18: The model estimates spring runoff but didn't estimate any runoff for the 1997 flood and missed peaks for other events. Why?

The models do estimate the 1997 peak runoff well for a few of the watersheds, however the single peak value is not well simulated for most. His is most likely due to issues related to the distribution of temperature from the observed locations to the individual modeling response units. The methodology for distributing temperature is identical to the method used to distribute precipitation; the PRISM long-term average monthly values over each 4km grid are used to distribute actual daily observations to other locations in the watersheds that don't have actual ground-based observations. Unfortunately, this relationship does not always work well during extreme rain on snow events (i.e., a different spatial distribution of temperature may be occurring during these events). As a result, we are often forced to settle for poor model performance during these extreme events in order to simulate the remaining time periods reasonably well.

Page 28: Revised estimates of basin outflow through Walker and Parker Gaps total 800 af/yr, 600 af/yr less than Huxel and Harris (1969; Lopes and Allander, 2009b, p. 32). Subsurface outflow also appears to be through the Wabuska lineament and, based on water levels in the area, is as much or greater than subsurface flow through the gaps. How do these revisions affect the model?

Inter-basin groundwater flows beneath the river channel or through geologic gaps in the surrounding bedrock (i.e., Adrian, Wabuska, Parker Gap and East Gap) were modeled using MODFLOW's GHB package. The GHB elevations were adjusted to obtain observed boundary fluxes primarily from Huxel and Harris (1969) using MODFLOW's GBOB observation package with annual net inflow and outflow volumes provided in the report. The GBOB calibration, however, was done under steady state conditions in the 1960s. The result of the calibration is shown in the figure below. No observed estimates were ever given for the East Gap and so the East Gap was not used in the GBOB calibration.

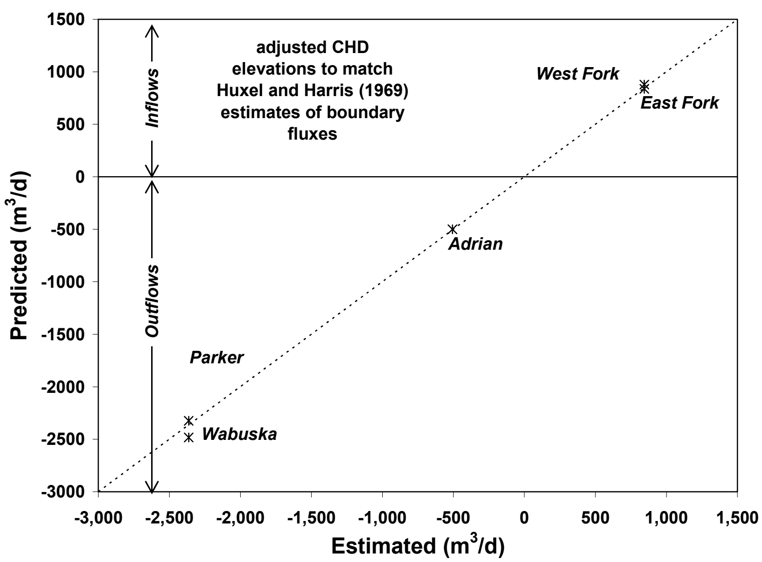
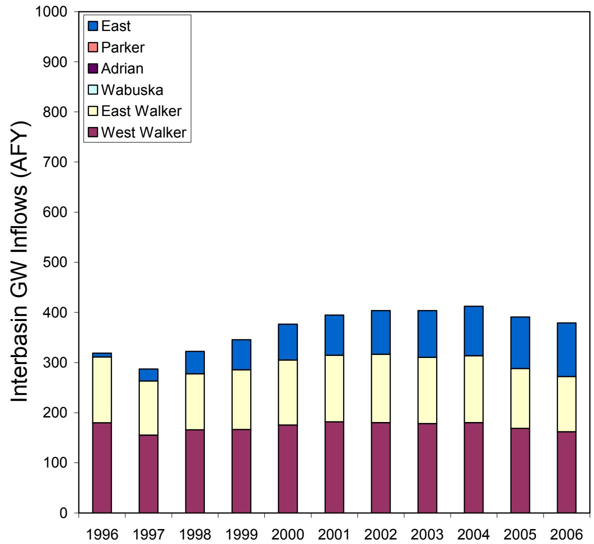
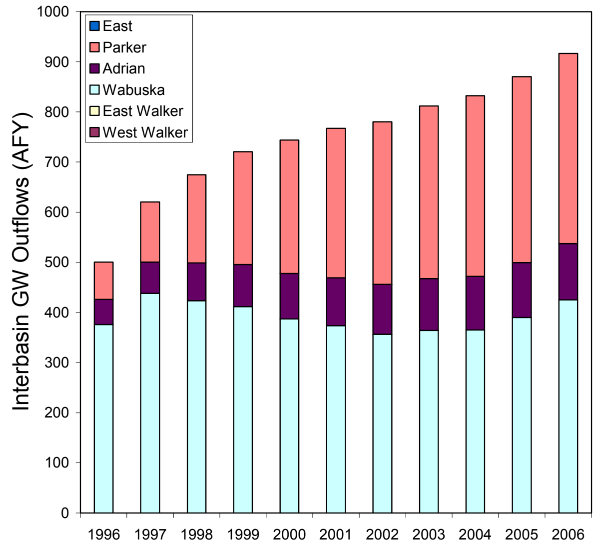


Figure: Predicted and observed interbasin groundwater flow for the 1960s steady state model. Quantities are in cubic meters per day NOT acre feet per year (AFY). For comparison computed fluxes in AFY are: Wabuska = -688, Parker = -735, Adrian = -148, West Walker = 248, East Walker = 260. Total In (without East Gap) = 508, Total Out (without East Gap) = 1571.

Since no flux was given for East Gap, water table elevations (estimates) from Huxel and Harris (1969) were used to establish the GHB elevation for this region.

Given the reviewers comments, we have rerun the transient model and tracked all interbasin groundwater flows during the entire transient run. See the figures below for annual input and output in AFY. A few points were discovered in this more complete analysis. First, East Gap is contributing water and this may not be correct. Second, Parker losses grow over time and may not be in equilibrium. Finally, all flows are reduced compared to the steady state calibration. These issues will need to be investigated and addressed in the second phase of the project.





Page 41: The SVGM was modeled as one layer. However, there are flowing wells in Smith Valley around the river and Artesia Lake so there must be confining layers. Well logs for the basin describe thick clay layers in the basin (Lopes and Allander, 2009a, p. 52). Is it appropriate to model this valley as one layer?

Given the available information to describe the hydraulic properties of the aquifer, we felt it was appropriate to take a parsimonious approach. Therefore, we utilized one model layer, which thereby assumes no vertical flow. In reality there are likely numerous clay lenses, etc, that cause complex flow patterns within the subsurface, but these were of less interest to us as compared to developing an accurate water balance for the system. It is highly unlikely that a multiple layer model would yield substantially different results in terms of simulated return flows to the river.

Page 47: The first sentence reads like regressions were done by Gallagher, not this study. Where are regression results? Others might want to use them.

The existing sentence in the report:

"Regressions of streamflow and groundwater withdrawals (Gallagher, 2004) are developed for Smith Valley using Hoye gage data (1994 to 2003), and for Mason Valley using the combined Hudson and Strosnider gage data (1995 to 2002)."

was modified to read:

"Regressions are developed in Smith Valley using Hoye gage data (1994 to 2003) and groundwater withdrawals (Gallagher, 2004), and in Mason Valley using the combined Hudson and Strosnider gage data (1995 to 2002) and groundwater withdrawals (Gallagher, 2004)."

The regression equations were not included in the report but will be available by the authors on request.

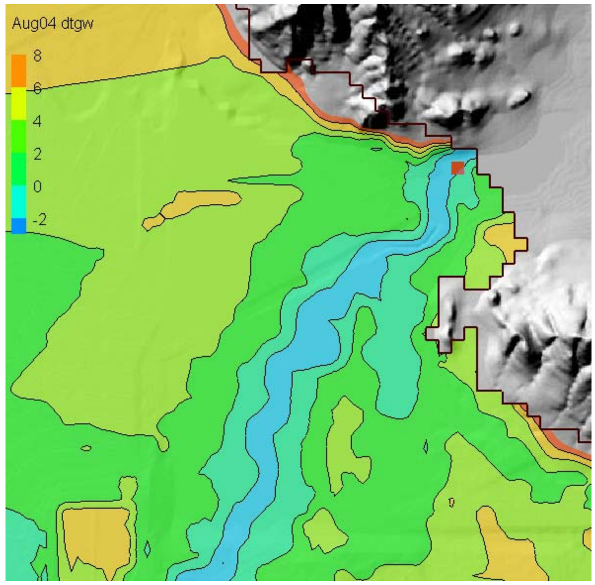
Page 51: The Maxey-Eakin method was mis-applied. M-E method does not specify where recharge occurs; it is only a basin-wide estimate.

We will look at more recent recharge estimates (i.e. USGS) during the second modeling phase. In reality the small amount of natural recharge does make much difference, except maybe in Smith Valley.

Page 53: Where is East Gap? This is the first and only use of term in entire report. There could be outflow through Wabuska lineament, how would this affect the model? Water 10 ft below land surface at Wabuska seems too deep. This reach is gaining at times. Water 20 ft below land also seems too deep for Adrian, it's a discharge area for Mason V. Why is water at Hudson 10 ft deep for Mason but 8 ft for Smith?

East Gap is marked in the map showing gages and gaps. It is to the south of Parker and constitutes a small alluvial gap along the eastern boundary of the modeled domain. GHB elevations at each location were calibrated to get estimated fluxes, except for the East Gap in which GHB elevations were taken from head maps in Huxel and Harris (1969). The Mason and Smith groundwater models were developed as separate entities and better correspondence between the separate models will be done in the second modeling phase.

Below is a map of modeled depth to groundwater for August 2004 in the Wabuska gage region. Positive depths are below ground surface and negative depths are above ground surface. Ground surface for the river is defined as the minimum elevation in the 100m-cell grid, while non-stream cells use an average elevation in the grid. The assumption is that water flows in the lowest elevation. As seen in this map, water elevations are about 2 m above land surface at Wabuska. Fluxes to and from the river are determined by the gradient between stream depths (as determined by the rating curves defining flow and depth) and groundwater. At the monthly scale, Wabuska is modeled as generally losing water.



Page 53: What is 20% infiltration along major ditches based on? This seems high. If there is 57,500 to 70,000 acre-ft/yr of irrigation recharge (p. 28), that would mean diversions are about 290,000 to 350,000 acre-ft/yr.

The local water district estimates that major delivery ditches lose 20 percent of the surface diversion to the groundwater via leakage. Calibration and sensitivity analysis were used to refine this preliminary estimate and found the model relatively insensitive to values of leakage below 30%. Therefore the initial estimate of 20% was maintained.

> Ditch leakage is computed as 20% of the surface diversion for a given month along a given ditch with totals for the entire basin on the order of 16,000 AFY to 38,000 AFY. Groundwater recharge from excess irrigation water ranges from 35,700 AFY to 66,400 AFY. Combining ditch leakage with irrigation recharge produces annual volumes of 60,400 AFY to 99,400 AFY) returned to the groundwater system. This net recharge is reasonable when compared to groundwater recharge volumes set forth by Huxel and Harris (1969) at 70,000 AFY. The Huxel and Harris (1969) recharge estimate occurred during early groundwater development when rates of withdrawal were low compared to modern-day volumes.

Page 64: Total gw inflow seems high, up to 30,000 af/yr higher than previous high estimate. Groundwater levels have been going down in valley since 1960 so pumpage exceeds average inflow.

> The simulation period covers periods of both high and low flow periods. Total groundwater flow is highly dependent on river flow because of the linkages to irrigation and groundwater pumping. Previous studies in which water balance estimates were generated did not cover such a large range in river flows. In conclusion, we don't feel that the groundwater inflow estimate is necessarily high, but during phase II of the study we will be further refining these estimates.

Page 64 Estimated recharge and riparian ET from surface-water budget is within this range, see Lopes and Allander (2009b).

It is nice to know that our results fit well within the context of the recent work done by the USGS. Our report was completed in 2008 and the referenced document (Lopes and Allander (2009) was not available at that time. It would be easy for us to add a sentence to our report now to indicate that our results fit well with the referenced document, however, we would like some additional time to review the document and understand the results before citing the work. In addition, if we cited the work, others may assume we had access to other information the report and wonder why we did not make other comparisons, etc. As a result, we have chosen to not cite the recent work in our report but are grateful that the reviewer has identified the work and recognized the similarities in the results.

Page 71: last paragraph. Gage 10293000 is downstream from Bridgeport Reservoir, not upstream. It's the east fork from Bridgeport to Mason Valley, not west.

The current paragraph:

"The MODSIM model extent begins upstream of Bridgeport Reservoir, CA at USGS gage 10293000 on the East Walker River, and at Coleville, CA at USGS gage 10296500 on the West Walker River and continues downstream to Wabuska, NV, at USGS gage 10301500 (Figure 41). Agricultural demands in Antelope Valley, Smith Valley, Mason Valley, and on the West Walker River from Bridgeport to Mason Valley are represented in the model. A monthly time step is used for the model and all volumes are calculated in acre-feet. The model is calibrated over the period 1996 to 2006 and simulations cover the same period."

was modified to read:

"The MODSIM model extent begins just below Bridgeport Reservoir, CA at USGS gage 10293000 on the East Walker River, and at Coleville, CA at USGS gage 10296500 on the West Walker River and continues downstream to Wabuska, NV, at USGS gage 10301500 (Figure 41). Agricultural demands in Antelope Valley, Smith Valley, Mason Valley, and on the East Walker River from Bridgeport to Mason Valley are represented in the model. A monthly time step is used for the model and all volumes are calculated in acre-feet. The model is calibrated over the period 1996 to 2006 and simulations cover the same period."

Page 73: How was equation 4 determined? Some explanation is needed.

The fundamental operation of the MODSIM modeling software is based on the assignment and minimization of costs (or penalties for failing to match selected time series or targets). In order to simulate continuous streamflow in terms of water rights with associated priorities, MOSIM requires the conversion of water right priorities into a cost. The standard equation used in MODSIM (see referenced user manual) is given in equation 4. We have performed a variety of experiments to investigate the significance of this equation and have determined that the results in the Walker are not sensitive to the equation structure at all. In fact, we could have just ranked the water right priorities from high to low using whole numbers and would have obtained the same results.

Project G: Economic Analysis of Water Conservation Practices for Agricultural Producers in the Walker River Basin

An important and challenging research project. It addresses a critical subject for the Acquisition Program. Data are analyzed in several ways that greatly contribute to the understanding of these crops, their production potential relative to applied water, their feasibility, and their risk profiles. It is clear that a tremendous amount of agronomic and statistical knowledge was required to conduct the study so comprehensively, using sophisticated tools. The project achieves what appears to be its stated objective "to determine the viability of these crops for both the region and the market." (p.5)

The Abstract, Introduction, and Conclusions sections are very well written. The conclusions are well substantiated by the research results.

The following critiques of the paper are offered:

The paper seems mis-titled. The phrase "water conservation practices" may include crop switching but also implies a broad set of technological, behavioral, and managerial practices for growing existing crops with less water. A better title would be "Economic Analysis of Alternative Water Conserving Crops for the Walker River Basin" or simply "Economic Analysis of Alternative Crops for the Walker River Basin."

The title has been changed from the original project title to one recommended by the reviewer.

The Analysis subsection of the Data and Methods section is very technical; it would be useful for most readers if it was explained more clearly.

This section has been edited somewhat to delete repetitive information and run-on sentences. The technical portion is appropriate for such a research report such as this.

A concern of the paper is the manner in which prices are handled.

The rationale for selecting the prices used for break-even yields and comparisons of net returns is not stated in the Yield Analysis section. More importantly, although the sets from which the relevant prices were chosen are made clear in a later section, neither a methodology for making the selections nor explicit justifications for the choices are provided. It appears that judgment by the researchers or by producer panels has been employed, rather than a systematic method. If that is the case, even if very good judgments were made, it calls into doubt the ability of the research results to be replicated scientifically. Clarification in the text should be added to discuss how methodology was developed and justification of choices used.

All prices were taken from the enterprise budgets, which are five-year averages, when historical data were available. If historical data was not available, the prices were chosen by producer panel. The text has been updated to discuss this and the enterprise budgets are now sited and also listed in the references.

Similarly, no systematic method appears to have been used for determining the points of triangular price distributions that were created for most of the crops in the study. The approach seems inconsistent from one crop to the next. These inconsistencies are troubling because they raise doubt on the reliability of the risk analysis results that provide the foundation for the study's conclusions. Perhaps an explanation of the method used for determining the points of triangular price distributions would help clarify this issue.

Historical data and that from the enterprise budgets were used. We have added citations for data and how or why used.

A related issue is that formal citations are omitted for the sources of the specific prices.

Sources or pricing have been added to the text.

The time value of money is handled in a manner that is not explained. Because costs were adjusted to 2009 values by a producer cost inflation factor, it appears that net returns were intended to be expressed in 2009 dollars. However, the way in which price distributions are developed for almost all of the crops is not consistent with such an approach – prices from various years were used. If there are valid reasons to neglect making revenues and costs temporally consistent, the reasons should be made clear.

The idea was to simulate through 2009, and in order to do so we adjusted cost of production by an inflation factor. There was no intention to express net returns in 2009 dollars.

There are two other methodological issues that arose regarding the risk analysis:

For three of the crops, the yield analysis results from WinEPIC were adjusted to account for marketability. It appears that these adjustments were not carried forward to the risk analysis, but if so this should be made clearer.

Yes, the marketable yields were used for the risk analysis. This is now mentioned in the analysis section.

The risk analysis makes use of WinEPIC yield output for Diplod soil in Yerington. The reader would benefit from the authors' assessment of the extent to which this limits the applicability of the study results to other soils and to Smith Valley.

Dithod soil was chosen due to is prevalence in Mason Valley, and Mason Valley (Yerington) was chosen as it is the largest agricultural producing area of the Basin. This is now mentioned in the text. This was done to show the risk and variability in the crops for illustration purposes. This analysis could have been done in another area or by all soils, but we do not believe it would have added much to the discussion. Additionally, we used yield response functions (adjusted for marketability) for each crop to build an analysis spreadsheet called WATER-ACIS for individual producers to use to analysis the options for their weather station and soil type. This spreadsheet and user guide is publicly available at: http://www.cabnr.unr.edu/curtis/Extension/Extension.html.

The attached word document contains comments covering the above critiques as well as more minor comments and suggested edits.

Comments and edits have been adjusted in the text.

Project H: Formulation and Implementation of Economic Development Strategies

A very informative study. The stated purpose of the study "was to look at possible economic impacts in each of the sub-regions, and in particular to look at a several potential outcomes under various scenarios in areas targeted for acquisition of water and water rights, and then to identify potential economic development opportunities that might help mitigate any potential negative impacts." This objective was achieved.

The study's recommendations for economic development strategies, as summarized in the paper's Executive Summary, seem well thought out, reasonable, and appropriate. The same is true for the recommendation on p.47 regarding funding and technical assistance for crop switching. It should also be included in the Executive Summary.

This review examined the summary level data pertaining to scenarios, economic impact examples, and the fiscal analysis. It did not examine the details of the analysis, such as those pertaining to individual crops and water right values. Based upon this level of review, the analysis and conclusions appear sound and reasonable. The only result that is of concern was the statement in the subsection on fiscal impacts to Lyon Co. that reads, "…total employment will likely be net unchanged…" (p.58). This over-simplification can be corrected easily with rewriting of a sentence or two. More minor comments (e.g. needs for clarification) and editing suggestions are contained in the accompanying Word file.

The Table of Contents is missing a couple of important subsections s following the one titled "Conclusions – Consequences to the agricultural economy of Mason Valley and Smith Valley."

A subsection heading was added – see below

Page 3: Table of Contents should show where the Hawthorne area impacts are discussed (p.49)

Added line in table of contents for Hawthorne area impact analysis (p.49)

Page 7: Removed reference to acquiring water rights because acquisitions will involve leasing of water, not just outright purchase of water rights.

Removed these references to water rights and used the term water instead. However, later in the document there is reference to both water rights acquisition and leasing, so only made these changes in the paragraph indicated.

Page 10: FYI, this may not be a good assumption. There are formidable water quality barriers that Homestretch may not overcome. Reclamation's EIS analysis did not assume the Homestretch option would be implemented in their analysis. Suggest maybe revising Example 3 to reflect a worst case scenario for impacts to ag (i.e. 100% ag water acquisition), and possibly both of the other examples, too.

The assumption was based in part on a potential for treating the water to remove/reduce "contaminants", and some language was added to provide more about this assumption. Language was also added to address what the worst case economic impact might be if this were no possible.

Page 11: Explain why not include market development for Great Basin wild rye? This would involve further market research and investigation of potential barriers to market growth, and potential promotion of the crop for appropriate uses such as revegetation.

Teff and two-row malt barley provide the possibility of value-added processing and market development, while the Great Basin Wild Rye would not involve value-added processing – only market development. While this might help in converting farmers to growing Great Basin Wild Rye, it would not result in the sort of job creation that the value-added processing (teff and two-row malt barley) accomplishes.

Page 12: Homestretch already produces power from the geothermal source water. I interpret the original reference to geothermal water to mean post-power production effluent and the edit is intended to make this more clear.

Suggestion implemented.

Page 12: Homestretch's main constituent of concern to NDEP and the Tribe is fluoride.

Suggestion implemented.

Page 17: Explain why East Walker area not included?

The Walker River Chronology published by the Nevada Division of Water Resources (http://water.nv.gov/Water Planning/walker/walker1.cfm) clearly shows in Table 2 (p.6) that there is no major agricultural area in the basin on the East Walker River in Nevada. The significant agricultural land on the East Walker is in California above Bridgeport.

Page 41: Footnote b needs to be modified to reflect current table numbering. The Net Econ Impact box for Scenario 4 needs attention, too.

Table 17 footnote b was changed, as were footnotes to tables 11, 12, 13, 15 and 16.

Page 47: This excellent recommendation needs to be included in the Executive Summary.

This comment, in a slightly modified version, was incorporated into the Executive Summary (p. 10).

Page 49: Text added noting the similarities of Figure 7 to graphs of discharge at Wabuska and Walker lake levels. Alternatively, consider inserting an appropriately scaled graph similar to Figure 6 in Adams and Chen's paper and letting the reader see for him/herself.

Change made.

Page 52: Please provide perspective. Minimal compared to what? 30 jobs is approximately equivalent to 1/8 of Mineral Co. unemployment.

"Lost jobs" do not automatically become "jobs regained" after more water begins flowing into Walker Lake. Assuming the project is successful in delivering an additional 50,000 AF annually to the Wabuska Gauge, we have no indication as to how long it may take to restore the fishery to the point where the approximately 30 lost jobs might be recovered. A modifier was added to this sentence.

Page 52: The wording in the last two sentences has been changed so as not to imply that existing reservoir management practices necessarily will change. It is thought by those working on the Acquisition Program that upstream reservoir operation is not going to change. Water will be released as before, probably during the ag season, and will just go farther downstream.

Suggestion implemented.

Page 54: Is this the way that NV counties refer to property taxes? Not sure what this means. Clarify?

This is the way that fiscal analysts who do fiscal studies for Nevada Counties refer to property taxes.

Page 57: Including school districts and cities in the county?

The sales tax numbers only reflect money coming to the county, not other entities such as school district, cities, etc. This was because the region of concern is not within any other cities or entities that receive sales tax. As far as the school district is concerned, the nature of the school funding formula means that they are unaffected by sales tax fluctuations which are made up by state revenues.

Page 57: This is equivalent to a combined local sales tax rate of approximately 3.8%. How does this reconcile with Table 26?

The sales taxes received average 3.8% because they reflect several different taxes (BCCRT, SCCRT, option, etc) which are shared in different proportions with different overlapping entities.

Page 58: Any explanation for why Mineral Co. sales tax receipts are up when Lyon Co's are way down?

Explanation added.

Page 59: This overstates the case per Table 21.

Sentence changed to rectify.

Page 59: How about "these workers and their families" instead of "these people," since the prior reference was to "temporary populations"?

Language changed, but most of the workers do not bring their family members, per discussions with John Snyder and with other farmers.

Page 59: Do you have a citation for this?

The Snyders and Peri Brothers, the two largest onion growers who employ the greatest number of migrant workers, both provide housing for the migrant workers.

Page 59: Why? Please elaborate. I could imagine that a concentration of newly unemployed migrant workers and their families might need social services from local govt just when those services are already strained.

According to John Snyder, the migrant workers come specifically for the work they are hired to do and leave when the work is done. Sniders have been hiring the workers from the same community (and from the same families) in Mexico for decades, and this is the pattern.

Project I: Development of a GIS Database in Support of Water Right Acquisitions in the Walker Basin

The review comments and edits were very helpful, and we appreciate the time the USGS took to review the project report.

Major Comments summarized in USGS Memorandum:

The Landsat section needs to include path, row, and scene data. It is unclear from the report what scenes were used and how they were manipulated, with the exception of the NDVI development.

Path, row, and descriptive scene data for the eight Landsat scenes used have been added to the Landsat Thematic Mapper (TM) satellite imagery section.

Throughout the various sections of the report, the authors tend to wander and describe how the data was used. This should be limited to the data use section and/or to the individual project reports. For example, how the Decision Support Tool Project (DST) used or requested data is mentioned in several sections. As a reader, this was distracting and diverted attention away from the report objective of describing the data and the data base development.

References to how the data were used by various other projects has been minimized in each of the data description sections. Full data use descriptions have been placed in the data use section of the report.

General comments and edits as marked in the body of the report

Comments and edits marked in the report were addressed as deemed appropriate. Most of the edits were incorporated and many of the comments were addressed in the appropriate sections.