EXHIBIT 90

Walker River Basin Assessment

Prepared For

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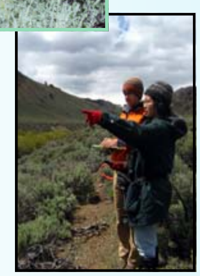


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1 INTRODUCTION AND BACKGROUND

1.1 Overview of Geographic Location and Recent History

The Walker River Basin[1] (the Basin) encompasses an area of approximately 3,938 mi^2 that includes portions of the Sierra Nevada and Basin and Range[2] physiographic regions[3] found in eastern California and western Nevada (Figure 1.1-1). The Walker River is the third-largest river in western Nevada, the Walker River's East and West Forks extend from their headwaters in the Sierra Nevada through the Sweetwater and Pine Grove Ranges, and after their confluence flow north through Smith and Mason Valleys before turning east and south into the Walker River's terminal lake, Walker Lake. The headwaters' catchments of the West and East Walker River tributaries drain the crest of the Sierra Nevada of eastern California where mountain peaks reach elevations up to 12,300 ft above mean sea level.

The climate at Bridgeport, CA is typical of high elevations on the eastern slope of the Sierra, with cold winters and precipitation mostly in the form of snow (Table 1.1-1). From the alpine headwaters regions, the tributaries each flow about 79 mi northeast into Nevada, dropping in elevation as much as 2,772 ft along the way to their confluence, and the formation of the main stem Walker River. The main stem of the Walker River travels another 71 mi, and descends another 328 ft, before flowing to its terminus at Walker Lake at an elevation of about 3,936 ft above mean sea level. Walker Lake, a desert terminal lake, is well within the western portion of the Basin and Range province in the rain shadow of the Sierra Nevada. At Hawthorne, NV, south of Walker Lake, precipitation occurs mostly as rain during erratic summer storms.

[1] Referring to the catchment area of a stream system. In this context the term shares a definition with watershed.
[2] Specifically referring to a region in western and southwestern North America typified by tectonically tilted faults blocks forming north-south trending mountain ranges separated by intervening valleys or basins.
[3] An area in which all parts are similar in geologic structure, and whose subsequent geomorphic history is unified and distinct from adjacent regions.

Figure 1.1-1. Geographic location of the Walker River Basin.

Table 1.1-1. High and low elevation precipitation and temperature measurement points. These locations represent the climatic extremes of the Basin. Locations can be found in Figure 2.1-1.

Location	Annual ppt. in inches	Avg. annual max. and min. temperature
Bridgeport	9	62° F and 24° F
Hawthorne	5	71° F and 41° F

The complex physiography of the Basin is mirrored by similarly complicated political and municipal divisions. The Nevada/California border separates the western 25% of the Basin. The 25% of the Basin in California is the headwaters region and is the source of the majority of the water supply to the Basin. However, the bulk of natural and anthropogenic consumption takes place in the remaining 75% of the Basin that lies in Nevada. In California, the Basin lies entirely within Mono County. Within Nevada, the Basin includes portions of Mineral, Douglas, Lyon, and Churchill Counties. Agriculture has been the the main source of human water use in the Basin for well over 100 years. Settlement and development of the Basin began in the mid-1800s with the first extensive development of irrigation systems occurring around 1860. The website of the State Engineer's Office contains a detailed chronology of the Walker River Basin (http://water.nv.gov/home/search_page.cfm). Some of the information found at the website is summarized here in Table 1.1-2.

Table 1.1-2. A timeline of significant events on the Walker River and associated waters (Horton, 1996).

Date	Location	Event	Purpose or Outcome
1837	Southwestern U.S	Introduction of tamarisk	This invasive species has displaced native tree species such as cottonwood and willow along the Walker River and its tributaries.
1859	Mason Valley	Ranching was established	Nathan Hockett Allen Mason started a ranching and cattle operation on over 30 square miles of the river.
1859	Virginia City	Gold discovered	It created a population increase in Northern Nevada.
1859	Walker Lake and surrounding areas	Land set aside for the Walker River Paiute Indian Reservation	Included Walker Lake and 318,809 acres of land near it.
1860	Upstream tributaries of Walker River	Irrigation	Diverted water for agriculture
1860s	Singatse Range	Copper discovered	Encouraged settlement
1861	Aurora	Gold discovered	Town of about 5,000 with stamping mills. The town collapsed by 1864 little mining continued until 1918.
1861	Nevada Territory	Fishing regulation	Made it illegal to catch fish with net, drag, basket, poison etc.

Date	Location	Event	Purpose or Outcome
1861-1865	Mason Valley	Ditch construction	
1862	Antelope Valley	Irrigation began	
1862		Homestead Act	Land rush to the West
1862	Nevada Territory	Water pollution regulation	It made it illegal to obstruct the natural flow of the stream and to dump sawdust, chips etc.into the water. Intended to protect irrigation but was also good for fish and wildlife. Did not apply to mining.
1862	Walker Lake	10 year ferry franchise	Issued to J.H. Rose to ferry people across the lake.
1864	Walker Lake and surrounding areas	Official establishment of the Walker River Paiute Indian Reservation	Included all the land originally set aside for the reservation.
1864	Walker River	Alfalfa introduced	Major forage crop on the Carson, Truckee and Walker rivers.
1864	West Walker	Franchise to W.G. Alban	Float timber
1866	Nevada	Chapter 100 of Nevada Revised Statues	Anyone constructing a ditch had to file with the county.
1870	Bodie	Mining increased	Increased freight traffic and agriculture demands.
1871	Nevada	Fish regulation	Made it illegal to fish from January 1st to September 1st with anything other than a hook and line. Also mandated the implementation of fish ladders on mill dams.
1880	East Shore of Walker Lake	Railroad construction	For the shipment of ore from the mines in Bodie.
1880s	West Walker River	Cattle ranching	Thomas Rickey set up operations which included most of Antelope Valley.
1881	Walker River	Railroad construction	Carson & Colorado lines to transport Lahontan cutthroat into Dayton for the tribe for free.
1881	Walker Lake	Lahontan fisheries	Trout caught at the north end of the lake but not found in the southern part because of high alkalinity.
1881	Singatse Range	First major copper mine	Built a smelter.
1881	Upstream from Walker Lake	High irrigation use	Extremely low water flow in the fall.
1881	Walker River	Salmon introduced	2,000 released at Schurz Station.
1882	Spragg's Dam	Lahontan fisheries	Regular use of nets to catch massive amounts of fish despite laws prohibiting it.
1885	Walker Lake	Lahontan fisheries	Lake abundant with cutthroat.
1885	Nevada	Prior appropriation	Supreme Court approved prior appropriation for water rights.
1889	Nevada	Chapter 113 of the Nevada Revised Statues	Regulation on water use and priority. Protection for irrigation interests along the major streams in Nevada.
1890	West Walker River	Construction of Colony Ditch	Diverted water for use in Smith Valley.
1892	Walker Lake	Decline of Lahontan cutthroat	Blamed on non-native fish and diversion dams which prevented spawning
1900	West Walker River	Low water	The flow of the West Walker is insufficient to meet all demands.

Date	Location	Event	Purpose or Outcome
1906	Walker River	Native water rights	The Walker River Paiute Tribe cedes 268,000 acres of reservation land to the U.S., including all the land around Walker Lake.
1920	West Walker River	Construction of Saroni Canal	Provide irrigation to Smith Valley.
1922	West Walker River	Closure of Topaz Reservoir	Storage of West Walker River flow begins in Topaz Reservoir.
1923	East Walker River	Closure of Bridgeport Reservoir	Storage of East Walker River flow and tributaries in Bridgeport Reservoir.
1924-1925	Walker River	No flow at Wabuska	Drought coupled with water use depletes the Walker River.
1928	West Walker River	Construction of West Side Canal	Provides irrigation to Mason Valley.
1958	Walker River	Federal Funds received for channel improvements	Channel of the Walker River was "cleared".
1960	Basin wide	Groundwater pumping becomes widespread	Groundwater becomes a major source of supplemental irrigation water
1988	East Walker River	Walker River Irrigation District drains Bridgeport Reservoir	Increased water temperatures and siltation downstream causes massive fish-kill. Subsequent litigation imposes minimum pool elevations and instream flows downstream of the reservoir.

The first form of legal protection of the water resources of the Basin came in a 1963 agreement between the California Department of Fish and Game, and the Walker River Irrigation District (WRID) that allowed for the enlargement of Bridgeport Reservoir under the condition that WRID would maintain a minimum pool of 1,500 acre-feet during years when conditions allowed. WRID would also have to agree to a minimum instream flow of the lesser of 50 cfs or the natural flow on the East Walker River.

During the following decade, national environmental legislation was passed that would eventually be instrumental in paving the way for more formal conservation efforts in the Basin. This legislation included the National Environmental Protection Act (1969) and the Clean Water Act (1972). The California Wild and Scenic River Act, passed in 1972 as well, would come to provide protection for some of the upper sections of the West Walker River.

The steady decline of Walker Lake's base elevation has resulted in dramatically increased levels of total dissolved solids[4] (TDS) in the lake that has severely impacted the fishery. The threat of loss of this terminal lake system and its fishery has mobilized a coordinated effort to improve the ecological integrity of the Basin. In 2006, through the legislation of the Desert Terminal Lakes Program, Public Law 109-103, Section 208 (c)(1), $10 million dollars was provided to the U.S. Fish and Wildlife Service (USFWS) to address riverine restoration and noxious weed eradication. This funding has prompted the USFWS to commence a Watershed Assessment of the Basin to prioritize restoration activities and guide funding of restoration projects.

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[4] The amount of all dissolved solids in water, primarily consisting of minerals and salts, but may also include organic matter.

1.2 Watershed Assessment Purpose and General Methodology

The purpose of this study is to provide the USFWS and all cooperating parties with a comprehensive analysis of current physical and biological processes, historic trends in alterations to these processes, and development of river restoration recommendations that are intended to preserve, enhance, restore, and sustain the Walker River ecological system, and by extension Walker Lake. Ecosystem restoration recommendations formulated in this report are general and are not intended as site-specific restoration and recovery plans. Otis Bay Ecological Services (OBEC) does, however, recommend that one of the next steps in the recovery process is to begin identifying potential restoration sites, and design site specific restoration plans. The assessments and recommendations within this report are based on current concepts from the sciences of fluvial[5] geomorphology[6] and landscape ecology. These generalized objectives, listed below, provide guidance for the assessment and presentation of the results:

1. Assess the physical environment of the Walker River to characterize the river and watershed. The assessment will describe the geology and geomorphology, the hydrology and flow pattern, and the river channel geometry and hydraulics.
    - Review the watershed geology.
    - Analyze the hydrologic record of all Walker River stream gages, including those on the East and West Forks, for those gages that have a sufficiently long record.
    - Assess the river geomorphology.
    - Model each delineated river segment using HEC-RAS to determine the channel hydraulic properties.
    - Calculate sediment transport rates for each river segment.
    - Determine trends in historic channel change using aerial photography in a GIS[7].
    - Provide a qualitative description of the potential sources and sinks of sediment in the Basin.

2. Assess the flora and fauna of the Walker River corridor to characterize vegetation community types and bird populations and to assess their condition.
    - Map all major riparian vegetation community types.
    - Determine trends in the growth or decline of riparian forests using aerial photography in a GIS.
    - Carry out bird monitoring using point count surveys and area search methods, to deduce species abundance and richness, to develop a species list for the Walker River riparian area[8], and to complete a habitat type assessment that is

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[5] General term for processes, organisms, or materials produced by, acting on or within river systems.
[6] The study of landscape forms and processes.
[7] Abbreviation for Geographic Information Systems.
[8]A region situated on or near the banks ofa river that provides an interface between stream and upland physical and biological systems.

correlated to species occurrence. Compile information on terrestrial and aquatic fauna and supplement literature sources with field studies.

3. Develop recommendations for future conservation strategies that focus on conserving and improving hydraulic conditions.
   - Build quantitative tools to guide recommendations for flows to sustain the ecological system (e.g., process, composition and structure) and dynamic physical environment (e.g., sediment transport, floodplain inundation).
   - Develop conservation-based recommendations for land use planning within the riverine corridor that will protect, enhance, restore, and sustain the Walker River riverine ecosystem in perpetuity.
   - Prioritize recommendations to first focus on protecting existing rich habitats, then on enhancing impacted habitats, and finally on restoration of degraded habitats with the recognition that opportunity and need may alter.

As stated above, the purpose of this study is to provide the USFWS and all cooperating parties with recommendations that are intended to preserve, enhance, restore, and sustain the Walker River ecological system. The recommendations are not intended to be an exact prescription for land use and management within the Walker River watershed. Rather, the recommendations are intended to facilitate future planning efforts to protect and recover valuable natural resources within the riverine cooridor.

1.3 Basic Approach to Physical Assessment and Restoration Recommendations

An updated approach to riverine restoration was used for this assessment. Rather than developing detailed designs of habitat structures, the restoration methods proposed for the Walker River focus on 1) restoring or sustaining ecological process and function, 2) connecting and/or developing landscape features, and 3) ensuring floodplain function from a watershed perspective. This approach has been used on the Truckee and Carson Rivers, and is an approved method by the United States Army Corps of Engineers (Corps) and has greater potential for long-term sustainability of the ecosystem.

1.3.1 Working Definition of Restoration

The appropriate definition of "river restoration" has been debated at great lengths in the scientific literature and academic community. Below is the working definition used in this assessment:

> Riverine ecosystem restoration entails re-establishing connectivity of landscape features on a broad spatial scale and the physical and ecological processes that sustain an ecosystem's native species at different scales, while upholding the value of the river for human use.

1.3.2 Restoration Methodology

Restoration methodology has a three prong approach: empirical, analytical, and historical. Using empirical methods, scientists determine the expected ecological integrity and native biological diversity from observation of similar systems, particularly those with little disturbance. Analytical procedures are used to quantify and simulate processes to detect if they are within expected ranges and assess impacts of proposed modifications. Historical methods entail reviewing available relevant records, including photography, journals, government records, and others to determine pre-existing conditions and the extent of change.

Analysis for restoration starts with a reconnaissance survey and the historical approach. These surveys are intended to detect the degree of channel and riparian modification and degradation[9] and the likely causes of problems related to any ecosystem decline. These surveys will help guide restoration planning by determining the predisturbance form and verifying the degree to which this form can be replicated in the restoration process (Kondolf and Downs, 1996).

The river restoration assessment initially focuses on a broad spatial scale that encompasses the entire watershed of the Walker River. The assessment then narrows its focus to the river segment scale of miles, and finally the study reach scale of hundreds of feet. Segment boundaries are separated by landscape-level geomorphic characteristics as well as local channel form and fluvial variables such as slope, bed particle size distribution, and sinuosity[10]. River reaches are manageable study areas that are accessible and representative of the overall segment. A pre-defined *(a-priori)* classification scheme was not attempted, rather each channel segment type is described as it is observed and measured in the field.

On the broad scale, geomorphic processes such as drainage basin and hydrologic characteristics are considered. On the river segment level, physical characteristics are determined from air photograph interpretation and low-elevation reconnaissance flights, detailed topographic data derived from LiDAR, and field inspections, which provide information regarding river channel pattern, major geomorphic features and landscape processes, and flora and fauna surveys. At the reach level, more detailed information is gathered describing channel geometry, hydraulics, bed material type, and sediment transport dynamics.

Finally, based on the results of the assessment, a tool set is developed to assist in targeting stream flow regimes that will suit desired restoration, and to rate geomorphic segments according to their potential for riverine ecosystem enhancement[11]. The recommendations are based on the best scientific observations possible within the scope of work and represent the minimal requirements necessary to restore and preserve the rich biological heritage of the river valley. This restoration approach focuses on preserving existing integrity, and addressing the underlying causes of riverine ecosystem decline rather than treating the symptoms. Addressing the underlying causes leads to long-term sustainable river function success.

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[9] A trend toward decreasing mean stream bed elevation usually through evacuation of sediment.

[10] A measure of stream curvature that is calculated by dividing the stream length between two points by the straight line distance between those same points.

[11] The act of attempting to improve the health and functionality of a community of organisms and the physical environment in which they interact.

2 BASELINE DATA COLLECTION

This section of the report presents the results of the bulk of the analysis of physical and ecological processes in the Basin. Each component of the assessment, that is the abiotic, and the biotic, will be presented with a complete description of methods, a summarization of the data collected and the results of the analysis of that data, and suggestions for conservation and restoration based on the findings of the baseline data collection. In total, these components comprise what is essentially the core of the Basin Assessment. All other recommendations for flow allocation, restoration prioritization, and restoration design will be based on the results of this baseline data collection. The physical assessment is presented here first, and the biological assessment is presented second. Abiotic aspects of the Basin such as hydrology and geomorphology underpin the Basin's ecology, and inform many basic aspects of restoration planning. The biological aspects of the Basin provide details on the health of the riverine ecosystem that we are trying to preserve.

2.1 Abiotic Data

2.1.1 Physical Assessment Methods

2.1.1.1 <u>IHA Analysis</u>

The method used to determine the extent of alteration to natural hydrology in the Basin is known as Indicators of Hydrologic Alteration (IHA) (Richter et al., 1996). This method uses a variety of hydrologic metrics to compare two series of historic hydrologic data. Often the two hydrologic series are for different time periods at the same location. These two time periods generally reflect "before" and "after" conditions for a particular alteration such as the installment of a dam. This use of the IHA alters the approach slightly and compares different locations for the same time period. The hydrologic record for one location is used as the reference, or unaltered, hydrology. The record at the second location is for a hydrologic condition that has been altered to some degree.

The IHA analysis completed here compares only a few of the many metrics of change that the method is capable of analyzing. Average annual hydrographs are compared in order to determine changes to the magnitude, shape and timing of rising limb, peak, and falling limb portions of the hydrograph. High and low flows are also compared. Seven day minimum flows were compared to assess alteration to extreme low flow conditions. The seven day minimum flow is the lowest discharge that persists for at least seven days. Three day maximum flows were used to assess alteration to extreme high flow conditions. The three day maximum flow is the highest discharge that persists for at least three days.

2.1.1.2 <u>Geomorphic Segment Designation</u>

In order to begin a systematic physical assessment of the Walker River, it was necessary to divide the Walker River and its two main tributaries, the East and West Walker Rivers, into segments based on a reconnaissance survey of the physical characteristics of each river. Segment divisions were made based on geomorphic and geologic characteristics of the channel, and adjacent drainage areas. Preliminary segment divisions were made by determining channel gradient, valley gradient, channel form based on consideration of platform and bedform attributes, bed material characteristics, and the characteristics of the surrounding landscape such as hill slopes, valley confinement, and potential hill slope/channel connection. A segment was designated as a continuous length of channel with similar geomorphic characteristics throughout. Divisions in segments occur at transitions between dissimilar channel types, such as areas where the river flows from an open valley into a constrained canyon. Investigation of these attributes was guided by information gathered from USGS 7.5' series topographic quadrangles, aerial photography, low elevation flights of the Basin, and field observations.

Following this preliminary designation, several methods of field investigation took place including low elevation aerial photography of geomorphic features of the stream corridor and adjacent hill slopes. The considerable length of river within the Basin, as well as large tracts of privately owned land, prohibits walking the length of each segment. Flying the Basin allowed for visual inspection of the entire river and provided a check of the validity of preliminary segment divisions. If any questions arose during topographic analysis or fly-overs, field investigation was utilized. This type of on-the-ground analysis may include determining the potential origin of landforms, relative ages of deposits, and characteristics of channel incision or aggradation[12]. The Walker River and its two main tributaries, the West and East Walker Rivers, were divided into a total of 24 geomorphic segments (Figure 2.1-1). Ten segments were established on the West Walker River, nine on the East Walker River, and five on the main Walker River.

[12] A trend toward increasing mean stream bed elevation usually through accumulation of sediment.

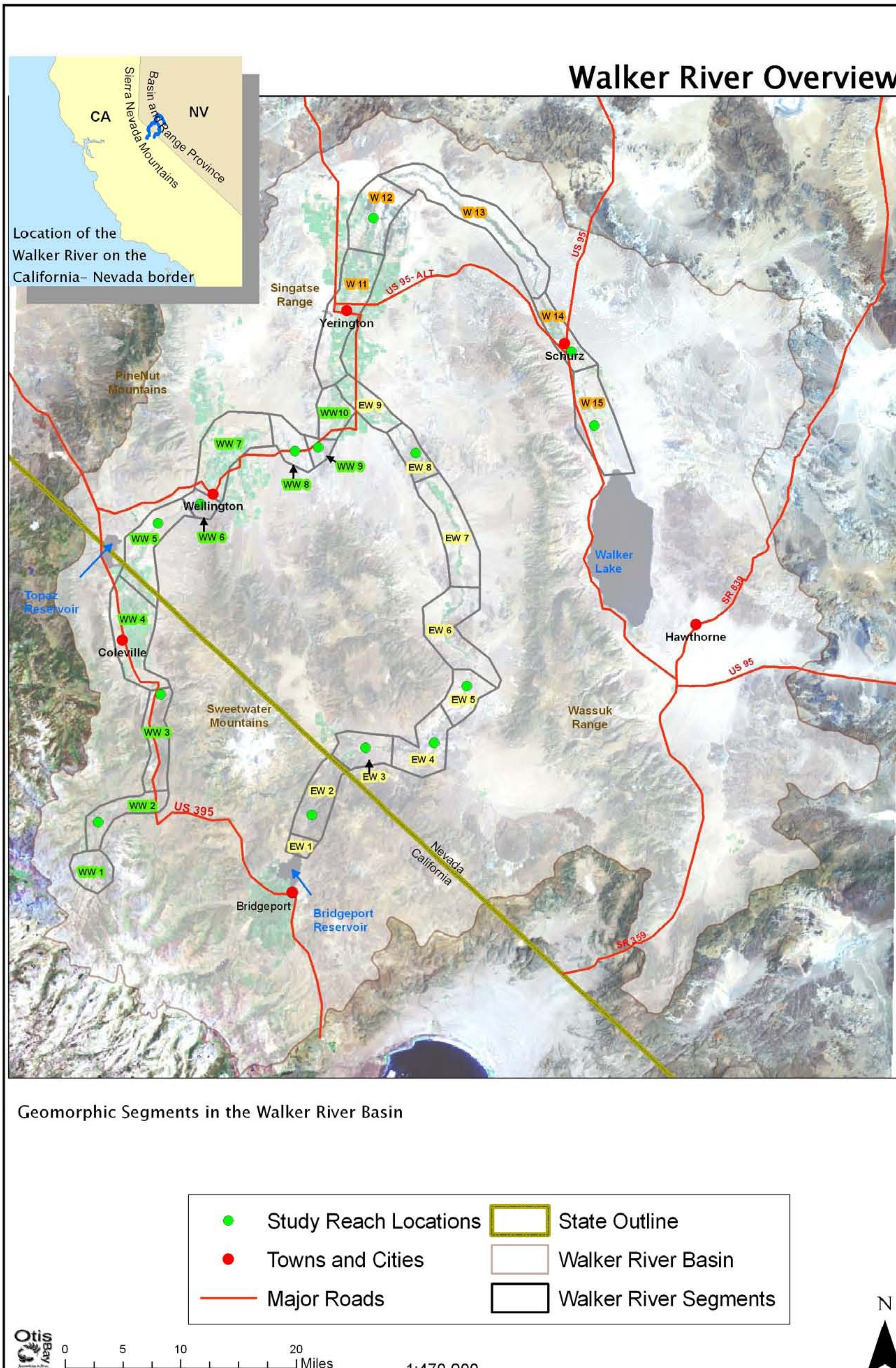

Figure 2.1-1. Map of the Walker River Basin displaying the delineated geomorphic segments throughout the Basin. Labels beginning with WW denote segments on the West Walker River. Labels beginning with EW denote segments on the East Walker River. Labels beginning with W denote segments on the main stem of the Walker River.

2.1.1.3 Historic Channel Change

Channel morphology and planform[13] are directly related to hydraulic and sedimentary factors within the contributing watershed (Knighton, 1998). Changes through time to the planform of the channel can be used to deduce changes to processes in the Basin. For example, a major flood or land use change could affect the sediment supply to a channel causing it to change its morphology and planform. Channel alteration could come in the form of widening, narrowing, or a change in course. These adjustments through time can be analyzed using historic references, maps, and aerial photography. The latter being the most quantifiable (Schumm and Lichty, 1963).

More recent studies of this type have used computer software as a tool to examine changes through time along rivers (Johnson, 1994; Merritt and Cooper, 2000). For this study, GIS and imagery software were used to first geo-reference[14] historic aerial photos and maps, and then attributes of the Walker River were carefully digitized[15] from these images.

The main data used in the historical analysis is geo-rectified aerial photos. The oldest photos are from 1938 and the newest are from 2005 and 2006[16]. Photos were also analyzed from 1994-1995[17]. These will be referred to as the 2006 and 1995 photos from here on. This was done to bracket the effects of the New Years Day flood of 1997, which was the flood of record[18] causing extensive flooding and damage in the Basin. Additional historical references were examined to learn about the river before irrigation diversions started around the turn of the century.

The active channel area and the channel center line were digitized. The active channel area was determined by creating a polygon[19] around the edge of the scoured channel where vegetation establishment is kept at a minimum because of frequent inundation (approximately every 1.0 to 1.5 years). The position of the center line was determined by digitizing a line down the approximate mid-line of the active channel polygon. At locations where the main channel split, the centerline was placed in the visually larger channel. These attributes are not always clear on the photos because of shadows, errors in geo-referencing, poor resolution, difficulty in identifying vegetation, etc. To reduce inconsistencies, one person completed all the digitizing. All the digitized layers are shown in Appendix A.

After the digitizing was complete, two other channel metrics were calculated and compared between the 1938, 1995, and the 2006 photos. The length of the channel center line was divided by the straight line length of the valley. This is referred to as sinuosity and is a measure of how much the river meanders across the floodplain. An average channel width is calculated by dividing the active channel area by the length of the channel centerline.

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[13] A dimension of stream geometry referring to an aerial, or map view of the stream.
[14] The act of defining a spatial position for a digital image.
[15] The act of creating an electronic representation of a feature found within a landscape, usually achieved in a GIS.
[16] Aerial photos were taken in 2005 in California and 2006 in Nevada.
[17] Aerial photos were taken in 1994 in California and 1995 in Nevada.
[18] The highest peak flow recorded since gaging of the flow of the river began.
[19] A polygon is a shape whose interior shares a common attribute.

Because of the limited coverage of the 1938 photos, they were compared separately from the 1995 photos to the 2006 photos (Figure 2.1-2). The geomorphic reaches had to be re-divided slightly to make sure the same section of channel is compared between photo sets. Where segments were broken up the segment is referred to as modified (mod). In the comparison from 1995 to 2006 all the geomorphic reaches are all complete.

The results show percent change for each metric. These are normalized to the metric value from 2006. For example, if channel width is listed at negative 20 percent, it means that the width was 20 percent less in 2006 than in 1938. Sinuosity and length both change at the same percent because sinuosity is the channel length divided by the valley length and the valley length does not change, so these are reported together.

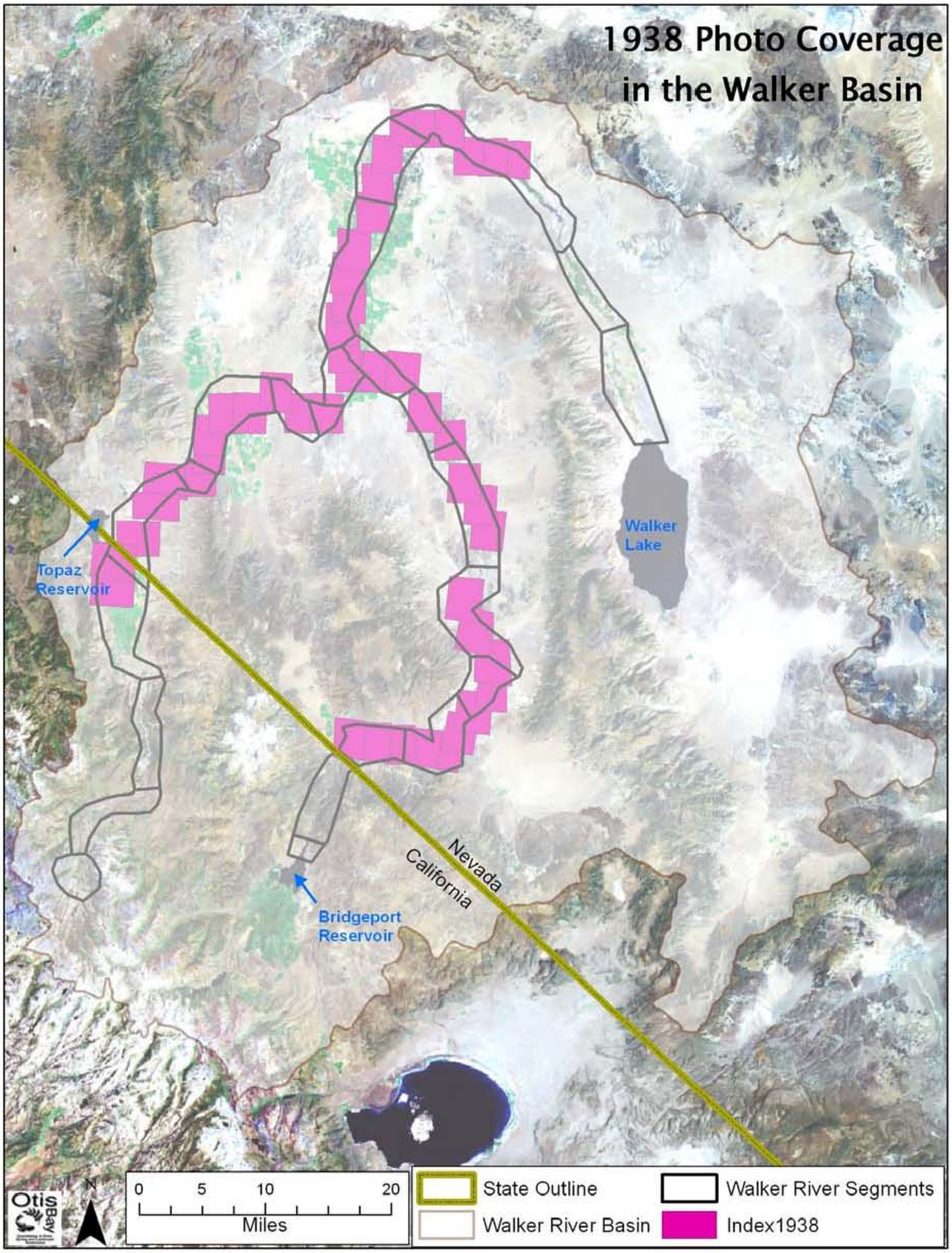


Figure 2.1-2. 1938 photo coverage in the Walker Basin.

2.1.1.4 Channel/Floodplain Connection

The importance of the physical connection of the channel and the adjacent floodplain cannot be overstated in discussing key elements to riverine ecosystem health. This connection facilitates the exchange of nutrients and materials within the overall transport system of the river. The connection is facilitated by exchange of surface water between the channel and floodplain at various stages of the annual hydrograph, and by subsurface water exchanged through the bed and banks with water in the channel. This discussion will focus on the surface connection, as a study of subsurface connection requires additional data collection that is beyond the scope of this assessment.

Many studies have been performed with the goal of determining an equilibrium frequency of inundation for an alluvial[20] channel. The conclusions of these studies are that self-formed alluvial channels in areas with similar climate and geology as the Walker River inundate their floodplain with a frequency of 1.5 to two years. This flow is referred to as the bank-full flow, or that flow that fills the channel to the height of the depositional floodplain. This suggests that a more or less frequently inundated floodplain is indicative of disequilibrium conditions. However, studies in arid regions and unique geomorphic environments show that floodplain inundation can occur at timescales outside the standard 1.5 to two year range for a self-formed channel. The appropriate question is what range of flows is responsible for maintaining channel form in a given system. This methodology holds that a two year recurrence of floodplain inundation is optimal, but does not suggest that return periods within five years are indicative of disequilibrium. Return periods of longer than five years or less than 1.5 years will be considered a less than desirable frequency indicating a potential disequilibrium relationship between the channel and floodplain.

For this section two methods are used to analyze connection of the river to its floodplain:

- Flood flows are modeled at study reaches using site survey information and hydraulic modeling software. The methods for this are explained below.
- Information about flood flow depth gathered at study reaches are then extrapolated to entire segments of the river using Light Detection and Ranging (LiDAR) topographic data.

LIDAR

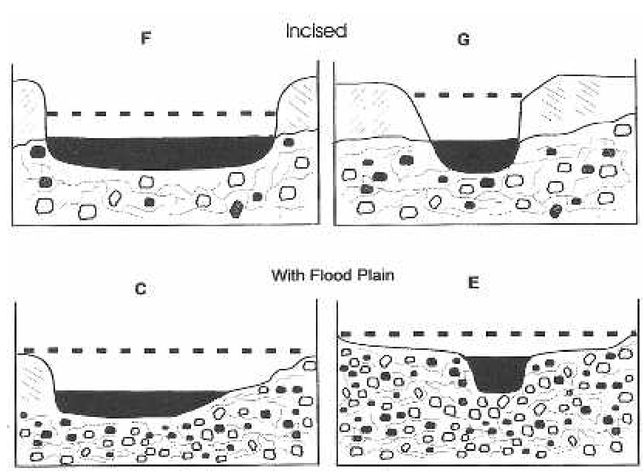
LiDAR is a method of using laser light beamed from low-flying aircraft to create very accurate topographic maps. For an overview of LiDAR methods see http://www.csc.noaa.gov/products/sccoasts/html/tutlid.htm. Root mean square errors (RMSE) are the standard statistical measure of accuracy of spatial information. The RMSE values for the Walker LiDAR are one foot in the horizontal and six inches in the vertical. This very accurate data can be used to “see” channel and floodplain topography using GIS software. The LiDAR for this project was flown in October 2006, so the LiDAR data also reflect low flow conditions in the Walker River, exposing the maximum channel area.

[20] Pertaining to stream processes and particularly depositional environments.

A GIS application developed at the University of Nevada, Reno was used as one method of determining channel/floodplain connection (Dilts, *personal communication*; Appendix B). The model essentially uses spatial statistics to map the relative elevation of land near the river to the low water surface of the river. The height above river model or HAR looks at a swath of land 1,600 ft on each side of the river, and calculates how high the land surface is above the river on a three ft (one meter) grid basis.

This model then allows one to pick an elevation above the river and map it. This mapping provides an indication of those sections of river that may be incised, or areas that may flood regularly, or be close enough to ground water to promote riparian vegetation. It is important to note that this elevation mapping can only be used as an indication of flood potential. To accurately map flooding would require the use of a flood-routing model such as HEC-RAS developed at a basin scale.

The HAR is applied to geomorphic segments that contain alluvial sections where floodplains develop. Canyon segments were excluded from this analysis because they have naturally restricted floodplains. The area that is mapped is referred to as the flood-prone area, and is defined as the area of floodplain that lies lower than twice the bank-full depth (Rosgen, 1994). The two year flood recurrence interval is being used to represent the bank-full depth as discussed above. The elevation of the two-year flood is calculated using the HEC-RAS model described below. For this analysis, the flood-prone areas were determined to be between the 25 and 100 year flood depth at the study reaches. This means that the flood-prone area mapped is a liberal estimate of what land would actually flood or be otherwise connected to the river. If the HAR mapping shows that twice the bank-full depth is still lower than the surrounding land then this can be an indicator that the channel is incised and not in contact with the floodplain (Figure 2.1-3).



-------- = Flood-Prone Width

Figure 2.1-3. Figure depicting incised channels (upper two) and channels connected to the floodplain (lower two.) Adapted from Rosgen, 1994.

2.1.1.5 Sediment Dynamics

A sediment budget approach was taken to examine processes occurring in the Walker River Basin. "A sediment budget is an accounting of the sources and depostion of sediment as it travels from the point of its origin to its eventual exit from a drainage basin" (Reid and Dunne, 1996). For this analysis, field observations, and erosion modeling are combined with results from the segment geomorphology, historical analysis, and channel/floodplain sections to qualitatively describe the sediment budget of the Walker.

The erosion model used is the Watershed Erosion and Prediction Project (WEPP). The WEPP is a process-based erosion model where local soil, landscape characteristics topography and weather inputs are used to simulate long-term erosion rates. The version used is a web based interface developed by the Agricultural Research Service and can be found here: http://milford.nserl.purdue.edu/wepp/weppV1.html. The results of WEPP modeling are presented in Appendix C.

The next step in developing a sediment budget for the Basin is to move beyond the qualitative and conceptual approach outlined above and attempt to quantify rates and magnitudes of sediment transport in the channels of the West, East, and Walker Rivers. Several approaches are being taken in order to apply empirical and numerical methods to that end. Initially, the SAMWin sediment transport model was used to estimate rates and annual amounts of bedload transport. Appendix D contains the results of this transport. The conclusions that can be drawn from the SAMWin modeling are largely inconclusive, and in some cases contradictory to other geomorphic evidence and hydraulic concepts. An empirical study is now being carried out in order to gather measurements of sediment mass flux at five locations in the Basin. This data will be used to construct sediment rating curves and annual load curves, as well as to calibrate the most current version of HEC-RAS and ultimately develop a numerical tool for modeling sediment transport under various design conditions. This work is ongoing and preliminary reports are forthcoming.

2.1.1.6 Study Reach Selection

Detailed physical analysis of processes operating at the channel scale could not be completed over the entire length of geomorphic segments due to logistical limitations. Shorter sections of river channel were established that could be used to collect a meaningful, but manageable amount of data. These shorter sections are termed study reaches. Though significant heterogeneity exists in channel form throughout any given segment of river, the information gathered in study reaches is used to represent the larger segment.

In selecting any particular study site location, the channel form and dominant geomorphic processes found within the larger segment were considered, and a physically representative reach was chosen. Study reaches typically span the length of a riffle pool sequence, from riffle crest to riffle crest (Figure 2.1-4). Measurements made in these reaches are at a high resolution, providing detailed information on channel morphology and hydraulics at what are essentially point locations in the Basin. Appendix E presents photographs and detailed descriptions of each study reach.

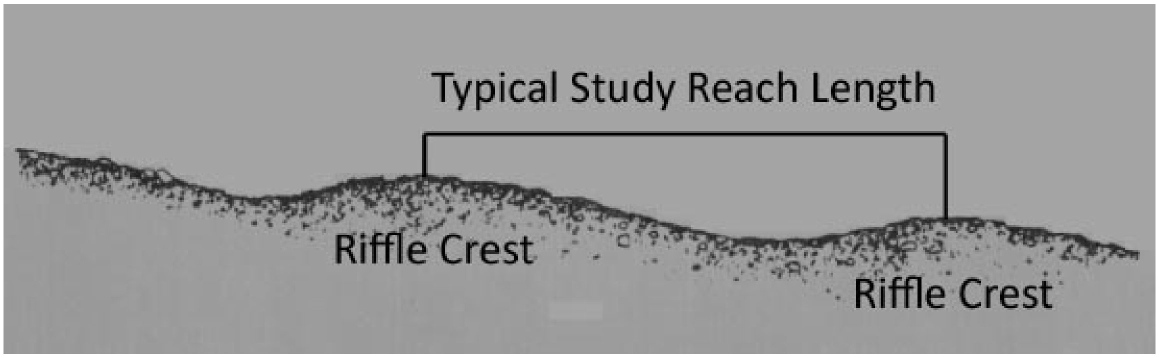


Figure 2.1-4. Longitudinal schematic of a streambed illustrating typical riffle pool morphology that was used to delineate study reaches. Adapted from www.fhwa.dot.gov/environment/fish2.htm**.**

2.1.1.7 Channel Cross-Section[21] Surveys

OBEC worked with Bureau of Reclamation (BOR) survey crews in order to survey channel cross-sections in each accessible study reach (Appendix F). A channel cross-section is composed of a series of survey points that, in planview, describe a straight line perpendicular to the average flow direction of the river. Cross-sections extended laterally to a practical distance in order to encompass the bankfull channel and some portion of the active floodplain. The points are placed at significant breaks in the slope of ground surface. When viewed looking downstream, the points describe topography at scales ranging from one to several feet in vertical relief. The BOR used a survey-grade GPS to obtain cross-section points. This method provides sub-centimeter accuracy on real-world geographic coordinates.

The primary purpose of measuring cross-sections was to provide input for subsequent 1-dimensional hydraulic modeling. Modeling results provide information regarding characteristics of cross-section form such as: area, hydraulic radius, width, mean depth, and the width-to-depth ratio, as well as information about the frequency of floodplain inundation. Therefore, cross-sections were established such that robust modeling environments could be built. Up and downstream bounding cross-sections were placed near riffle crests. These features act as hydraulic controls on water surface elevations and energy gradients in the reach. Thus, they provide adequate boundary conditions for numerical models. Within these boundaries, cross-sections were placed approximately every channel width, providing at total of 4 to 6 measured cross-sections per reach.

Surveys were completed in each accessible study reach. Five to six cross-sections were surveyed in each reach depending on reach length. Cross-sections span the width of the wetted channel, and any geomorphic surfaces up to the highest floodplain or terrace elevation. One cross-section had to be discarded in both WW2 and EW5 due to unresolved errors in the original survey. However, cross-sections located at the downstream hydraulic control were maintained in both

[21] A dimension of stream geometry that defines a cross-stream view perpendicular to the mean direction of flow.

instances, and the accuracy of the hydraulic model is not expected to be diminished. At least two benchmarks were installed by BOR surveyors using a survey grade GPS system at each location in order to re-occupy the survey if desired. However, surveys at W14 and W15 were completed after work with BOR surveyors had ended. Thus coordinates on benchmarks and survey points at these sites are in an arbitrary grid. For figures on these cross-section surveys, points were visually adjusted. This was accomplished by editing the points in GIS, and rotating the entire point set around a common point (usually a bench mark) as accurately as possible. The error on the horizontal distance between the rotated points, and the real-world location of the point could be 10's of feet. However, the lack of real-world coordinates at these locations does not affect modeling, or the ability to re-occupy the survey.

2.1.1.8 Hydraulic Modeling

The Army Corps of Engineers' Hydraulic Engineering Center River Analysis System (HEC-RAS v 3.1.3) was used to estimate the hydraulics of each surveyed study reach. Using measured cross-sections and gage records for geometric and steady flow inputs, respectively, hydraulic conditions were modeled for a variety of flow conditions ranging from low flow through the largest recorded instantaneous discharge. Initially, models were calibrated to a field-measured low flow discharge. Boundary conditions including channel roughness and energy slope were slightly modified until a satisfactory agreement was achieved between modeled and measured water surface elevations. Following calibration, flows were modeled at discharges estimated to recur at 1.5, 5, 10, 25, 50 and 100 year intervals. The analysis estimated the approximate recurrence of overbank flow, or the smallest discharge that begins to inundate the floodplain. A separate series of flows was modeled to extract hydraulic variables as input to subsequent sediment transport models. Flows input into the model included the entire range of recorded discharges. Appendix F presents detailed results of hydraulic modeling.

HEC-RAS INPUTS

Cross-Section Geometry

Raw data collected from field surveys was processed by converting the original three-dimensional coordinates for each point into two-dimensional coordinates described by a distance and elevation. The first point on the left of each cross-section (looking downstream) was taken to be the zero distance point. Distances along a cross-section were relative to this endpoint. The downstream distance in between cross-sections was also required. Distances were calculated for the channel centerline, and left and right overbank points. Hydraulic roughness values were assigned to each cross-section individually. A program function was used, which varies values of Manning's roughness horizontally.

Steady-Flow Data

Modeling steady flow water surface elevations and hydraulics also requires the input of discharge data and boundary conditions. Discrete volumetric discharge values were input, and hydraulics were computed for each separately. Discharge values that ranged from extreme low to extreme high flows were included. Several choices of boundary conditions were possible. Normal depth boundary conditions were used. This required an energy slope value, which was substituted with the average water surface slope. For any of the estimated water surface profiles, observed water surface elevations can be specified. When activated, these provide a visual check on the accuracy of the model calibration.

Model Calibration

By varying hydraulic roughness values and boundary conditions, water surface profiles can be adjusted to match observed water surface elevations. At the time of this modeling effort, only low flow water surface elevations were measured. The elevation of the low water surface provides a relatively poor water surface calibration due to the increased effect of bed roughness elements. When the depth of the stream is roughly the same as the average bed sediment diameter, then the bed material exerts a greater effect on flow resistance than it would at higher flows. The roughness values used to calibrate the low flow water surface may not be consistent with conditions during geomorphically effective discharges[22]. Therefore, conservative adjustments of hydraulic parameters were made. Attempts to match observed water surfaces without unrealistically altering channel roughness and boundary conditions were made.

HEC-RAS OUTPUTS

Water surface elevations and hydraulics for several flow conditions were estimated. One series of water surface profiles was run for flood discharges estimated to recur at 1, 1.1, 1.25, 1.5, 2, 2.3, 5, 10, 25, 50, and 100 year intervals (Appendix G). Outputs of this model run were utilized in analyzing potential recurrence of floodplain inundation, and hydraulic geometry. In analyzing inundation recurrence, consideration was given to a water surface elevation that just overtopped the highest bank forming a laterally extensive depositional floodplain. Classical fluvial geomorphic literature suggests that alluvial channel geometry is adjusted to a geomorphically effective discharge that correlates well with bankfull discharge which has been found to occur about every 1.5 to 2 years (Leopold et al., 1964; Wolman and Leopold, 1957). These relationships have been debated in more recent literature that suggest a wider range of recurrence intervals for bankfull discharge, and more disparate correlations between the recurrence of bankfull and effective discharge in any given reach (Gomez et al., 2007; Petit and Pauquet, 1997). Results of such analysis often depend on the unique characteristics of the timing and magnitude of water and sediment supply to a given river. This analysis uses the conclusions presented in the classic studies that suggest that the optimal timing of bankfull discharge, and thus floodplain inundation, in an alluvial channel occurs about every 1.5 to 2 years. By using the classic effective discharge model, the results can be compared against a larger and more established body of literature.

A second set of hydraulic estimates were made in order to generate input to sediment transport models. Calibrated boundary conditions and channel geometry was maintained, but steady flow inputs were changed. Hydraulic conditions and water surface profiles were estimated for 10 discharges distributed over the flow duration series derived from a gage that was most appropriate to a given reach. Estimated hydraulic variables used as input for sediment transport modeling include velocity (v), mean channel depth (D), mean channel width (W), and water surface slope at the estimated bankfull discharge (Slope Q_{bf}).

[22] The discharge that, over time, is responsible for transporting the majority of the annual sediment load through a given reach.

2.1.1.9 Grain Size Analysis

Grain size analysis refers to the characterization and classification of the stream bed sediments. This analysis is based on a classification scheme known as the Udden-Wentworth Scale (Figure 2.1-5). This scale divides size classes by both millimeters, which are the units presented here, and by phi units. Phi units are expressed as the $-\log_2$ of the grain size in mm. For instance a 2mm grain is reported as -1phi. All mention of size classes and their divisions will be referring to Figure 2.1-5.

Two basic techniques were employed in order to characterize stream bed grain size in each reach. In coarse bedded reaches, the pebble count method of Wolman (1954) was implemented. This is a "random walk" in which the observer predetermines the path (for example longitudinal along the centerline, or diagonally from bank to bank) and the step length (for example a full stride or heel-to-toe) in order to obtain at least 100 measurements in a reach. Once the walk has begun, the observer takes a step, bends over without looking at the streambed, and collects the first pebble that is felt at the toe of his boot. The intermediate axis of this pebble is then measured. An Albert Scientific Field Sieve-Gravelometer was used in order to measure gravel and cobble size material in the field (4mm and larger). In predominantly coarse reaches, bed material smaller than 4 mm in diameter was not differentiated into various size classes, but categorized as material smaller than 4mm.

In reaches with predominantly fine bed material, samples were collected and dry-sieved in a laboratory. Field samples were collected by taking a scoop of material from the channel centerline at each cross-section. All the scooped material from a reach was combined in a single large zip-lock bag. The field samples were air dried and split down to an appropriate size for analysis that depended on the grain size distribution of the sample. Each split sample was weighed before sieving. All samples were sieved with stainless steel square mesh sieves at a 0.5 phi interval, where phi = -log2(D) and D = the particle diameter in mm. Samples with particles coarser than 8 mm were passed through a set of rocker sieves, shaken by hand and visually inspected to ensure that all particles passed through the appropriate sieve. All grains that passed through the 11.3 mm rocker sieve were then passed through a stack of round sieves that was shaken for a minimum of 15 minutes on a Tyler Rotap sieve shaker. The fraction of the sample on each sieve was weighed to 0.01 g with an electronic balance. To ensure no sample was lost in processing, the split sample weight was compared with the summed weight of all size fractions. The average processing loss was 0.14% and the maximum was 0.33%. These constitute acceptable sampling losses.

Once bed material was sieved, and size fractions were split and weighed, a grain size distribution was constructed for each reach (Appendix H). This distribution is a curve that describes the bed material in terms of the percent of the bed finer than a given size fraction. These curves are used to determine the size of the median material, 16^{th} percentile of material, 65^{th} percentile, and so on. Grain size analysis characterizes the distribution of sediment sizes on the bed of the river. The data gathered is used as a fundamental geomorphic characteristic, and as input to sediment transport models.

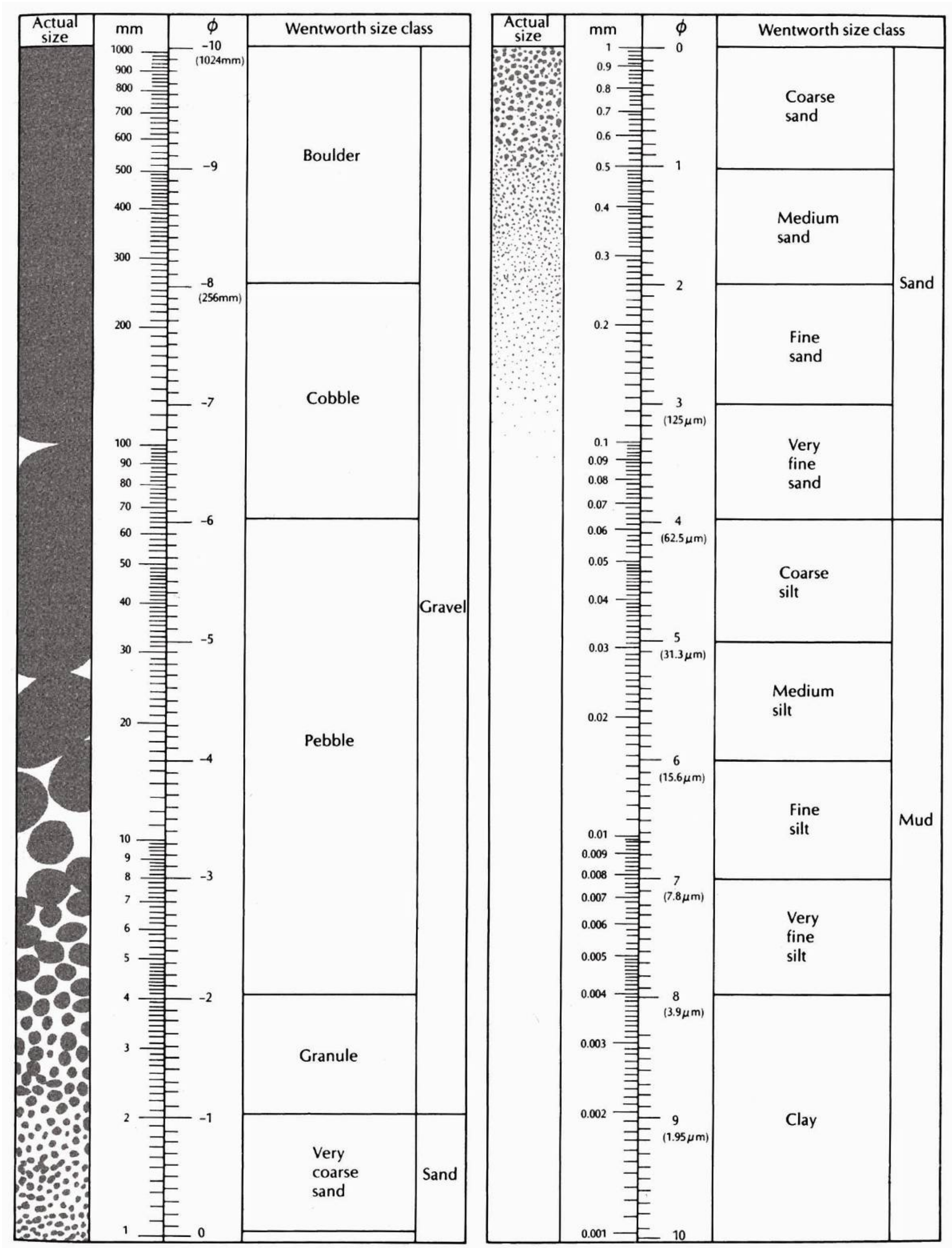


Figure 2.1-5. The Udden-Wentworth Scale as presented in Sedimentary Geology (Prothero and Schwab, 1996).

2.1.2 *Geologic Characteristics*

2.1.2.1 Recent Regional Geologic History

Table 2.1-1 succinctly presents the history of geologic events in what is now the state of Nevada. This broad regional history provides an overview of the processes, which are directly linked to plate tectonics[23] along the western edge of the North American Plate that have resulted in the current geology of the Basin. The geomorphology of Walker River is ultimately controlled by the structure of the Sierra and Basin and Range Provinces, and the rock types found in the Basin. Geology directly or indirectly controls climate and precipitation patterns, weathering, erosion, hillslope processes, soil formation, vegetation distribution, and a host of other physical variables. The geologic history described here will focus on relatively recent events, driven by climate change, that have caused landscape disturbances that the Walker River is actively responding to in terms of geomorphic form and process.

During recent geologic times (~1.5 Ma to present), climate change has significantly altered the landscape in the Walker River Basin. Between 3 and 6 glacial events took place during the Pleistocene (1.5 Ma[24] to 15 Ka[25]) (Bischoff, 2001; James et al., 2002). The majority of the glacial deposits in the Basin can be found in the headwater regions of the Sierra Nevada, and result from more recent glaciations which occurred between 79 to 15 Ka (Dohrenwend, 1982). From youngest to oldest, these events are known as the Tioga, Tenaya, and Tahoe glaciations.

Pleistocene climate dynamics affected water levels in Walker Lake driving lake elevations to fluctuate over a wide range (Meyers and Benson, 1987). During relatively wet climatic periods, there is evidence of high stand elevations of 4,085 to 4,117 ft in elevation (Adams, 2007). These high lake elevations may have facilitated the connection of Walker Lake to the spatially extensive paleo-Lake Lahontan basin. During drier periods lake levels may have dropped to the point of desiccation. Geomorphic evidence suggests that the desiccation of Walker Lake may have been due to diversion of the Walker River into the Carson Sink at Adrian Valley on the west side of Mason Valley (Figure 2.1-6). The combined effects of fluctuations in runoff, inter-basin connections, and lake level resulted in the deposition of multiple lacustrine[26] sequences and fluvial deltaic complexes during the late Pleistocene and Holocene. These deposits have been exposed at locations in the Basin including the Smith Valley and along the lower Walker River during the current period of lake elevation recession.

[23] A geological theory that holds that the Earth's outer crust is broken into plates that move relative to one another.
[24] An abbreviation for the term Mega-anum, which refers to a period of 1 million years, ie 5 Ma is 5,000,000 years.
[25] An abbreviation for the term Kilo-anum, which refers to a period of 1 thousand years, ie 500 Ka is 500,000 years.
[26] Pertaining to lake or wetland processes and particularly depositional environments.

Table 2.1-1. Brief presentation of geologic events in Nevada taken from Price, 2004.

Million years before present		
	CENOZOIC	
	Quaternary	Modern earthquakes, mountain building, volcanism, and geothermal activity are expressions of Basin and Range extension that began in the Tertiary Period. The crust is being pulled apart in Nevada, causing valleys to drop relative to mountains. Prior to 10,000 years ago, ice ages caused glaciers to form in the higher mountains and large lakes to develop, in places connecting today's valleys.
1.6		
	Tertiary	Basin and Range extension began about 30 to 40 million years ago. Igneous activity during the Tertiary Period was caused not only by extension but also by subduction (descent of oceanic crust into the Earth's mantle) of oceanic plates beneath the North American Plate and, in northern Nevada, by motion of the crust over the Yellowstone hot spot in the mantle. Numerous Nevada ore deposits, including most major gold and silver deposits and the copper ores near Battle Mountain, formed during this time. Gypsum deposits formed from evaporating lakes in southern Nevada.
65		
	MESOZOIC	
	Cretaceous	The Cretaceous Period and Mesozoic Era ended abruptly with the extinction of dinosaurs and many marine species; chemical, mineralogical, and other geological evidence suggests that these extinctions were caused by a large meteorite striking the Earth. Numerous granitic igneous intrusions, scattered throughout Nevada, originated from subduction along the west coast of North America. Much of the granite in the Sierra Nevada formed at this time. The igneous activity caused many metallic mineral deposits to form, including the copper-gold-silver-lead-zinc ores at Ruth, near Ely in White Pine County, copper-molybdenum ores north of Tonopah in Nye County, and tungsten ores in several mining districts. In southern and eastern Nevada, sheets of rocks were folded and thrust from the west to the east during the Sevier Orogeny (mountain building), which began in Middle Jurassic time and ended at or beyond the end of the Cretaceous Period.
144		
	Jurassic	A subduction zone to the west caused igneous intrusions, volcanism, and associated ore deposits, including copper deposits near Yerington. Sandstones, including those in the Valley of Fire, were deposited in southeastern Nevada, and sedimentary gypsum deposits formed in northwestern Nevada.
208		
	Triassic	The general geography of Nevada during the Triassic Period was similar to that during the Jurassic Period—igneous activity in the west and deposition of sedimentary rocks in continental to shallow marine environments to the east. Explosive volcanism produced thick ash-flow tuffs in west-central Nevada. Economically important limestone, gypsum, and silica-sand deposits formed in southern Nevada. The Sonoma Orogeny, which began during Late Permian time and ended in Early Triassic time, moved rocks from the west to the east along the Golconda Thrust in central Nevada. The large marine reptiles at Berlin-Ichthyosaur State Park lived during the Triassic Period.
251		
	PALEOZOIC	
	Permian	Volcanism to the west and deposition of thick limestones to the east were characteristics of much of the Paleozoic Era in the Great Basin. Some marine gypsum deposits formed in southern Nevada.
290		
	Pennsylvanian	The Antler highland, formed earlier, was eroded and shed sediments into the basins to the east. Carbonate rocks were deposited in eastern and southern Nevada.
320		
	Mississippian	During the Antler Orogeny, from Late Devonian to Early Mississippian time, rocks were folded and thrust from the west to the east. The Roberts Mountains Thrust, below which many of the gold deposits in north-central Nevada occur, formed at this time. Conglomerate, sandstone, siltstone, and shale were deposited in the thick basin of sediments derived from the Antler highland, and carbonate rocks were deposited further east.
360		
	Devonian	Limestone was deposited in eastern Nevada, and shale, chert, and economically important barite were deposited in northeastern and central parts of the state. No record of middle to lower Paleozoic rocks exists in the western part of the state. The quiet, shallow-marine tectonic setting that persisted earlier in the Paleozoic Era began to change, as small land masses from the Pacific Ocean collided with western North America.
418		
	Silurian	Carbonate rocks (dolomite and limestone) in the eastern part of the state and silica-rich rocks (shale, sandstone, and chert) in the central part of the state record similar deposition to that during the rest of the middle to early Paleozoic Era.
438		
	Ordovician	Marine deposition during the Ordovician Period was similar to that during the rest of the early Paleozoic Era, with the exception of basalts (metamorphosed to greenstones) locally interbedded with sedimentary rocks found today in the central part of the state. Some sedimentary barite deposits and copper-zinc-silver ores formed in sea-floor sediments during this time.
490		
	Cambrian	Middle and Upper Cambrian deposition resembled that during much of the Paleozoic Era, with carbonate rocks to the east and shale plus sandstone to the west. Lower Cambrian and uppermost Precambrian rocks are characterized by quartzite and metamorphosed siltstone throughout much of Nevada.
543		
	PRECAMBRIAN	
		The oldest rocks in Nevada (at least 2,500 million years old in the East Humboldt Range in northeastern Nevada and at least 1,700 million years old in southern Nevada) are metamorphic rocks (including gneiss, schist, marble, and metamorphosed granite, pyroxenite, hornblendite, and pegmatite). Precambrian rocks also include granites (about 1,450 million years old) and younger sedimentary rocks. Beginning approximately 750 million years ago, Antarctica and Australia may have rifted away from western North America, setting the stage for the development of a western continental margin that is similar to the Atlantic coast of today. A shallow marine, tectonically quiet setting persisted in eastern Nevada for the next 700 million years.

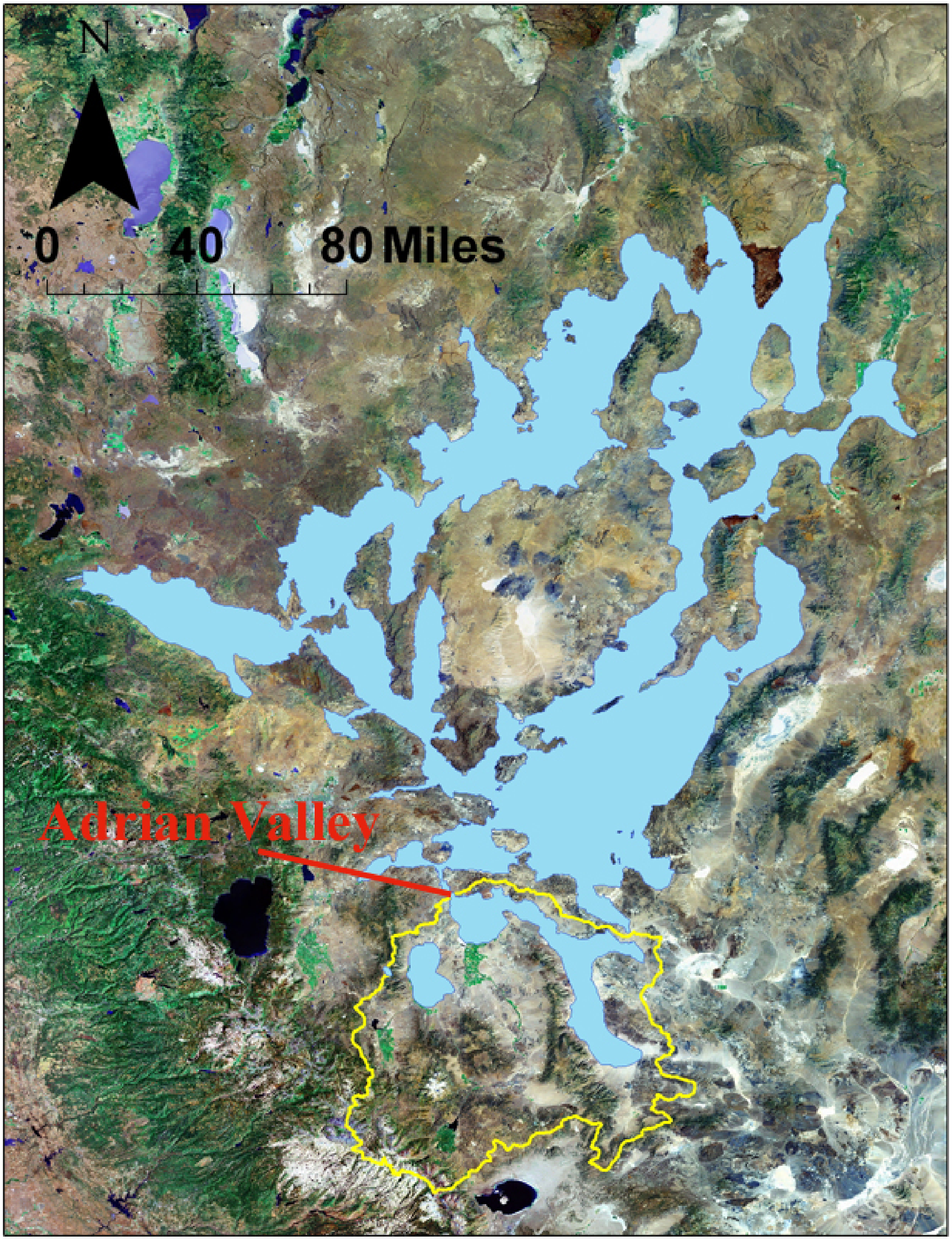


Figure 2.1-6. Geographical extent of the high-stand of the Lake Lahontan system. The Walker River Basin is outlined in yellow. The point of connection of Walker Lake to Lake Lahontan, as well as the potential point of diversion of the Walker River into the Carson Basin at Adrian Valley is noted. (Adapted from the Keck Library website of the University of Nevada Reno, ftp://nas.library.unr.edu/keck/31301GBGEOS/gbgeoscience/pluvialutm.zip)

2.1.2.2 Geology of the Walker River Basin

Note that descriptions of bed rock types and their distribution in the Basin in all sections are derived from four common sources (Halsey, 1953; Smith 1930; Ludington et al., 2005; Raines et al., 2003). Figure 2.1-7 provides a map of the rock types and their distributions in the Basin.

THE WEST WALKER RIVER

The headwaters of the West Walker River are found within the Sierra Nevada of eastern California. Rock types in this region are mainly Mesozoic granites[27] common to the Sierra Nevada. Moving down the flanks of the Sierra, bedrock types begin to include Tertiary extrusive[28] volcanics mainly composed of basalts[29]. Surficial deposits include Quaternary glacial deposits consisting of moraines[30] and outwash material (Dohrenwend, 1982). East dipping normal faults[31] of the West Walker River fault zone offset Tioga age (13-20 ka) glacial moraines in this region (Sawyer, 1995).

The physical boundary of the Sierra Nevada and the Basin and Range physiographic regions is somewhat indistinct in this area. Antelope Valley is a relatively lowered structural block (graben[32]) bordered by east dipping normal faults of the Antelope Valley Fault Zone to the east and west. This is typical of the Basin and Range, but geologic studies have placed this area in the Sierra Nevada physiographic region (Sawyer et al., 1998). Rocks to the west of the valley are composed of Mesozoic granites, Cretaceous marine sediments, and Tertiary volcanics. Hills flanking the valley to east include west-tilted structural blocks on the western edge of the Basin and Range, with outcrops of Tertiary basalts, and Cretaceous marine sandstones[33], shale[34], and terrestrial conglomerates[35].

Exiting Antelope Valley, the river flows northeast and bisects the Pine Nut Mountains through Hoye Canyon. Within Hoye Canyon, the West Walker flows through Middle to Late Miocene andesite and andesite breccias[36]. In Smith Valley, the river flows across the central portion of the Smith Valley Fault Zone (Adams and Sawyer, 1999a). This is a fairly continuous group of

[27] A general term for rock types that are crystalline, quartz bearing plutons, and encompasses rock types such as granodiorite.
[28] Referring to rocks that were formed at or near the Earth's surface volcanically.
[29] A general term for dark colored igneous rocks that are commonly extrusive, and encompassing rocks such as andesite.
[30] A feature of glacial landscapes composed of material pushed to the side (lateral moraine) or front (end moraine) of a glacial ice mass.
[31] A break in the Earth's crust that accommodates tectonic movement, found in various forms including normal, thrust, and strike-slip.
[32] A relatively depressed block of the Earth's crust that is bound be faults along its long edges, topographically expressed as a valley bound by mountain ranges along fault lines.
[33] A sedimentary rock type formed by the deposition and lithification of sand in various depositional environments.
[34] A sedimentary rock type formed by the deposition and lithification of fine grain material such as silt or clay.
[35] A sedimentary rock composed of large (> 2mm) rounded rock fragments set in a fine grain matrix such as sand or silt and commonly cemented by calcium carbonate, hardened clay, or iron oxide.
[36] A sedimentary rock composed of large (> 2mm) angular rock fragments set in a fine grain matrix such as sand or silt and commonly cemented by calcium carbonate, hardened clay, or iron oxide.

normal faults that dip from the southwest to the northeast. The Smith Valley is likely a west-tilted graben controlled by these faults.

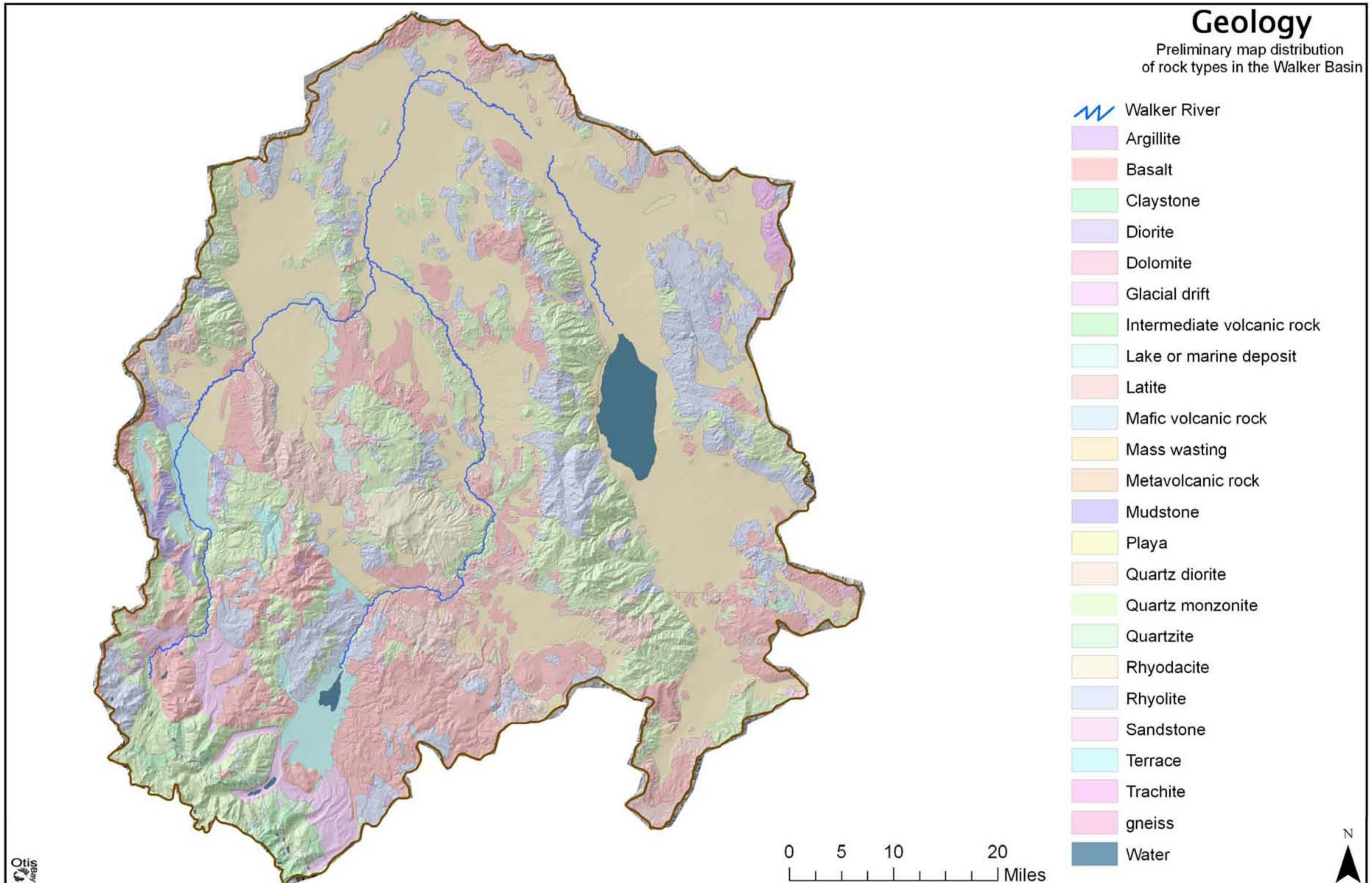


Figure 2.1-7. Map of rock types and distribution in the Basin. The map is produced by merging two maps produced for California and for Nevada. In some cases, mapping along the state border has resulted in abrupt changes in interpretation of rock type. This abrupt change is probably not a physical reality, but simply a product of different interpretations. The original classifications were used in this map.

The river continues on its northeasterly course making a short crossing of Smith Valley and bisecting the Singatse Range through Wilson Canyon. Within Wilson Canyon, several units are present including Jurassic and Miocene age igneous rocks, and late Eocene to Miocene sedimentary rocks composed of tuffaceous material. Upon exiting Wilson Canyon the river flows across the Singatse Range Front Fault (Adams and Sawyer, 1999b). This east-dipping normal fault has uplifted the range, exposing the previously described bedrock.

EAST WALKER RIVER

Like the West Walker, the headwaters of the East Walker River are in the Sierra Nevada. Rock types and quaternary glacial deposits in this area above Bridgeport Reservoir are similar to the Mesozoic granites and extrusive volcanics, Tertiary basalts, and moraines deposited by glaciations throughout the Pleistocene. Downstream of the Bridgeport Reservoir, the dominant rock type becomes Tertiary rhyolite and basalt, as well as Tertiary pyroclastic and volcanic mudflow deposits associated with this volcanism. The structural geology in this area includes a group of discontinuous and widely distributed normal faults to the east of the Sweetwater Range and north of the Bodie Hills (Adams, 1998).

Just north of the California/Nevada border, bedrock types include Tertiary age limestones and andesites. Downstream of this, the East Walker enters a series of canyons cut into the east flank of the Sweetwater Range. This mountain range is a large, west-tilted structural block of the Basin and Range physiographic region. The bedrock exposed in these canyons includes late to middle Miocene age andesite and andesite breccias, and Mesozoic granite.

The river exits the canyon at the south end of Pine Grove Flat. Pine Grove Flat is an elevated valley to the west of the Cambridge Hills. A series of widely distributed east-dipping normal faults exert geologic structural control on this area (Adams and Sawyer, 1998a). Turning to the east, the river incises at the south end of the Cambridge Hills. The main rock types of the Cambridge Hills are Jurassic granites and Tertiary basalts, though at the point of incision, Cretaceous age granodiorite is also exposed. Exiting this narrow point of incision through the Cambridge Hills, the river flows into a relatively wide valley. The valley is a graben, with east-dipping normal faults of the Cambridge Hills fault zone representing the structural control in the common extensional style of the Basin and Range physiographic region (Adams and Sawyer, 1998b). The faults have caused a west-tilting of the valley floor, causing the river to flow close to the base of steep hillslopes on the west side of the valley, while large alluvial fan complexes have been generated from the east. This is a common feature of the graben valleys in the Basin. The Wassuk Range rises to the east of the valley, providing the source for the eroded material forming the alluvial fans. The river flows north through the valley, and eventually exits through a short canyon that incises the north end of the Cambridge Hills. After exiting this canyon, the East Walker River flows into the Mason Valley toward its confluence with the West Walker River.

WALKER RIVER

The confluence of the East and West Walker Rivers occurs at the south end of the Mason Valley on the west side near the foot of the Singatse Range. As previously described, Jurassic granites and Tertiary sedimentary rocks are exposed in the Wilson Canyon area of the Singatse Range.

An increasing abundance of early Oligocene to early Miocene age rhyolite occurs toward the north end of the range. This range rises sharply from the valley floor along the trace of the Singatse Range front fault. This is an east-dipping normal fault that has caused relative down-drop of the valley floor, as well as a west-tilting of the valley. As a result, the river runs along the western edge of the valley for much of its length. A series of sloughs, wetlands, and abandoned channels in the northeast portion of the valley may be evidence of the westward migration of the river down the cross-valley gradient created by movement along the range front fault. This is a documented fluvial response to tilting of grabens in the Basin and Range (Peakall, 1998).

Low hills rise along the east side of Mason Valley. These are composed of Jurassic granite and early Oligocene to early Miocene rhyolite. A series of distributed normal faults, which dip to the southwest, create small ranges separated by northwest trending drainages. Eventually, these rise to the Wassuk Range. The Walker River exits the Mason Valley by turning sharply to the east, incising through the northern end of the Wassuk Range, then continuing to turn and eventually running south along the front of the range. This is another example of tectonic influence on channel position and dynamics. The Wassuk Range front fault is an east-dipping normal fault that has uplifted the range and relatively dropped the Walker Lake Basin. Westward tilting of the Basin has also occurred. As the level of the lake has dropped over the last century, the lengthening Walker River channel has migrated westward toward the fault escarpment (Blair and McPherson, 1994). The range itself is a large west-tilted structural block of the Basin and Range. The range is composed mainly of granite that varies in age from mid-Mesozoic to Cenozoic, with some Tertiary limestones, rhyolite, and andesite.

Several ranges of small hills and mountains rise to the east of the Basin. These include the Desert Mountains at the northwest end, and the Agai Pah Hills and Gillis Range at the southeast end. The rock types located in these areas are much the same as those found in the Wassuk Range. However, granite becomes a relatively minor constituent, while Tertiary rhyolite and andesite become the dominant rock types.

2.1.3 Hydrology of the Walker River Basin

2.1.3.1 Analyses of Walker River Hydrologic Records

Streamflow in natural channels varies widely depending on a number of characteristics both intrinsic to the Basin (geology, elevation, aspect, basin shape, etc.) and extrinsic (weather and climate). In order to understand the physical and biological processes that occur in any riverine ecosystem one must first understand the variability of streamflow conditions that act as the foundation for that system. The following hydrologic analyses were completed in order to characterize the streamflow of the Basin, and to present that data in a consistent and meaningful form that can help to guide future management activities for the river.

The United States Geological Survey (USGS) currently maintains gages along both the East and West Forks of the Walker River in California and Nevada, as well as gages on several smaller streams within the Basin. Several of these gages have been in operation for many years. Each USGS streamflow gage records the water stage, at frequent intervals, which is associated with a specific discharge through actual streamflow measurements. These gages provide an excellent record of the hydrologic regime within the Basin over the last century. Some gages in the Basin that operated during shorter time periods have been discontinued for various reasons, and others are still operational. Due to the large number of gages in the Basin (approximately 58), the scope of this report will be limited to detailed analyses at 11 gages: two on the East Walker River, one on the Little Walker River, five on the West Walker River, and three on the mainstem of the Walker River (Figure 2.1-8). These gage records were selected because they are located on the major forks of the river.

The 11 USGS gages included in this report are listed in Table 2.1-2, along with a summary of some relevant gage characteristics, including; station name, USGS station number, drainage basin area, elevation of the gage datum, and the latitude and longitude and NAD system of each gage location. Basin areas range from 63.1 square miles for station number 10295500 (LITTLE WALKER RIVER NEAR BRIDGEPORT, CA) to 2,850 square miles for station number 10302000 (WALKER RIVER AT SCHURZ, NV). Gage elevations range between 4,120 ft for station number 10302000 (WALKER RIVER AT SCHURZ, NV) and 7,111.32 ft for station number 10295200 (WEST WALKER RIVER ABOVE LEAVITT MEADOW NEAR COLEVILLE, CA).

Table 2.1-2. Walker River Gage Summary. Note that the names given are the official USGS nomenclature, and will be used for gage names throughout the section.

Station Name	USGS Station #	Drainage Basin Area (mi^2)	Elevation of Gage Datum (ft)	Latitide	Longitude	NAD
E WALKER R NR BRIDGEPORT, CA	10293000	359.0	6400.00	38°19'40"	119°12'50"	27
E WALKER R AB STROSNIDER D NR MASON, NV	10293500	1100.0	4574.10	38°48'49.37"	119°02'52.77"	83
W WALKER R A LEAVITT MD NR COLEVILLE CA	10295200	73.4	7111.32	38°19'50"	119°33'05"	27
L WALKER R NR BRIDGEPORT, CA	10295500	63.1	6790.00	38°21'39"	119°26'38"	27
W WALKER R BLW L WALKER R NR COLEVILLE, CA	10296000	181	6591.39	38°22'47"	119°26'57"	27
W WALKER R NR COLEVILLE, CA	10296500	250	5520.00	38°30'48"	119°26'56"	27
W WALKER R AT HOYE BRIDGE NR WELLINGTON, NV	10297500	497	4980.00	38°43'41.03"	119°25'40.3"	83
W WALKER R NR HUDSON, NV	10300000	964	4650.00	38°48'35"	119°13'35"	27
WALKER R NR MASON, NV	10300600	2400	4420.00	38°55'11"	119°11'20"	27
WALKER R NR WABUSKA, NV	10301500	2600	4300.00	39°09'08.86"	119°05'56"	83
WALKER RIVER AT SCHURZ, NV	10302000	2850	4120.00	38°56'57"	118°48'25"	27

USGS gage records typically include two types of information: (1) daily mean discharge data, and (2) instantaneous peak discharge data. The availability of these data types and the period of record vary greatly because the gages were installed at different times and operated for different time periods.

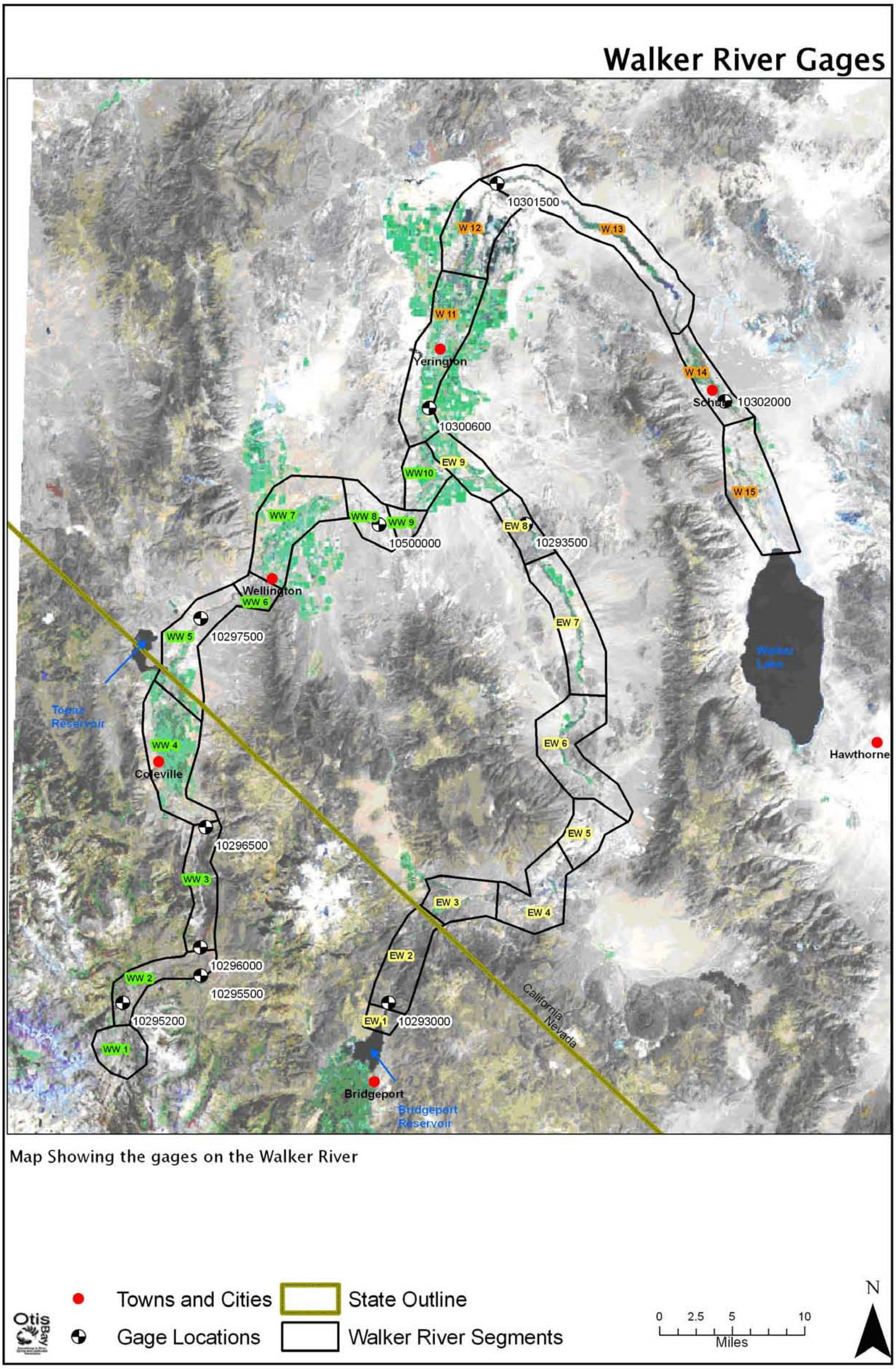


Figure 2.1-8. USGS gage locations within the Basin.

DAILY DATA

The daily mean discharge records from all 11 gages are summarized in Table 2.1-3. Parameters reported include the station name, the station number, the basin area, the mean discharge for the period of record, the number of daily mean discharges that were analyzed, the dates of operation, and the approximate number of years analyzed. Three of these gages are no longer in service and thus have periods of record that do not necessarily correspond to the other gages: these gages are shown in blue text in Table 2.1-3. Mean discharges for the gages included in the daily streamflow analyses range from a low of approximately 53.1 cfs, for station number 10295500 (LITTLE WALKER RIVER NEAR BRIDGEPORT, CA), to a high of approximately 338.2 cfs, for station number 10300600 (WALKER RIVER NEAR MASON, NV), which is a discontinued gage.

Table 2.1-3. Daily Streamflow Summary Table.

Station Name	USGS Station #	Drainage Basin Area (mi^2)	Mean Daily Discharge (ft^3/s)	Number of Days Included in Analyses	Dates of Operation (including breaks in service)
E WALKER R NR BRIDGEPORT, CA	10293000	359.0	146.0	30019	1921 to present
E WALKER R AB STROSNIDER D NR MASON, NV	10293500	1100.0	164.4	17916	1947 to present
W WALKER R A LEAVITT MD NR COLEVILLE CA	10295200	73.4	154.2	7032	1945 to 1964
L WALKER R NR BRIDGEPORT, CA	10295500	63.1	53.1	18262	1944 to present
W WALKER R BLW L WALKER R NR COLEVILLE, CA	10296000	181	268.9	24290	1938 to present
W WALKER R NR COLEVILLE, CA	10296500	250	282.0	27841	1902 to present
W WALKER R AT HOYE BRIDGE NR WELLINGTON, NV	10297500	497	244.4	21583	1910 to present
W WALKER R NR HUDSON, NV	10300000	964	210.3	21557	1914 to present
WALKER R NR MASON, NV	10300600	2400	338.2	3806	1974 to 1984
WALKER R NR WABUSKA, NV	10301500	2600	165.1	30403	1902 to present
WALKER RIVER AT SCHURZ, NV	10302000	2850	146.1	7185	1913 to 1933

Most western snowmelt dominated stream systems show a pattern of increasing discharge with increasing basin area, but the major streams in the Walker River Basin do not show this trend (Figure 2.1-9). Data from Table 2.1-3 suggest a generally increasing trend in mean daily discharge with increasing drainage basin area for the upper reaches of the West Walker River, but that trend extends downstream only as far as the gage near Coleville (station number 10296500) and is not present lower in the Basin.

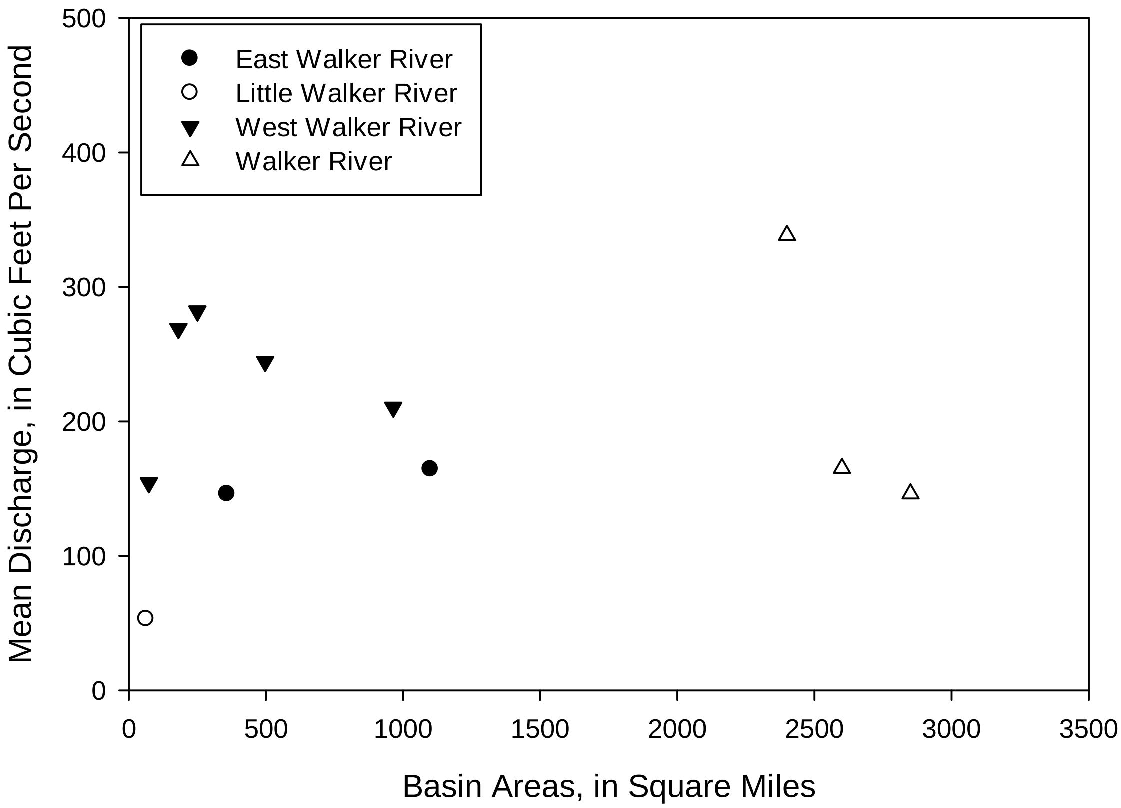


Figure 2.1-9. Plot of basin area versus mean discharge for 11 gages in the Walker River Basin.

MAGNITUDE AND FREQUENCY

Peak flow analyses were completed using the standard Log Pearson Type III method. Only gage records with over 20 years of peak flow data were included for streamflow magnitude and frequency analyses. Table 2.1-4 lists peak flow summary information for all 11 gages that were included in this report. It shows the station names and numbers, the number of years when peak flow was recorded, and the magnitude of the flood of record. It also includes basic notes about the peak flow records. One gage, Walker River near Mason 10300600, had a record shorter than 20 years and was omitted from further analyses (red text in Table 2.1-4).

Table 2.1-4 includes a summary of estimated peak discharges with selected recurrence intervals (2-year, 10-year, and 100-year) for several Walker Basin gages. Each of these computations was based on a somewhat different period of record, thus caution must be used when interpreting results. However, these estimates do represent the high flows that have occurred at each gage during its entire operational period, and thus are useful for comparison purposes.

Table 2.1-4. Annual Peak Streamflow Summary Table.

Station Name	USGS Station #	# Peaks in Record	2-Year Event (cfs)	10-Year Event (cfs)	100-Year Event (cfs)	Flood of Record (FOR) (cfs)	Year (FOR)	Comments
E WALKER R NR BRIDGEPORT, CA	10293000	82	447	1031	2186	1910	1997	1923 to present
E WALKER R AB STROSNIDER D NR MASON, NV	10293500	56	485	1482	4086	2820	1986	1947 to present - the 1997 event was 2610 cfs
W WALKER R A LEAVITT MD NR COLEVILLE CA	10295200	23	1180	1858	2822	2810	1951	1946 to 1970
L WALKER R NR BRIDGEPORT, CA	10295500	51	335	847	2089	2540	1997	1945 to present
W WALKER R BLW L WALKER R NR COLEVILLE, CA	10296000	67	1803	3923	8174	12300	1997	1937 to present
W WALKER R NR COLEVILLE, CA	10296500	79	1747	3610	7128	12500	1997	1903 to present
W WALKER R AT HOYE BRIDGE NR WELLINGTON, NV	10297500	58	970	2394	5996	11500	1997	1921 to present
W WALKER R NR HUDSON, NV	10300000	65	818	2396	6637	11400	1997	1915 to present
WALKER R NR MASON, NV	10300600	11	N/A	N/A	N/A	N/A	N/A	Not Included - Record is too short
WALKER R NR WABUSKA, NV	10301500	84	600	2438	7069	3280	1906	1903 to present - 1997 event was 2600 cfs
WALKER RIVER AT SCHURZ, NV	10302000	20	549	2656	8691	2530	1914	1914 to 1933 (short record - included)

The flood that occurred in early January of 1997 was the flood of record at all but two of the gages that were operational during the event: station numbers 10293500 (East Walker River above Strosnider Ditch near Mason, NV) and 10301500 (Walker River Near Wabuska, NV), for which the flood of record occurred in June of 1986 and 1906, respectively. During the 1997 flood, the highest peak discharges occurred at the two gages located near Coleville, CA.

Weibull plotting positions offer a simple way to estimate flood frequency from measured data, without assuming a certain distribution of the data. Plotting positions for each flood in the record were computed and converted to recurrence intervals by applying the following formulas:

$$\text{(1)} \qquad \text{Weibull Plotting Position} = \frac{\text{Flood Rank}}{\text{Number of Records} + 1}$$

$$\text{(2)} \qquad \text{Recurrence Interval} = \frac{1}{\text{Weibull Plotting Position}}$$

Detailed results from the analyses of magnitude and frequency for Walker Basin gages, including the full range of computed recurrence intervals with 95% confidence upper and lower bounds, are shown in Figures I-1 through I-11 in Appendix I.

2.1.3.2 Flow Duration

Flow duration relations reveal a great deal about the overall distribution of discharge in a river system. These relations (also called flow duration curves) plot a given stream discharge against the percentage of time that the given discharge was equaled or exceeded in the historic record. Figures I-12 through I-22 in Appendix I show flow duration relations, for the period of record, for all 11 gages. For illustrative purposes, the flow duration relations for the gages in the Walker Basin are shown together in Figure 2.1-10. To read this plot, select a discharge (from the Y-axis) and follow horizontally across the graph until you arrive at the plotted line for the gage of interest, then go down to the X-axis. The values shown on the X-axis represent the percentage of time that the selected discharge was equaled or exceeded during the historic time period.

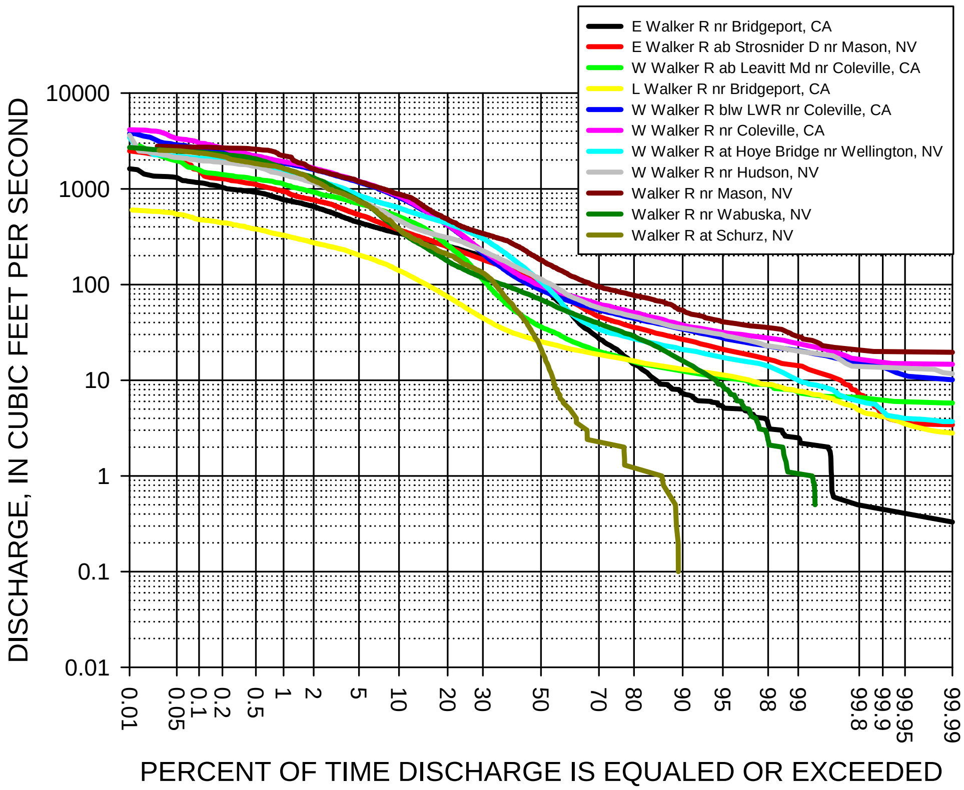


Figure 2.1-10. Flow duration relations for 11 gages in the Walker River Basin.

Most of the flow duration curves in Figure 2.1-10 have a classic shape of a snowmelt dominated stream in the western US, but three of the curves deviate substantially from the other curves. The gages at (1) East Walker River near Bridgeport, CA, (2) Walker River near Wabuska, NV, and (3) Walker River at Schurz, NV, all show a curve shape that is typical of streams with substantial water depletions and/or human-induced flow alteration. The low flows at these gages are extremely low: much lower than the other streams in the Basin. These extremely low flows make it difficult to compare the other relations directly, given the varying magnitude of the discharges.

Dimensionless Flow Duration

Hydrologic analyses are often aided by non-dimensionalizing certain hydrologic variables in a way that allows streams with drainage basins of varying size to be compared directly. Flow duration curves can be non-dimensionalized by dividing the discharge values (normally plotted on the Y-axis) by the mean discharge for the gage record (Table 2.1-3). This procedure allows for comparison of flow variability in the system and results in Y-axis units that are equal to the mean annual discharge for the gage being considered. In other words, a dimensionless discharge of 1 for any gage is equal to the mean annual discharge for that gage; a value of 10 is equal to 10 times the mean annual discharge, and so on.

The 11 flow duration curves that were presented in Figure 2.1-10, were non-dimensionalized using the procedure outlined above. The dimensionless results are shown in Figure 2.1-11. Individual plots of dimensionless flow duration are included in Figures I-23 through I-33 of Appendix I.

Examination of Figure 2.1-11 reveals that many of the Walker gages plot very close together when non-dimensionalized, despite the differences in the length of the period of record and drainage basin size. Again, most of these gage records display a classic dimensionless flow duration curve shape for snowmelt dominated streams that are not greatly influenced by flow manipulation, but three curves (East Walker River near Bridgeport, CA, Walker River near Wabuska, NV, and Walker River at Schurz, NV) deviate from the classic shape. Non-dimensionalizing these gage records illustrates the deviation from the normal shape more clearly and suggests that further exploration of the streamflow at these gages is needed to explain the differences from the less altered streams.

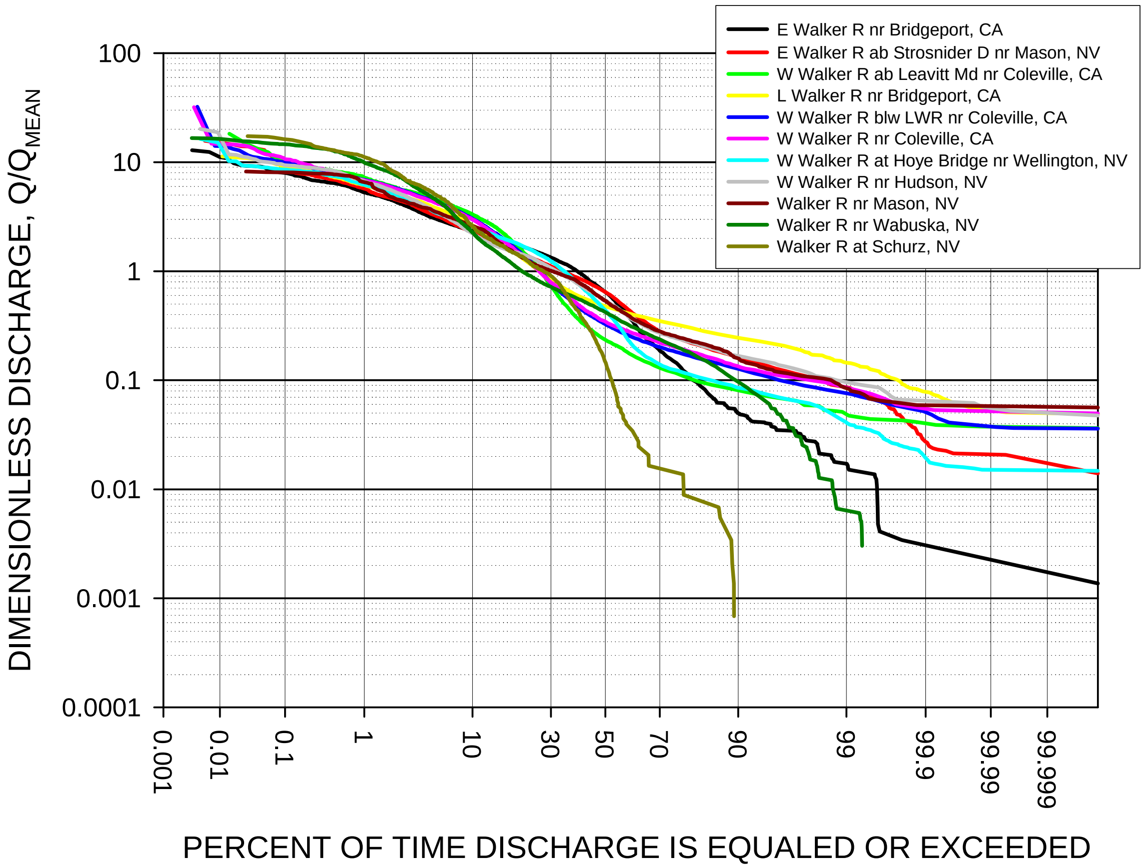


Figure 2.1-11. Dimensionless flow duration relations for 11 gages in the Walker River Basin.

2.1.3.3 Timing

The timing of river flows is a particularly important component of the hydrologic influences on many biological processes. For example, the timing of seed dispersal and its temporal correlation with the declining limb of the hydrograph is critically important for cottonwood and willow establishment. The timing of peak discharge in the Walker River Basin is presented in this report as it relates to two principal descriptors of flow: (1) monthly mean discharge, and (2) annual instantaneous peak discharge.

TIMING OF MONTHLY MEAN DISCHARGE

The gage records of 11 USGS gaging stations that have periods of record longer than 10 years were analyzed to determine the mean streamflow that has occurred during each month of each year. Selected results are discussed below.

Timing for the West Walker River

Streamflow in the West Walker River is not influenced by any large dams in the upper reaches, but it is influenced by diversions that feed Topaz Reservoir. As a result, the gages higher in the Basin exhibit a wider range of variability than gages in the lower Basin. The gages at Leavitt Meadow and below the Little Walker River are located above Topaz Reservoir, a large impoundment that receives diverted streamflow from the West Walker. These gages exhibit discharge patterns that are typical of snowmelt-dominated rivers in the western United States, with high flows in May and June and substantially reduced discharge in July. However, the gage near Wellington, below Bridgeport reservoir, clearly shows the effects of flow redistribution, with diminished flow during May and June, and higher than expected flows during the summer months (Figure 2.1-12).

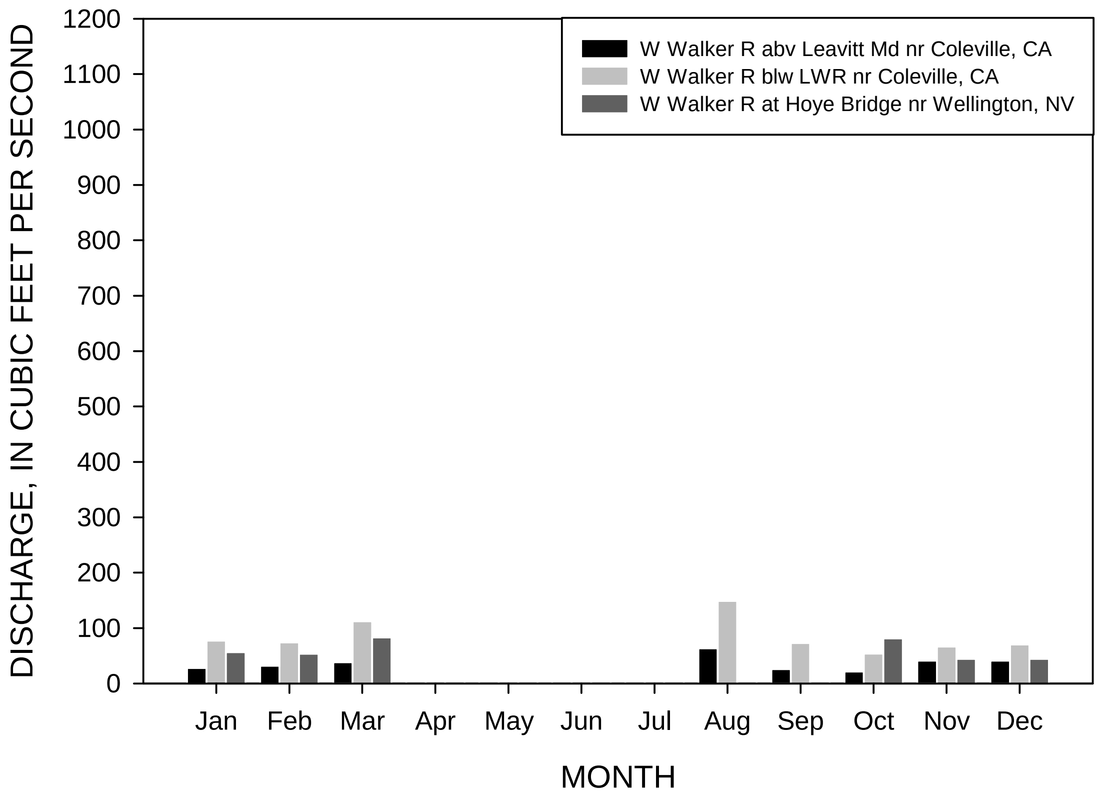


Figure 2.1-12. Monthly mean discharge for West Walker gages: W Walker R abv Leavitt Md nr Coleville, CA, W Walker R blw LWR nr Coleville, CA, and W Walker R at Hoye Bridge nr Wellington, NV.

The two gages in the lower reaches of the West Walker begin to show a very clear pattern of streamflow depletion. Figure 2.1-13 reveals that the river at Hudson has lower monthly mean flows than upstream at Hoye Bridge between the months of April and October, which corresponds to the irrigation season. From November to March, when irrigation is not occurring, the Hudson gage has higher discharge.

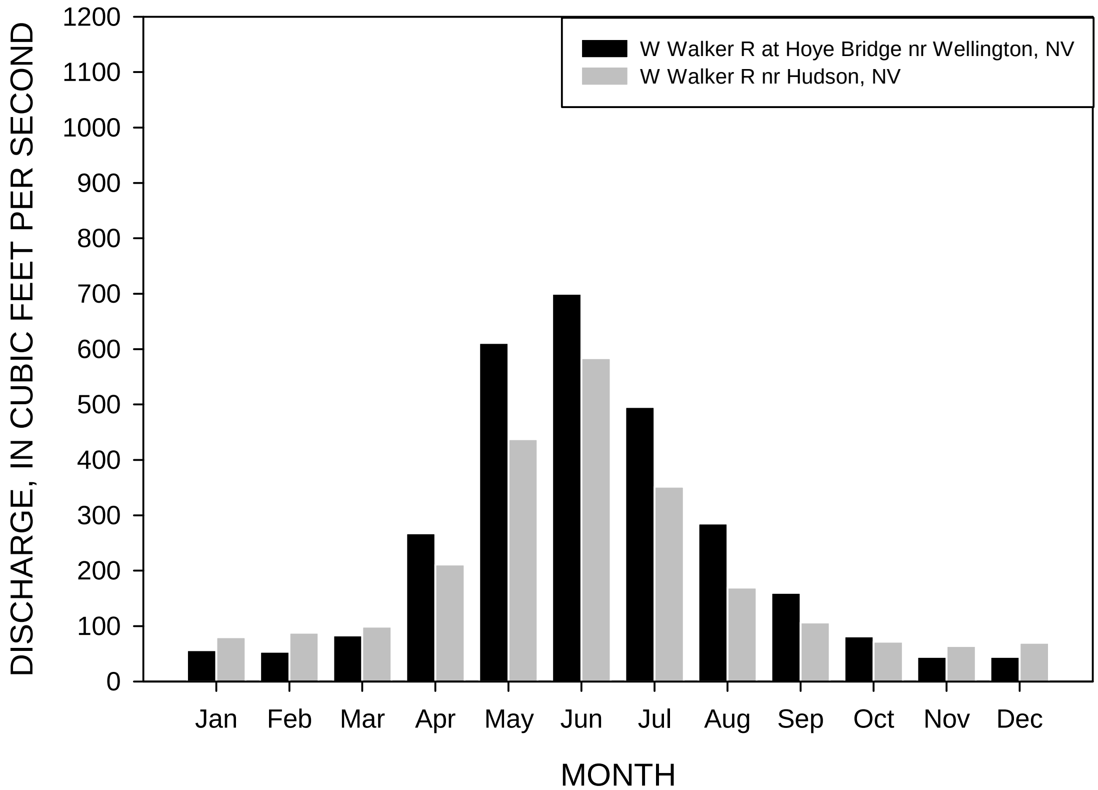


Figure 2.1-13. Monthly mean discharge for downstream West Walker gages: West Walker R at Hoye Bridge nr Wellington, NV and West Walker R nr Hudson, NV.

Timing for the East Walker River

Streamflow in the East Walker River is influenced by the release patterns of Bridgeport Dam, which is located upstream of both of the East Walker streamflow gages (Figure 2.1-8). The dam impounds the East Walker River forming Bridgeport Reservoir with a capacity of 42,455 acre-ft. Reservoirs, in general, tend to smooth out the temporal variability of the rivers they impound, and Bridgeport Dam is no exception. Figure 2.1-14 includes plots of mean monthly discharge for both gages on the East Walker. The discharges exhibit some temporal variability, but much less than would be expected in a typical snowmelt-dominated river in the western United States.

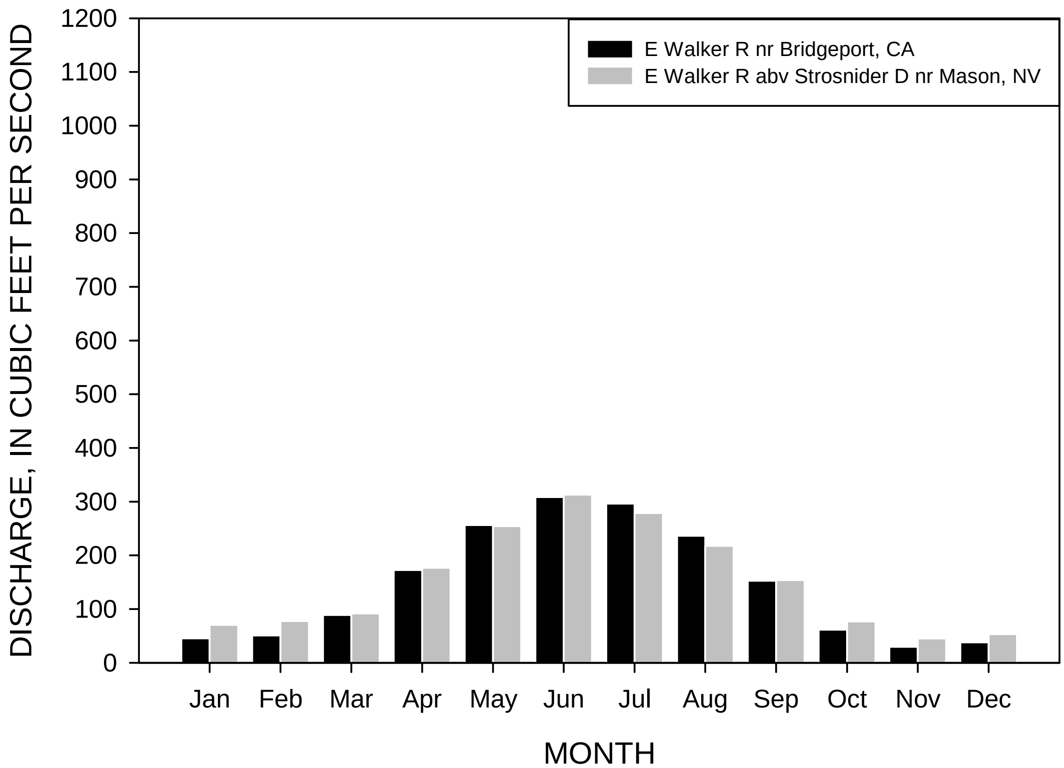


Figure 2.1-14. Monthly mean discharge for East Walker gages: E Walker R nr Bridgeport, CA and E Walker R abv Strosnider D nr Mason, NV.

Timing for the Walker River

Below the confluence of the East and West Walker Rivers, very few tributaries enter the river. The drainage basin area continues to increase in the downstream direction, but the basin area that is added does not contribute much runoff to the system due to lower elevation and reduced precipitation. The lack of tributary inflow in this reach serves to highlight the role of streamflow diversion in altering the natural hydrology of the system. Water depletion in this reach is pronounced and readily apparent in virtually every metric analyzed.

Figure 2.1-15 includes plots of three gages on the mainstem of the Walker River, which clearly illustrate the influence of water depletions on the Walker River. Many diversions exist in this reach of the river. The diversions dewater the system causing a general decrease in flows downstream. Some natural water loss is probably occurring as well in certain sections of the river due to naturally losing groundwater regimes.

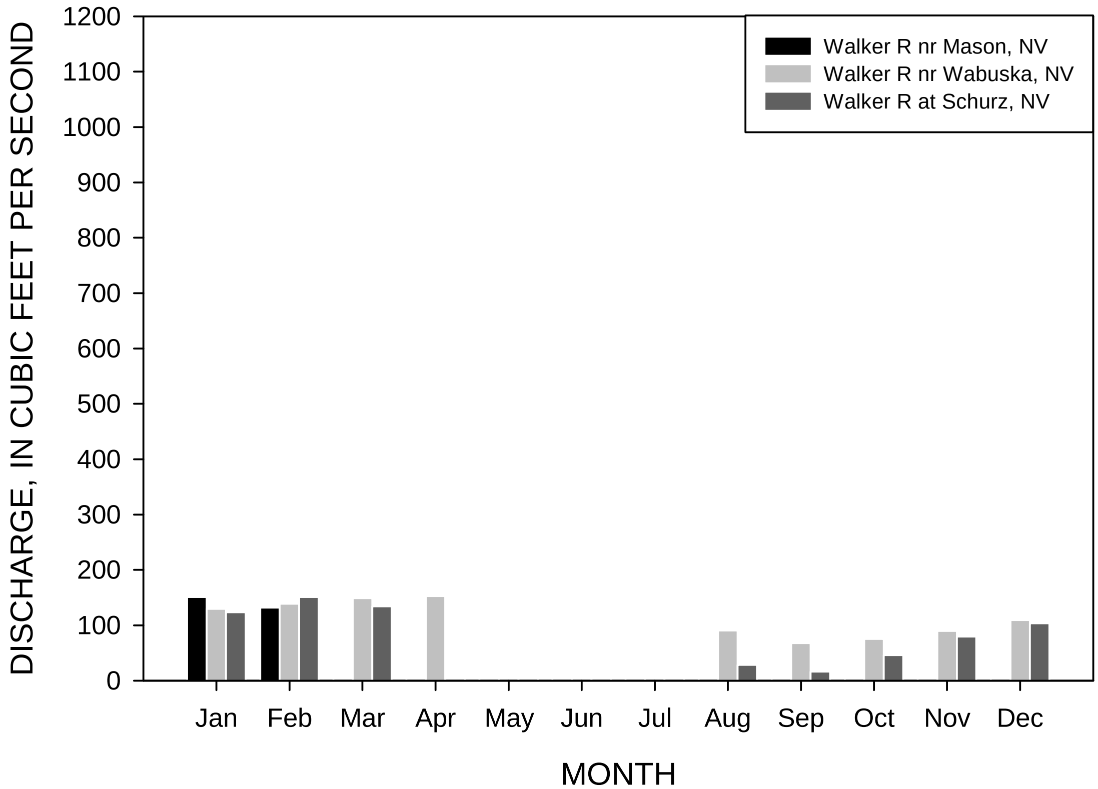


Figure 2.1-15. Mean monthly discharge for Walker gages: Walker R nr Mason, NV, Walker R nr Wabuska, NV, and Walker R at Schurz, NV.

Individual plots of monthly mean discharge for all 11 gages are included in Figures I-34 through I-44 (Appendix I).

TIMING OF ANNUAL INSTANTANEOUS PEAK DISCHARGE

The timing of annual instantaneous peak discharge in the Walker River Basin was characterized for each gage by developing 3 relationships: (1) month versus annual peak discharge, (2) month versus the mean of annual peaks, and (3) month versus number of annual peaks.

Timing for the West Walker River

Figure 2.1-16 provides a similar series of plots for the West Walker River near Coleville, CA. The overall pattern is very similar to the East Walker, but peaks have occurred in fewer months. The peaks nearly always occur during May and June, with June being the most likely month of occurrence. This pattern is relatively unaffected by water diversion or impoundment, and reflects more natural timing. As with the East Walker, the winter floods occur infrequently, but tend to be larger events than the snowmelt peaks.

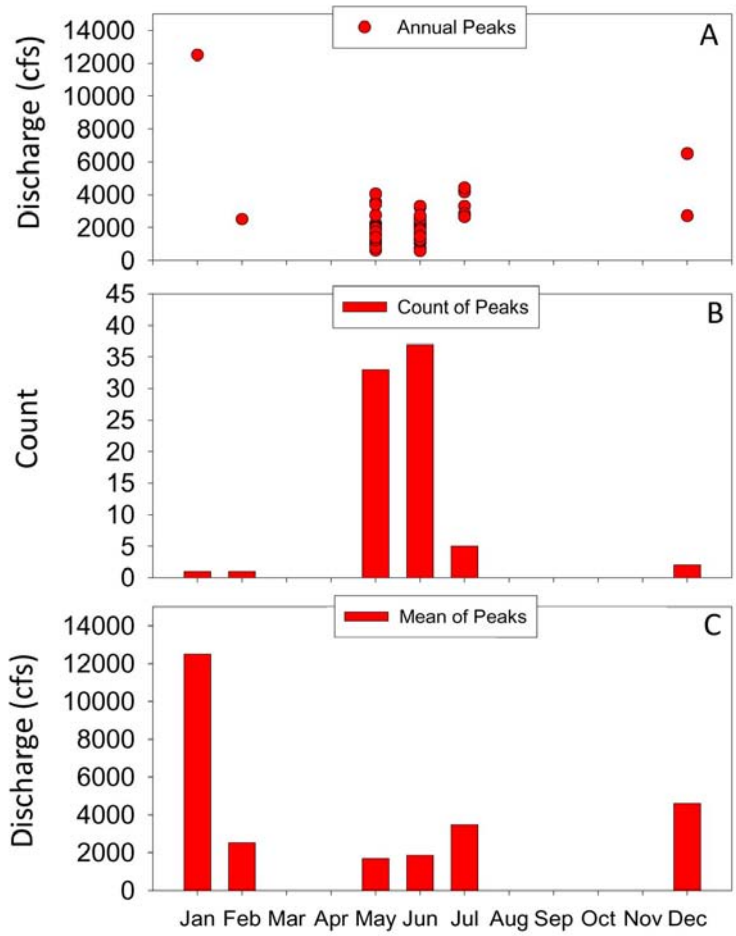


Figure 2.1-16. Timing of annual peak discharges for the West Walker River near Coleville, CA.

Timing for the East Walker River

The timing of flood peaks on the Walker River varies from year to year, mostly due to the effects of two different climatic scenarios that produce the flooding: (1) spring melting of high mountain snowpack, or (2) intense rain and/or rain-on-snow events. Figure 2.1-17 illustrates the effect these climatic factors have on the timing of annual streamflow peaks in the Walker Basin.

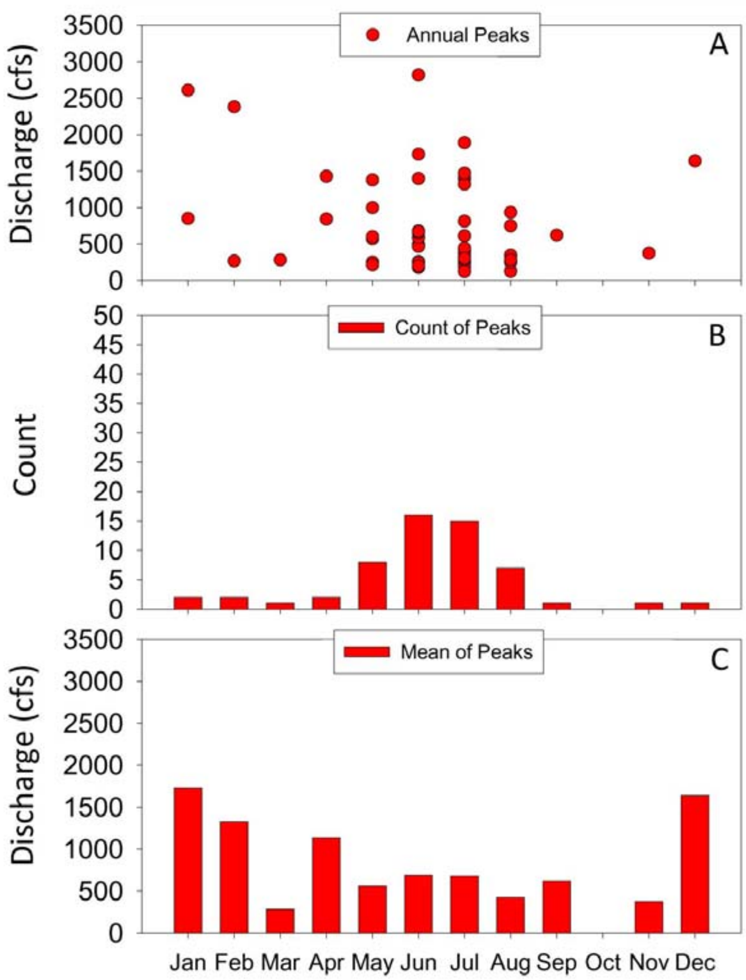


Figure 2.1-17. Timing of annual peak discharges for the East Walker River above Strosnider Ditch near Mason, NV.

Figure 2.1-17 plots the distribution of annual peak discharges for the East Walker gage near Mason, NV, which generally represents the character of peak flow for that basin. Plot A of the figure shows the month of occurrence and magnitude of each annual peak in the record. Notice that several of the larger peaks occurred during the winter months. These winter peaks are usually triggered by rain-on-snow events. Plot B in Figure 2.1-17 provides a frequency distribution for the month of peak flows occurrence. This plot illustrates that most annual peaks result from snowmelt runoff in early summer, with June and July being the most likely month of peak flow occurrence. Comparison of this pattern to natural hydrology at this site is impossible due to a lack of pre-disturbance records. However, the presence of a reservoir upstream may have moved natural peaks to later times in the year. Peaks during the winter months are far less common, but they do occur on occasion and they are larger on average than the snowmelt peaks, despite the infrequency of their occurrence.

Timing for the Walker River

Figure 2.1-18 shows a similar series of plots for the Walker River near Wabuska, NV. This gage is located downstream of the confluence of the East and West Walker Rivers. The overall distribution of annual peaks is similar to the gages on the East and West Walker Rivers, but the magnitude of the winter storms are greatly attenuated by storage areas upstream of the gage.

The winter storms in the Walker Basin tend to be of relatively high magnitude and short duration when compared to snowmelt runoff peaks. These large events are buffered substantially by overbank storage areas in the lower Basin. Areas of overbank storage include low lying areas in the floodplain. As flood levels rise, these areas fill with still or slow moving water, effectively storing flood waters and reducing the magnitude flood peaks. Longer duration events including snowmelt runoff peaks, are also buffered, but to a lesser extent.

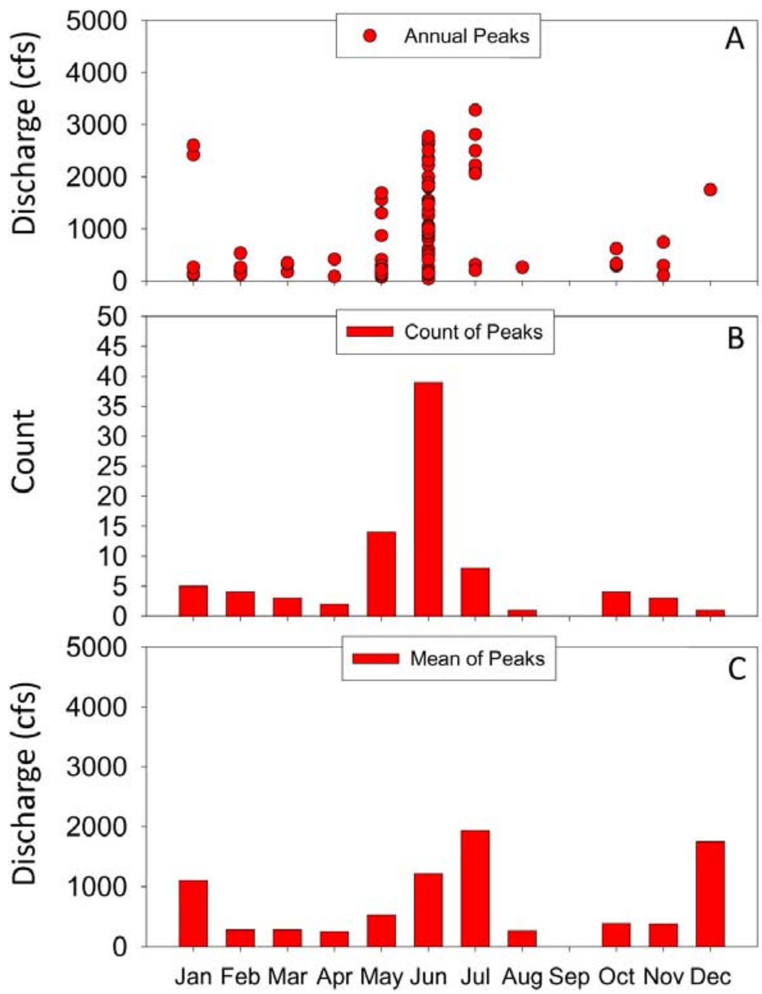


Figure 2.1-18. Timing of annual peak discharges for the Walker River near Wabuska, NV.

Figure 2.1-19 illustrates the buffering capacity of the Walker River. The short-duration 1997 flood was 11,400 cfs on the West Walker near Hudson, and 2,610 cfs on the East Walker near Mason, but despite combining the two flows, the same event was attenuated to only 2,600 cfs at the Wabuska gage, which represents an attenuation[37] of over 81% of the combined flow. However, the longer duration 1986 snowmelt peak was 1,970 cfs on the West Walker near Hudson, and 2,820 cfs on the East Walker near Mason, and the peak at Wabuska was buffered to 2,770 cfs that year, which represents an attenuation of only 42%. In both cases, the degree of attenuation was substantial, but it was much more pronounced in the high-magnitude short-duration event. Overbank storage areas that are accessed only during periods of extremely high discharge are probably responsible for the difference in buffering capacity between large floods and more moderate events.

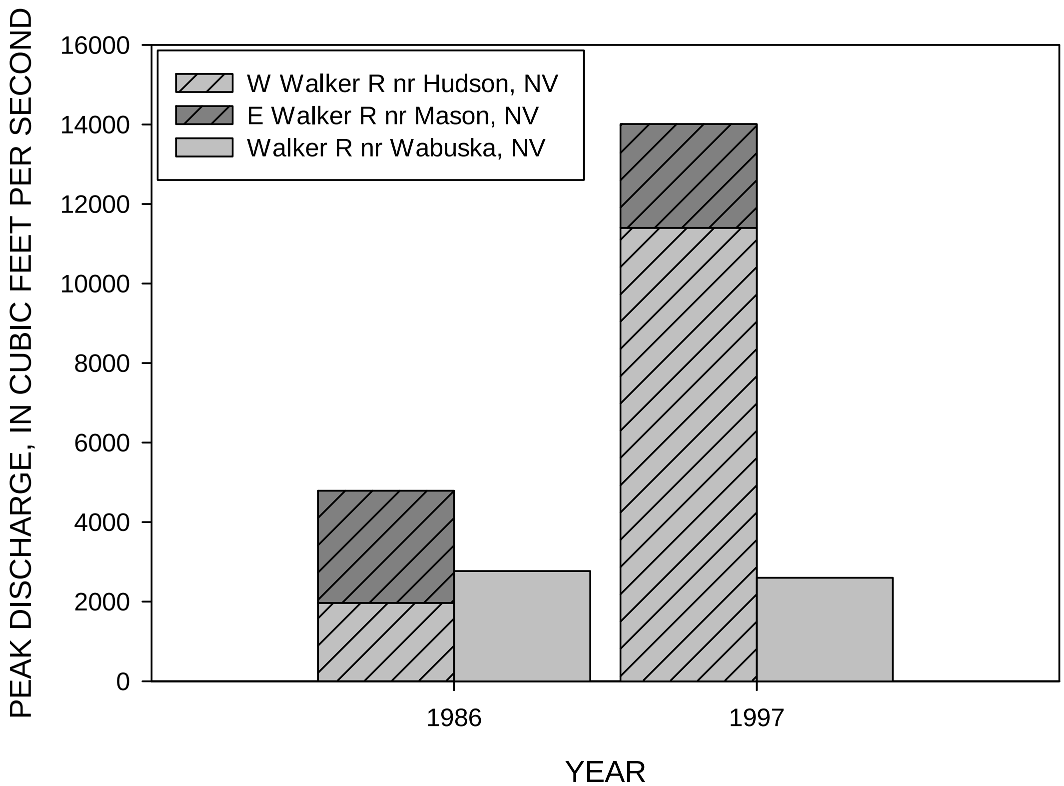


Figure 2.1-19. Buffering of peak discharges on the Walker River.

Individual plots of the timing of peak flows for all eleven gages are included in Figures I-45 through I-55 in Appendix I.

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[37] The process that decreases the magnitude of flood peaks, and slows their downstream travel time.

2.1.3.4 Natural Hydrologic Regime

The Walker River's natural hydrologic regime is probably best expressed by the West Walker gage below the Little Walker River: it is characterized by the following: (1) moderate magnitude, long duration snowmelt peaks that ordinarily occur in May and June, (2) a short period of declining, moderate flow following spring runoff, (3) a period of low flow (base flow) that ordinarily occurs from August to March, and (4) periodic high intensity, short duration peak flows that occur during winter months.

Typical hydrographs are presented for the gage below the Little Walker River on the West Walker for an average water year (2000, Figure 2.1-20), a below average water year (1992, Figure 2.1-21), and an above average water year (1986, Figure 2.1-22). All three plots are shown with identical scales to illustrate the differences in overall runoff volume that can occur between different years within the Walker River Basin.

The 2000 water year was selected to illustrate average yearly runoff conditions (Figure 2.1-20) because its peak discharge was near the average for the period of record. The hydrograph captures all of the primary patterns of the natural hydrologic regime listed above, in as close to a natural state as can be found in the Basin.

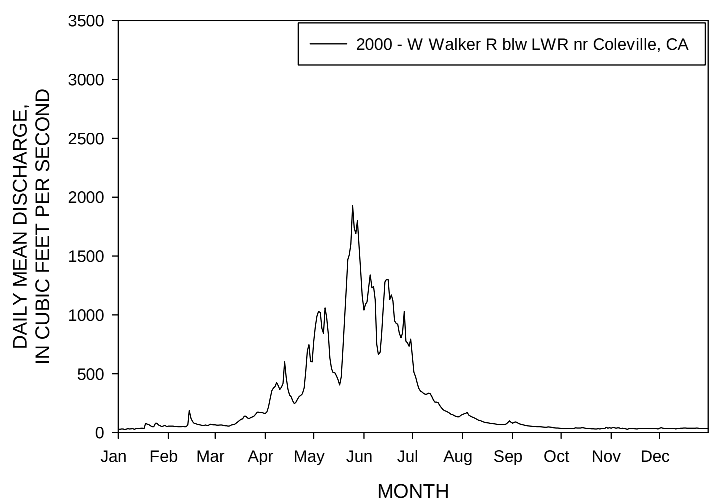


Figure 2.1-20. Average year hydrograph for 2000 (W Walker R blw LWR nr Coleville, CA).

The below average water year plot (1992, Figure 2.1-21) shows typical characteristics of a dry year, with a low magnitude snowmelt peak of short duration, followed by low flows throughout the remainder of the year. In 1992, an early runoff peak began in April and peaked in early May, which is somewhat typical for low water years. This early peak was followed by a small spike in July, but neither peak was large in relative terms.

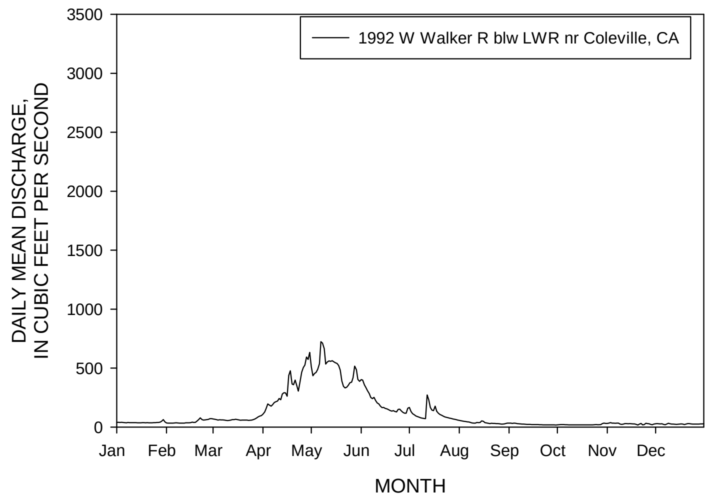


Figure 2.1-21. Dry year hydrograph for 1992 (W Walker R blw LWR nr Coleville, CA).

An above average water year example (1986, Figure 2.1-22) shows a high magnitude spring snowmelt peak of long duration, followed by an extremely long period of high runoff on the receding limb of the hydrograph. Several additional smaller peaks occurred during this year, and baseflows[38] remained higher than normal.

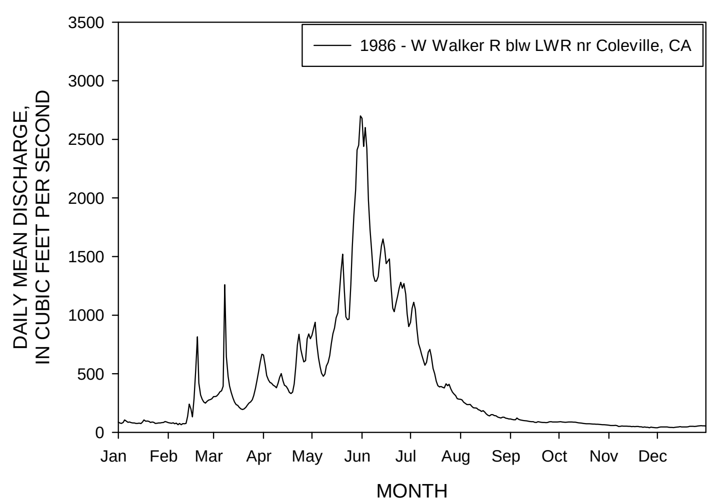


Figure 2.1-22. Wet year hydrograph for 1986 (W Walker R blw LWR nr Coleville, CA).

[38] A stream discharge that characterizes the annual low flow regime, typically fed by groundwater in natural systems, but could be unnaturally supplemented by reservoir releases or agricultural return flow.

A hydrograph from 1997 illustrates the flood of record which occurred in January when warm rains rapidly melted much of the existing snowpack (Figure 2.1-23). This rain-on-snow event produced an extremely high-magnitude flood of relatively short duration. These large winter events occur infrequently in the Basin, but may be of hydrologic and geomorphic importance because of capability of such flows to completely alter channel and floodplain morphology.

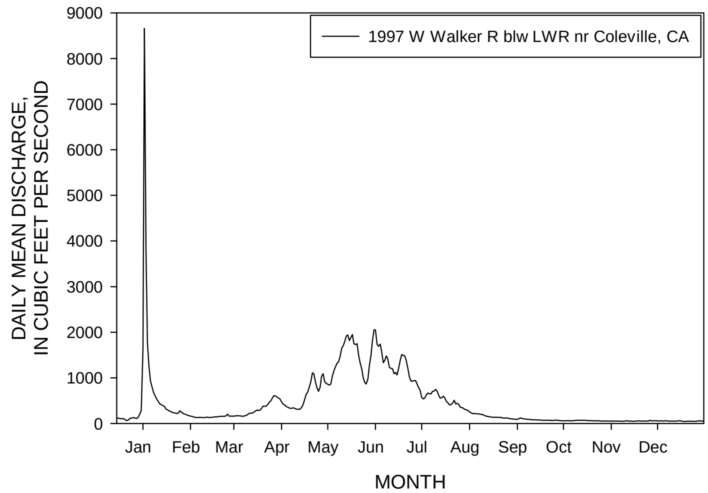


Figure 2.1-23. Winter peak example hydrograph for 1997 (W Walker R blw LWR nr Coleville, CA).

2.1.3.5 Annual Volume Comparisons

Annual streamflow volumes were computed from the daily mean data for several gages in the Basin. These computations provide a way to estimate the total volume of water loss that occurs between various locations on the river. Figure 2.1-24 plots the combined annual volume of the East and West Walker Rivers (E Walker R abv Strosnider D nr Mason, NV, and W Walker R nr Coleville, CA) against the volume of the Walker near Wabuska. The water loss in the system is apparent.

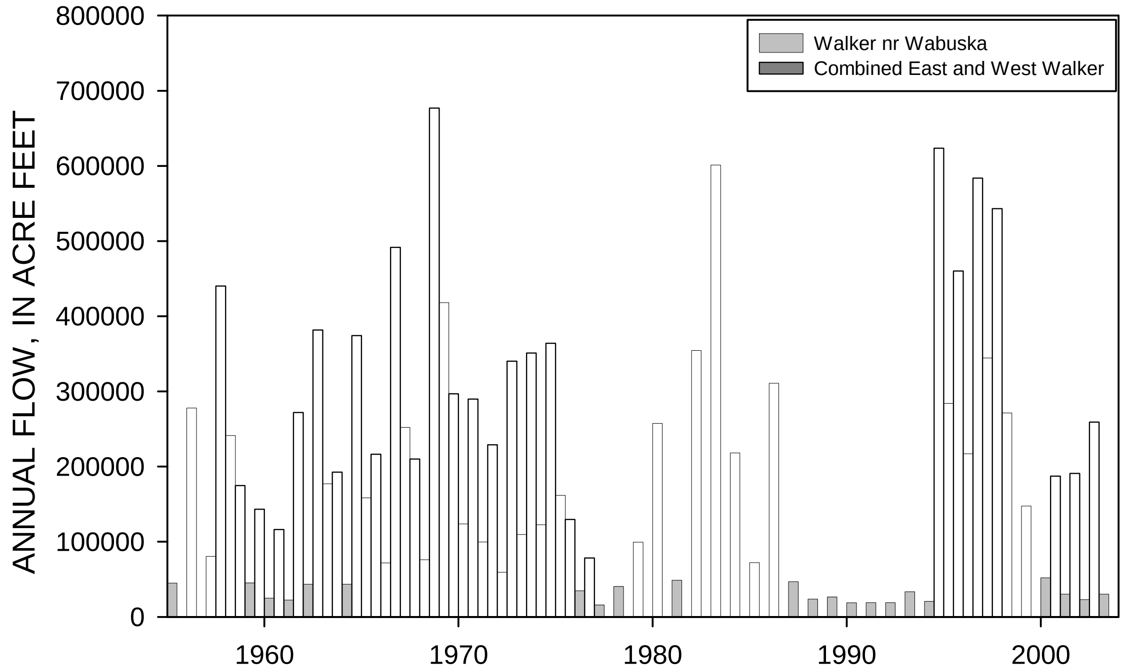


Figure 2.1-24. Comparison of water volumes for the East and West Walker Rivers combined (dark) and the Walker near Wabuska (light).

During the years when all three gages operated, the average water loss was over 65%, with a maximum loss of approximately 88% and a minimum of approximately 38%. These water losses are probably due to many factors, both human induced and natural. Water diversion for agricultural and other uses is certainly a factor, as is evaporation and transpiration. Losses caused by groundwater gradients away from the channel, whether natural or from groundwater pumping, may also play an important role.

2.1.3.6 Hydrologic Alteration

The preceding analysis of hydrologic records of gages in the Basin provides information on the current function of the Basin hydrology. This is critical in understanding what hydrologic resources are available for restoration efforts. It is also very important to try and understand how the current water management infrastructure alters the hydrologic regime. Through this type of analysis, a more detailed characterization is made for areas above and below large diversions or storage facilities. We use a modified IHA analysis as described in section 2.1.1.

THE WEST WALKER RIVER

The West Walker River is the only river included in this assessment that displays a natural hydrologic regime at any point along its length. This natural hydrology can be found upstream of Antelope Valley, represented by the Coleville gage. Upon entering this first agricultural valley, the hydrology of the West Walker River is altered by storage and diversions that have cumulative influence up to its confluence with the East Walker River in Mason Valley. The single-most significant feature of anthropogenic alteration to the hydrology of the West Walker is Topaz Reservoir. This facility provides off-channel storage for water users in Smith and Mason Valleys. The effect of Topaz is to reduce flood peaks, to increase flows on the declining limb, and to decrease baseflows. As the river flows through each successive agricultural area, increasing amounts of water are diverted and this effect is compounded (Figure 2.1-25).

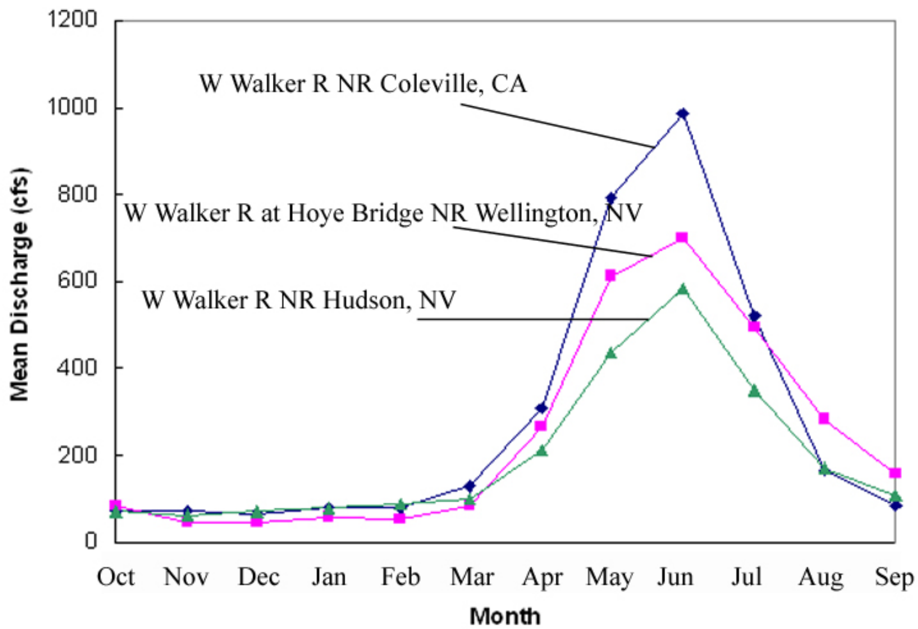


Figure 2.1-25. Comparison of monthly mean discharge values for three gages on the West Walker River. Note the consistent reduction in peak discharge, and the increase in declining flows, particularly for the gage at Hoye Bridge.

The effects of these alterations can be illustrated by taking a more detailed look at the hydrology. Using IHA, the high and low ends of the records were analyzed for the three gages in Figure 2.1-25 using Coleville as the unaltered reference gage. A 7-day minimum flow and the 3-day maximum flow were reviewed, starting with the Coleville gage and the Hoye Bridge gage. The 7-day minimum presents the minimum of mean values for continuous 7 day periods for each year. This gives an idea of how low flows are affected by human water use. The 3-day maximum takes the same approach to analyze the effects of hydrologic alteration on high flows. First reference hydrology at Coleville is compared to the altered hydrology at Hoye Bridge (Figure 2.1-26). In this comparison it is observed that the low end flows have been driven lower by the effects of storage and diversion in Antelope Valley. The median value for 7-day minimum flows has been reduced by 38% at Hoye Bridge in comparison to the gage near Coleville. The range of values between the 75th and 25th percentile values has also been reduced at Hoye Bridge, indicating reduced variability. The same basic affect can be seen in comparing the 3-day maximum. Here, the median value at Hoye Bridge has been reduced by about 40%

though the range between the 75th and 25th percentile flows has not been affected as much for the high flows.

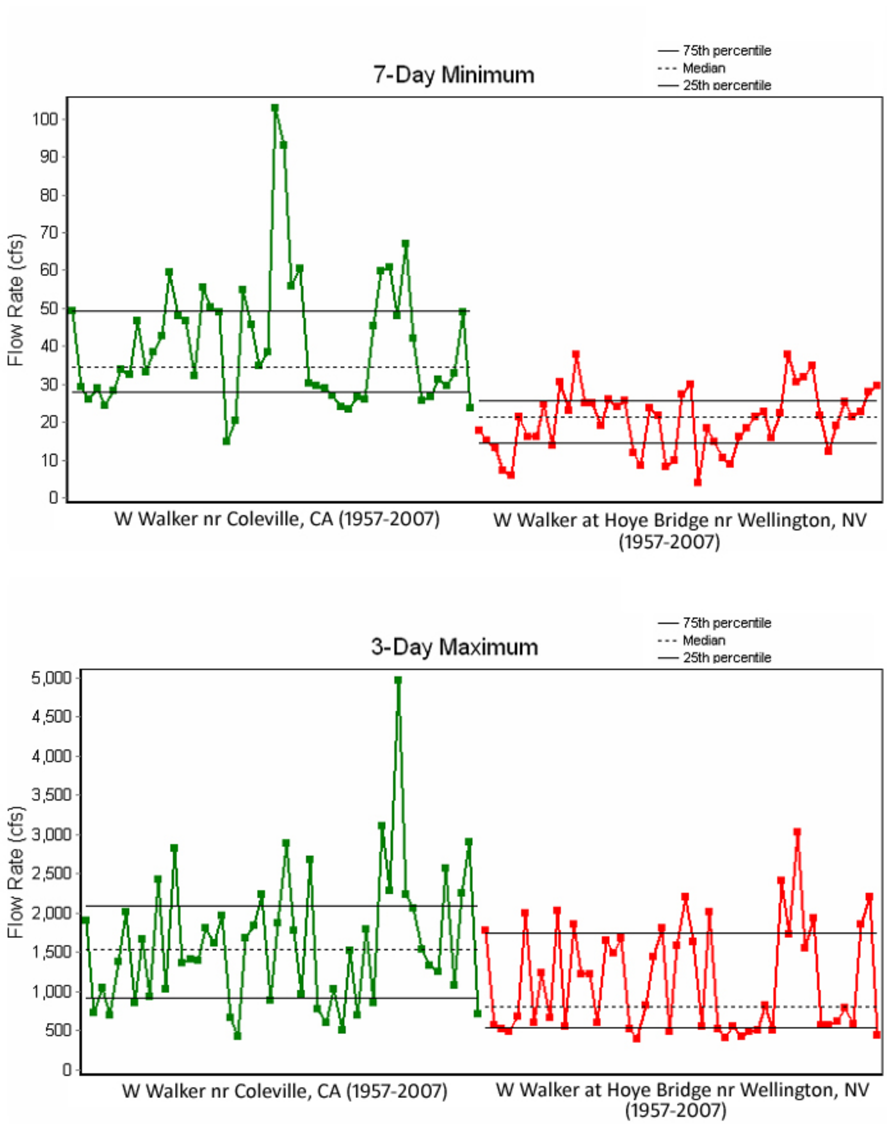
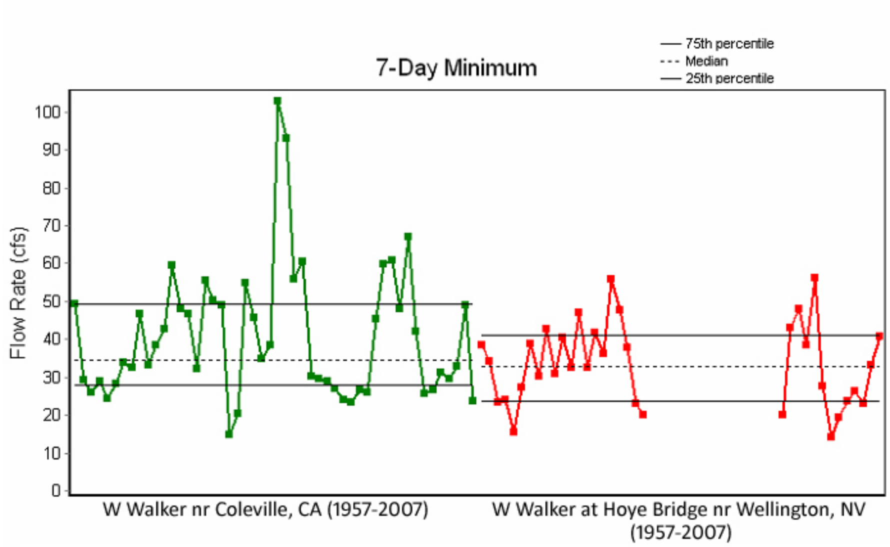


Figure 2.1-26. Comparison of 7-day minimum and 3-day maximum IHA analysis for the gages at Coleville and Hoye Bridge.

The same comparison was made between the reference hydrology of the gage near Coleville and the gage near Hudson (Figure 2.1-27). Interestingly, reductions in minimum flows are less between Hudson and the reference hydrology of Coleville than they were for Hoye Bridge. At Hudson there is a 4% decrease in the median 7-day minimum flow value. However, the reduction in peak flows of 55% is greater at Hudson than Hoye. There is a better maintenance of baseflows at Hudson, but greater loss of peak flow events.



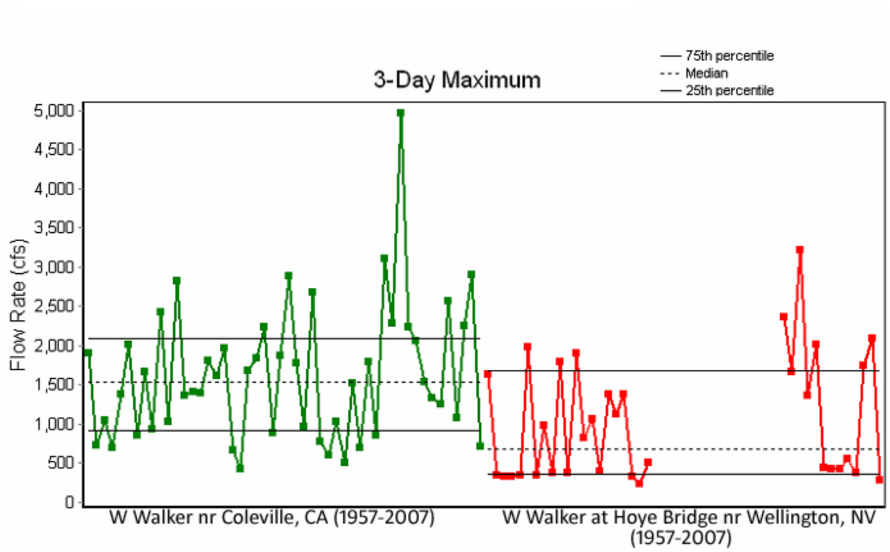


Figure 2.1-27. Comparison of 7-day minimum and 3-day maximum IHA analysis for the gages at Coleville and Hudson. The gap in data on the right represent periods when the gage did not operate.

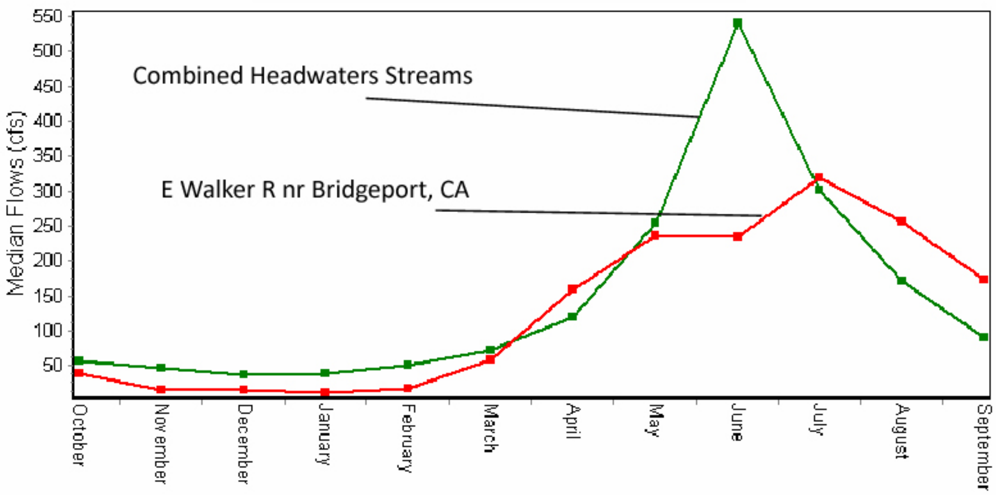
Natural spatial variation in streamflow would still be present on the West Walker even without anthropogenic influence. Natural differences in streamflow between gages could result from groundwater gains and losses or evapotranspiration. Giving one conceptual model as an example, one might expect streamflow to be naturally depleted at the upstream end of the valleys as surface water is lost to the shallow unconfined aquifer. This would be gained at the downstream end of the valleys as the river flows into a canyon, and groundwater is forced to the surface by the thinning alluvial aquifer. However, human water use provides a positive feedback that amplifies these natural water depletions.

EAST WALKER RIVER

The largest water resource management structure on the East Walker River is Bridgeport Reservoir. Though several other small dams and numerous diversions exist from the headwaters and throughout its length, none have the impact of Bridgeport Reservoir. The position of the reservoir on the East Walker and its operation, result in altered hydrology throughout the entire studied length of the river. Under natural conditions, the hydrology and geomorphology of the East Walker would be driven by an annual snowmelt hydrograph. However, the snowmelt pulse is immediately impounded by the reservoir, and a snowmelt hydrograph is not observed downstream.

There are less agricultural areas along the East Walker River in comparison to the West Walker. Therefore, there is reduced water depletion between valleys of the East Walker than the West Walker. In fact, a 10% increase was observed in the mean annual flow between the gage below Bridgeport Reservoir and the gage above Strosnider Ditch. This is compared to a 14% decrease between the mean annual discharge at the gage near Hoye Bridge and the gage near Hudson on the West Walker River.

The consistency of the geomorphology over the length of the East Walker River, and the dominant effect of Bridgeport Reservoir on the downstream hydrology of the East Walker River, strengthens the assumption that a comparison of the gage record below Bridgeport Reservoir with the combined gage records of the headwater streams flowing into the reservoir is sufficient to characterize alterations to the undisturbed hydrology of the East Walker River (Figure 2.1-28). The cumulative tributary flow record represents the reference natural hydrology for the East Walker River. The downstream effects of reservoirs have been studied extensively (Brandt, 2000; Grant et al., 2003). Reservoirs have been shown to have a significant impact on the downstream geomorphology and hydrology of rivers. Bridgeport Reservoir is no different in this regard, and appears to produce some of the typical impairments caused by irrigation storage dams: a reduction in the annual runoff peak, increased magnitude of flows on the declining limb of the hydrograph, and suppression of baseflow discharge during winter months.



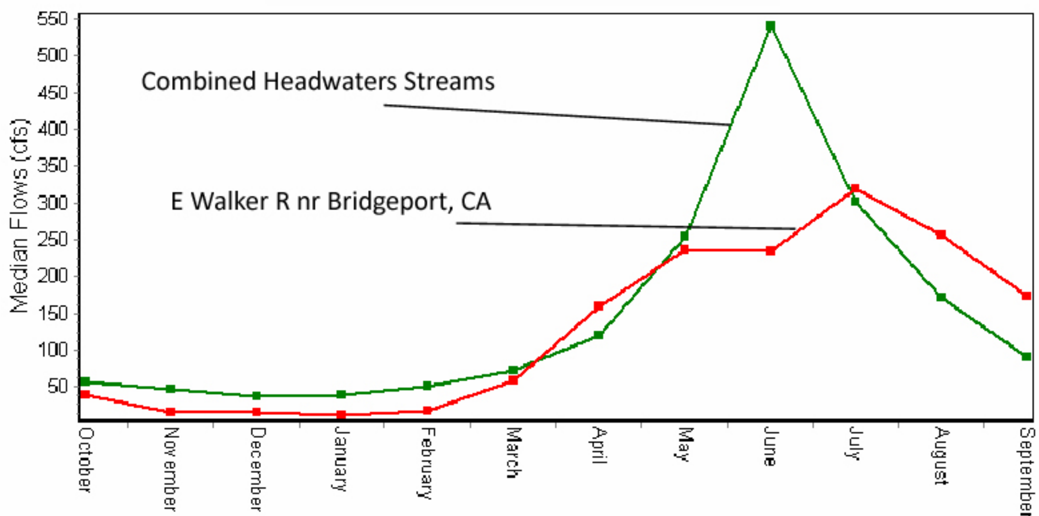


Figure 2.1-28. Comparison of monthly mean discharge values for the combined headwaters streams against the Bridgeport gage and against the gage above Strosnider ditch on the East Walker River. Note the reduction in peak discharge, and the increase in flows on the declining limb, and the reduction in winter base flows with similar patterns for both gages downstream of the reservoir.

Using the same flow records analyzed in Figure 2.1-28, IHA analysis was used to assess alterations to the 7-day minimum flows and the 3-day maximum flows below Bridgeport Reservoir and at the gage above Strosnider Ditch. The comparison shows a more drastic reduction in low flows than in high flows (Figure 2.1-29). While median values for high flows are 26% lower below the reservoir, median values for low flows are 71% lower below the reservoir. A reduction in spread between the 25th and 75th percentile values for low flows was observed.

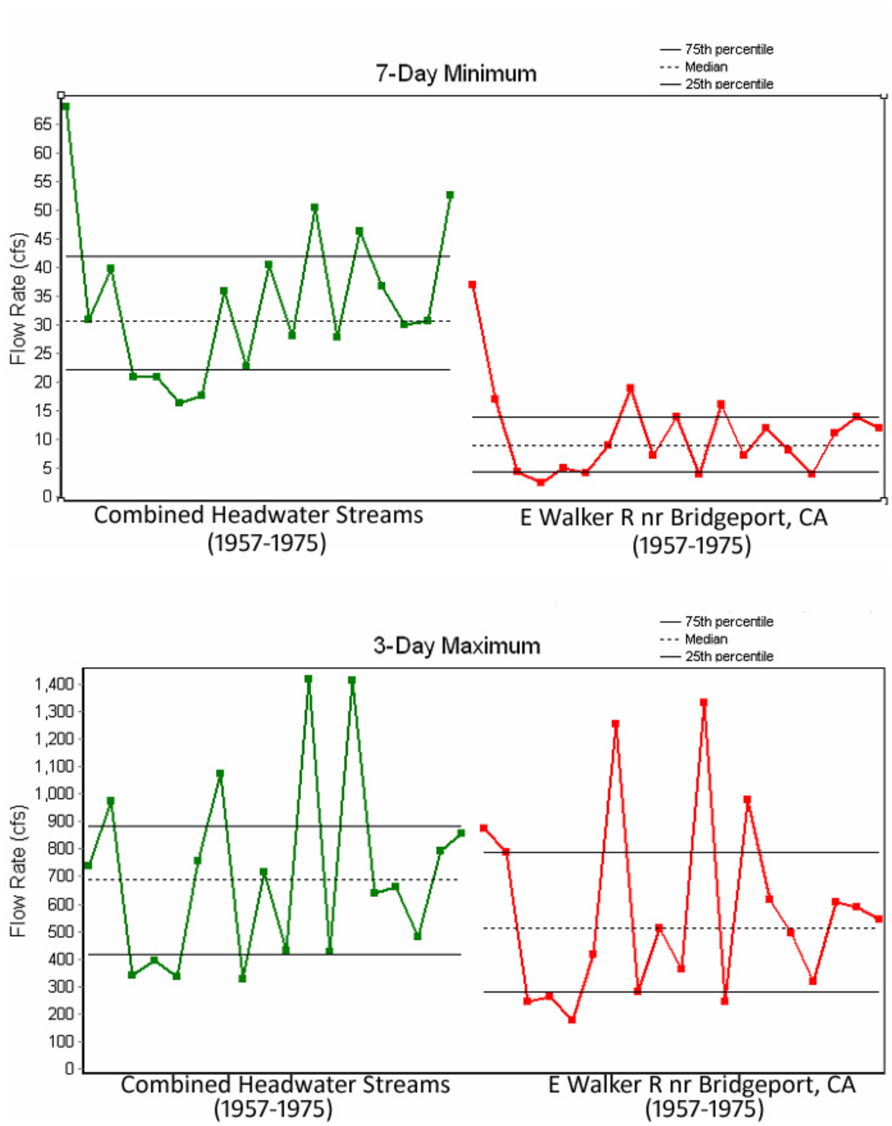


Figure 2.1-29. Comparison of 7-day minimum and 3-day maximum IHA analysis for the gages combining the inflow to Bridgeport Reservoir, and the gage below Bridgeport Reservoir.

Aside from large and immediate anthropogenic alterations to streamflow variation, natural losses and gains in streamflow might also be subdued on the East Walker in comparison to the West Walker and Walker Rivers. The East Walker River is continuously laterally confined with a fairly consistent slope and lacks valley/canyon alternating morphology. This might limit large swings in streamflow due to groundwater dynamics. On the East Walker, the largest driver of natural streamflow variation is likely to be evapotranspiration which would cause diel[39] fluctuation in response to daily increases in plant transpiration.

WALKER RIVER

The hydrology of the Walker River in Mason Valley is the product of the combined hydrology of the East and West Walker Rivers, as well as the effects of diversion within the valley. Mason Valley is the largest agricultural area in the Basin, and water consumption is significant. About 110,000 acre-ft of water are used in the valley each year (Horton, 1996). This use constitutes about 43% of the total agricultural water use in the Basin. As might be expected, comparison of the monthly mean values for the period of record at the gage near Wabuska to the combined reference inflow produced by adding the flow record at Coleville to the combined flow records of the tributary streams upstream of Bridgeport Reservoir suggests that flows for the entire hydrograph are reduced (Figure 2.1-30). This is particularly true for peak flows.

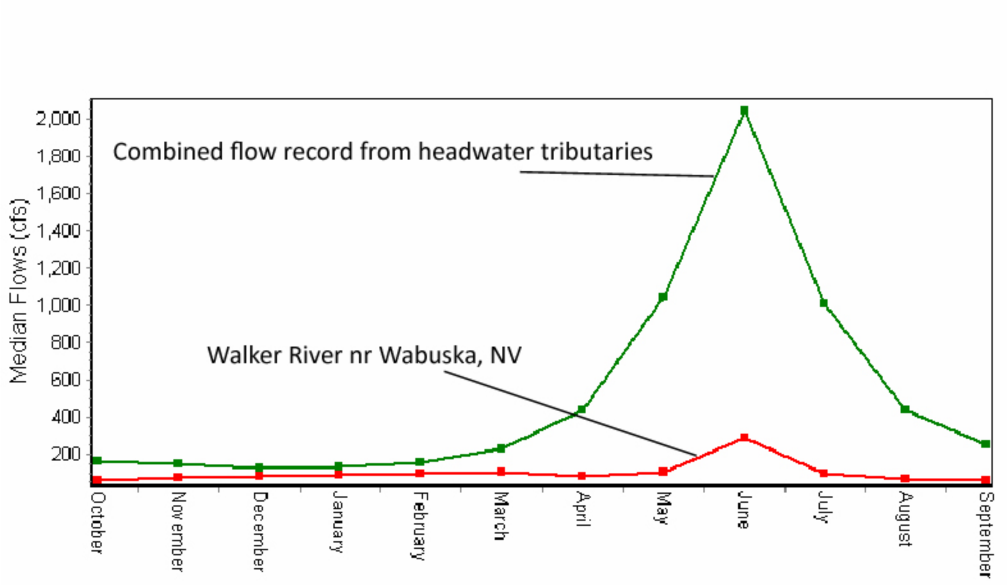


Figure 2.1-30. Comparison of monthly mean discharge values for the combined flows of the headwaters streams to the East and West Walker Rivers with the gage near Wabuska. Note the substantial reduction in rising limb, peak, and declining limb flows.

In applying an IHA style analysis to gain more detailed insight into the hydrology at the Wabuska gage, a comparison was completed of the combined reference flows of the East Walker and West Walker Rivers (Figure 2.1-31). These comparisons do not include years after 1975. Following that year, the gages on the headwaters went offline for several years, making a comparison of a longer time period impossible. However, the current water use was in-place during the represented time period. A comparison of the hydrology at Wabuska to the reference hydrology of the headwaters indicated both low and high flows are depressed. The mean value

[39] Referring to a 24-hour period usually used to record the fluctuation of a physical process, such as a diel temperature fluctuation.

of 7-day minimum flows at Wabuska for the period of comparison is 77% less than for the combined headwaters record. The variability between the 75th and 25th percentile of the low flows at Wabuska is less when compared to the headwater streams. Comparison of the mean 3-day maximum flows at Wabuska show that these representative high flows are 72% less than for the headwater streams.

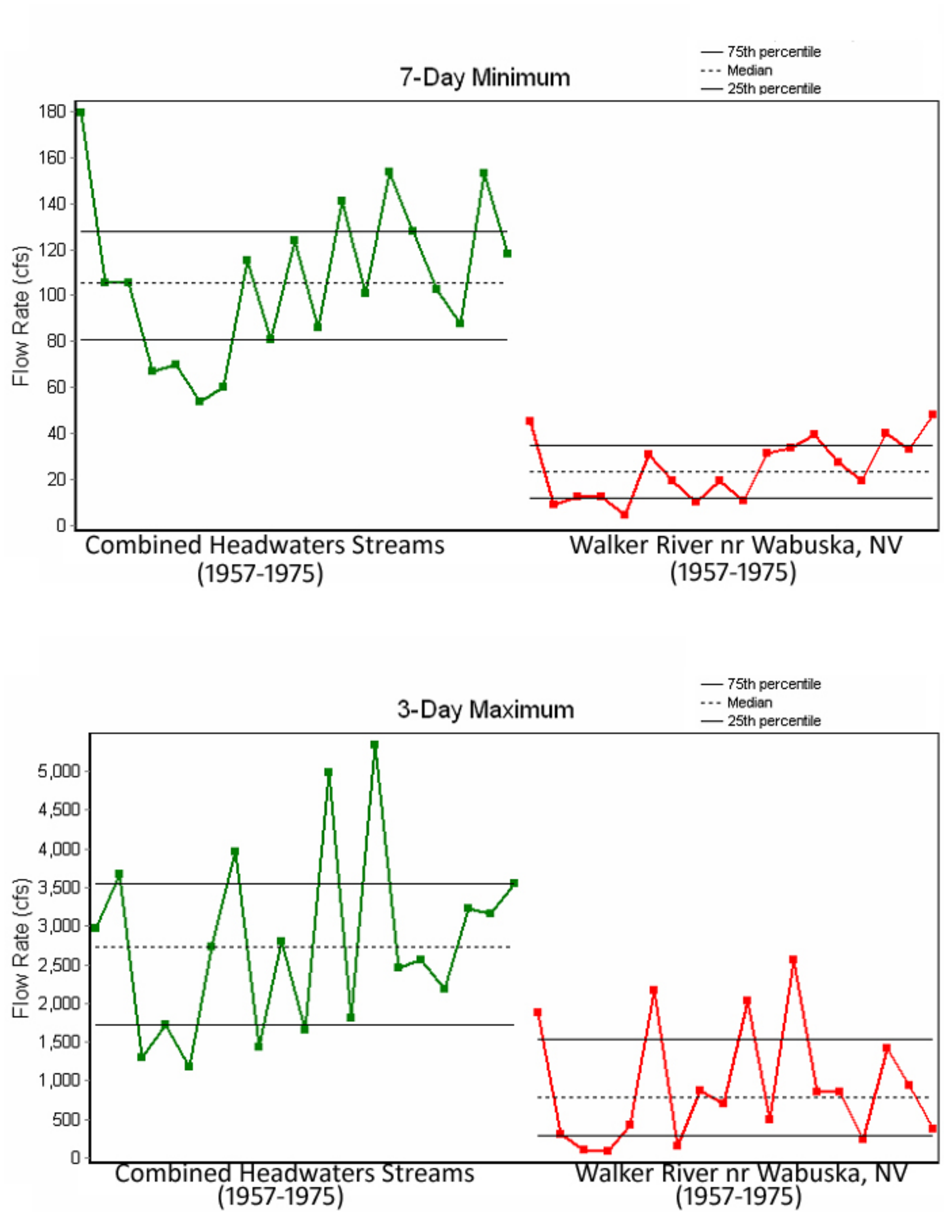


Figure 2.1-31. Comparison of 7-day minimum and 3-day maximum IHA analysis for the gages combining the natural reference flow records of the West Walker and East Walker Rivers with the gage at Wabuska on the Walker River.

Mason Valley is an area where surface streamflow might naturally be lost to the alluvial aquifer as the tributary rivers flowed out of their respective canyons and into Mason Valley. In any case, some attenuation of the annual runoff signal in a semi-arid basin is expected when comparing headwaters hydrology with a point far downstream. The degree to which this attenuation has been exacerbated by human water use is difficult to assess without a pre-disturbance record at each gage. However, an attempt can be made to determine the additional hydrologic alteration that takes place within Mason Valley by comparing the record at Wabuska to the combined flow at the East Walker River gage above Strosnider Ditch and the West Walker gage at Hudson. The pronounced differences in mean monthly flow values at Wabuska in comparison to the combined tributary inflow measured just upstream of the confluence suggests that water use in the valley is having a significant impact on the already altered flow regimes of the primary tributaries (Figure 2.1-32). Most obviously there is a large reduction in the runoff hydrograph including the rising limb, peak flows, and the declining limb. There is variable effect to the baseflow portion of the hydrograph with some reduced and some increased monthly mean flows.

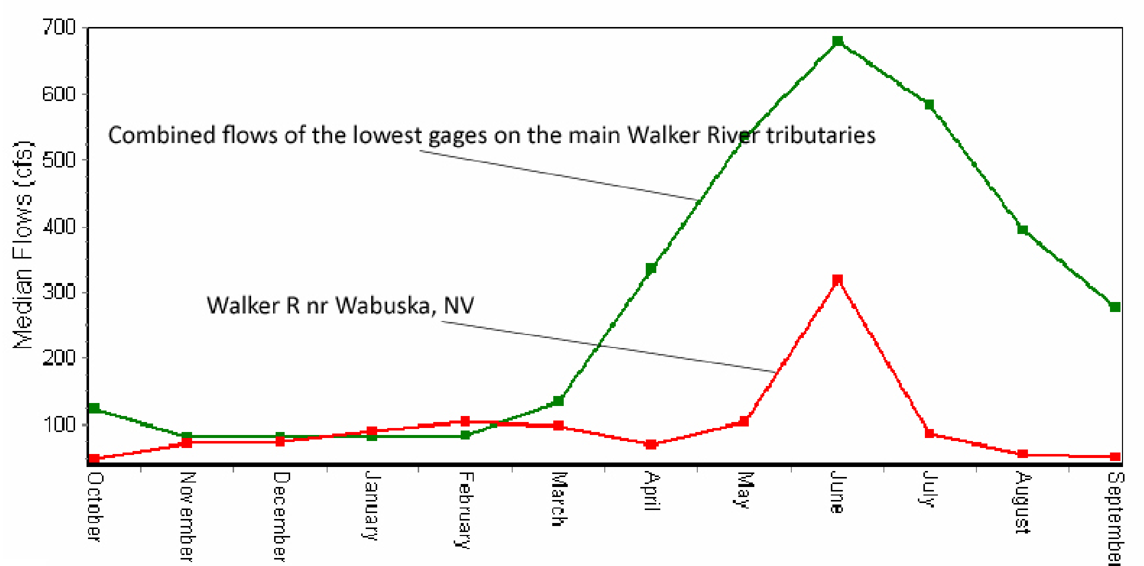


Figure 2.1-32. Comparison of monthly mean discharge values for the combined flows of the East and West Walker Rivers near the confluence with the gage near Wabuska.

An IHA analysis of the effects of water use in Mason Valley shows trends that are similar to alterations demonstrated for the West Walker and East Walker Rivers (Figure 2.1-33). Median values of low flows represented by the 7-day minimum have been reduced by about 69% at Wabuska in comparison to the combined inflow to Mason Valley. High flows represented by the median value for 3-day maximum flow have been reduced by about 18%.

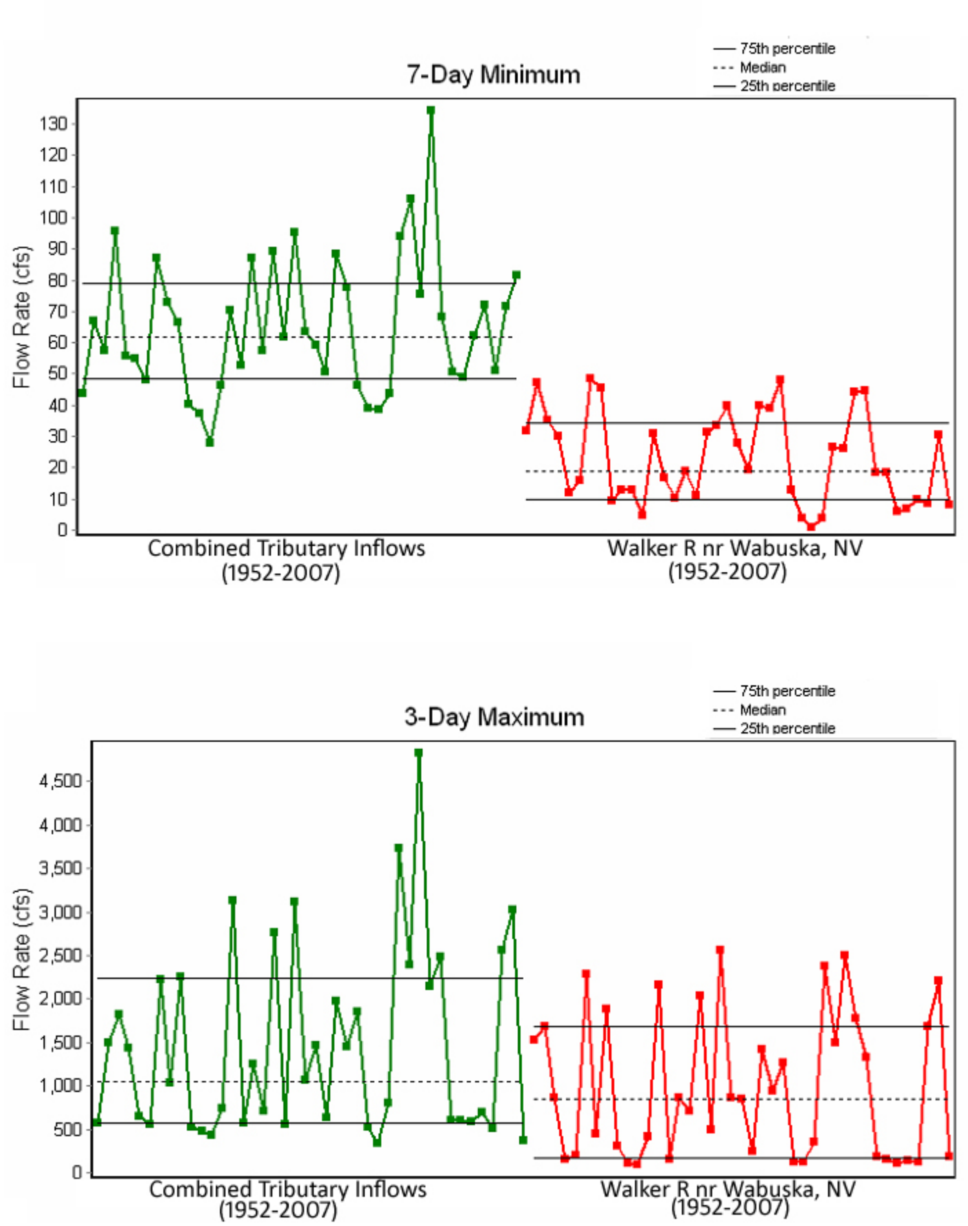


Figure 2.1-33. Comparison of 7-day minimum and 3-day maximum IHA analysis for the gages combining the flow records of the West Walker and East Walker Rivers measured near their confluence with the gage at Wabuska on the Walker River.

Below Mason Valley, hydrology is affected by the operation of Weber Reservoir. A significant difference between the hydrologic impacts of this reservoir and others found in the Basin is that the hydrologic signal upstream of the reservoir is already impacted by human activity. The operation of Weber Reservoir does not alter a natural signal, but further alters an impacted signal delivered from upstream. The effect of Weber Reservoir provides the final alteration before flows reach Walker Lake. Gage records of the Walker River near Wabuska were used to assess alteration to hydrology caused by the operation of Weber Reservoir. The effect of Weber

Reservoir on monthly mean flows is to reduce the peak, and translate it to an earlier point in time (Figure 2.1-34). Another interesting aspect of the hydrologic alteration below Weber Reservoir is that discharge reaches a baseflow level in June, when the rest of the Basin is seeing a peak in flow. These low flows are sustained through the summer months. The unique aspects of these alterations may be due to differences in operating procedures at Weber Reservoir. Performing an IHA analysis of 7-day minimum flows and 3-day maximum flows on these two gages shows that flow alteration has the most impact on low flows (Figure 2.1-35). The mean 7-day minimum flow at the lateral siphon near Schurz is being reported as zero. However, there has been some speculation as to the accuracy of this gage, and a zero flow reading is suspect. During the IHA analysis, about 90 no flow days were found for the period of comparison at the lateral siphon. The mean value for Wabuska for the 7-day minimum is 14 cfs, representing a 100% decrease in flows below Weber Reservoir for the representative lowest flows. High flows are essentially unaltered with only a 1% reduction in the 3-day maximum at the lateral siphon. Declining lake levels are likely to have an effect on groundwater gradients, and surface water discharge. However, no speculation will be offered on the specific effects without knowledge of the groundwater regime.

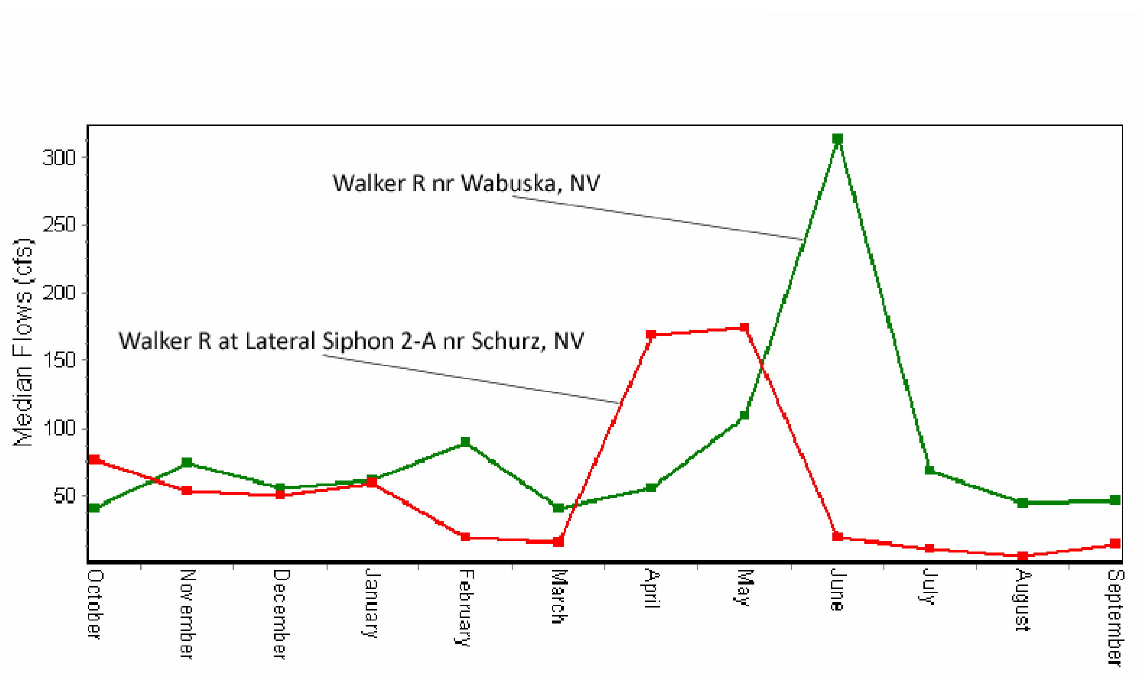


Figure 2.1-34. Comparison of monthly mean discharge values for the gage near Wabuska with the gage at Lateral Siphon 2-A near Schurz. Note the reduction in peak discharge and a temporal translation to earlier time.

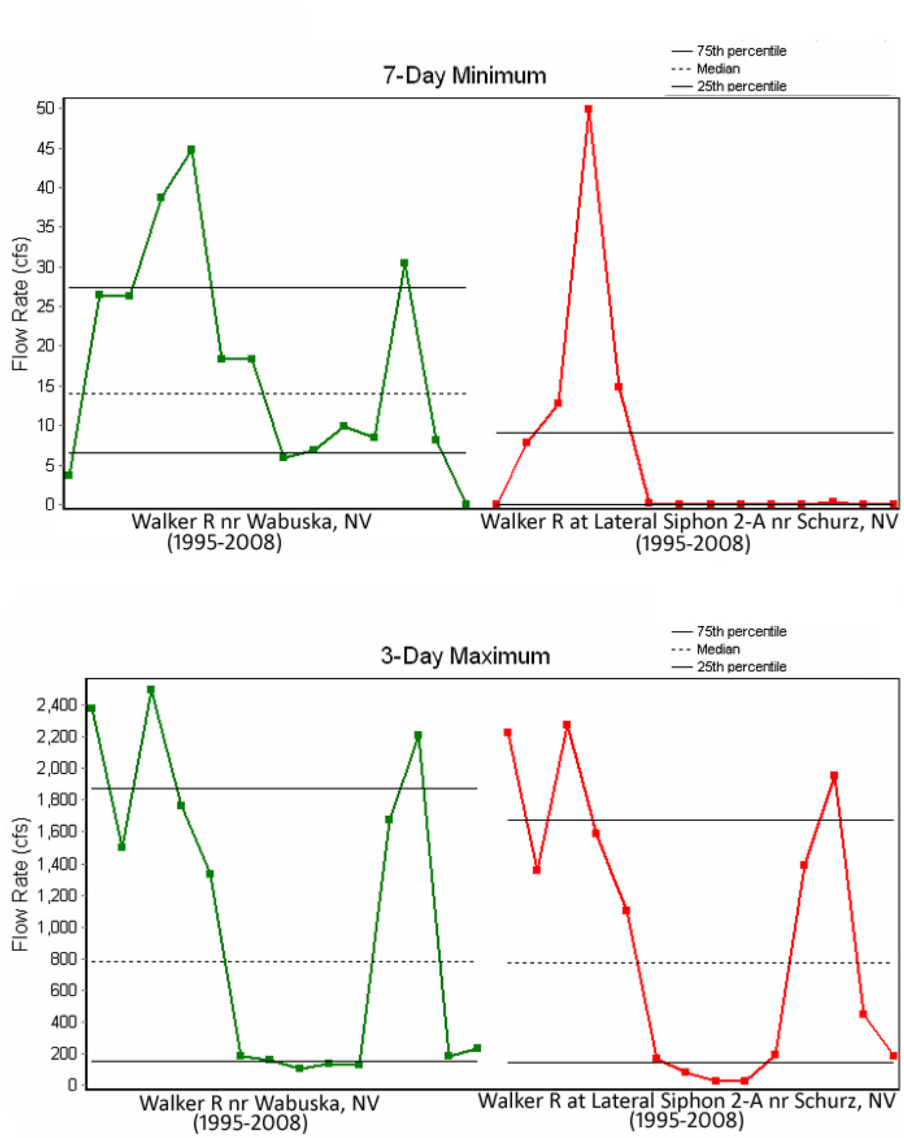


Figure 2.1-35. Comparison of 7-day minimum and 3-day maximum IHA analysis for the gage near Wabuska with the gage at lateral siphon 2-A near Schurz.

Even in an unaltered system, it is unlikely that the hydrology of the lower Walker River would exactly resemble the snowmelt hydrographs of the upper Basin. There would be natural reductions in flood peaks, and attenuation of the flood signal with longer rising and falling limbs of the hydrograph. These changes would be influenced by groundwater gains and losses, evapotranspiration, and attenuation of peak flows through overbank flooding upstream. The expected effects of these types of natural hydrologic processes are not reflected in the comparisons above. The alterations to natural hydrology and subsequent alterations moving downstream, show clear indication that anthropogenic activity is changing the natural flow regime.

2.1.4 Geomorphic Analysis

2.1.4.1 West Walker River Geomorphic Segment Descriptions

The geomorphic segment is the basic spatial unit of analysis in the geomorphic assessment of the Basin. The analyses of processes or forms at smaller or larger scales use segments for reference. Therefore, descriptions of each segment for the West Walker River are presented here first.

WEST WALKER 2

The segment can generally be described as alternating meandering alluvial channels divided by high gradient canyons with step-pool morphology. In the alluvial portions of the segment, the river has incised glacial outwash deposits, and formed an inset floodplain along the eastern portions of their respective valleys. The canyon portions of the segment have little or no floodplain.

Table 2.1-5. Summary of some physical characteristics of West Walker 2 (WW2).

Distance from Walker Lake (to upstream end of segment) (mi)	134
Segment Length (mi)	12
Upstream Elevation (ft)	7,198
Channel Slope	0.01
Valley Slope	0.013
Sinuosity	1.32
Average Width (ft)	43
Median Grain Size of Bed Material (mm)	30

WW2 consists of Pickel and Leavitt Meadows, and two canyon reaches separating the meadows within the Sierra Nevada Mountains (Figure 2.1-36). Some consideration was given to making segment divisions between these alternating canyons meadow sections which would have added several additional segments for study without increasing the understanding of the geomorphology of the area. It was effective to include these areas in one segment that encompassed the geomorphology of the headwaters region. The morphology of these reaches is partially affected by a relatively recent history of glaciation. Glacial deposits of Tioga (12-24 ka) and Tahoe (59 to 74 ka) age are found in the area (Dohrenwend, 1982). Other major depositional features include land slide and alluvial fan deposits.

The meadow sections can be generally characterized as low gradient meandering streams with sand and gravel beds. Well developed floodplains are present within the meadows exhibiting evidence of channel migration including meander[40] scars, and oxbows on the floodplain, and cut-banks and point bar development in the channel. In Leavitt Meadow, active floodplain surfaces are vegetated mainly by willow and other small shrubs, and sage, pine, and aspen on higher elevation surfaces. Limited riparian vegetation is present in Pickel Meadow. Separating the two meadows is a deeply incised (~300 ft) high gradient canyon displaying a cobble and boulder bed

[40] One of a series of regular, freely developing sinuous curves, bends, or loops in the course of a river.

organized into cascade/pool morphology. Within the canyon, high cut banks (~15 to 60 ft) in many places expose unconsolidated hillslope and alluvial material. As the river flows out of Pickel Meadow, the valley becomes increasingly confined, and the gradient increases.

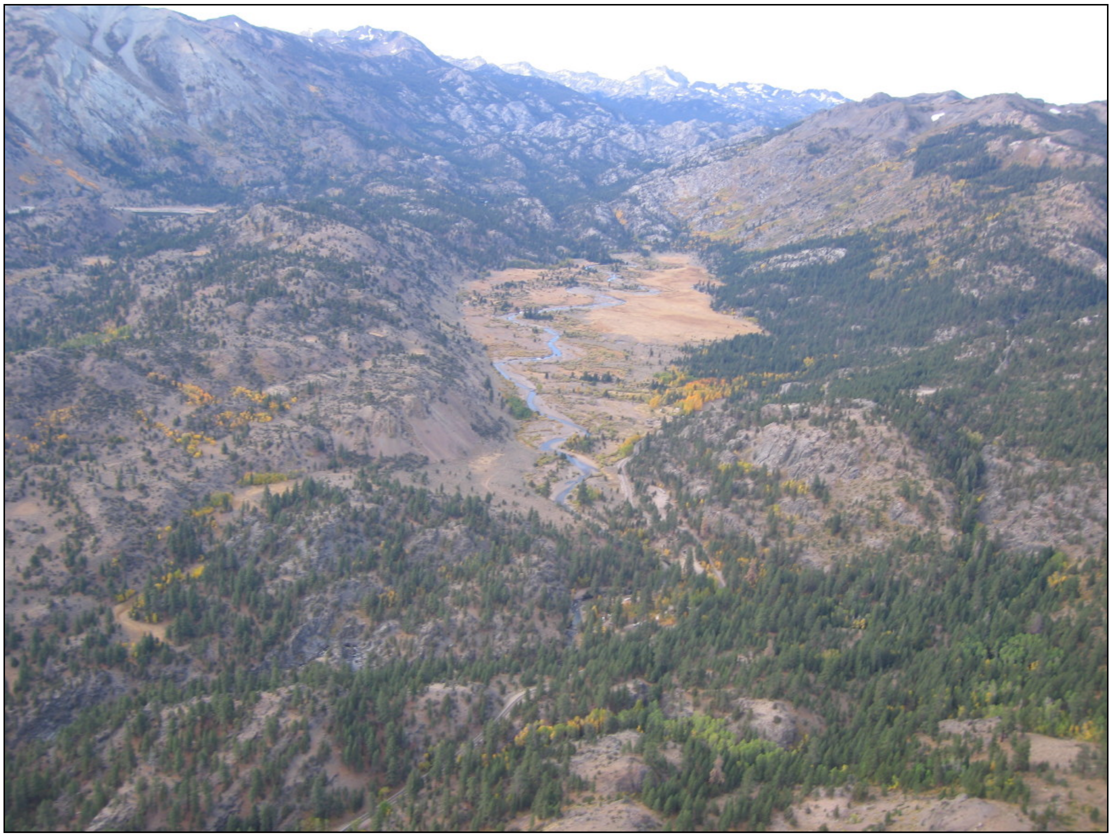


Figure 2.1-36. Oblique aerial photo of Leavitt Meadow on the West Walker River with a view looking upstream toward the crest of the Sierra Nevada. The photograph illustrates the alternate valley-canyon morphology typical of segment WW2.

WEST WALKER 3

The segment can generally be described as a steep, laterally confined channel with riffle-pool, or step pool bed morphology. There is limited floodplain width in this segment.

Table 2.1-6. Summary of some physical characteristics of West Walker 3 (WW3).

Distance from Walker Lake (to upstream end of segment) (mi)	122
Segment Length (mi)	11.3
Upstream Elevation (ft)	6,581
Channel Slope	0.019
Valley Slope	0.021
Sinuosity	1.11
Average Width (ft)	45
Median Grain Size of Bed Material (mm)	137

WW3 begins just downstream of the West Walker's confluence with the Little Walker River. Here, the river enters a high gradient canyon with the Sierra Nevada to the west, and the Sweetwater Range to the east (Figure 2.1-37). The canyon is structurally controlled by the West Walker River fault zone (Sawyer, 1995). This fault zone is a region of down-to-the-east normal faults with recent (< 20 ka) movement. The canyon width and the Highway 395 roadway laterally confine the river in this segment. The bed substrate within this segment is composed mainly of coarse material ranging from gravel to boulder. This material is organized into reaches that are dominated by gravel and cobble and have pool-riffle morphology, and reaches that are dominated by coarser cobbles and boulders and have step-pool or boulder cascade morphology. Lower gradient reaches within the segment are accumulation zones for gravel and contain some large gravel bars. Hillslope material is often deposited directly into or very near the stream in this reach creating potential sediment sources. Following the flooding of 1997, significant channel and bank modification took place within the segment. In some areas stream banks were rip-rapped, and grouted.

Figure 2.1-37. Low elevation oblique aerial photograph of the West Walker River in segment WW3. The view is looking upstream toward the crest of the Sierra. The photo captures the narrow valley confinement and direct hillslope connection to the channel in many locations.

WEST WALKER 4

The segment can generally be described as meandering and alluvial, forming as the West Walker flows into Antelope Valley from the canyon upstream. The valley becomes wide, and relic channel and meander scars suggest a historically wide floodplain.

Table 2.1-7. Summary of some physical characteristics of West Walker 4 (WW4).

Distance from Walker Lake (to upstream end of segment) (mi)	112
Segment Length (mi)	11.7
Upstream Elevation (ft)	5,439
Channel Slope	0.007
Valley Slope	0.009
Sinuosity	1.26
Average Width (ft)	68
Median Grain Size of Bed Material (mm)	-

At the upstream end of WW4, the West Walker River flows into Antelope Valley (Figure 2.1-38). Antelope Valley is an extensional graben controlled by faults on the west and east sides of the valley (Sawyer et. al., 1998). The faults on the west edge are down-to-the-east normal faults that form high range-front escarpments. To the east, the geomorphic expression of fault traces is less pronounced, and the type of movement less well known. Entering the valley, the river flows along the steep front of the Sierra Nevada on the west side of the valley at the edge of Holocene age alluvial fan deposits (Dohrenwend, 1982). Aerial photos suggest historic east to west channel migration. Long, coalescing alluvial fans of Holocene and Pleistocene age, border the valley to the east. They originate from the foothills of the Sweetwater Range, and the Wellington Hills. Much of historic alluvial valley is now utilized for agricultural activity. Near the river and above the active floodplain, there is a broad, sagebrush flat composed of poorly sorted cobbles to silt that Dohrenwend (1982) suggests is undifferentiated Holocene basin fill. Nearer the channel there is a well developed inset floodplain composed of sand and covered by riparian vegetation including willow and Russian olive. Active bars within the channel are composed of sand and gravel. The banks in this segment include both fine and gravelly material and are vertical and eroding in places. Bank erosion is not widespread and occurs mainly on meander bends and may be more or less balanced by floodplain deposition.

Figure 2.1-38. Low elevation oblique aerial photo of the West Walker River in WW4 in the Antelope Valley. The view is looking upstream. Note the geomorphic features in the foreground such as channel scars on the floodplain, and the large point bars in the active channel.

WEST WALKER 5

The segment can generally be described as low-gradient, meandering, and alluvial. However, valley width decreases in this segment, and the channel impinges against hillslopes at some locations, particularly near the downstream end.

Table 2.1-8. Summary of some physical characteristics of West Walker 5 (WW5).

Distance from Walker Lake (to upstream end of segment) (mi)	101
Segment Length (mi)	16.6
Upstream Elevation (ft)	5,006
Channel Slope	0.001
Valley Slope	0.0018
Sinuosity	1.76
Average Width (ft)	53
Median Grain Size of Bed Material (mm)	2.5

WW5 begins just downstream of the Topaz Reservoir diversion. It is still within the Antelope Valley and is affected by the same regional geology as WW4. The portion of the segment between the Topaz Reservoir diversion and the Topaz Reservoir return flow is somewhat dewatered relative to the channel downstream of the return flow. In general, this segment can be characterized as a low-gradient, sinuous stream flowing over a sand and gravel bed, though there appear to be sections of straightened channel (Figure 2.1-39). A fairly extensive riparian zone and active floodplain are maintained in this segment. Significant evidence of channel migration in the form of abandoned meander loops, scroll bar deposits, meander scars, and oxbows are apparent. In-channel deposition occurs in the form of point bars, and alternating bars. Valley confinement increases downstream as the river turns to flow northeast and encounters broad alluvial fans that slope to the valley floor from the Wellington Hills to the southeast, and shorter fans are generated from the Pine Nut Mountains to the northwest.

Figure 2.1-39. Low elevation oblique aerial photograph of the West Walker River in WW5. The view is looking upstream. The return flow canal of Topaz Reservoir can be seen in the upper right-hand corner of the image.

WEST WALKER 6

The segment can generally be described as a steep, laterally confined canyon with riffle-pool bed morphology, and laterally limited floodplain width.

Table 2.1-9. Summary of some physical characteristics of West Walker 6 (WW6).

Distance from Walker Lake (to upstream end of segment) (mi)	87
Segment Length (mi)	2.5
Upstream Elevation (ft)	4,939
Channel Slope	0.008
Valley Slope	0.009
Sinuosity	1.17
Average Width (ft)	47
Median Grain Size of Bed Material (mm)	95

Segment WW6 flows through Hoye Canyon (Figure 2.1-40), forming a gap at the northwest extent of the Wellington Hills, and southeast extent of the Pine Nut Mountains. These mountain ranges compose a west-tilted structural block controlled by small discontinuous normal faults to the west, and a long continuous zone of normal faults to the east called the Smith Valley fault zone (Adams and Sawyer, 1998b, 1999b). Within the canyon, the river is narrowly confined, and high-gradient. Hillslope deposits frequently reach the valley floor delivering coarse material to the stream. This material creates localized constrictions which cause upstream backwaters, and downstream riffles. The river meanders within the narrow curvature of the canyon, and there is deposition of narrow gravel point bars. Some of these point bars are capped by, or contain inset sand deposits. In the wider portions of the canyon, a narrow, heavily vegetated depositional surface has developed about 8 ft above the current elevation of the channel. An irrigation ditch parallels the river through the canyon and a large diversion dam at the downstream end of the canyon provides additional irrigation to the Smith Valley.

Figure 2.1-40. This aerial photograph was taken looking upstream at Hoye Canyon, and WW6. The view is looking upstream. Antelope Valley is visible in the upper background.

WEST WALKER 7

The segment starts at another point of transition between canyon and valley morphology, and can generally be described as low-gradient, and historically meandering though some channelization appears to have taken place.

Table 2.1-10. Summary of some physical characteristics of West Walker 7 (WW7).

Distance from Walker Lake (to upstream end of segment) (mi)	85
Segment Length (mi)	10.9
Upstream Elevation (ft)	4,819
Channel Slope	0.0025
Valley Slope	0.003
Sinuosity	1.17
Average Width (ft)	56
Median Grain Size of Bed Material (mm)	-

At the upstream end of WW7, the West Walker River exits Hoye canyon and flows into Smith Valley (Figure 2.1-41). In this segment, the West Walker is wholly within the Basin and Range physiographic province. The geology and geomorphology of the Smith Valley is typical of this region. The valley is a graben bound by normal faults to the east and west. Pronounced range front escarpments are formed on the up-thrown range, and alluvial fans deliver sediment to the downthrown basin. Initially the river flows north along the western edge of the valley at the foot of the Pine Nut Mountains. The river then turns, flowing northeast across the width of the valley towards the Singatse Range. Within the valley, the river is low-gradient, and relatively low sinuosity. Oxbows and meander scars suggest evidence of a historically sinuous channel, particularly at the upstream end of the segment. Agricultural development has obscured much of the historic floodplain. In many locations, agricultural fields encroach onto the river, particularly to the east.

Figure 2.1-41. The aerial photograph was taken over the Smith Valley, and depicts the West Walker River in WW7. The view is looking upstream. Notice the artificially straightened channel. This section of channel was sinuous in 1938.

WEST WALKER 8

The segment can generally be described as a low-gradient, with a meander pattern that is laterally restricted as the river incises alluvial fan deposits.

Table 2.1-11. Summary of some physical characteristics of West Walker 8 (WW8).

Distance from Walker Lake (to upstream end of segment) (mi)	74
Segment Length (mi)	5
Upstream Elevation (ft)	4,682
Channel Slope	0.003
Valley Slope	0.004
Sinuosity	1.3
Average Width (ft)	53
Median Grain Size of Bed Material (mm)	0.72

As the river flows northeast across the Smith Valley, it begins to incise alluvial fan deposits generated from the Singatse Range to the east. The width of the alluvial valley becomes increasingly confined downstream. Channel sinuosity in WW8 increases relative to WW7, meandering across a narrow floodplain exhibiting some riparian vegetation, which can be dense near the stream. Agricultural activity is minor in this portion of the valley. The channel in this segment appears to be broad and shallow with deposition of sand and small gravel in longitudinal and point bars (Figure 2.1-42).

Figure 2.1-42. Aerial photograph depicting the West Walker River flowing through the downstream end of the Smith Valley in WW8. The view is looking downstream. Despite increasing valley confinement as the river incises alluvial fan deposits, the channel is more sinuous than in other parts of the valley. (Google Earth, 2008).

WEST WALKER 9

The segment can generally be described as a steep, confined canyon with riffle-pool bed morphology and little to no floodplain.

Table 2.1-12. Summary of some physical characteristics of West Walker 9 (WW9).

Distance from Walker Lake (to upstream end of segment) (mi)	69.5
Segment Length (mi)	1.8
Upstream Elevation (ft)	4,651
Channel Slope	0.012
Valley Slope	0.014
Sinuosity	1.13
Average Width (ft)	35
Median Grain Size of Bed Material (mm)	73

The West Walker River flows through Wilson Canyon in WW9 (Figure 2.1-43). This canyon bisects the Singatse Range, the structural footwall of normal faults in the Singatse Range fault zone that runs along the eastern edge of the range (Adams and Sawyer, 1999a). Within the canyon, the river is narrowly confined, being directly constrained by bedrock outcrops in some locations, and by the road corridor. The gradient is steep, and the stream bed is composed of cobble/boulder size material organized in riffle-pool sequences. Adjacent hillslopes and side-canyons deliver colluvium directly to, or very near, the channel in many locations. Sand to cobble size material is deposited on the insides of bends, and longitudinal bars. A narrow, well vegetated riparian zone and floodplain is set within the confines of the road and canyon walls.

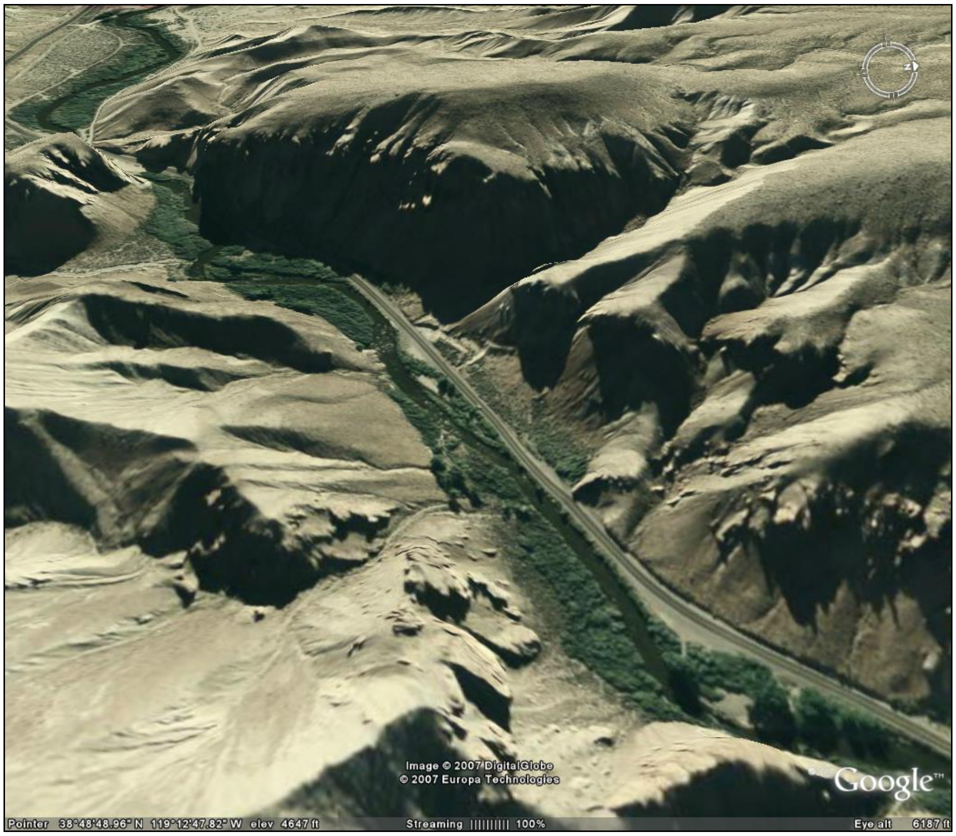


Figure 2.1-43. Aerial photograph of the West Walker River flowing through Wilson Canyon in WW9. Flow is from the top left corner to the bottom right corner of the image. Here the narrow valley and roadway confine the channel planform and link hillslope processes directly to the channel. (Google Earth, 2008).

WEST WALKER 10

The segment can generally be described as low-gradient, and freely meandering with evidence of channel migration over a relatively wide area.

Table 2.1-13. Summary of some physical characteristics of West Walker 10 (WW10).

Distance from Walker Lake (to upstream end of segment) (mi)	67.8
Segment Length (mi)	7.1
Upstream Elevation (ft)	4,551
Channel Slope	0.003
Valley Slope	0.004
Sinuosity	1.3
Average Width (ft)	47
Median Grain Size of Bed Material (mm)	-

Upon exiting Wilson Canyon, the West Walker River flows north into Mason Valley and WW10 (Figure 2.1-44). Its position along the extreme western edge of its modern floodplain is likely the result of down-to-the-east movement along normal faults in the Singatse Range fault zone. The river is low-gradient and sinuous in this segment. Abundant oxbows and meander scars are visible on the floodplain, indicating active channel migration in the past. Much of the potential historic floodplain has been developed for agricultural purposes. Some fairly wide floodplain areas are still present, with relatively extensive riparian vegetation. Aerial photos suggest the presence of some significant side-channel or sloughs in this segment.

Figure 2.1-44. Aerial photograph of the West Walker River exiting Wilson Canyon and flowing north into the Mason Valley toward its confluence with the East Walker River. The view is looking upstream. As the river flows into the valley, sinuosity increases, and has been relatively unimpeded by agricultural development. (Google Earth, 2008).

2.1.4.2 <u>Historic Channel Change of the West Walker River</u>

An analysis and comparison of historic and current channel planform is a primary component of the geomorphic assessment. In this analysis of channel planform, changes in sinuosity and channel length, active channel area, and channel width were compared. The nature of changes in these attributes over time can be used to infer trends in geomorphic process. Please note that more detailed interpretation of planform change will follow the completion of various research projects currently underway in the Basin. Methodologies for air photo interpretation and evaluating channel change are described in section 2.1.1.3 of this report. The results of the photo analysis for the West Walker River are shown in Figure 2.1-45. The complete set of 2006 photos with all the digitized layers of the historical analysis are shown in Appendix A.

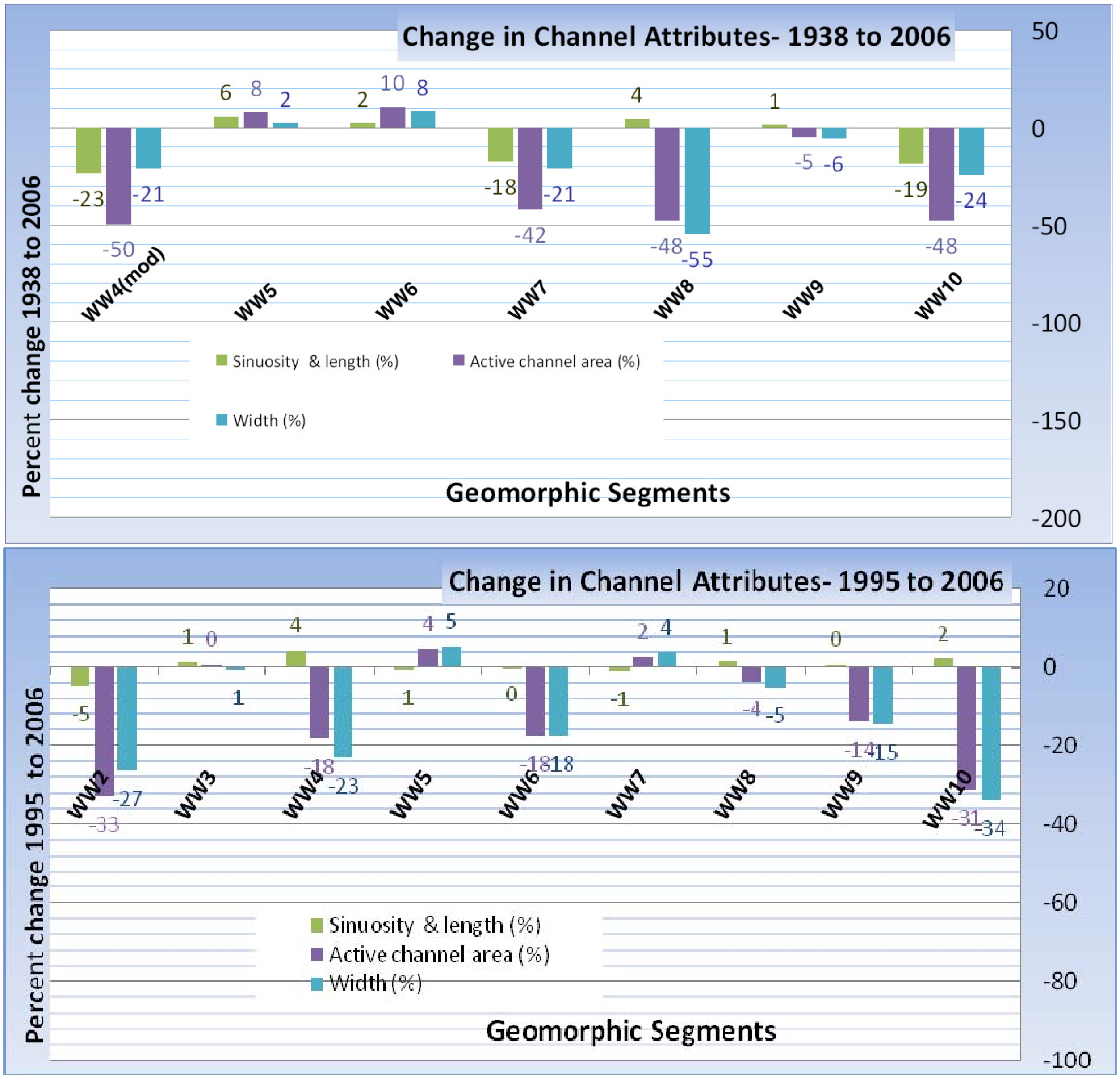


Figure 2.1-45. Results of the photo analysis for the West Walker River. Top figure compares 1938 to 2006; bottom figure compares 1995 to 2006.

Looking at the results, some trends are noteworthy:

- The magnitude of change is greater from 1938 to the present when compared to more recent changes, despite the 1997 flood.
- With the exception of WW5 and WW6, most segments analyzed have narrowed and the active channel area has been reduced. This is true when comparing both 1938 to 2006, and 1995 to 2006.
- Most changes to sinuosity and length were reductions reflected in the analysis of the time period 1930 to present. Reductions in sinuosity and length are not as notable curing more recent times.
- Any increases in width, active channel area, sinuosity, or length are small in comparison to reductions in these metrics.

More specific segment results are discussed below. Reference to planform adjustment in the following text is for the period from 1938 to the present. The GIS analysis is shown in its entirety in Appendix A.

WEST WALKER 2

The headwaters of the West Walker River flow out of wilderness areas on the Sierra crest, and are relatively pristine. Photos from 1938 were not obtained for this area, but geomorphic evidence for channel change is found in the meadow areas in the form of meander scars, and point bar deposition with opposing cut-bank erosion. It is expected that the lower gradient alluvial channels are much more adjustable than segments where the channel is confined by coarse boulders and bedrock.

Changes to the alignment of the West Walker River in Leavitt Meadows are evident when comparing the 1995 and 2006 photo sets, which bracket the 1997 flood (Figure 2.1-46). In some places the river moved 300 ft laterally. The largest channel movements occur where meanders appear to have been cut off, and the channel has naturally straightened out. The most recent aerial photography of Leavitt Meadows shows large, unvegetated point bars on the inside of many bends, suggesting point bar building. The channel above the meadows is quite steep (0.03 slope) when compared to the meadow (0.005 slope). The steep headwater areas rapidly deliver water and sediment to the meadow. The velocity of the river slows upon entering the meadow, causing deposition that may instigate a change in the river’s course during high runoff periods and supply material for point bar development.

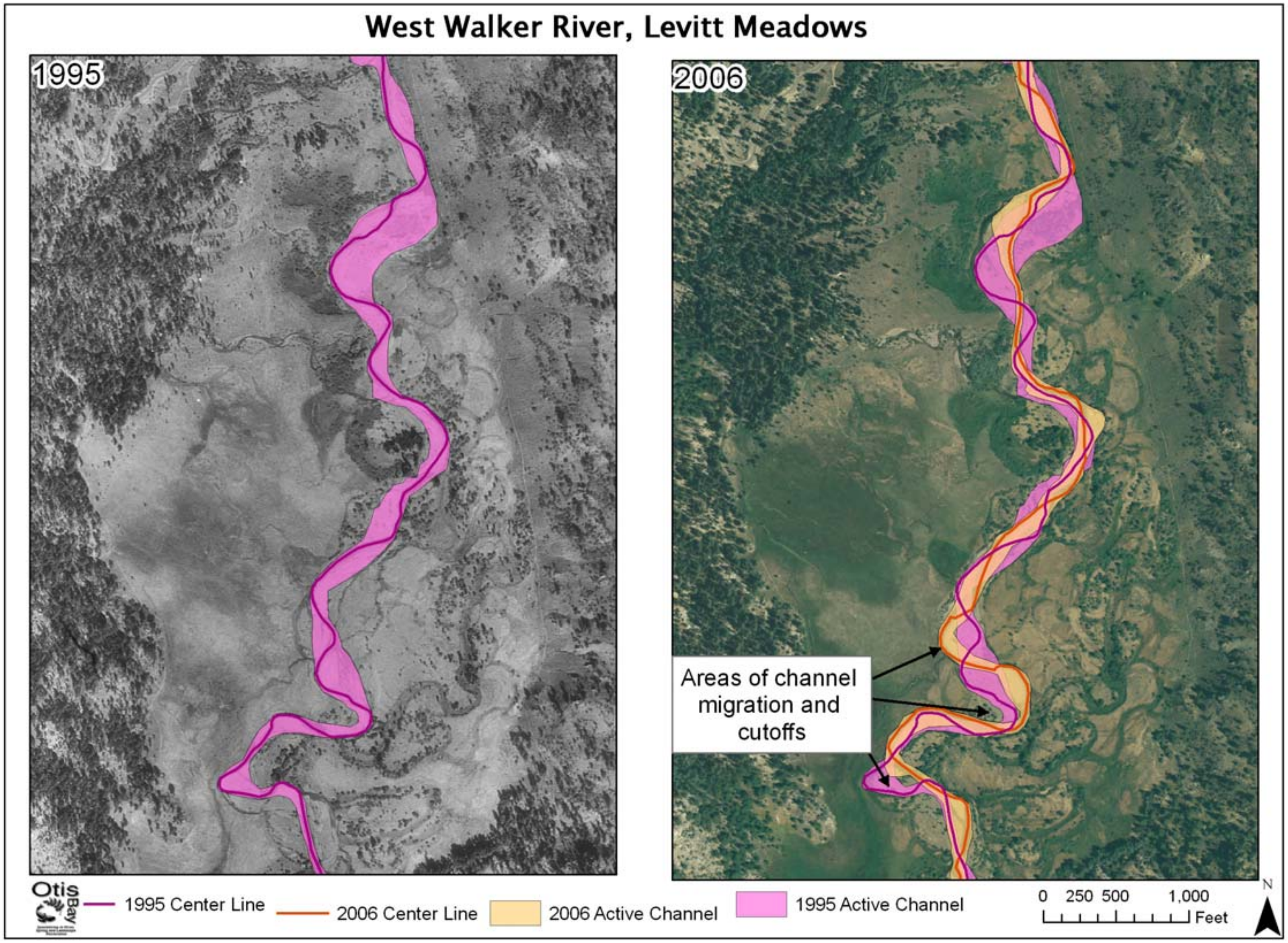


Figure 2.1-46. 1995 and 2006 aerial photos showing channel change in segment WW2, Leavitt Meadows. Flow is from bottom to top.

WEST WALKER 3

The West Walker River flows through a steep canyon between the Sierra front and the Sweetwater Range in WW3. Its proximity to these steep hillslopes, which are composed of weathered granite and easily erodible volcanic deposits, creates a geomorphically active environment. Hillslope processes are a driving force for channel form in this segment as evidenced by numerous debris flow paths and active erosional features at the hillslope/channel interface (Figure 2.1-47 through Figure 2.1-50). Despite these active features, lateral confinement and coarse bed material limit the magnitude of channel adjustment that is possible in this segment, and little net change has occurred in sinuosity, length, or channel width since 1938.

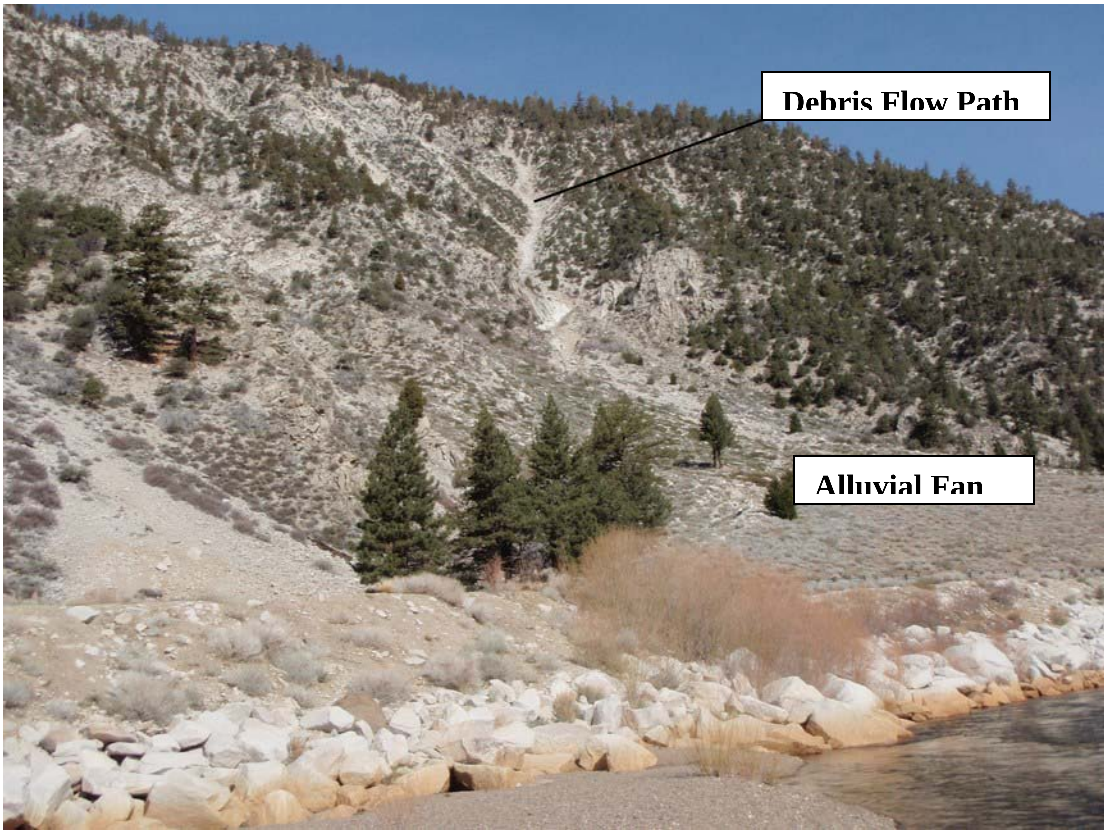


Figure 2.1-47. Debris flow paths above West Walker River near Chris Flat. Material delivered along this path drives channel adjustment at this location.

Figure 2.1-48. Active erosion at toe of slope contributes sediment to the West Walker River downstream of Chris Flat, with fine material being carried away, and coarse material being added to the bed. The view is looking downstream.

Despite its dynamic nature, this canyon has been found to be the easiest roadway through the mountains in this area. Therefore, the channel has had to be altered and armored to accommodate roads in this rugged environment (Figure 2.1-47 through Figure 2.1-50). Streambank armoring, and highway maintenance serve to limit the tolerable lateral adjustment of the channel in WW3, another factor contributing to small overall change in planform characteristics since 1938.

Figure 2.1-49. A postcard of the Walker Canyon from the 1930s, note the riprap and lack of riparian vegetation on the corner (from http://www.floodgap.com/roadgap/395/u9/). The view is looking upstream.

Figure 2.1-50. Riprap protecting highway and structures in modern times near the downstream end of WW3. The view is looking downstream.

The 1997 flood caused severe damage in the Walker Canyon along Highway 395, destroying the road and several structures (Figure 2.1-51). This flood was a historical event and was almost twice as large as the previous flood of record. The channel and road were reconstructed following the flood and the impact to the river is examined in further detail in the sediment dynamics section (2.1.4.12). If the channel had not been reset following this event, the magnitude of historical planform change in this segment calculated from recent aerial photographs would be greater.

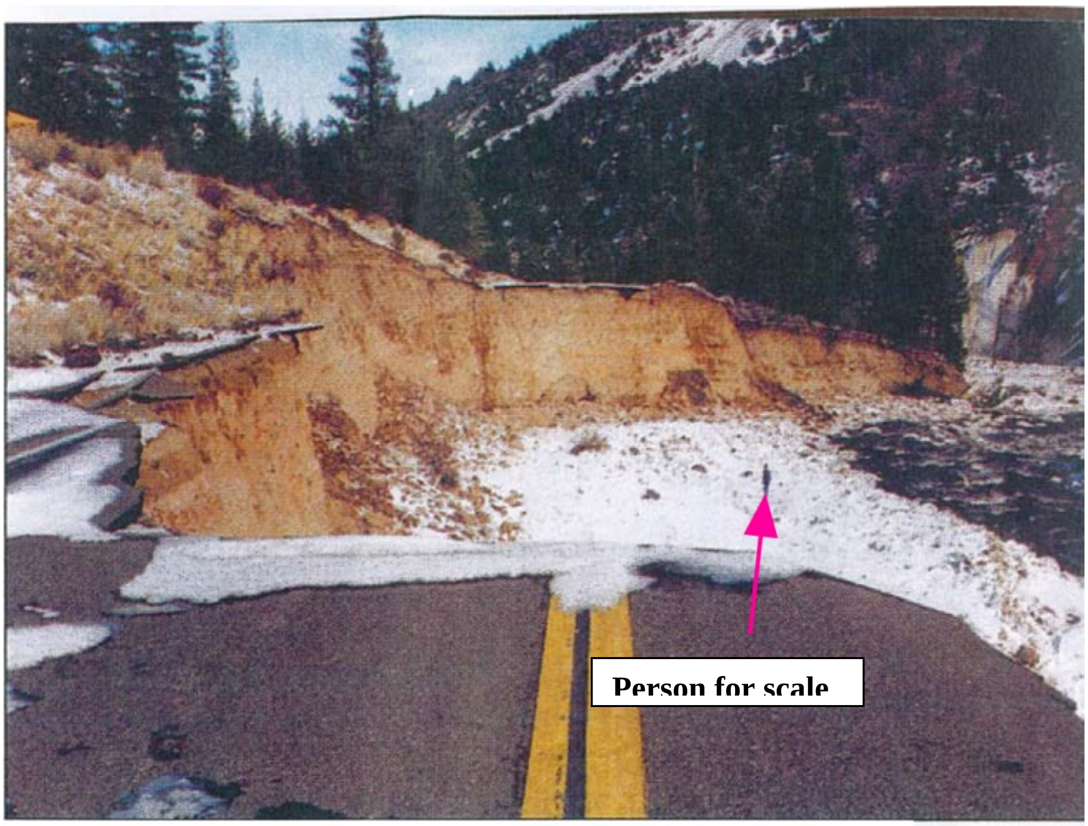


Figure 2.1-51. The photo illustrates the magnitude of erosion of the highway by the flood of 1997. Note the person for scale (from Schmidt, 1997).

WEST WALKER 4-5

The coverage of the 1938 photos only extends up river as far as Coleville in Antelope Valley. Because of this only the last 3.6 miles of segment WW4 are analyzed from 1938. The modified section is referred to as WW4 (mod). In WW4, the average channel width decreases 50%, and length and sinuosity decrease by 23%. Likely causes include natural meander cut-off, encroachment by agricultural fields and anthropogenic straightening, and effects of the channel diversion to Topaz (Figure 2.1-52). Completion of Topaz reservoir was completed in 1921 marking the initiation of water diversion from the West Walker River in Antelope Valley. The reservoir was subsequently expanded in 1938 to its current capacity (DWR, 1992).

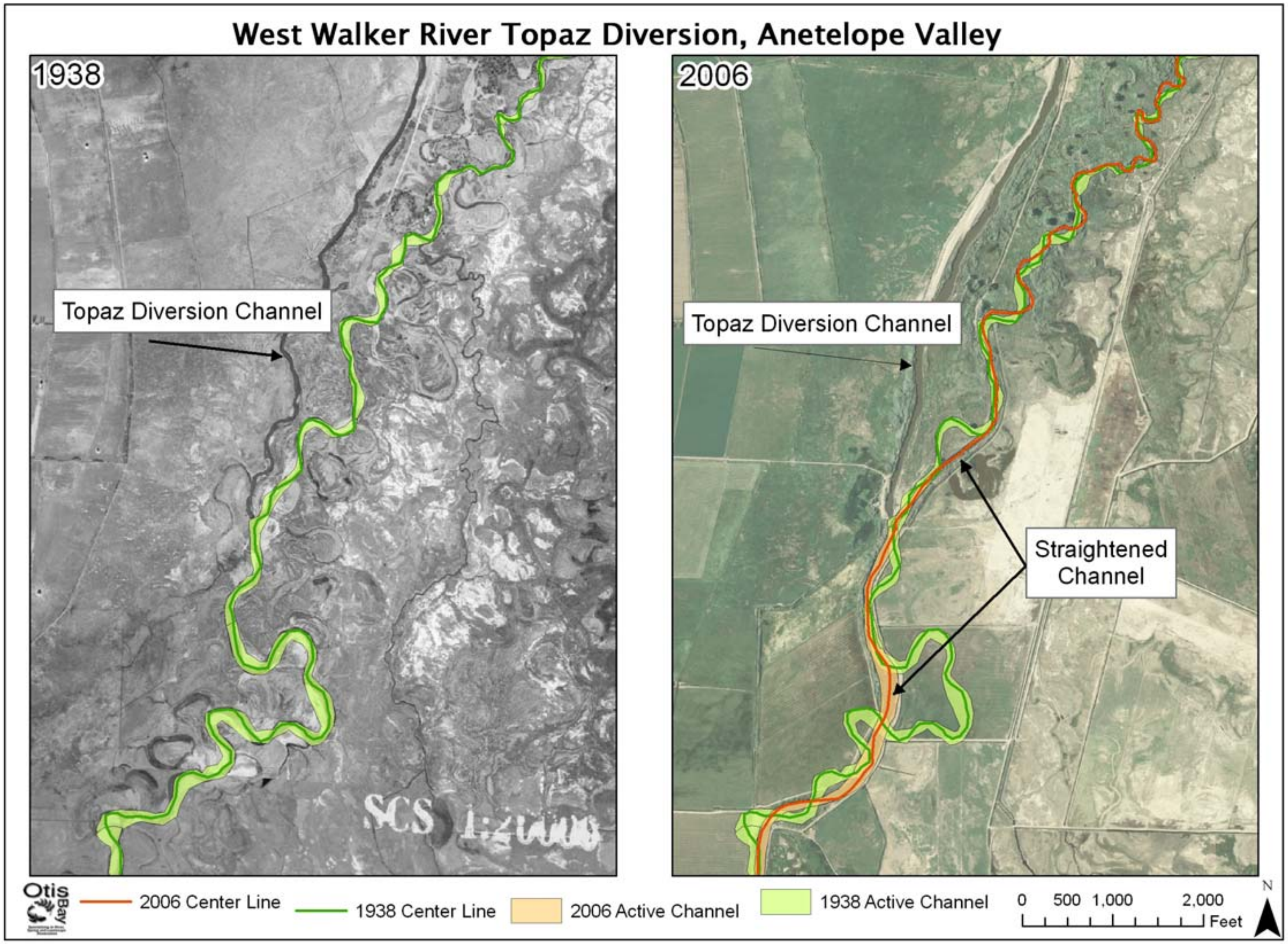


Figure 2.1-52. Comparison of the 1938 and the 2006 photos in the area of the Topaz diversion in WW4 and WW5. Flow is from bottom to top.

The Topaz diversion has had a dramatic affect on the river channel. The diversion alters the hydrology and sediment delivery downstream. This is apparent when comparing the portion of the channel in between the diversion and the return flow (the bypass reach), with the channel downstream of the Topaz return flow. In comparing the bypass reach with the channel below the Topaz return flow, it is clear that the channel is much narrower in the bypass reach than the channel just downstream of the return. A historic trend for increased narrowing through time is apparent; in 1938 the bypass channel is 25% narrower than below the return, and in 2006 the bypass channel is 63% narrower than below the return. The total magnitude of this difference is partially due to contemporaneous narrowing of the bypass channel, and widening of the channel downstream of the return.

Below the return flow in WW5, where discharge is increased relative to the bypass reach, change does not appear to be as drastic. Active channel area and width decrease around 20%. Length and sinuosity increase by 8%. The channel has cut off some meanders, other meanders are enlarging or translating downstream, and the channel has migrated laterally in areas (Figure 2.1-53). This channel change is indicative of natural alluvial river behavior. In the area immediately downstream from the Topaz return flow, the width of the channel approximately doubles between 1938 and 1995. Before the Topaz diversion was built, it is likely that the channel was not so dissimilar above and below the return channel.

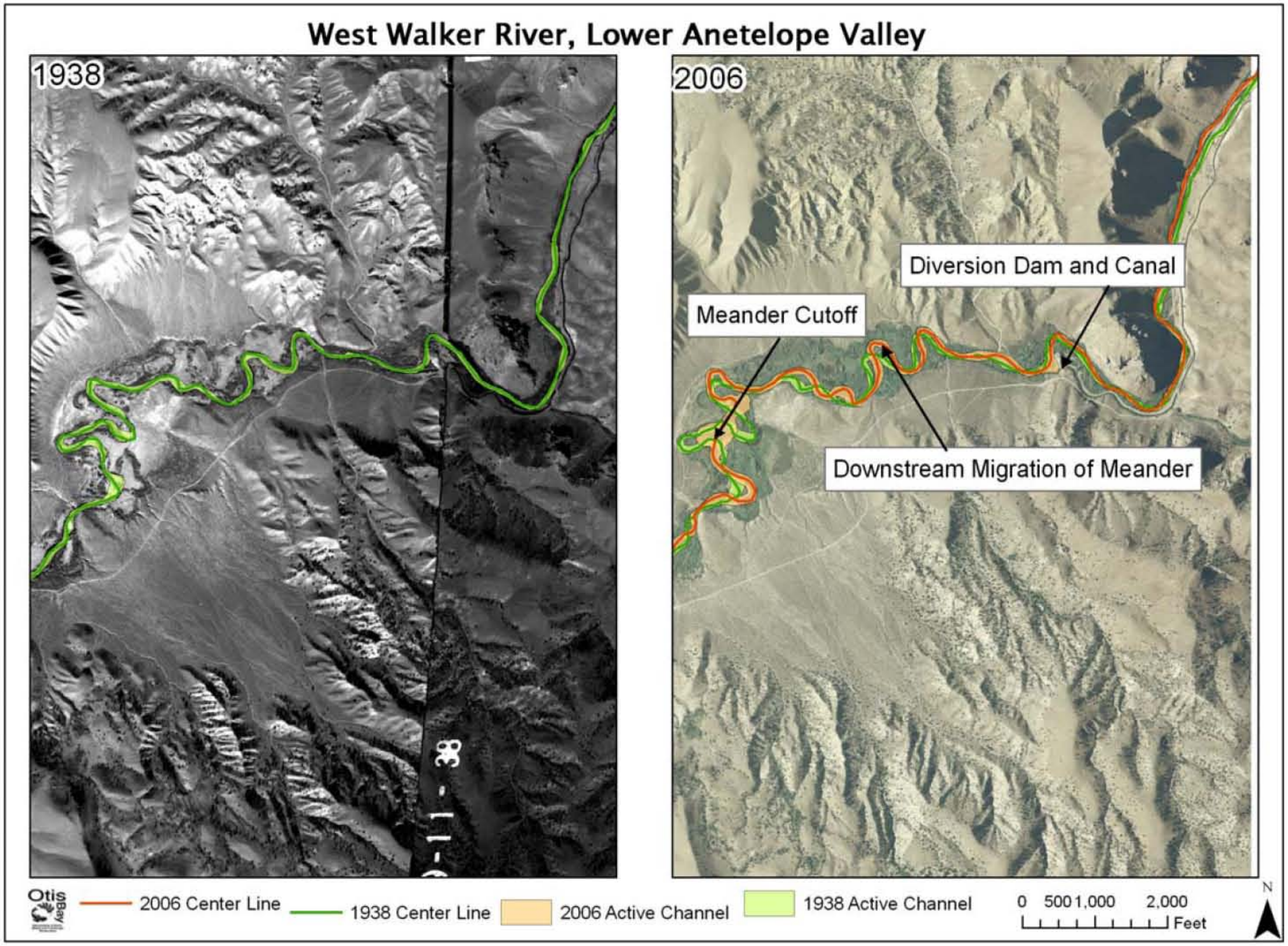


Figure 2.1-53. The photo depicts the transition between WW5 and WW6 at the head of Hoye Canyon. Flow is from left to right.

WEST WALKER 6

Changes to the planform of the West Walker River in Hoye Canyon (WW6) are minimal. Three diversion dams and four canals were built in the canyon by 1938. The engineering of these structures is common in that the relatively high elevation at the top of the canyon is used to keep water at higher elevation for irrigation in Smith Valley. The result is water depletion in the canyon. One interesting change between the 1938 and 2003 photos is that the coverage of riparian forest seems to increase in density, potentially due to leakage from the canals.

WEST WALKER 7

Segment WW7 is in Smith Valley, the second major agriculture valley encountered in the downstream direction. Within this segment the West Walker River is a low gradient alluvial river, and agriculture use was well underway by 1938. Between 1938 and 2006, the channel appears to have been anthropogenically straightened for the first four miles and the last 3.5 miles before WW8. The acreage of irrigated fields near the river increases dramatically between 1938 and 2003 (Figure 2.1-54). The activities have likely contributed to reductions in active channel width, area, and sinuosity in this segment. The channel loses nearly two miles of length and 45 acres of active channel area. Channel straightening can have many unintended effects. Increased slope can cause channel downcutting, disconnection of the channel and floodplain, and delivery of larger flood peaks downstream to Mason Valley.

In addition to direct alteration to the West Walker River in segment WW7, there has been significant depletion of a major tributary that likely to have had some effect on the planform of the West Walker River as well. Desert Creek is a perennial stream that drains the west and south sides of the Sweetwater Range. It then flows out into Smith Valley. It is also the largest tributary that enters the Walker River in one of the lower agricultural valleys. In the 1938 photos, a natural channel can be traced to the river, but it is already being affected by ditches. In the 2006 photo, the natural stream channel is gone and all water appears to be routed into ditches (Figure 2.1-55).

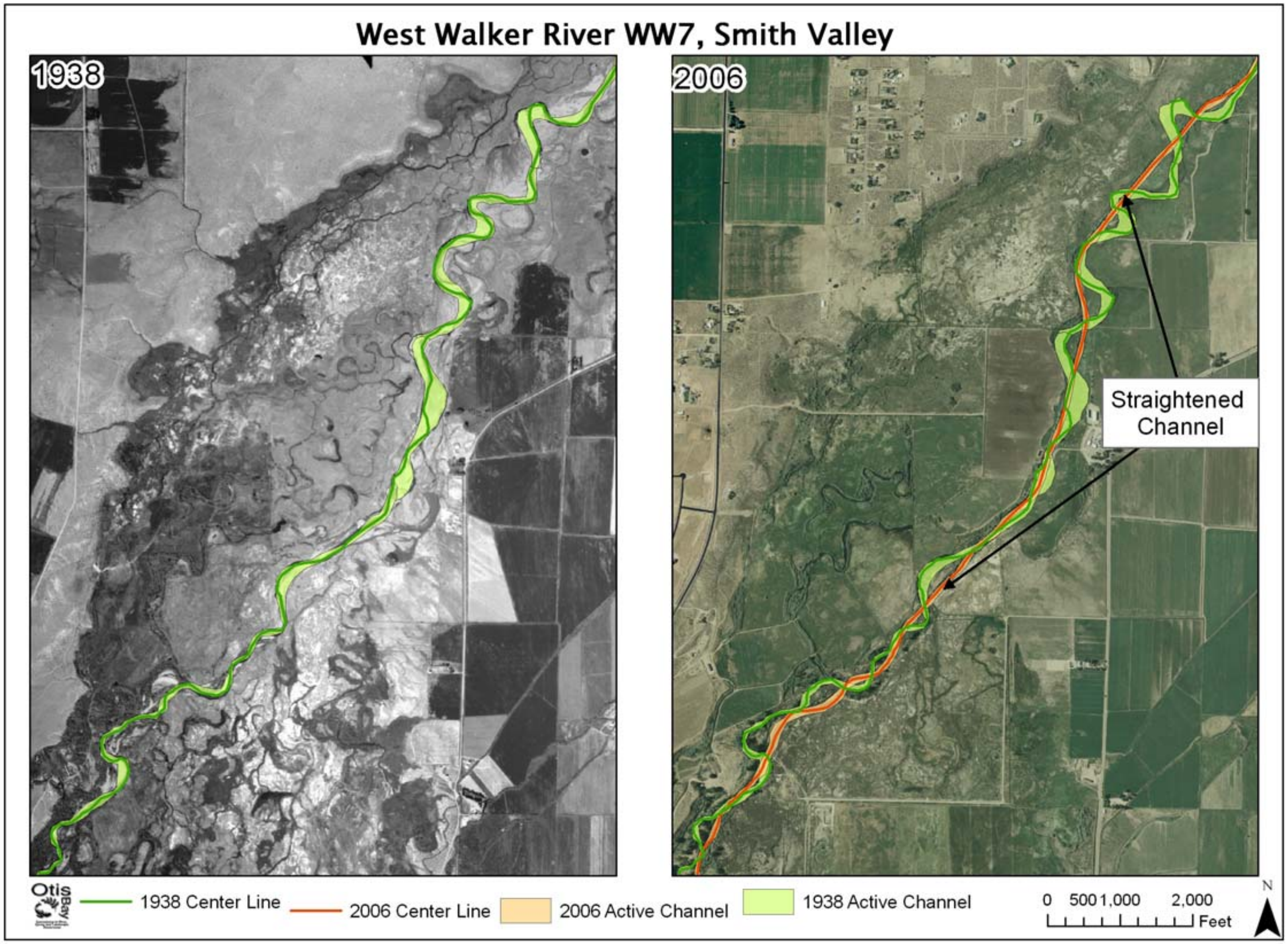


Figure 2.1-54. WW7 photo series showing channel straightening and agriculture encroachment between 1938 and 2006. Flow is from the bottom left to the top right.

Figure 2.1-55. Series of pictures showing Desert Creek in its canyon (upper left), the dry creek bed in Smith Valley (upper right), and one of the ditches capturing its flow (lower left). The latter two are taken at highway 338.

WEST WALKER 8-9-10

As the West Walker leaves Smith Valley it becomes confined by valley walls, but the gradient does not increase until it reaches Wilson Canyon (segments WW8 and WW9). Once again the channel exhibits a narrowing trend from 1938 to 2006 (Figure 2.1-56). Unlike upstream reaches, the channel does not to appear to have been straightened and the sinuosity increases slightly in the 2006 photo. By 2006, the active bars evident in 1938 appear to have been stabilized by vegetation in areas. Road density has increased dramatically at the OHV area upstream of Wilson Canyon. Unmaintained roads such as these have been shown to increase the delivery of sediment to streams. As in Hoye Canyon, several canals start in, and just downstream, of Wilson Canyon, and these are evident in both sets of photos. The water withdrawals of these canals would decrease discharge in the channel, and potentially the capacity of the river to transport sediment.

As the West Walker River enters Mason Valley (WW10), the riparian corridor in the initial two miles has not been developed and the river now appears to function much as it did in 1938. The river is dynamic and has changed course with meander growth and cutoffs. Further downstream, it appears to have been straightened and fields have been established along the river post-1938 (Figures A-21 through 22 in Appendix A). This is similar to what was found in Smith Valley.

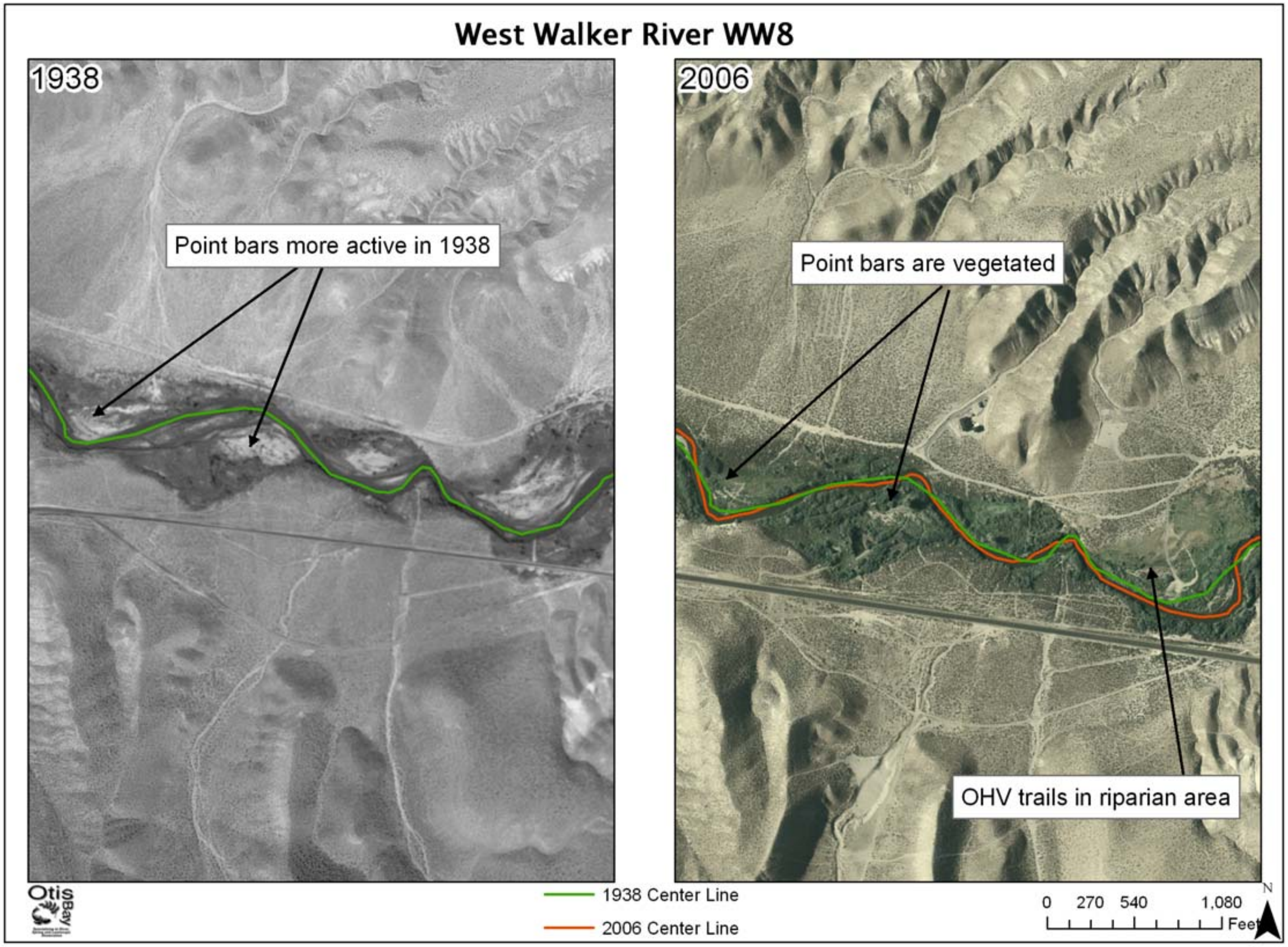


Figure 2.1-56. Photo series of the West Walker River at WW8, note narrower channel due to increased vegetation. There is also a recent proliferation of OHV trails. Flow is from left to right.

2.1.4.3 Channel/Floodplain Connection on the West Walker River

The connection of the channel to its adjacent floodplain is one of the most important physical characteristics of a river system in terms of sustaining riverine processes and ecosystem health. A combination of analytical techniques was used in order to assess the connection. HEC-RAS was used at the reach-scale, providing high resolution flow simulation to determine the frequency of inundation of observed geomorphic surfaces. The HAR was used in order to generate more general results suggesting areas that are prone to flooding and therefore connected to the channel. The HAR results do not indicate frequency of inundation.

WW2-WW3

HEC-RAS modeling suggests that there is a strong channel/floodplain connection in upper segments of the West Walker at the modeled study reaches. At WW2, frequently scoured floodplain surfaces are inundated by flows with recurrences between 1.5 to 5 years (Figure 2.1-57). However, there are high cut-banks on river right in the study reach that are topped by a terrace that is not inundated by flows less than the 10 year flood. This type of channel-floodplain connection may be typical for the meadow portions of the segment. But the canyon that divides Leavitt and Pickel Meadows has a limited floodplain width, and this inundation frequency is not likely to be the same. WW3 is a canyon segment, though not with the same morphology as the canyon in WW2. At the study reach in WW3, there is a narrow inset floodplain surface that is inundated by the 2 year flood (Figure 2.1-58). However, this may not be an alluvial surface. Following the 1997 flood of record, much of the river and floodplain was reconstructed by the California Department of Transportation (CalTrans). It is unknown how channel-floodplain connection was incorporated into design of this reconstruction. Visual inspection of WW3 suggests that there are some low elevation surfaces throughout the segment that may be inundated by floods with 2 to 5 year recurrences. At the study reach location, there is a higher elevation surface with evidence of flooding including debris, and high flow channels. This surface is inundated with a frequency of between 50 and 100 years. The presence of high flow channels and flood debris in trees suggests that the flood of 1997 is likely to have occupied this surface.

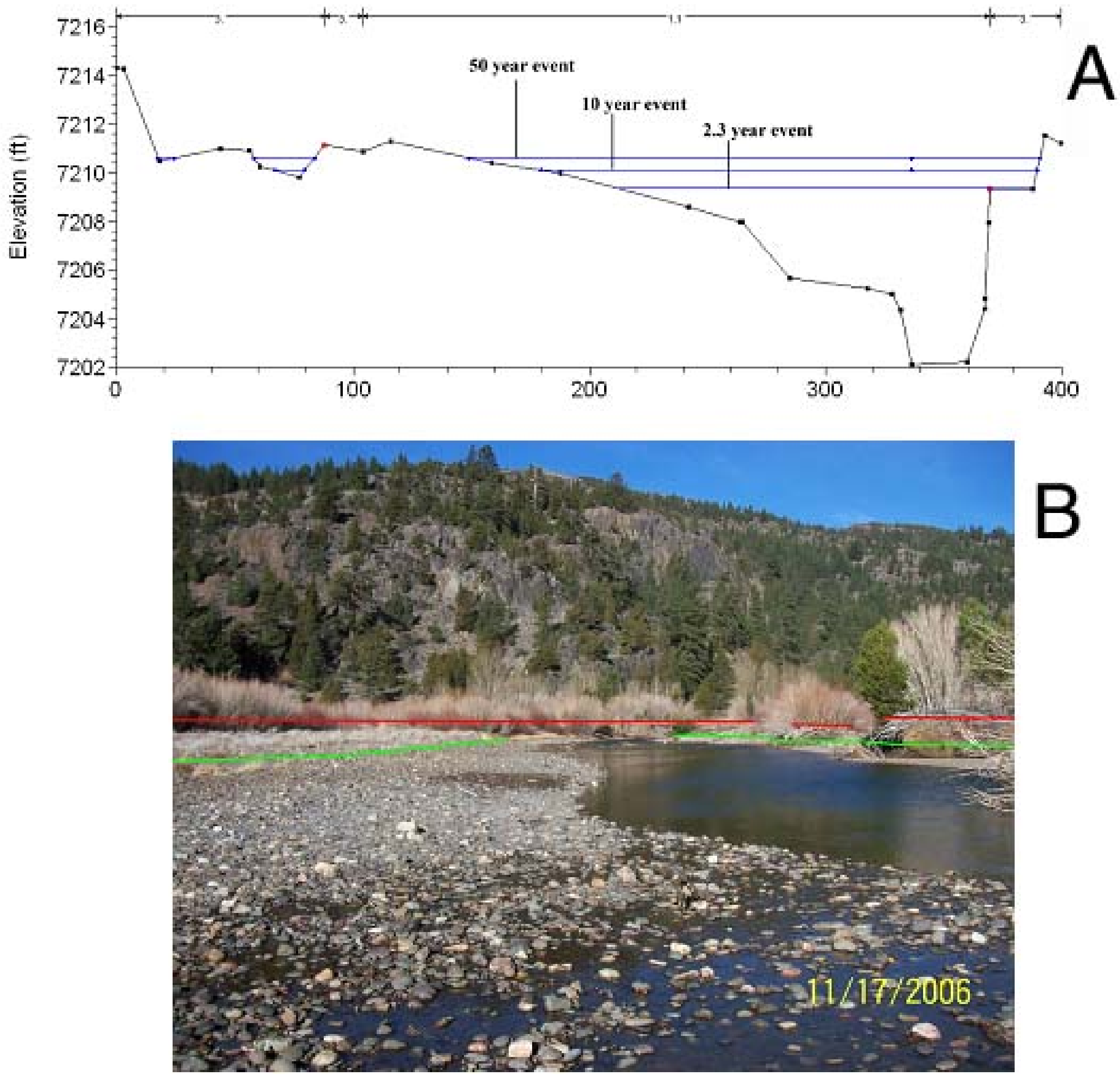


Figure 2.1-57. 2.1-57 A displays a typical cross-section plot for study reach WW2 depicting hydraulically modeled water surface elevations estimated to inundate the observed geomorphic surfaces. 2.1-57 B is a photo of study reach WW2 taken from river left looking downstream. Discharge is about 58 cfs. For comparison, the 2.3 year recurrence flow is about 1,251 cfs. The green line depicts the approximate elevation of the 2.3 year flood water surface, and the red line depicts the approximate elevation of the 50 year flood water surface.

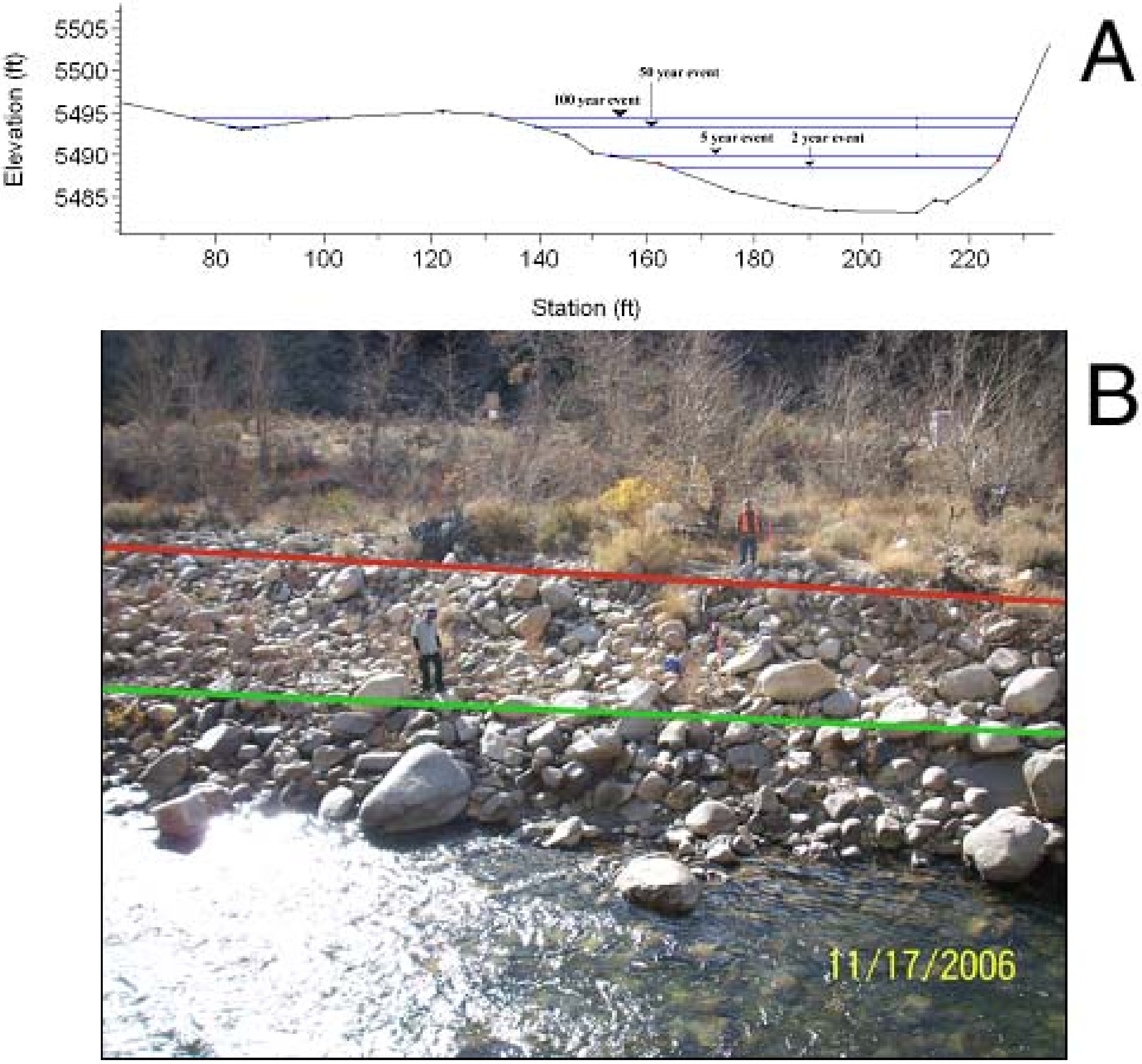


Figure 2.1-58. 2.1-58 A depicts a typical cross-section plot for study reach WW3 depicting hydraulically modeled water surface elevations estimated to inundate the two observed geomorphic surfaces. 2.1-58 B is a photo of deposits along river left of study reach WW3 taken from cliff on river right. Flow is from left to right and at a discharge of about 73 cfs. For comparison, the 1 year recurrence flow is about 570 cfs. The green line depicts the streamside edge of the surface inundated by the 2 year flood, and the red line depicts the stream side edge of the surface inundated by flows between the 50 and 100 year floods.

WW4

In abroad valley, such as WW4, the classic model of lateral floodplain accretion[41] can be applied to analyze channel change. This conceptual model operates under the assumptions that as a river

[41] The accumulation of mass to a surface. In the case of floodplain accretion this is accomplished through deposition of sediment, and the extension of the existing floodplain.

migrates laterally, deposition on the inside of a bend is balanced by erosion on the outside of a bed. Here sediment transport is expected to be balanced by sediment deposition and the channel would be adjusted to overbank flooding at about a two-year recurrence. A long period of channel migration by this process would eventually lead to a broad valley flat with large flood-prone areas. Viewing the the HAR model run for segment WW4 in light of this equilibrium concept, results suggest some non-equilibrium conditions. The river is incised initially near the town of Walker but further down the valley there is some incision. However most areas appear connected to the river (Figure 2.1-59). The flood-prone depth was found by extrapolating the results of hydraulic modeling from nearby segments to the channel in WW4 and was estimated to be approximately 8.5 ft. This is approximately the depth of the 100 year flood, so it is a liberal estimate of floodplain connection. A substantial amount of material was delivered to WW4 by the 1997 flood. Deposition of this material in the channel may have caused increased frequency of overbank flooding.

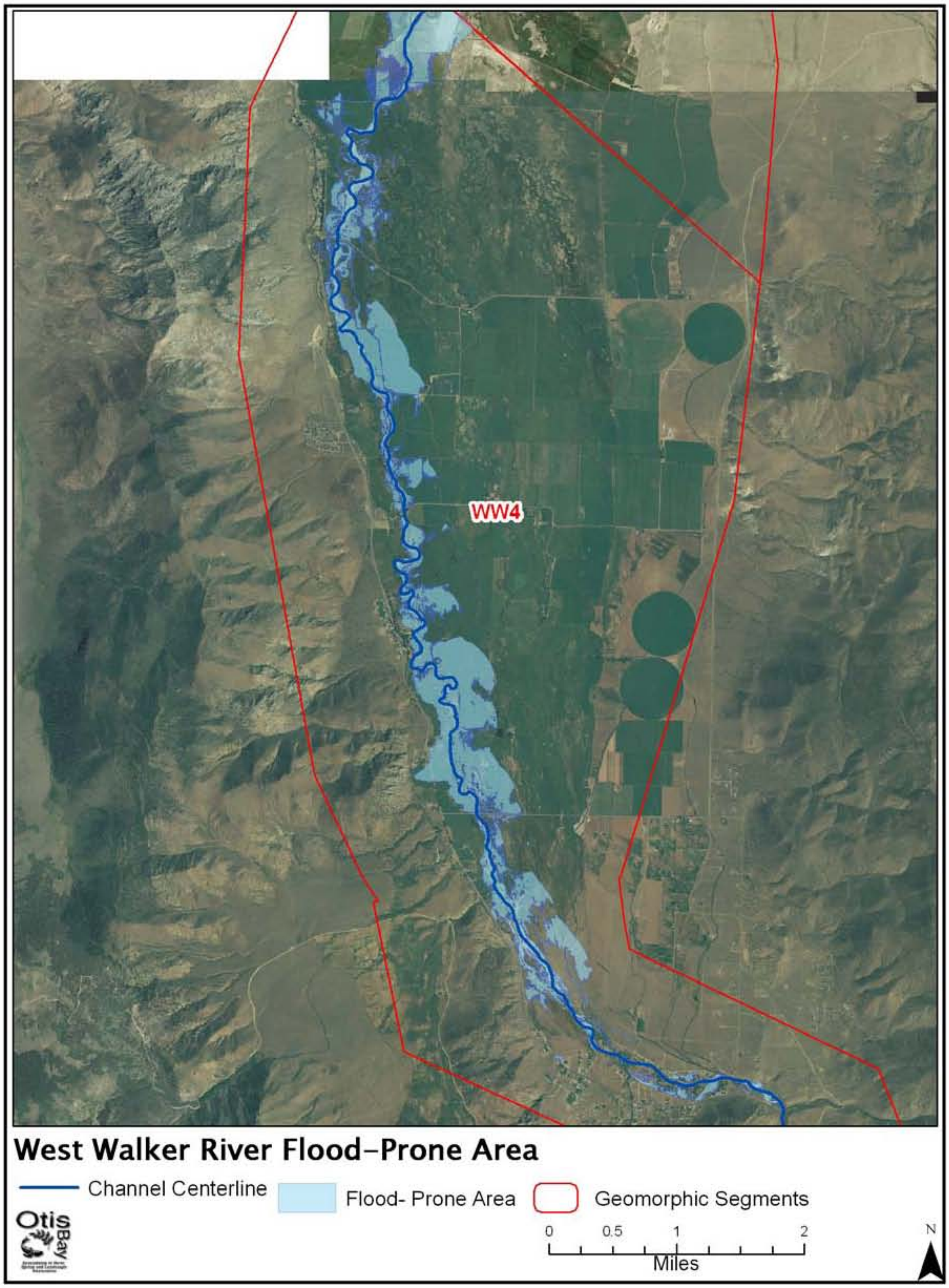


Figure 2.1-59. Flood-prone area at WW4; note that often cottonwood forest corresponds with this lower lying land. Flow is from bottom to top.

WW5

Anthropogenic alterations to land-use and hydrology can change channel and floodplain connection. Often these alterations occur over short time periods that do not permit the channel to adjust. Changes in the magnitude and timing of water and sediment delivery to the channel will effect flooding. Results of HAR modeling suggest that this is the case for the West Walker River. At study reach WW5, the river reaches the Topaz diversion structure, and looking at the flood-prone area map it appears this area is not incised and has a large flood-prone area. Below the return flow from Topaz Reservoir, decreased flood-prone area is observed (Figure 2.1-60). This is likely the result of flow alteration, and degradation of the channel below the confluence.

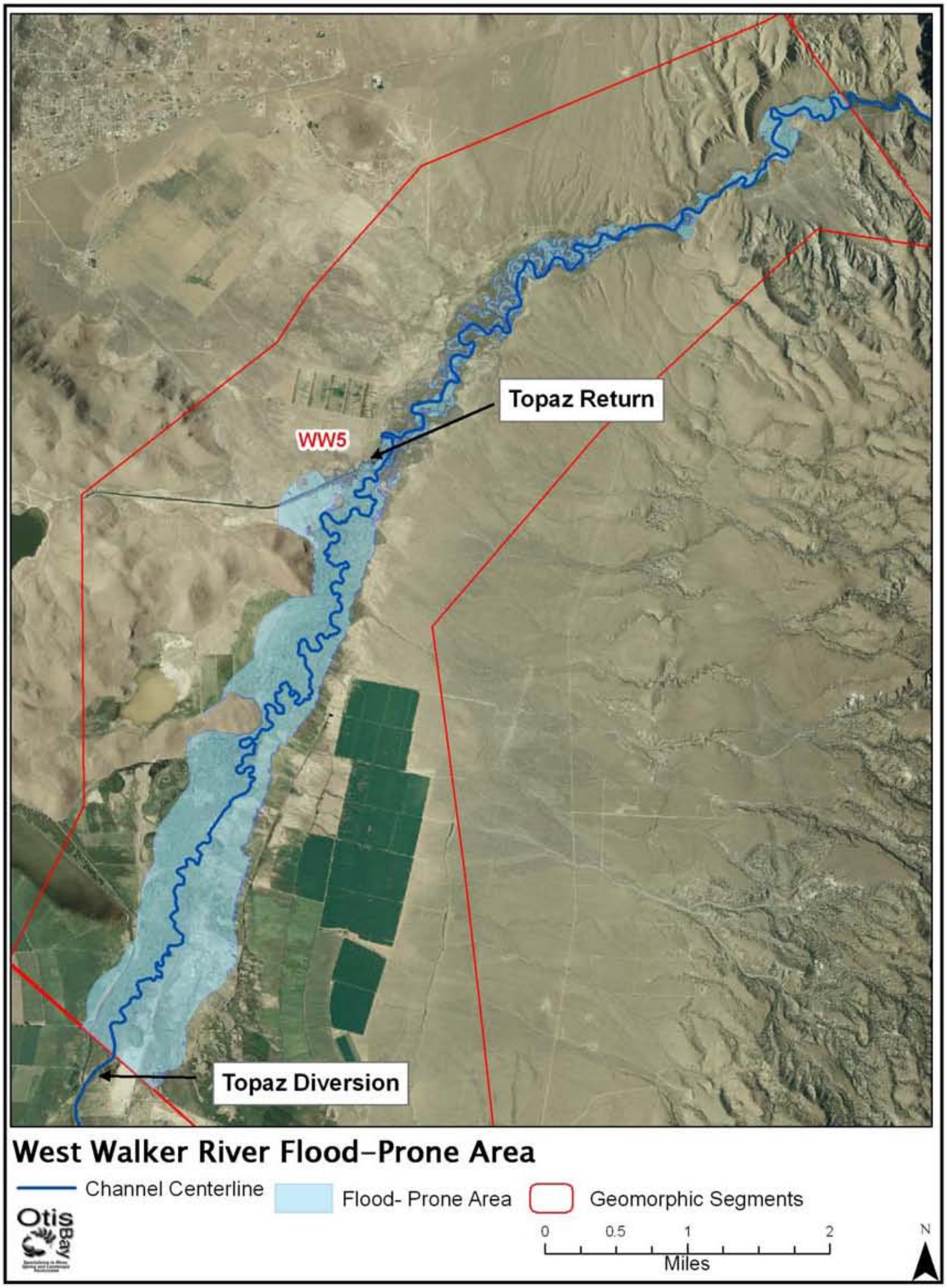


Figure 2.1-60. Flood-prone area at WW5; note that the flood-prone area decreases drastically where the Topaz return flow joins the channel suggesting river downstream is somewhat incised. The flood-prone depth was estimated to be 7.5 ft. Flow is from bottom to top.

HEC-RAS modeling results at the WW5 study reach support the conclusions of the HAR model. The study reach is located just below the Topaz return ditch. At this location, floodplain surfaces that are at approximately the same elevation as the alluvial valley are inundated by flows that recur between 5 and 10 years (Figure 2.1-61). Recurrences at these intervals would not be expected for an equilibrium channel in this geomorphic setting. There are inset surfaces that are more frequently inundated, but the extent of these surfaces is limited.

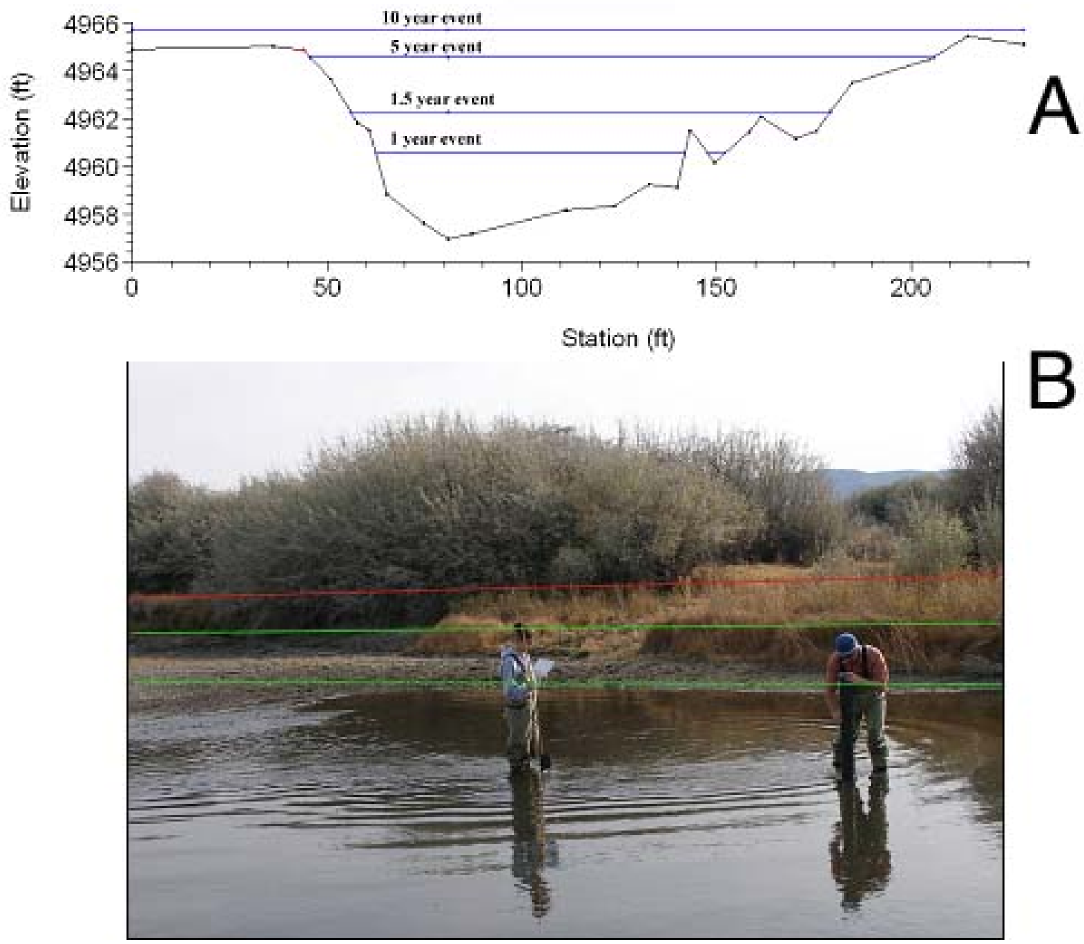


Figure 2.1-61. 2.1-61 A depicts a typical cross-section plot in study reach WW5 of estimated water surface elevations at flows responsible for inundating the various geomorphic surfaces. 2.1-61 B is a photograph of geomorphic surfaces in study reach WW5 taken during a water clarity test. The photo is taken from river left, flow is from right to left and at a discharge of about 50 cfs. For reference the 1 year return flow is about 302 cfs. The two green lines depict the elevations of the streamside edges of two inset surfaces with varying degrees of vegetation and stability that are inundated by flows that recur between 1 and 1.5 yrs. The red line depicts the elevation of the streamside edge of the higher elevation floodplain that is inundated between 5 and 10 yr flood events.

WW6

The West Walker River flows into Hoye Canyon in WW6. The expected natural limits on the lateral extent of a canyon floodplain made HAR impractical. Only HEC-RAS results were used to deduce the potential for floodplain connection in WW6. At the study reach in WW6, it appears that the lowest floodplain surfaces are not inundated by flows less than the 25 year flood (Figure 2.1-62). Higher surfaces at this site are the result of a road grade, and are intentionally set high above the channel. Farther downstream in the reach as the canyon widens, there are lower surfaces that may be more frequently inundated, but these are not extensive.

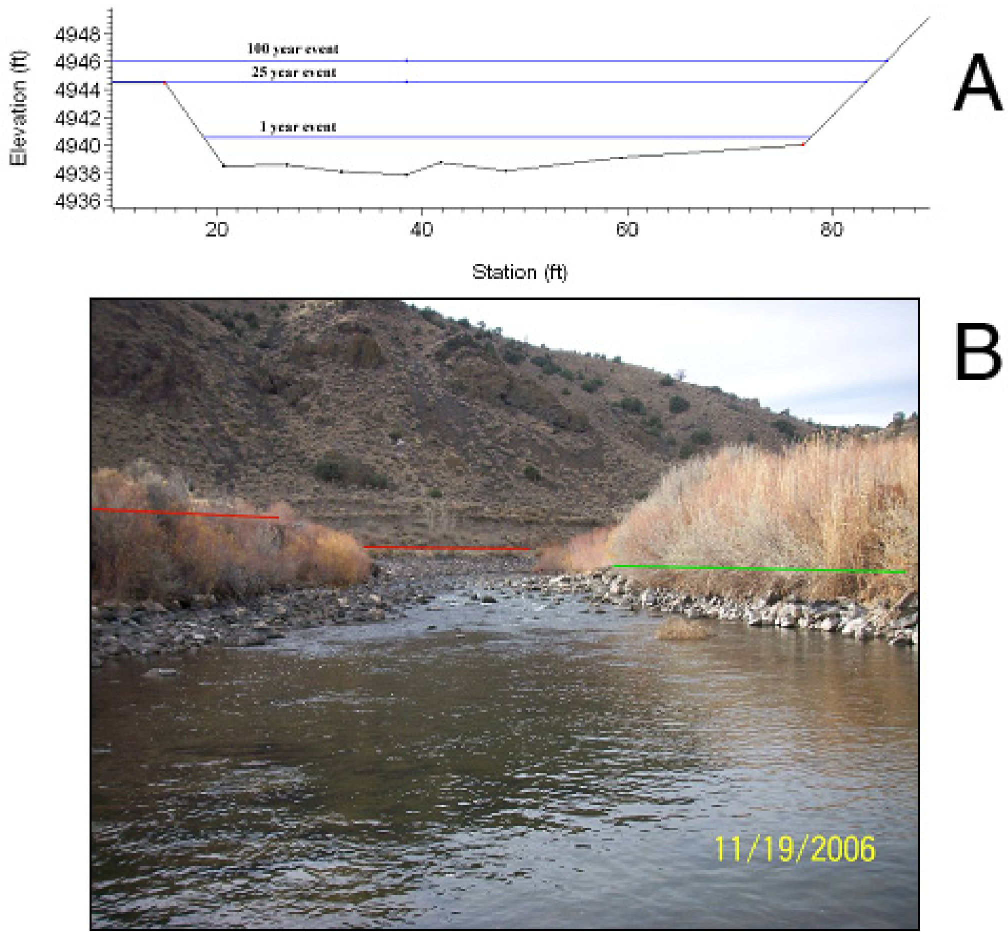


Figure 2.1-62. 2.1-62 A depicts a typical cross section plot of water surface elevations estimated to inundate the various geomorphic surfaces found in study reach WW6. 2.1-62 B is a photograph of study reach WW6 geomorphic surfaces taken looking upstream from the center of the channel. The red line depicts the elevation of the road surface on river right that forms a high surface that is not inundated by the 100 yr flood (left side of picture). The green line depicts the elevation of the streamside edge of the 25 yr floodplain on river left (right side of picture). Lower elevation gravels that are frequently inundated can be seen at the edge of the wetted channel on both sides.

WW7-WW8

There is no study reach at WW7 for HEC-RAS modeling, but the flood-prone area is mapped with the HAR model. The modeled depth is once again deduced from the HEC-RAS results of the up- and downstream study reaches and is estimated to be approximately 11 ft. This is estimated to correspond approximately with the 50 year flood. It is interesting to note that the area that was straightened after 1938 and has apparently not incised. There is still a considerable flood-prone area bordering the channelized portion of the segment. Often, channels that are straightened will begin to incise because of increased slope and flow velocity. However, if the river is low energy and the sediment load is high then aggradation may occur. There is a straightened section of river in the middle of the WW7 that apparently has not incised (Figure 2.1-63).

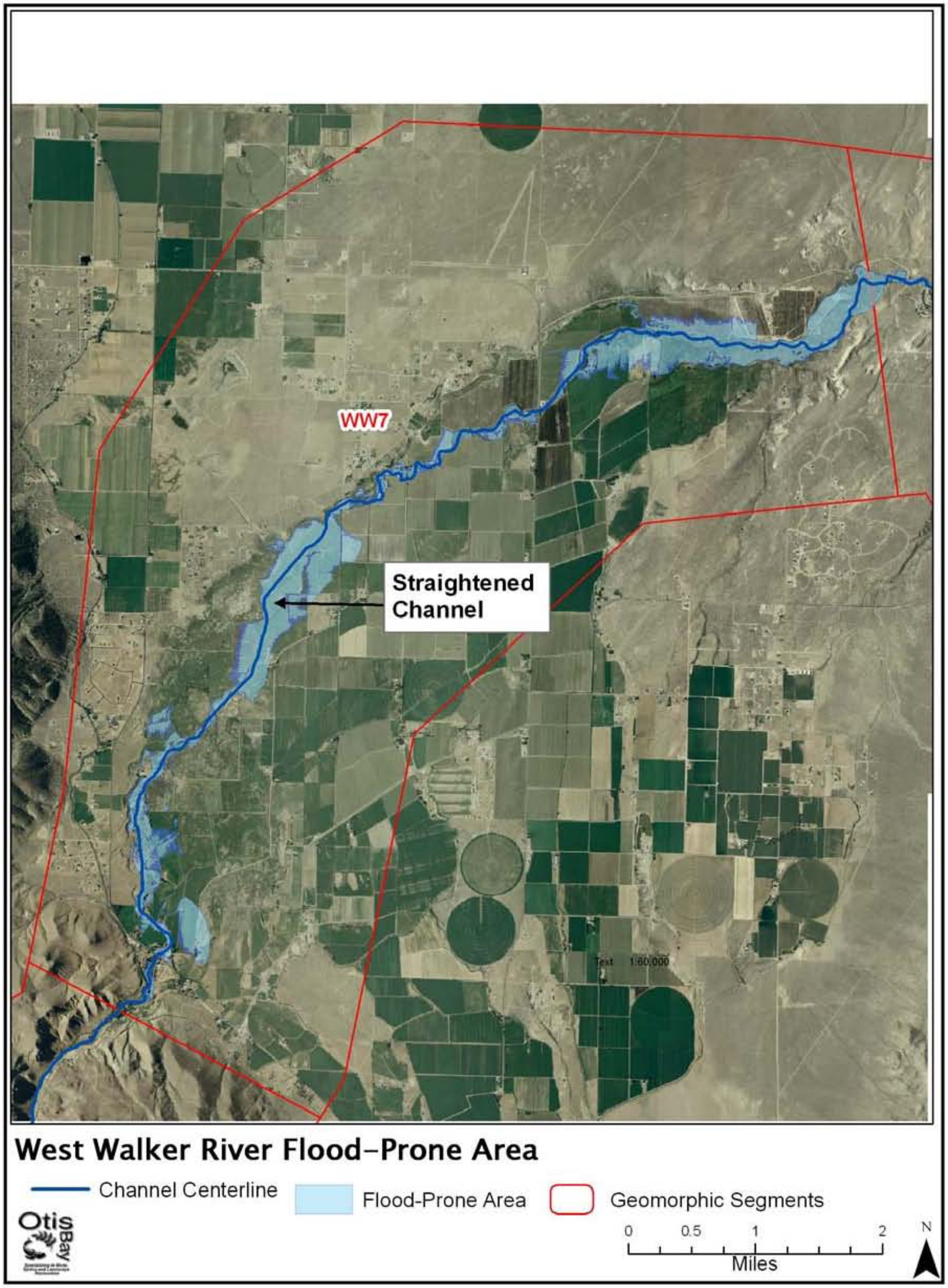


Figure 2.1-63. The flood-prone area at WW7; notice that the flood-prone area decreases in the middle of the valley. Flow is from bottom to top.

The results of the HAR model suggest that segment WW8 has a flood prone area that essentially extends between the limits of incised alluvial fan surfaces that border the channel on both sides. The flood-prone depth is the same as in WW7, 11ft (Figure 2.1-64). Although the river is contained in a more confined valley here, the floodplain connection is potentially good.

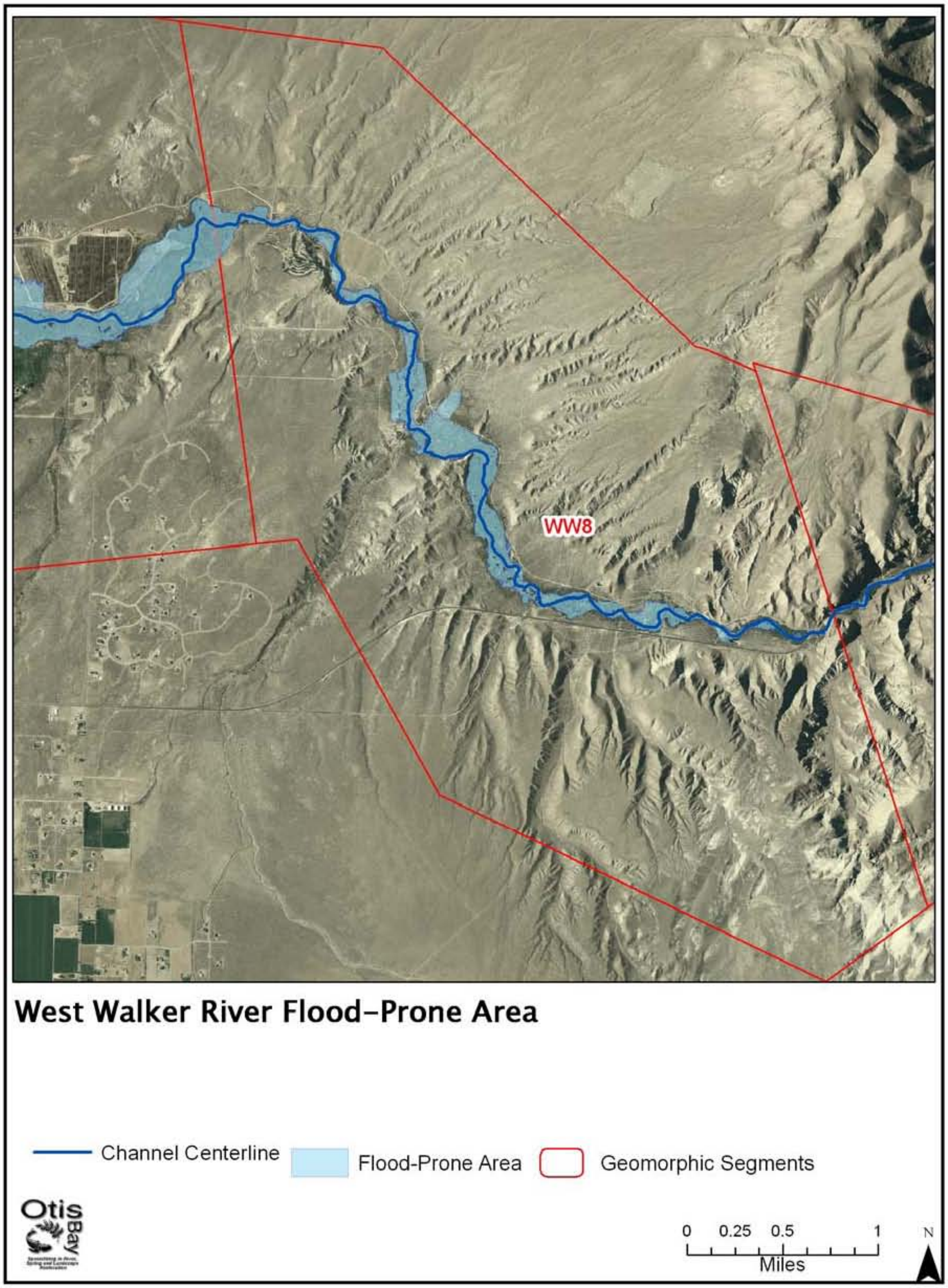


Figure 2.1-64. The flood-prone area at WW8. Flow is from left to right.

The results of HEC-RAS modeling at the study reach in WW8 supports the results of HAR modeling. Here, there are floodplain surfaces inundated by flows recurring between 2.3 and 5 years (Figure 2.1-65). This segment appears to have a fairly natural channel-floodplain connection.

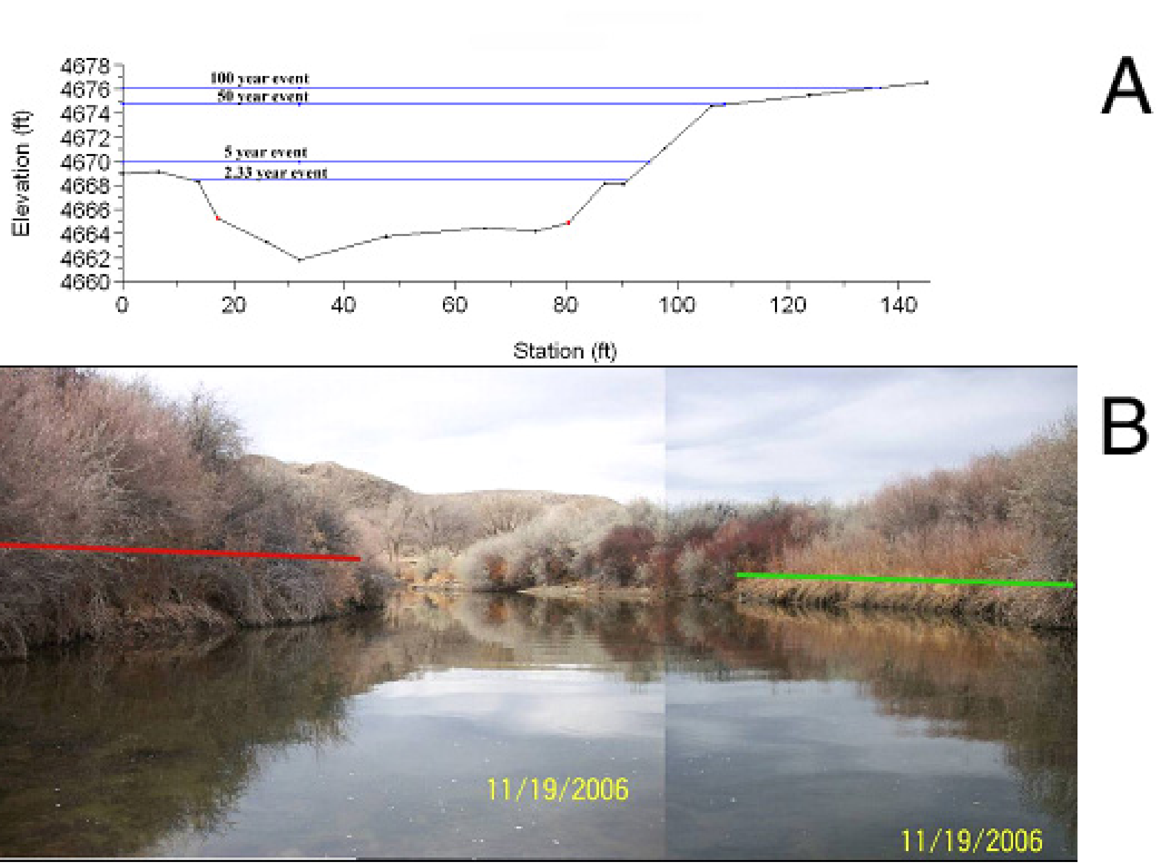
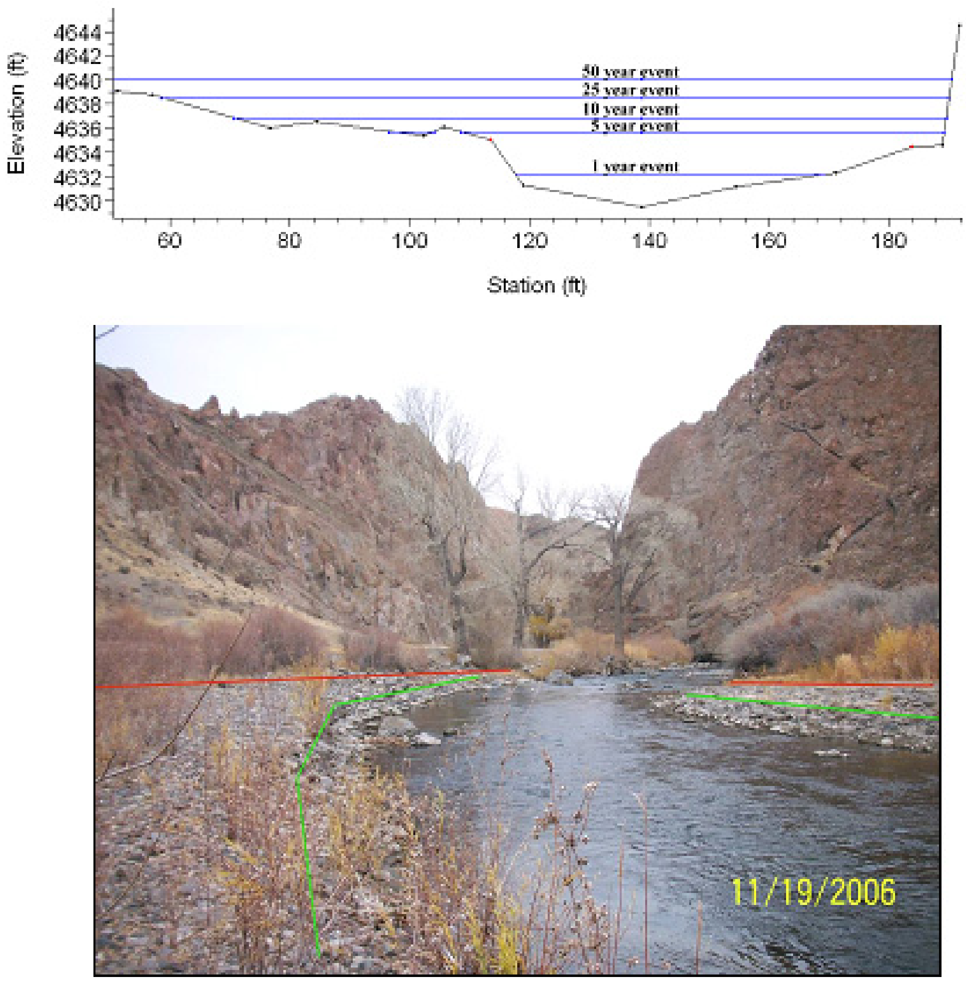


Figure 2.1-65. 2.1-65 A depicts a typical cross-section plot of estimated water surface elevations for flows inundating geomorphic surfaces in study reach WW8. Note that the view is looking downstream. 2.1-65 B is a photograph of study reach WW8 taken looking upstream from the channel center. The red line depicts the elevation of the streamside edge of the floodplain on river right that is inundated at a recurrence of about 2 yrs (left side of picture), and the green line depicts the elevation of the streamside edge of the floodplain on river left that is inundated at recurrences between 2 and 5 yrs (right side of picture).

WW9

At the study reach in WW9, HEC-RAS results suggest that floodplain surfaces are inundated by flows recurring between 5 and 10 years (Figure 2.1-66). This does not necessarily represent impaired floodplain connection however, as channel-forming processes in a canyon segment would be expected to differ somewhat from broad alluvial valleys. Several geomorphic features of the canyon such as the size of bed material, the source of bed material, side canyon contributions, and hillslope processes might all be expected to change the recurrence of bankfull discharge in a canyon. The HAR model was not applied to this canyon due to the expected natural limitation on floodplain development.



A

B

Figure 2.1-66. 2.1-66 A depicts a typical cross-section plot, looking down stream, of estimated water surface elevations for several flows responsible for inundation of the various geomorphic surfaces at a representative cross-section in study reach WW9. 2.1-66 B is a photograph of geomorphic surface in study reach WW9. Image is taken looking downstream from river left at a flow of about 44 cfs, flow is into the page. For reference, the 1 year recurrence flow is about 161 cfs. The green lines depict the elevation of the streamside edges of lower elevation surfaces on river right and left that are inundated yearly, and the red lines depict the streamside edges of higher surfaces that begin to be inundated by a 5 yr flow event.

WW10

The HAR model was run for segment WW10 in Mason Valley. Without a study reach in this segment, a hydraulic model was not developed. Therefore, the flood-prone depth of 11 ft used in the WW7 and WW8 was applied in WW10 as well. These are other valley segments under similar hydrologic conditions. HAR model results suggest that, with the exception of a straightened section east of the pivot irrigation (round) fields, the channel is connected to the floodplain in WW10 (Figure 2.1-67). The majority of the flood-prone area in this segment is in remnant channels, oxbows, and some nearby agricultural fields.

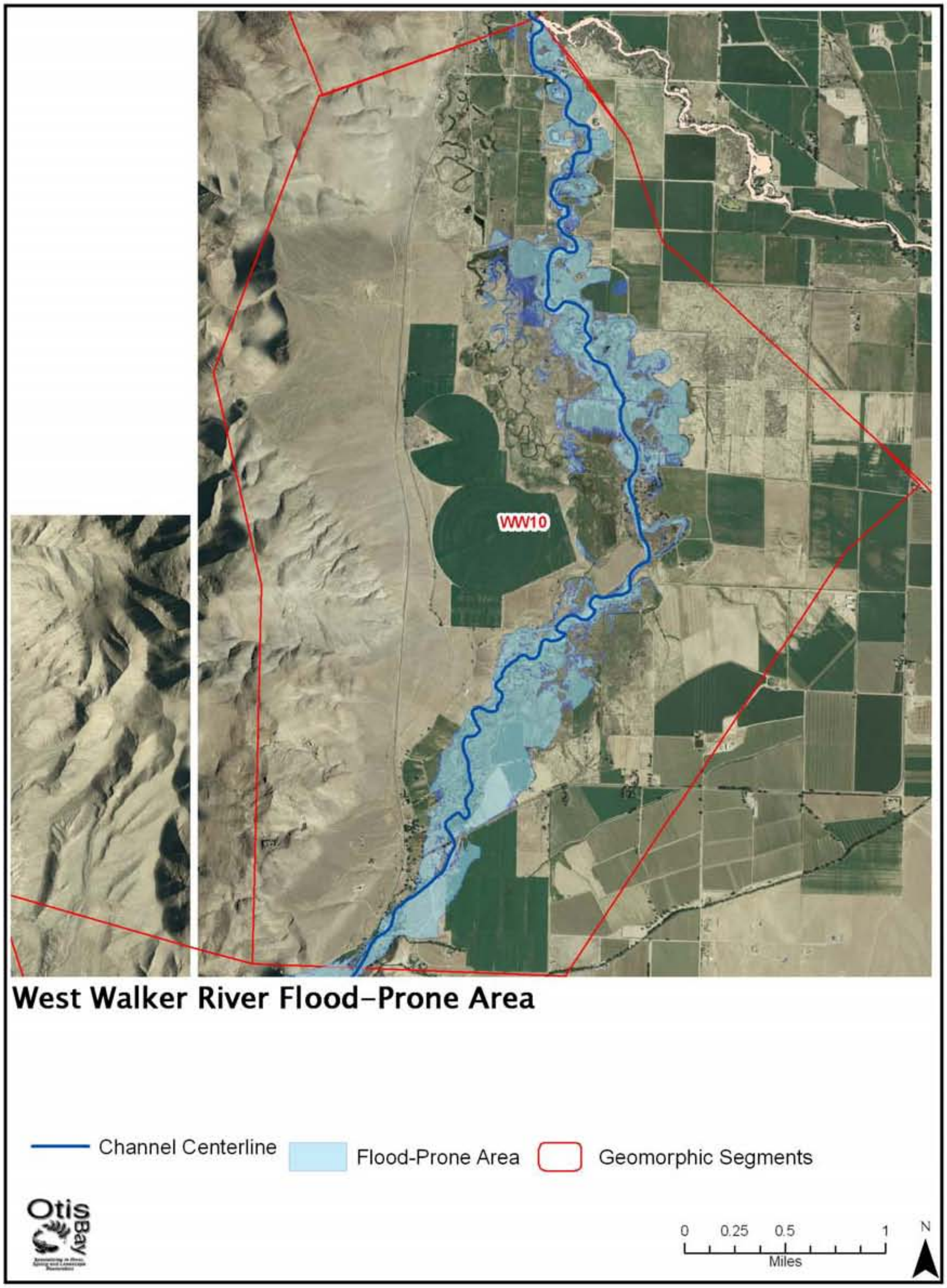


Figure 2.1-67. The flood-prone area in WW10; note that the flood-prone area decreases in the middle of the segment. This area was most likely straightened. Flow is from bottom to top

2.1.4.4 Channel-Scale Geomorphology of the West Walker River

Measurements of channel attributes such as cross-section geometry and bed substrate characteristics were measured in study reaches. These measurements are summarized below for study reaches on the West Walker River. Measurements obtained in a study reach are meant to represent the larger geomorphic segment, though it is acknowledged that substantial variation in channel morphology can occur within any given geomorphic segment.

CROSS-SECTION GEOMETRY

The established HEC-RAS model estimated cross-section geometry for all study reaches in all segments on the West Walker River. The discharge used for modeling and comparison corresponds to the 5% exceedence on the flow duration curve derived for the gage appropriate for each reach (Table 2.1-14). This discharge varies between study reaches, but the duration of the flow is the same for each study reach. In general, lower gradient valley reaches on the West Walker have larger cross-sectional areas, topwidths, and depths. Successive study reaches basically represent alternation between canyon and valley geomorphology controlled by Basin and Range tectonics. These differences are reflected in the large (sometimes over 100%) differences between geometric values between successive reaches. The West Walker River has more variability in channel geometry between study reaches than either the East Walker or Walker Rivers. This variability seems to decrease moving in the downstream direction.

Table 2.1-14. Cross-section geometry values for the West Walker River. Values for each metric are means calculated from all the cross-sections in a particular reach. Note that the values reported in Table 2.1-14 are averages of values from each cross-section in the reach. This results in reported values of Mean Depth .

Reach (5% exceedence)	Area (ft^2)	Top Width (W) (ft)	Mean Depth (D) (ft)	W/D
WW2 (702 cfs)	318.1	141.7	2.4	68.5
WW3 (1220 cfs)	219.4	55.0	4.0	14.1
WW5 (874 cfs)	405.0	108.4	3.8	29.4
WW6 (874 cfs)	191.7	65.4	2.9	22.5
WW8 (762 cfs)	292.5	77.0	3.8	20.4
WW9 (762 cfs)	243.6	85.0	2.8	30.1

GRAIN SIZE ANALYSIS

Grain size analysis characterizes the distribution of sediment sizes on the bed of the river. The data gathered is used as a fundamental geomorphic characteristic, and as input to sediment transport models. The size fractions that are most commonly used as variables in transport functions are listed in Table 2.1-15 for each study reach.

Table 2.1-15. Results of grain size analysis for the West Walker River. Values for the D16 represent the size of the 16th percentile particle in millimeters, the D50 is the 50th percentile particle in millimeters, and so on.

Reach	D16 (mm)	D50 (mm)	D84 (mm)	D90 (mm)
WW2	< 6	30	70	87
WW3	32	135	220	280
WW5	0.52	2.5	6.1	7.7
WW6	8	95	205	240
WW8	0.3	0.72	1.2	1.5
WW9	< 4	73	230	300

Results of this analysis suggest that the accessible geomorphic segments on the West Walker River are mainly gravel-bed streams. The three canyon reaches, WW3, WW6, and WW9 had median grain sizes of 135, 95, and 73 mm respectively. These particles could be classified as cobbles. WW8, a lower gradient segment located in Smith Valley had the smallest median grain size of 0.72 mm which is coarse sand. Valley segments are the least accessible. Increased accessibility to valley reaches would likely result in an increase in the number of reaches with distributions in the sand range.

A trend of downstream fining of the median grain size was observed, especially within and between geomorphically similar segments. This is a common occurrence in fluvial geomorphology (Reid and Dunne, 2003). This trend could prove useful in estimating conditions in adjacent segments, with similar geomorphology, that have restricted access. Plots of grain size distribution for each study reach are presented in Appendix H.

2.1.4.5 East Walker River Geomorphic Segment Descriptions

Descriptions of geomorphic segments of the East Walker River are presented here, similar to the above descriptions of the West Walker River.

EAST WALKER 2

The segment can generally be described as steep, with riffle-pool bed morphology, and restricted meanders that are laterally confined by the narrowness of the canyon, and the mass wasting deposits that commonly reach and impinge on the channel.

Table 2.1-16. Summary of some physical characteristics of East Walker 2 (EW2).

Distance from Walker Lake (to upstream end of segment) (mi)	129
Segment Length (mi)	8.6
Upstream Elevation (ft)	6,438
Channel Slope	0.010
Valley Slope	0.011
Sinuosity	1.13
Average Width (ft)	42
Median Grain Size of Bed Material (mm)	93

EW2 begins just downstream of the Bridgeport Reservoir outflow (Figure 2.1-68). To the east, the steep lower slopes of the Sweetwater Mountains deliver colluvium directly to the stream at many locations. To the west, the Bodie Hills and Masonic Mountains present a source of colluvium to the canyon. Most colluvial deposits adjacent to the stream appear to be vegetated and stable. Steep banks are created at locations where the stream has worked into the toe of these deposits. Overall, the segment is high-gradient, with a gravel/cobble bed organized into riffle-pool sequences. There is deposition of alternating bars and point bars composed of gravel and cobble. In several sections, stable, vegetated gravel bars divide the stream. In general, riparian vegetation is dense near the stream throughout most of this segment. Near the middle of the reach, mass-wasting has created a channel constriction and ponded backwater. Large amounts of fine material appear to have been deposited in this vicinity, creating a wide cattail area with multiple narrow channels, and isolated ponds.

Figure 2.1-68. Aerial photograph of EW2 downstream of Bridgeport Reservoir as it flows through a relatively restrictive canyon. Flow is from the bottom to the top of the image.

EAST WALKER 3

The segment can generally be described as meandering and alluvial, valley constriction is reduced here, and there is evidence of a historically wide floodplain, restricted only where the channel incises alluvial fan deposits.

Table 2.1-17. Summary of some physical characteristics of East Walker 3 (EW3).

Distance from Walker Lake (to upstream end of segment) (mi)	120.8
Segment Length (mi)	6
Upstream Elevation (ft)	5,918
Channel Slope	0.006
Valley Slope	0.007
Sinuosity	1.21
Average Width (ft)	41
Median Grain Size of Bed Material (mm)	90

In segment EW3, the valley width increases and an alluvial valley has developed (Figure 2.1-69). The valley margins are often defined by terraced alluvial fans and pediment surfaces whose sources are the Masonic Mountains to the south, and the Pine Grove Hills to the north (Dohrenwend, 1982). This segment is low-gradient and sinuous. In some locations, flow is divided into multiple channels separated by well-vegetated bars or islands. The stream bed is composed of gravel and organized in riffle-pool sequences. Finer gravels and sand are deposited in alternating bars and point bars. The river corridor consists of a significant floodplain with dense riparian vegetation, and inactive alluvial surfaces covered with upland vegetation.

Figure 2.1-69. Aerial photo of the East Walker River in the area of the Rosaschi Ranch in EW3. Flow is from left to right across the image. The historically wide alluvial valley and unrestricted meander pattern are evident in the image.

EAST WALKER 4

The segment can generally be described as moderately steep, with riffle-pool bed morphology, and reduced valley width in comparison to EW3 with a restricted meander pattern.

Table 2.1-18. Summary of some physical characteristics of East Walker 4 (EW4).

Distance from Walker Lake (to upstream end of segment) (mi)	115.2
Segment Length (mi)	12
Upstream Elevation (ft)	5,709
Channel Slope	0.005
Valley Slope	0.006
Sinuosity	1.27
Average Width (ft)	38
Median Grain Size of Bed Material (mm)	60

Valley confinement increases at the upstream end of EW4 as the gradient increases and the river incises a relatively deep canyon. Much of the segment within the canyon is inaccessible by vehicle. Aerial photos suggest steep hillslopes directly border the stream in many places (Figure 2.1-70). The gradient remains low, and a meandering planform is evident, though channel migration is restricted. The streambed is composed of gravel/cobble material organized in riffle-pool sequences. Point bar deposition is common. At the downstream end of the segment, the canyon widens, and a well-vegetated floodplain develops.

Figure 2.1-70. Aerial photo of the East Walker River in EW4. Flow is from the bottom to the top of the image. The confined meandering planform and closely coupled hillslopes processes are evident from the photograph.

EAST WALKER 5

The segment can generally be described as high gradient with a riffle-pool bed morphology, and low sinuosity due to lateral constriction in a narrow canyon.

Table 2.1-19. Summary of some physical characteristics of East Walker 5 (EW5).

Distance from Walker Lake (to upstream end of segment) (mi)	104.3
Segment Length (mi)	5.3
Upstream Elevation (ft)	5,411
Channel Slope	0.0094
Valley Slope	0.01
Sinuosity	1.07
Average Width (ft)	41
Median Grain Size of Bed Material (mm)	64

In EW5, the river continues to flow through a relatively narrow canyon (Figure 2.1-71). The gradient of the river increases, and significant rapids (noted on USGS 7.5" Quads) are formed. These rapids may be associated with deposition of colluvium from adjacent hillslopes and large side canyons. Deposition of cobble and gravel point bars, alternating bars, and longitudinal bars has created a multi-thread channel in places. Again, these features could be the result of the reworking of colluvium delivered to the stream channel. At the upstream end of the segment, a narrow floodplain and riparian zone is present. This vegetated floodplain surface widens downstream.

Figure 2.1-71. Aerial photograph of the East Walker River in EW5. Flow is from the bottom to the top of the page. The narrow confinement, low sinuosity, and closely coupled hillslope processes typical of the reach are evident in the image.

EAST WALKER 6

The segment can generally be described as being alluvial, having a moderate gradient, riffle-pool bed morphology, and restricted meanders formed as the valley width increases and a wider floodplain develops.

Table 2.1-20. Summary of some physical characteristics of East Walker 6 (EW6).

Distance from Walker Lake (to upstream end of segment) (mi)	99.2
Segment Length (mi)	13.9
Upstream Elevation (ft)	5,146
Channel Slope	0.005
Valley Slope	0.007
Sinuosity	1.44
Average Width (ft)	32
Median Grain Size of Bed Material (mm)	-

At the upstream end of EW6, the river exits the canyon and flows into the southern end of Pine Grove Flat, a relatively open valley (Figure 2.1-72). The valley floor is developed for grazing and other agricultural activities. Some areas appear to have been channelized, and lack a wide floodplain or riparian zone. This is particularly apparent in the middle of the reach. The river turns northeast and flows through a canyon separating the Cambridge and Gray Hills. The stream bed is primarily composed of gravel organized into riffle-pool sequences. In unconstrained portions, depositional features such as point bars and alternating bars are visibly apparent in aerial photography.

Figure 2.1-72. Aerial photograph of the East Walker River in EW6. Flow is from the bottom to the top of the page. As shown in the photograph, sinuosity increases downstream.

EAST WALKER 7

The segment flows into a relatively wide valley and can generally be described as alluvial with a low gradient, and meandering planform.

Table 2.1-21. Summary of some physical characteristics of East Walker 7 (EW7).

Distance from Walker Lake (to upstream end of segment) (mi)	87.3
Segment Length (mi)	16.4
Upstream Elevation (ft)	4,802
Channel Slope	0.002
Valley Slope	0.003
Sinuosity	1.65
Average Width (ft)	29
Median Grain Size of Bed Material (mm)	-

EW7 begins as the river flows out of the canyon at the downstream end of EW6. The valley widens, bordered to the west by the Cambridge Hills, and to the East by the Wassuk Range (Figure 2.1-73). The river flows on the far west side of the valley. Its position is likely due to movement on the Cambridge Hills fault which has resulted in westward tilting of the valley floor (Adams and Sawyer, 1998b). Long, low-angle, surfaces composed of alluvial fan deposits, pediments, and abandoned fluvial gravels slope to the valley floor from the east (Dohrenwend, 1982). Significant agricultural development of this valley currently limits the extent of the river's floodplain. Oxbows and meander scars can be discerned in aerial photographs, suggesting a much wider historic alluvial valley.

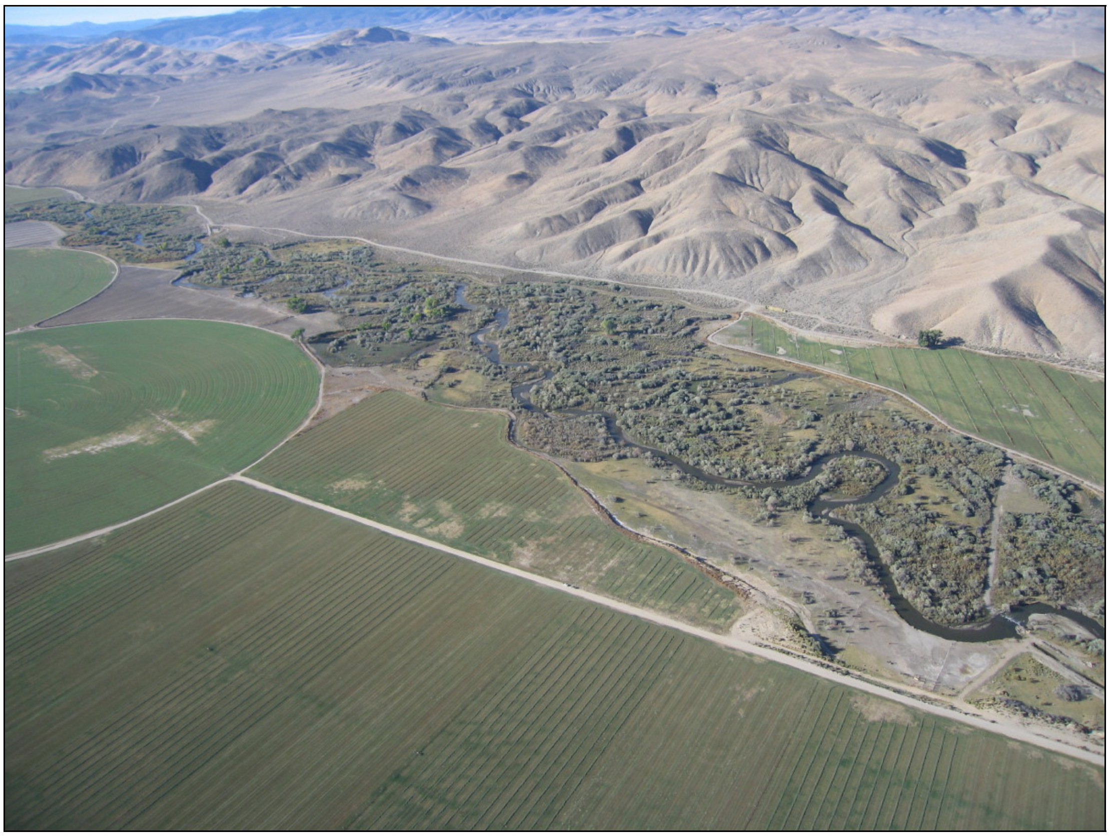


Figure 2.1-73. Aerial photograph of the East Walker River in EW7. Flow is from left to right across the page. Despite encroachment by agricultural development, the channel retains a sinuous planform.

EAST WALKER 8

The segment can generally be described as low-gradient and meandering though valley constriction increases, and the width of the floodplain decreases.

Table 2.1-22. Summary of some physical characteristics of East Walker 8 (EW8).

Distance from Walker Lake (to upstream end of segment) (mi)	74
Segment Length (mi)	8.6
Upstream Elevation (ft)	4,620
Channel Slope	0.002
Valley Slope	0.003
Sinuosity	1.49
Average Width (ft)	48
Median Grain Size of Bed Material (mm)	-

At the upstream end of EW8, the river incises a canyon in the Cambridge Hills (Figure 2.1-74). The river is fairly low-gradient, and exhibits a restricted meandering pattern within the confinement of the canyon. The stream bed is composed of mobile sand over gravel and cobble. Sand and small gravel are deposited in alternating bars and point bars. Frequent meander scars suggest that the channel has migrated within the canyon. At the downstream end of the segment, the river flows into the southeastern portion of Mason Valley.

Figure 2.1-74. Aerial photo of the East Walker River in EW8. Flow is from left to right across the page. Notice the increasing valley confinement in the downstream direction.

EAST WALKER 9

The segment begins as the East Walker flows into Mason Valley and can generally be described as a freely meandering without lateral restriction through a wide historic floodplain, though recent development has encroached on the channel.

Table 2.1-23. Summary of some physical characteristics of East Walker 9 (EW9).

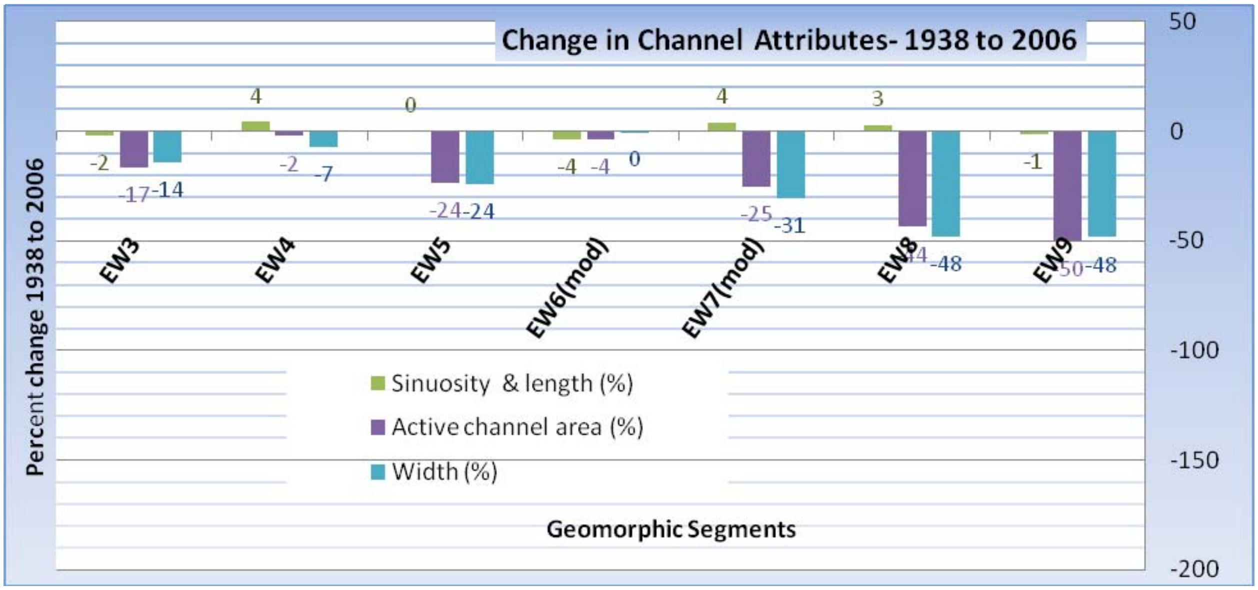
Distance from Walker Lake (to upstream end of segment) (mi)	66.8
Segment Length (mi)	8.6
Upstream Elevation (ft)	4,525
Channel Slope	0.002
Valley Slope	0.003
Sinuosity	1.35
Average Width (ft)	30
Median Grain Size of Bed Material (mm)	-

Segment EW9 is found entirely within the Mason Valley (Figure 2.1-75). Agricultural development has proceeded across much of the historic floodplain. Meander scars and oxbows, visible in aerial photography, are found across these developed surfaces. The current channel is low-gradient, with a bed composed of sand, and organized in riffle-pool sequences. The river is frequently channelized through agricultural fields.

Figure 2.1-75. Aerial photograph of the East Walker River flowing through the Mason Valley in EW9. Flow is from the bottom to the top of the page. The portion of the river shown here flows northeast across the valley to the confluence of the East and West Walker Rivers. There is no hillslope constraint on channel planform, yet the channel is relatively straight possibly due to development in the floodplain.

2.1.4.6 Historic Channel Change of the East Walker River

The results of the photo analysis for the East Walker River are shown in Figure 2.1-76. An analysis and comparison of historic and current channel planform is a primary component of the geomorphic assessment. In this analysis of channel planform, changes in sinuosity and channel length, active channel area, and channel width were compared. The nature of changes in these attributes over time can be used to infer trends in geomorphic process. Please note that more detailed interpretation of planform change will follow the completion of various research projects currently underway in the Basin. Methodologies for air photo interpretation and evaluating channel change are described in section 2.1.1.3 of this report. The complete set of 2006 photos with all the digitized layers of the historical analysis are shown in Appendix A.



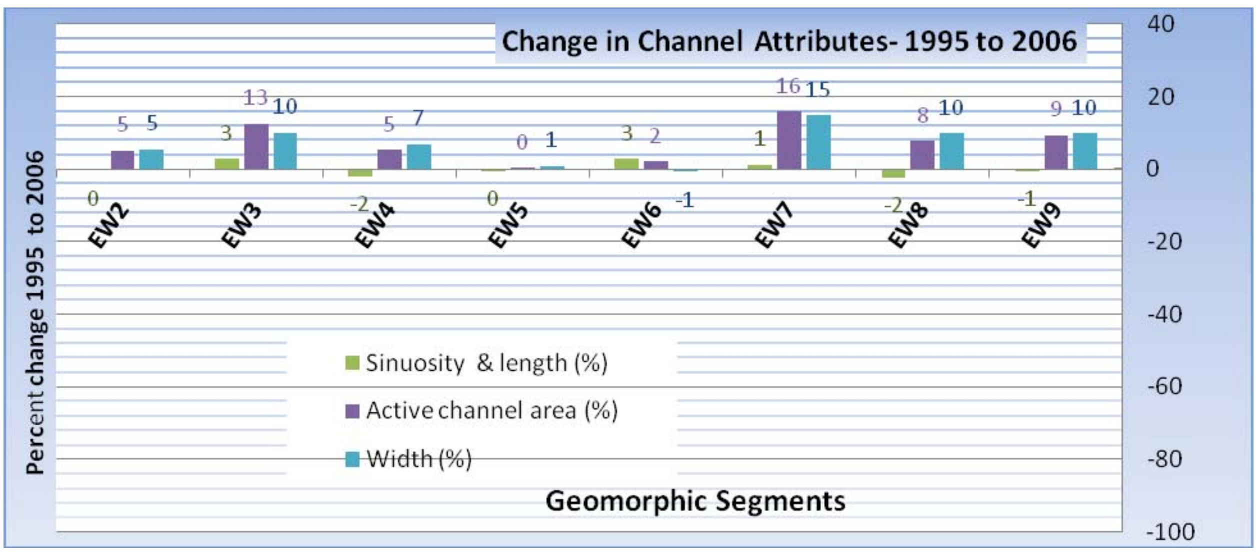


Figure 2.1-76. Results of the photo analysis for the East Walker River. Top figure compares 1938 to 2006; bottom figure compares 1995 to 2006.

Looking at the results, some trends are noteworthy:

- Chanel straightening and riparian encroachment is much less extensive in the East Walker River when compared to the West Walker River and Walker River. One of the reasons for this is the lack of large valleys along the East Walker River. An exception to this is when the river enters Mason Valley.
- The magnitude of change is much greater from 1938 to the present when compared to more recent changes despite the 1997 flood.

- Most segments analyzed have narrowed and active channel area has been reduced both from 1938 to 2006; the magnitude is greatest in the two lower segments, EW8 and EW9.
- Most segments appear to have widened since 1996, which is opposite the trend in the West Walker River.

The GIS analysis is not shown in its entirety in this section of the report, but can be found in Appendix A.

EAST WALKER 2

1938 photo coverage was not obtained for this segment. The channel shares the narrow valley with a state highway, but the channel appears much less dynamic when compared to the West Walker River Canyon. The road corridor most likely dates back to the 1860s. The channel has not changed substantially between 1995 and 2006.

EAST WALKER 3

The coverage from the 1938 photos begins at Rosaschi Ranch, which is no longer an active ranch, and the land is now owned by the United States Forest Service. The channel here is dynamic over time but, does not appear to be changing dramatically (Figure 2.1-77).

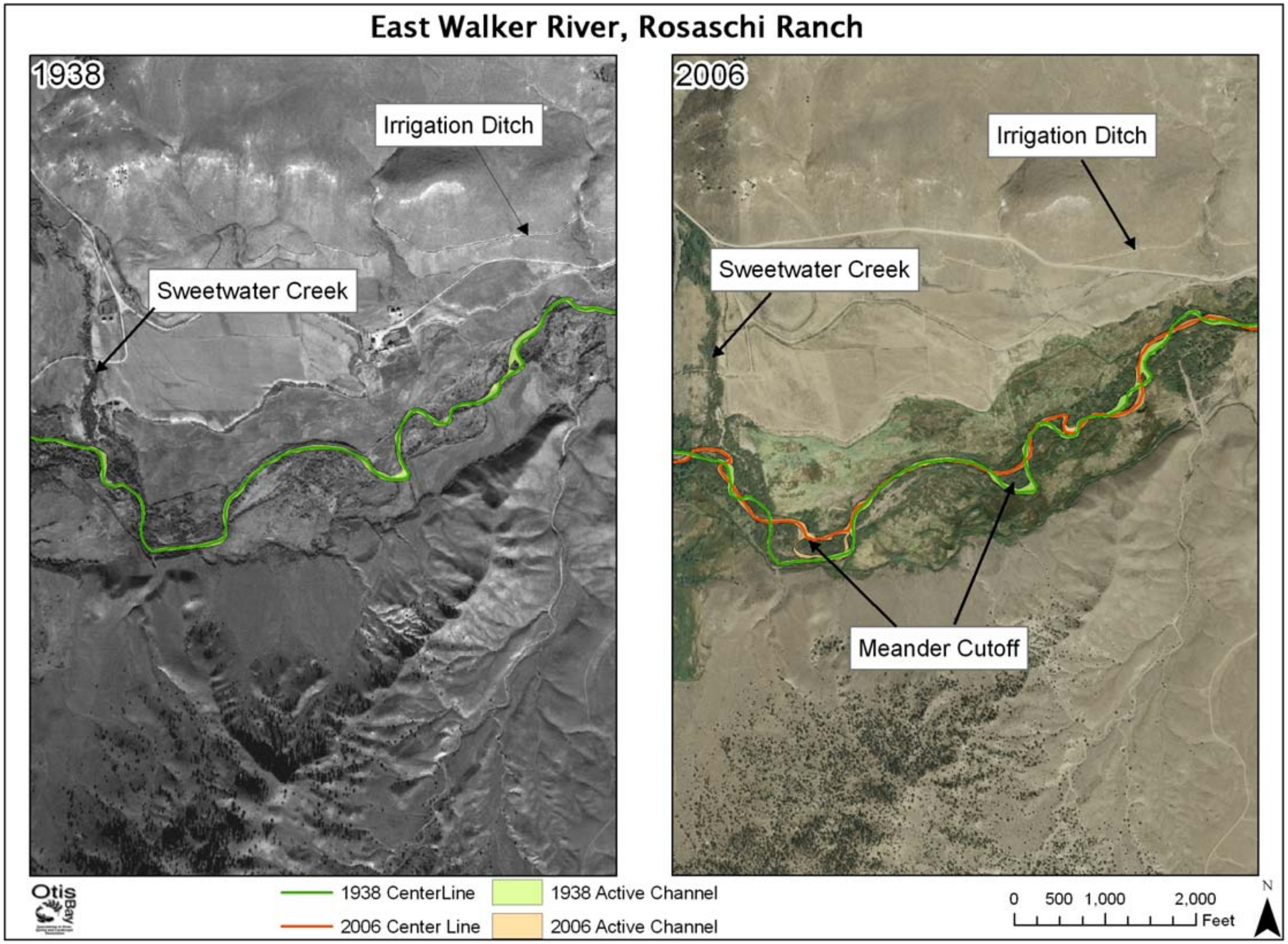


Figure 2.1-77. Photo series of the Rosaschi area. Note abandoned ditch, ranch and dynamic channel. Flow is from left to right.

EAST WALKER 4

At EW4, the East Walker River starts dropping into more confined canyons, but a narrow floodplain is present for much of the length of the segment. Since 1938 the channel has changed course slightly through this floodplain, but large magnitude changes are not evident. A sizeable debris flow occurred in a drainage flowing out of the north side of the canyon at some point between 1938 and 1995 forcing the channel against the opposite side of the canyon, this source of natural channel alteration will be discussed further in the sediment source section. Motorized traffic on roads and trails has increased in the area where the river flows near the road.

EAST WALKER 5-6

In EW5, the East Walker River enters a fairly remote area. The gradient increases, and in places there is little or no floodplain. The location of the channel has remained fairly constant in this segment. At EW6, the valley floor widens and agriculture activity begins to occur. The channel here includes sections that appear straight in the 1938 photos and are more sinuous now (Figure 2.1-78). These sections do not to appear to have been anthropogenically straightened before 1938.

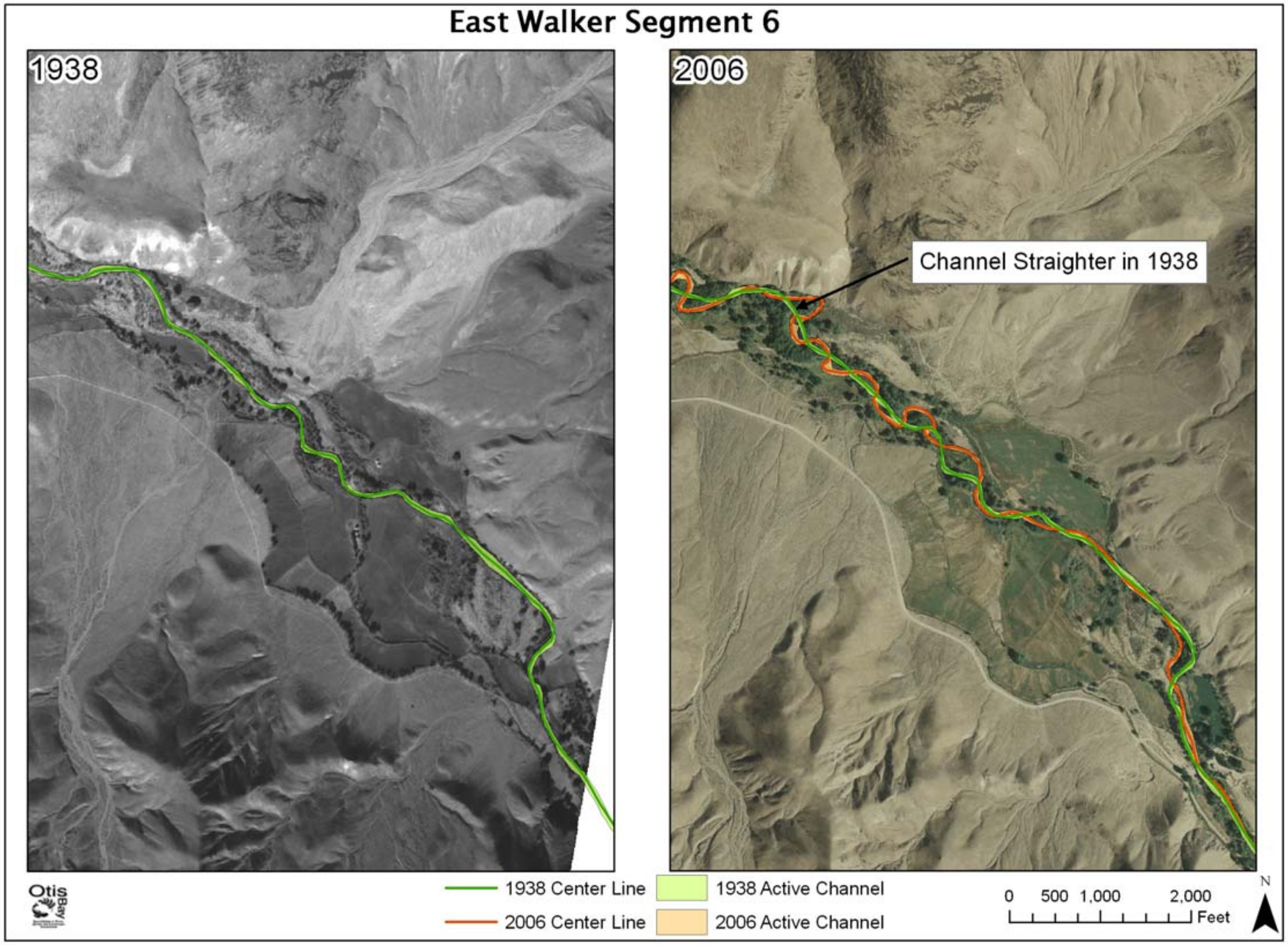


Figure 2.1-78. East Walker River at EW6. Note channel is more sinuous in 2006 when compared to 1938. Flow is from left to right.

East Walker 7-8

Further down the valley, the narrowing and decreasing active channel area trends continue. Through most of EW7, the riparian area has not been severely encroached upon and the river is actively meandering. Meander cutoffs in EW7 and EW8 have formed since 1995 and have created islands that divide the channel (Figure 2.1-79). Ultimately the old channel may be filled in and cutoff from the main river.

Figure 2.1-79. Series of photos showing an example of meandering, cutoffs and vegetated island formation that is occurring in both EW7 and EW8. A length of segment EW8 is shown here. Flow is from bottom to top.

East Walker 9

At EW9 the East Walker River enters Mason Valley. In 1938, agricultural fields and several diversions are in place along the river, but it appears that fields do not encroach on the channel itself, except for an area near Missouri Flat. By 2006, agricultural encroachment has increased here more than any other segment on the East Walker River (Figure 2.1-80).

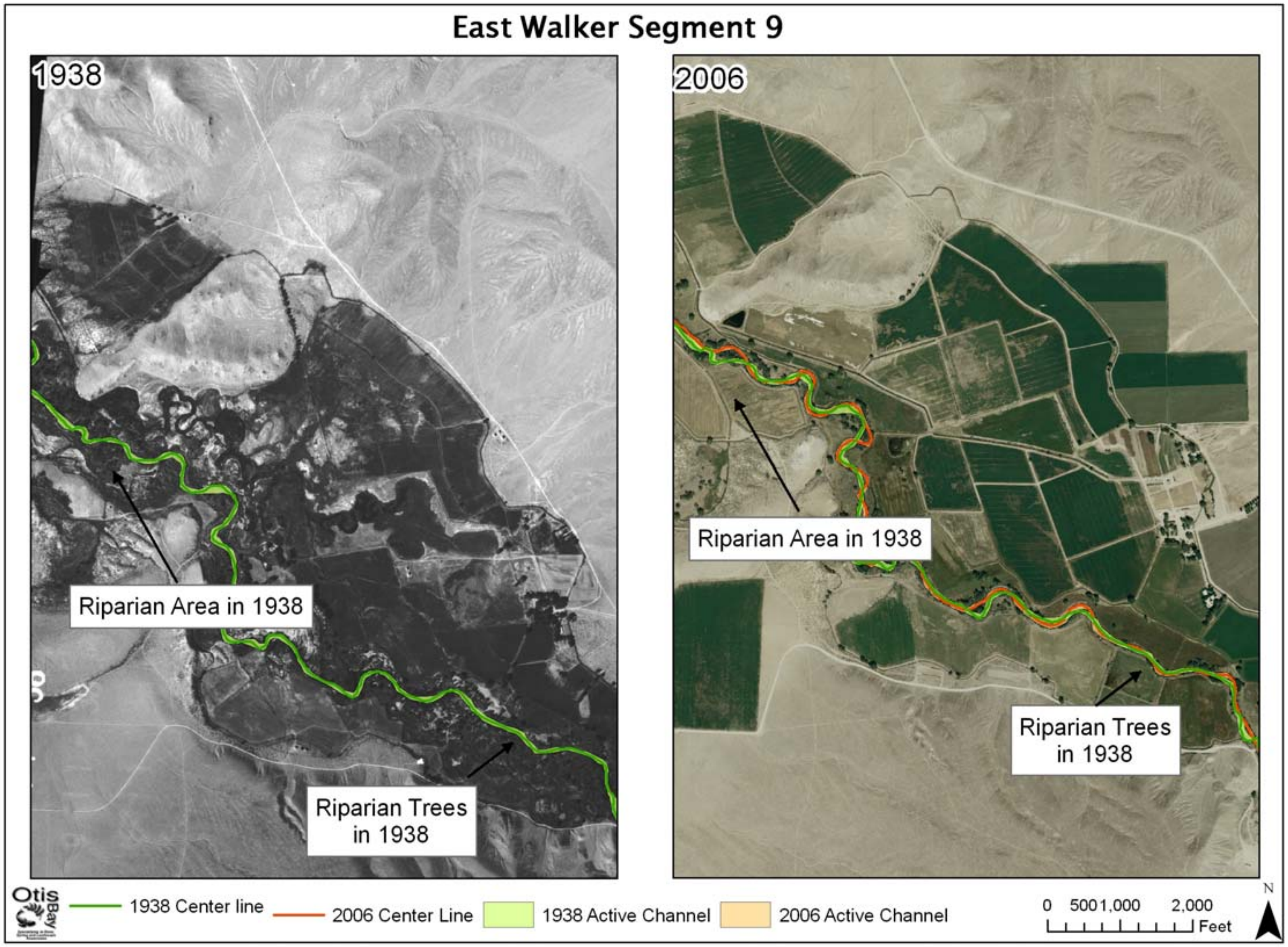


Figure 2.1-80. Photo series of the West Walker River at WW9. Note reduction in riparian area between photos. Flow is from left to right.

2.1.4.7 Channel/Floodplain Connection on the East Walker River

The connection of the channel to its adjacent floodplain is one of the most important physical characteristics of a river system in terms of sustaining riverine processes and ecosystem health. A combination of analytical techniques was used in order to assess the connection. HEC-RAS was used at the reach-scale, providing high resolution flow simulation to determine the frequency of inundation of observed geomorphic surfaces. The HAR was used in order to generate more general results suggesting areas that are prone to flooding and therefore connected to the channel. The HAR results do not indicate frequency of inundation.

With few broad alluvial valleys on the East Walker River, and more continuous canyon segments, the lateral extent of flood-prone areas estimated by the HAR model, and the frequency of overbank flooding estimated by the HEC-RAS model could be expected to naturally differ from the West Walker and Walker Rivers. In comparison to valley segments, the canyons of the East Walker exhibit more direct hillslope sediment input that would create localized sediment surplus, and lateral confinement that would naturally restrict extensive floodplain development.

EW2

Though few valleys exist on the East Walker River, the first two segments are two of the least laterally confined segments. These segments would be expected to have some of the most extensive flood-prone areas on the East Walker. However, HEC-RAS modeling for the study reach in EW2 estimates that the floodplain is accessed by flows between the 10 and 25-year floods (Figure 2.1-81). This suggests that there is no classic alluvial channel-floodplain connection at this segment. The results of the HAR model in EW2 support these results. The HAR shows that the flood-prone area is virtually the same as the active channel. This is another line of evidence supporting a potential lack of channel/floodplain connection in EW2. Bridgeport Dam has probably had some effect on floodplain connection in this segment.

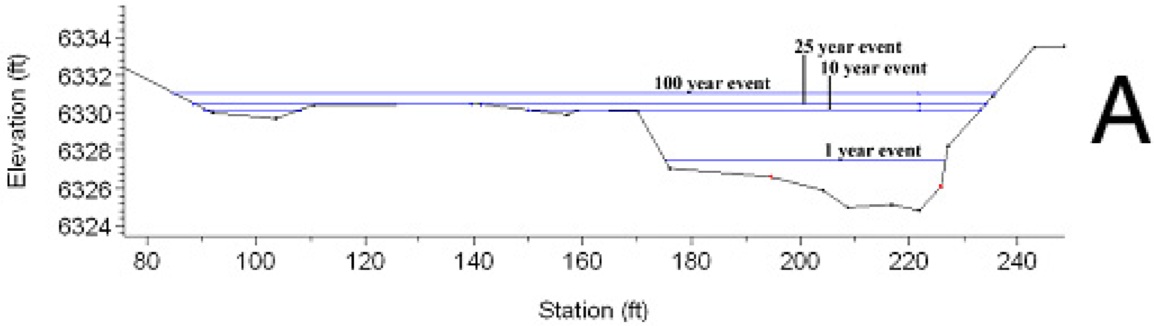


Figure 2.1-81. 2.1-81 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach EW2. Flow is into the page, putting river left on the left side of the image. 2.1-81 B is a photograph of study reach EW2 taken looking upstream from the channel center. Flow is out of the page at a discharge of about 24 cfs. For reference, the 1 year recurrence flow is about 109 cfs. The red line depicts the elevation of the streamside edge of the colluvial terrace on river right that is not inundated by the 100 yr flood. The green line depicts the elevation of the streamside edge of the river left floodplain that is inundated by the 10 yr event. Frequently inundated channel gravels can be seen in the lower left of the image.

EW3

HEC-RAS results at the study reach in EW3 suggest that floodplain inundation occurs at a higher frequency than in EW2. A laterally extensive low-elevation surface on river left is variably inundated by flows beginning with the 1.25 year flood (Figure 2.1-82). This is relatively frequent, and suggests a more natural connection at this location. The HAR results agree with this and show an increased flood-prone area, relative to EW2, along the whole segment (Figure

2.1-83). The flood-prone depth here is 5.5 ft and corresponds approximately with the 100 year flood, so this is a liberal estimate of floodplain connection.

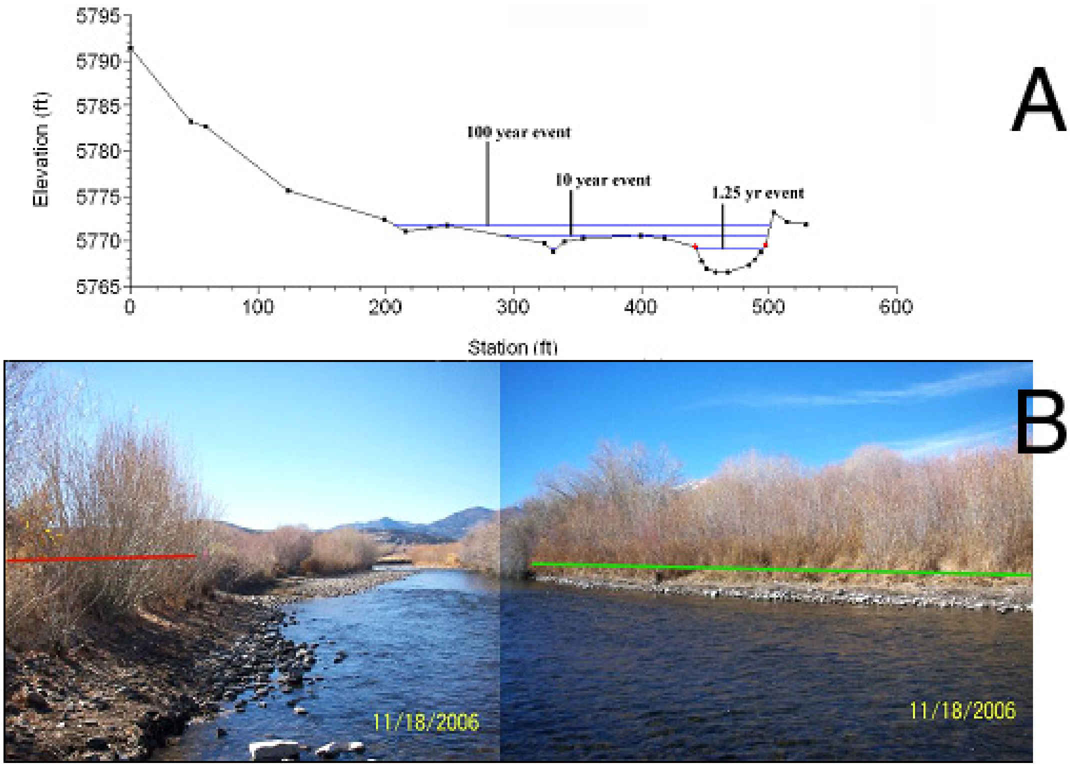


Figure 2.1-82. 2.1-82 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach EW3. Flow is into the page, putting river left on the left side of the image. 2.1-82 B is a photograph of study reach EW3 taken looking upstream from the channel center. Flow is out of the page at a discharge of about 24 cfs. For reference, the 1 year recurrence flow is about 109 cfs. The red line depicts the elevation of the streamside edge of the levee on river right that is not overtopped by the 100 yr flood. The green line depicts the elevation of the streamside edge of the river left floodplain which fully inundated by a 10 yr flood.

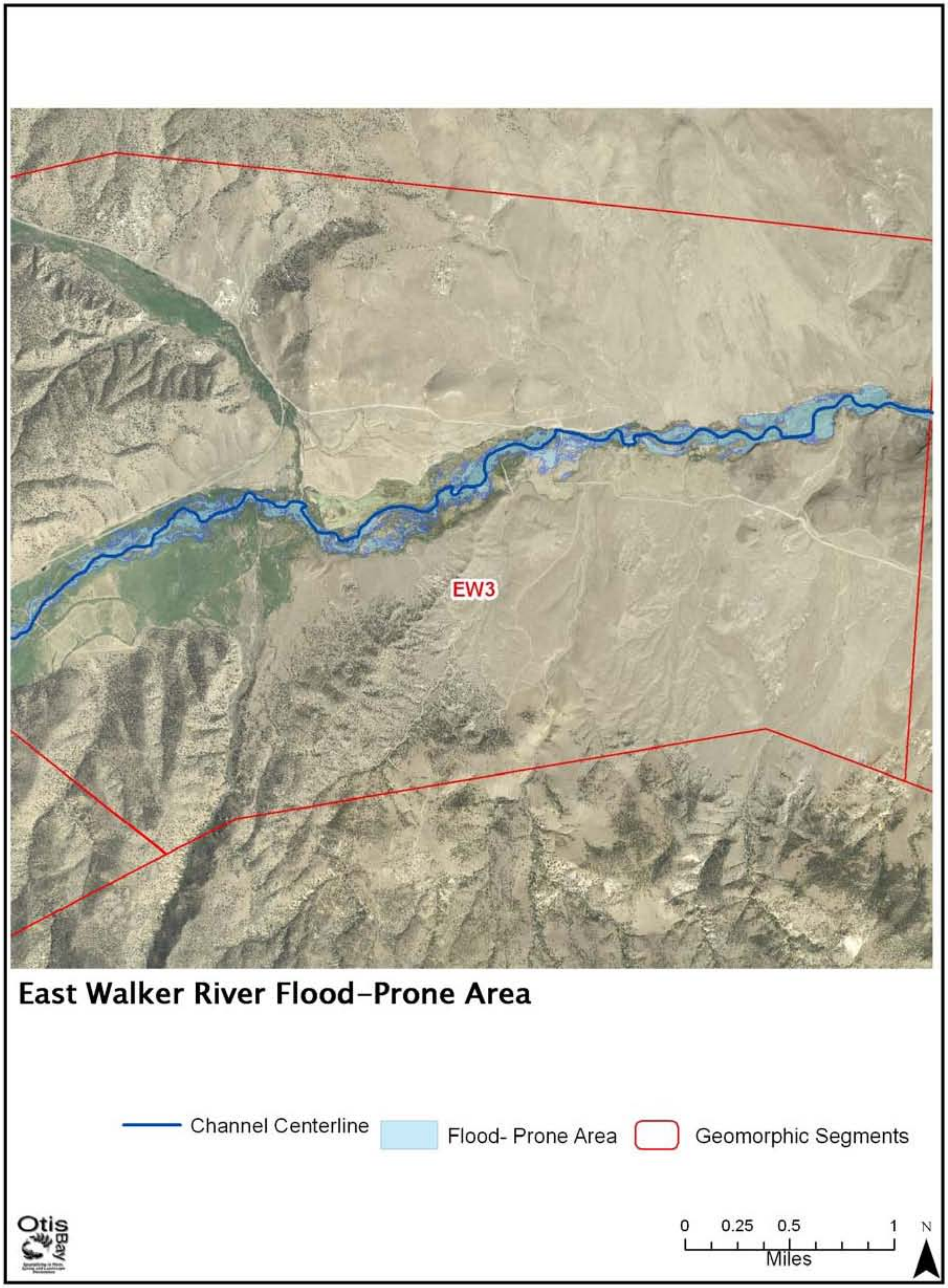


Figure 2.1-83. The EW3 flood-prone area is depicted in purple; note that the flood-prone area increases toward the end of the segment.

EW4-EW5

Downstream of EW3, the East Walker River enters a long series of more laterally confined canyons in segments EW4 and EW5. The HEC-RAS models developed in these study reaches are representative of long stretches of the East Walker River that flow in canyons running along the front of the Sweetwater Range. At study reach EW4, there are laterally extensive surfaces that appear to be floodplain that extend to the canyon walls. However, the lowest of these are not inundated by flows less than the 50 year flood (Figure 2.1-84). Even so, the lowest surface does have deposits of bare sand and flood debris that indicate a more frequent recurrence of moving water. The flood-prone area mapping results of the HAR model in EW4 shows that where lateral restriction of canyon walls is widened, the predicted flood-prone area increases accordingly (Figure 2.1-85). This is true for most of the East Walker River before it reaches Mason Valley. The flood-prone depth is between six and seven feet for the whole East Walker River. It should be noted here that the study reach in EW4 is located at a more restricted area than some other locations in the segment where larger flood-prone areas are predicted.

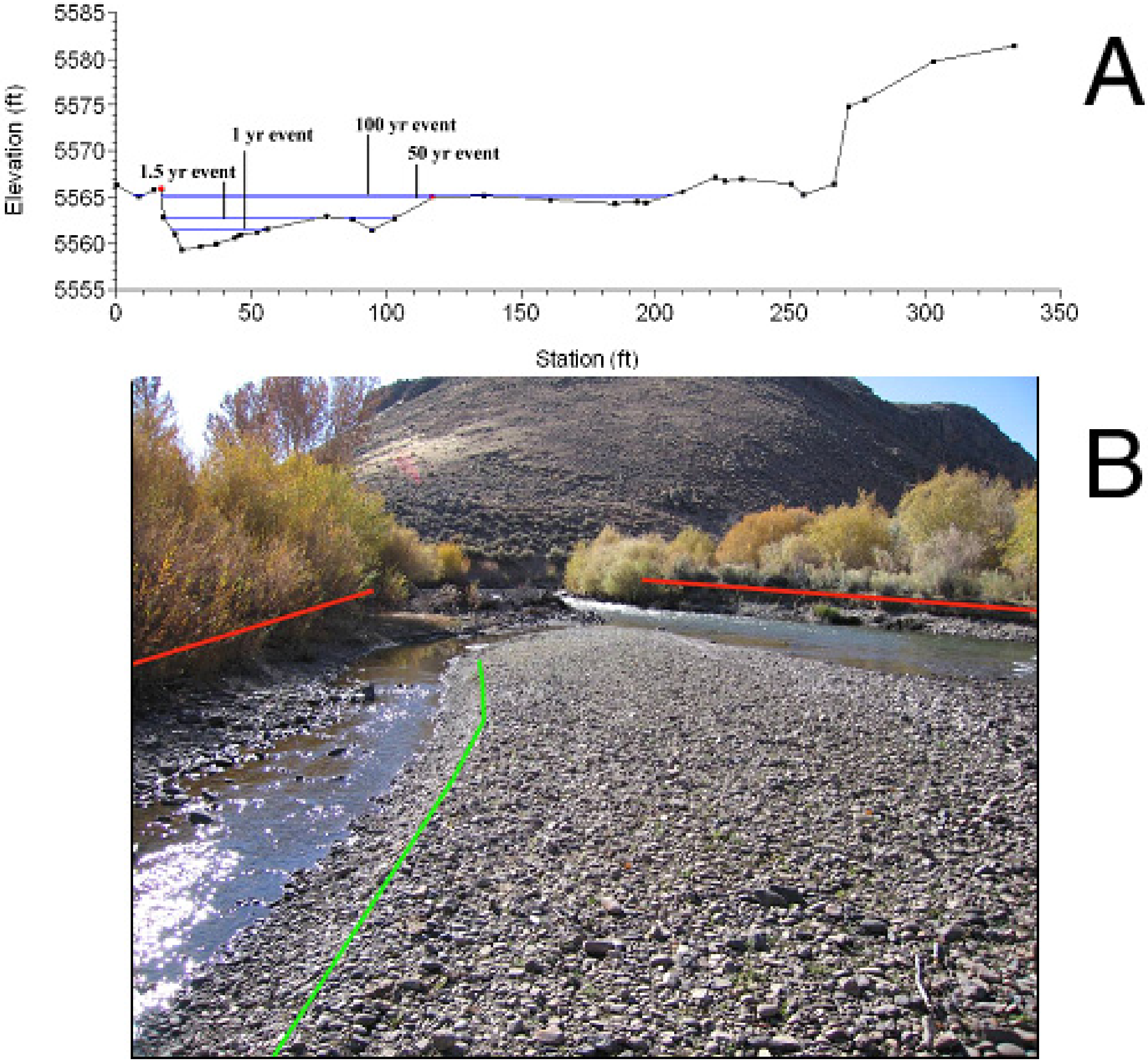


Figure 2.1-84. 2.1-84 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach EW4. Flow is into the page, putting river left on the left side of the image. 2.1-84 B is a photograph of study reach EW4 depicting the main geomorphic surfaces. The photo is taken at a stream discharge of about 136 cfs. For reference the 1 year recurrence flood is about 109 cfs at the Bridgeport, CA gage. The green line delineates the crest of the gravel bar, which is inundated about every 1.5 years. The bar slopes down toward the main channel, and the broader surface is inundated with increasing frequency toward the channel. The two red lines delineate the streamside edges of the highest terrace elevations, which contain the 100 year flood.

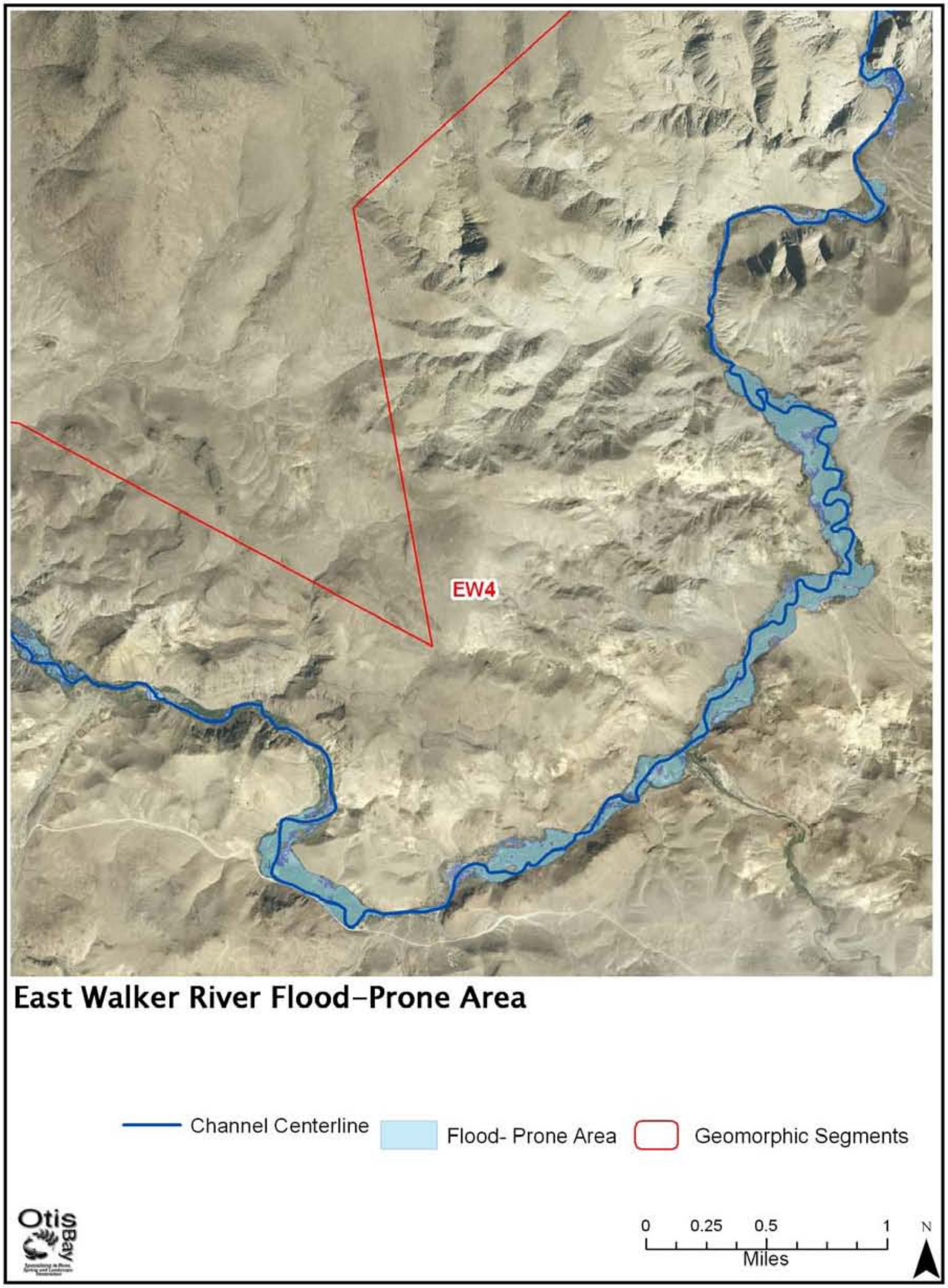
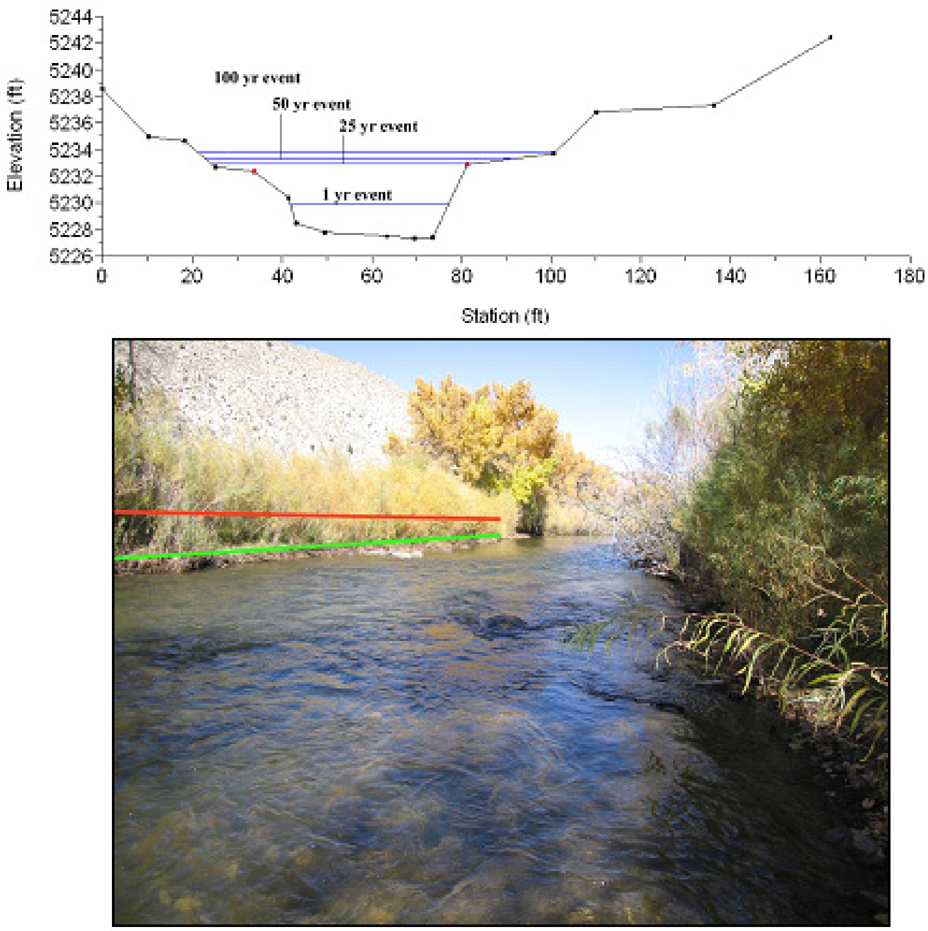


Figure 2.1-85. The flood-prone area at; EW4 note that flood-prone areas expand where canyon confinement decreases. Flow is from left to right.

At the study reach in EW5, HEC-RAS modeling suggests that the narrow floodplain surfaces on both sides of the river are inundated by flows recurring between 10 and 25 years (Figure 2.1-86). This disconnection of the channel and floodplain in this segment could be the result of natural limitations mentioned previously, coupled with reduced peak flows from Bridgeport Reservoir. The natural limitations on floodplain development in this segment made HAR modeling impractical.



A

B

Figure 2.1-86. 2.1-86 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach EW5. Flow is into the page, putting river left on the left side of the image. Photograph of geomorphic surfaces in study reach EW5. 2.1-86 B is a photograph is taken looking downstream, with a streamflow of about 56 cfs. For reference the 1 year recurrence flood event is about 109 cfs at the Bridgeport gage. The green line depicts low-elevation surface that are inundated more frequently that every 1 year. The red line depicts the approximate elevation of the high floodplain that is inundated no more frequently than every 25 years.

EW6-EW7

In segment EW6, the East Walker River leaves the canyons, and begins to flow through broader valley sections. As in the upstream canyons, the East Walker River tends to have larger flood-prone areas where valley width increases. Though study reaches were not established in these two segments, the results of HAR modeling for segment EW7 illustrate the trend toward an increased flood-prone area in the valleys (Figure 2.1-87).

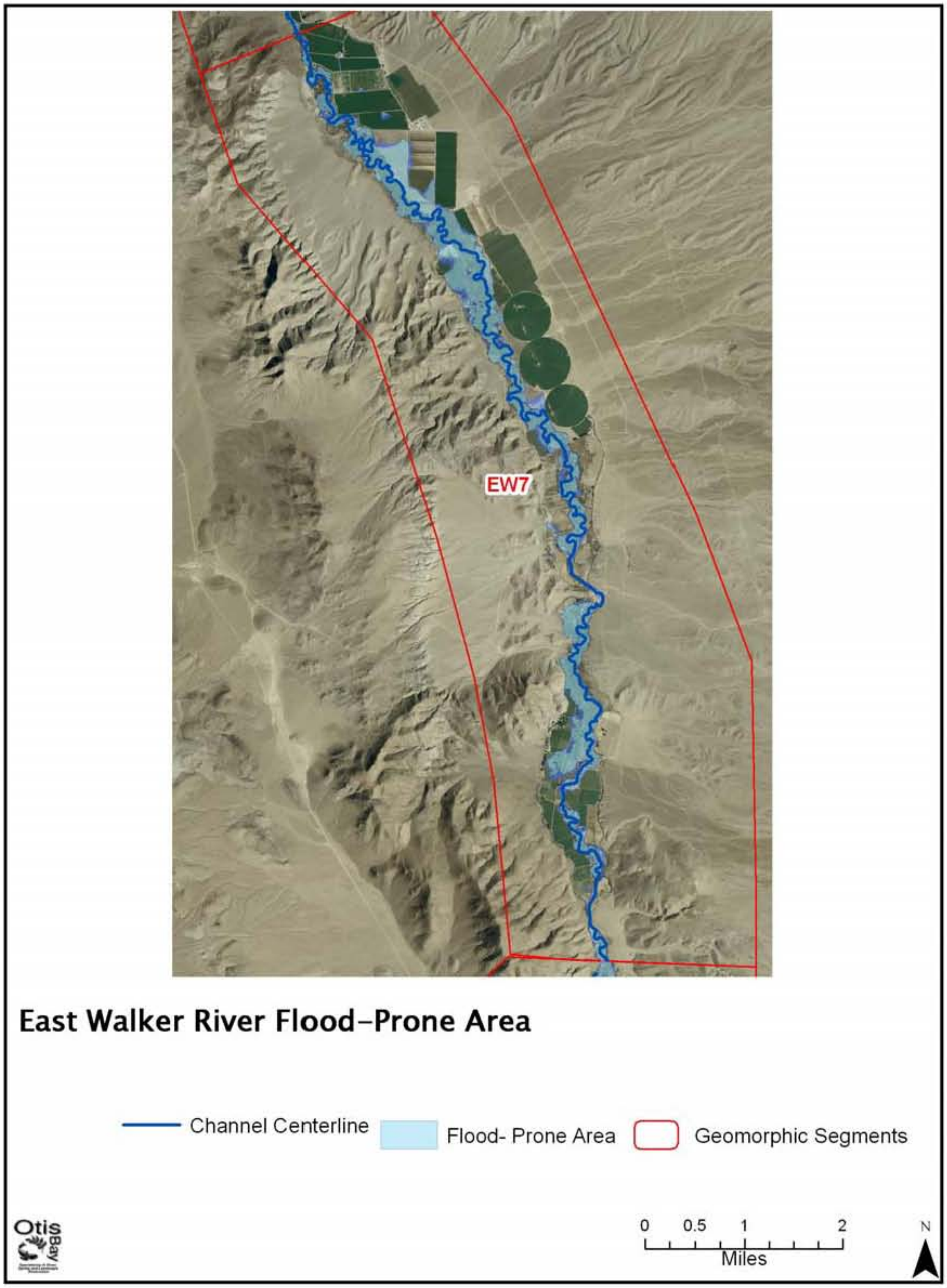


Figure 2.1-87. The flood-prone area at EW7; note flood-prone agricultural fields. At the top of the figure, the river flows into EW8, lateral restriction increases, and the flood-prone area decreases again. Flow is from top to bottom.

EW8

At study reach EW8, the floodplain surface is accessed by flows between the 10 and 25 year floods (Figure 2.1-88). This suggests that frequent overbank flow, and thus a strong connection between the channel and the floodplain is not present in this segment. The lowest surfaces adjacent to the channel are all vegetated with well established riparian species, and do not show signs of frequent inundation. The results of the HAR model for this segment agree with the HEC-RAS results, predicting a narrow flood-prone area through most of the segment.

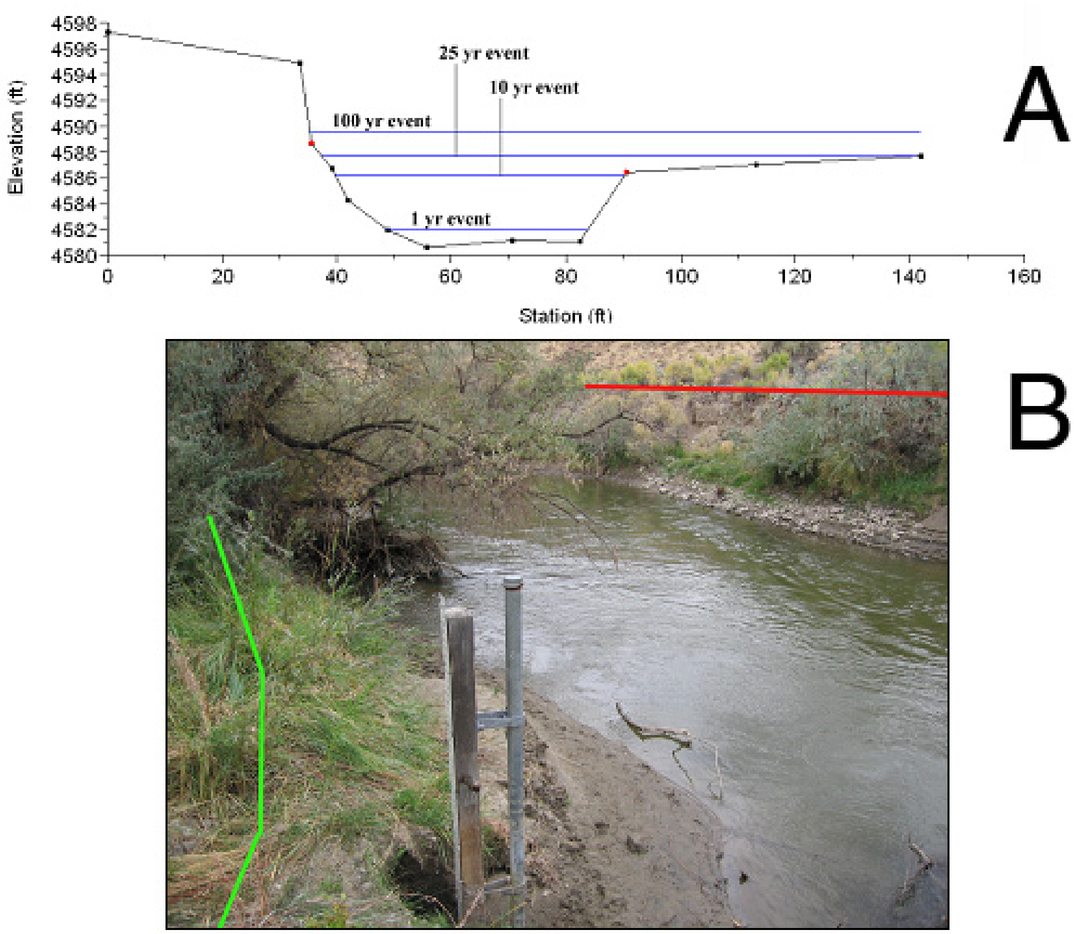


Figure 2.1-88. 2.1-88 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach EW8. Flow is into the page, putting river left on the left side of the image. 2.1-88 B is a photograph of study reach EW8 taken looking upstream at a discharge of about 137 cfs. For reference the one year recurrence flood is about 142 cfs. The red line depicts the top of the high cut-bank caused by the river incising colluvium on the outside of the bend. This surface is not inundated by the 100 yr flood. The green line depicts the streamside edge of the lower elevation floodplain surface on the inside of the bend that is inundated by flows between the 10 and 25 yr floods.

EW9

A study reach was not established in segment EW9 due to limited access, so HEC-RAS modeling was not completed. However, HAR modeling suggests a contradictory trend in the flood-prone area relative to the rest of the East Walker River. In other segments, the flood-prone area was shown to increase where valley width increased. Segment EW9 flows into Mason Valley, where there is virtually no lateral restriction in floodplain development. However, the HAR predicts one of the smallest flood-prone areas of all segments of the East Walker River (Figure 2.1-89). It appears that the river has incised into its historic floodplain, and a strong channel/floodplain connection is not present in this segment. Several factors could be contributing to this trend: the historic aerial photos presented previously for this reach show a dramatic reduction in the riparian area with fields being developed directly adjacent to the channel. There is likely some bank hardening and channel straightening that is associated with the agricultural development. Increased velocities resulting from these actions are often factors in river incision.

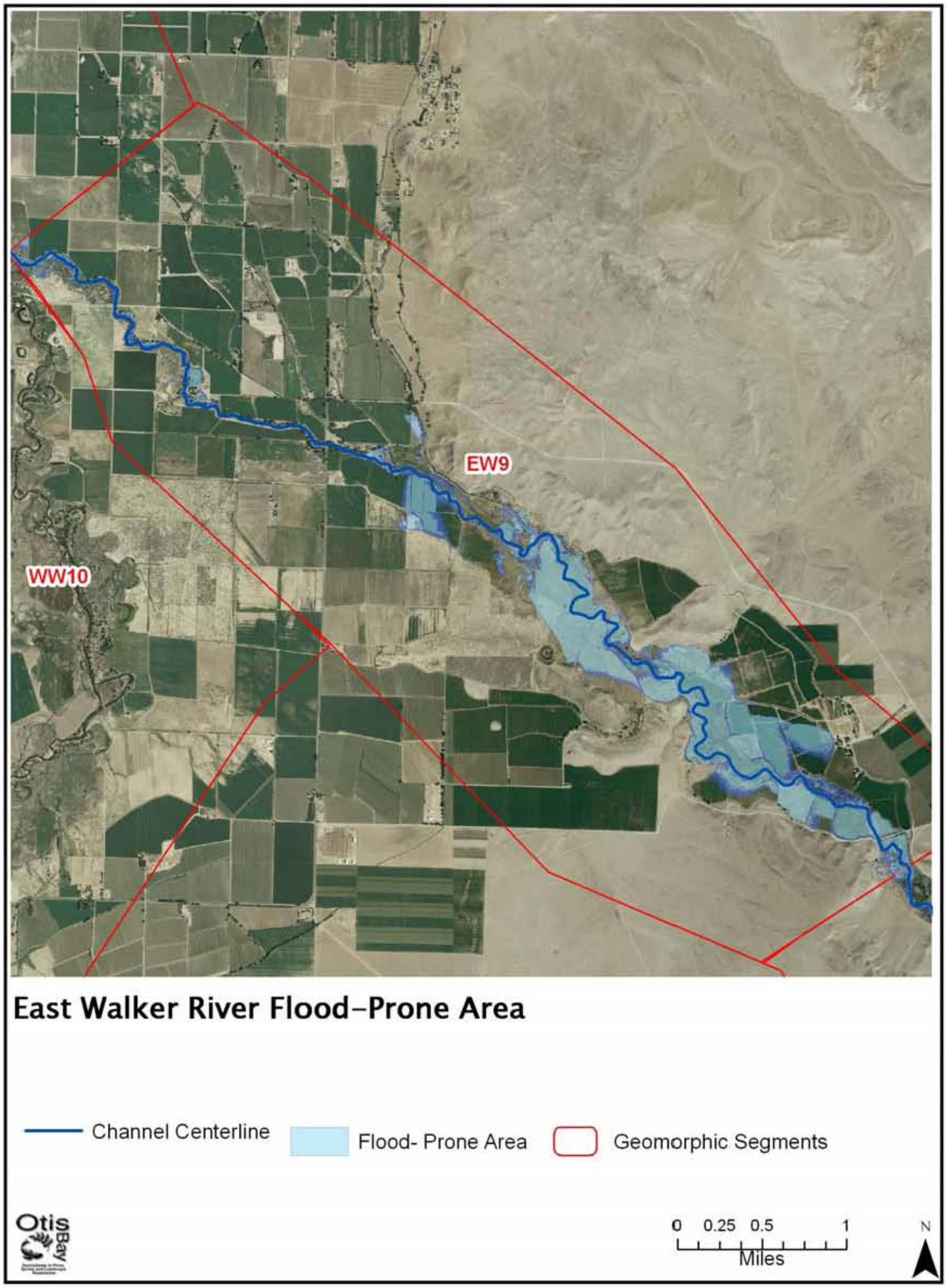


Figure 2.1-89. The flood-prone area at EW9. Note that in the lower part of the segment, the flood-prone area is very narrow, with no buffer from agricultural activity. Flow is from right to left.

2.1.4.8 Channel-Scale Geomorphology of the East Walker River

Measurements of channel attributes such as cross-section geometry and bed substrate characteristics were measured in study reaches. These measurements are summarized below for study reaches on the East Walker River. Measurements obtained in a study reach are meant to represent the larger geomorphic segment, though it is acknowledged that substantial variation in channel morphology can occur within any given geomorphic segment.

CROSS-SECTION GEOMETRY

Reduced variation in channel geometry was observed between study reaches of the East Walker River (Table 2.1-24). This is the combined product of relative geomorphic continuity and similar hydrology along the East Walker. The geomorphology is consistent because the East Walker flows sub-parallel to local faults, rather than bisecting them as the West Walker does. The slope and bed material stay fairly consistent for the length of the river, except for the lower reach at EW8. There are fewer gages on the East Walker than the West Walker, and it is possible that higher hydrologic resolution would change estimates of 5% exceedence flows for some study reaches, therefore changing the geometry of the channel at those flows. However, differences in flow between the upstream gage and the downstream gage on this river are small for average flows and small floods, and differences in the 5% exceedence flows may be insufficient to alter channel geometry substantially.

Table 2.1-24. Cross-section geometry values for the East Walker River. Note that the values in Table 2.1-24 are averages from all cross-section in a reach, and are not derived from other values in the table.

Reach (5% exceedence)	Area (ft^2)	Top Width (ft)	Mean Depth (ft)	W/D
EW2 (453 cfs)	118.7	69.6	1.7	42.7
EW3 (453 cfs)	163.9	97.9	1.8	59.8
EW4 (453 cfs)	118.8	71.6	1.7	44.0
EW5 (453 cfs)	119.4	52.5	2.4	24.4
EW8 (547 cfs)	141.9	50.2	2.9	18.0

GRAIN SIZE ANALYSIS

Grain size analysis characterizes the distribution of sediment sizes on the bed of the river. The data gathered is used as a fundamental geomorphic characteristic, and as input to sediment transport models. The size fractions that are most commonly used as variables in transport functions are listed in Table 2.1-25 for each study reach.

Table 2.1-25. Results of grain size analysis for the East Walker River. Values for the D16 represent the size of the 16th percentile particle in millimeters, the D50 is the 50th percentile particle in millimeters, and so on.

Reach	D16 (mm)	D50 (mm)	D84 (mm)	D90 (mm)
EW2	53	93	170	210
EW3	50	90	137	150
EW4	27	60	110	180
EW5	< 4	64	140	200
EW8	< 4	10	25	31

Study reaches on the East Walker River were equally coarse in their distribution. EW2, EW3, and EW5 had median grain size of 93, 90, and 64 mm respectively putting them in the cobble class. EW4 had a median grain size of 60 mm which is near the transition size between pebbles and cobbles. EW8 had the smallest median grain size of 10 mm, still placing it in the pebble size class.

A trend of downstream fining of the median grain size was observed, especially within and between geomorphically similar segments. This is a common occurrence in fluvial geomorphology (Reid and Dunne, 2003). This trend could prove useful in estimating conditions in adjacent segments, with similar geomorphology, that have restricted access. Plots of grain size distribution for each study reach are presented in Appendix H.

2.1.4.9 Walker River Geomorphic Segment Descriptions

The geomorphic segment is the basic spatial unit of analysis in the geomorphic assessment of the Basin. The analyses of processes or forms at smaller or larger scales use segments for reference. Therefore, descriptions of each segment for the Walker River are presented here first.

WALKER RIVER 11

The segment can generally be described as alluvial with a low-gradient, meandering channel that migrated over a relatively wide historic floodplain. Movement along the Singatse range front fault tends to force a net west migration direction, causing the river to move against the front of the range and restricting migration in that direction. Development of the floodplain for agriculture has also likely reduced the degree of lateral movement.

Table 2.1-26. Summary of some physical characteristics of Walker 11 (W11).

Distance from Walker Lake (to upstream end of segment) (mi)	58.8
Segment Length (mi)	13.5
Upstream Elevation (ft)	4,428
Channel Slope	0.0012
Valley Slope	0.0015
Sinuosity	1.23
Average Width (ft)	56
Median Grain Size of Bed Material (mm)	-

W11 begins at the confluence of the West and East Walker Rivers (Figure 2.1-90). Following this confluence, the river flows north along the front of the Singatse Range. Directly downstream of the confluence, the river is relatively sinuous, meandering across a fairly wide floodplain. Continuing downstream from the confluence, the channel appears to be diked, and loses much of its sinuosity for the remainder of the segment. Some sections within this straightened portion still exhibit point bar deposition, and cut-bank development within an inset floodplain.

Figure 2.1-90. Aerial photograph of the Walker River flowing through the Mason Valley in W11. The view is looking upstream. The sinuous pattern below the confluence of the East and West Walker Rivers is evident at the top of the image. As floodplain development is increased, stream curvature is decreased. This can be seen at the bottom, downstream, portion of the image. (Google Earth, 2008).

WALKER RIVER 12

The segment can generally be described as alluvial with a meandering channel that is one of the least laterally restricted segments in Mason Valley. The river moves away from the front of the Singatse Range. The historic floodplain is wide in this segment, with relic channels, and small distributary channels across much of the valley floor.

Table 2.1-27. summary of some physical characteristics of Walker 12 (W12).

Distance from Walker Lake (to upstream end of segment) (mi)	45.3
Segment Length (mi)	6.5
Upstream Elevation (ft)	4,330
Channel Slope	0.0011
Valley Slope	0.0015
Sinuosity	1.33
Average Width (ft)	26
Median Grain Size of Bed Material (mm)	0.81

W12 flows through a portion of the Mason Valley that has been under the management of the Nevada Department of Wildlife since 1955 (Figure 2.1-91). This has produced a relatively undeveloped condition that could be representative of the river prior to development in the Mason Valley. However, irrigation has altered the natural hydrology in this segment. This segment is low-gradient and sinuous. There is significant sand deposition on point bars, alternating bars, and in the adjacent floodplain. The floodplain is heavily vegetated, and fairly extensive. Wetlands and sloughs are frequent in the floodplain. The position of the river in this region has potentially varied widely during Quaternary time. There is geologic evidence that the river flowed out of the Walker Basin and into the Carson Sink through the Adrian Valley (Adams, 2007).

Figure 2.1-91. Aerial photograph of the Walker River flowing through the MVWMA in W12. The view is looking downstream. Relative to other areas of the Mason Valley, there is little floodplain development, and the channel may retain some of its historical morphology. (Google Earth, 2008).

WALKER RIVER 13

The segment can generally be described as alluvial and meandering, though the channel becomes indistinct and marshy near the upstream end of Weber Reservoir. Much of the historic floodplain has been left undeveloped in this segment. The channel incises lacustrine and alluvial fan deposits in this segment, and the terraces formed by incision present natural barriers to lateral channel migration.

Table 2.1-28. Summary of some physical characteristics of Walker 13 (W13).

Distance from Walker Lake (to upstream end of segment) (mi)	38.9
Segment Length (mi)	20.3
Upstream Elevation (ft)	4,282
Channel Slope	0.0012
Valley Slope	0.0017
Sinuosity	1.42
Average Width (ft)	36
Median Grain Size of Bed Material (mm)	-

The river turns sharply east then south in W13, leaving the open Mason Valley and flowing into incised fluvial and lacustrine deposits that form terraces on both sides of the river valley (Figure 2.1-92). Within the lateral confinement of these terraces, the river remains low gradient and sinuous with a well developed and unrestricted meander pattern. Well preserved meander scars, scroll bar deposits, and oxbows attest to a history of significant meander migration. Sinuous sections display point bar deposition and cut-bank erosion. Straighter sections display alternating bar deposition. The alluvial valley is well vegetated, and at the downstream end of the segment, the channel becomes split into multiple smaller channel that flow into sloughs and marches without a discernible main thread.

Figure 2.1-92. Aerial photograph of the Walker River upstream of Weber Reservoir in W13. The view is looking upstream. The river has incised lake and alluvial fan deposits here and created an inset alluvial valley. Historical evidence of channel migration is supported by oxbows and abandoned channels in the floodplain. (Google Earth, 2008).

WALKER RIVER 14

The two segments below Weber Reservoir are unique, in that they are actively incising in response to base level decline at Walker Lake. So, though W14 can generally be described as alluvial, its meander pattern is restricted by high terraces formed through rapid incision, and a significant floodplain has not developed.

Table 2.1-29. Summary of some physical characteristics of Walker 14 (W14).

Distance from Walker Lake (to upstream end of segment) (mi)	18.5
Segment Length (mi)	8.5
Upstream Elevation (ft)	4,148
Channel Slope	0.001
Valley Slope	0.0017
Sinuosity	1.7
Average Width (ft)	49
Median Grain Size of Bed Material (mm)	1.4

W14 extends from below Weber Reservoir to the most recently exposed Walker Lake delta (Figure 2.1-93). On the ground observations were made downstream of the siphon at Schurz. In this region, the channel is narrowly incised up to 25 ft forming high vertical to near vertical banks. The channel incises lacustrine deposits from remnant high stands of Walker Lake (Adams, 2007). Narrow inset floodplain deposits occur within this confined corridor. Lateral migration in the form of large point bar deposits is evidenced by opposing steep cut-banks. Banks are actively slumping throughout the segment. The channel is generally low gradient, and displays an entrenched meander pattern. Downstream, channel confinement decreases somewhat.

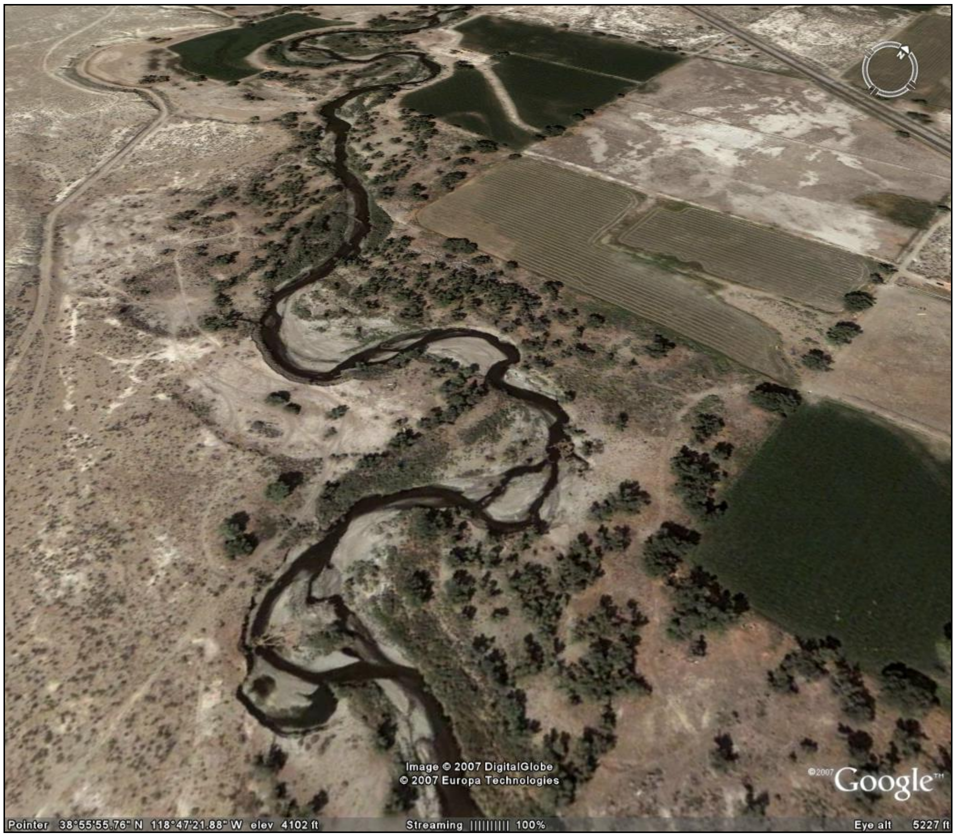


Figure 2.1-93. Aerial photograph of the Walker River downstream of the town of Schurz in W14. The view is looking upstream. The river has been incising lake sediments in response to base level drop of Walker Lake. (Google Earth, 2008).

WALKER RIVER 15

The segment shares many geomorphic characteristics with W14 in that it is an alluvial, meandering channel that is actively and rapidly incising in response to base level decline at Walker Lake. Towards the downstream end of the segment, the lengthening channel that flows over newly exposed deltaic deposits has not experienced large enough flows to incise to the depth as upstream portions of the segment.

Table 2.1-30. Summary of some physical characteristics of Walker 15 (W15).

Distance from Walker Lake (to upstream end of segment) (mi)	10
Segment Length (mi)	10
Upstream Elevation (ft)	4,086
Channel Slope	0.001
Valley Slope	0.0015
Sinuosity	1.5
Average Width (ft)	75
Median Grain Size of Bed Material (mm)	0.68

Segment W15 is located where the most recent fluvial deltaic deposits of the Walker River are exposed upstream of Walker Lake (Figure 2.1-94). The channel is deeply incised throughout the segment, and the river is low gradient and meandering. At the upstream end, the morphology is similar to W14. However, moving downstream the lateral confinement decreases until there is a fairly wide (> 500 ft) inset floodplain. Evidence points to significant channel migration within this corridor. Active aggradation is indicated by wide, shallow channels that are braided at baseflow. The low flow channel pattern is dominated by unstable bar forms, as well as stabilizing vegetated clumps. Larger patterns, especially those visible on aerial photos are generally abandoned channels that are now located on terrace surfaces up to 20 ft above the current water surface elevation. As the lake level has dropped over the last century, the lengthening channel has adjusted by westward migration towards the Wassuk Range fault (Adams, 2007). This cross-valley gradient is also likely to be influencing channel migration rates.

Figure 2.1-94. Aerial photograph of the Walker River upstream of Walker Lake in W15. Flow is from left to right. In response to base level decline, the river has incised fluvial deltaic deposits and established a wide inset floodplain. The wide shallow nature of the channel, and channels abandoned as incision progresses, can be seen in the photograph. (Google Earth, 2008).

2.1.4.10 Historic Channel Change of the Walker River

An analysis and comparison of historic and current channel planform is a primary component of the geomorphic assessment. In this analysis of channel planform, changes in sinuosity and channel length, active channel area, and channel width were compared. The nature of changes in these attributes over time can be used to infer trends in geomorphic process. Please note that more detailed interpretation of planform change will follow the completion of various research projects currently underway in the Basin. Methodologies for air photo interpretation and evaluating channel change are described in section 2.1.1.3 of this report. The results of the photo analysis for the Walker River are shown in Figure 2.1-95. The complete set of 2006 with all the digitized layers of the historical analysis are shown in Appendix A. It should be noted that researchers at the Desert Research Institute are currently completing a historic analysis of segments W14 and W15, and these segments are therefore not analyzed here but will be incorporated in future analysis and decision making.

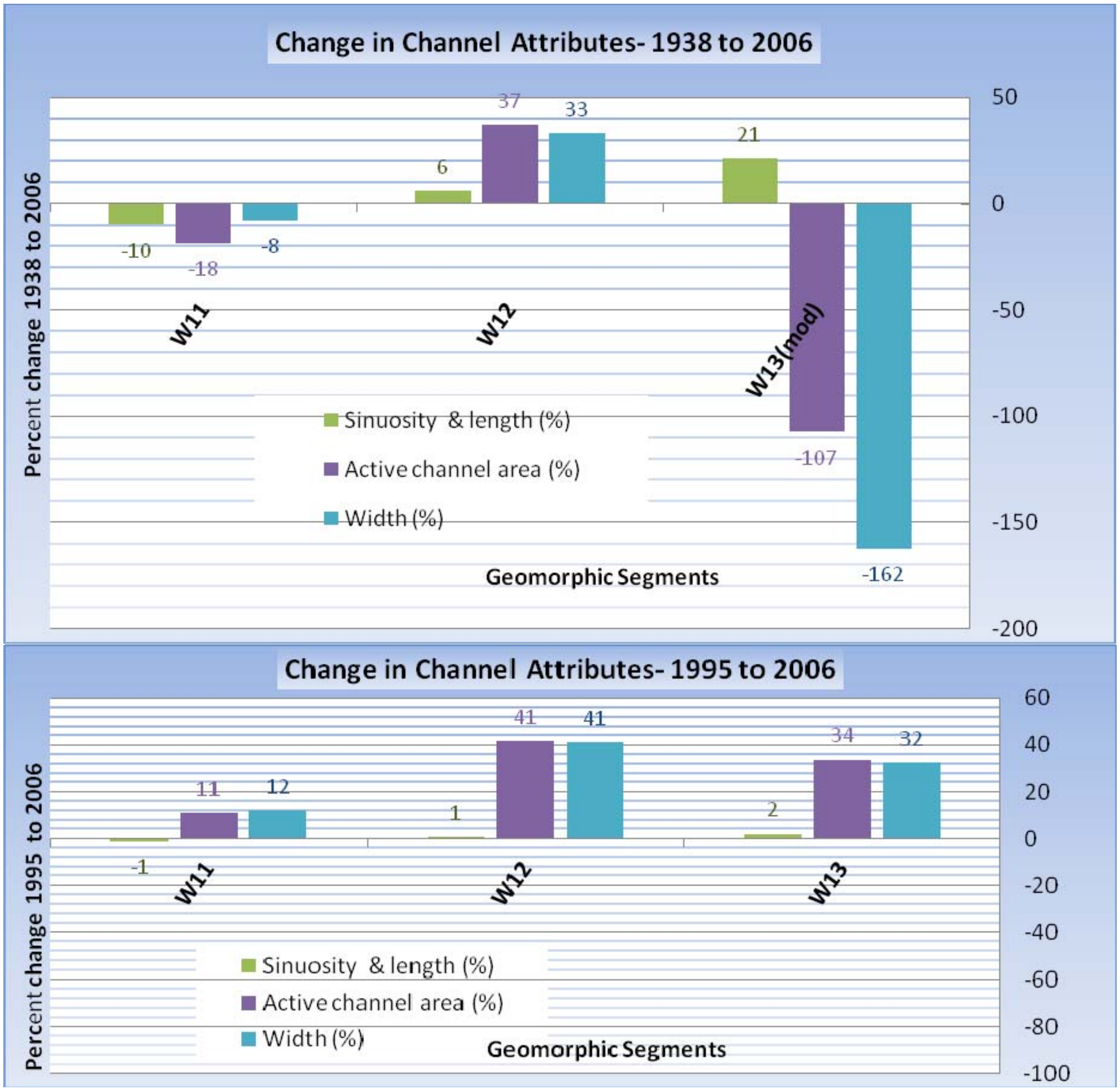


Figure 2.1-95. Results of the photo analysis for the Walker River. Top figure compares 1938 to 2006; bottom figure compares 1995 to 2006.

Looking at the results, some trends are noteworthy:

- W11 in southern Mason Valley has narrowed since 1938, and has lost sinuosity, but the channel has widened recently.
- W12 has shown to be widening and growing more sinuous.
- W13 has narrowed substantially and has grown more sinuous since 1938.

More specific segment results are discussed below with the primary focus being the change from 1938 to the present.

WALKER RIVER 11

The Main Walker is actively meandering near the confluence of the West and East Walker Rivers, but within 1.5 miles north of the confluence, the channel appears straightened. The riparian area of the river near Mason has been replaced by agriculture in the 1938 photos. In contrast, the area north of Yerington appears much more natural in the 1938 photos. In the more modern photos, the river appears straightened the channel is simplified (Figure 2.1-96). The channel dimensions described in an historic account from March, 1868 (pre-water diversions), state that the channel was 300 ft across and two ft deep, which is about three times the current active channel width (Stewart, 1995).

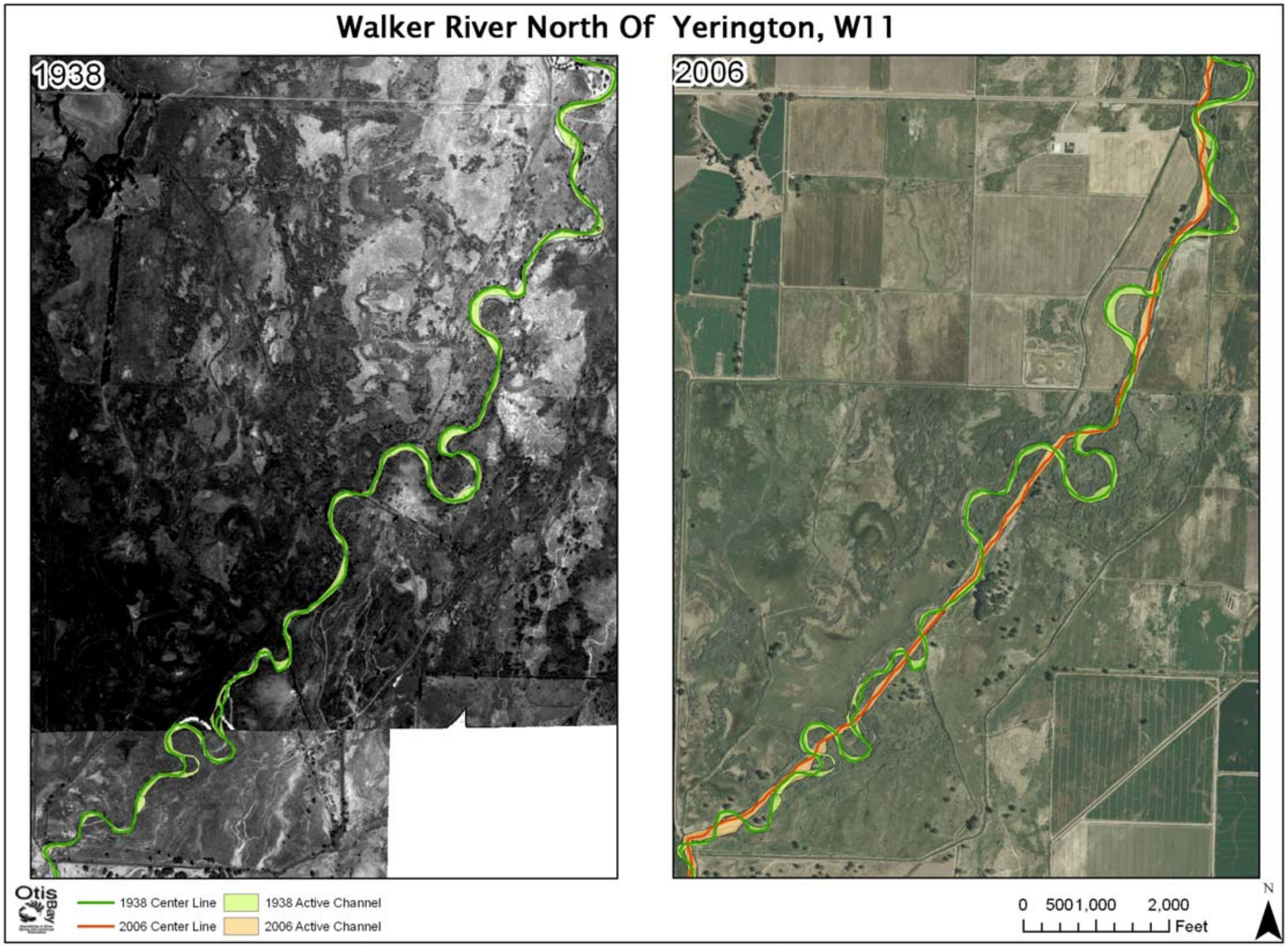
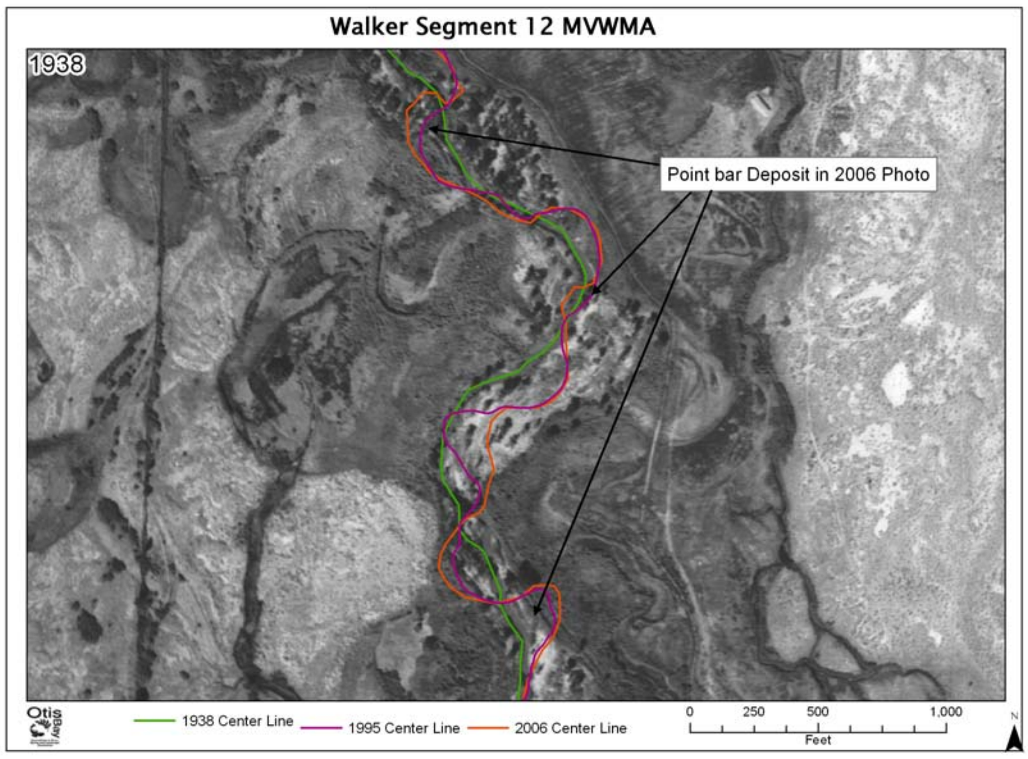
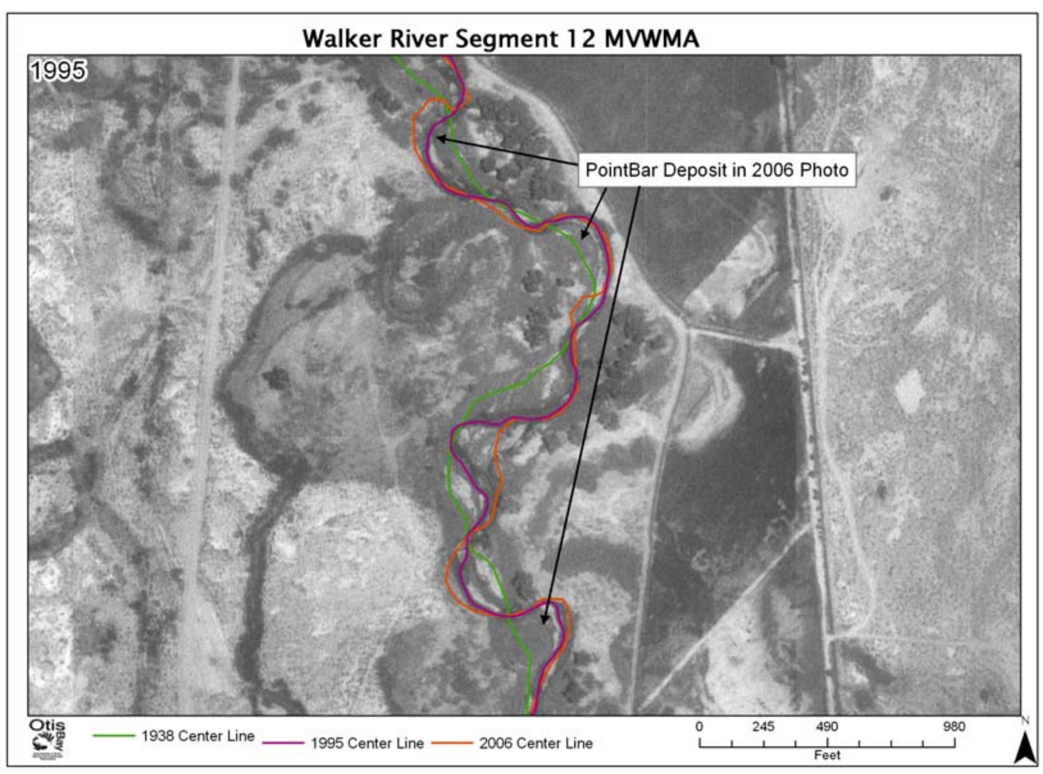


Figure 2.1-96. Photo series of the Walker River in W11. The channel in this area has been straightened since 1938. Flow is from top to bottom.

WALKER RIVER 12

The channel in the Mason Valley Wildlife Management Area (MVWMA) has not been straightened as in W11, but changes have occurred. Recently, point bars lacking vegetation appear in the 2006 photos that are not present in 1995. Because these deposits are not stabilized by vegetation, they are counted as active channel and lead to an increase in width of 41% from 1995 to 2006. W12 is also one of the only segments to show widening since 1938 (Figure 2.1-97). This level of channel activity may indicate increased rates of deposition in this segment.





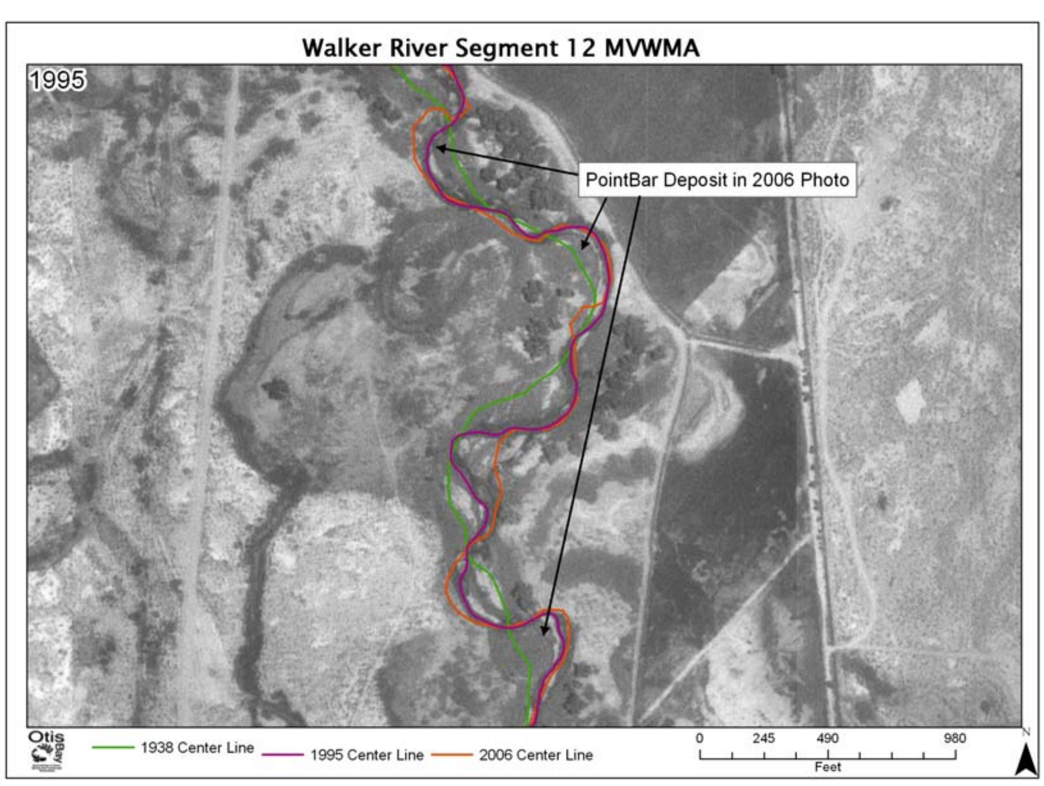
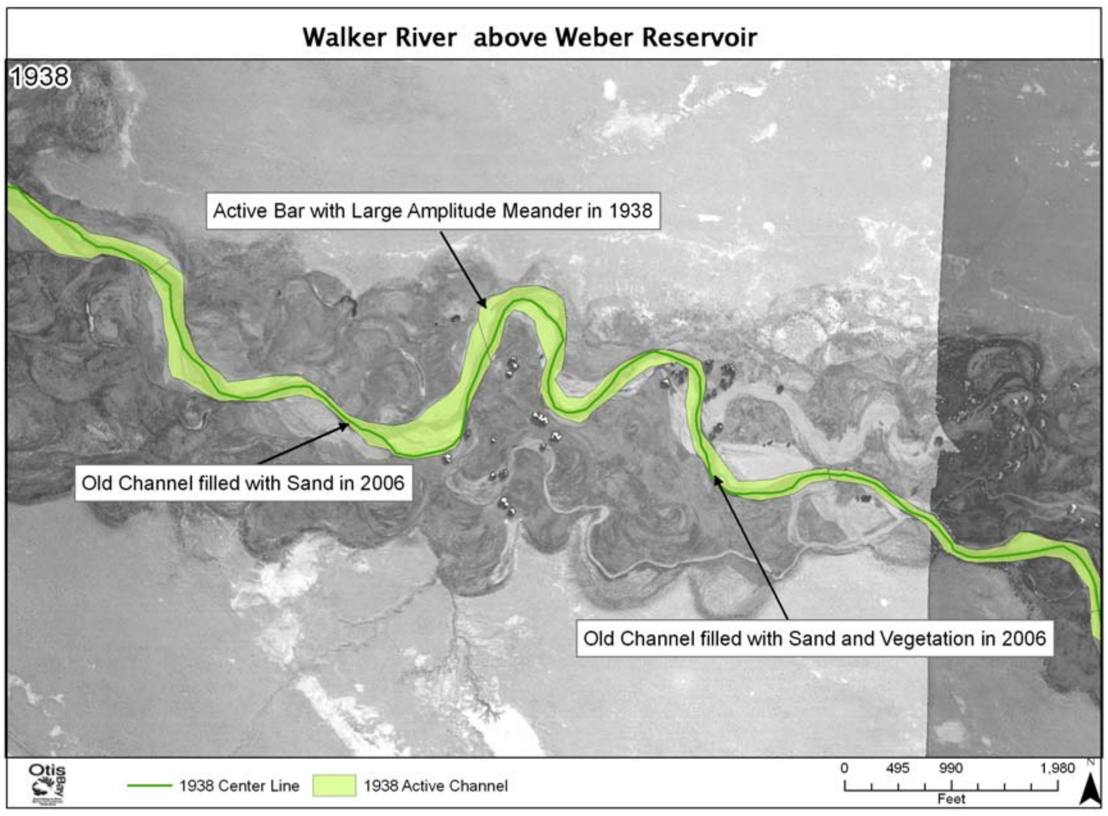
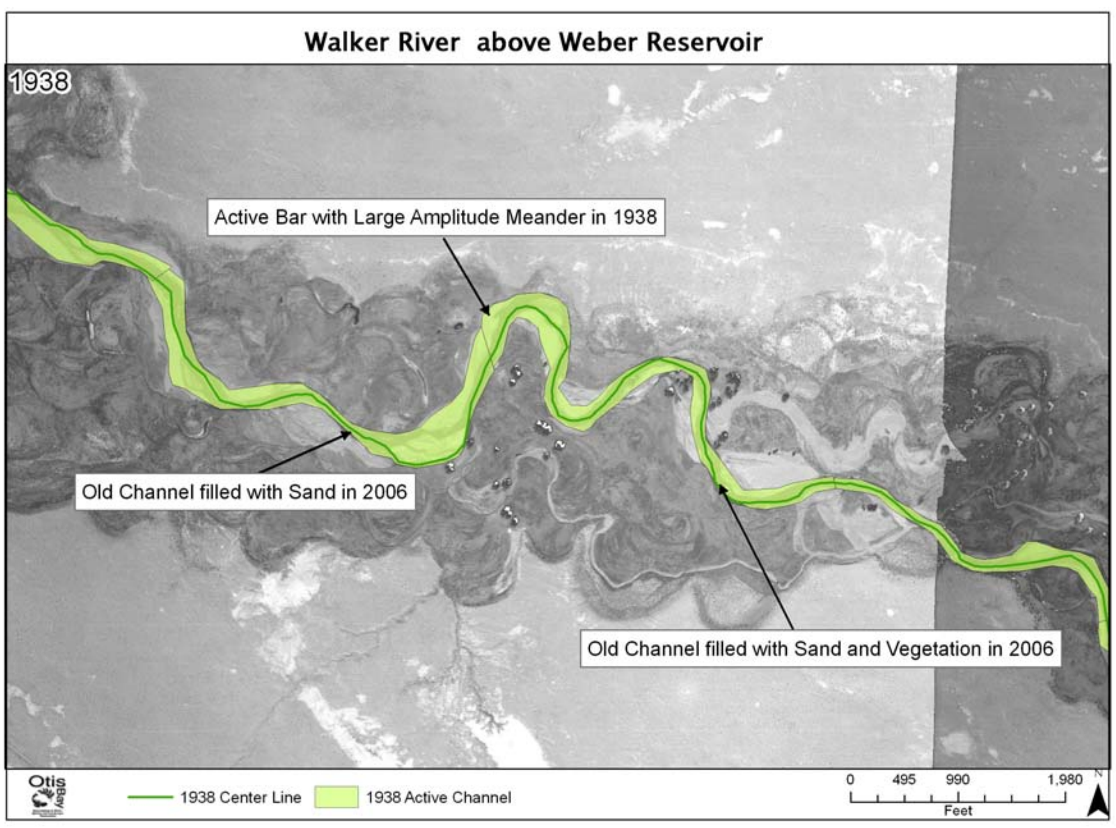


Figure 2.1-97. Series of photos showing point bar deposition in MVWMA; digitized active channel is not shown here so the point bars can be seen easier. Flow is from top to bottom in all images.

WALKER RIVER 13

Change in the segment downstream of the refuge (W13), is dramatic. The channel in 1938 is characterized by large amplitude meanders with large active, non-vegetated, point bars. By 1995 these bars have been stabilized by vegetation and are no longer active. By 2006 many areas of the old channel have been abandoned and filled in with sediment. The channel width has decreased by 162%. In 2006 the river is shown to reoccupy an older more sinuous channel with lower amplitude meanders (Figure 2.1-98). In places, the channel practically disappears, and is replaced by wetlands and sand-filled relic channels. Historic observations in this area list the channel width between 99 and 382 ft at the end of June 1904 (Stewart, 1995). This is similar to what was found on the 1938 photos where the average width is 260 ft compared to 80 ft in 2006.





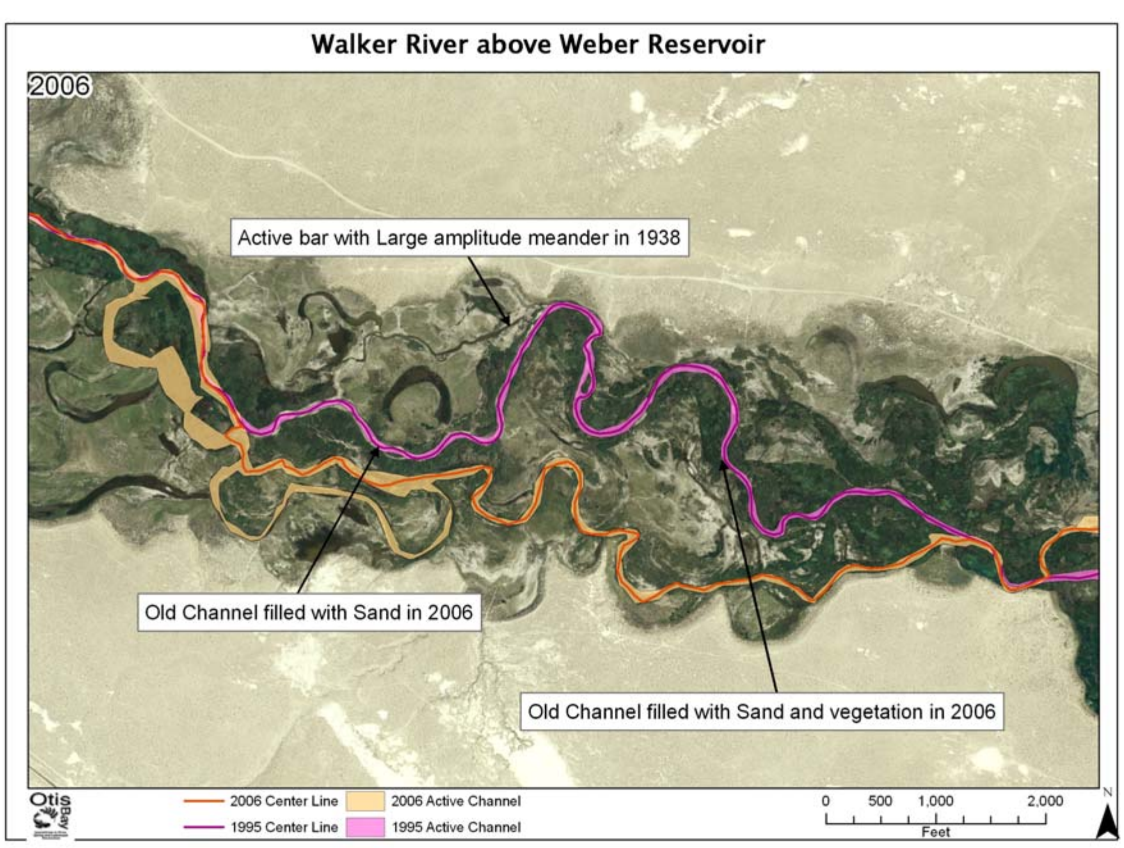


Figure 2.1-98. Series of photos showing channel change through time above Weber Reservoir in W13. Flow is from left to right in all images.

2.1.4.11 Channel/Floodplain Connection on the Walker River

The connection of the channel to its adjacent floodplain is one of the most important physical characteristics of a river system in terms of sustaining riverine processes and ecosystem health. A combination of analytical techniques was used in order to assess the connection. HEC-RAS was used at the reach-scale, providing high resolution flow simulation to determine the frequency of inundation of observed geomorphic surfaces. The HAR was used in order to generate more general results suggesting areas that are prone to flooding and therefore connected to the channel. The HAR results do not indicate frequency of inundation.

The Walker River flows through laterally unrestricted valleys for most of the rest of its length, unlike its two main tributary streams which have several canyon segments each. In locations where the Walker River does become restricted, it is usually due to the river's incision into easily erodible lacustrine or fluvial deltaic deposits, as in W13, W14, and W15. The bed material is primarily sand sized in all segments of the Walker River. It can be expected that a channel formed naturally in these conditions would be an alluvial channel, adjusted to its incoming sediment load, and connected to its floodplain by overbank flooding at intervals from 1.5 to 5 years. Substantial deviation from this frequency would be reason to suspect some perturbation and disequilibrium condition.

W11

A HEC-RAS model could not be developed for this segment due to access issues and a lack of a study reach. The HAR was used to predict potential floodplain connectivity in W11. At the upstream end of the segment, the flood-prone area is relatively narrow, and discontinuous. This can be partly attributed to the river's position on the extreme west side of the valley against the front of the Singatse Range, limiting the natural extent of the floodplain in that direction. However the predicted flood-prone area increases in the downstream direction as the river flows away from the mountain front and takes a path through the middle of the valley. An interesting observation is that the area around Yerington where the river has been straightened and dredged historically, has not incised into its floodplain. The flood-prone depth is set at about seven ft from the W12 study reach which corresponds approximately with a 25 year flood (Figure 2.1-99).

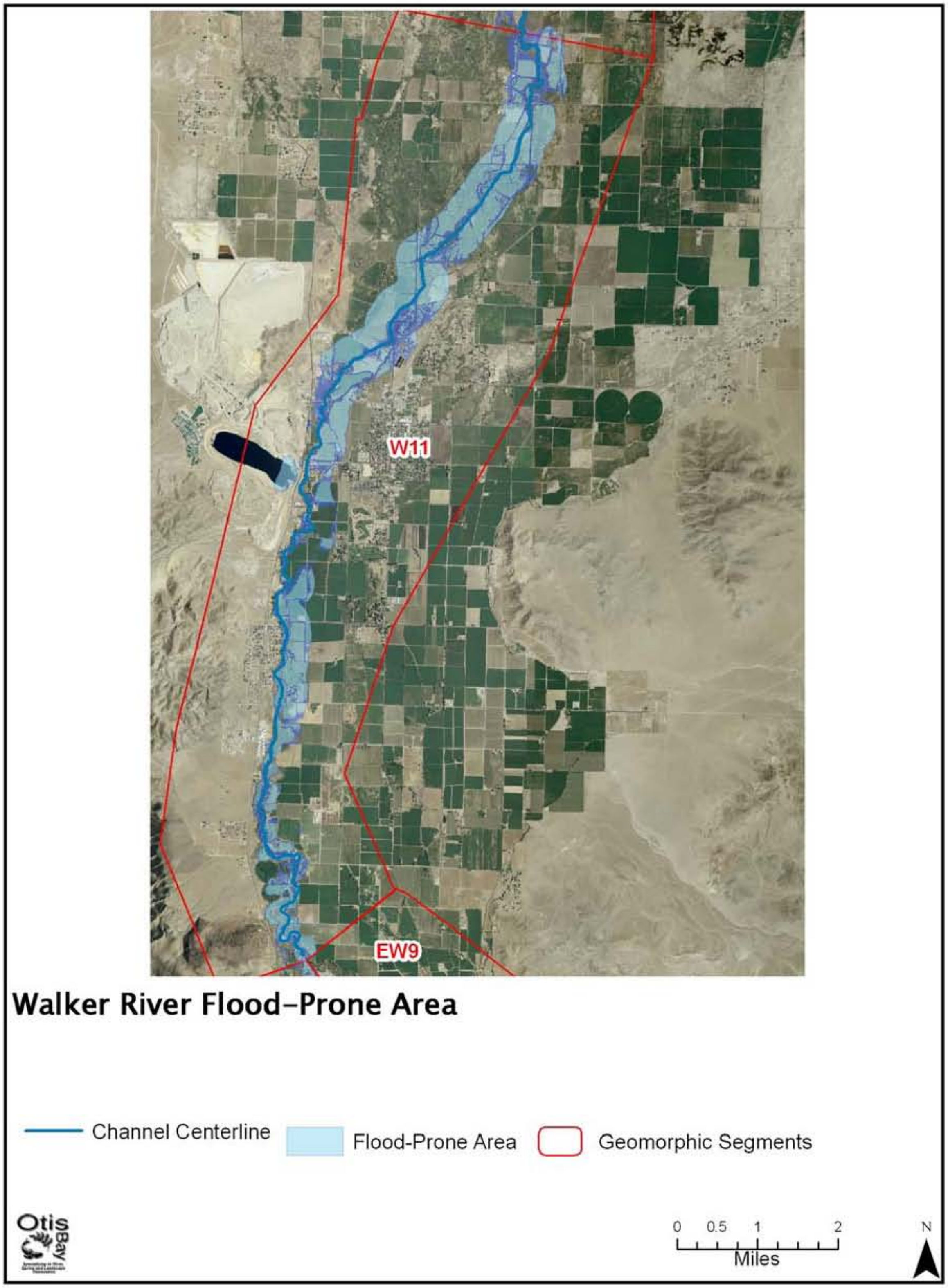


Figure 2.1-99. The flood-prone area at W11. Note the connected floodplain towards the northern part of the segment. Flow is from bottom to top.

W12

HEC-RAS modeling at the study reach in segment W12 at the MVWMA suggests that the floodplain is inundated by flows between the five and ten year floods (Figure 2.1-100). This represents a poor channel/floodplain connection resulting from possible channel incision at this location. Results of the HAR model support these results. Segment W12 is composed of two distinct areas: a narrow flood-prone area filling in low lying oxbows and relic channels, and areas where there is no flood-prone area at all. In the case of the latter, the river is potentially incised and disconnected (Figure 2.1-101).

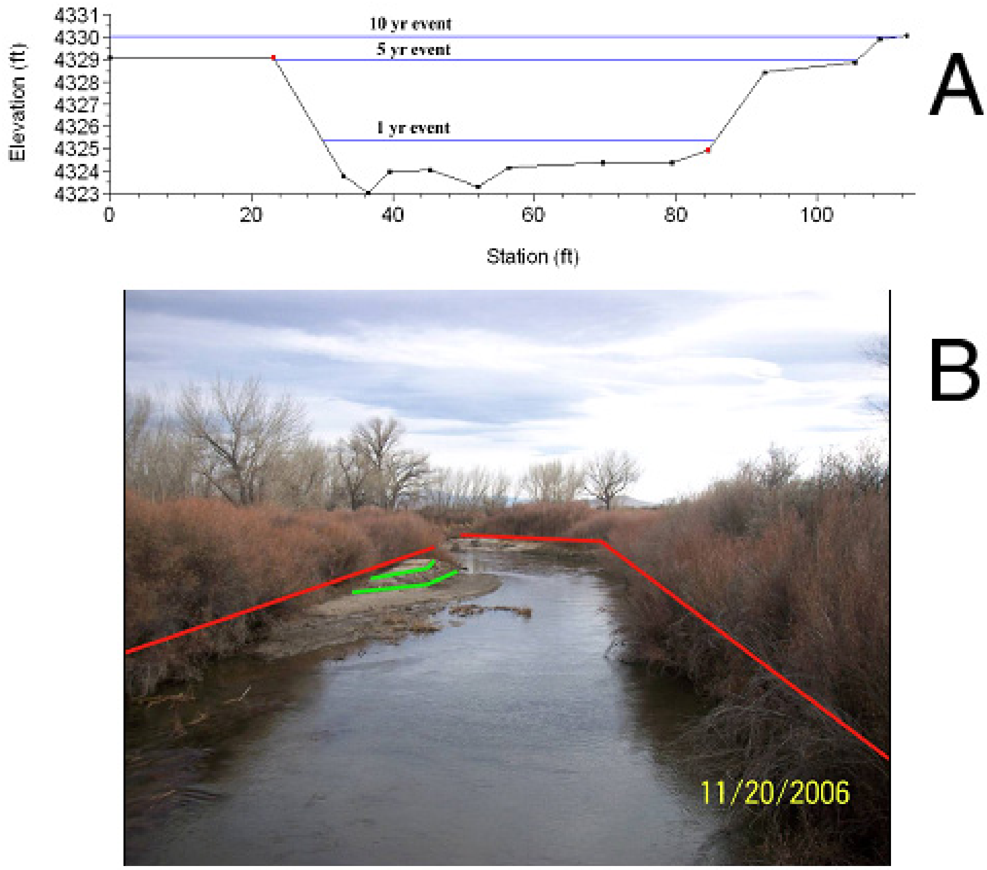


Figure 2.1-100. 2.1-100 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach W12. Flow is into the page, putting river left on the left side of the image. 2.1-100 B is a photograph of study reach W12 taken looking upstream at a flow of about 90 cfs. For reference the 1 year recurrence flood is about 36 cfs. The red lines delineate the approximate elevation of a laterally extensive floodplain that is inundated by flows between the 5 and 10 year floods. The green lines delineate streamside edges of transient depositional features that are more inundated approximately every year.

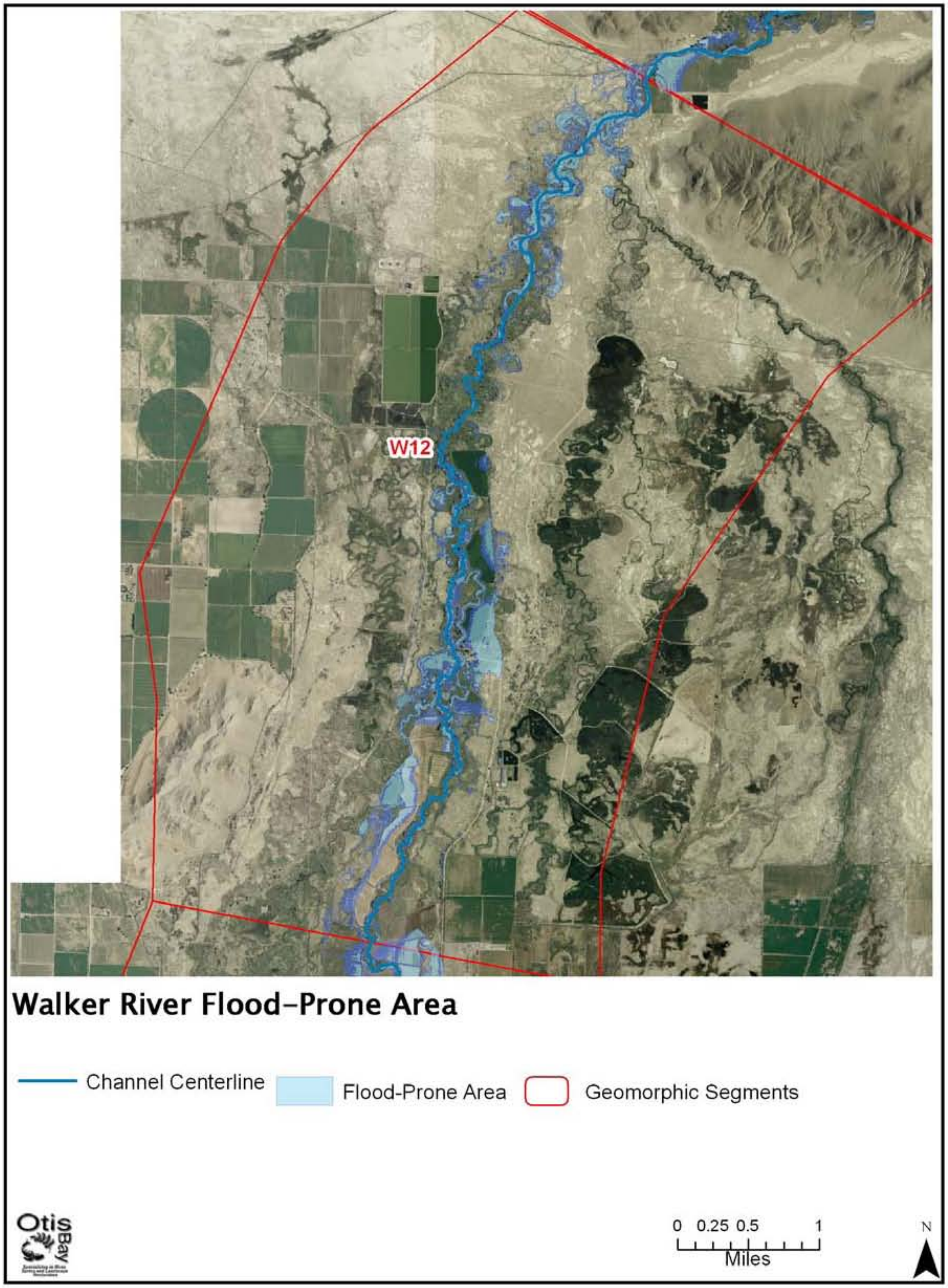


Figure 2.1-101. The flood-prone area at W12. Note that the flood-prone area is very narrow. Flow is from bottom to top.

W13

Floodplain connection was not assessed in W13. This was due to access issues that prohibited the establishment of a study reach. Although a LiDAR flight was done in this area, the coverage was of a different quality than LiDAR in the upper Basin, and the HAR model could not be applied.

W14-W15

On the lower Walker River, below the town of Schurz, a consistently declining base level at Walker Lake has caused the river to incise dramatically. An equilibrium connection between the channel and floodplain would not be expected to exist here. Geomorphic adjustments that are made during periods of steady base level are disrupted with every decline in lake level. HEC-RAS modeling shows that the high terraces along the channel are not inundated by flows of even the 100 year flood's magnitude. Developing inset surfaces are inundated at the study reach location in W14 and W15 by floods with 5 to 10 year recurrences (Figure 2.1-102 and Figure 2.1-103). Visual inspection of W15 suggests that there is increased lateral floodplain development at elevations that would allow more frequent floodplain inundation.

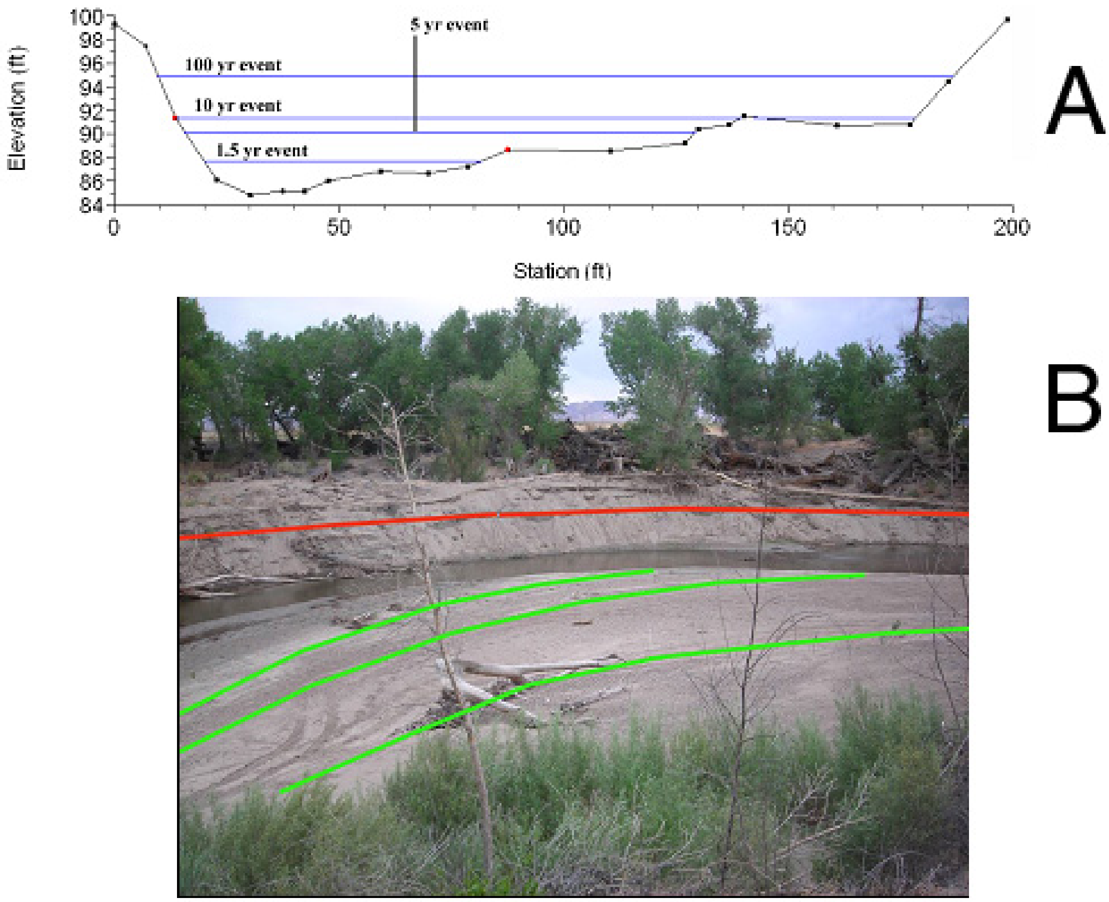


Figure 2.1-102. 2.1-102 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach W14. Flow is into the page, putting river left on the left side of the image. 2.1-102 B is a photograph of study reach W14 taken from river right, looking across the stream at a discharge of about 28 cfs, the 1 year recurrence flood is about 22 cfs. The red line depicts the approximate elevation of the 100 year flood which is contained within high elevation banks and terraces seen here on river left, and out of sight on river right. The green lines depict stepped surfaces that are found across the point bar, and which are inundated at various frequencies between 1.5 and 10 years.

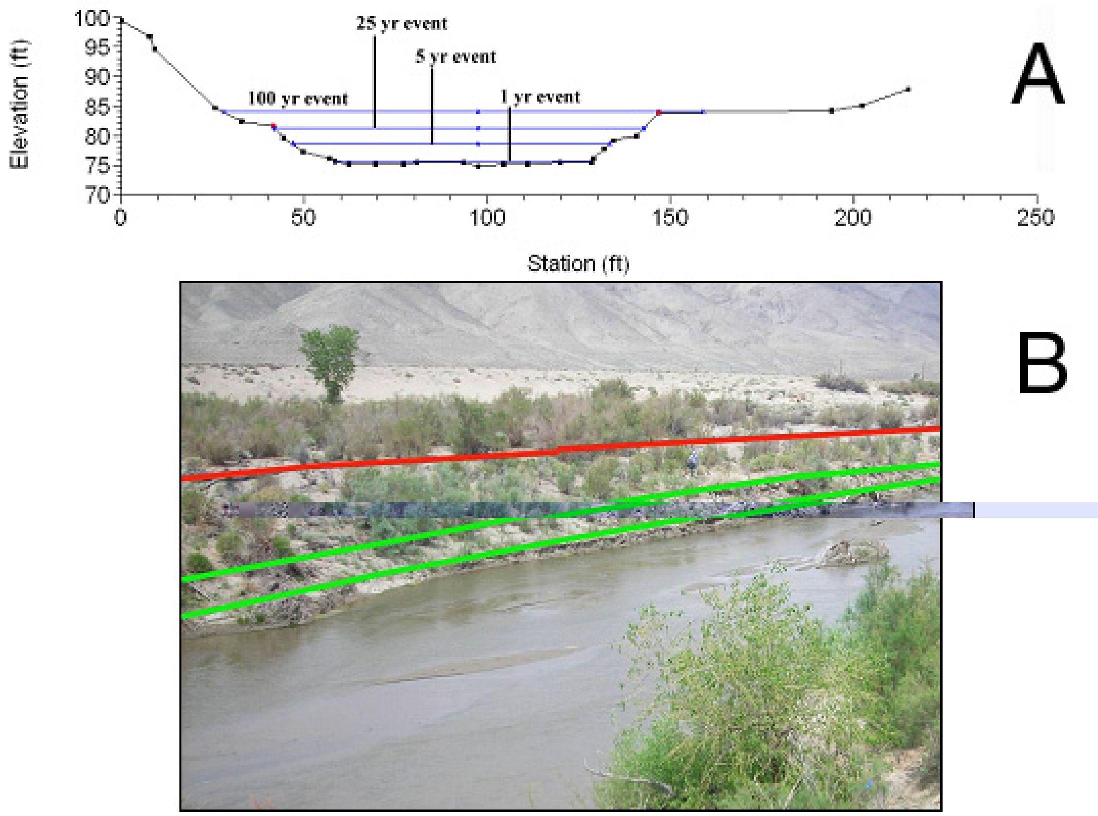


Figure 2.1-103. 2.1-103 A depicts a typical cross-section plot of estimated water surface elevations of flows inundating various geomorphic surfaces found in study reach W15. Flow is into the page, putting river left on the left side of the image. 2.1-103 B is a photograph of study reach W15 taken looking obliquely upstream from river left at a discharge of about 30 cfs. For reference the 1 year recurrence flood is about 22 cfs. The red line delineates the approximate streamside edge of the terrace that is inundated by the 100 year flood. The green lines delineate the approximate streamside edges of two lower surfaces inundated by flows between the 5 and 25 yr floods.

2.1.4.12 <u>Channel-Scale Geomorphology of the Walker River</u>

Measurements of channel attributes such as cross-section geometry and bed substrate characteristics were measured in study reaches. These measurements are summarized below for study reaches on the Walker River. Measurements obtained in study reaches are meant to represent the larger geomorphic segment, though it is acknowledged that substantial variation in channel morphology can occur within any given geomorphic segment.

CROSS-SECTION GEOMETRY

As with the East Walker River, the Walker River shows little variation in cross-section geometry for the 5% exceedence flow when compared to the West Walker River (Table 2.1-31). The most noticeable difference in cross-section geometry is between W12 and the lower river reaches of

W14 and W15. We see that in the lower river, the channel widens and shallows, thus reducing the width to depth ratio.

Table 2.1-31. Cross-section geometry values for the Walker River. Note that the values in Table 2.1-31 are averages of all cross-section in a reach, and are not generated from any other values in the table.

Reach (5% exceedence)	Area (ft^2)	Top Width (ft)	Mean Depth (ft)	W/D
W12 (766 cfs)	190.3	69.3	2.8	25.4
W14 (923 cfs)	203.9	88.8	2.3	39.5
W15 (923 cfs)	197.3	81.7	2.4	33.9

GRAIN SIZE ANALYSIS

Grain size analysis characterizes the distribution of sediment sizes on the bed of the river. The data gathered is used as a fundamental geomorphic characteristic, and as input to sediment transport models. The size fractions that are most commonly used as variables in transport functions are listed in Table 2.1-32 for each study reach.

Table 2.1-32. Results of grain size analysis for the Walker River. Values for the D16 represent the size of the 16^{th} percentile particle in millimeters, the D50 is the 50^{th} percentile particle in millimeters, and so on.

Reach	D16 (mm)	D50 (mm)	D84 (mm)	D90 (mm)
W12	0.41	0.81	2.3	3.3
W14	0.48	1.4	5.6	7.4
W15	0.37	0.68	1.4	1.8

On the Walker River, grain size distributions were substantially finer than on either of the tributary rivers. Median grain sizes in W12, W14, and W15 were 0.81, 1.4, and 0.68 mm, respectively, placing all Walker River reaches in the sand size class. Inspection of exposed bank stratigraphy along these segments suggests that sand size material is the only source of local sediment inputs. These deposits are largely composed of lacustrine and fluvial deltaic deposits associated with Lake Lahontan and high stands of Walker Lake.

A trend of downstream fining of the median grain size was observed, especially within and between geomorphically similar segments. This is a common occurrence in fluvial geomorphology (Reid and Dunne, 2003). This trend could prove useful in estimating conditions in adjacent segments, with similar geomorphology, that have restricted access. Plots of grain size distribution for each study reach are presented in Appendix H.

2.1.4.13 Sediment Dynamics

In the previous sections, the current and historic geomorphology of the Basin was presented. This information covered current conditions at segment and reach scales, changes to planform characteristics at the segment, or multi-segment scale, and channel/floodplain connection at the segment or multi-segment scale. The following section will present descriptions of potential erosion sources, depositional areas, and mechanisms for these processes in the Basin.

The Walker River Basin contains a series of depositional alluvial reaches interspaced with steeper canyon reaches. In the headwater areas and the canyon areas, hillslope processes are delivering sediment directly to the main channels and tributaries of the Walker River. In the valleys the picture is less clear. Over geologic time the valleys are depositional sinks where large quantities of sediment have been deposited as tectonic movement lowers valley elevations and the mountains are thrust up (Dilles and Gans, 1995). The stream gradients decrease rapidly in the large valleys and the river loses the power to transport coarse sediment. This can be illustrated in segment WW3 on the West Walker where a fairly coarse river bed (D50 of 135mm) transitions to what appears to be a much finer grained bed at observable locations a few miles downstream at WW4. Over geologic time the valleys are depositional areas, but the shorter term sediment budget is more difficult to discern. In the short term, the river may erode meander bends, but also balance this erosion with point bar deposition and general aggradation of the valley during overbank floods.

The arid climate and flat topography cause the erosion of upland areas from natural runoff in the valleys to be relatively minimal. Some significant erosion may occur because of irrigation runoff and periodic convective storms. A 30 year simulation run on an acre of land in Smith Valley using the WEPP model shows the sediment yield at 0.1 tons/acre/year. Conversely, on the steep slopes of the Walker Canyon the same model predicts an average sediment yield of 1.0 tons/acre/year. Generally, the steeper and more confined segments of the river are where large loads of coarse sediment are being delivered to the channel. In these canyons there is less opportunity for sediment to be stored before it reaches the channel. This is in contrast to the valleys where much of the sediment eroded from the mountains will get stored in alluvial fans at the range fronts before it can reach the channel. This complies with the concept of a graded or equilibrium condition in which the rate at which sediment enters a reach is roughly equal to what that reach will deliver downstream, and the channel will adjust to accomplish that task (Gilbert, 1877; Mackin, 1948). Often rivers are steeper where large amounts of sediment are delivered, but rivers can adjust in other ways.

Lane (1955) came up with a balance in order to illustrate how rivers can adjust to changes in sediment and discharge (Figure 2.1-104). If the main balance tilts one way or the other, the river is out of equilibrium and may adjust its morphology to try and regain an equilibrium condition. In the case of many rivers including the Walker River, a stream may adjust its width or slope, therefore increasing or decreasing its unit discharge. For example, if a river is being delivered a certain amount and size of sediment and discharge is decreased, the river may narrow, thus storing sediment and using less water to maintain a channel (Petts, 1979).

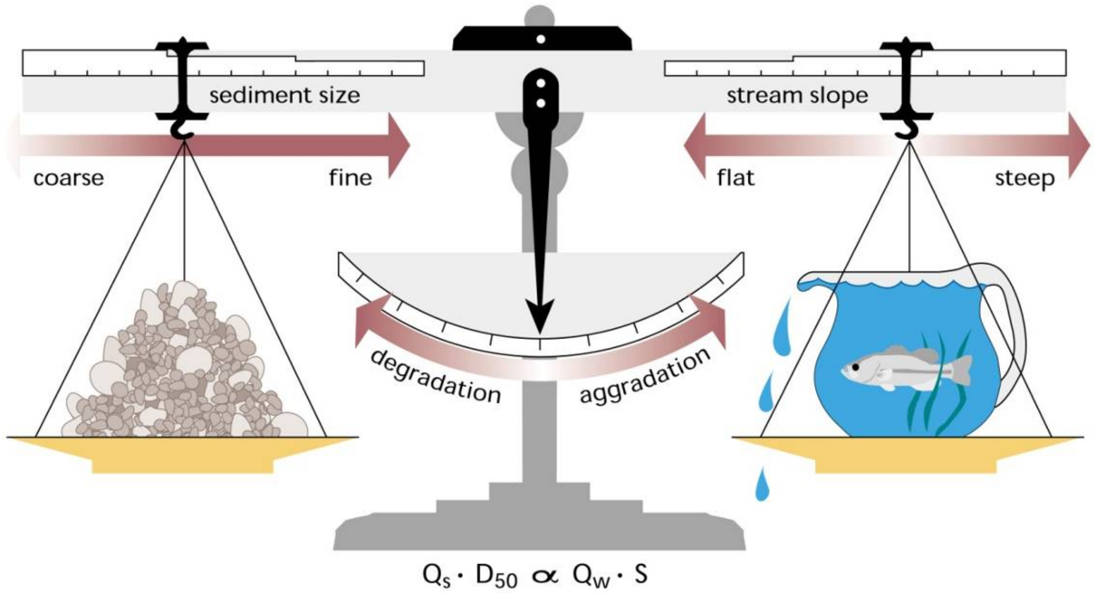


Figure 2.1-104. Lane's balance where Q_s is sediment load, D_{50} is median grain sized, Q_w is discharge, and S is slope. From FISRWG, 1998.

The historical analysis shows that in the valley segments of the Walker River the channel is narrowing. Williams (1978) found that the Platte River has narrowed 10-30 percent over 40-60 years and sinuosity has increased slightly since dams have reduced the peak flows by 10-30 percent. Similar changes appear to be happening to the Walker below the dams and irrigation diversions.

Due to anthropogenic influences, some areas in the Basin are most likely eroding at a faster rate than would happen naturally. Road construction and maintenance, urbanization, cattle grazing, mining, dams, channel alteration and farming have all been shown to affect sediment dynamics by various mechanisms (Dunne and Leopold, 1978).

To better understand these processes, and quantify them, a sediment routing model of the Walker River Basin is necessary. To construct this model, sediment sampling is being conducted at sites along the river. Samples are taken at a range of flows and this data is used to construct a sediment/discharge relationship. Then the relationship can be combined with flow records, and other data including the historical analysis to model and quantify sources and sinks of sediment in the Basin. The USFWS and its partners expect to complete this in the next two to three years. The resulting report will be an amendment to this document. Preliminary sediment transport estimates using the SAMWin software package are presented in Appendix D. The results of this modeling effort were insufficient to provide reliable predictive capability for sediment transport rates and annual loads, thus creating the need for the current study.

The results of the qualitative sediment budget approach are presented in the following sections. First sediment sources and sinks for the West Walker River are presented, followed by those for the East Walker River, and finally for the Walker River.

WEST WALKER 1-3

The headwaters of the West Walker River are along granitic and a formally glaciated portion of the Sierra Crest and the river continues to rework old glacier deposits in this area. The river flows through two low gradient meadows that are dynamic but appear to be in equilibrium. Then the river enters a canyon (WW3). Here the river is contained in a steep canyon between the Sierra and the Sweetwater Range. This area is geomorphically active as evidenced by landslide deposits that have dammed the channel, debris flow channels, and the recent complete resetting of the channel during the 1997 flood.

The landslide at Chris Flat at the start of the canyon is particularly interesting. There is evidence of trees previously been buried by deposition in a backwater of a landslide, the trees are now being exhumed and sediment is being remobilized by the river. During the 1997 flood this area degraded about four feet supplying several thousand tons of stored sediment to the river. (Figure 2.1-105 and Figure 2.1-106).

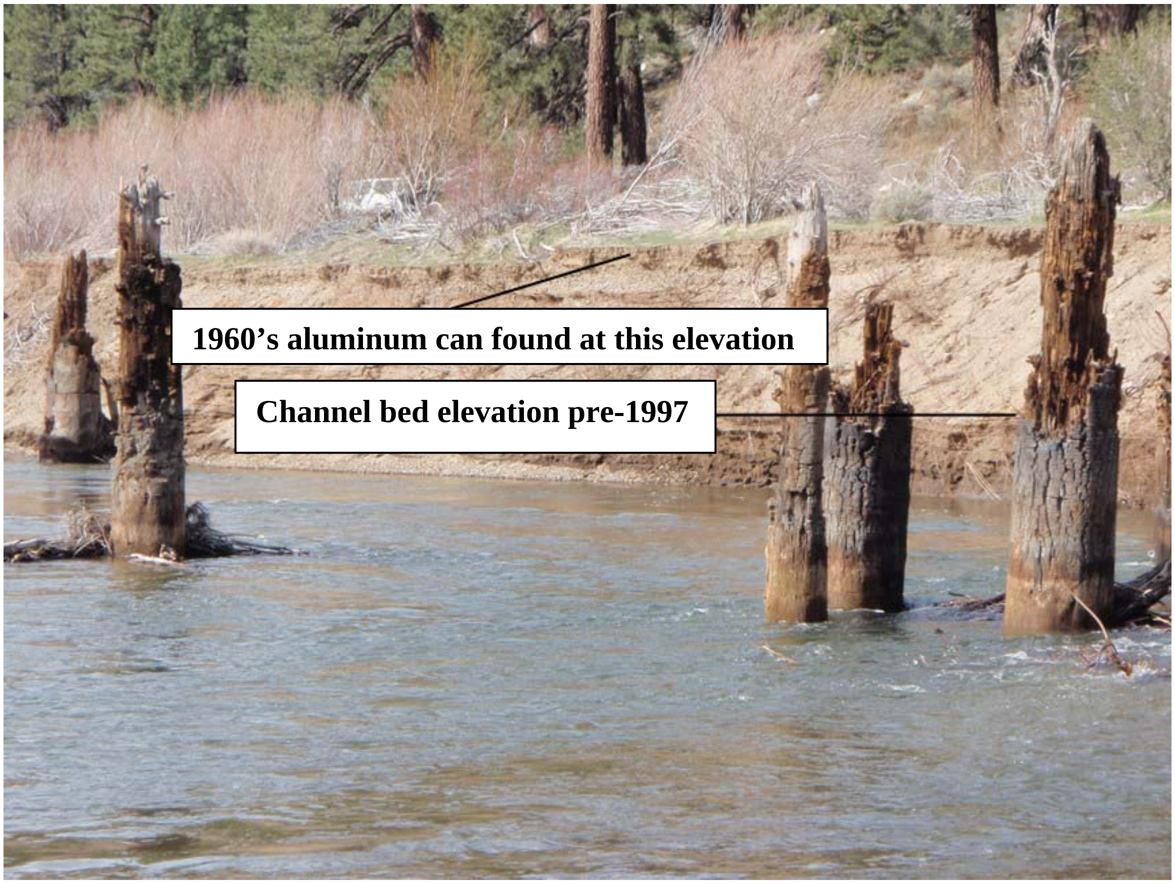


Figure 2.1-105. Chris Flat exhumed trees and terrace. Total bank height is about eight ft. 1997 bed elevation is about four ft above the water.

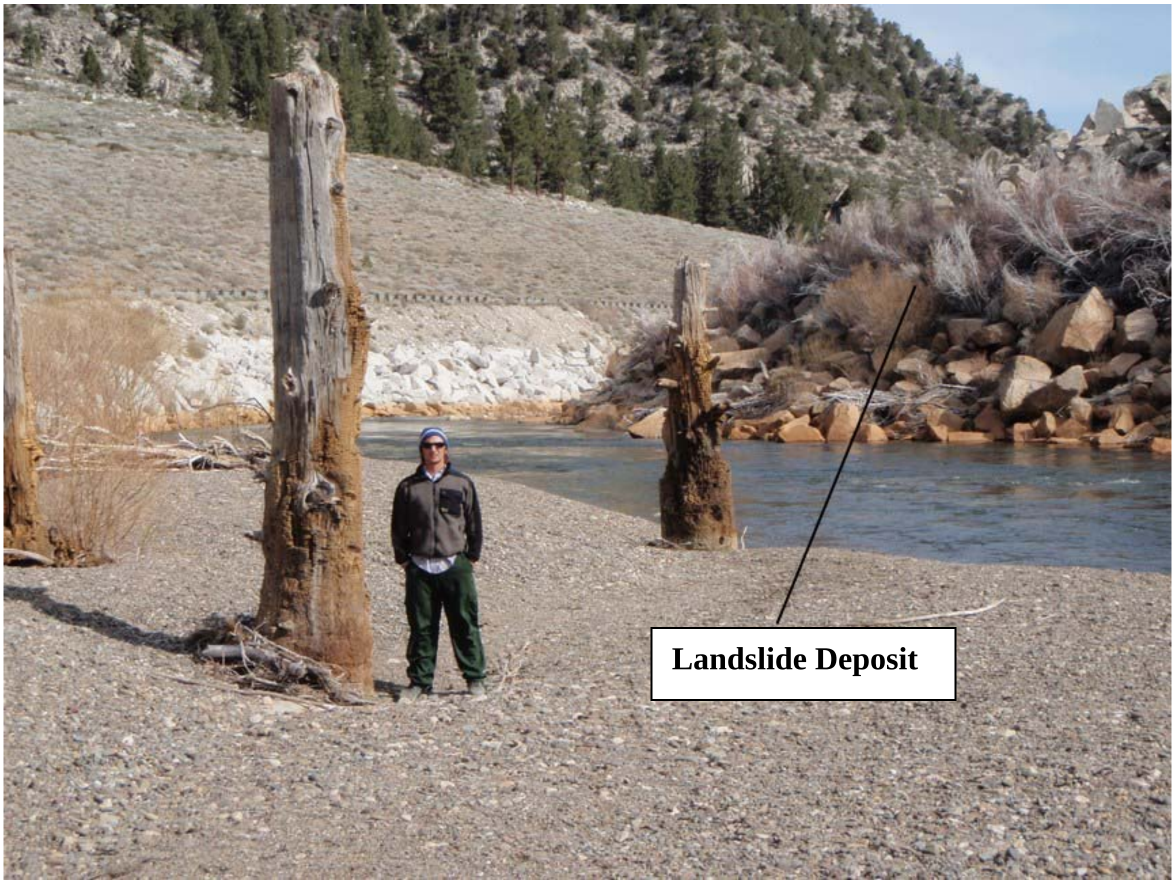


Figure 2.1-106. Landslide deposit and highway.

Downstream of Chris Flat are several areas of mass wasting including debris flow paths and large eroding slopes. Much of the bedrock in this area is non-glaciated granitic rock that tends to produce coarse sandy soil known as grus. The result is that sediment ranging from sand to large boulders is being supplied to this segment (Figure 2.1-107 and Figure 2.1-108).

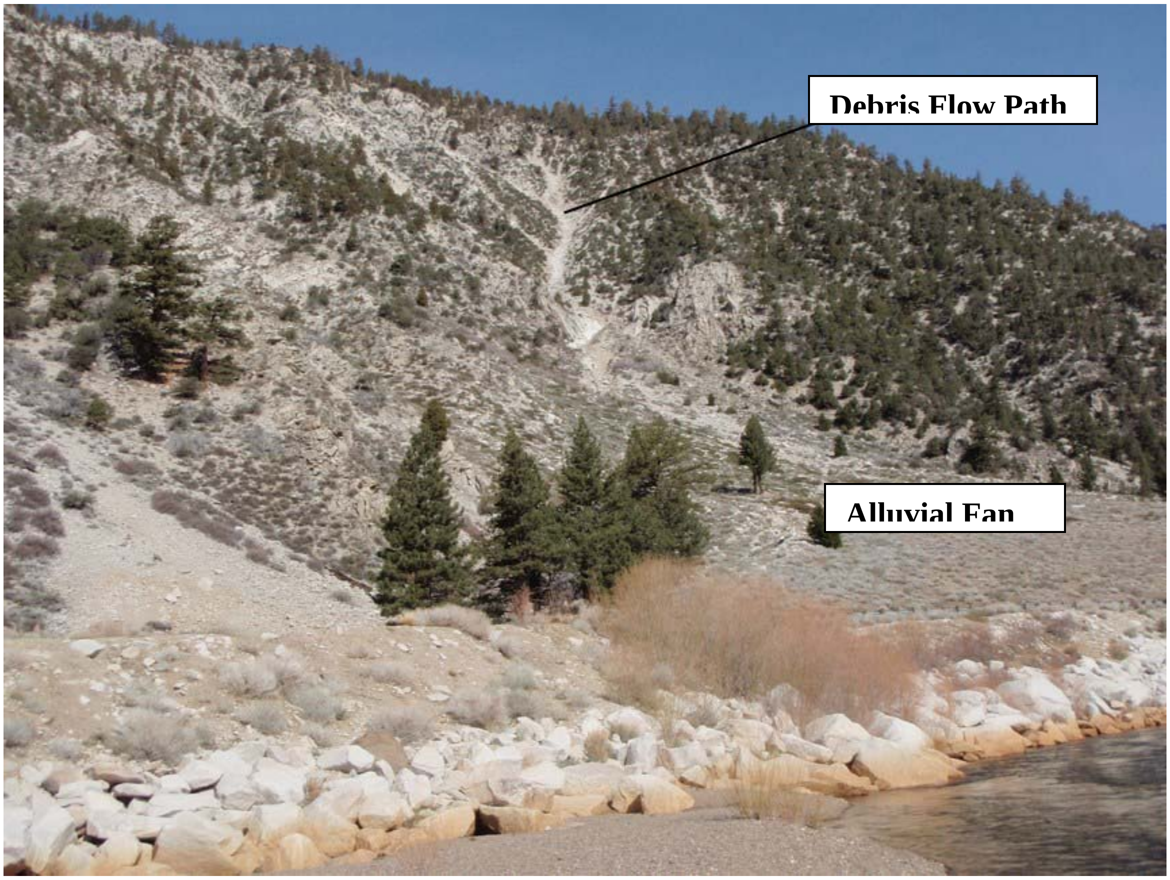


Figure 2.1-107. Debris flow path coming off the west side of the Walker Canyon just below Chris Flat.

Figure 2.1-108. Slope eroding into the West Walker. Also note the cutbank which represents erosion since the channel was reconstructed in 1997. This erosion appears to be caused be widening of the channel.

The 1997 flood, which was the flood of record (12,500 cfs), reworked the entire channel in the canyon and destroyed the highway in many places. The channel completely reset itself. Post-flood, the California Department of Transportation (CalTrans) reconstructed the river channel in its old location, and returned the highway to its former location (Figure 2.1-109). Over 300,000 cubic yards of fill were brought in to rebuild the highway (Holstie, *personal communication*). Large amounts of sediment were mobilized by the flood and, although not quantified here, it is expected that a large portion of the sediment was transported all the way out to Antelope Valley.

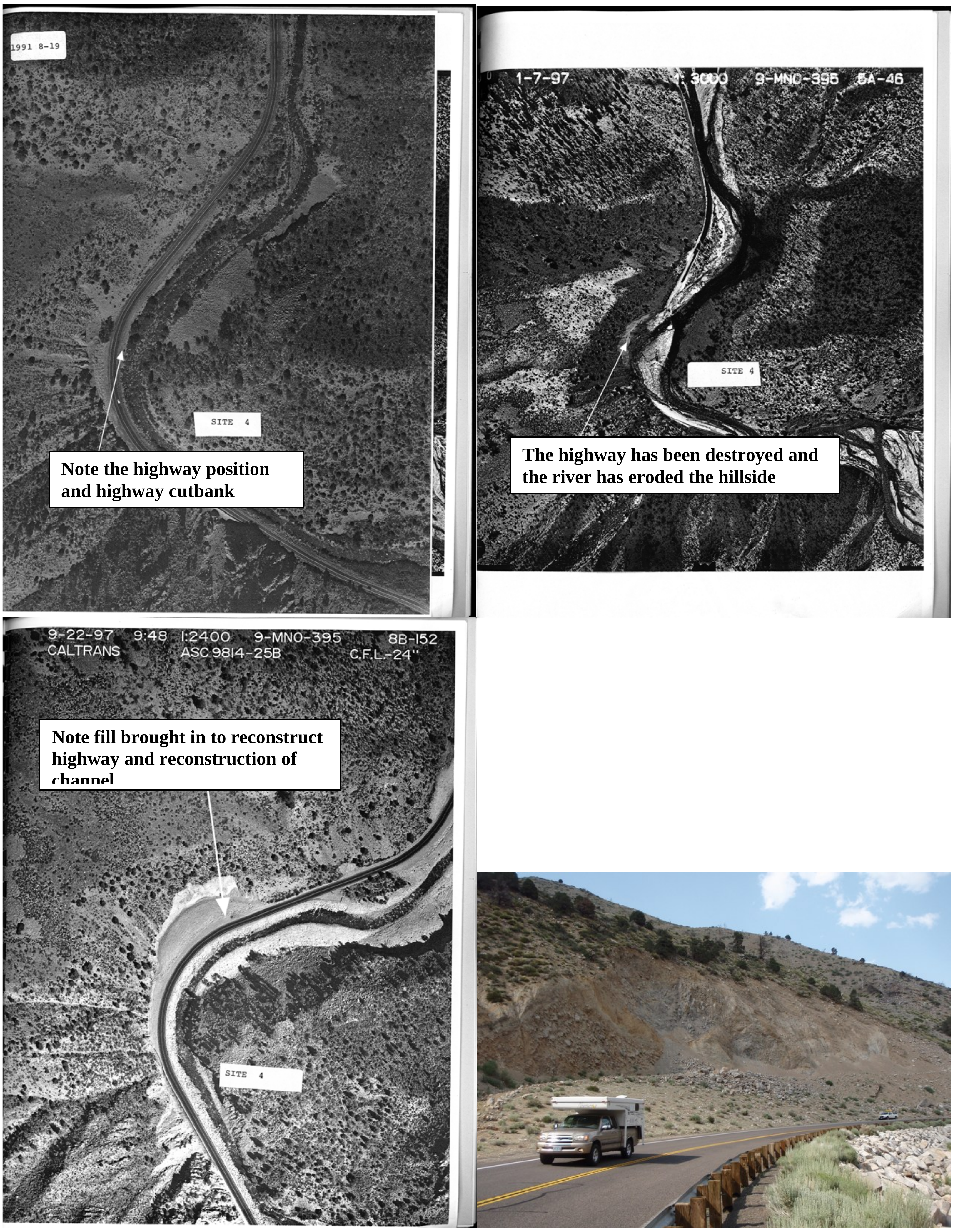


Figure 2.1-109. This is a series of three aerial and one ground level photo of the same corner in the Walker Canyon showing pre-flood, immediately post flood, and the reconstructed highway and river channel. Note the large amount of erosion into the hillside where the highway disappeared in 1997. Top three images are from Delk, 1999. Flow is from bottom to top in the aerial photographs.

WEST WALKER 4-6

As mentioned earlier, the gradient of the West Walker River decreases from an average of 0.025 in WW3 to 0.008 in WW4. Referring to Lane's balance it is clear that since the slope has decreased, the river cannot transport the same load of sediment. The large clasts are either stored in the channel or in the floodplain until they degrade into smaller sizes that the river can transport further down in the system. The median grain size of segment WW3 is 137 mm and in segment WW5 it is 2.5 mm. Looking at aerial photos, deposition and channel change are evident from the 1997 flood in Antelope Valley (Figure 2.1-110).

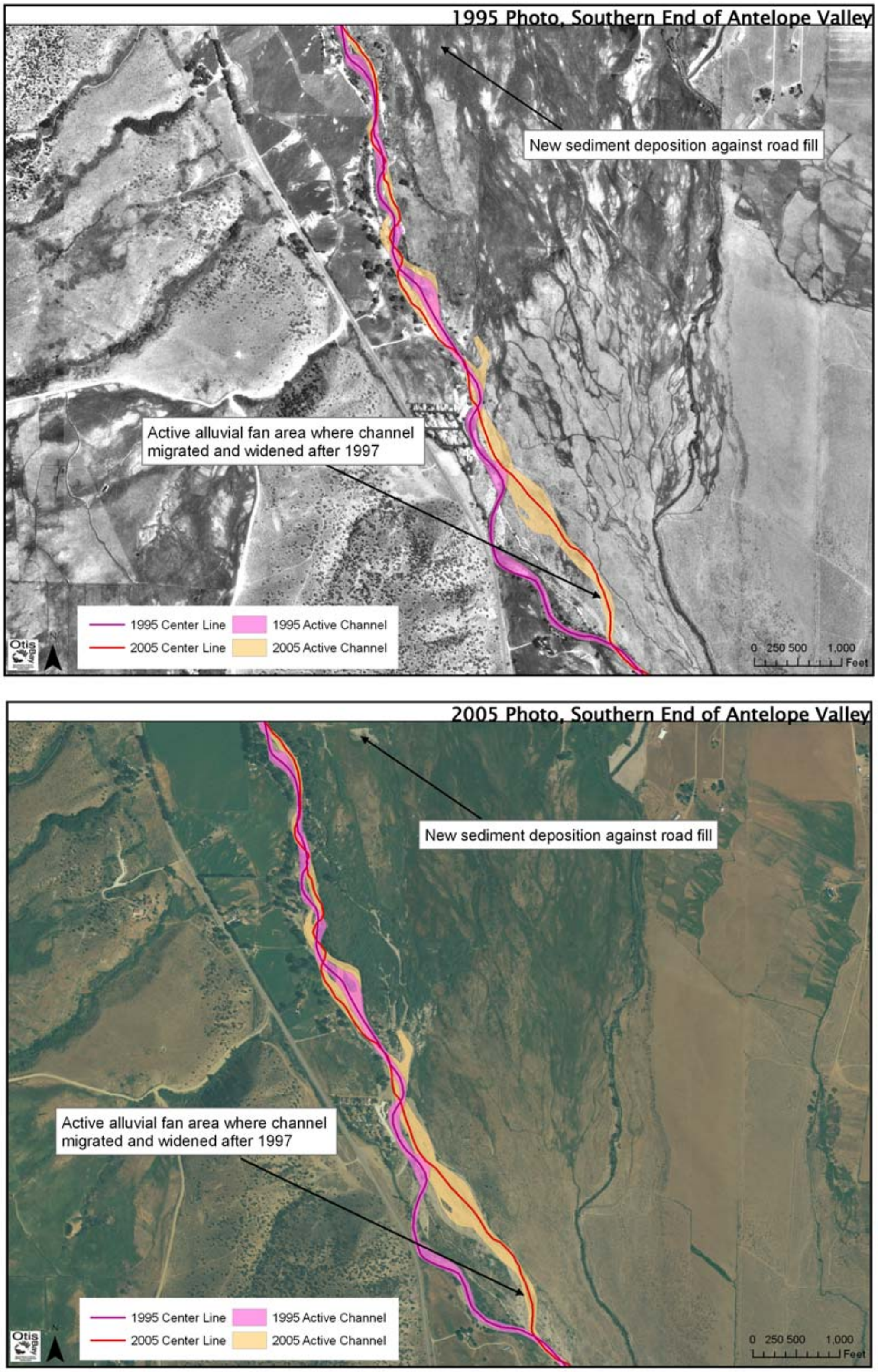


Figure 2.1-110. Sediment deposition in upstream section of WW4. Flow is from bottom to top.

Moving downstream the gradient decreases to around 0.008 near the diversion structure at Topaz. This structure diverts water to Topaz Reservoir which provides off channel storage. The width of the main channel of the West Walker River is half as wide below the diversion as above. This suggests that the since the diversion has been constructed, sediment has been stored at the channel margins as the width decreases. This is a direct result of the diversion reducing the power of the stream to transport sediment here. The HAR model also shows that this area has a substantial flood-prone area downstream of the diversion (Figure 2.1-60). In fact, during large floods the river flow downstream of the diversion structure would backup and water would move toward Topaz Reservoir. This all suggests deposition in this area, and increased flood potential. During the 1997 flood this backwater effect caused damage to the diversion channel and outlet works, and sediment-laden flood flow caused a fish kill in the reservoir. The channel and diversion structure have recently been re-engineered for improved functionality (NDEP, 2008).

After the confluence with the Topaz return flow, the West Walker is characterized by active meandering, large actively eroding cutbanks, and point bar deposition. Traditionally, one would expect some degradation here because of the relatively sediment-free water from the return (see Figure 2.1-104), and this appears to be the case immediately below the confluence at the study reach for WW5. Although non-sediment laden water is released from Topaz, the return channel has very steep banks that will be a source of sediment for some time (Figure 2.1-111). According to the hydraulic modeling, it takes a flood with a 10 yr recurrence interval to get water onto the floodplain downstream of the return channel, where in traditional views a 1.5 to 2 yr flow would inundate the floodplain. The HAR map also shows a decrease in connection to the floodplain from above to below the confluence (Figure 2.1-60).

Figure 2.1-111. Over steepened banks on the Topaz return channel. These banks are approximately 20 ft high.

In WW5 the West Walker River is eroding into high cutbanks that expose old fluvial deposits (Figure 2.1-112). This erosion is contributing many tons of sediment to the river. Although, as the river meanders and erodes the outer banks, at the same time, point bars are being deposited on the inside of the bends. The high cutbanks are being replaced with relatively low point bars (Figure 2.1-113), and evidence that the river has widened in the recent past suggests that there is a net export of sediment from this segment. This phenomenon can be countered by flood flows depositing sediment up on the floodplain, but the river is not very well connected to the floodplain here (Lauer and Parker, 2006).

Figure 2.1-112. River is eroding into old floodplain deposits. Banks are six to eight feet high.

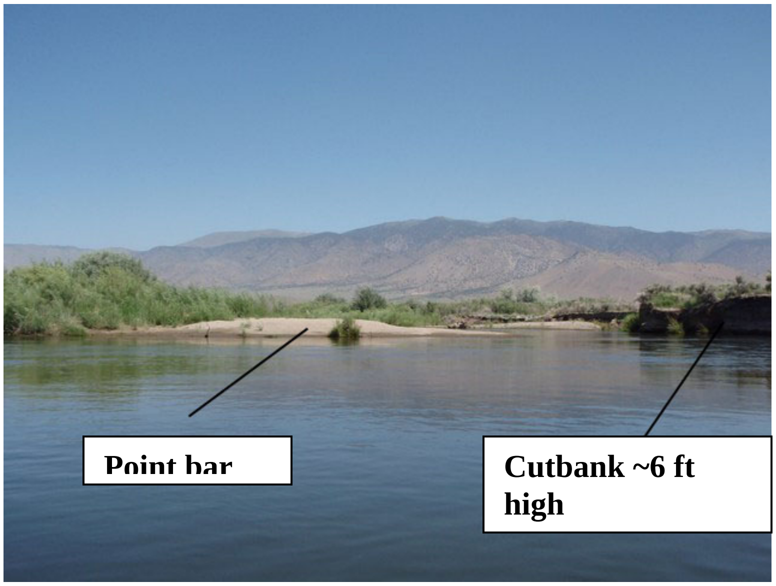


Figure 2.1-113. Point bar deposition opposite a high cut-bank.

Below here the West Walker enters Hoye Canyon, where coarse colluvium is contributed to the channel and sand is expected to be transported through this steeper, higher energy, section of river.

WEST WALKER 7-8

By looking at historical analysis and the flood-prone area mapping from the HAR models some deductions can be made about sediment dynamics in Smith Valley. The channel in this area has narrowed and lost length since 1938 according to the historical analysis (Figure 2.1-54 and Figure 2.1-56). Despite this the river appears to be mostly connected to its floodplain (Figure 2.1-63 through Figure 2.1-65). If flow is held constant, and the channel is straightened and narrowed, shear stress would increase on the bed of the river causing erosion and degradation of the channel. If the river is not incising despite narrowing and shortening, it is most likely near equilibrium or aggrading. One caveat to this would be if the bed of the channel is somehow resistant to erosion, but all indications are that the bed of the West Walker River in Smith Valley is mostly sand which is not resistant to erosion. The other phenomena that would explain this would be if the flow of the river has decreased compared to historical times. There is evidence for this presented in the Hydrology Section (2.1.3).

WEST WALKER 9-10

Coarse sediment is delivered to the West Walker River at Wilson Canyon, but soon after the canyon the river is once again in a large alluvial valley. The scenario appears similar to West Walker 7-8 in that most of the channel appears to not be incised. There is a short section of channel that does appear to be incised to the east of pivot irrigated fields. This area may be eroding and contributing sediment to the channel (Figure 2.1-67).

Sediment dynamics on the West Walker River are expected to differ from the East Walker River in terms of the proximity of source areas, the size and type of material available in the channel, and ultimately the sediment load that is delivered to the Walker River. This is due in large part to differences in the geomorphology. The West Walker is composed of a series of valleys separated by steep canyons, whereas the East Walker has more continuous canyon morphology. The following sections present a qualitative approach to analyzing sediment dynamics on the East Walker River.

EAST WALKER 2-3

Bridgeport Reservoir precludes the East Walker from receiving sediment from its Sierran headwaters. All the sediment transported by the East Walker River must be generated downstream of the reservoir. Below the reservoir in EW2, the channel is relatively steep and confined in a canyon. Evidence suggests that coarse sediment and colluvium in the river is contributed by landslides and debris flows. In contrast to the West Walker River, hillslope processes do not appear very active in recent times. Even though the highway encroaches on the river in places, the majority of the stream banks are densely vegetated.

Near Rosaschi Ranch the river enters a larger valley (EW3) and receives additional flow and sediment from Sweetwater Creek which is a relatively large undammed tributary. The river is actively meandering here and there are areas of bank erosion and point bar deposition. The river is connected to its floodplain according to the results of HEC-RAS and HAR modeling, and does not appear to be actively incising. Larger trees along some of the banks appear to slow bank erosion (Figure 2.1-114).

Figure 2.1-114. Actively meandering channel through Rosaschi Ranch. Note cohesive blocks of sediment falling in river and how vegetation is slowing erosion in the bottom left picture.

EAST WALKER 4-5

Below EW3, the river enters a series of canyons containing narrow floodplain areas (EW4). The hillslopes of these canyons are more actively eroding than the canyon walls upstream. Geology includes hydrothermally altered volcanic rocks and granite, which both contribute significant fine-grained sediment to the river. Approximately three miles downstream of Rosaschi Ranch is a good example of a debris flow that has delivered sediment to the East Walker River. The area looks inactive in the 1938 photo. Then a debris flow has come down from the north and looks fresh in the 1995 photo, and even appears to be blocking the channel. In the 1998 and 2006 imagery it is clear the river has been forced against the opposite side of the canyon, and is reworking and eroding through the new deposit. Vegetation establishes after some time and starts to help stabilize the area (Figure 2.1-115). From ground level, the erosional gully is evident. This debris flow probably occurred when a thunderstorm or frontal system delivered intense rain to this highly erodible area (Figure 2.1-116 through Figure 2.1-119). There are several drainages throughout EW4 and EW5 that have likely produced similar debris flows over time. In EW5 there is plentiful decomposed granite or grus being eroded off of the steep canyon walls and delivered to the channel (Figure 2.1-120 through Figure 2.1-122). This area naturally produces relatively large amounts of sediment.

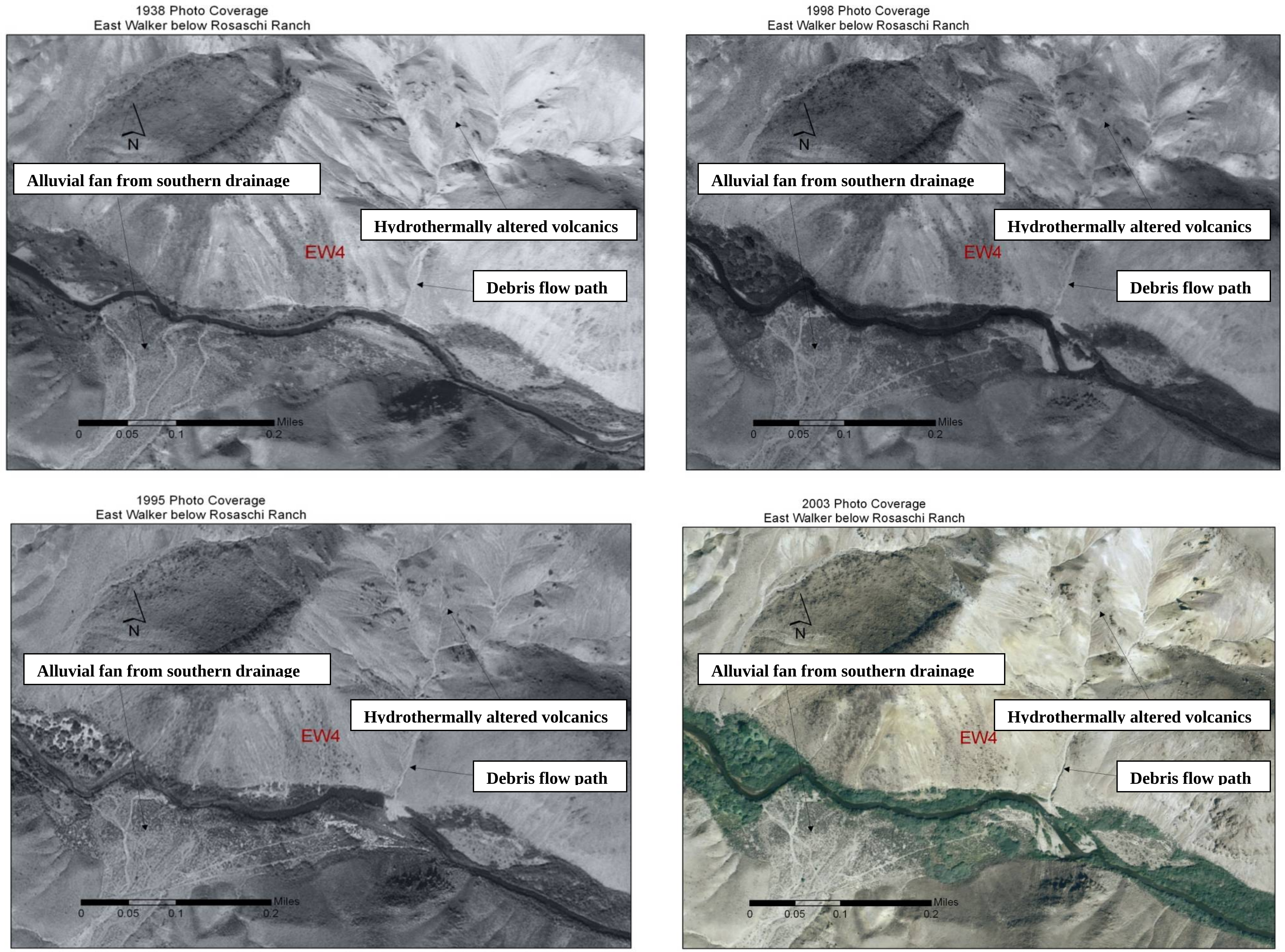


Figure 2.1-115. Series of four photographs showing the evolution of a debris flow contributing sediment to the East Walker in EW4. Flow is from left to right in all photos.

Figure 2.1-116. Erosive upland area.

Figure 2.1-117. Main debris flow gully.

Figure 2.1-118. Looking south toward river of gully with gully right of center in picture.

Figure 2.1-119. Multiple terraces at mouth of the gully represent different erosional periods.

Figure 2.1-120. Grus-filled gully EW5.

Figure 2.1-121. Note sand in the East Walker River.

Figure 2.1-122. Large grus deposit eroding into river.

EAST WALKER 6-8

The character of the river in these segments alternates between narrow alluvial valleys that are utilized for agriculture, and more confined areas where the river may be connected to the hillsides. Looking at the flood-prone area mapping, the river is generally in connection with a floodplain (Figure 2.1-87).

In EW6 the river has maintained similar characteristics through time, with the exception of the fact that it is more sinuous now than in 1938 (Figure 2.1-78). The river is maintaining its width and decreasing its slope, which suggests that it transports less or smaller sized sediment now compared to 1938 (Figure 2.1-104). This could be due to less sediment coming off of the headwater areas that were more heavily mined and grazed in the past, or it could be a response to the impoundment of the East Walker River behind Bridgeport Dam.

At EW7 and EW8 the gradient lessens and the river is dynamic over time. These segments have narrowed since 1938, but have widened since 1995 (Figure 2.1-79). Several meander cutoffs have formed vegetated islands at EW7 since 1995. A logical explanation for the narrowing would be the decrease in discharge, because of Bridgeport Reservoir. The recent widening and island formation may be related to a pulse of sediment being moved into this area of the river by the 1997 flood, or other recent high-water years.

EAST WALKER 9

Despite the geomorphic placement of this segment in a wide alluvial valley, the channel is confined and the downstream end of EW9 appears disconnected from its floodplain (Figure 2.1-89). Sediment delivery from upstream segments prevents this section from being sediment “starved”, a condition that would result in channel incision. Channel sections that are incised appear to be anthropogenically straightened or dredged.

The East Walker River is a potentially significant source of sediment in the Basin due to closely linked hillslope erosion that delivers decomposed granite and volcanic rock to the channel. The consistently steep grade of the river ensures the downstream transport of this material. However, reduced flows out of Bridgeport Reservoir have the potential to decrease the transport capacity of the river.

WALKER 11

Segment WW11 begins after the confluence of the East and West Walker Rivers, combining the flow and sediment supplied by these tributaries. Just downstream of the confluence, the channel appears to be freely meandering, and adjusting naturally. Farther downstream in Mason Valley, there are anthropogenically straightened sections of channel that pose barriers to floodplain connection. The river maintains connectivity to its floodplain in other areas of this segment despite straightening that has occurred since 1938 (Figure 2.1-96 and Figure 2.1-98). Some widening has occurred between 1995 and 2006, this may be due to increased sediment and discharge related to recent high water years including the 1997 flood of record (Figure 2.1-95).

WALKER 12

The Walker River at W12 incorporates the MVWMA and minimally developed lands to the north. Portions of this segment may be representative of the historic channel condition in Mason Valley. The natural condition is partially due to minimal anthropogenic activity in the channel, few constraints on planform adjustment, and a relatively extensive area of well-developed floodplain with oxbows and sloughs.

The last major diversion on the Walker River is just upstream of the segment, and is a potential source of high sediment loads. Increased sediment delivery combined with low flows in this segment limit the river's transport capacity, and results in deposition. Analysis of historic aerial imagery supports this, indicating that the modern channel is more sinous than in 1938. Increased sinuosity is created by point bar deposition that drives the lateral growth of meander bends (Figure 2.1-97).

WALKER 13

The Walker River at W13 has similar characteristics to W12 with low discharge and evidence of sediment deposition in the channel. Historic imagery suggests that the river has avulsed and shifted position frequently. Relic channels that are now filled with sand may be evidence of locations where rapid deposition resulted in channel avulsion[42]. The river has narrowed dramatically since 1938, and in locations upstream of Weber Reservoir appears anastomozing and lacks a clearly defined channel.

Reservoirs provide locations to calculate average sediment loads. In 1972, the USGS estimated that since its completion in 1935, Weber Reservoir had lost 2,300 acre feet of storage (18% of its original capacity) due to sedimentation (DWR, 1992). This results in an estimated annual sediment load of 130,000 tons per year[43] flowing into the reservoir.

WALKER 14

Downstream of the town of Schurz, the dramatic declines in the elevation of Walker Lake over the last 100 years have contributed to increasingly unstable and dynamic geomorphic river conditions. As lake level declines the rate of river incision increases, resulting in significant river incision of localized depths greater than 20 feet, though fine grained sediment. The incising river bed has resulted in multiple terraces and abandoned channels. These geomorphic features indicate periods of river stability associated with a static lake level, followed by resumed incision as lake levels decrease again. The amount of material eroded by this process would be substantial and some aspects of this process have been studied by Dr. Ken Adams of the Desert Research Institute. Results of his study should be finalized in 2009.

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[42] A process by which a river leaves its current channel and establishes a new path, sometimes during a single event.
[43] Used 1.26 tons of sand per cubic yard.

Lateral Siphon 2-A, is an old irrigation pipe, that is located on the river bottom perpendicular to the river. This lateral siphon is partially buried in the streambed, providing some local grade control. The pipe is located immediately downstream from the town of Schurz and is the only erosion control feature preventing the headcut from continuing to migrate upstream. However, the siphon is not actively maintained, and its failure (washed out in a storm, etc.) could result in the migration of channel incision upstream toward Schurz and Weber Reservoir.

WALKER 15

Walker 15 is located on the increasingly exposed Walker Lake delta. Walker 15 is almost completely composed of old lake bottom deposits that have been exposed due to the declining lake level. Similar to W14, the declining lake levels have severely destabilized this segment. Channel incision through fine-grain lacustrine deposits is dramatic and the magnitude of lateral migration in this segment is increased compared to W14, suggesting even larger sediment loads are eroded from this reach and delivered to Walker Lake.

As the river has incised, groundwater levels have dropped. This has resulted in decreased upland grazing opportunities and increased the grazing pressure on the channel banks and nearby floodplain, further increasing bank instability and erosion.

The previous portions of the sediment dynamics section 2.1.4.13 describe the processes specifically contributing to sediment delivery to the channel on the West Walker, East Walker, and Walker Rivers. The following sections will describe potential sources of anthropogenic erosion throughout the basin that could apply to several areas.

UPLAND ANTHROPOGENIC SEDIMENT SOURCES

Although much of the Walker River Basin is less developed than many river systems in the United States and even the local region, there are many areas where anthropogenic disturbances are likely to be causing accelerated erosion or deposition. To fully understand the role these areas play in the current sediment budget of the Walker River would take extensive surveys and is beyond the scope of this assessment, but some examples are given below.

Mining

The upland locations of most historic mining locations prevented direct impacts to river channels in the Basin. Currently, most mines in the area are relatively inactive. However, unfavorable soil chemistry limits revegetation resulting in long-term erodibility of tailings piles.

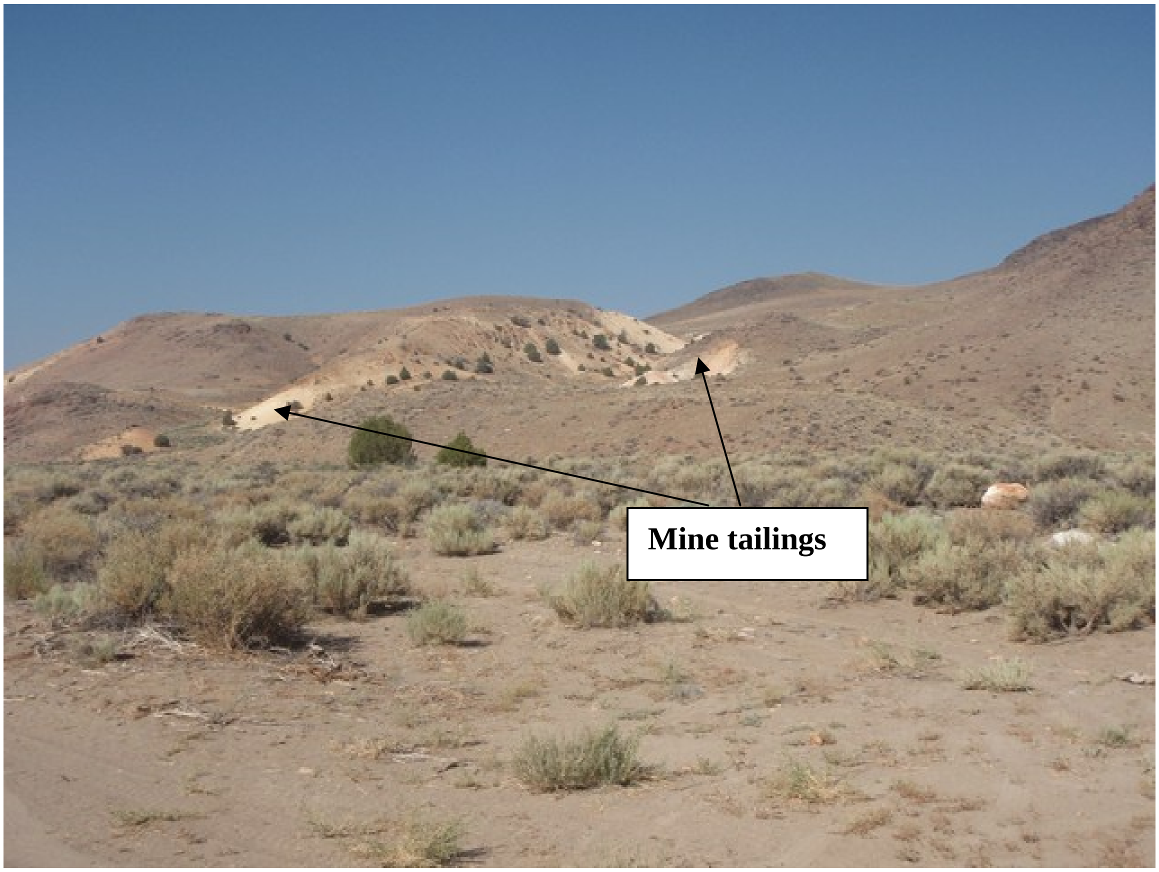


Figure 2.1-123. Mine tailings near Rosaschi Ranch in East Walker Basin.

Roads

Road-derived sediment delivered to the channel has been shown to increase turbidity and suspended sediment concentrations, alter channel substrate and morphology, and adversely affect water quality (Cederholm et al., 1981; Bilby et al., 1989; Waters, 1995). In particular, unimproved road surfaces across native soil can be a source of fine sediment erosion (Reid and Dunne, 1984).

Maintenance of roads can loosen soil and increase erosion (Figure 2.1-124 and Figure 2.1-125). Stormwater best management practices (BMPs) such as straw mulch, silt fences, etc. should be used to minimize such impacts (http://www.bmpdatabase.org/BMPPerformance.htm).

Figure 2.1-124. Large gully erosion off of highway fill slope near Wilson Canyon. The cutslope has just been regraded and no BMP's were evident.

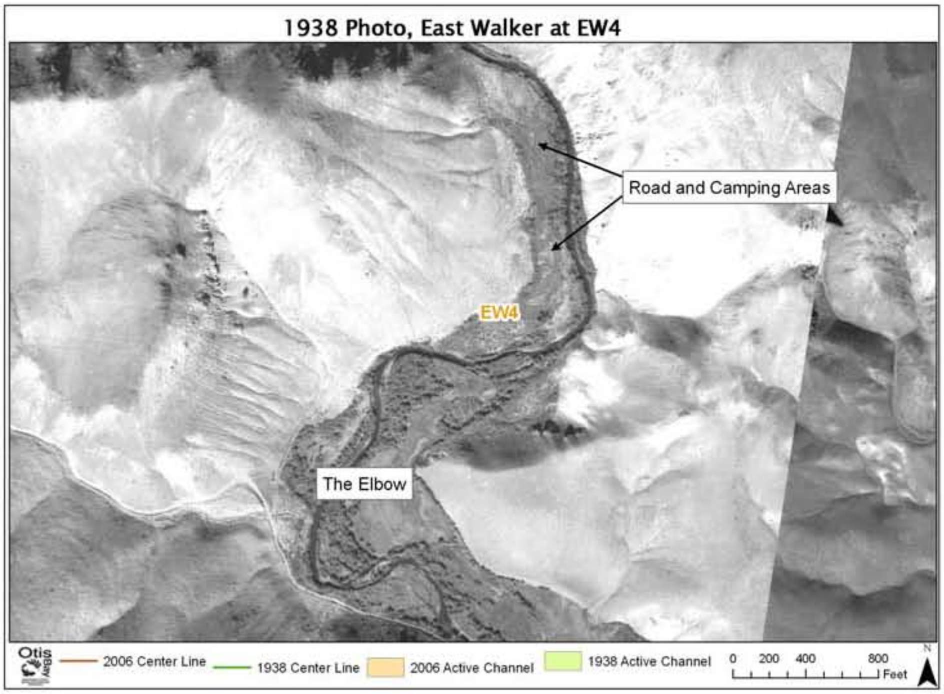
Figure 2.1-125. Sediment off of fill slope routed to culvert, no BMPs present.

Maintenance was also a cause of erosion on the road to Hawthorne (Forest Service Road 28) near the Elbow on the East Walker. The road has been graded and the spoils, which are loose and easily eroded, have been side-cast into a drainage that leads to the river, and into the river itself. A general BMP is to not side-cast when grading around drainages. (Figure 2.1-126 and Figure 2.1-127).

Figure 2.1-126. Side-cast berm has collapsed into the drainage.

Figure 2.1-127. Side-cast pushed directly into the river.

Large areas of soil compaction in the riparian area can inhibit vegetation growth and cause erosion of sediment. Notice the density of near-stream impacted areas near the Elbow (Figure 2.1-128). Off-road vehicle trails have impacts similar to small roads except they can be steeper, and engineered drainage is not required. Off-road trail density has increased in the West Walker near Wilson Canyon as shown by this photo series (Figure 2.1-129).



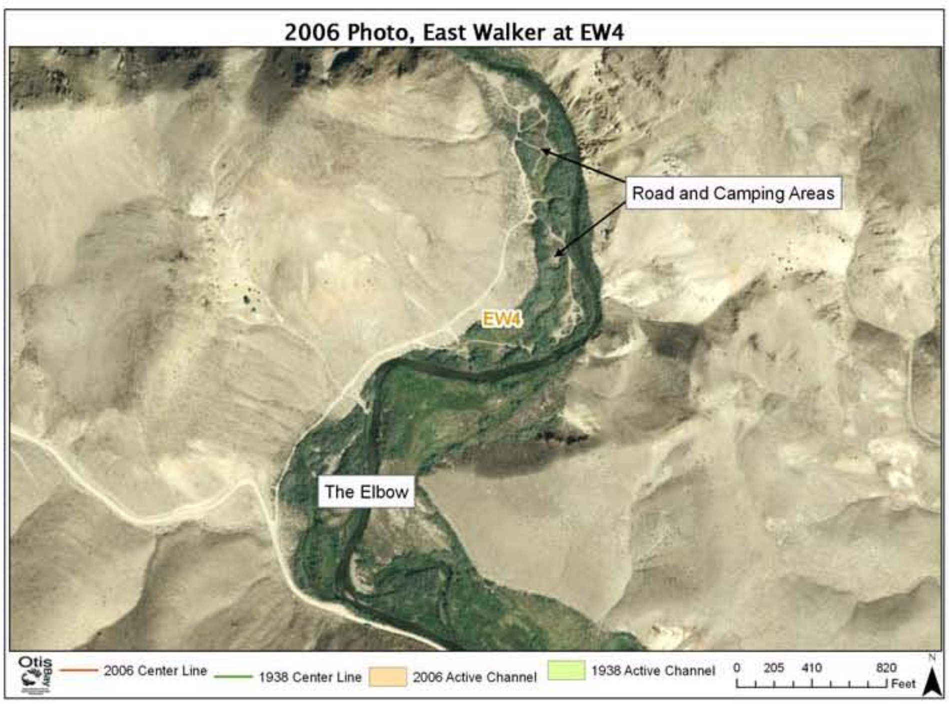
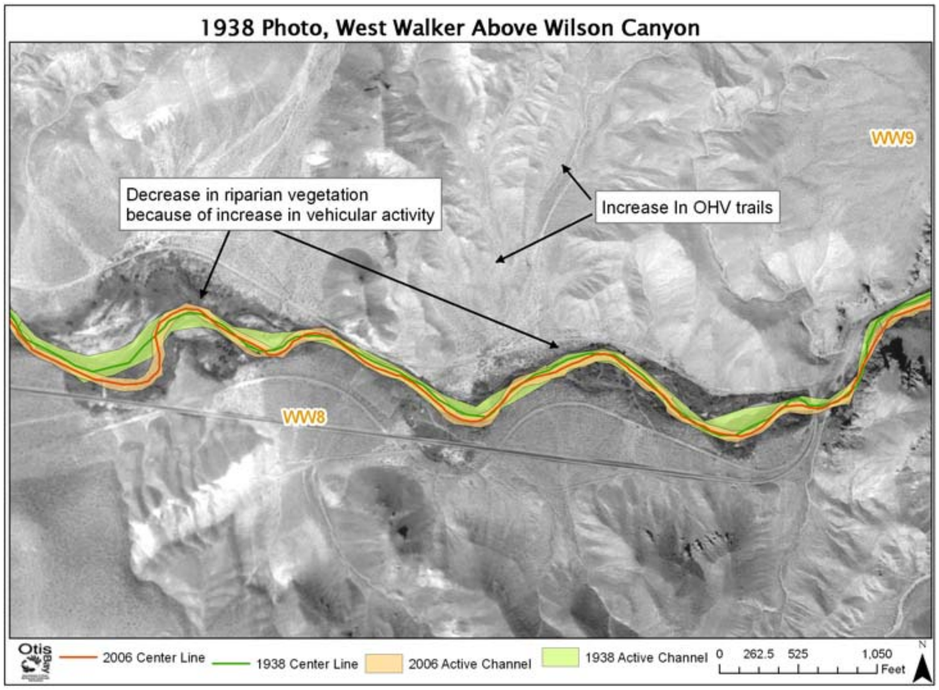


Figure 2.1-128. Increase of denuded and compacted soil in the riparian area of EW4. Flow is from top to bottom.



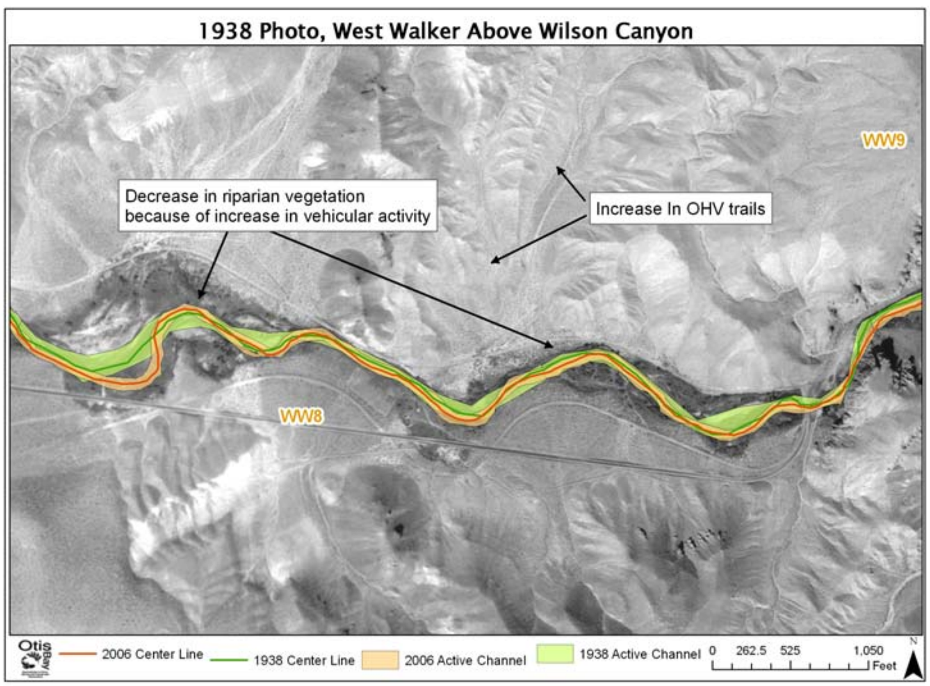


Figure 2.1-129. Increase of motorized recreation impacting vegetation and likely causing accelerated erosion near Wilson Canyon. Flow is from left to right.

Grazing

Segment W13, just upstream of Weber Reservoir, was one of the few heavily grazed areas visited during the field survey. In this area extensive grazing has impacted areas of riparian vegetation. Figures compare the river channel just upstream of Weber Reservoir with the channel in the MVWMA where grazing is limited (Figure 2.1-130 and Figure 2.1-131).

Figure 2.1-130. Walker River just upstream of Weber Reservoir.

Figure 2.1-131. Walker River in MVWMA.

Hot Springs Canyon Creek which is located on the west side of the Bodie Hills in California has been listed as impaired in regards to sediment because of accelerated erosion, due to grazing. Recent improvements in grazing practices on BLM land have led the Lahontan Regional Board to recommend that it be de-listed (http://www.waterboards.ca.gov/lahontan/water_issues/programs/tmdl/bodie_hills/docs/factsheet_hotsprings_delist.pdf, 2008).

Dredging

Straightening and dredging of the channel can change sediment dynamics in rivers dramatically. Straightening causes the slope of the river to increase. This will increase the power of the stream which, in turn, can cause down-cutting and erosion. If the cross-sectional area is increased through dredging, the river may preferentially deposit sediment to regain the same cross-sectional area (Dunne and Leopold, 1978). Dredged areas were not surveyed in this assessment, but continued problems with sedimentation in Mason Valley would suggest that, at least there, the latter scenario applies.

Dams and Diversions

Dams and diversions can also affect sediment dynamics in many complex ways. The upstream impacts of dams include flow impoundment, decreased slope, and sediment dropping out of transport. This will cause many of the smaller dams to fill up completely. If a dam is blocking sediment but, not water, the clean water below the diversion will possess more power to erode sediment (see Figure 2.1-104). If substantial water is removed as well as sediment, the result could tip the balance either way. If sediment makes it through the dam with less water to transport the sediment, then it is possible to have aggradation below the dam. A variety of outcomes may result from modifications of channel geometry, sediment discharge, and water discharge.

2.1.4.14 Recommendations for Enhancement of Physical Processes

The results of the physical portion of the assessment of the Walker River Basin create a picture of a system that is at a critical transition point between a relatively healthy, functioning system, and a system that moves increasingly toward a trajectory of degradation and loss of ecological value. The Truckee and Carson Rivers, the two most comparable regional river systems, are both in a state of greater decline than the Walker River. Therefore, in both a local and regional sense, a valuable situation exists in the Basin where important ecological resources can be kept intact, and significant enhancement is possible through protection and conservation of existing resources with the need for large-scale channel reconstruction applying to only a few segments. Perhaps the most critical step in enhancing ecological value on the watershed scale is the development and implementation of a naturalized flow regime. Flows are impacted throughout the Basin by storage and diversion resulting in decreased average flows in most months of the year, as well as decreases in extreme high and low flows. These changes can result in alteration and possibly degradation of channel and floodplain conditions. A method for structuring an in-stream flow regime is developed in Section 3.1.

In addition to naturalizing stream flow, protection of existing resources in the Basin will form a foundational cornerstone of restoration activities. Any restoration planning that involves consideration of bank-stabilization or channel and floodplain reconstruction will need to include adequate protection of the existing riparian resources in order to be viable as successful and sustainable projects. However, if increased ecological value of the system is to be achieved, it may be necessary to implement more active restoration techniques, such as construction, that focuses on re-establishing channel-floodplain connections, stabilizing streambanks, and increasing in-stream habitat.

This assessment will be useful in formulating restoration strategies at a large-scale, grouping similar areas and applying basic statements of restoration options that apply to many segments. The next step will be to identify segments where restoration benefits will likely have the greatest benefit, followed by developing more detailed restoration plans for chosen segments, or areas within segments. Here, the first level of planning is addressed by identifying three basic channel types in the Basin, divided by both channel morphology and by the nature of human modification as well, and presenting an overall approach for each channel type. The three channel types are high-gradient, laterally restricted canyon segments (Type 1), low-gradient freely meandering valley segments with little or no channel modification (Type 2), and low-gradient valley segments with significant channel modification (Type 3). The set of options open to restoration will differ between the channel types.

Type 1 segments include all the confined canyons in the Basin which include the canyon portions of WW2, and all of segments WW3, WW6, WW9, EW2, and EW5. The lateral confinement and coarse bed material found in these segments makes them the least geomorphically adjustable. The lack of open space has also limited the amount of agricultural development in these areas. These two facts make the canyon segments the least impacted overall in the Basin, and best candidates for passive approaches. The primary approach in these segments is to protect the channel and narrow floodplains that exist. Limiting vehicle traffic and implementing prescribed grazing plans can prevent hillslope disturbance and vegetation denudation. In some segments such as WW3 where there is an established roadway and no grazing, this is not a problem. However, in other areas, particularly on the East Walker, there is little restriction to off-road vehicle travel and dispersed camping. A management plan for these segments might include riparian livestock management, establishment of a few well-maintained roads, elimination of roads near the channel, and limiting camping in the riparian zone to established areas.

Type 2 segments include those that flow with unrestricted meander patterns, and have undergone little or no anthropogenic channel modification. However, within this type of channel there is a further division based on bed material. There are those Type 2 segment with gravel beds, and those with sand beds. Type 2 segments with gravel beds include valley portion of WW2, and all of segments WW4, EW3, EW4, EW6, EW7, and EW8. Type 2 segments with sand beds include WW5, WW8, W12, and W13. Agricultural activity becomes more widespread in all these segments. As with Type 1 segments, all of these Type 2 segments will benefit from establishing a protected riparian corridor, and especially by limiting grazing in the riparian zone, thereby preserving the existing channel and floodplain integrity, which is fairly high in many locations. Type 2 segments with sand bed channels will also need to be assessed for the need to implement erosion control, or bed and bank rehabilitation measures. In these segments, the bank material can be uncohesive, and if grazing has been widespread then uncohesive banks can become disturbed and eroded.

Type 3 segments include those low-gradient segments that meander though valleys but have been subject to some degree of channel modification. These segments include WW7, WW10, EW9, and W11. The highest magnitude of negative impacts to channel and floodplain integrity has occurred in these segments. Measures to restore ecological integrity will be more active by necessity. The same basic principle of protecting the riparian corridor will apply in these segments as well. However, greater measure must be taken to widen the buffer of the riparian zone in order to re-establish natural channel dynamics. If particularly modified segments are identified as priorities for restoration, plans for large-scale reconstruction of the channel and floodplain may be developed in order to achieve re-establishment of channel/floodplain connection and other critical physical processes.

It should be noted that W14 and W15 were not included in any of the three categories above. These segments are severely degraded having undergone dramatic incision and widening in response to declining base level at Walker Lake. Therefore, the common suggestions mentioned above do not apply. A special effort is being made to address the unique challenges that are presented in this reach. USFWS is collaborating with researchers and experts from UNR, DRI, the USGS, and the BOR to develop specialized recommendations for these two segments. These recommendations are likely to focus on how to stop further head-cutting and incision, and the most effective methods of delivering water to ghdhdfghfdgthe Walker Lake in order to stabilize base level.

2.2 Biotic Data

2.2.1 Vegetation

2.2.1.1 Vegetation Assessment Methods

VEGETATION SURVEY

Vegetation communities were identified and mapped (Appendix J, K) to provide baseline information on the location and extent of plant communities found throughout the Basin so that future shifts in species composition and density can be noted in forthcoming vegetation efforts. This work will be more immediately used to evaluate current habitat conditions and help guide restoration projects. The map was created using a two step method: prediction and validation. Prediction refers to the delineation of vegetation communities on aerial photography, at a 1:2,000 map scale, and the further refinement of these polygons with site visits. Validation was done after the vegetation map was created in order to estimate the accuracy of each mapped vegetation class.

All field work related to the prediction and creation of the vegetation map was conducted in the summer of 2007. The aerial photography used in the creation of the map was from the 2006 National Agriculture Imagery Program (NAIP) with 1-meter resolution. Vegetation communities were identified and digitized in ARCView 9.2 software.

Site visits allowed for the refinement of the vegetation map prior to validation. All site validation was completed during the summer of 2008. Locations for site visits were selected from a random stratified sampling of vegetation types. Random stratified sampling was used so that each vegetation type was equally represented in the assessment without selection bias by the field crew. We used GIS to select the starting point of each set of transects in a given vegetation type. Collected data include vegetation cover along transects, height measurements of woody, forb, and graminoid vegetation, and site photographs. Where possible, a set of four transects were surveyed at a site, within a given vegetation type. Transects were laid out in the same randomly selected direction from the starting point. Additional transects were laid 10 m to the right of the previous transect so that they were all parallel to the initial transect. If the patch was not large enough to survey four transects, data were only collected from two transects. Plant species data were collected at approximately 200 transect sites.

Delineation and validation only occurred on public lands and private lands where access was granted. The Walker River Paiute Tribe (WRPT) allowed access to the entire Tribal Lands for purposes of vegetation mapping and weed information gathering. Public Lands mapped include those managed by the United States Forest Service (USFS), the Bureau of Land Management (BLM), the State of Nevada, the Nevada Department of Wildlife (NDOW) and the California Department of Fish and Game (CDFG).

HISTORICAL ANALYSIS

Cottonwoods (*Populus fremontii*) are indicators of sustainable river function. Both recently scoured surfaces and a gradual decline in flow height or discharge are necessary for the establishment and survival of cottonwoods to maturity (Mahoney and Rood 1998). This combination of factors commonly occurs on point bars. Scoured river channels are a result of high flows with enough force to remove sediment and established vegetation. Rivers in equilbrium are balanced by aggradation and degradation, with point bars being a location of sediment aggradation and cottonwood recruitment. The continued establishment and maturation of successive generations of cottonwoods are indicators of of riverine health. Additionally, cottonwoods provide a tree canopy structure that attracts riparian bird species. Examining both cottonwood recruitment and the survival, expansion, and decline in cover of established stands is crucial in determining the value of habitat and is indicative of current abiotic river processes.

A decrease in the establishment of new cottonwood trees is detrimental to river systems, and can occur due to a variety of causes. A potential reduction in recruitment sites (recently scoured surfaces in the active channel) due to channel narrowing, and an increase in the number of vegetated islands in the active-channel, was found in the historical analysis of channe planform in Section 2.1. Increases in sediment supply and decreases in stream flow can move a river system out of balance, and potentially towards aggradation (Figure 2.1-104). This process can be self-perpetuating as already established vegetation, and vegetation growing on newly aggraded surfaces, will continue to slow water velocity causing more sediment to aggrade on site and making it less likely for a flood event to scour surfaces. Decreased stream flow and increased vegetation in the active channel have been observed on the Walker River (Section 2.1). Increased sediment supply can be inferred from some results of historical planform analysis, such as a trend in channel narrowing. These processes can reduce the number of sites available for cottonwood recruitment.

Aerial photography from 1938, the 1950s and 2006 were used to assess historical changes in both the river channel (Section 2.1) and the recruitment and survival of cottonwoods. However, the resolution of historical aerial photography is not fine[44] enough to confidently determine sites of recent recruitment. Changes in the recruitment of cottonwoods are expected to relate to the amount of recently scoured surface open for recruitment. The historic channel change results are discussed in regards to their potential effects on cottonwood recruitment since evidence of recent recruitment could not confidently be identified from the aerial photography.

The persistence of riparian vegetation was evaluated based on the persistence and changes in cover of cottonwoods in historic and recent aerial photography. Patches and individuals of mature cottonwoods could be identified in all sets of photographs. Additionally, two classes of cottonwood patches were mapped in 2007: cottonwood

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[44] Referring to the resolution of an image where more detail can be seen in a finer image than a coarser image.

forests with a xeric[45] understory and cottonwood forests with a riparian understory. Recent recruitment in cottonwood stands in either community type was not expected. Although these two cottonwood communities cannot be distinguished in the historical photographs, xeric communities were expected to be more likely to have lost cottonwood cover because xeric understory vegetation indicates a considerable decrease in the water table since cottonwood establishment. Cottonwoods can not survive if their roots are not in contact with the water table. Cottonwood communities with riparian understories are likely to have younger stands of cottonwoods and cottonwood trees are expected to increase in cover in these communities.

Historical photography from 1938 and the 1950s was georeferenced and used in this analysis. In each river segment containing cottonwood forests, two polygons were randomly selected from both the mature cottonwood forest with riparian understory and the mature cottonwood forest with xeric understory vegetation classes. The selected polygons were laid over both sets of historical aerial photography and the 2006 NAIP. Cottonwood cover was visually estimated in each polygon for each time period in which there was imagery (Figure 2.2-1). Average cottonwood cover in each river segment was plotted respective to the year the image was taken. Unfortunately, there are gaps in the cover data because aerial imagery does not exist in all locations in all years. Polygons were eliminated if a change in cover could be related to human disturbance and a new polygon was selected. For example, cottonwoods have been planted around homesteads. If a homestead was observed within the polygon, the polygon was dropped from analysis. Additionally, not all river segments were analyzed due to the rarity of cottonwood trees along some portions of the river.

[45] Pertaining to an arid or hyperarid climate where the loss of moisture from evapotranspiration exceeds the moisture received from precipitation.

2006 NAIP,
90 % Cottonwood Cover

1938 aerial photography,
40 % Cottonwood Cover

Figure 2.2-1. Aerial photography showing an increase in existing cottonwood cover for a individual polygon between 2006 and 1938 (F within a selected polygon).

2.2.1.2 A Description of Historical Recruitment Conditions

Section 2.1 examines changes to the sinuosity and the average width of the active channel. This is the section of the channel that is frequently scoured, where vegetation is kept at a minimum. Cottonwood seedlings recruit on the edges of this active channel. Because most river segments have narrowed since 1938, overall, there has been a reduction in the number of cottonwood recruitment sites since 1938 (Figure 2.2-2). Although the West Walker has lost length and sinuousity since 1938, the East and Walker Rivers have gained length and sinuosity. The impacts of these changes on cottonwood recruitment are discussed individually for the Walker River and the East and West tributaries. The Lower Walker River (W14 and W15) is not addressed in this analysis because aerial photography from 1938 does not exist for this portion of the river.

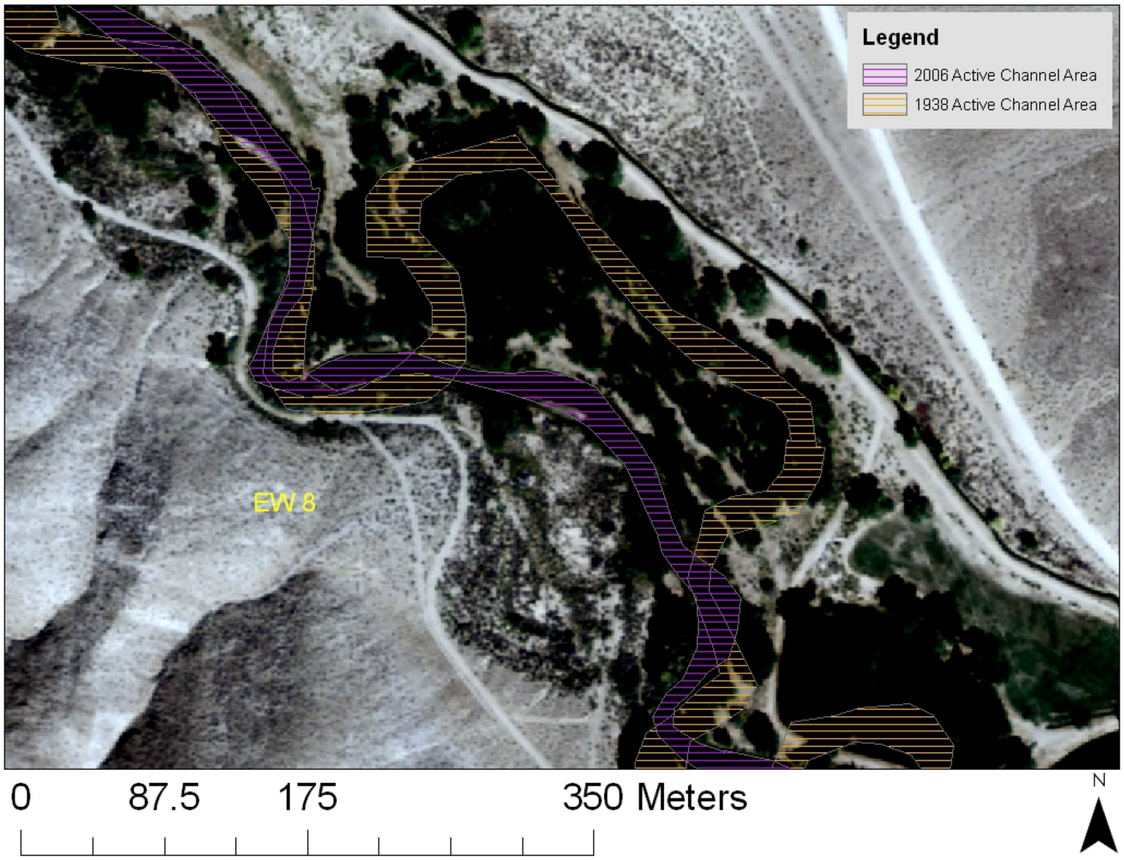

Figure 2.2-2. Aerial photography showing an increase in cottonwood cover between 2006 and 1938 (F within a selected polygon).

WEST WALKER RIVER

Most segments of the West Walker River (segments WW5, WW6, WW8, and WW9) have increased in length and sinuosity since 1938 but all segments, with the exception of WW6, have decreased in active channel width. Increases in length and sinuosity do not exceed 4%. Decreases in active channel area up to 55% indicate that the West Walker River is now less suitable for cottonwood recruitment than it was in 1938.

EAST WALKER RIVER

Some segments of the East Walker River have lost length and sinuosity (EW3, EW6, and EW9) and others have increased in length and sinuosity (EW4, EW7, and EW8). None of these changes in length or sinuosity are greater than 4%. All segments have lost up to 50% of their active channel area indicating that the East Walker River is also less suitable for cottonwood recruitment now when compared to the amount of recruitment surface that existed in 1938.

WALKER RIVER

The Walker River has mostly increased in length and sinuosity (W12 and W13) and mostly decreased in active channel area (W11 and W13). A dramatic decrease in active channel area in W13 of 162% makes the main stem of the Walker River extremely unsuitable for cottonwood recruitment when compared to the active channel conditions of 1938.

2.2.1.3 A Description of Historical Cottonwood Stands

In areas that were at one time environmentally suitable for recruitment of cottonwood forests, cover of both mature cottonwood forests with riparian understory and mature cottonwood forests with xeric understory, has increased in recent years. This implies that the water table has not decreased at such a rate to threaten the survival of already established cottonwood trees.

An increase in tree cover since the 1930s is apparent when looking at the cottonwood forests with riparian understories (Figure 2.2-3). When looking at the cottonwood forests with xeric understories or a combination of cottonwood forests with riparian or xeric understories, there is still an increase in cover, although it is not a steady increase through time (Figure 2.2-4 and Figure 2.2-5). Specifically when looking at EW9 and WW9 (Figure 2.2-4), tree cover decreases between the 1930s and the 1950s before increasing to current levels. Perhaps these sites are at critical water table depths where they are demonstrating site specific alterations in water table depth.

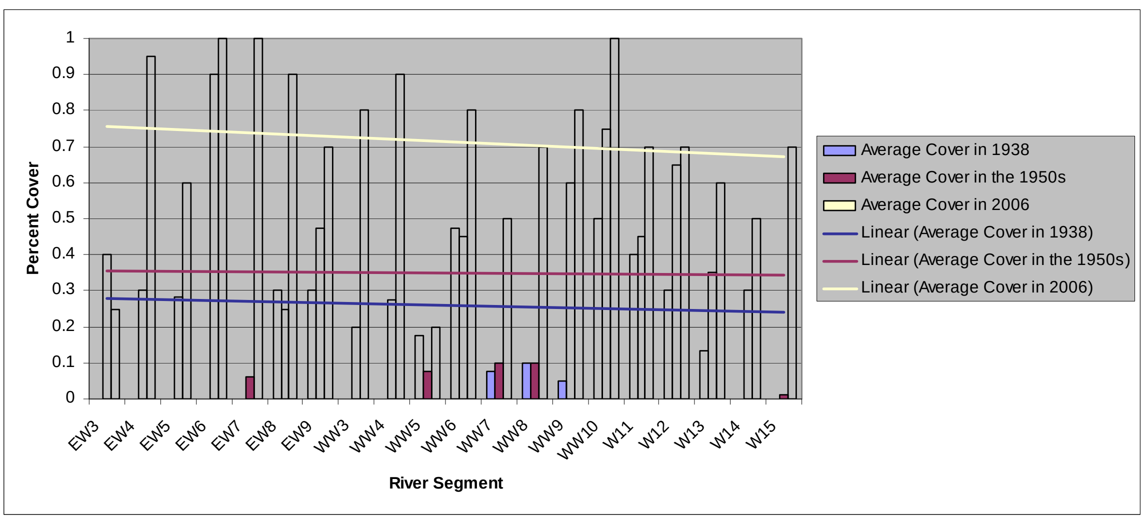

Figure 2.2-3. Bar graph showing the amount of cottonwood cover in the 1930s, the 1950s and on sites currently known to have cottonwood forests with a riparian understory. Linear trend lines show the average cover across all river segments.

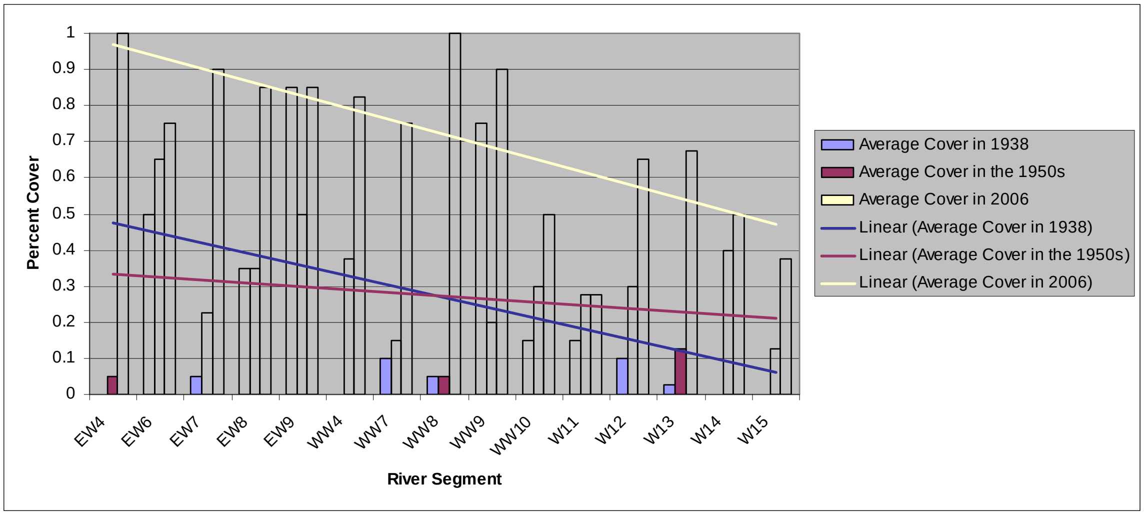

Figure 2.2-4. Bar graph showing the amount of cottonwood cover in the 1930s, the 1950s and on sites currently known to have cottonwood forests with a xeric understory. Linear trend lines show the average cover across all river segments.

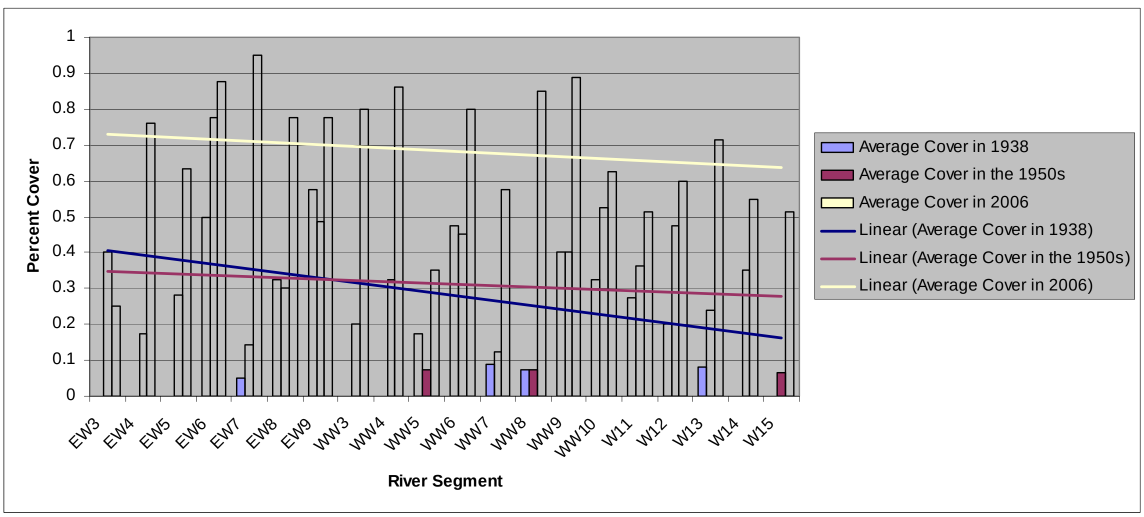

Figure 2.2-5. Bar graph showing the amount of cottonwood cover in the 1930s, the 1950s and on sites currently known to have cottonwood forests with either a riparian or a xeric understory. Linear trend lines show the average cover across all river segments.

Paired, two-tailed, student t-tests were used to see if cottonwood canopy cover at one point in time was statistically different from cottonwood cover at another point in time (Table 2.2-1). Significant differences in cover exist between the 1930s when compared to current cover and the 1950s when compared with current cover. Tree cover assessed in the 1930s and 1950s was not significantly different.

Table 2.2-1. T-statistics and (p-values) of paired, 2-tailed t-tests comparing cottonwood cover between years.

Date of Photo Set	1930s	1950s
1950s	-1.54 (0.15)	
2005	-6.82 (<0.00)	-8.17 (<0.00)

Historical aerial imagery was lacking from or only had partial coverage of several river segments (Table 2.2-2). However, for the majority of the Walker River, an increase in previously established tree cover was observed.

Table 2.2-2. Summary of the number of sites and reaches evaluated to estimate changes in cottonwood cover.

Cottonwood Type	Number of Sites (Number of Reaches)		
	1930s	1950s	2006
Xeric Understory	20 (11)	28 (15)	28 (15)
Riparian Understory	38 (20)	38 (20)	23 (13)

2.2.1.4 <u>Existing Vegetation Community Types and Distributions</u>

BACKGROUND ON WALKER RIVER VEGETATION

Vegetation inventory work has been completed on the upper parts of the Walker River and in the Sierra Nevada (Billings, 1951; Rundel et al., 1977), Bodie Hills, Wassuk (Bell and Johnson, 1980) and the Sweetwater (Lavin, 1983) mountain ranges surrounding the river. These projects focused on inventory of plant species, species diversity, and plant ecology, but did not delimit vegetation communities. To date, no vegetation survey work has been published on the lower sections of the Walker River. This effort fills in some of these data gaps and includes vegetation community descriptions and survey data for the East Walker River, the West Walker River, and the Walker River.

Vegetation of the Walker River Basin corridor can be divided into two broad categories that are influenced by elevation and soil type. The upper river is at the confluence of Great Basin and Sierra Nevada vegetation types. The lower Walker River is dominated by Great Basin vegetation.

The work focused on:

- Further delimiting vegetation communities,

- Mapping discrete patches of those vegetation communities along the East Walker, West Walker, and the Walker River corridor,
- Providing an inventory of species present during the 2007 surveys,
- Providing a measure of cover of each vegetation type and relating those vegetation types to wildlife use.

Over the past century, the Walker River has been subjected to numerous disturbances including alterations to the river channel, diversions, development, and grazing. As a result, several vegetation types have been reduced, specifically, riparian forest, riparian shrublands, wet meadow and emergent marsh wetlands. Additionally, native plant associations have been compromised by the introduction and establishment of undesirable, non-native species associated with disturbance activities. As riparian and wetland habitats are fragmented and lost, the diversity and abundance of wildlife species also decline. The only way to quantify these changes is with the analysis of vegetation composition. The Walker River vegetation mapping effort by USFWS and the University of Nevada, Reno (UNR) was made to fill this need so that wise management decisions can be made and effective restoration projects may be undertaken to sustain the health of the Walker River.

VEGETATION COMMUNITIES

Fifteen vegetation types were mapped and acreage calculated (Table 2.2-3, Figure 2.2-6) along the Walker River in California and Nevada. Vegetation maps are presented in Appendix K. Species lists are presented in Appendix J, Tables J-1 and J-2[46].

For the purposes of data collection and river characterization, the Walker River was divided into individual segments based upon geomorphology, bed characteristics, and other geological and hydrological variables (See Section 2.1).

Table 2.2-3. Summary of the accuracy and acreage of each vegetation type mapped on the Walker River in 2007.

Vegetation Type	Acreage	% of Total Acreage Mapped	# of validation sites predicted correctly / # of validation sites in the vegetation type	The true vegetation type of mis-predicted validation sites.
Agricultural and Developed Land	32,000	29.11	16/18	1 alkali shrub 1 riparian shrub
Alkali Meadow	1,800	1.64	9/15	1 agriculture 2 alkali shrub 2 riparian shrub

[46] Common names and scientific names for plants are used for the first occurrence of a species then only the common name for the remainder of this document. Appendix J Table J-2 has both scientific and common names listed. If no common name exists then only the scientific name is presented.

Vegetation Type	**Acreage**	**% of Total Acreage Mapped**	**# of validation sites predicted correctly / # of validation sites in the vegetation type**	**The true vegetation type of mis-predicted validation sites.**
				1 xeric shrub
Alkali Shrub	7,000	6.37	9/11	1 riparian shrub 1 xeric shrub
Big Sagebrush	19,060	17.34	46/57	1 alkali shrub 7 agriculture 1 Jeffrey pine 1 riparian shrub 1 xeric shrub
Early Successional Riparian	710	0.65	12/14	1 big sagebrush 1 wet meadow
Emergent Marsh/ Wetland	1,300	1.18	22/22	
Jeffery Pine Forest	2,700	2.46	20/23	3 pinyon-juniper
Mature Cottonwood w/ Riparian Understory	1,100	1.00	6/6	
Mature Cottonwood w/ Xeric Understory	1,200	1.09	7/11	3 mature cottonwood w/ riparian shrub 1 riparian shrub
Pinyon-Juniper Woodland	6,800	6.19	20/20	
Playa	350	0.32	12/15	3 xeric shrub
Riparian Shrub	6,500	5.91	30/32	1 emergent marsh 1 wet meadow
Tamarisk	2,700	2.46	8/8	
Wet Meadow	1,640	1.49	17/25	1 alkali meadow 5 emergent marsh 2 riparian shrub
Xeric Shrub	25,000	22.75	12/14	1 riparian shrub 1 tamarisk
Unclassified	50	0.05		
TOTAL ACREAGE MAPPED	109,910			

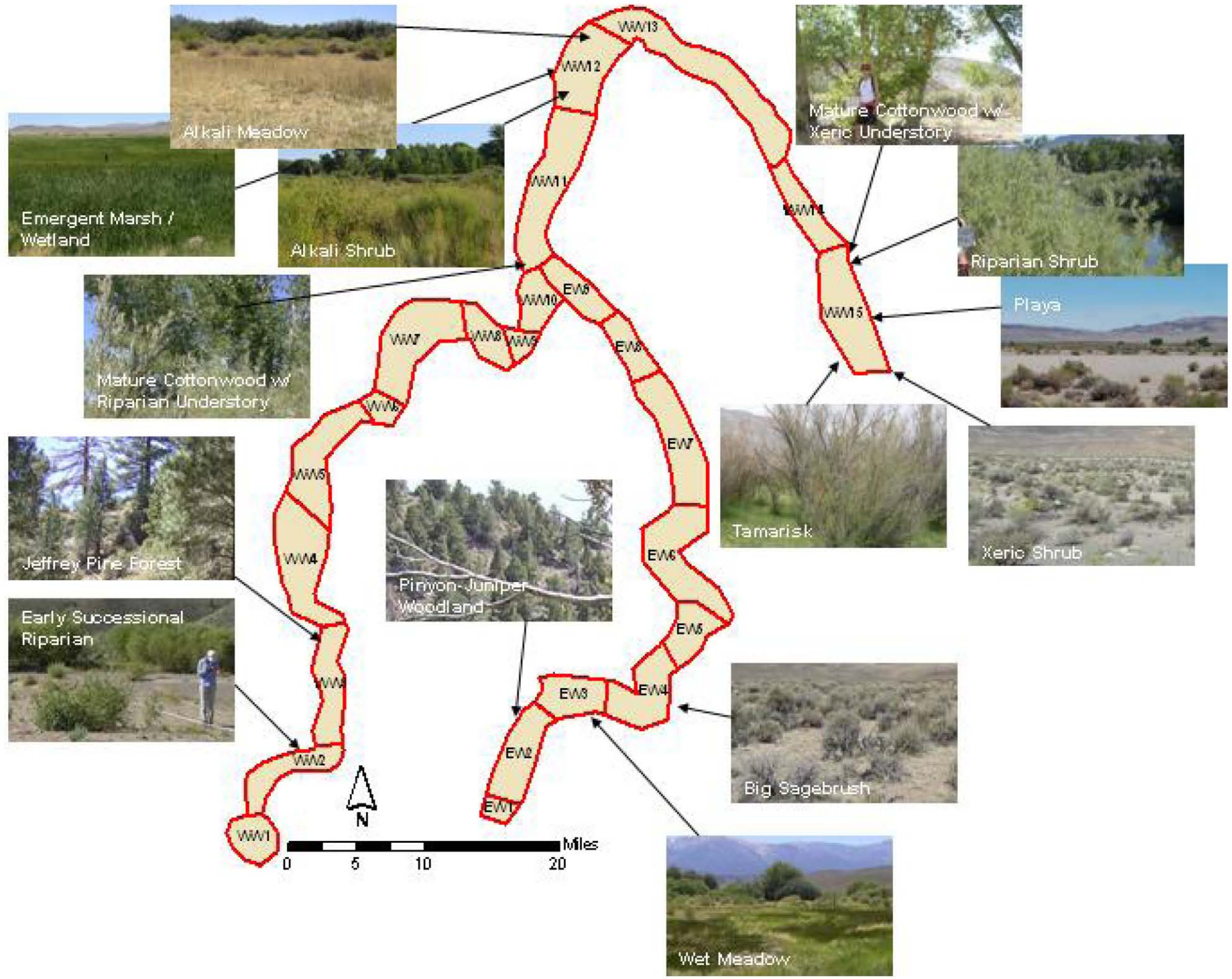

Figure 2.2-6. Examples of vegetation types and their respective locations by geomorphic segment.

Agricultural and Developed Lands

Mapped agricultural and developed lands include vegetation that is currently farmed, including irrigated fields, orchards, grazing lands, commercial and residential development. Access to private land was limited, therefore most of the agricultural and developed lands were identified by extrapolating from vegetation communities where access was available. These areas did not receive the same field mapping effort as the other vegetation classes in either the creation of the vegetation map or the validation. Agricultural lands make up approximately 32,000 acres of the mapped area or 29.13% of total acreage mapped (Table 2.2-3).

Alkali Meadow

The alkali meadow vegetation type is found on raised surfaces. Alkali soils generally have a pH higher than 6.4. This is indicated by the tolerances of the plant species found within this vegetation type (USDA PLANTS database, assessed October 2, 2008). Alkali meadows are mostly found along middle and lower reaches of the East Walker, West Walker and Walker Rivers. Alkali meadow is found on raised surfaces near the river but may also be found at some distance from the river provided groundwater is approximately one to three meters deep. Along the Walker River, alkali sacaton and inland saltgrass are the dominant and characteristic plant species (Figure 2.2-6). Associated species across the entire range include Hall's meadow hawksbeard (*Crepis acuminata*), creeping wildrye, Baltic rush, ricegrass and *Hordeum jubatum*. Alkali meadow covers about 1,800 acres and makes up 1.64% of total acreage mapped (Table 2.2-3).

Alkali Shrub

Alkali shrub communities are found on raised surfaces. Alkali soils generally have a pH higher than 6.4. This is indicated by the tolerances of the plant species found within this vegetation type (USDA PLANTS database, assessed October 2, 2008). Alkali shrub is mostly found along middle and lower reaches of the East Walker, West Walker and Walker Rivers. Alkali shrub is found on raised surfaces near the river but may also be found at some distance from the river provided groundwater is approximately 2 to 6 meters deep. Groundwater may be shallower on a seasonal or semi-permanent basis and alkali meadow species may be found in high abundance with shrubs. Dominant shrub species are Torrey's saltbush, four wing saltbush and shadscale (Figure 2.2-6). Alkali shrub vegetation covers approximately 7,000 acres and makes up 6.37% of total acreage mapped (Table 2.2-3).

Big Sagebrush

Upland shrub community types dominated by big sagebrush occur on floodplain terraces, older river terraces, adjacent to channels, and adjacent to ephemeral and perennial creeks. Dominant shrub species include big sagebrush, littleleaf horsebrush (*Tetradymia glabrata*), rubber rabbitbrush, antelope bitterbrush (*Purshia tridentata*), hop sage (*Grayia spinosa*), greasewood, Torrey saltbush and four-wing saltbush (Figure 2.2-6). Graminoids include creeping wildrye, basin wildrye, *Poa* species and inland saltgrass. Wood's rose may be present. Forb cover is generally low and may include lupine and hawksbeard. Big sagebrush covers approximately 19,060 acres and makes up 17.34% of the total acreage mapped (Table 2.2-3).

Early Successional Riparian

Early successional riparian vegetation is recognized by a dominance of coyote willows (*Salix exigua*) (Figure 2.2-6). Dominant graminoids include *Cyperus aristata*, *C. rivularis*, *Muhlenbergia* species and *Poa* species. Forbs include yarrow (*Achillea millefolium*), dock (*Rumex hymenosepala* and *R. crispus*) and lady's thumb (*Polygonum persicaria)*.

Early successional riparian vegetation is found on point bars. Point bars are formed by depositional actions of the river and are highly active fluvial surfaces. These surfaces provide areas for recruitment and expansion of important riparian vegetation. Point bars are found in most reaches except where the river has been highly altered via river channelization[47]. Early successional riparian vegetation makes up approximately 710 acres and 0.65% of total acreage mapped (Table 2.2-3).

Emergent Marsh/Wetland Vegetation

Emergent marsh wetlands are seasonally and/or semi permanently flooded wetlands associated with oxbow and backwater areas within close proximity to the active channel. Dominant plant species include bulrush (*Scirpus acutus*), cattail (*Typha* spp.), speedwell, Baltic rush and lady's thumb (Figure 2.2-6). Emergent marsh or wetland vegetation is found at wetlands and along old oxbows and channels. The emergent marsh / wetland vegetation type covers approximately 1,300 acres and makes up 1.18% of total acreage mapped (Table 2.2-3).

Jeffrey Pine Forest

The Jeffrey pine forest vegetation type consists of forests dominated by coniferous vegetation (Figure 2.2-6). This type is found predominantly along the West Walker from the Leavitt Meadows area down through Chris Flats. As with pinyon-juniper vegetation, Jeffrey pine forests would not typically be thought of as riparian. The proximity to the river for many miles along the upper reaches of the West Walker suggests that Jeffrey pine forests should be considered in this mapping effort.

Dominant species in the overstory include Jeffrey pine, curl leaf mahogany and juniper species. Abundant shrubs include big sagebrush and bitterbrush. Common grasses include *Stipa* species and *Poa* species. Common forbs include a variety of buckwheats (*Eriogonum* spp.). Jeffrey pine forests cover approximately 2,700 acres and make up 2.46% of total acreage mapped (Table 2.2-3).

[47] The process in which a river or stream is straightened. This results in increased water velocity which carries more sediment and will deepen a river channel. Deeper channels tend to have relatively high and unstable bank which are low in vegetative cover.

Mature Cottonwood with Riparian Shrub Understory

Mature cottonwood with a riparian understory consists of a fully grown canopy of cottonwood and/or red willow with tree canopies generally less than one tree-height apart, with an understory layer of riparian vegetation. At lower elevations of the Walker River, Fremont cottonwood dominates and at higher elevations of the Walker River, black cottonwood dominates the overstory tree canopy. Black cottonwood is found below 2,800 m in elevation and Fremont cottonwood is found below 2,000 m in elevation. The two species hybridize where they overlap in elevation. Understory dominant species typically include coyote willow, Wood's rose, buffaloberry and big sagebrush (Figure 2.2-6). Grasses present include creeping wild rye, basin wild rye and saltgrass. Forbs present include heliotrope and horsetail species. This vegetation community type is typically found on terraces and along edges of wetlands. This type covers approximately 1,100 acres and makes up 1.00% of total acreage mapped (Table 2.2-3).

Mature Cottonwood with Xeric Understory

Mature cottonwood with a xeric understory consists of fully grown tree canopies composed of Fremont cottonwood and/or black cottonwood, generally less than one tree-height apart. At lower elevations of the Walker River, Fremont cottonwood dominates and at higher elevations of the Walker River, black cottonwood dominates the overstory tree canopy. Black cottonwood is found below 2,800 m in elevation and Fremont cottonwood is found below 2,000 m in elevation. The two species hybridize where they overlap in elevation. Most of the tree canopy has a recognizable layer of xeric shrubs in the understory. Dominant shrub understory species include big sagebrush (*Artemisia tridentata*), greasewood (*Sarcobatus vermiculatus*), fourwing saltbush (*Atriplex canescens*), Torrey's saltbush (*Atriplex torreyi*), and rabbitbrush (*Chrysothamnus nauseosus*) (Figure 2.2-6). Grasses present include creeping wild rye, basin wild rye and saltgrass. Forbs present include heliotrope (*Heliotropium curassavicum*) and horsetail (*Equisetum*) species. This vegetation type is typically found on old benches or terraces. The type covers approximately 1,200 acres and makes up 1.09% of total acreage mapped (Table 2.2-3).

Pinyon-Juniper Woodland

Pinyon-juniper woodland is comprised of single leaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) along the Walker River (Figure 2.2-6). Pinyon-juniper woodland is a common vegetation type across the entire Great Basin. Single leaf pinyon and Utah juniper dominate the trees however other tree species such as curl leaf mahogany (*Cerocarpus ledifolius*) may be abundant locally. Abundant shrubs include big sagebrush, bitterbrush and ephedra. Common grasses include *Stipa* species and *Poa* species. Common forbs include a variety of buckwheats (*Eriogonum* spp.) and Douglas' dustymaiden.

Pinyon-juniper woodland is found mostly on the East Walker River from Bridgeport reservoir downstream through the Rosaschi Ranch area. While pinyon-juniper woodland would not typically be thought of as riparian vegetation, the proximity of this vegetation type to the East Walker along its upper reaches suggests that the pinyon-juniper woodland type should be mapped and considered as riparian for this effort. Noxious weeds were not mapped in any part of the pinyon-juniper vegetation type. Pinyon-juniper woodlands cover approximately 6,800 acres and make up 6.19% of total acreage mapped (Table 2.2-3).

Playa

Playa vegetation is found on flat areas within the xeric shrub type. Soils and drainage patterns create unfavorable conditions for plant growth. These differences in soils and hydrology make playa communities distinct when compared to the other plant community types. Plant species are the same as in xeric shrublands however overall vegetation cover is low (Figure 2.2-6). Playa vegetation is considered within this study due to its landscape position relative to the Walker River. Playa vegetation covers about 350 acres and makes up 0.32% of total acreage mapped (Table 2.2-3).

Riparian Shrub

Riparian shrub vegetation consists of free-standing patches of shrub willows such as coyote willow or other riparian shrubs such as buffaloberry (*Shepherdia argentea*) and Wood's rose (*Rosa woodsii*) (Figure 2.2-6). Dominant graminoids were a variety of *Poa* species, Baltic rush (*Juncus balticus*), creeping wild rye (*Leymus triticoides*), basin wild rye (*Elymus cinereus*) and various sedge (*Carex*) species. Dominant forbs included yarrow and speedwell (*Veronica americana*). The riparian shrub vegetation type has no forest canopy above the shrubs and is often found in low spots or wet meadows away from the river. Riparian shrub covers about 6,500 acres and makes up 5.92% of total acreage mapped (Table 2.2-3).

Tamarisk

Tamarisk (*Tamarix ramosissima*, *Tamarix chinensis*) is a non-native riparian species that establishes and thrives not only in riparian areas, but on the upper terraces where willow and cottonwood species cannot establish and thrive. This phreatophyte forms dense stands and produces large quantities of leaf litter, crowding out native species that would typically occur in these areas (Figure 2.2-6). Tamarisk-dominated vegetation is common across the western US, particularly along irrigation ditches, canals, spring outflows, and water impoundment structures. Tamarisk sites are indicative of shallow water tables within reach of tamarisk roots, which can grow at least as deep as 12 ft (per. observation).

It is important to consider site histories when mapping tamarisk and when developing restoration and revegetation strategies. Many tamarisk dominated sites have the potential to be restored back to native plant communities. The amount of effort needed to achieve native plant communities will vary by site.

Much of the lower Walker River was part of Walker Lake until as recently as 30 to 40 years ago (Figure 2.2-7). Tamarisk sites located near the perimeter of the current lake have shallower water tables and inturn, a higher potential of being restored to wetter plant communities than sites on high terraces. Restoration efforts and potential changes in water management may help to increase lake levels and naturally submerge tamarisk on the lake shore. Tamarisk is intolerant of submergence and these areas should naturally transition back into native vegetation. The tamarisk vegetation mapped during summer 2007 covers approximately 2,700 acres and makes up 2.46% of total acreage mapped (Table 2.2-3). Although tamarisk is established between areas mapped as tamarisk and Walker Lake, the extent of mapped tamarisk cover ends where the vegetation map ends. If the vegetation map extended to the lake, closest to the lake

Tamarisk stands along the Walker River commonly have overstories composed of Fremont cottonwood, Gooding's willow and red willow (*Salix laevigata*). Common understory species include rabbitbrush, *Atriplex* spp. and cattails. Common grasses are creeping wild rye and saltgrass. Common forbs include showy milkweed and yarrow.

Much of the tamarisk on the lower Walker has been subjected to beetle introductions. The leaf beetle (*Diorhabda elongata*) has shown some success in defoliating the tamarisk. Some plots have understory species such as saltgrass and creeping wild rye in relatively high cover and careful monitoring will indicate if continued tamarisk defoliation will aid in allowing native vegetation to recover.

Wet Meadow

Wet meadow or seasonally wet meadow has little or no open water and no woody vegetation layers. Dominant plant species include Nebraska sedge, Baltic rush, spikerushes, and a variety of introduced and native grasses, including reed canary grass (Figure 2.2-6). The wet meadow vegetation type is found adjacent to wetlands, old oxbows, and channels. Rabbitbrush and sagebrush species may be present in low quantities where wet meadow transitions into big sagebrush shrublands on upper stream terraces. Wet meadows cover approximately 1,600 acres and make up 1.46% of total acreage mapped (Table 2.2-3).

Xeric Shrub

Xeric shrublands are found on arid uplands along the lower and mid-reaches of the Walker River. Dominant shrub species include desert thorn (*Lycium shockleyii)*, greasewood, black greasewood (*Sarcobatus bailyeii*), shadscale, four wing saltbush, catclaw horsebrush (*Tetradymia spinescens*), common horsebrush (*Tetradymia cansescens*), dune horsebrush (*Tetradymia tetrameres*), rabbitbrush and turpentine broom (*Thamsnosma montana*) (Figure 2.2-6). Forb cover was limited to a few mustard species. There is minimal graminoid cover in the xeric shrub type. Ricegrass (*Oryzopsis hymenoides*) was the only grass that occurred in several plots. Xeric shrub vegetation would not typically be considered in a riparian mapping effort but the physical proximity of the type to the Walker suggests that xeric shrub vegetation should be mapped and considered for any analyses. Xeric shrub vegetation covers approximately 25,000 acres of the corridor and makes up 22.76% of total acreage mapped (Table 2.2-3).

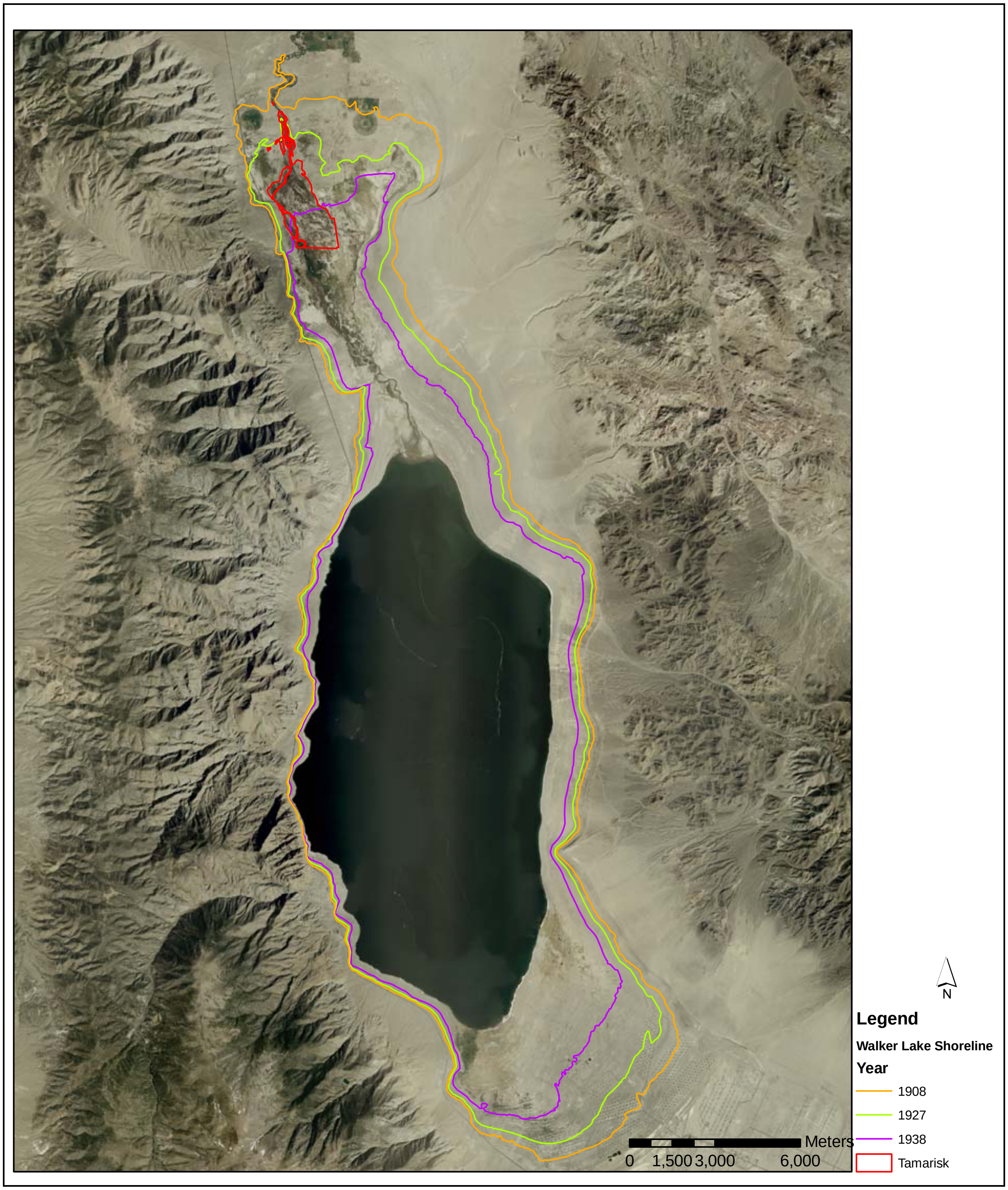

Figure 2.2-7. Decline in water levels of Walker Lake calculated for 1908, 1927, and 1938. Mapped tamarisk stands are delineated in red. The actual extent of Tamarisk is potentially greater, and future mapping will extend to the Walker Lake.

Unclassified

During the field mapping and polygon delineation in the lab, a small number of polygons were left unclassified. This is due to low confidence in correctly classifying these polygons, and the amount of area covered. Future mapping will provide the information necessary to classify these polygons. These polygons totaled 50 acres in area and accounted for 0.05% of the total mapped area.

VALIDATION OF THE VEGETATION SURVEY

In the summer of 2008, validation points were randomly generated in GIS by vegetation type and as many as possible were visited. The statistical rigor of this validation is limited by the number of points that were accessed. More weight should be given to the accuracy of the vegetation types in which more points were validated. High accuracy of a vegetation type with few validation points may indicate high accuracy or there may not have been enough validation points visited. Further validation of such vegetation types would reduce this uncertainty. At each validation point, ocular estimates of plant cover by dominant species were recorded. If the actual vegetation type did not match the description of the mapped type, the most appropriate vegetation type was selected from the previously defined categories and recorded. Photographs were taken to document each point.

Some vegetation classes in the initial mapping effort were grouped because they were judged to be closely related and showed significant errors in classification that could easily be resolved by grouping related classes. The intensity of sampling effort for the validation of the vegetation map did not exceed 25 points in anyone one vegetation type. The validation of vegetation types described below, where sampling intensity exceeds 25 points, are a result of this reclassification.

Any future users of the vegetation map should be aware of which types were mistaken for one another. Cases in which a vegetation type were mistaken for an unrelated type such as a site predicted as being dominated by early successional riparian vegetation, which in actuality was dominated by the sagebrush type, could be due to a section of aerial photography with poor quality. Closely related vegetation types such as emergent marsh wetland and wet meadow, (where an increase in seasonal flooding would likely result in the transition of a site from a wet meadow to an emergent marsh) should be used with caution if the results of an analysis depend upon an accurate distinction of these two vegetation types. An analysis that does not depend upon the distinction of these two vegetation types will benefit from the increased accuracy of these two vegetation types.

Early Successional Riparian

Early successional riparian vegetation is easily identified by a dominance of coyote willow. This vegetation type was predicted with good accuracy. Only two sites were inaccurately predicted. One site was wet meadow and the other was big sagebrush (Table 2.2-3). No errors were found in which another vegetation type was mistaken for emergent riparian. This vegetation type was mapped with a good deal of accuracy.

Riparian Shrub

Riparian shrub vegetation is dominated by coyote willow and buffaloberry and is often found at some distance from the river. Only two sites were inaccurately predicted in this vegetation type. One site was emergent marsh and the other was wet meadow (Table 2.2-3). As no other errors were found in the mapping of this vegetation type, this vegetation type was mapped with good accuracy.

Mature Cottonwood with Riparian Shrub Understory

Mature cottonwood with a riparian shrub understory has a cottonwood overstory and the dominant shrub species include coyote willow, Wood's rose, buffaloberry and big sagebrush. Six sites were visited in this vegetation type for validation and all 6 were correctly classified. This vegetation type was accurately mapped.

Mature Cottonwood with Xeric Understory

Mature cottonwood with a xeric understory has a cottonwood overstory and the dominant shrub species may include sagebrush, saltbushes, greasewood, and rabbitbrushes. This class was most commonly mistaken for mature cottonwood with a riparian understory. This occurred in 3 of the 11 validation sites in the vegetation type. One additional site was misclassified when it was actually high density riparian shrub. This particular site was mapped as being surrounded by riparian shrub and it is probably not an error of scale but interpretation and should not be of concern. As 7 of the 11 validation sites in this vegetation type were correctly classified, this type was mapped with a fair amount of accuracy. However, if the map is being used for a purpose that does not necessitate the user to differentiate between cottonwood forests with different understory compositions, the mature cottonwood with a xeric understory type should be combined with the mature cottonwood with riparian shrub understory to increase the accuracy of this vegetation type.

Wet Meadow

Wet meadow vegetation is dominated by Nebraska sedge, Baltic rush, spikerushes, and a variety of grasses. This vegetation type had moderate map accuracy with 17/25 sites found to be correct in validation. One site was predicted as being wet meadow when it was determined to be alkali meadow in validation. Five sites predicted to be wet meadow were determined to be emergent marsh in validation (Table 2.2-3).

Four of the five sites that were classified as wet meadow that were found to be emergent marsh during validation were found within the MVWMA over a distance of < 2.5 km. These errors might be location specific, or changes in the local environmental conditions might be responsible for changes in the vegetation since the aerial photography was flown in 2006 and the waterfowl pond series in the area has been reworked.

Wet meadows are drier than the emergent marsh type, although both could be considered wetlands. Some sites that were predicted to be other vegetation classes were determined to be wet meadow. These include one site that was predicted to be emergent riparian, one site that was predicted to be riparian shrub, and one site that was predicted to be xeric shrub. The presence of both wet meadow and emergent marsh vegetation types are important to several wildlife species. Small mammals such as shrews and voles use wet meadows. Emergent marshes are important for amphibians and birds, specifically rails and bitterns. Given the apparent value of both vegetation types, they were not combined.

Emergent Marsh/Wetland Vegetation

Emergent marsh wetland vegetation is dominated by bulrush, cattail, speedwell, Baltic rush and lady's thumb. This vegetation type was accurately mapped as all of the 22 sites that were validated and predicted to be emergent marsh were correctly mapped.

Alkali Meadow

Dominant plant species found in the alkali meadow vegetation type include alkali sacaton and inland saltgrass. Nine of the 15 validated alkali meadow sites were correctly classified. Two of the 15 sites were found to be alkali shrub which can be difficult to separate from alkali meadow as the two have similar understory compositions and differ primarily in shrub cover. The 4 other sites that were misclassified were mostly distinct categories: agriculture, high density riparian shrub, low density riparian shrub, and xeric shrub. Only one site that was predicted as being another vegetation class, wet meadow, was found to be alkali meadow. The alkali meadow vegetation class was predicted with a fair amount of accuracy.

Alkali Shrub

Dominant species in the alkali shrub vegetation type include Torrey's saltbush, four wing saltbush and shadscale. Nine of 11 validated sites were correctly predicted as being alkali shrub. One misclassification was in actuality xeric shrub and another was low density riparian shrub. One site that was predicted as being agriculture and two sites that were predicted as being alkali meadow were found to be alkali shrub. The alkali shrub vegetation type was predicted with good accuracy.

Big Sagebrush

Dominant sagebrush species include big sagebrush, rubber rabbitbrush, antelope bitterbrush (*Purshia tridentata*), greasewood, Torrey saltbush and four-wing saltbush. Forty-six of 57 sites were validated that were predicted as being in the big sagebrush vegetation class. Sites that were mistaken for this vegetation type included one of each of the following: alkali shrub, Jeffrey pine, riparian shrub, and xeric shrub. The other seven of sites that were misclassified were validated as being agriculture. All of these misclassifications were found at Rosaschi Ranch. Rosaschi Ranch has been subjected to restoration efforts by the USFWS, U.S. Forest Service, and the USDA Agricultural Research Service. As these efforts have been in the recent past, it is realistic to expect these restoration sites to be dominated by early seral species such as grasses. However, the grass species on these sites were lumped so it is impossible to tell if they are predominately native species. These seem to be errors of interpretation. Although these sites are currently not dominated by big sagebrush or rabbitbrush, these seven sites, if dropped from the validation would increase the accuracy to the vegetation type to 46/50.

Pinyon-Juniper Woodland

All validation points that were predicted as being pinyon-juniper woodland were accurately mapped. Three sites that were predicted as being Jeffrey pine were actually pinyon-juniper woodland.

Jeffrey Pine Forest

Most Jeffrey pine forests were mapped accurately. Three of 23 validation sites were in fact pinyon-juniper woodlands. One site that was predicted as being sagebrush was Jeffrey pine forest. This vegetation class was accurately mapped.

Xeric Shrub

Most sites predicted as being dominated by xeric shrub communities were (12 of 14). One site that was predicted to be xeric shrub was actually wet meadow and another was high density riparian shrub. Most errors concerning this vegetation class refer to three sites that were predicted as being playa but higher than expected shrub cover suggested that they belong in the xeric shrub class 3 sites. This vegetation type was accurately mapped.

Playa

Inaccuracies in the mapping of the playa vegetation type exist on the boundaries of this vegetation type with xeric shrub communities. Three sites that were predicted as being playa were validated as xeric shrub. Other vegetation types were not mistaken for playa communities. This vegetation type was accurately mapped.

Tamarisk

Validation efforts found that all sites predicted as being dominated by tamarisk were mapped correctly. Additionally, there were no cases of another predicted plant community being dominated by tamarisk.

Agricultural and Developed Lands

Some agricultural fields had previously been mapped by the Desert Research Institute. These mapped fields were used to validate areas delineated as agricultural fields on the vegetation map and additional points were validated. There were a few errors in the mapping of agricultural lands. Sites predicted as being dominated by agricultural lands were mistaken once as alkali shrub and once as high density riparian shrub. In the second case, a patch of willows established between two sites that belonged in the agricultural class. Seven sites that were predicted as being big sagebrush with high cover of rabbitbrush were validated as being agricultural lands. Two of these overlap with restoration efforts at Rosaschi Ranch which were planted with sagebrush and rabbitbrush. There is a large potential for error in this vegetation class as it indicates disturbance of the other classes. With time, some of these disturbances may cease and longer lived plants might return on their own. However, at the time of validation, 12 of 14 validated sites were correctly mapped indicating that this vegetation type was accurately mapped.

2.2.1.5 Restoration Concepts and General Recommendations

Below are general concepts of ecological restoration that are dependent upon intact native plant communities. These concepts should be considered once site specific restoration plans are underway. The health of native plant communities should be monitored to as indicators of habitat quality and river function.

HABITAT COMPLEXITY

Restoration efforts along the Walker River will be include restoration measures that recover natural river function. This will include sustaining a variety of channel, forested, meadow, and wetland habitats which will benefit many wildlife species and is vital to river function. Stream restoration helps to preserve Nevada's rich biological heritage through the recovery of ecosystem function and consequent preservation, creation, and perpetuation of suitable wildlife habitats. Studies have shown that complex, diverse vegetation provides the highest quality habitat for reptiles (Driscoll, 2004), birds (MacArthur and MacArthur, 1961; Tomoff 1974; Hurlbert, 2004), mammals (August, 1983) and invertebrates (Kennedy et al., 2002).

Species rich and structurally diverse communities tend to be more resistant to invasion by noxious weedy species (Levine and D'Antonio, 1999; Kennedy et al., 2002). Non-native plant and animal species provide substantial threats to biodiversity and are responsible for large economic losses to agriculture (Pimental et al., 2000). Diverse communities not only provide resistance to invasive species, but they also tend to be more resilient to natural disturbances such as fire and floods (Poiani et al., 2000). Present day loss of habitat diversity and complexity on the Walker River threaten several native riparian community populations.

Over time, anthropogenic changes to natural river flow regimes have reduced the diversity of mixed riparian habitats. Formerly wide swaths of intact riparian habitat have today become fragmented and patchy. Northern leopard frogs, which inhabit oxbow ponds associated with active river channel migration, were once considered to be the "commonest and most widespread" frog species in Nevada (Linsdale, 1940), but due to wetland losses, these frogs have declined so much in western Nevada that local extirpations have likely occurred (Hitchcock, 2001). Also currently on the decline are wetland-marsh dependent birds such as rails, which nest in thick emergent vegetation associated with river side channels, sloughs, and oxbows. Other examples include the willow flycatcher and the greater sage grouse, two species known to occur on the Walker River and which respectively depend upon the long-term presence of intact, healthy riparian willow and upland sage habitats. Due to population declines these birds have been listed as Nevada Partners in Flight priority species. These and many other declining native wildlife species have narrow ecological limits. These species with narrow ecological limits cannot adapt quickly enough to survive in newly altered or disturbed habitats. Thus preservation, conservation, and restoration actions to protect and enhance diverse and complex habitats that are resistant and resilient to disturbance are needed to support the native Walker River riparian obligate species.

ACTIVE REVEGETATION

Critical to the success of restoration projects is the implementation of active revegetation efforts. There is much discussion in the restoration science community concerning 'passive' restoration where the hope is that if some environmental condition is returned to a previous state, such as re-watering a spring, then the native vegetation will recover. This suggestion is based upon ideas that vegetation succession is an orderly, linear process and that management actions will result in predictable plant assemblages (Clements, 1916; Dyksterhuis, 1949). Current work in plant community ecology shows that plant community dynamics are complex and sometimes unpredictable. Removing a disturbance or restoring a water supply may not reverse changes in vegetation (Laycock, 1991). The establishment of aggressive nonnative weeds and animals, the extirpation of native plants and animals and the removal of natural disturbance regimes all contribute to unpredictable and sometimes undesirable outcomes of passive restoration. Revegetation should focus on assisting the plant communities to take desirable trajectories. Revegetation efforts along the Walker River should include but not be limited to pole plantings of *Salix* and *Populus* species, sod installation of saltgrass (*Distichlis spicata*) and other graminoids, container plantings of trees such as red willow, various shrubs, forbs and graminoids and seeding of native graminoids and forbs. Without sufficient water, xeric sites will remain so and the establishment of native species will take active restoration efforts and supplemental water. Plant succession in arid landscapes is slow. Irrigation on particularly arid sites will ensure that seeding efforts are productive. Without enough natural precipitation, as will happen in dry years, seed viability may be lost before plants germinate and establish. Removal of aggressive nonnative weeds will be necessary to eliminate competition with desired species whose establishment and survival would be compromised. Specific revegetation plans will be unique for individual sites and at that time details such as which species and plant numbers will be determined.

Passive restoration measures such as fencing riparian areas to exclude grazing can show a strong positive response in productive sites. Willows that propagate vegetatively such as *Salix exigua* will rapidly recolonize floodplains. Co-dominants such as Wood's rose and understory forbs and grasses will also recolonize. It is likely that weedy species such as salt cedar and tall white top may also take advantage of similar conditions and careful monitoring should be implemented. Removal of invasive species should be part of any restoration plan. Passive techniques such as fencing should be used together with active methods on the Walker River.

WEEDS AND WEED TREATMENTS

Weed location, treatment and monitoring are critical parts of a complete restoration plan. During the 2007 Walker River vegetation mapping, locations of weeds were recorded. Additional information concerning weed distribution was gathered from various agencies and entities. The information collected and subsequent documentation is presented in a separate sub report.

Future weed mapping and eradication efforts are being developed in the Basin. In 2008 noxious weed mapping and eradication began on the East Walker River, with the goal of moving to the West Walker and Main Walker in future years. This project was developed by the Mason and Smith Valley Conservation Districts and the USFWS with input from the Walker River Weed District and the local Cooperative Weed Management Area. Long-term benefits of these efforts will be reduced noxious weeds throughout the watershed, improved riparian zone, increased habitat, and improved water quality. Funding for this project was provided through the USFWS – Lahontan NFH Complex and Partners for Fish and Wildlife.

OVERALL CONDITION OF WALKER RIVER VEGETATION

Over the past 100 to150 years there has been significant alteration to the vegetation and plant communities throughout the Walker River Basin. However, compared to the Truckee and Carson Rivers the Walker River vegetation has retained a relatively high amount of native species diversity and cover (Caicco, 1998; Otis Bay 2008). Analysis of historical information and aerial photography revealed an increase in the canopy cover of existing cottonwood dominated riparian forests between 1938 and 2006. However, recruitment of cottonwoods has potentially declined due to a reduction in the availability of establishment surfaces in the active channel and adjacent floodplain, and alterations to natural flow patterns. Compared to the Truckee River, decline in this vegetation type has been at a reduced pace on the Walker River.

A lack of cottonwood recruitment along the Walker River indicates that the health of the river system is at a point of transition. Without recruitment, mature trees will not be replaced and the cover of riparian forests will decline. A decline in the amount of riparian forest will lead to declines in avian species diversity and abundance, along with decreased water quality and increased susceptibility to erosion. Additionally, a lack of recruitment surfaces indicates that river processes of aggradation and degradation are out of equilibrium.

Overgrazing along many segments of the river has caused significant damage to the banks of the river via high amounts of vegetation disturbance. Fencing exclosures in riparian areas that are in close proximity to heavy grazing will help in maintaining the ecological condition of riparian vegetation. Many noxious weed species favor disturbed areas and will continue to be a problem where these disturbances are not addressed.

2.2.2 Birds of the Walker River

The Walker River system supports a great variety of riparian and wetland habitats, which in turn support a diversity of wildlife. The headwaters and upper reaches of the two forks are dominated by aspen, shrub-willow, and wet meadow communities, while the lowland reaches are characterized by Fremont cottonwood communities (*Populus fremontii*) with mixed understory shrubs and agricultural areas. The final reach of the Walker River, which terminates in Walker Lake, is dominated by introduced tamarisk (*Tamarix* spp.).

In cooperation with the Great Basin Bird Observatory (GBBO)[48], OBEC completed a baseline inventory of breeding birds to assist in conservation and restoration planning for the Walker River. Breeding bird communities were assessed in the spring and summer of 2006 and surveys have continued through the summer of 2008, using standard multi-species inventory protocols and habitat assessments, focused on:

- Documenting the bird diversity, species distributions, and relative abundances of conservation priority species of the Walker River's riparian areas;
- Determining habitat associations of select "indicator" species and conservation priority species, and ;
- Developing recommendations for conservation and restoration priorities based on the results of the inventory in the context of regional riparian bird inventories that are conducted concurrently with the Walker River surveys.

Preliminary findings of species diversity along the Walker River are based on 18 point count transects that were surveyed from 2006 through 2008. The results of these surveys are presented here. Further, analyses of bird-habitat associations and recommendations for conservation and restoration priorities that will be derived from this inventory will be presented in a separate report by GBBO.

2.2.2.1 Methods[49]

POINT COUNT SURVEYS

Birds were surveyed using the multi-species inventory protocol of point count surveys. These surveys follow the protocol for GBBO's statewide landbird monitoring program, the Nevada Bird Count. The surveys were conducted between May 25 and July 10 in 2006, 2007, and 2008 between sunrise and 10:00 a.m. in fair weather conditions. The point count transect locations were selected within the riparian corridor based on accessibility. Seven transects were located in "montane riparian" or "aspen" habitat, which is typically dominated by aspen or shrub-willow,

[48] Additional avian analysis is included in a separate report by GBBO titled *Habitat Models for Six Focal Species of Breeding Birds of the Walker River* (2008).
[49] Details of all the survey protocols for the point count surveys, habitat assessments, and area searches, can be viewed on the Great Basin Bird Observatory's website www.gbbo.org.

and 11 transects were located in "lowland riparian" habitat, which is dominated by Fremont cottonwood. Within each accessible section of river, the start location of each transect was selected randomly. Each transect consisted of 10 points, spaced apart at 800-1,000 ft.[50] Bird detections were recorded in three distance intervals measured with a range finder from the survey point: <55 yd, 55-110 yd, and >110 yd. Flyovers were indicated as such on the data sheet. At each survey point, a 10-minute survey was conducted, once during the setup season in 2006, twice per season in 2007, and three times per season in 2008. Twelve transects were set up and surveyed in 2006, fifteen transects were surveyed in 2007, and eighteen transects were surveyed in 2008. The additional count replicates and new transects in 2007 and 2008 were added to give a more complete data set as riparian land access was granted in areas that were inaccessible in 2006. Due to land access limitations, bird transects were surveyed in half of the geomorphic segments (see Section 2.1.4 for detailed segment descriptions) for the West and East Walker River segments. On the main stem of the river, bird surveys were completed on all of the geomorphic segments (Table 2.2-4, Figure 2.2-8). All coordinates for the points surveyed are listed in Appendix L.

Table 2.2-4. Location of each bird transect by geomorphic segment and the years in which surveys were completed. Two letter codes in front of the transect names denote habitat type: AS (aspen), MR (montane riparian), and LR (lowland riparian).

Geomorphic Segment	Bird Transect Name	Years Surveyed
Walker River Tributaries		
-	AS-5217	2006, 2007, 2008
-	MR-Little Walker	2006, 2007, 2008
-	MR-Mill Creek	2006, 2007, 2008
-	MR-Virginia Creek	2006, 2007, 2008
West Walker River		
WW2	MR-Pickel Meadow	2006, 2007, 2008
WW3	-	-
WW4	-	-
WW5	LR-WWFFR	2008
WW6	-	-
WW7	-	-
WW8	LR-Wilson	2006, 2007, 2008
WW9	LR-Wilson	2006, 2007, 2008
WW10	-	-
East Walker River		
EW2	MR-30424	2006, 2007, 2008
EW3	MR-Rosaschi	2006, 2007, 2008
EW4	LR-Elbow LR-Raccoon	2007, 2008 2007, 2008
EW5	-	-
EW6	-	-
EW7	-	-
EW8	LR-WalkerRD	2006, 2007, 2008

[50] Units have been converted from metric to English units. The original metric units used in the surveys are specified in the survey protocols.

Geomorphic Segment	Bird Transect Name	Years Surveyed
EW9	-	-
Walker River		
W11	LR-Mason	2006, 2007, 2008
W12	LR-Mason LR-Mason2	2006, 2007, 2008 2006, 2007, 2008
Lower Walker River		
W13	LR-Julian LR-JBS	2008 2007, 2008
W14	LR-Schurz	2008
W15	LR-DEWalker	2007, 2008

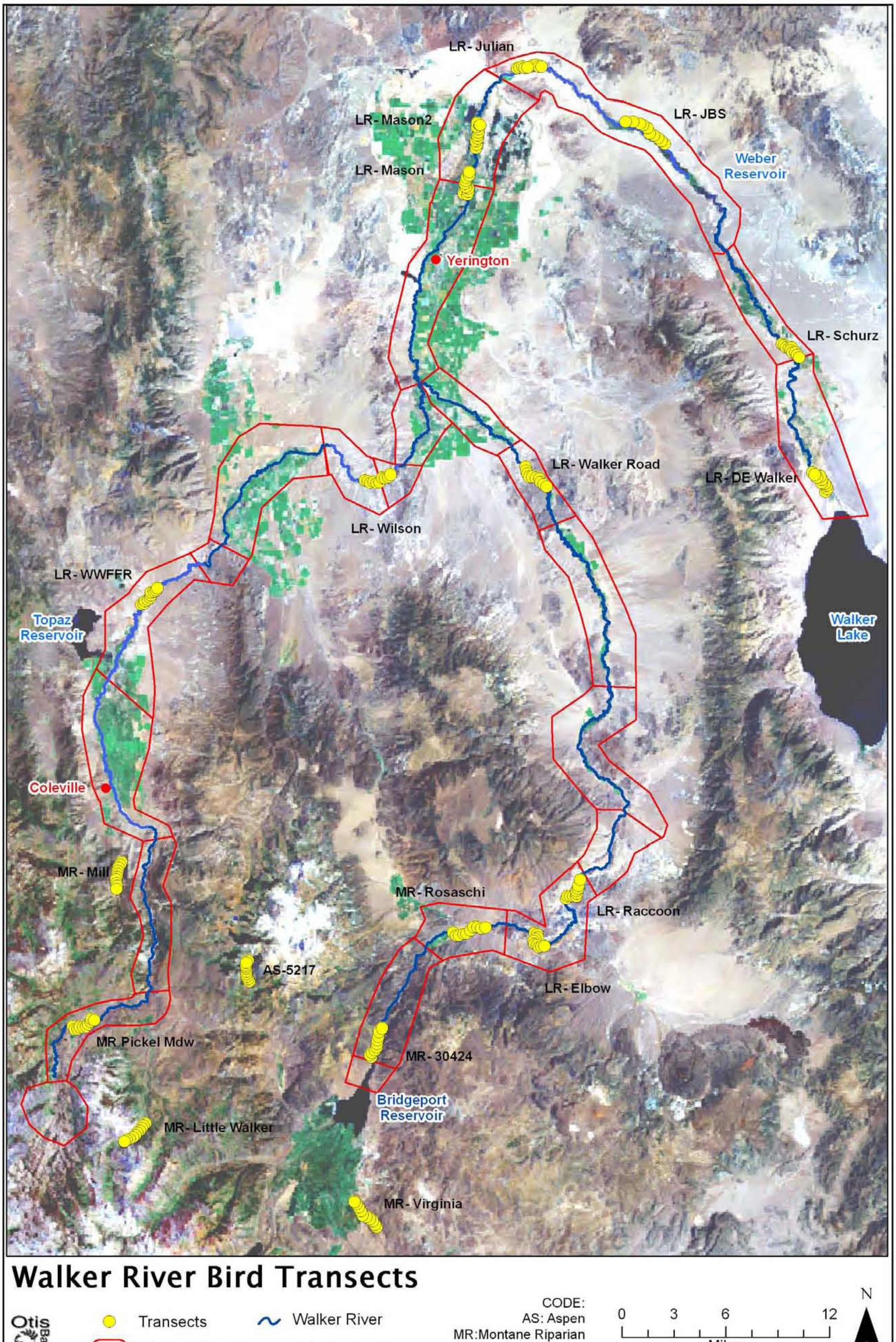

Figure 2.2-8. Map of point count transects surveyed on the Walker River.

Application of the point count method can be especially useful when one is interested in relative changes in bird populations, and when a large area, such as the Walker River, needs to be covered by the monitoring effort. This method has the advantage of quickly assessing presence and abundance of birds during the breeding season, and detecting widespread population trends over time, both gradual and sudden.

HABITAT ASSESSMENTS

In addition to the point count surveys, detailed habitat assessments were implemented at each survey point of 16 transects in 2007 and 2008. Two transects were omitted from the habitat surveys due to access issues. The habitat assessments were completed so that relationships between the presence of bird species and availability of different habitat types could be made.

At each habitat survey point, photos were taken to give a snapshot of the vegetation cover condition in 2007 and 2008. Four 100 ft vegetation transects positioned perpendicular to each other were surveyed at each bird transect point. The direction of the first vegetation transect line was randomly chosen and the other three lines set accordingly. Plant species and heights along 1-yd intervals of the transect line were then identified to the lowest taxonomic level possible and recorded on a datasheet. All plants were classified according to the codes listed in Table 2.2-5. Trees located within 2 yd along each side of the vegetation transect lines were also recorded for an estimate of tree density. Lastly, the entire circular bird point plot was sketched to delineate broad habitat types (e.g. cottonwood forest vs. sagebrush).

Table 2.2-5. Codes from GBBO's habitat assessment protocol that were used to classify important plant cover types for birds detected on the Walker River breeding bird point count surveys.

VEGETATION CLASSIFICATION CODES
BG = Bare Ground C = Cactus CWD = Coarse Woody Debris (downed woody material, at least 10cm diameter at the largest end, and at least 1 m long) – note, if less than this, include as litter; if it is still standing, it should be tallied as either Sh/D or T/D. EMV = Emergent Vegetation (e.g., hydric species, emerging from water, such as Typha and Scirpus) F = Forb (herbaceous non-graminoids) G = Graminoid (grass-like plants: grasses, rushes, sedges) L = Litter MG = Mesic Graminoid (moist graminoids, not part of permanent or mostly permanent marsh, such as Carex, Juncus

VEGETATION CLASSIFICATION CODES
R = Rock (at least 10 cm) Sh = Shrub/Woody species (Live) – please note, that some shrubs may be mostly dead, but with a portion of live crown – if the point hits a portion of the shrub that is dead, use Sh/D, even if elsewhere on the shrub is alive. Sh/D = Shrub/Woody species (Dead) T = Tree (Live) T/D = Snag W = Water Y = Yucca

Because the emphasis of these surveys was on bird habitat use (e.g. for cover, nesting, and forage), these vegetation classification codes differ from those used in the general Walker vegetation surveys (Section 2.2.1). Structural components were highlighted in the bird habitat assessment surveys, while the codes used in the Walker River vegetation map (Appendix K) reflect vegetation communities.

AREA SEARCHES AND SPOT MAPPING EFFORTS

Three intensive area search surveys were completed in the 2008 field season as well. This survey method was employed along with the rapid point count surveys. The more intensive area search surveys were used to help detect those bird species that were likely to be poorly detectable in the rapid point count surveys. Examples of detections that could be missed in a 10-minute point count include birds that have soft vocalizations, secretive behaviors, or birds that temporarily move off of their breeding territory (e.g. if they are out foraging).

For the intensive area search surveys, three sites along the Walker River were randomly picked (Figure 2.2-9). Area plots ranging from 15-20 acres in size were set up: 1) Pickel Meadow located on the West Walker (19 acres); 2) The Elbow located on the East Walker (15.5 acres); and 3) Mason Valley located within the wildlife management area on the Walker River (20 acres). Two surveyors visited each plot eight times during the breeding season of 2008. During the visits, the plot was systematically searched for birds, and each observed bird's location was accurately recorded using an overlay on an aerial photo. Breeding evidence was also determined and recorded on the overlay, and each confirmed or probable territory was individually tracked throughout the season. The data were then compiled at the end of the season to determine the number, location, and estimated size of breeding territories that could be confirmed that summer.

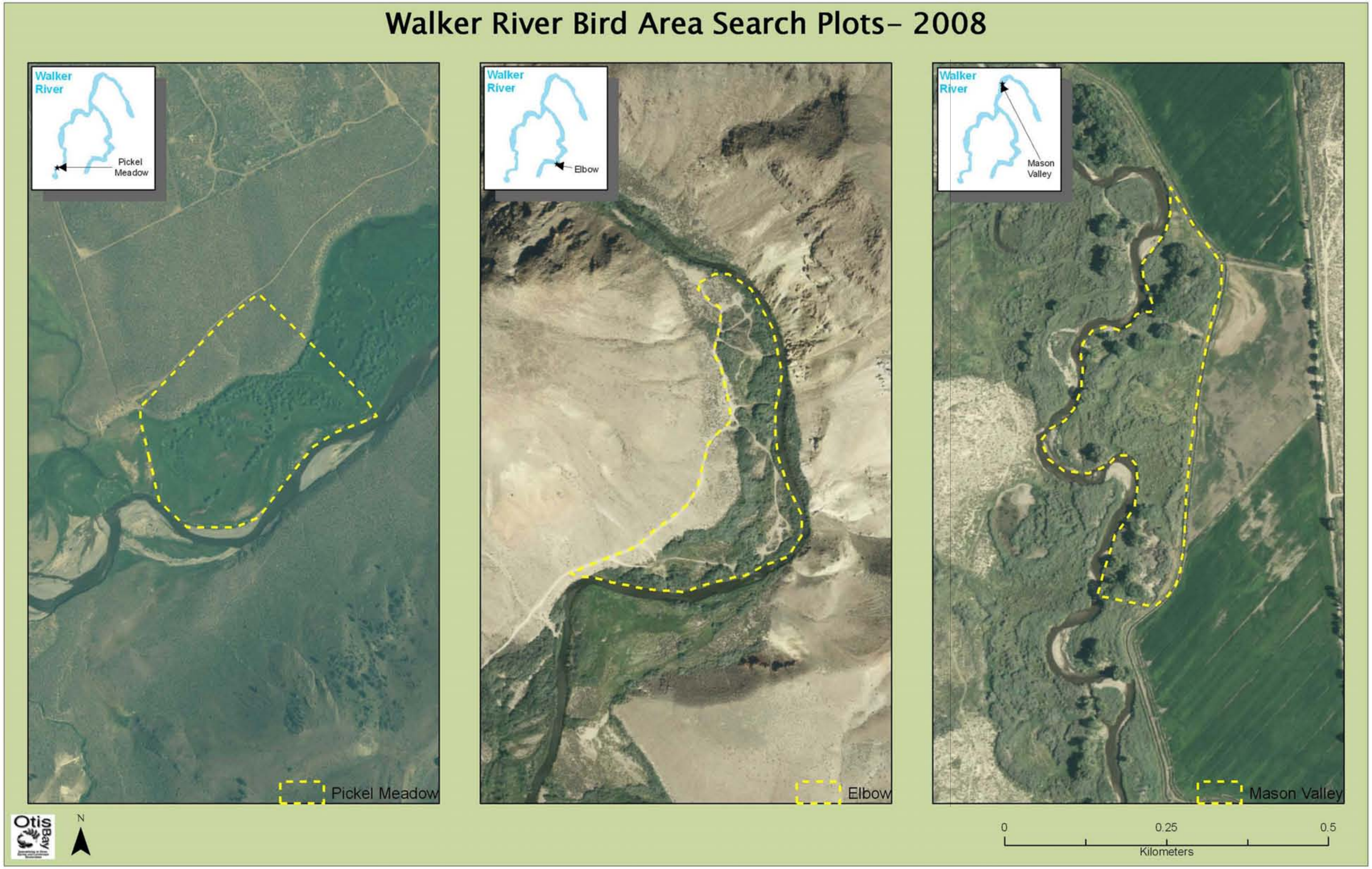

Figure 2.2-9. Location maps of the three intensive area search plots surveyed in 2008 on the Walker River.

2.2.2.2 Results

A summarized species list generated from the 18 point count transects in the three years of inventory, and the 2008 intensive area searches, is provided in Table 2.2-6. Species detected in these surveys totaled 150, with confirmed breeding evidence found for 69 species. The species found in the highest abundances included red-winged blackbird, spotted towhee, brown-headed cowbird, song sparrow, and mourning dove. Not too surprisingly, the most commonly found species were found to be confirmed breeders, while those species that were rarest tended to be migrant species passing through the area. Species with the widest distribution along the river included the brown-headed cowbird, yellow warbler, and song sparrow. These three species were detected on all 18 point count transects, in both lowland and montane riparian habitats. Other widely distributed species included the American robin, red-winged blackbird, spotted towhee, Bewick's wren, California quail, black-headed grosbeak, Bullock's oriole, mourning dove, and European starling. All scientific names are listed in Table 2.2-6.

Table 2.2-6. Bird species, in decreasing order of abundance, detected on the Walker River during the 2006-2008 point count and 2008 area search surveys.

# spp	# obs	Relative Abundance[1]	Species	Frequency[2]	Habitat[3]	Breeding Status[4]
1	898	A	Red-winged Blackbird *Agelaius phoeniceus*	15	LR, MR	Confirmed
2	782	A	Spotted Towhee *Pipilo maculatus*	15	LR, MR, AS	Confirmed
3	779	A	Brown-headed Cowbird *Molothrus ater*	18	LR, MR, AS	Confirmed
4	683	A	Song Sparrow *Melospiza melodia*	18	LR, MR, AS	Confirmed
5	636	A	Mourning Dove *Zenaida macroura*	14	LR, MR	Confirmed
6	631	A	Cliff Swallow *Petrochelidon pyrrhonota*	3	LR, MR	Confirmed
7	468	A	American Robin *Turdus migratorius*	16	LR, MR, AS	Confirmed
8	447	A	Yellow Warbler *Dendroica petechia*	18	LR, MR, AS	Confirmed
9	432	A	Brewer's Blackbird *Euphagus cyanocephalus*	13	LR, MR	Confirmed
10	410	A	Bewick's Wren *Thryomanes bewickii*	15	LR, MR	Confirmed
11	344	A	California Quail *Callipepla californica*	15	LR, MR	Confirmed
12	294	A	Black-headed Grosbeak *Pheucticus melanocephalus*	15	LR, MR, AS	Confirmed
13	293	A	Bullock's Oriole *Icterus bullockii*	15	LR, MR	Confirmed

# spp	# obs	Relative Abundance[1]	Species	Frequency[2]	Habitat[3]	Breeding Status[4]
14	268	A	Western Wood-pewee *Contopus sordidulus*	13	LR, MR, AS	Confirmed
15	262	A	Western Kingbird *Tyrannus verticalis*	12	LR, MR	Confirmed
16	251	A	House Wren *Troglodytes aedon*	11	LR, MR, AS	Confirmed
17	195	C	Killdeer *Charadrius vociferous*	12	LR, MR	Confirmed
18	194	C	House Finch *Carpodacus mexicanus*	12	LR, MR	Confirmed
19	178	C	Western Meadowlark *Sturnella neglecta*	12	LR, MR	Confirmed
20	167	C	Black-billed Magpie *Pica hudsonia*	9	LR, MR	Confirmed
21	141	C	American White Pelican *Pelcanus erythrorhynchos*	2	LR	Transient
22	136	C	Warbling Vireo *Vireo gilvus*	10	LR, MR, AS	Confirmed
23	129	C	European Starling *Sturnus vulgaris*	14	LR, MR	Confirmed
24	126	C	Dark-eyed Junco (Oregon) *Junco hyemalis*	3	MR, AS	Confirmed
25	122	C	Yellow-headed Blackbird *Xanthocephalus xanthocephalus*	4	LR, MR	Probable
26	116	C	Lazuli Bunting *Passerina amoena*	13	LR, MR	Confirmed
27	113	C	Northern Flicker (Red-shafted) *Colaptes auratus*	12	LR, MR, AS	Confirmed
28	91	C	Brewer's Sparrow *Spizella breweri*	11	LR, MR, AS	Confirmed
29	91	C	Spotted Sandpiper *Actitis macularius*	9	LR, MR	Probable
30	89	C	Steller's Jay *Cyanocitta stelleri*	8	LR, MR, AS	Confirmed
31	88	C	Green-tailed Towhee *Pipilo chlorurus*	4	MR, AS	Confirmed
32	87	C	Mountain Chickadee *Poecile gambeli*	6	MR, AS	Confirmed
33	84	C	Black-throated Sparrow *Amphispiza bilineata*	9	LR, MR	Confirmed
34	83	C	Ash-throated Flycatcher *Myiarchus cinerascens*	6	LR	Confirmed
35	80	C	Blue-gray Gnatcatcher *Polioptila caerulea*	13	LR, MR	Confirmed
36	66	U	Lark Sparrow *Chondestes grammacus*	9	LR, MR	Confirmed
37	65	U	Blue Grosbeak *Passerina caerulea*	8	LR, MR	Probable

# spp	# obs	Relative Abundance[1]	Species	Frequency[2]	Habitat[3]	Breeding Status[4]
38	55	U	Horned Lark *Eremophila alpestris*	5	LR, MR	Confirmed
39	51	U	Northern Rough-winged Swallow *Stelgidopteryx serripennis*	9	LR, MR	Confirmed
40	49	U	Bushtit *Psaltriparis minimus*	9	LR, MR	Confirmed
41	48	U	Dusky Flycatcher *Empidonax oberholseri*	2	MR, AS	Probable
42	46	U	Pinyon Jay *Gymnorhinus cyanocephalus*	4	MR	Transient
43	45	U	Mallard *Anas platyrhynchos*	13	LR, MR	Confirmed
44	44	U	Common Raven *Corvus corax*	12	LR, MR	Confirmed
45	43	U	Willow Flycatcher *Empidonax traillii*	5	LR, MR	Probable
46	41	U	Fox Sparrow *Passerella iliaca*	4	MR, AS	Probable
47	40	U	Yellow-rumped Warbler (Audubon's) *Dendroica coronata*	5	MR, AS	Confirmed
48	36	U	Red-breasted Sapsucker *Sphyrapicus ruber*	3	MR, AS	Confirmed
49	34	U	Rock Wren *Salpinctes obsoletus*	8	LR, MR, AS	Probable
50	33	U	Cassin's Finch *Carpodacus cassinii*	3	MR, AS	Confirmed
51	32	U	Black Phoebe *Sayornis nigricans*	8	LR, MR	Confirmed
52	32	U	Red-tailed Hawk *Buteo jamaicensis*	11	LR, MR	Confirmed
53	32	U	Yellow-breasted Chat *Icteria virens*	7	LR, MR	Probable
54	31	U	American Kestrel *Falco sparverius*	11	LR, MR	Confirmed
55	31	U	Clark's Nutcracker *Nucifraga columbiana*	5	MR, AS	Transient
56	30	U	Violet-green Swallow *Tachycineta thalassina*	5	LR, MR, AS	Probable
57	30	U	White-faced Ibis *Plegadis chihi*	1	LR	Probable
58	26	U	Canada Goose *Branta canadensis*	2	LR, MR	Probable
59	25	U	Bank Swallow *Riparia riparia*	4	LR	Confirmed
60	25	U	Lesser Goldfinch *Carduelis psaltria*	3	LR, MR	Migrant

# spp	# obs	Relative Abundance[1]	Species	Frequency[2]	Habitat[3]	Breeding Status[4]
61	24	U	Great Egret *Ardea alba*	1	LR	Unknown
62	23	U	Western Bluebird *Sialia mexicana*	2	LR	Confirmed
63	23	U	White-crowned Sparrow (Mountain) *Zonotrichia leucophrys*	3	MR, AS	Probable
64	23	U	White-throated Swift *Aeronautes saxatalis*	1	LR	Confirmed
65	22	U	House Sparrow *Passer domesticus*	4	LR, MR	Probable
66	22	U	Orange-crowned Warbler *Vermivora celata*	5	MR, AS	Confirmed
67	22	U	Western Tanager *Piranga ludoviciana*	7	LR, MR, AS	Probable
68	21	U	Wilson's Snipe *Gallinago delicata*	4	LR, MR	Confirmed
69	20	U	American Crow *Corvus brachyrhynchos*	5	LR, MR	Probable
70	19	U	MacGillivray's Warbler *Oporornis tolmiei*	5	LR, MR	Migrant
71	19	U	Ring-necked Pheasant *Phasianus colchicus*	2	LR	Game
72	18	U	Cinnamon Teal *Anas cyanoptera*	3	LR, MR	Probable
73	17	U	Wild Turkey *Meleagris gallopavo*	2	LR	Game
74	16	U	American Coot *Fulica americana*	3	LR, MR	Confirmed
75	14	R	Brown Creeper *Certhia americana*	2	MR, AS	Confirmed
76	14	R	Common Merganser *Mergus merganser*	2	LR, MR	Confirmed
77	14	R	Common Nighthawk *Chordeiles minor*	6	LR, MR	Transient
78	14	R	Gadwall *Anas strepera*	3	LR, MR	Probable
79	14	R	Mountain Bluebird *Sialia currucoides*	3	MR, AS	Probable
80	14	R	Vesper Sparrow *Pooecetes gramineus*	3	MR	Confirmed
81	13	R	Pine Siskin *Carduelis pinus*	3	MR, AS	Probable
82	13	R	Rock Pigeon *Columba livia*	1	LR	Probable
83	12	R	Hermit Thrush *Catharus guttatus*	2	MR, AS	Confirmed
84	12	R	Townsend's Solitaire *Myadestes townsendi*	2	MR, AS	Probable

# spp	# obs	Relative Abundance[1]	Species	Frequency[2]	Habitat[3]	Breeding Status[4]
85	11	R	Hairy Woodpecker *Picoides villosus*	6	LR, MR, AS	Probable
86	10	R	Savannah Sparrow *Passerculus sandwichensis*	2	LR, MR	Probable
87	9	R	Downy Woodpecker *Picoides pubescens*	5	LR, MR	Confirmed
88	9	R	Rufous Hummingbird *Selasphorus rufus*	3	MR	Migrant
89	9	R	Sage Sparrow *Amphispiza belli*	4	LR, MR	Probable
90	9	R	Wilson's Warbler *Wilsonia pusilla*	4	LR, MR	Migrant
91	8	R	Belted Kingfisher *Ceryle alcyon*	5	LR, MR	Probable
92	8	R	Western Scrub Jay *Aphelocoma californica*	1	MR	Probable
93	7	R	Chukar *Alectoris chukar*	3	LR	Confirmed
94	7	R	Cooper's Hawk *Accipiter cooperi*	4	LR, MR	Probable
95	7	R	Olive-sided Flycatcher *Contopus cooperi*	1	AS	Probable
96	6	R	Barn Swallow *Hirundo rustica*	1	MR	Confirmed
97	6	R	Common Yellowthroat *Geothlypis trichas*	4	LR	Probable
98	6	R	Great Blue Heron *Ardea herodias*	3	LR	Probable
99	6	R	Northern Mockingbird *Mimus polyglottos*	5	LR, MR	Probable
100	6	R	Ruby-crowned Kinglet *Regulus calendula*	2	MR, AS	Probable
101	6	R	Wood Duck *Aix sponsa*	3	LR	Probable
102	5	R	Black-crowned Night Heron *Nycticorax nycticorax*	2	LR, MR	Confirmed
103	5	R	Rose-breasted Grosbeak *Pheucticus ludovicianus*	1	AS	Vagrant
104	4	R	Blue-winged Teal *Anas discors*	2	LR	Unknown
105	4	R	Canyon Wren *Catherpes mexicanus*	1	LR	Confirmed
106	4	R	Chipping Sparrow *Spizella passerine*	2	MR	Probable
107	4	R	Eurasian Collared Dove *Streptopelia decaocto*	2	LR	Probable
108	4	R	Great Horned Owl *Bubo virginianus*	3	LR	Confirmed

# spp	# obs	Relative Abundance[1]	Species	Frequency[2]	Habitat[3]	Breeding Status[4]
109	4	R	Tree Swallow *Tachycineta bicolor*	3	LR, MR	Confirmed
110	3	R	American Avocet *Recurvirostra americana*	1	LR	Unknown
111	3	R	American Dipper *Cinclus mexicanus*	2	MR	Probable
112	3	R	Say's Phoebe *Sayornis saya*	2	LR	Transient
113	3	R	White-breasted Nuthatch *Sitta carolinensis*	1	MR	Probable
114	2	R	Black-necked Stilt *Himantopus mexicanus*	1	LR	Unknown
115	2	R	Caspian Tern *Sterna caspia*	1	LR, MR	Transient
116	2	R	Double-crested Cormorant *Phalacrocorax auritus*	2	LR	Transient
117	2	R	Golden-crowned Kinglet *Regulus satrapa*	1	AS	Transient
118	2	R	Northern Shoveler *Anas clypeata*	1	LR	Unknown
119	2	R	Osprey *Pandion haliaetus*	3	LR	Confirmed
120	2	R	Red-breasted Nuthatch *Sitta canadensis*	1	MR	Transient
121	2	R	Sage Thrasher *Oreoscoptes montanus*	1	LR	Transient
122	1	R	American Bittern *Botaurus lentiginosus*	1	LR	Unknown
123	1	R	Clark's Grebe *Aechmophorus clarkii*	1	LR	Unknown
124	1	R	Gray Flycatcher *Empidonax wrightii*	1	LR	Migrant
125	1	R	Green Heron *Butorides virescens*	1	LR	Migrant
126	1	R	Green-winged Teal *Anas crecca*	2	LR	Confirmed
127	1	R	Lewis's Woodpecker *Melanerpes lewis*	1	MR	Migrant
128	1	R	Magnolia Warbler *Dendroica magnolia*	1	MR	Vagrant
129	1	R	Short-eared Owl *Asio flammeus*	1	LR	Vagrant
130	1	R	Townsend's Warbler *Dendroica townsendi*	1	LR	Migrant
131	1	R	Virginia Rail *Rallus limicola*	1	LR	Unknown
132	1	R	Williamson's Sapsucker *Sphyrapicus thyroideus*	1	AS	Probable

# spp	# obs	Relative Abundance[1]	Species	Frequency[2]	Habitat[3]	Breeding Status[4]
			Incidental and Flyover Detections			
133	-		American Wigeon *Anas americana*	1	LR	Unknown
134	-		Bald Eagle *Haliaeetus leucocephalus*	2	MR	Transient
135	-		California Gull *Larus californicus*	4	LR, MR	Transient
136	-		Cassin's Vireo *Vireo cassinii*	1	LR	Probable
137	-		Common Poorwill *Phalaenoptilus nuttallii*	1	AS	Transient
138	-		Forster's Tern *Sterna forsteri*	2	LR, MR	Confirmed
139	-		Golden Eagle *Aquila chrysaetos*	1	AS	Migrant
140	-		Greater Sage-Grouse *Centrocercus urophasianus*	1	MR	Confirmed
141	-		Northern Harrier *Circus cyaneus*	3	LR	Probable
142	-		Northern Pintail *Anas acuta*	2	MR	Unknown
143	-		Plumbeous Vireo *Vireo plumbeus*	1	LR	Probable
144	-		Ring-billed Gull *Larus delawarensis*	1	MR	Transient
145	-		Snowy Egret *Egretta thula*	1	LR	Unknown
146	-		Sooty Grouse *Dendragapus fuliginosus*	2	MR, AS	Confirmed
147	-		Swainson's Hawk *Buteo swainsoni*	1	LR	Probable
148	-		Swainson's Thrush *Catharus ustulatus*	1	MR	Transient
149	-		Turkey Vulture *Cathartes aura*	10	LR, MR	Transient
150	-		Wilson's Phalarope *Phalaropus tricolor*	1	MR	Transient

[1]Relative abundance ranks based on total number of detections in 2006-2008: >200 = Abundant; 76-200 = Common; 16-75 = Uncommon; and ≤15 = Rare.
[2] Number of transects at which species was detected (total number = 18).
[3]Habitat Codes: LR = Lowland Riparian; MR = Montane Riparian; AS = Aspen
[4]Status Codes: Confirmed = positive breeding evidence found; Probable = no breeding evidence found but based on range maps and behavior observed, this species is likely breeding within the Walker River corridor; Transient = species breeding just outside of the river corridor (e.g. Mono Lake, deep forest); Migrant = species occurs during migration to its breeding/wintering grounds; Vagrant = species found well outside of its normal distribution range; Unknown = unknown breeding status; Game = introduced game bird.

2.2.2.3 Comparison of Historic and Present Bird Communities

In order to assess the status of current bird populations of the Walker River, we searched the literature for past records of bird occurrences for comparison. Table 2.2-7 presents bird species recorded on the river or on Walker Lake prior to 1960 and notes if these historically recorded species were detected in the 2006-2008 surveys.

Table 2.2-7. Species found on written record prior to 1960 within the Walker River Basin.

#	Species	Location	On Recent Surveys?
1	American Coot	Walker Lake	Yes
2	American Kestrel	West Walker River	Yes
3	American Robin	West Walker River	Yes
4	American White Pelican	Walker Lake	Yes
5	American Wigeon	Walker Basin, CA	Yes
6	Ash-throated Flycatcher	West Walker River	Yes
7	Bewick's Wren	Walker Basin, CA, West Walker River	Yes
8	Black-billed Magpie	West Walker River	Yes
9	Black-throated Sparrow	West Walker River, Lower Walker River	Yes
10	Blue Grosbeak	Walker Basin, CA	Yes
11	Brewer's Blackbird	West Walker River, Lower Walker River, Walker Lake	Yes
12	Brown-headed cowbird	East Walker River	Yes
13	Bullock's Oriole	West Walker River, Lower Walker River	Yes
14	Bushtit	Walker Basin, CA, West Walker River	Yes
15	California Condor (questionable record)	Lower Walker River	No
16	California Gull	West Walker River, Walker Lake	Yes
17	California Quail	Walker Basin, CA, East Walker River	Yes
18	Canada Goose	Walker Lake	Yes
19	Canvasback	Walker Basin, CA	No
20	Canyon Towhee	Walker Basin, CA	No
21	Canyon Wren	Walker Basin, CA	Yes
22	Cinnamon Teal	Walker Lake	Yes
23	Cliff Swallow	West Walker River	Yes
24	Common Loon	Walker Lake	No
25	Common Merganser	Walker Lake	Yes
26	Common Nighthawk	East Walker River	Yes
27	Common Poorwill	West Walker River	Yes
28	Common Raven	Walker Lake	Yes
29	Common Yellowthroat	Walker Basin, CA, West Walker River	Yes
30	Cooper's Hawk	Walker Basin, CA	Yes
31	Downy Woodpecker	Walker Basin, CA, West Walker River	Yes
32	Eared Grebe	Walker Lake	No
33	Fox Sparrow	East Walker River	Yes
34	Golden-crowned Sparrow	Walker Basin, CA	No
35	Great Blue Heron	West Walker River	Yes

#	Species	Location	On Recent Surveys?
36	Great Horned Owl	Lower Walker River	Yes
37	Hairy Woodpecker	Lower Walker River	Yes
38	Herring Gull	Walker Lake	No
39	Horned Lark	East Walker River, Lower Walker River	Yes
40	House Finch	Walker Basin, CA, West Walker River	Yes
41	Juniper Titmouse	Walker Basin, CA	No
42	Killdeer	Walker Basin, CA, West Walker River	Yes
43	Lazuli Bunting	West Walker River, Lower Walker River	Yes
44	Lesser Goldfinch	Walker Basin, CA, West Walker River	Yes
45	Lewis's Woodpecker	Walker Basin, CA	Yes
46	Loggerhead Shrike	Walker Lake	No
47	Marsh Wren	West Walker River	No
48	Merlin	Walker Basin, CA	No
49	Mountain Chickadee	West Walker River	Yes
50	Mountain Quail	Walker Basin, CA	No
51	Mourning Dove	West Walker River	Yes
52	Northern Flicker	West Walker River	Yes
53	Northern Harrier	Walker Basin, CA, Mainstem Walker River	Yes
54	Northern Pintail	Walker Lake	Yes
55	Peregrine Falcon	Walker Lake	No
56	Pine siskin	Walker Basin, CA	Yes
57	Pinyon Jay	East Walker River	Yes
58	Prairie Falcon	Walker Lake	No
59	Red-tailed Hawk	Walker Basin, CA	Yes
60	Red-winged Blackbird	West Walker River	Yes
61	Rock Wren	Walker Basin, CA, Walker Lake	Yes
62	Ruddy Duck	Walker Lake	No
63	Savannah Sparrow	Walker Basin, CA, West Walker River	Yes
64	Say's Phoebe	Walker Lake, East Walker River	Yes
65	Sharp-shinned Hawk	Mainstem Walker River	No
66	Snowy Plover	Walker Lake	No
67	Solitary Sandpiper	Walker Lake	No
68	Song Sparrow	Walker Basin, CA	Yes
69	Sora	Lower Walker River	No
70	Spotted Towhee	Walker Basin, CA, West Walker River	Yes
71	Steller's Jay	Walker Basin, CA	Yes
72	Swainson's Hawk	Mainstem Walker River	Yes
73	Tundra Swan	Walker Lake	No
74	Turkey Vulture	Mainstem Walker River, Walker Lake	Yes
75	Varied Thrush	Walker Basin, CA	No
76	Virginia Rail	Walker Basin, CA	Yes
77	Warbling Vireo	Lower Walker River	Yes
78	Western Bluebird	Lower Walker River	Yes
79	Western Grebe	Walker Lake	No
80	Western Meadowlark	Walker Basin, CA, West Walker River	Yes
81	Western Scrub Jay	Walker Basin, CA	Yes
82	White-crowned Sparrow	Walker Basin, CA	Yes
83	White-headed Woodpecker	Walker Basin, CA	No
84	Willow Flycatcher	West Walker River	Yes

#	Species	Location	On Recent Surveys?
85	Wrentit	Walker Basin, CA	No
86	Yellow Warbler	West Walker River , Lower Walker River	Yes
87	Yellow-breasted Chat	West Walker River	Yes

References: Alcorn, 1988; Gabrielson, 1949; Henshaw, 1876; Linsdale, 1951, 1936; MVZ, 2008.

Some bird species present on this list were not found on the 2006-2008 surveys. However, several of these missing species may not have been detected due to differences in the timing and location of the past and present surveys. For example, the 2006-2008 surveys did not include Walker Lake, thus lake dwelling birds such as loons, grebes, and some ducks were not detected. Likewise, some of the higher elevation tributaries in California were also not surveyed because the tributaries were outside of the primary Walker River assessment area. The present surveys were also constrained to the breeding summer months and hence did not record overwintering species such as the rough-legged hawk or the tundra swan. Nocturnal species such as owls that remain quiet during the day may also have been more difficult to detect on the morning point count and area search surveys. Thus, the absence of birds in the aforementioned categories from the 2006-2008 breeding bird surveys may or may not show a true declining population trend.

However, a few key bird species that occur on the historical list, and which should have been detected on the current bird surveys include marsh-dwelling birds such as the sora and marsh wren. Marsh complexes are rare on the Walker River today (Appendix K), and the current bird survey data reflect this, with only one Virginia rail, another marsh-dwelling bird, detected on the lower river in 3 seasons of surveys. Although historic abundance rank data were not available, the presence of soras and marsh wrens on the river in the 1930s (Linsdale, 1936) suggests that wetland habitats were once more common along the river.

Additional species of note that appear on the historical list, but which were not observed on the current surveys include the snowy plover and the western burrowing owl. Snowy plovers were observed in the 1930s (Linsdale, 1936), and were found at the south end of Walker Lake in 1980, a wet water year (Herman et al., 1988). Recent surveys for snowy plovers completed by GBBO at Walker Lake in 2007, a drought year, found no snowy plovers in this area (Ballard, 2007, *personal communication.*). Likewise, western burrowing owls, which were observed in Wilson Canyon in 1978, were not found on the LR-Wilson point-count transect that was run in 2006-2008. Both the snowy plover and the western burrowing owl have experienced population declines throughout their ranges and are considered conservation priority species[51] in Nevada. Thus, the absence of these two species, along with the previously mentioned marsh wren and sora, are probably not artifacts of survey bias, but represent real regional population declines that likely reflect land use and habitat changes over time.

[51] Species deemed vulnerable to population decline and prioritized for management action.

A few introduced species were found to be on the river today but were not noted in the historical list. These include the European starling, first introduced to the eastern U.S. in 1890 and found in Nevada in 1947 (Weitzel, 1988), the house sparrow, and the Eurasian collared dove. All of these species are commensals[52] with human development. The European starling and house sparrow are of concern to conservationists because both of these species may compete with native birds for nesting cavities. However, Koenig (2003) suggests, at least in the case of the European starling, that factors beyond European starling spread and cavity competition alone may be responsible for native bird population declines in North America. The Eurasian collared dove was not detected until the 2008 surveys, suggesting that this is a very recently established bird species. The Eurasian collared dove was recorded on the LR-Mason 2 and LR-Schurz transects on points that were close to human habitation. At this time, the long-term effects of the Eurasian collared dove's presence on native bird populations are unknown. Future monitoring studies will provide more information as this species expands its range.

Native species that were common on the recent surveys, but which were not recorded historically include the song sparrow, black-headed grosbeak, western wood-pewee, house wren, and yellow-headed blackbird. The first three species are associated with riparian shrub and woodlands, while the last two species are generally associated with more altered habitats. Many more species were recorded in the 2006-2008 surveys, perhaps because these surveys were conducted in a more systematic manner than the previously recorded observations.

Over 70% of the species listed in Table 2.2-7 were also detected on the recent surveys. Thus, except for those species highlighted above, the overall bird communities of the Walker River appear not to have changed much. Overall, the preliminary results of the breeding bird inventory of the Walker River are encouraging. As expected for a system that has been heavily modified, the most abundant and most widely distributed species include some disturbance-associated species, such as brown-headed cowbird and mourning dove, but they also include species that are riparian obligates in the Great Basin, such as song sparrow and yellow warbler, suggesting the presence of a riparian corridor that is still largely intact. In comparison, yellow warblers are underrepresented on the Truckee River due to wide-spread loss of their required breeding habitat, shrub willows and mid-story riparian trees (Ammon, 2002).

Conservation of riparian systems in the arid West is critically important for preserving the native bird populations. Although riparian habitats cover less than 1% of the western U.S., roughly 2/3-3/4 of the regional, non-game landbird species are associated with riparian areas during breeding (reviewed in Bock et al., 1992). Riparian areas also provide birds with important wintering grounds, migration stopover sites, and dispersal corridors (RHJV, 2004).

In desert riparian areas, trees provide important canopy cover, nesting, perching and foraging habitat for birds, and a comparison study of various desert riparian vegetation associations found cottonwood-willow forests to support the highest diversity of bird

[52] A close symbiotic relationship in which one organism benefits while the host organism is unaffected.

species throughout the year (England et al., 1984). Breeding bird data from tributaries to the lower Owens River showed nest density to be greater in structurally complex habitats populated by plants such as water birch (*Betula occidentalis*), black oak (*Quercus kelloggii*), big sagebrush (*Artemisia tridentata*), willows (*Salix exigua*, *S. laevigata*, *S. lasiolepis* or *S. lucida*), black cottonwood (*Populus trichocarpa*) and Jeffrey pine (*Pinus jeffreyi*) (Heath and Ballard, 2003). Bird species do not usually favor single-canopy, monotypic stands of vegetation such as tamarisk (*Tamarix* spp.) or arrowweed (*Pluchea* spp.) (Meents et al., 1984; Ohmart, 1994).

Tamarisk invasion is a symptom of a degraded riparian corridor, and on Nevada's western rivers, large stands of tamarisk are common below dams on low-gradient stretches where the natural flow regime has been greatly altered. Cattle grazing and land conversion for agriculture have also changed the native riparian vegetation community structure. Ohmart (1994) states that over the past century, likely greater than 95% of the riparian habitats in the West have been altered, degraded, or destroyed. This destruction of riparian habitat is the most important cause of the decline of landbird species in the western U.S. (DeSante and George, 1994).

Some of the bird species found on the Walker River are currently experiencing population declines over their known distribution range and thus are considered conservation priority species. These species are listed in Table 2.2-8. These conservation priority species were identified based on local and regional bird conservation initiatives. These lists are designed to be used for conservation and restoration planning with the goal of maintaining or increasing local populations of conservation species.

Table 2.2-8. List of conservation priority species that have been detected along the Walker River in the springs and summers of 2006, 2007, and 2008. Species are listed in alphabetical order.

Species	Conservation Status*
American Avocet	NV-PIF: priority
American White Pelican	NV-PIF: priority IW Waterbird Conservation Plan: high concern National Colonial Waterbird Conservation Plan: moderate concern
Ash-throated Flycatcher	NV-PIF: priority
Bald Eagle	Continental PIF: stewardship species
Bank Swallow	NV-PIF: priority
Black-crowned Night-Heron	IW Waterbird Conservation Plan: moderate concern National Colonial Waterbird Conservation Plan: moderate concern
Black-throated Sparrow	Continental PIF: stewardship species
Blue Grosbeak	NV-PIF: priority
Brewer's Sparrow	Continental PIF: watch list species
California Gull	IW Waterbird Conservation Plan: moderate concern National Colonial Waterbird Conservation Plan: moderate concern
Cassin's Finch	Continental PIF: stewardship species
Clark's Grebe	NV-PIF: priority

Species	Conservation Status*
	National Colonial Waterbird Conservation Plan: low concern
Clark's Nutcracker	Continental PIF: stewardship species
Cooper's Hawk	NV-PIF: priority
Dusky Flycatcher	Continental PIF: stewardship species
Fox Sparrow	Continental PIF: stewardship species
Gray Flycatcher	NV-PIF: priority Continental PIF: stewardship species
Great Blue Heron	IW Waterbird Conservation Plan: moderate concern
Green-tailed Towhee	Continental PIF: stewardship species
Lewis's Woodpecker	Continental PIF: watch list species NV-PIF: priority
MacGillivray's Warbler	NV-PIF: priority
Mountain Bluebird	Continental PIF: stewardship species
Olive-sided Flycatcher	Continental PIF: watch list species NV-PIF: priority
Orange-crowned Warbler	NV-PIF: priority
Pinyon Jay	Continental PIF: watch list species NV-PIF: priority
Red-breasted Sapsucker	Continental PIF: stewardship species
Rufous Hummingbird	Continental PIF: watch list species
Sage Sparrow	Continental PIF: stewardship species NV-PIF: priority
Sage Thrasher	Continental PIF: stewardship species NV-PIF: priority
Short-eared Owl	NV-PIF: priority
Snowy Egret	IW Waterbird Conservation Plan: high concern National Colonial Waterbird Conservation Plan: high concern
Steller's Jay	Continental PIF: stewardship species
Vesper Sparrow	NV-PIF: priority
Western Bluebird	NV-PIF: priority
Western Scrub Jay	Continental PIF: stewardship species
White-faced Ibis	IW Waterbird Conservation Plan: low concern National Colonial Waterbird Conservation Plan: high concern NV-PIF: priority
White-throated Swift	Continental PIF: watch list species
Williamson’s Sapsucker	Continental PIF: stewardship species
Willow Flycatcher	Continental PIF: watch list species NV-PIF: priority
Wilson’s Warbler	NV-PIF: priority
Yellow-breasted Chat	NV-PIF: priority
Yellow-headed Blackbird	Continental PIF: stewardship species

* NV-PIF = Nevada Bird Conservation Plan (Neel 1999);
Continental PIF = North American Landbird Conservation Plan (Rich et al. 2004):
Watch List species: highest conservation concern
Stewardship species: moderate conservation concern;
IW Waterbird Conservation Plan = Intermountain West Waterbird Conservation Plan (Ivey and Herziger 2005);
National Colonial Waterbird Conservation Plan (Kushlan et al. 2002).

Species detected as incidental and flyover species on the 2006-2008 surveys that are also considered species of conservation priority in Nevada, but which do not appear in the above table include the bald eagle, California gull, Forster's tern, greater sage-grouse, snowy egret, sooty grouse, Swainson's hawk, and Wilson's phalarope. Reversing the declining trend of these conservation priority species, and other riparian bird species as well, will only be achieved through the preservation and restoration of the habitats that these birds require.

2.2.2.4 Management and Restoration Recommendations

Some river corridor management recommendations that will benefit riparian health and hence, native riparian bird populations, on the Walker River are listed below.

1) *Preserve/restore the riparian corridor.*
   Because riparian habitats are so important to many species of landbirds, preservation and restoration of native tree, shrub, forb, and grass communities will provide desirable cover, food, and nesting structures for many breeding bird populations (Lynn et al., 1988; Ohmart, 1994). Because larger, patches of riparian habitat greater than 0.5 ha in size are more beneficial to breeding riparian birds (Ohmart, 1994), larger, intact patches of riparian habitat should be prioritized for preservation/restoration. In addition, oxbow ponds and wet meadow complexes that may have diminished over time as natural flood events and river meandering were restricted by various land uses and water management, could be restored to recover the wetland habitat component in the Walker River riparian corridor. Wetland recovery would not only benefit diminishing populations of wetland bird species, but also a suite of other plants and organisms that are associated with this habitat type. Riparian forest and wetland complex succession can be sustained with a return to the natural flow regime, which is essential to the recovery of the native riparian vegetation communities on the Walker River.

2) *Consider the quality of the habitat patch and the habitat patch mosaic.*
   The quality of the riparian greenbelt and its connection to more xeric upland vegetation communities along the corridor can also affect riparian bird population growth or decline. Within the greener riparian belt, greater amounts of overlapping vertical canopy layers in a riparian plant community correlates with higher densities of most bird species (Ohmart, 1994). In addition, taller forbs and graminoids growing under shrubs and taller plants provide more cover for birds that are nesting closer to the ground (Larison et al., 2001). Adjacent to the riparian zone, upland areas provide important sources of cover, shade and food for birds. Dense shrubs, such as quailbush (*Atriplex lentiformis*) shade the ground and prevent drying of the litter, which in turn supports insects for foraging birds (Ohmart, 1994). Cowbird parasitism, which reduces native bird survivorship, is more subdued in habitats with healthy, herbaceous ground cover (Heath and Ballard, 2005) and along riparian belts buffered by vegetated shrub uplands. In contrast, agricultural fields and areas with sparse ground cover that are adjacent to

riparian areas may attract cowbirds and nest predators that could diminish the reproductive success of riparian birds (Heath and Ballard, 2005). Along the Walker River, conservation and restoration of healthy, multi-canopied riparian habitat patches that are connected to adjacent vegetated upland shrub areas will enhance not only riparian vegetation communities, but also riparian bird species' reproduction rates and survivorship.

3) *Restrict human development and manage livestock grazing in the riparian corridor.*
   To reduce predation and parasitism of native riparian bird nests, additional human developments within or adjacent to the riparian corridor should be avoided (Heath and Ballard, 2005), while existing buildings, grazing and agricultural use areas should be kept > 1 km away from the riparian zone (RHJV, 2004). Grazing domestic livestock can be greatly detrimental to the riparian corridor when managed improperly. Cattle exclusion in some areas, and wise grazing management in the riparian zone will allow for diminished grazing, trampling, and erosion impacts along the Walker River corridor, so that riparian recovery can take place, while likely also benefiting livestock health (GAO, 1988, in Ohmart, 1994).

Because birds are an important part of the riverine ecosystem, the health of the bird communities reflects the health of the river. This section of the report focuses on the conservation of the riparian landbirds of the Walker River, because "by managing for a diversity of birds, we will also protect many other elements of biodiversity and the natural processes that are an integral part of the riparian ecosystem" (RHJV, 2004). Bird surveys are an important means of tracking the overall changes to the riparian condition over time. The Walker River 2006 -2008 surveys, along with the compiled species table of birds seen on the river in the previous century, provide a baseline species list that may be used for comparison as continued bird monitoring along the river tracks the ongoing changes in the riparian corridor that are a result of current and future conservation / management actions.

2.2.3 Macroinvertebrates

Benthic macroinvertebrates are commonly used in analyses of river quality as they are often good indicators of environmental health. Macroinvertebrates can provide information about past and present condition in the river and when invertebrate data is combined with current chemical and physical data, the environmental quality can be assessed. Because they are relatively easy to collect in the field and will respond to changes in stream habitat, macroinvertebrates may be used in rapid assessments for stream quality. Samples were collected from one site on the West Walker River for the purpose of assessing the water quality in stream segment WW5. The results of the surveys are presented here. Additional macroinvertebrate studies on the Walker River were completed by the Desert Research Institute, and the results from this study will be completed in the spring of 2009. These additional results will be incorporated as deemed appropriate in future restoration planning.

2.2.3.1 Methods

Macroinvertebrate samples were taken from 10 sites (Figure 2.2-10) on the West Walker River near Topaz Reservoir. Of those ten sites, three were used in the stream macroinvertebrate analysis, including (downstream to upstream): Site #4) Below the Topaz outflow confluence; Site #5) At the confluence where outflow water from Topaz returns to the West Walker; and Site #10) Above the diversion to Topaz Reservoir (Figure 2.2-11). These three sites were selected for analysis because they represent a gradient of decreasing substrate size. Also, sample site #10, the most upstream site, contains types of organisms that could be recruited downstream to diversity-poor sites such as sample site #4.

Prior to collection in the field, bottom stream substrates were visually described. Macroinvertebrate collections were then made with a Hess Sampler (0.086 m^2 sample area, 500µm mesh collecting net, by Wildlife Supply Company). The area within the sampler was vigorously disturbed to separate the invertebrates from the substrate, and then the invertebrates were washed into the collection cup (Figure 2.2-12). At five of the Hess sampler locations (#5, #6, #7, #8 and #9) artificial substrate tubs were inserted. The tubs consisted of either 2,800 cm^3 or 3,744 cm^3 plastic containers in which the bottoms were cut out and a plastic mesh was installed with glue. The mesh allowed for water to pass through the tub, connecting it to the hyporheic[53] flows. The top of the tub was placed at ground level and then filled in with surrounding substrate. The tubs were left for a period of at least four weeks to allow for colonization and then collected. Substrate tub contents were analyzed for species list purposes only.

BIAS

Every sampling method has its bias. The design of the Hess sampler limits the depth and velocity at which the sampler can be used. Any depth greater than 40 cm allows the water to flow over the top of the sampler, leading to a loss of organisms. The placement of the sampler may cause invertebrates on the surface to be washed out. The Hess sampler also fails to collect invertebrates in the hyporheic zone since this sampling method does not reach the depths of the hyporheic zone.

[53] A region beneath and lateral to a stream bed, where surface water and shallow groundwater mixing occur.

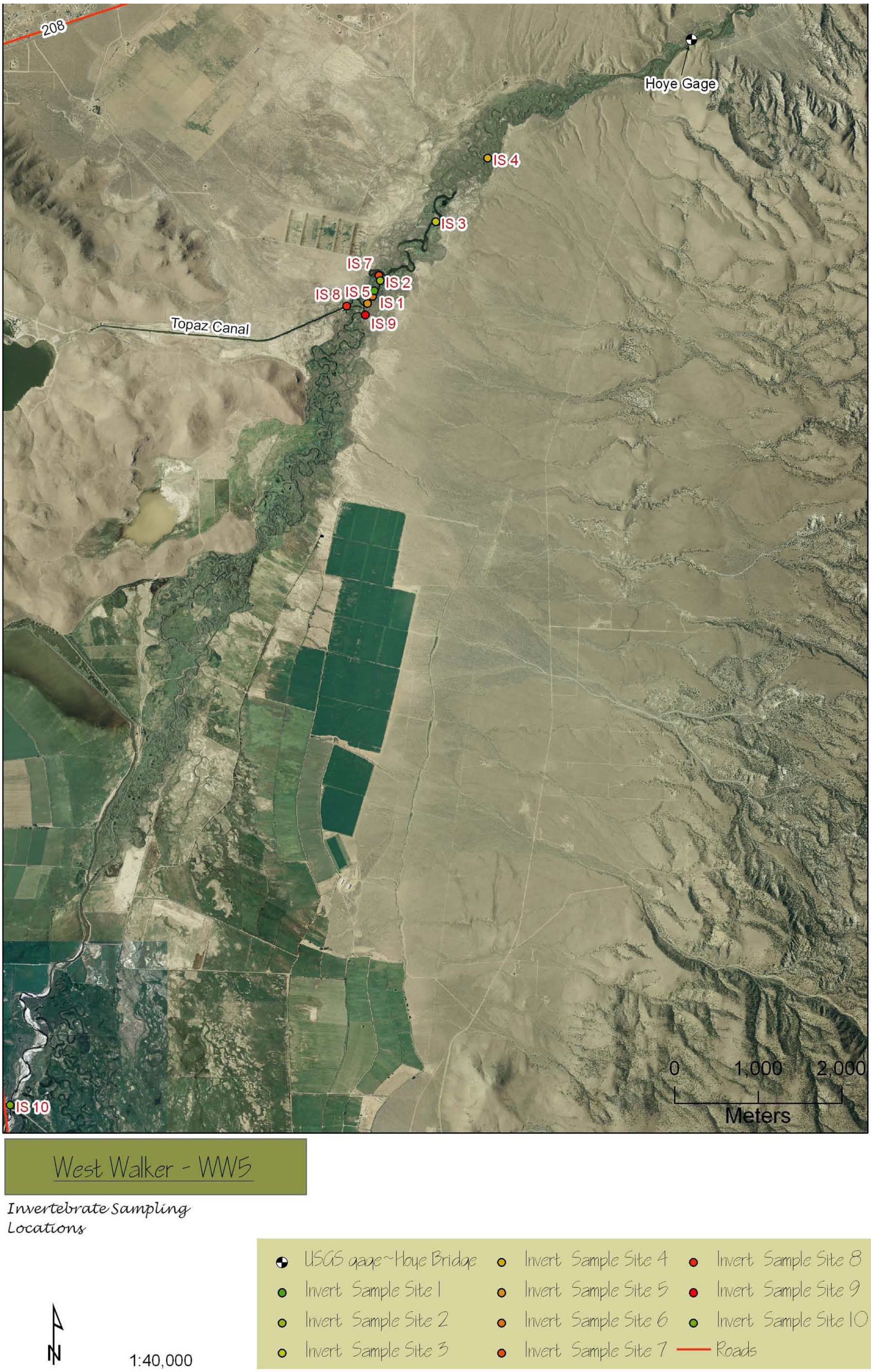

Figure 2.2-10. Invertebrate sampling locations on the West Walker near Topaz Reservoir.

However, even with its bias, the Hess sampler is a common macroinvertebrate sampling method in many macroinvertebrate surveys. The substrate samplers were used to test the utility of the Hess sampler. Substrate samplers were placed very near to the location of each Hess sample location. Little difference in taxa composition was found between the two methods. Only a few different taxon were obtained by the substrate samplers that were missed by the Hess sampler (Refer to the species list in Appendix M), thus the Hess samples still give a good representation of the macroinvertebrate community.

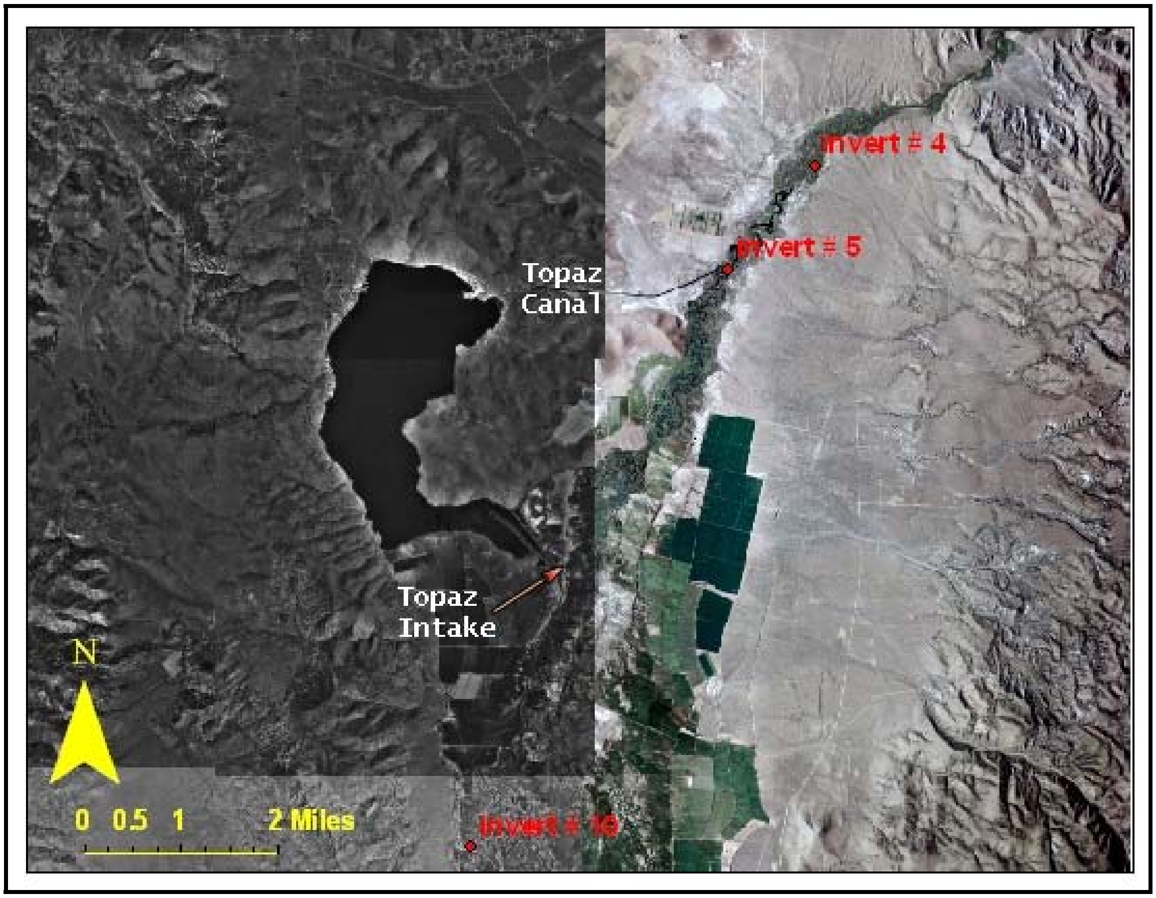

Figure 2.2-11. Map of three sampling locations used for analysis.

Abiotic factors including velocity, water depth and substrate were measured in the field. All macroinvertebrates that were collected either by the Hess Sampler or by artificial substrate sampler were first preserved in 70% ethanol and then sorted in the laboratory (Figure 2.2-12). Insect orders were identified by OBEC, and further identification of the collected samples down to family or genus/species level was performed by entomologist Dr. Andy Hicks, at the University of Colorado. The full species list of sampled invertebrates can be found in Appendix M.

Figure 2.2-12. Depiction of Hess sampler being used at invertebrate site 5.

After samples were identified by OBEC, Level I analysis, Ephemeroptera, Plecoptera, Trichoptera (EPT) analysis, community structure analysis and total abundance and taxa analysis were performed.

Level I Analysis – Samples were separated down to order and then counted to assess the total number of each order. A grand total was calculated and the percent of the total, which each order represents, was assessed. The sample was then separated into sensitive orders (EPT) and tolerant orders (Oligochaeta, Diptera, and Gastropoda). An adequate sample was one in which each of the three EPT orders were represented and the tolerant orders make up less than 50% of the total sample.

EPT Analysis - Analysis of macroinvertebrate orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) was performed as a simple enumeration. For each sample, the total number of organisms was counted and then the total number or EPT organisms were counted. The EPT was calculated as the percent of total that the EPT organisms represented.

Community Structure – Analysis of community structure involved breaking down samples into order and then calculating the percent which each order represented. A balanced community was one in which no one order made up more than 50% of the total organisms.

Total Abundance – A count of the total number of organisms was made and the three sample sites were compared against one another. Total abundance was used to give an illustration of the productivity of the site.

Total Taxa – Samples were separated down to family level based on difference of appearance within each order and the total number of families was counted in each sample.

2.2.3.2 Results

SUBSTRATE

Differences were observed between the three sample sites. Site #4 contained no gravels and the substrate consisted entirely of coarse sand. Site #5's substrate consisted of smaller gravels (size 2-45 mm) in a medium to coarse sand matrix. At Site #10, the stream substrate consisted of larger gravels (size ≤ 64 mm) in a coarse sand matrix.

Not surprisingly, the macroinvertebrate communities at each of the sample sites also differed, likely in response to the variable bottom substrates.

LEVEL I ANALYSIS

For this study, a Level I analysis is presented to assess the general condition of the West Walker River. Under level I analysis, only sample #10 represented an adequate community since all three sensitive orders were present and none of the orders made up more than 50% of the total (Figure 2.2-18). Samples #4 and #5 are considered limited and not adequate due to the lack of Plecoptera taxa. Sample #4 is additionally limited due to the dominance of sediment-tolerant midge larvae (Figure 2.2-16).

EPT ANALYSIS

Differences in EPT were found between each of the three sites. Sample site #5 had EPT making up well over 50% of the total sample (Figure 2.2-13). However, Sample site #5 was unbalanced in terms of community structure with Ephemeroptera making up over 50% of the total organisms. Sample site #10 represented a well balanced community with all three EPT orders represented and no one order making up more than 50% of the total (Figure 2.2-18). Sample site #10 also had the most taxa abundance with 19 different taxa (Figure 2.2-14).

Figure 2.2-13. Bar graph representing the percent of the total sample which the EPT orders represent.

Figure 2.2-14. Bar graph representing total number of families for each sampling site.

Figure 2.2-15. Bar graph representing total number of organisms for each sampling site.

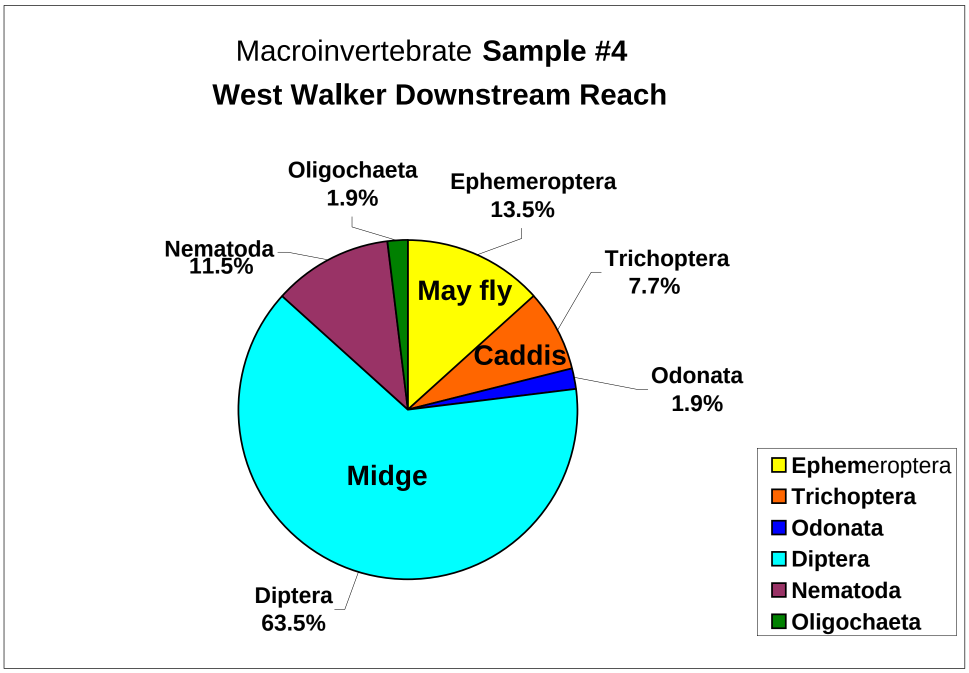

Figure 2.2-16. Pie graph representing the macroinvertebrates collected at Site 4.

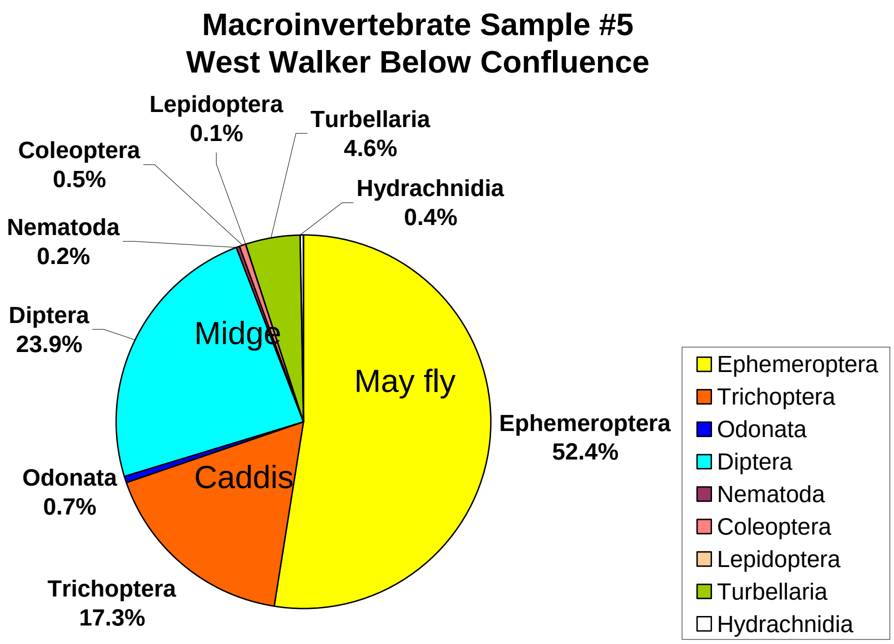

Figure 2.2-17. Pie graph representing the macroinvertebrates collected at Site 5 – Confluence.

Figure 2.2-18. Pie graph representing the macroinvertebrates collected at Site 10 - Above the diversion to Topaz Lake.

2.2.3.3 Discussion

Level I analysis of the three samples illustrates how unbalanced sample #4 and sample #5 are versus sample #10 in community composition. In general, taxa richness (the number of different groups present) decreases with decreasing stream conditions. Sample #4 (Figure 2.2-14) has the least number of taxa, indicating that the water in this stretch of stream is more perturbed than at sample sites 5 and 10. Diptera is the dominant order at site #4, indicating that the particular substrate habitat found there is not adequate to support a very diverse and balanced macroinvertebrate community and thus is not adequate to support a healthy population of predatory fish. Most of the Diptera species are quite tolerant of sandy substrates since they are burrowing organisms.

However, in all three sample sites, Tipulidae, or crane flies, which also belong to Diptera, were found. Although these burrowers are tolerant of sedimented streams, they are still an indicator of good water quality. Thus differences in community composition between the three samples are more likely due to differences in the substrate type rather than a degradation of water quality.

Benthic metrics, or measurements of diversity and abundance of collected macroinvertebrate samples at various taxa levels, are often used in rapid stream bioassessments using macroinvertebrates in the scientific literature. Biotic indices are often used to measure stream habitat quality, but many of these indices have been developed for specific regions. This report focuses on the types of macroinvertebrates that were found in the stream surveys, and compares the data to general trends that benthic metrics follow in response to stream habitat disturbance (Table 2.2-9).

Table 2.2-9. Some benthic metrics and the predicted direction of metric response to increasing perturbation (compiled from Barbour et al., 1999) and a comparison of macroinvertebrate response at Site 4 (well below the outflow) relative to Site 10 (above the Topaz diversion) on the West Walker River.

Category	Metric	Definition	Predicted Response	Site 4 Response Relative to Site 10
Richness Measures	Total No. Taxa	Measures the overall variety of the macroinvertebrate assemblage	Decrease	Decrease
	No. EPT Taxa	Number of taxa in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)	Decrease	Decrease
	No. Plecoptera Taxa	Number of stonefly taxa (usually genus or	Decrease	Decrease

Category	Metric	Definition	Predicted Response	Site 4 Response Relative to Site 10
		species level)		
Composition Measures	% EPT	Percent of the composite of mayfly, stonefly, and caddisfly larvae	Decrease	Decrease
	% Ephemeroptera	Percent of mayfly nymphs	Decrease	Decrease
	% Plecoptera	Percent of stonefly nymphs	Decrease	Decrease
	% Trichoptera	Percent of caddisfly larvae	Decrease	Decrease
	% Diptera	Percent of all “true” fly larvae	Increase	Increase
	% Other Diptera and Non-insects	Composite of those organisms generally considered to be tolerant to a wide range of environmental conditions	Increase	Increase
Tolerance/Intolerance Measures	No. of Intolerant Taxa	Taxa richness of those organisms considered to be sensitive to perturbation	Decrease	Decrease
	% Tolerant Organisms	Percent of macrobenthos considered to be tolerant of various types of perturbation	Increase	Increase
	% Dominant Taxon	Measures the dominance of the single most abundant taxon. Can be calculated as dominant 2,3,4, or 5 taxa	Increase	Increase
	% Sediment Tolerant Organisms	Percent of infaunal macrobenthos tolerant of perturbation	Increase	Increase

Compared to Site #10, Site #4 benthic metrics follow trends towards a more degraded river. However, because a higher diversity of inverts exist at Site #10, these can recruit downstream to Site #4 if the river channel is restored, sediment inputs are controlled, and stream substrates are enhanced (e.g. larger rocks are introduced) for macroinvertebrates and fish.

3 RESTORATION PLANNING AND MANAGEMENT TOOLS

The completion of a basin-scale assessment of baseline physical and biological components provides a dataset that forms the basis of informed restoration planning, successful implementation of restoration design, and meaningful monitoring of completed projects. Each step of the planning, designing, implementing, and monitoring of restoration activities in the Basin should consider the results of the assessment.

Some important conclusions drawn from the baseline data collection are:

■ In general, the Basin is in physically and biologically intact, particularly relative to other river systems in the region. This statement excludes the Lower Walker River below the town of Schurz where the channel has incised dramatically. This area warrants special consideration, and is receiving that consideration through parallel research being conducted by UNR, DRI, and other partners of the USFWS. Elsewhere in the Basin, there is an opportunity to conserve and protect existing environmental resources before they become irretrievably degraded. These protection measures can be passive to a large extent and may include prescribed grazing plans such as fencing the riparian corridor to allow for the regeneration of riparian vegetation.

■ Despite the favorable conditions for many passive restoration measures, some more active steps may need to be implemented due to the following factors:

> -Hydrologic alteration in the Basin has resulted in unnaturally decreased flows, with the trend increasing further downstream in the Basin.
>
> -There is a historic trend of channel narrowing, and decreased active channel area throughout the Basin. This is a problem of aggradation due to some combination of flow reduction and increased sediment load. The consequences can affect the entire river system. Channel narrowing can lead to simplification of channel hydraulics and reduce instream habitat. If narrowing is accompandied by increase in mean bed elevation, then overbank flood frequency may be increased. If narrowing is accompanied by bed incision, then overbank flooding can be decreased, and water table levels can drop. Channel simplification can lead to decreased cottonwood recruitment area which will eventually lead to a declining riparian forest. This forest currently supports a rich diversity of bird species, which would be negatively impacted by a decrease in riparian habitat.
>
> - In most observed areas of the Basin, channel incision is localized, and not of an alarming magnitude. However, many areas display a channel/floodplain connection that is less than desirable. In the absence of extreme channel incision or extensive levying of streambanks, this disconnection may be the result of decreased peak flows. A persistence of this disconnection will eventually lead to elimination of wetland habitats and their associated species, decline in riparian vegetation and a shift toward xeric communities, and a generally less dynamic system.

In order to systematically address these issues, two tools are developed here to assist in the planning of restoration in the Basin. The first is an ecosystem flow assessment intended to provide a means to design flow regimes that can be applied to enhancing dynamic geomorphic processes, and ecosystem functions. A more natural hydrology will be fundamental to begin correcting the problems stated above. The second tool presented here is a rating and ranking system designed to prioritize restoration activities in the Basin. This system will provide a way for restoration managers and practitioners to identify locations for effective restoration.

3.1 Ecosystem Flow Assessment Framework

Developing a tool for analyzing ecosystem flows is dependent on the previous presentation of hydrology, alteration to hydrology, the geomorphology of the Basin and historic changes, and the current and historic biology of the Basin. Recommendations for flow regimes will be placed in the context of those analyses. The following section presents the development of an analysis for an ecosystem flow tool.

3.1.1 The Functional Importance of Natural Flow Variability

In every riverine ecosystem, the stream flow regimen is a major element of ecological process. Ecologists have demonstrated that alteration of natural processes, such as the natural flow regimen, can have profound effects on ecosystem sustainability and can sometimes push systems to new states that defy restoration attempts (Rapport et al., 1998; Cronk, 1995; Mahoney and Rood, 1998).

Of the three key defining elements of ecological systems, *composition*, *structure*, and *process*, stream flows contribute all three of them. The stream and associated habitat types, as well as variable abiotic conditions created by the stream, contribute to the composition. Stream flows provide the primary structure that supports all aquatic organisms and many terrestrial organisms. Stream flows contribute processes in the form of (1) sediment transport, scour and deposition; (2) channel and floodplain forming processes; (3) disturbance and dynamics; (4) riparian aquifer recharge; (5) seed distribution, germination, and growth; (6) organism migration and colonization; and (7) genetic dispersal and mixing. Stream flows are the keystone of all riverine ecosystems and significant alteration of the flow regimen will result in dramatic changes to the ecosystem.

Development of ecosystem flows for the Walker River were based on the assumption that organisms living in the riverine environment have adapted to and depend on a flow pattern that varies across seasons and across years. For example, some fish species require high flows that will rework and clean gravels to make gravel beds suitable for spawning and to stimulate the fish to spawn. Cottonwood trees and willows need high flows to scour existing vegetation to reduce competition and recharge riparian aquifers to supply water for survival and growth. Declining flows, or declining river stage, encourage deep root growth and support plant survival as roots grow down to the capillary-rise zone of the seasonally low water table. Late summer/early fall low flows are needed to supply water to maintain seedlings and prevent drought stress in mature trees (as well as create conditions to support diverse invertebrate and fish communities). Flow variability across years is also important. For example, high flows during one year dynamically alter the riverine environment creating suitable geomorphic surfaces for riparian forest regeneration in following years (Rood and Gourley, 1996; Everitt, 1968).

3.1.2 Natural Hydrologic Variability of the Walker River

The natural flow pattern of the Walker River is dominated by spring snowmelt peaks of low to moderate relative magnitude that typically occur in May or early June. Mean monthly discharges on the Walker River are normally highest during the months of April, May, and June and lowest during August, September, and October. Intense rain and/or rain-on-snow events can also produce occasional high magnitude, short duration peaks at various times throughout the year, although they rarely occur between the months of July and September.

3.1.3 Relationship of Walker River Native Species to Natural Flow Variability

In recent evolutionary history, native riverine species were sustained by natural flow regimens that varied with seasonal and annual weather fluctuations. In the case of the Walker River, this natural variation ranged over 1,000s of cfs on a relatively regular basis between heavy snowmelt events and drought cycles. Native biota, such as fish, invertebrates, amphibians, and riparian plants have therefore presumably adapted to such variation in flow regimes, at least since the past ice age. In fact, important processes responsible for sustaining native species, for example the process of recruiting and sustaining riparian vegetation, depend on the river’s natural flow variability (Scott et al., 1997; Mahoney and Rood, 1993). Moreover, recent evidence suggests that artificially constant flow regimes may sometimes favor exotic species, such as salt cedar (*Tamarix ramossisima*), over native species (Shafroth et al., 2002). Thus, to sustain and perpetuate the native aquatic and riparian ecosystem, managed flow regimes would ideally mimic natural variation in stream flow both seasonally and across years.

3.1.4 Human Alterations to Natural Flow Variability in the Walker River Basin

Water use in the Basin has been ongoing for well over 100 years, since the first European settlers moved into the region in order to develop farms and cattle ranches. The record of these uses is well documented by Horton (1996). Details of Horton’s historical and current account of water use in the Basin are presented in Table 1.1-2.

In addition to the specific events outlined in Table 1.1-2, many general trends in water use were prevalent that altered the natural hydrologic regime. During the late 19th and early 20th century, irrigated lands increased dramatically with the aid of such legislation as the Homestead Act of 1862. Inspection of Table 1.1-2 indicates that water shortages have occurred in the Basin throughout its European settlement, indicating over-allocation of resources, coupled with frequent low-water years. A current estimate of total acreage with water rights is presented in Table 3.1-1. Table 3.1-2 presents a current estimate of a water budget for each major agricultural valley in the Basin. Inspection of these tables, particularly Table 3.1-2, indicates that water in the Basin is currently completey allocated.

Table 3.1-1. Surface water-right acreage in the Basin (Horton, 1996).

Location	Acreage
Bridgeport Valley	28,069
Antelope Valley and upstream	18,765
Mason Valley	58,648
Tribal Lands	2,100

Table 3.1-2. Estimated water budgets for major agricultural valleys in the Basin (Horton, 1996).

Location	Surface Water Inflow (acre-ft)	Surface Water Outflow (acre-ft)	Flow Consumed (acre-ft)	% of Inflow Consumed
Bridgeport Valley	132,000	107,000	25,000	9.7
Antelope Valley	195,000	180,000	15,000	5.8
Smith Valley	189,000	133,000	56,000	21.7
Mason Valley	238,000	128,000	110,000	42.6
Tribal Lands	128,000	76,000	52,000	20.2

3.1.5 Water Diversion

The earliest sources of anthropogenic alterations to the hydrologic regime were in the form of agricultural diversions. Federal court records note the diversion of the Walker River as early as 1860 (Table 1.1-2). The majority of this work occurred in Mason Valley with construction of 13 ditches recorded between 1861 and 1865 including the Spragg and McLeod ditches which are still in operation. Modern diversions are still most numerous in Mason Valley (Table 3.1-3).

Table 3.1-3. Principal diversions in the Basin (Horton, 1996)

Source of Diversion	Area of Use	Name
West Walker	Smith Valley	Saroni
West Walker	Smith Valley	Plymouth
West Walker	Smith Valley	Colony
West Walker	Smith Valley	Simpson

Source of Diversion	Area of Use	Name
West Walker	Smith Valley	West Walker
West Walker	Smith Valley	Gage Peterson
West Walker	Smith Valley	Fullstone
West Walker	Mason Valley	Tunnel
West Walker	Mason Valley	D and GW
West Walker	Mason Valley	Lee Sanders
West Walker	Mason Valley	West Side
West Walker	Mason Valley	Kelly Alkali
East Walker	Lower East Walker Valley	High
East Walker	Lower East Walker Valley	Pitchfork Ranch
East Walker	Mason Valley	G and W Consolidated
East Walker	Mason Valley	Hall
East Walker	Mason Valley	Baker
East Walker	Mason Valley	Nelson
Walker River	Mason Valley	Spragg
Walker River	Mason Valley	McLeod
Walker River	Mason Valley	Nichol-Merrit
Walker River	Mason Valley	Campbell

3.1.6 Water Storage

Water storage in the Basin is controlled by three significant reservoirs, and several smaller reservoirs. The Walker River and its two main tributaries each have one large storage facility, and the East and West Walker each have multiple smaller water storage projects usually located on headwater lakes (Table 3.1-4).

Table 3.1-4. Principal storage facilities found in the Basin. Note that all listed capacities are as-built and do not reflect subsequent loss of storage due to sedimentation. (Horton, 1996)

Reservoir	Capacity (acre-feet)	Year of Priority	Area of Decree
West Walker River Storage Facilities			
Black	350	1907	Sonora Junction
Lobdell	500	1864	Smith Valley
Poore	1,200	1901	Antelope Valley
Topaz	59,439	1922 completion	Smith and Mason Valleys
East Walker River Storage Facilities			
Green Lakes	400	1895	Bridgeport
Upper Twin Lake	2050	1905 and 1906	Bridgeport
Lower Twin Lake	4,050	1888 and 1905	Bridgeport
Bridgeport	42,455	1923 completion	All downstream users
Walker River			
Weber	13,000	1935	Tribal Lands

3.1.7 Methods for Development of Ecosystem Flows for the Walker River

Ecosystem flow requirements for managed rivers have traditionally been determined using *Instream Flow Incremental Methodology* (IFIM). This method entails modeling flows that maximize what is considered the optimal aquatic habitat for the target fish. Several important limitations of IFIM however, led to the development of an alternative method for determining ecosystem flows, which is the proposed method to be implemented on the Carson, Truckee, and Walker Rivers.

The primary limitation of IFIM lies in its inability to simulate the dynamic nature of a fluvial system and the variable needs of organisms that have evolved in variable flow regimes. Moreover, IFIM fails to address the need to maintain fluvial processes such as sediment entrainment and transport, which continually shape the physical environment, including riffle-pool development, channel geometry, and channel migration. In conclusion, IFIM is neither designed nor intended to simulate variable natural flow regimes. Thus, recommendations that are solely based on IFIM may lead to artificial flow regimes with potentially grave short-comings over those methods that approximate the natural hydrograph. While IFIM provides insight into specific flow needs of single species and should continue to be used for this purpose, a more comprehensive approach to flow management designed to sustain the natural riverine ecosystem and its native biota needs to be used in this large scale restoration assessment.

The method of determining ecosystem flow requirements for the Basin has several features: (1) it evaluates the entire range of natural flow conditions; (2) it integrates the needs of multiple organisms such as fish, invertebrates, and riparian vegetation; and (3) it addresses the sediment transport processes that control channel geometry and perpetuate a dynamic riverine system. Flow regime recommendations derived from this methodology will mimic the natural hydrologic patterns that sustain the riverine ecosystem and its native species.

Evaluation of the flow regimes of the East, West and Walker Rivers involved subjecting gage records to a variety of analytical procedures, such as Log - Pearson III flood frequency estimates, flow duration relations, monthly mean discharges, and flood peak magnitude-timing evaluation. In our analyses, we consider five key characteristics of flow variability: (1) *magnitude*, (2) *frequency*, (3) *duration*, (4) *timing*, and (5) *rate of change*. It is the assessment and management of these five variables that constitute the essence of ecosystem flows.

Developing recommendations for ecosystem flows requires a three step process: (1) determination of the magnitude, frequency, duration, timing, and rate of change for the natural flow regimen; (2) managing available water to mimic the natural flow regime as closely as possible; (3) finding new sources of water if existing quantities that were available for environmental purposes are determined to be inadequate to sustain the riverine ecosystem.

Several sources of information and analyses were used to formulate the flow recommendations: (1) determination from many scientific literature sources that variable flows across seasons and across years are needed to maintain a riverine ecosystem; (2) analysis of non-dimensional flow duration of unregulated streams in the northwestern Nevada region; (3) and analysis of geomorphically effective Walker River discharge

Flow management will be challenging on the Walker River because instream water levels are influenced by multiple surface diversions, groundwater withdrawal, the snowpack, and weather conditions. Water management is over seen by two entities: the Walker River Irrigation District (WRID) is responsible for managing storage water and the Walker River Water Master (federally appointed) is responsible for overseeing surface water and ensuring the Walker River Decree is enforced.

3.1.8 Surrogate Stream Flow Analysis

Human activities have directly or indirectly influenced the streamflow of the Walker River. The *Hydrology of the Walker River* section of this report, which presents a thorough analysis of gage records for the mainstem of the Walker River and selected tributaries, illustrates many of the hydrologic alterations. While these records are useful for characterizing the streamflow conditions of the river, they were not sufficient for determining the ecologically appropriate range of flows because they did not attempt to assess the degree of human alteration of the natural streamflow patterns of the Walker River. We therefore used surrogate streams that flow from the eastern Sierra Mountains and located in the same general geographic region as the Walker River. The natural flow regimes of these selected surrogate streams have minimal human alteration.

Personnel from the Carson City, Nevada office of the USGS provided a list of thirteen gages on nearby rivers and streams with minimal hydrologic alteration that could be used as reference areas in this study. Data from these streams were used to derive the appropriate overall natural streamflow variability of the Walker River by employing a dimensionless rescaling technique.

The list of appropriate gages, provided by the USGS, included two gages located on the West Walker River, one gage on the Little Walker River, as well as several other streams in the area. From the original thirteen gage records analyzed, four were determined to be outliers and were eliminated from further analyses (for a more detailed explanation see the “Analytical Results” Section 3.1.10). The remaining nine gage records were used in the final analysis to represent the streamflow variability of streams in the geographical area with minimal hydrologic alteration:

- West Fork Carson River at Woodfords, CA (Station #10310000),
- West Walker River near Coleville, CA (Station #10296500),
- West Walker River below Little Walker River near Coleville, CA (Station #10296000)
- Trout Creek near Tahoe Valley, CA (Station #10336780),

- Sagehen Creek near Truckee, CA (Station # 10343500),
- Little Walker River near Bridgeport, CA (Station #10295500),
- East Fork Carson River near Gardnerville, NV (Station #10309000),
- East Fork Carson River below Markleeville Creek near Markleeville, CA (Station #10308200),
- Buckeye Creek near Bridgeport, CA (Station #10291500).

3.1.9 Analytical Procedures

All thirteen gage records recommended by USGS personnel were analyzed using the first four steps outlined below. These four steps provided a way to determine outliers from the group, and four stations were eliminated because their streamflow was inconsistent with the other nine stations (see "Analytical Results" Section 3.1.10). The remaining nine gage records were then used to complete steps 5 through 10. These procedures were originally developed as part of an ecosystem flow study which was completed for the nearby Truckee and Carson Rivers (OBEC 2004, 2008); however, the results are useful for a similar application to the Walker River due to the close geographical proximity of the three rivers and physical and biological similarities.

Step 1 - A list of area streams that met the selection criteria was compiled. Streams had to (1) have minimal human alteration to the upstream watershed and (2) have available streamflow gaging station data.

Step 2 - The records of mean daily streamflow for each gaged stream were obtained and standard flow duration curves were constructed. A flow duration curve plots the mean daily streamflow against the percent of time that the streamflow had been equaled or exceeded during the period of record.

Step 3 - The flow duration curves for each gaging station were non-dimensionalized by dividing each mean daily discharge by the mean discharge for the entire period of record.

Step 4 - The flow duration curves from all stations analyzed were plotted together and visually compared to each other to identify similarities and differences. Nine of the gage records produced curves that were very similar to each other, indicating that the overall variability in streamflow was similar for these streams.

Step 5 - The mean daily discharge for each month of each year was computed for the entire gage record of each of the nine streams. For example, the mean daily streamflow was computed for January 1963, February 1963, March 1963, etc.

Step 6 - A duration curve was constructed for each month (Jan-Dec) using the monthly averages computed in step 5. The result is twelve flow duration curves for each gage (one for each month of the year) that define the range of flow variability that exists during each month on that stream.

Step 7 - The monthly duration curves developed in Step 6 were non-dimensionalized using the same method that was outlined in Step 3.

Step 8 - Points were interpolated along each duration curve at 10% increments using a standard Lagrange interpolation scheme. This allows us to identify important characteristics of the curves (wettest 10%, driest 20%, etc.).

Step 9 - The median value from the nine gaging stations for each 10% increment of each month were determined and that value was used to establish the overall dimensionless ecosystem flow recommendations table.

Step 10 - Dimensionless discharges determined in Step 9 can be re-dimensionalized for any Walker River gage by multiplying the dimensionless discharge value by the mean daily discharge for the period of record at the desired gage. The result is a series of monthly mean discharge recommendations for water years ranked by percentile.

Although the method described above appears complex at first examination, it is actually quite easy to apply the results to any given stream in the appropriate geographical region.

3.1.10 Analytical Results-Overall Streamflow Duration Curves

This analysis began with a review of the stream flow regimen analysis that took place for the Carson and Truckee rivers. The analytical procedures that were applied to these two rivers were assumed to be applicable to the Walker River given the similar geographic location, similar hydrology (snowmelt dominated annual hydrograph), and historical resource development. Therefore, we started with the nine gage records that were determined appropriate for duration curve analysis on the Carson River, and updated the records with the last several years of daily stream flow records. From these records, we developed the nine streamflow duration curves shown in Figure 3.1-1.

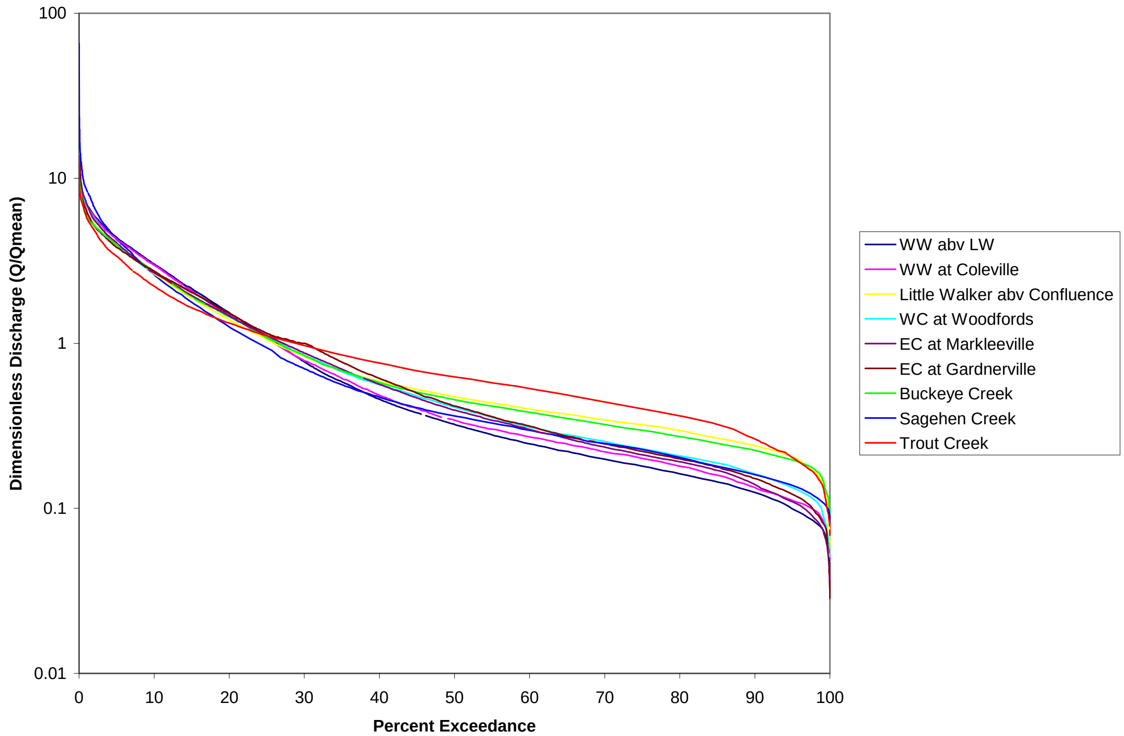

Figure 3.1-1. Dimensionless streamflow duration curves for the nine gages used in surrogate streamflow analysis.

This figure is the result of analytical steps 1-3. These are the non-dimensionalized curves used in surrogate streamflow analysis. These curves fall together relatively well, and constitute a "natural" streamflow regimen for the region of the Walker River. The similarity of the curves is especially significant considering that various drainage basin areas that support the streams. When we compare these natural regimes with curves constructed from gage records in areas with significant water use in the Walker Basin, we can begin to see where some of the primary differences are (Figure 3.1-2).

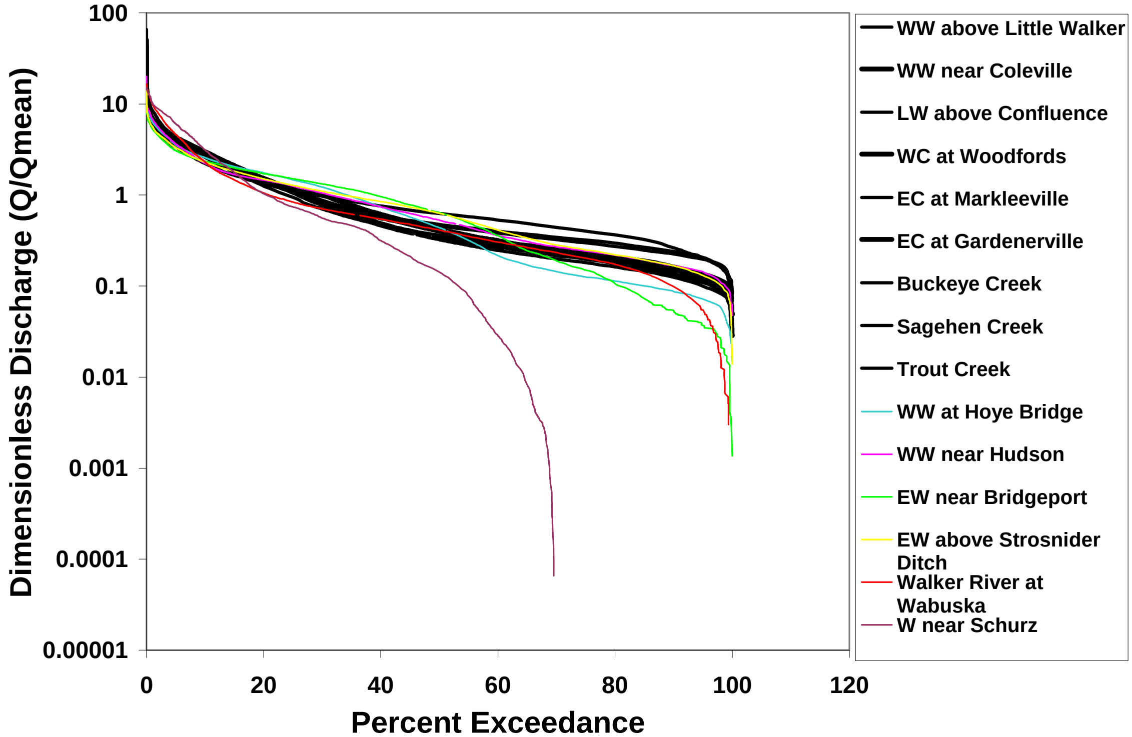

Figure 3.1-2. Dimensionless streamflow duration curves for the nine surrogate streams in black, and other gages in the Basin in color.

It is apparent from these non-dimensionalized curves that for several of the gages in the Basin, discharges are depleted throughout the range of flows, and particularly for baseflows. The West Walker River gage at Hoye Bridge near Wellington, Nevada is the only gage that experiences some elevated high flows. Water released from Topaz Reservoir may be responsible for causing this increase in dimensionless discharge at the 20% exceedence level. Gages farther downstream on the West Walker do not reflect increased discharge from these releases because the water is subsequently diverted. The gage near Schurz on the Walker River experiences the most significant decrease in baseflow discharge in the Basin, though it should be noted that the accuracy of this gage has been questioned. The effects of Weber Reservoir are probably the cause of this decline. Similar declines, though of a smaller magnitude, are seen below Bridgeport Reservoir on the East Walker River.

3.1.11 Analytical Results – Monthly Streamflow Duration Curves

Monthly minimum, median, and maximum values from all nine gages were used to determine a wide range of potential flows. A table of the minimum dimensionless discharge for each 10% exceedance increment of each month was tabulated (Table 3.1-5). This table captures the variability present during each month of the year for unaltered streams in the area surrounding the Walker River.

Table 3.1-5. Values of dimensionless discharge estimates for the minimums of 9 stream gages analyzed.

Dimensionless Discharge Estimates											
Minimum of 9 Streams Used for Analysis											
	Water Year Percentile										
Month	Min	10	20	30	40	50	60	70	80	90	Max
Jan	0.0026	0.11	0.14	0.16	0.17	0.19	0.22	0.27	0.34	0.41	1.86
Feb	0.0052	0.14	0.16	0.18	0.20	0.22	0.25	0.30	0.37	0.46	0.91
Mar	0.0078	0.21	0.24	0.29	0.33	0.39	0.43	0.46	0.49	0.64	1.15
Apr	0.0104	0.46	0.54	0.65	0.74	0.78	0.85	0.90	1.16	1.30	1.78
May	0.0130	0.67	0.87	1.25	1.55	1.77	2.39	2.72	3.09	3.93	5.20
Jun	0.0156	0.28	0.42	0.57	0.80	1.19	1.86	2.41	3.38	4.71	7.01
Jul	0.0181	0.18	0.21	0.25	0.30	0.38	0.52	0.65	0.23	1.27	3.04
Aug	0.0207	0.14	0.17	0.21	0.23	0.26	0.29	0.32	0.41	0.48	0.99
Sep	0.0233	0.08	0.11	0.14	0.17	0.21	0.25	0.27	0.34	0.40	0.67
Oct	0.0259	0.09	0.10	0.13	0.16	0.18	0.19	0.23	0.26	0.32	0.67
Nov	0.0285	0.11	0.13	0.16	0.17	0.19	0.19	0.23	0.28	0.38	0.71
Dec	0.0311	0.11	0.14	0.15	0.16	0.19	0.20	0.21	0.29	0.42	0.84

Table 3.1-5 can be re-dimensionalized to estimate desired streamflow variability of various gages on the Walker River by multiplying the values in the table by the mean annual discharge of the Walker River at that gage. For example, using the mean annual discharge of 245.8 cfs for the West Walker River at Hoye Bridge near Wellington, NV gage, the minimum dimensionless estimates from Table 3.1-5 were re-dimensionalized into minimum discharge estimates in cubic feet per second for each percentile of each month (Table 3.1-6). Similar tables are presented for the median and maximum monthly values and applied to the same example gage (Table 3.1-7 through Table 3.1-10). This technique is used to guide all subsequent ecosystem flow recommendations.

Table 3.1-6. Re-dimensionalizing discharge values for minimums at the gage at Hoye Bridge near Wellington, NV.

Monthly Discharge Estimates											
Minimum Values Re-dimensionalized for West Walker River at Hoye Bridge near Wellington, NV											
Mean Q	245.8										
Month	**Min**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**Max**
Jan	0.6	28.1	33.7	38.3	42.3	47.7	54.1	66.2	82.7	100.2	455.9
Feb	1.3	34.0	39.1	45.4	49.4	53.5	60.5	72.8	92.1	112.0	222.6
Mar	1.9	50.8	58.0	71.8	82.2	96.4	105.5	112.0	121.2	157.1	283.0
Apr	2.5	112.0	132.7	159.8	181.8	191.4	207.7	220.9	284.6	320.1	437.9
May	3.2	165.5	214.9	306.7	380.4	435.8	586.5	667.3	758.2	964.7	1277.0
Jun	3.8	68.6	102.3	139.9	197.8	292.6	456.1	593.3	831.5	1158.4	1722.2
Jul	4.5	44.2	52.8	61.7	74.0	93.3	127.8	158.9	55.9	312.8	746.7
Aug	5.1	34.8	41.9	50.5	56.3	62.7	70.6	78.6	100.9	116.8	242.2
Sep	5.7	20.6	27.9	34.4	42.5	51.9	61.0	67.1	82.8	99.5	164.8
Oct	6.4	21.3	25.8	31.3	38.4	43.9	47.5	57.1	65.0	77.7	163.4
Nov	7.0	27.2	31.8	39.2	42.9	45.7	47.9	57.1	68.2	93.4	175.4
Dec	7.6	27.5	33.7	37.2	40.2	45.7	50.0	51.0	70.8	102.4	207.3

Taken together, Table 3.1-6 through Table 3.1-10 illustrate an important point: the estimated natural flow regime at the various gages is variable in time. If the flow is re-dimensionalized for all the gages in the Basin, it would be expected that this variability would be true in the spatial dimension as well. This natural variability is a critical component of riverine health and sustainability that is lost through the hydrologic alteration that exists in the Basin. Flow variability forms the basis of key physical and ecological functions of a riverine system. The estimated monthly discharges that are calculated during the preceding analytical procedure produce a minimum range of monthly values. These are not to be taken as flow recommendations in themselves. Specific recommendations would depend on the target goals for the flow regime such as stream temperature issues, cottonwood recruitment, or channel maintenance.

Table 3.1-7. Median dimensionless discharge values.

Dimensionless Discharge Estimates											
Median of 9 Stream Used for Analysis											
	Water Year Percentile										
Month	**Min**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**Max**
Jan	0.018	0.20	0.24	0.28	0.31	0.35	0.40	0.47	0.60	0.93	4.31
Feb	0.037	0.24	0.28	0.31	0.35	0.39	0.45	0.52	0.66	0.89	1.95
Mar	0.055	0.34	0.41	0.48	0.54	0.64	0.70	0.78	0.92	1.14	2.34
Apr	0.074	0.72	0.92	1.10	1.27	1.39	1.53	1.70	1.93	2.30	2.95
May	0.074	1.53	1.89	2.25	2.66	3.05	3.64	4.06	4.73	5.50	7.68
Jun	0.074	1.09	1.62	2.11	2.83	3.44	4.12	4.66	5.17	6.45	9.29
Jul	0.068	0.39	0.50	0.71	1.00	1.31	1.86	2.37	2.74	3.91	7.56
Aug	0.062	0.20	0.26	0.32	0.41	0.51	0.63	0.76	0.96	1.36	2.48
Sep	0.068	0.16	0.19	0.24	0.28	0.33	0.38	0.44	0.53	0.72	1.14
Oct	0.075	0.17	0.20	0.22	0.27	0.31	0.34	0.38	0.45	0.52	1.14
Nov	0.10	0.20	0.23	0.27	0.30	0.33	0.36	0.41	1.96	0.64	1.64
Dec	0.11	0.19	0.23	0.27	0.29	0.33	0.36	0.41	0.99	0.86	2.00

Table 3.1-8. Median discharge values re-dimensionalized for the gage at West Walker River at Hoye Bridge near Wellington, NV.

Median Discharge Estimates											
Median Values Re-dimensionalized for Hoye Bridge											
Mean Q	245.8										
Month	**Min**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**Max**
Jan	4.5	48.5	59.9	68.3	77.1	86.0	98.4	116.6	148.5	227.5	1059.6
Feb	9.1	59.1	68.2	77.4	85.2	95.7	110.5	129.0	162.2	218.9	479.5
Mar	13.6	82.4	100.5	117.8	131.6	158.3	173.0	191.2	225.6	279.1	575.8
Apr	18.1	177.9	224.9	269.3	310.9	341.6	375.0	417.5	474.2	564.7	725.6
May	18.2	377.1	464.8	554.1	653.3	750.2	895.3	998.3	1163.5	1351.9	1887.8
Jun	18.2	269.0	397.5	517.8	695.2	846.3	1011.8	1144.8	1271.8	1584.0	2283.7
Jul	16.8	96.6	123.4	174.6	244.9	321.6	456.4	582.5	673.6	961.6	1858.3
Aug	15.3	50.3	63.6	77.9	99.7	126.1	154.2	187.8	235.8	335.3	608.3
Sep	16.6	38.9	46.8	59.1	69.6	80.8	94.2	108.6	129.3	176.6	280.6
Oct	18.5	40.6	48.1	55.2	66.0	75.8	83.1	93.8	111.2	127.1	279.1
Nov	25.7	48.0	55.4	66.2	73.8	80.5	88.2	100.2	482.8	158.2	404.0
Dec	26.6	47.6	56.8	65.2	72.1	80.5	89.1	100.3	243.0	211.2	492.2

Table 3.1-9. Maximum dimensionless discharge values.

Dimensionless Discharge Estimates											
Maximum of 9 Stream Used for Analysis											
	Water Year Percentile										
Month	Min	10	20	30	40	50	60	70	80	90	Max
Jan	0.082	0.31	0.39	0.45	0.50	0.56	0.62	0.70	0.87	1.53	8.27
Feb	0.16	0.40	0.45	0.51	0.55	0.62	0.71	0.78	1.00	1.22	4.19
Mar	0.25	0.51	0.69	0.83	0.90	1.29	1.11	1.25	1.57	1.88	4.11
Apr	0.33	1.44	1.91	2.29	2.51	2.71	2.91	3.12	3.61	4.33	5.81
May	0.25	4.05	4.96	5.34	6.34	7.18	8.01	8.49	10.01	10.86	16.77
Jun	0.16	2.87	4.58	5.71	8.26	9.06	10.59	11.60	12.59	15.51	18.78
Jul	0.14	0.93	1.13	1.92	2.67	3.57	4.89	6.09	7.27	10.00	22.78
Aug	0.13	0.40	0.51	0.66	0.95	1.09	1.37	1.65	2.08	3.33	6.59
Sep	0.13	0.28	0.33	0.50	0.57	0.63	0.72	0.82	0.99	1.53	2.46
Oct	0.14	0.27	0.33	0.39	0.48	0.55	0.61	0.68	0.82	0.90	2.73
Nov	0.19	0.32	0.36	0.45	0.50	0.57	0.61	0.69	0.81	1.06	2.88
Dec	0.22	0.31	0.37	0.42	0.46	0.53	0.59	0.67	0.78	1.69	3.61

Table 3.1-10. Maximum discharge values re-dimensionalized for the gage at West Walker at Hoye Bridge near Wellington, NV.

Maximum Discharge Estimates											
Maximum Values Re-dimensionalized for Hoye Bridge											
Mean Q	245.8										
Month	Min	10	20	30	40	50	60	70	80	90	Max
Jan	20.2	75.5	94.8	110.4	123.0	136.5	151.3	171.6	214.3	375.4	2033.1
Feb	40.4	99.1	110.5	126.3	135.2	152.2	174.8	192.5	245.3	298.7	1029.3
Mar	60.5	125.8	170.1	203.5	222.0	316.8	272.3	306.4	386.0	461.4	1009.1
Apr	80.7	354.7	470.0	562.1	617.4	665.0	714.9	766.3	887.8	1064.0	1428.8
May	60.5	994.8	1219.4	1313.6	1557.8	1765.8	1967.5	2086.4	2459.5	2670.0	4122.4
Jun	40.5	705.9	1125.1	1403.2	2030.0	2226.3	2602.9	2851.8	3093.1	3811.5	4616.7
Jul	33.8	228.8	276.8	471.7	657.3	877.3	1201.0	1495.8	1785.6	2457.3	5598.4
Aug	31.9	99.3	124.5	163.1	233.2	267.3	337.4	404.8	510.4	819.5	1619.8
Sep	31.9	68.1	81.3	121.8	140.2	155.0	176.1	201.7	244.4	375.2	604.3
Oct	33.8	65.6	81.0	95.7	117.7	134.0	150.7	166.8	200.4	222.0	671.7
Nov	47.3	78.7	88.5	111.4	123.4	139.3	148.7	170.3	199.0	261.0	707.1
Dec	54.1	76.9	90.3	102.6	113.9	131.4	145.8	165.6	192.6	415.7	888.0

3.1.12 Implementing the Ecosystem Flow Framework

3.1.12.1 Targeting Physical and Ecological Process Flows

The ecosystem flow framework presented in the previous several sections is in a form that will allow the dimensionless flow duration curves to be re-dimensionalized in various ways. The examples of re-dimensionalization presented in Table 3.1-6, Table 3.1-8, and Table 3.1-10 illustrate a simple re-dimensionalization to average values of low, median, and high hydrographs. However, if particular functions of the riverine system are targeted for enhancement, then the ecosystem flow framework can be used to develop flow recommendations to enhance that process. A few process flow targets are described below.

EFFECTIVE DISCHARGE

While high magnitude flows individually entrain and transport more sediment than any lower magnitude single event, they do not transport the bulk of sediment moving through the system. In fact, flows responsible for most of the river's sediment transport, or work, are the moderate magnitude annual peaks that occur frequently (i.e., between a 1 and 5 year return interval). These frequently occurring peak flows are called the dominant or effective discharges.

To avoid major disruption of the river system and ecosystem, the effective discharge must be maintained in the approximate range of the undisturbed system (Andrews and Nankervis, 1995; Everitt, 1993; Williams, 1978). Maintaining the effective discharge is important for the riverine ecosystem, as these flows shape the channel, control channel geometry, maintain diverse hydraulic habitats, and provide dynamics in the system. Changes or disruption of these flows almost always result in dramatic changes in the river morphology and ecology.

The current estimates of effective discharge derived from numerical modeling using SAMWin are inconclusive (Appendix C). Suggestions regarding flow requirements for channel maintenance will be made using the results of an ongoing sediment transport study.

CHANNEL/FLOODPLAIN CONNECTION

A point that has been reiterated in this assessment is that the connection of the channel to floodplain through surface and groundwater flow is essential to physical and ecosystem processes throughout the river system. Floodplain inundation at times of high flow benefits the system through floodwater storage, exchange of nutrients, and the creation and maintenance of wetland habitats. Subsurface connection is also vital to maintaining a water table elevation that will sustain riparian vegetation, and promote exchange of surface water with the shallow groundwater table.

COTTONWOOD RECRUITMENT

The recruitment of new cottonwood trees is essential to sustainability of the riparian forest, and all the ecological value that is associated with it. Current cottonwood patches are in relatively good health, but the surfaces available for recruitment have been diminished, and the timing of flows that is essential to cottonwood growth has been altered. The successful establishment of cottonwood seedlings is orchestrated to the natural timing of spring runoff. The deposition of the seed, the establishment of the root, and the growth of the young plant depend on the natural timing of the rise, peak and fall of flows. If the peak occurs too early or late, the timing of seed release may be missed, and if the falling limb is too abrupt, or high flows are unnaturally sustained into the summer, then seed establishment may be unsuccessful.

3.1.12.2 Decision Process

Flow management that can adjust to changing weather patterns and environmental needs appears to be the best solution for inherently dynamic and unpredictable river ecosystems. A framework upon which to base resource management decisions that are central to the preservation and restoration of the Walker River riverine ecosystem is presented below.

WATER AVAILABILITY – PRIMARY DECISION FACTORS

1. The abundance of water in the snow pack, assessed in at the beginning of April, generally gives a good indication of the expected water supply for the next two quarters of the year. The amount of available water will greatly influence the selection of the flow regime.

2. The expected Walker River flows, before manipulation for environmental purposes, gives managers valuable information about the amount of flow augmentation needed for environmental purposes. In years where ecosystem flows are naturally high, and reservoir levels are adequate, many goals of environmental flow management may already be met with minimal change.

ECOSYSTEM MANAGEMENT - SECONDARY DECISION FACTORS

1. The time since flows equaled or exceeded the effective discharge is a factor that takes into consideration frequent mobilization of the bed material that serves to maintain channel form, and underpins a more biologically diverse riverine system. In many natural systems, the effective discharge is equaled or exceeded about every 2 years.

2. The targeted maximum water temperatures should be an objective to meet the annual ecosystem goals. Water temperature is a primary factor in overall water quality. For example, conditions become lethal for certain fish, incubating eggs, and invertebrates when temperatures become too high. The quantity of river flow, the depth of the channel, and surface water/ground water interactions are related to river water temperature.

3. The level of drought stress conditions on riparian plants in most recent years is certainly related to the stream flow levels. Mature riparian trees are adapted to handle infrequent drought stress, but successive years of stress can be lethal. In turn, the health of the riparian vegetation affects water quality, bank stability, and channel form.

3.2 Rating and Ranking of the Geomorphic Segments

In order to provide recommendations for the recovery and management of the Walker River ecosystem, an assessment of recovery potential was completed for all segments. The following assessment provides a basis for proposing recovery and management recommendations and also allows the determination of priority areas or river segments within the assessment area. The assessment process was completed using aerial photography, topographic maps, vegetation mapping results, noxious weed surveys, channel cross section measurements, hydraulic modeling results, sediment transport modeling results, and field observations. Please note that detailed measurements, data collection efforts, and field investigations were not completed at all locations along each segment due to logistical contraint. The goal of this assessment was to give an overall view of current conditions. Therefore, detailed field measurements, data collection efforts, and field investigation activities have been used to assess the overall condition of each individual segment with the recognition that these data are site specific. However, aerial photography provides sufficient resolution for the description of broad, landscape scale features which are the primary criteria contained in the following assessment.

The methods used to assess the potential for restoration and enhancement activities within each river segment are described below. The scoring system was designed to quantify physical characteristics of the riverine ecosystem that are necessary to allow the recovery to occur. Assessment criteria were developed in order to assess river channel, floodplain, and ecosystem recovery potential. The assessment criteria were defined based on conditions specific to the Walker River and similar rivers in the region including the Carson and Truckee Rivers. The assessment criteria provide a framework on which to score each river segment for overall restoration and recovery potential. These criteria are defined in Section 3.2.1. The scoring of the individual river segments, based on the assessment criteria, allows further refinement of restoration recommendations.

3.2.1 Scoring Criteria

The river segment evaluation and scoring system is based on eight key management activities or riverine characteristics that are needed for recovery of the segment. This system is based on elements of landscape ecology, plant ecology, aquatic ecology, and fluvial geomorphology. The eight key management activities are: (1) legal protection of land and water; (2) utilizing and preserving the variability of the natural hydrology; (3) locating and protecting areas undisturbed by urban development so the river can re-establish a sinuous channel and riparian forest; (4) re-establishing river continuity by removing, bypassing, or updating in-channel structures to allow for passage of aquatic organisms and sediment; (5) retaining or enhancing the existing connectivity to the floodplain; (6) protecting or improving the water quality of flows in the lower river; (7) implementing new land management practices that greatly reduce or eliminate the impacts of grazing on the river corridor, create a variety of wetland types in the floodplain, and allow the river to regain its migrating, sinuous pattern to develop habitat complexity; and (8) releasing the river from artificially hardened banks, and protecting areas where bank hardening has not occurred thereby re-initiating dynamic fluvial processes.

Ultimately, 22 criteria (summarized in Table 3.2-1) were selected for use in rating the geomorphic segments. The development and selection of criteria focused on processes and features of the river system that all have the potential to enhance the river system as part of a restoration effort. If restoration was carried out, any of these criteria have the potential increase water quality, and increase stream flow. This summary provides a score sheet by which each segment can be rated, and ultimately ranked in order of its restoration potential. By inspecting Table 3.2-1, it becomes apparent that some criteria score particular management activities multiple times. This was done intentionally in order to weight criteria that will be most important in proceeding with restoration efforts. For instance there are several criteria that score the development or subsequent fragmentation of the channel and floodplain. This is done in order to give added importance to encroachment. Areas with less development of the channel and floodplain will be given higher scores for those criteria.

Table 3.2-1. Field evaluation criteria applied to each of the segments of the Walker River evaluation area.

Criteria	**Measurement/Rankings**[54]
1) Encroachment and fragmentation	• Measured in number of features, and scored relative to other segments in the Basin • Rank: 5 = no encroachments; 4 = few; 3 = some; 2 = many; 1 = extensive

[54] Please see detailed descriptions for scoring criteria below Table 3.2-1.

Criteria	**Measurement/Rankings**[54]
2) Potential to reduce fragmentation	• Measured in apparent permanence of fragmenting structure • Rank: 2 = Impermanent objects creating fragmentation; 0 = permanent objects creating fragmentation
3) Relatively unaltered flow regime	• Measured by applicable USGS gage, and score given to the dimensionless flow duration curve for that gage
4) Frequent recurrence of geomorphically effective flows	• Measured by estimated recurrence of geomorphically effective flows assumed to optimally occur between 1.5 and 2.3 years • Rank: 3 = between 1.5 and 2.3 years; 2 = between 2.3 and 5 years; 1 = between 5 and 10 years; 0 = over 10 years.
5) Degree of long-term channel instability: aggradation/degradation, entrenchment, avulsion, etc.	• Measured in percent change in channel form relative to historic condition measured on aerial photos • Rank: 3 = <20% change; 2 = 21-50% change; 1 = 51-80% change; 0 = >80% historic change
6) Potential to mitigate channel instability issues	• Measured by the drivers of instability and potential restoration mitigation • Rank: 4 = high; 3 = good; 2 = moderate; 1 = low; 0 = poor

Criteria	Measurement/Rankings[54]
7) Channel and floodplain reconnection potential	• Measured by assessing the difficulty of reconnecting the channel and floodplain • Rank: 5 = very high; 4 = high; 3 = moderate; 2 = low; 1 = impossible
8) Diversity of existing hydraulic zones	• Measured by field assessment of hydraulic complexity • Rank: 5 = very diverse; 3 = moderately diverse; 1 = homogeneous
9) Average existing floodplain width	• Measured in percent • Rank: 5 = extensive floodplain; 4 = large floodplain; 3 moderate floodplain; 2 = narrow floodplain; 1 = minimal floodplain
10) Potential for floodplain expansion	• Measured in percent • Rank: 5 = extensive expansion; 4 = large expansion; 3 = moderate expansion; 2 = some expansion; 1 = minimal expansion.
11) Amount of existing riparian forest	• Measured in relative acres • Rank: 5 = very abundant; 4 = abundant; 3 = moderately abundant; 2 = sparse; 1 = absent
12) Quality of existing riparian forest	• Measured by vegetation type • Rank: 5 = excellent; 4 = above average; 3 = average; 2 = below average; 1 = undesirable

Criteria	Measurement/Rankings[54]
13) Potential for riparian forest recovery	• Measured in relative cover • Rank: 4 = high; 3 = moderate; 2 = low; 1 = very low
14) Amount of naturally existing wetlands	• Measured in relative wetland cover • Rank: 5 = very abundant; 4 = abundant; 3 = moderately abundant; 2 = sparse; 1 = absent
15) Quality of naturally existing wetlands	• Measured by vegetation type • Rank: 3 = high quality; 2 = moderate quality; 1 = low quality
16) Potential to increase wetlands	• Measured by combined wetland presence and hydrology • Rank: 2 = high; 1 = moderate, 0 = low.
17) Amount of tamarisk	• Measured in percentages that reflect presence and dominance • Rank: 5 = absence of tamarisk; 4 = present but not in patches; 3 = present in mappable patches; 2 = >25% but < 50% cover; 1 = >50% cover.
18) Amount of noxious weeds	• Measured in number and type of noxious weed species present • Rank: 5 = absence of Category A noxious weeds; 4 = 1 or 2 species present; 3 = 3 species present; 2 = 4 species present; 1 = presence of hydrilla.

Criteria	Measurement/Rankings[54]
19) Degree of historic alteration to cottonwood forests	• Measured in survival of historic patches • Rank: 2 = majority of surviving patches; 1 = majority of lost cottonwood patches
20) Degree of regular vegetation disturbance	• Measured in percent of segment found in agricultural land-use (this being the largest cause of frequent vegetation disturbance) • Rank: 5 = 0-20%; 4 = 21-40%; 3 = 41-60%; 2 = 61-80%; 1 = 81-100%
21) Connection to landscape features	• Measured in number of features the segment is connected to • Rank: 5 = very high; 4 = high; 3 = moderate; 2 = low; 1 = very low
22) Restoration continuity	• Measured by the proximity of high scoring segments • Rank: 4 = up and downstream; 2 = up or downstream; 0 = no adjacent segments score high

Detailed descriptions of each criteria, and the method used for applying each criteria in scoring are described below.

(1) *Encroachment and fragmentation* analyses the presence and nature of structures such as dams, water diversions, erosion control structures, revetment, pipelines, roads, bridges, houses, commercial buildings, parks, dams, canals, etc. Permanent structures act as impediments to riverine restoration and commonly result in the fragmentation of aquatic habitats. Protecting against future development and the placement of additional domestic wells can directly impact water quantity. Scoring this criterion is based on a semi-quantitative assessment using aerial photography, GIS, and field observations. Scoring is relative to other segments in the Basin. Each segment will be assessed by counting the features that cause fragmentation, and noting the type and extent of that feature. Once this has been done for each segment, a relative scoring will be developed. Those segments with the least amount of fragmentation will set the high standard for the Basin, and scoring will be relative to those least fragmented reaches. A natural, free flowing meandering river with no diversion structures will score as no encroachments, while a segment that has major roadways paralleling the channel, urban or industrial development in the floodplain, multiple bridges and diversion will be given low scores. The relative scoring will be as follows: no encroachments = 5, few = 4, some = 3, many = 2, extensive = 1.

(2) *Potential to reduce fragmentation* is a score based in the likelihood of channel of floodplain structures to be removed or re-engineered as part of the restoration process. For instance, a small and outdated diversion dam may be removed or re-engineered to allow for passage of aquatic organisms and sediment. This will result in a high score for potential to reduce fragmentation. However, the presence of a large or vital impoundment or municipal structure that must be avoided by restoration activities will result in a low score. Specific rankings are as follows: cause of fragmentation potentially impermanent = 2, cause of fragmentation permanent = 0.

(3) *Relatively unaltered flow regime* scores segments based on the nature of dimensionless flow durations curves developed from the daily flow values for the period of record at the USGS gage nearest the segment being scored (Figure 3.2-1). The score given to a particular curve will be with reference to the curve developed for the gage on the West Walker River near Coleville, which is colored pink in Figure 3.2-1. The numbers for certain curves or groups of curves, 1-4 in Figure 3.2-1, are the scores given to the curves and their associated gages. The score is dependent on the similarity between the curve for a particular gage and the reference curve. Dissimilarity between the two curves will be caused by alterations such as impoundments and diversions that unnaturally decrease peak flows, alter the timing of peaks, or increase baseflow levels. Therefore the most highly altered dimensionless flow duration curves will receive the lowest score, and more increasingly similar curves will receive higher scores. Segments will receive a score of one through four for this criteria based on the gage that best represents the hydrology in that segment.

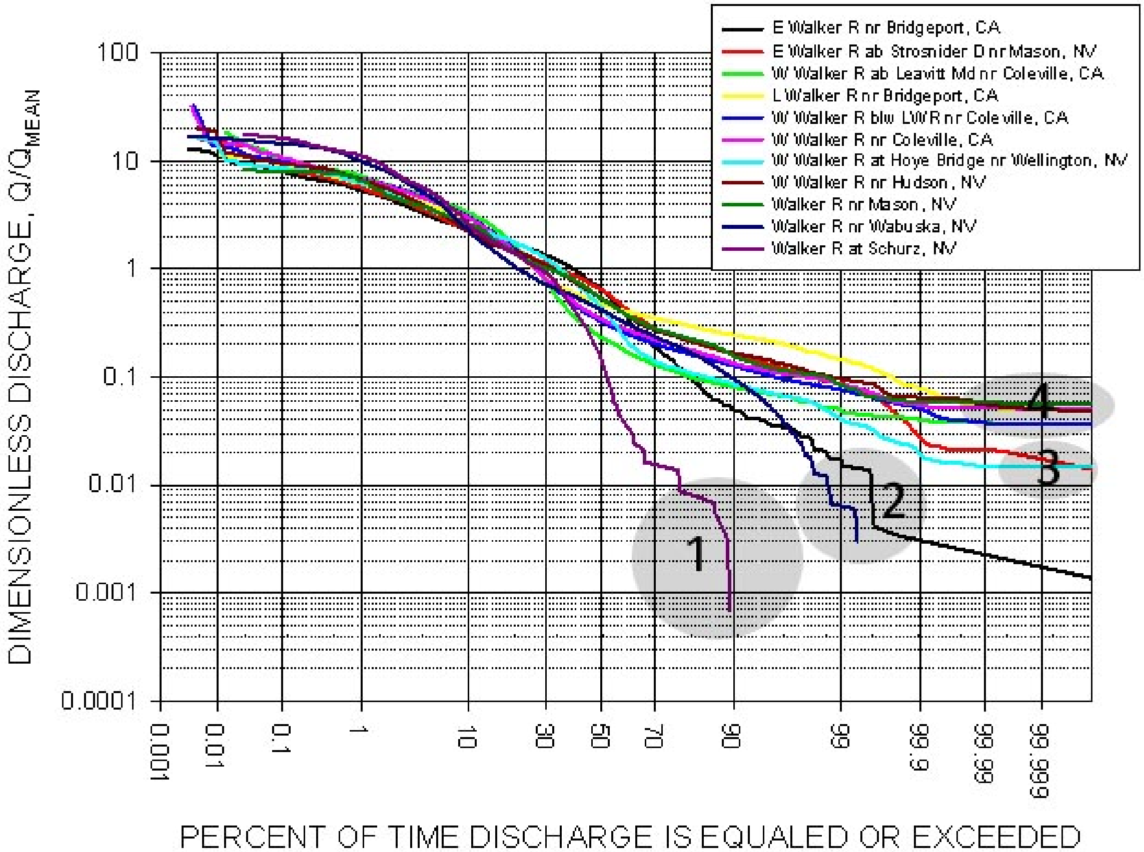

Figure 3.2-1. Scores given to the dimensionless flow duration curves for USGS gages.

(4) *Frequent recurrence of geomorphically effective flows* would score segments based on estimates of the recurrence interval of discharges that transport the majority of the estimated annual sediment load. The frequency of this flow event would optimally occur between 1.5 and 5 years. Increased or decreased frequency of such flows would result in a lower score for the segment. The scoring for this criteria would be as follows: effective discharge for the segment occurs between every 1.5 and 2.3 years = 3, effective discharge for the segment occurs between every 2.3 and 5 years = 2, effective discharge for the segment occurs between 5 and 10 years = 1, effective discharge occurs over 10 years = 0.

(5) *Degree of long-term channel instability: aggradation/degradation, entrenchment, avulsion, etc.* is a geomorphic scoring criteria that would draw from analysis of historical aerial photos and field observations to identify segments that have systematically and substantially altered their channel pattern or floodplain connection since 1938 (the year of the oldest available aerial photos). This may include a historically meandering segment whose sinuosity is currently reduced, or a segment that has undergone extensive aggradation and is now subject to increased frequency of overbank flooding, channel avulsion, or increased rates of meander migration. Stable segments that do not exhibit the symptoms of such instabilities would score higher under this criterion. The criteria would score as follows: <20% historic change = 3, 20%-50% historic change = 2, 51-80% historic change = 1, >80% historic change = 0.

(6) *Potential to mitigate channel instability issues* is scored by determining the potential source of instability making a qualitative assessment of the likelihood of restoration activities correcting the problem. If channel instability is caused by reduced bank vegetation and subsequent erosion, a high score would be given for the segment if activities such as riparian fencing and bank stability structures would likely reduce bank erosion. If instability appears to be the result of the compound effects of alterations to hydrology and land-use upstream, and changes to these sources is not a restoration option, then the segment would receive a low score in this category. The criteria would score as follows: Low-instability driven by local factors corrected through potential restoration = 4 (high), low-instability driven by local factors not corrected through potential restoration = 3 (good), high instability driven by local factors corrected through potential restoration = 2 (moderate), high-instability driven by local factors not corrected through potential restoration = 1 (low), high-instability driven by watershed factors = 0 (poor).

(7) *Channel and floodplain reconnection potential* is scored according to the consideration of previously discussed criteria including existing floodplain width, potential for floodplain expansion, and encroachments into the channel and floodplain. In addition, estimated frequency of floodplain inundation will be considered. For example, if the channel is deeply incised and flooding is infrequent, or if extensive urban development is present within the floodplain, then the segment will score low in this category. However, the combined presence of a wide floodplain with a low degree of urban development and a channel with the potential for frequent flooding will result in a high score for this criterion. Possible techniques for restoring a floodplain connection ranged from passive channel migration that will likely create a new floodplain within a few decades (very high reconnection potential = 5); passive channel migration combined with partial construction of a channel and some grade control (high reconnection potential = 4); construction of a new channel on the floodplain and filling the channel to raise its bed (moderate reconnection potential = 3); excavation of banks to form a new floodplain (low reconnection potential = 2); and "impossible to reconnect," (very low to no reconnection potential = 1).

(8) *Diversity of existing hydraulic zones* is measured by determining the relative channel area composed of zones that exhibit hydraulics characteristics distinct from surrounding areas of the channel (Figure 3.2-2). A hydraulic zone is primarily defined by two variables: water depth and water velocity (Figure 3.2-3). Differences in water depth and velocity are sometimes expressed by varying degrees of water surface disturbance. Qualitative assessments of hydraulic diversity within each river segment are made during field inspections. Using the examples provided in Figure 3.2-2, an observer makes a visual inspection of as much of the length of a particular segment as is practical. The visual inspection is used to give the segment a qualitative score based on the examples in Figure 3.2-2. High diversity of hydraulic zones generally translates to a system with a high diversity of aquatic organisms; that is, meandering stream channels with well-developed riffle-pool sequences generally provide a high diversity of hydraulic zones (Figure 3.2-2 and Figure 3.2-3), while channelized rivers usually lack such diversity. The existing aquatic habitat diversity ranks as follows: Very diverse = 5; moderately diverse = 3; and relatively homogeneous = 1.

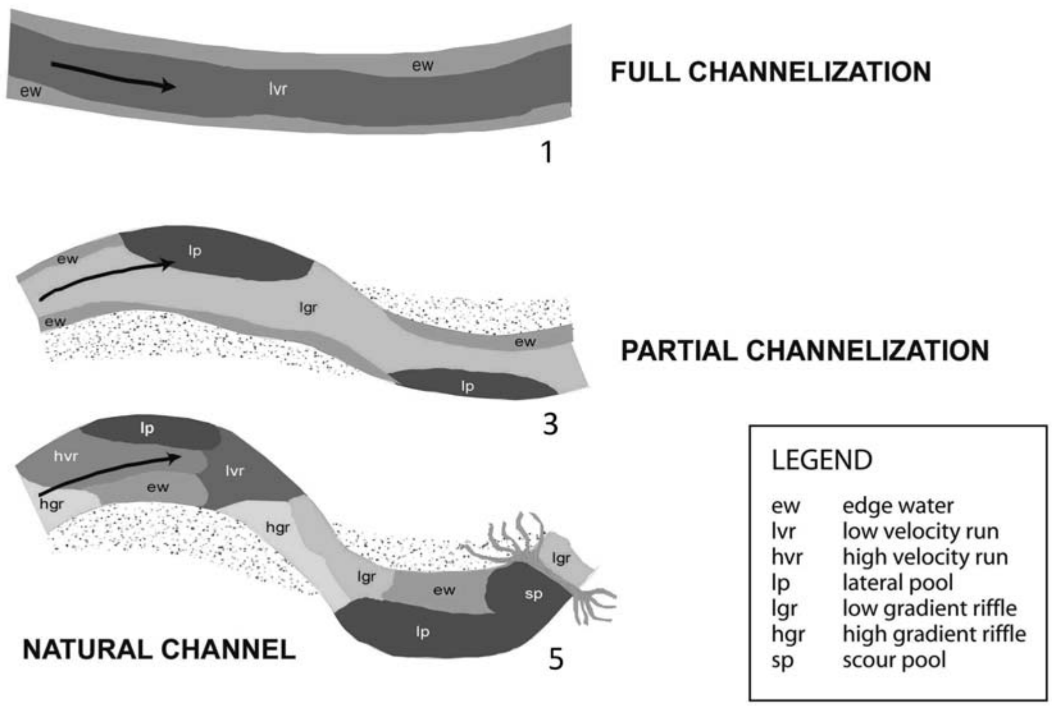

Figure 3.2-2. Well-developed meandering riffle and pool sequence produces diverse hydraulic habitats.

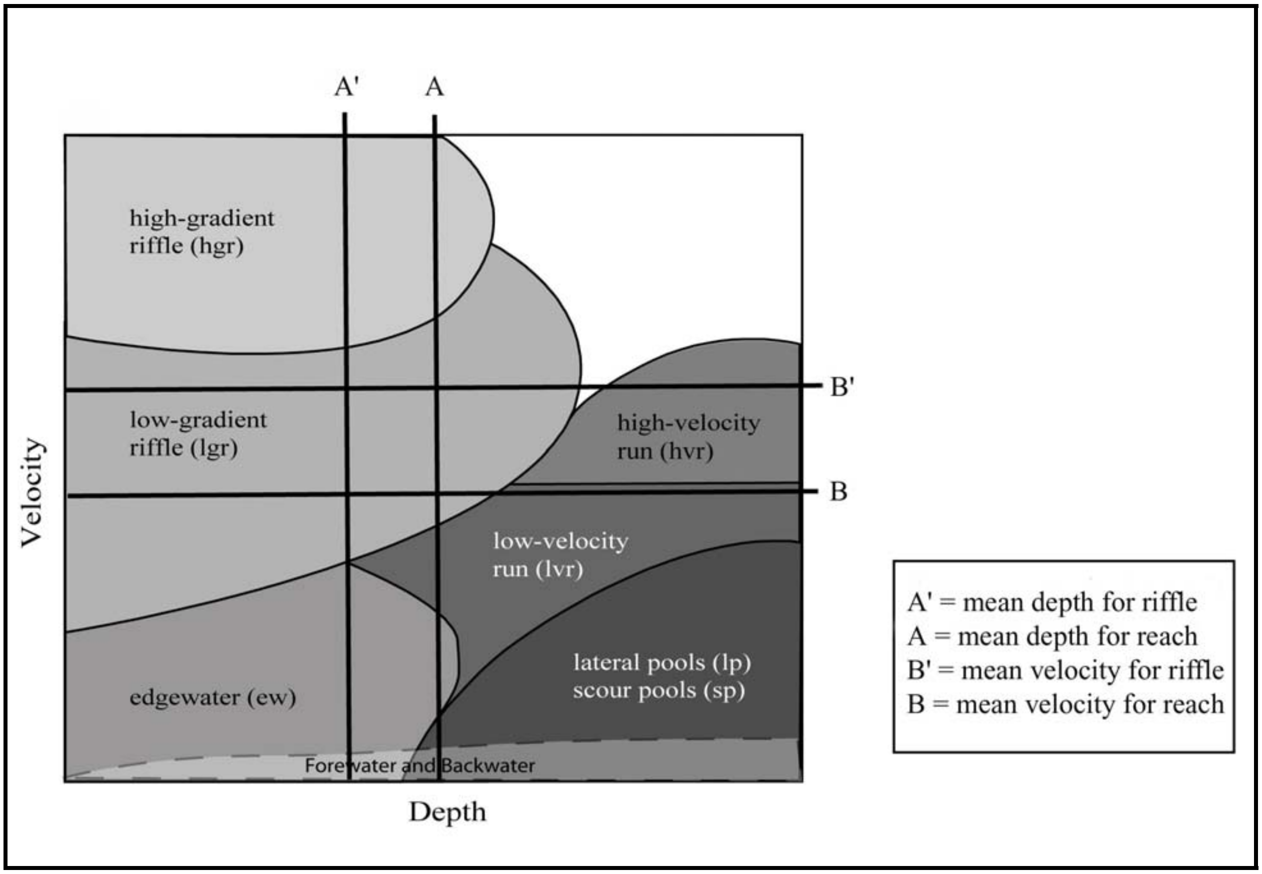

Figure 3.2-3. Plot of hydraulic zones for stream channels.

(9) *Existing floodplain area* is a critically important metric for assessing potential riparian forest restoration. This criterion is one of the primary factors with regard to both the maintenance of existing riparian habitat and future recovery of riparian habitat. In this assessment, the existing floodplain area is estimated by modeling what land would be inundated by a typical "flood" within 1,640 feet of both sides of the channel.[55] The depth of this flood is defined as twice the bankfull or 2-year flood (Rosgen, 1994; Figure 3.2-4).[56] This method of measuring floodplain area is corroborated using the distribution and relative abundance of the riparian vegetation types described in Section 2.2.1.4. River segments with large relative floodplain areas received the highest scores for these criteria. The specific scoring method for relative existing floodplain area is defined by dividing the area of floodplain by the area in each segment that is examined by the model. That result is then multiplied by 100 to give a percentage of the area that is floodplain. 75-100 (extensive floodplain) = 5; 50-74 (large floodplain) = 4; 25-50 moderate floodplain = 3; 35-25 (narrow floodplain) = 2; and <5 minimal floodplain= 1.

[55] Elevations are determined using the HAR model described in section 2.1

[56] The bankfull surface elevation was determined using a HEC-RAS simulation of a 2-year recurrence peak flow, or if not available , was estimated using field estimations. This elevation was assumed to be the same throughout a geomorphic reach.

(10) *Potential for floodplain expansion* is measured in the same manner as the *existing floodplain area* (criteria 9) with the additional assumption that the future restoration activities raise the channel bed in order to reconnect the river to its floodplain. Therefore, the floodplain expansion was measured by using the model described above to map the area on either side of the channel that would be inundated by the same "typical" flood if the bed of the rivers was raised another two feet[57] (Figure 3.2-5). The specific scoring method for potential floodplain expansion is defined by dividing the area of expansion by the area in each segment that is examined by the model. That result is then multiplied by 100 to give a percentage of the area that is floodplain. 75-100 (extensive expansion) = 5; 50-74 (large expansion) = 4; 49-35 (moderate expansion); 34-5 (some expansion) = 3; and <5 minimal expansion = 1

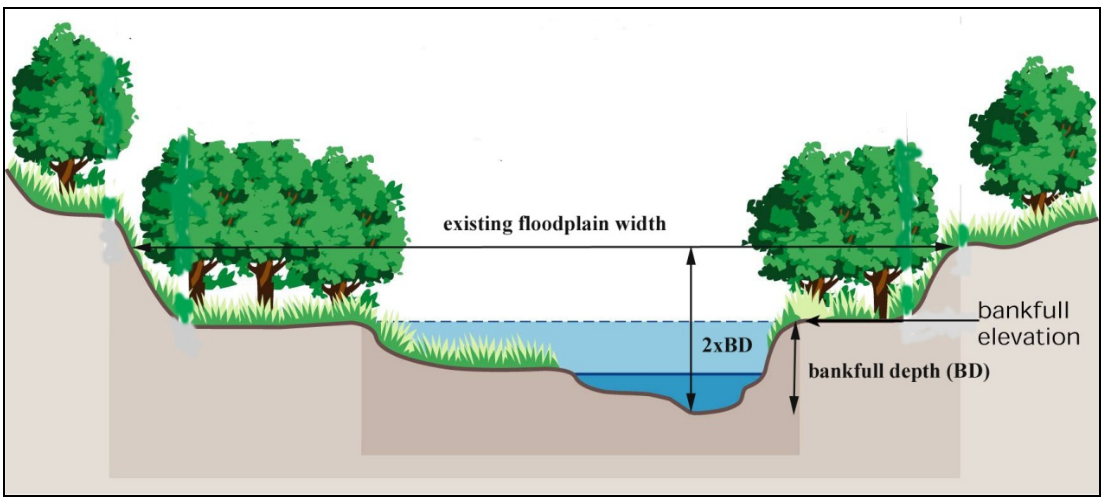

Figure 3.2-4. Schematic of a hypothetical cross section showing the method used to estimate existing floodplain widths.

[57] Typical elevation increase of large river restoration projects in the Great Basin.

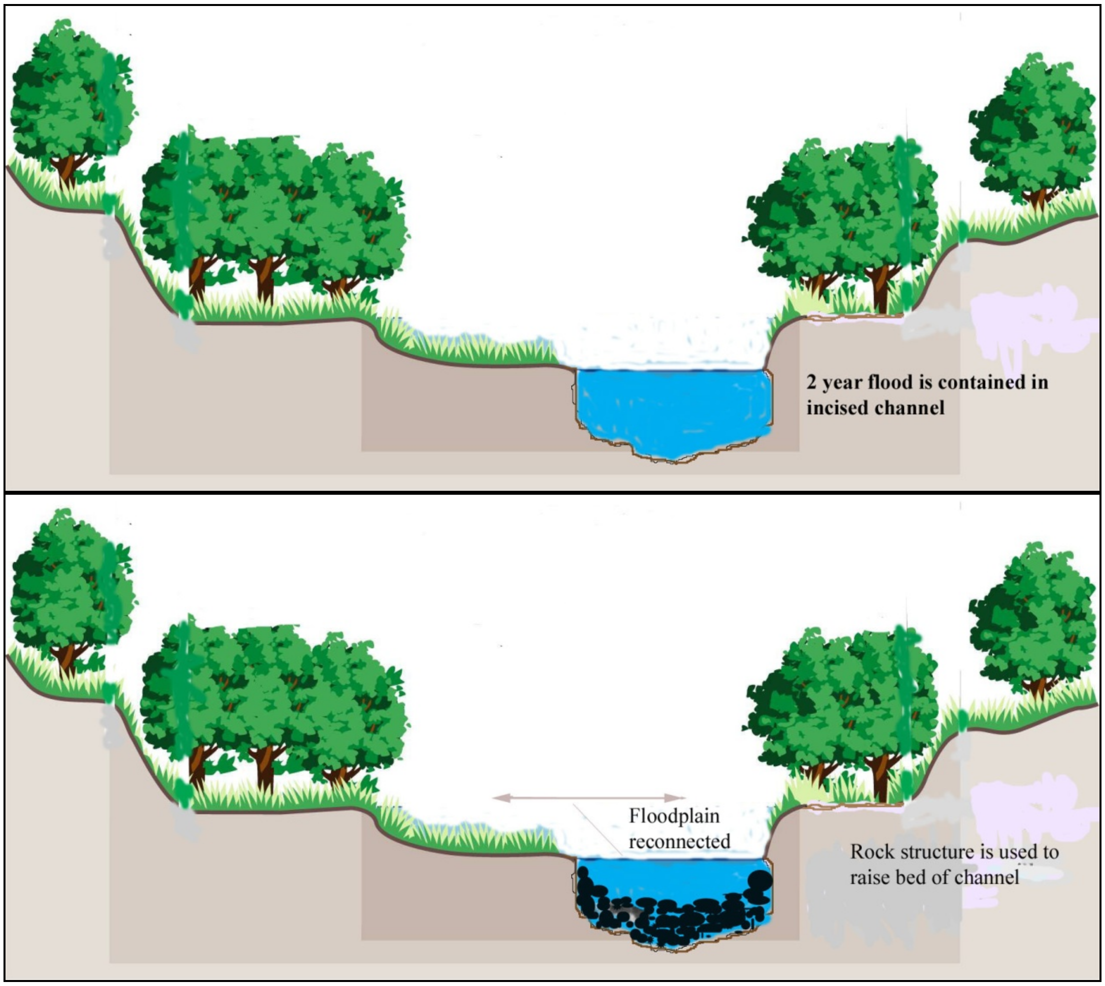

Figure 3.2-5. Schematic of a hypothetical cross section showing the method used to estimate potential floodplain widths.

(11) The *amount of existing riparian forest* describes areas of riparian vegetation connected to the floodplain or the associated water table. Initial restoration activity should focus on preservation of the existing forest patches. Riparian forest vegetation acreage is determined from ArcGIS coverage of the riparian forest mapping units for mature Fremont cottonwood forest with a xeric shrub understory, mature Fremont cottonwood forest with a riparian shrub understory, riparian shrublands, and early successional riparian shrublands described in Section 2.2.1.4. The calculated acreages of riparian forest vegetation are shown in Table 2.2-3. When determining riparian vegetation cover, the scoring criteria consists of groups of trees (cottonwoods and/or willows) of five or more individuals, each within 100 feet of another individual tree within that group. Acreages are determined by drawing polygons around qualifying groups of trees and then calculating the area. The sites are then scored according to the relative number of potentially preserved acres of riparian forest compared to the mapped area for the river reach. *Existing riparian forest*, measured in relative acres, scores as follows: 100-91% (very abundant) =5; 90-61 (abundant) = 4; 60-11 (moderately abundant) = 3; 10-2 (sparse) = 2; 1-0 (absent) = 1.

(12) Assessment of the *quality of existing riparian forest* is based on field observation and aerial photography analysis. Several vegetation communities exist that fall within the general category of riparian forest. These communities show differences in their ability to persist and their use as habitat for riparian obligate animal species. The presence of riparian-obligate bird species, which can be easily surveyed, may be used as an indicator of habitat quality. High quality bird habitat has a complex, multi-canopied structure, giving increased value to riparian vegetation with a cottonwood overstory. Cottonwood forests with riparian forest understories may show recruitment in high flood years, given that the forests are within the floodplain. The riparian shrub vegetation, like the previous two categories are vital to riparian ecosystems, but are less indicative of quality habitat for bird species. Riparian shrub patches that are close to the river, are likely to remain riparian shrub and are not in need of active restoration. Cottonwood forest with xeric understories will lose overstory canopies once the cottonwoods pass maturity. These patches will transition into xeric shrublands without recruitment by riparian species. *Quality of existing riparian forest* is assessed by the dominance of the preferred vegetation types: cottonwood forest with riparian understory, within the floodplain (excellent) = 5, cottonwood forest with riparian understory outside of the floodplain (above average) = 4, riparian shrub (average) = 3, cottonwood forest with xeric understory (below average) = 2, absence of native riparian vegetation in the floodplain (undesirable) = 1.

(13) *Potential for riparian forest recovery* accounts for the physical characteristics of a given site including potential for flooding, erosion, scour, deposition, and river migration. A lower score for riparian forest recovery potential can result from a high degree of entrenchment, confined channel conditions, limited space available for recovery due to development, or a combination of these factors. In addition, a segment that did not historically support a broad riparian forest, such as Segment WW6, would receive a low score for this criterion.

Depth to ground water is the most important factor in determining *potential riparian forest recovery*. For example, cottonwood trees only persist where the ground water surface is within approximately seven feet of the surface. Ground water levels deeper than seven feet usually result in upland vegetation conditions. In determining this score, we estimate that the lowest ground water levels occur during baseflow periods following irrigation season, and that beneficial restoration activities will result in raised stream bed elevations. Raising the stream bed at hydraulic controls such as riffle crests will raise the baseflow water surface elevation, and thus the lowest ground water levels. Previous channel restoration suggests that an increase of two feet in base flow water surface elevation is to be expected. The depth of the groundwater is determined by taking a ground water elevation that matches the base flow level elevation in the river. The restored/raised base flow surface elevation is extrapolated horizontally and used as the ground water level during the driest part of the year. Finally, the acreage of all floodplain areas is measured where the groundwater is within nine feet or less of the ground surface. Nine feet is the depth to ground water used with an increased stream bed elevation that will bring the nine foot depths within the seven foot range needed for cottonwood trees to persist. These sites are then scored according to the number of potentially restored acres of riparian forest. The *potential for riparian forest recovery*, measured in relative cover, scores as follows: 100-61 (high) = 4; 60-9 (moderate) = 3; 8-2 (low) = 2; and 1-0 (very low) =1.

(14) The *amount of naturally existing wetlands* is calculated within each river segment. The acreage of existing wetlands is determined by calculating the combined coverage of the emergent marsh and wet meadow vegetation types described in Section 2.2.1.4. These areas intentionally exclude features such as stock ponds, flood irrigated fields, or other man-made areas that have the appearance of wetlands, but do not provide the same ecological function as natural wetlands. Ground truthing of the vegetation map shows that the combination of the wet meadow and emergent marsh vegetation classes were mapped with 97% accuracy. The acreages of both classes are shown in Table 2.2-3. The amount of existing wetland is ranked by the relative wetland cover compared to the mapped area in each segment as follows: 100-91 = 5 (very abundant); 90-61 = 4 (abundant); 60-11 = 3 (moderately abundant); 10-1 = 2 (sparse); and 0 acres = 1 (absent).

(15) The *quality of naturally existing wetlands* is ranked within each segment based on a comparison perimeter to area ratio of wetlands in each segment. Decreased perimeter to area ratios indicate that there is more core habitat and often less anthropogenic disturbance due to connected habitat, which favors disturbance sensitive species. Although emergent marsh / wetland vegetation is dominated by species that invade river channels and reduce water velocity, these areas are important to sensitive wildlife species such as rails and bitterns. Common plant species found in emergent marshes include bulrush (*Scirpus acutus*), cattail (*Typha latifolia*). The wet meadow vegetation type has little or no open water and no woody vegetation. This vegetation type is commonly used by amphibian and small mammal species such as voles and shrews. Dominant plant species include Nebraska sedge (*Carex nebrascensis*), Baltic Rush (*Juncus balticus*), spikerush (*Eleocharis* sp.), various grass species such as reed fescue (*Festuca arundinacea*) and velvet grass (*Holcus lanatus*). This assessment is completed using vegetation mapping results to calculate the perimeter to area ratio of the combination of these vegetation classes. The smallest ratio of perimeter to area found in each segment, will be used to rank that segment, as this will describe the greatest amount of core wetland habitat in that segment. As there are 24 segments, the eight segments with the lowest ratio will receive a score of 3 (high quality), any segments fall within the middle of the ranking will receive a moderate quality score of 2, and the last eight, some of which will not contain wetland habitat will receive a score of 0 (low quality).

(16) *Potential to increase wetlands* is based on both the presence of existing wetlands and the hydrology that would support wetland species. A GIS layer is created from an extrapolation of the restored/raised base flow surface elevation. Areas will be selected where the surface soil is expected to be inundated throughout some part of the year. If existing wetlands are present within the inundated areas, it is expected that wetlands will increase passively in those areas. If existing wetlands are not present within inundated areas, active restoration would facilitate an increase in wetlands. Therefore the *potential to increase wetlands* is rated by the dominance of the following conditions: inundated areas where wetlands are present = 2 (high), inundated areas where wetlands are absent = 1 (moderate), absence of inundated areas = 0 (low).

(17) *Amount of tamarisk* is of concern in riparian ecosystems because this species has the ability to greatly reduce the cover of native plant species, facilitate the invasion of perennial pepperweed (*Lepidium latifolium*), and alter site hydrology by establishing in areas that are too xeric for native riparian species and simultaneously accessing groundwater. The amount of tamarisk is rated by both dominance and presence: tamarisk absent from the segment = 5, tamarisk present in the segment but not mapped as patches = 4, tamarisk present in the segment as patches = 3, relative tamarisk cover > 25% but <50% = 2, relative tamarisk cover >50% = 1.

(18) Once introduced, the *amount of noxious weeds* can be favored by the same conditions that favor native plant species. It is important to ensure that restoration efforts are not thwarted by promoting noxious weeds. Noxious weeds should be treated in initial restoration efforts. The Nevada Department of Agriculture has three categories of invasive weeds. Category A includes weeds that are not found or are limited in distribution throughout the state; actively excluded from the state and actively eradicated wherever found; actively eradicated from nursery stock dealer premises; control required by the state in all infestations. Category A species found in the Walker River Basin include hydrilla (*Hydrilla verticillata*), houndstongue (*Cynoglossum officinale*), sow thistle (*Sonchus arvensis*), spotted knapweed (*Centaurea maculosa*) and yellow starthistle (*Centaurea solstiltialis*). As hydrilla is particularly difficult to eradicate and can be spread when segments break loose, any river segment with hydrilla will rank low in regards to restoration potential. Eradication of other weeds is most effective before flowering. As phenology differs amongst species, sites will be rated based upon the number of noxious weed species that it contains. Therefore the amount of noxious weeds will be ranked as: presence of hydrilla = 1, presence of four noxious weed species = 2, presence of three noxious weed species = 3, presence of one or two noxious weed species = 4, absence of all Category A noxious weed species = 5.

(19) *Degree of historic alteration to cottonwood forests* is being used as an indicator of the degree of historic alteration to the riparian vegetation in the Walker River Basin. Cottonwoods were selected because they are relatively easy to identify in aerial photographs from 1938, 1956, and 2006. Additionally, cottonwoods are phreatophytes, meaning that they are connected to the water table. They are therefore the most persistent riparian species in regards to changes in hydrology. To assess this criterion, all aerial photographs that could be obtained from 1938 and 1956 were georeferenced. The presence and cover of cottonwood forests in each series of photographs were compared with cottonwood forest classes that exist as a result of the 2007 vegetation map: mature cottonwood forests with a xeric understory and mature cottonwood forests with a riparian understory. The vegetation map was created with the 2006 aerial photographs.

In each river segment, two polygons of each cottonwood forest type were randomly selected. These polygons were examined in the 1938 and 1956 photos to assess if cottonwood cover had increased, decreased, or stayed the same between from the historical photo when compared with the current photos. Degree of historic alteration to Cottonwood forests are ranked by river segment as having a majority of surviving or increasing patches = 2, or a majority of declining cottonwood patches = 1.

(20) *Degree of regular vegetation disturbance* is assessed as frequent disturbance alters plant community structure, favoring ruderal and often non-native plant species. Communities classified as "agriculture" on the 2007 vegetation map include areas that have been used for farming and grazing lands. The relative area of mapped agriculture compared to the total mapped area for a particular river segment is being used to assess the degree of regular vegetation disturbance. Therefore, areas with light to no disturbance are ranked higher in regards to restoration potential: 0-20% agriculture = 5, 21-40% agriculture = 4, 41-60% agriculture = 3, 61-80% agriculture = 2, 81-100% agriculture =1.

(21) *Connection to landscape features* describes the channel's existing interaction with natural features and habitats such as oxbow ponds, wetlands, certain upland habitats, canyons or springs. Natural landscape features or uncommon habitats often enrich the biodiversity of a river segment and are considered in our assessment because they add to the overall diversity of the riverine biota. Both field surveys and aerial photographs are used to determine the presence and connectivity of the above listed landscape features. A high number of landscape features receives a high score, while none or very few receives a low score: >8 (very high) = 5; 8-7 (high) = 4; 6-5 (moderate) = 3; 4 (low) = 2; and ≤ 3 (very low) = 1.

(22) *Restoration continuity* scores segments based on their proximity to other high scoring segments. By restoring adjacent segments, a more continuous restored river corridor can be created which provides greater potential ecological benefits than isolated projects can provide. Segments adjacent to high scoring segments up and downstream = 4, segments adjacent to either an up or downstream segment = 2, segments not adjacent to any high scoring segments = 0.

Applying this scoring system will generate a prioritized list of restoration sites. At the top of the list will be those segments showing the most potential for restoration success and potential to increase water quality. In order to move to this step, decisions must be made regarding the priorities for restoration in the Basin. USFWS will weigh the comments of a select group of scientists and professionals to comment on rating criteria and determine what factors are most important in determining the appropriate set of rating criteria. Once the final set of rating criteria has been selected, then the system can be applied and ratings can be made. The final rating of segments will provide a score that will rank segments according to their viability as restoration areas.

4 LIST OF ACRONYMS AND ABBREVIATIONS

ASTM- American Society for Testing and Materials

BLM- Bureau of Land Management

BMPs- Best Management Practices

BOR- Bureau of Reclamation

CalTrans- California Department of Transportation

CDFG- California Department of Fish and Game

Corps- United States Army Corps of Engineers

DEM- Digital Elevation Model

DLG- Digital Line Graph

DOS- Disk Operating System

DRI- Desert Research Institute

DTLP- Desert Terminal Lakes Program

DWR- Department of Water Resources, California

EPT- Ephemeroptera, Plecoptera, and Tricoptera

GAO- General Accounting Office

GBBO- Great Basin Bird Observatory

GIS- Geographic Information System

GPS- Global Positioning System

HAR- Height Above River Model

HEC-RAS- Hydraulic Engineering Center River Analysis System, version 3.1.3, developed by the U.S. Army Corps of Engineers

IFIM- Instream Flow Incremental Methodology

IHA- Indicators of Hydrologic Alteration

LiDAR- Light Detection and Ranging, a remote sensing system used to collect topographic data

MVWMA- Mason Valley Wildlife Management Area

NAD- North American Datum

NAIP- National Agriculture Imagery Program

NDOW- Nevada Department of Wildlife

NFH- National Fish Hatchery

NRCS- Natural Resources Conservation Service

OBEC- Otis Bay Ecological Consultants

OHV- Off-highway Vehicle

PIF- Partners in Flight

RHJV- Riparian Habitat Joint Venture

RMSE- Root Mean Square Error

TDS- Total Dissolved Solids

UNR- University of Nevada, Reno

USDA- United States Department of Agriculture

USFS- United States Forest Service

USFWS- United States Fish and Wildlife Service

USGS- United States Geological Survey

WEPP- Watershed Erosion and Prediction Project

WRID- Walker River Irrigation District

WRPT- Walker River Paiute Tribe

5 GLOSSARY OF TERMS

Accretion- The accumulation of mass to a surface. In the case of floodplain accretion this is accomplished through deposition of sediment, and the extension of the existing floodplain.

Aggradation- A trend toward increasing mean stream bed elevation usually through accumulation of sediment.

Alluvial- Pertaining to stream processes and particularly depositional environments.

Attenuation- In this context, the process t hat decreases the magnitude of flood peaks and slows their downstream travel time.

Avulsion- A process by which a river leaves its current channel and establishes a new path, sometimes during a single event.

Basalt- A general term for dark colored igneous rocks that are commonly extrusive, and encompassing rocks such as andesite.

Baseflow- A stream discharge that characterizes the annual low flow regime, typically fed by groundwater in natural systems, but could be unnaturally supplemented by reservoir releases or agricultural return flow.

Basin- Referring to the catchment area of a stream system. In this context the term shares a definition with watershed.

Basin and Range- Specifically referring to a region in western and southwestern North America typified by tectonically tilted faults blocks forming north-south trending mountain ranges separated by intervening valleys or basins.

Breccia- A sedimentary rock composed of large (> 2mm) angular rock fragments set in a fine grain matrix such as sand or silt and commonly cemented by calcium carbonate, hardened clay, or iron oxide.

Channelization- The process in which a river or stream is straightened. This results in increased water velocity which carries more sediment and will deepen a river channel. Deeper channels tend to have relatively high and unstable banks which are low in vegetative cover.

Conglomerate- A sedimentary rock composed of large (> 2mm) rounded rock fragments set in a fine grain matrix such as sand or silt and commonly cemented by calcium carbonate, hardened clay, or iron oxide.

Cross-section- A dimension of stream geometry that defines a cross-stream view perpendicular to the mean direction of flow.

Degradation- A trend toward decreasing mean stream bed elevation usually through evacuation of sediment.

Diel- Referring to a 24-hour period usually used to record the fluctuation of a physical process, such as a diel temperature fluctuation.

Digitize- The act of creating an electronic representation of a feature found within a landscape, usually achieved in a GIS.

Ecosystem enhancement- The act of attempting to improve the health and functionality of a community of organisms and the physical environment in which they interact.

Effective Discharge- The discharge that, over time, is responsible for transporting the majority of the annual sediment load through a given reach.

Extrusive- Referring to rocks that were formed at or near the Earth's surface volcanically.

Fault- A break in the Earth's crust that accommodates tectonic movement, found in various forms including normal, thrust, and strike-slip.

Fine- Referring to the resolution of an image where more detail can be seen in a finer image than a coarser image.

Flood of record- The highest observed river stage or discharge at a given location during the period of record keeping. (Not necessarily the highest known stage).

Fluvial- General term for processes, organisms, or materials produced by, acting on or within river systems.

Geomorphology- The study of landscape forms and processes.

Geo-reference- The act of defining a spatial position for a digital image.

GIS- Abbreviation for Geographic Information Systems.

Graben- A relatively depressed block of the Earth's crust that is bound be faults along its long edges, topographically expressed as a valley bound by mountain ranges along fault lines.

Granite- A general term for rock types that are crystalline, quartz bearing plutons[58], and encompasses rock types such as granodiorite.

[58] A body of igneous rock that formed beneath the Earth's surface by crystallization of magma.

Flood attenuation- The process that decreases the magnitude of flood peaks, and slows their downstream travel time.

Ka- An abbreviation for the term Kilo-anum, which refers to a period of 1 thousand years, i.e. 500 Ma is 500,000 years.

Lacustrine- Pertaining to lake or wetland processes and particularly depositional environments.

Ma- An abbreviation for the term Mega-anum, which refers to a period of 1 million years, i.e. 5 Ma is 5,000,000 years.

Meander- One of a series of regular, freely developing sinuous curves, bends, or loops in the course of a river.

Moraine- A feature of glacial landscapes composed of material pushed to the side (lateral moraine) or front (end moraine) of a glacial ice mass.

Normal-fault- A type of fault where movement is accommodated by the downward movement of a block of the Earth's crust, usually produced by extension of the Earth's crust.

Physiographic Region- An area in which all parts are similar in geologic structure, and whose subsequent geomorphic history is unified and distinct from adjacent regions.

Planform- A dimension of stream geometry referring to an aerial, or map view of the stream.

Pluton- A body of igneous rock that formed beneath the Earth's surface by crystallization of magma.

Polygon- A polygon is a shape whose interior shares a common attribute.

Riparian Area- A region situated on or near the banks of a river that provides an interface between stream and upland physical and biological systems.

Sandstone- A sedimentary rock type formed by the deposition and lithification of sand in various depositional environments.

Shale- A sedimentary rock type formed by the deposition and lithification of fine grain material such as silt or clay.

Sinuosity- A measure of stream curvature that is calculated by dividing the stream length between two points by the straight line distance between those same points.

Tectonics- A geological theory that holds that the Earth's outer crust is broken into plates that move relative to one another.

Total Dissolved Solids- The amount of all dissolved solids in water, primarily consisting of minerals and salts, but may also include organic matter.

Xeric- Pertaining to an arid or hyperarid climate where the loss of moisture from evapotranspiration exceeds the moisture received from precipitation.

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