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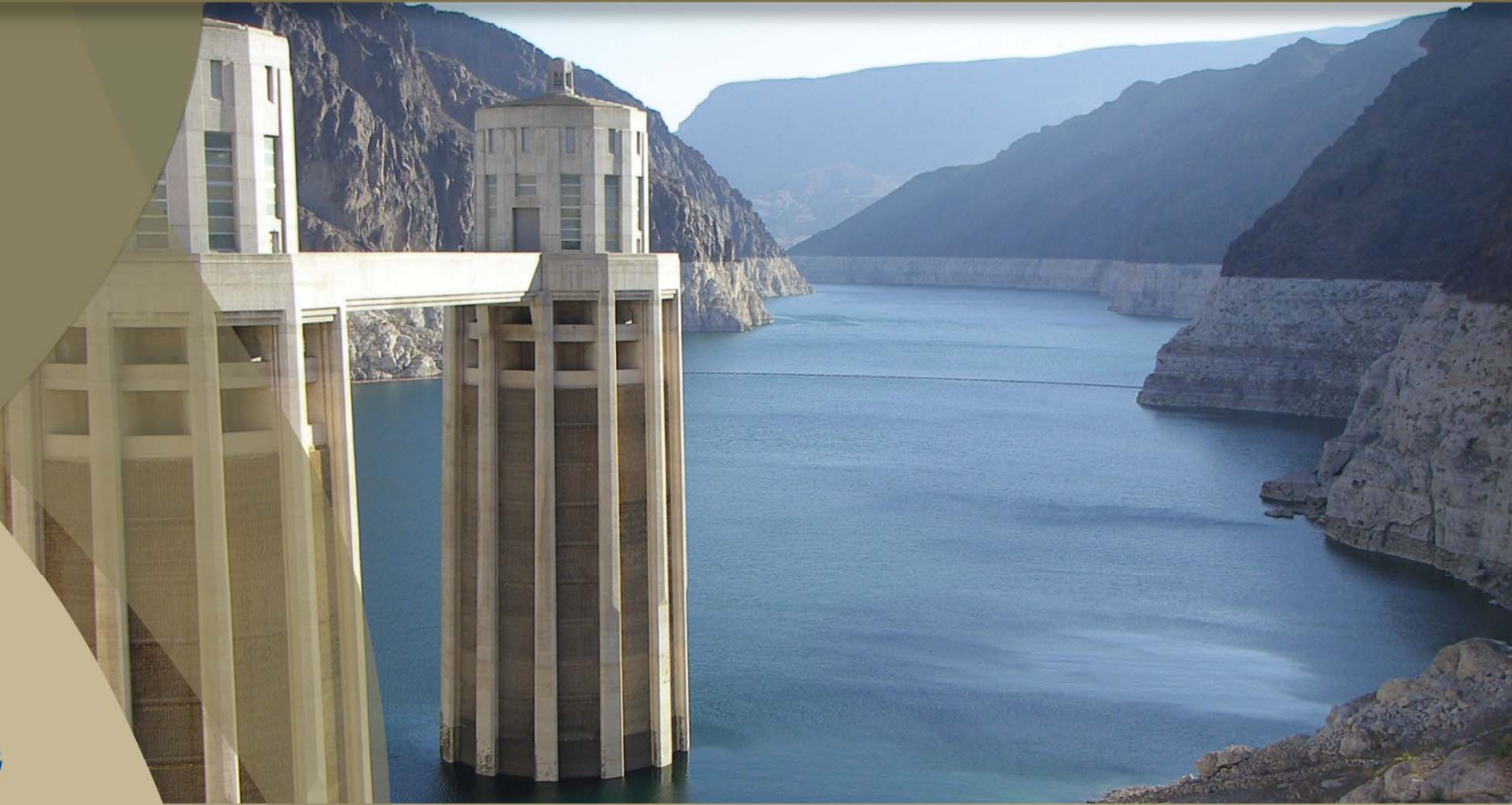
SOUTHERN NEVADA
WATER AUTHORITY

Presentation For:

McClendon Testimony

TERRY MCLENDON
ECOLOGIST

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EDUCATION

BSc	Range Management	Texas Tech University	1971
MSc	Range Science	Colorado State University	1973
PhD	Range Ecology/Statistics	Texas Tech University	1979

SUMMARY

Dr. McLendon has 40 years research and consulting experience in the areas of plant ecology, restoration of disturbed lands, ecological modeling, ecological risk assessment, range and land management, watershed dynamics, and statistical ecology. He is the originator and co-developer of the EDYS ecological model, has authored or co-authored over 120 scientific and technical publications, has been a faculty member at three universities, and currently serves on the adjunct faculties at Texas Tech University and Colorado State University. Dr. McLendon has served as expert witness in litigation support relative to effects of hazardous materials on plants and animals and on effects of groundwater withdrawal on vegetation, has provided testimony to regulatory agencies both nationally and internationally, and has taught shortcourses for the National Park Service (vegetation sampling and monitoring and vegetation restoration), USEPA (statistical ecology, ecological risk assessment), and Montana Department of Environmental Quality (water-balance cover designs, land application of waste water). Dr. McLendon has been author or co-author on over 70 presentations at scientific meetings.

Dr. McLendon has managed over $ 14 million in research and consulting projects in 15 states (AZ, CA, CO, HI, ID, IL, KS, ME, MT, NM, NV, TX, UT, WA, WY), Australia, Indonesia, Mexico, and Peru. His areas of expertise include ecological modeling, vegetation-groundwater linkages, design of water-balance covers for mined-land reclamation, secondary ecological succession, restoration ecology, and vegetation sampling.

PROFESSIONAL EXPERIENCE

2007-date	Ecological Consultant	KS2 Ecological Field Services LLC
2001-2006	Principal Scientist	MWH Inc.
2001-2005	Business Unit Manager	MWH Inc.
1998-2001	Vice President	Shepherd Miller Inc.
1996-1998	Associate Professor	University of Texas at El Paso
1996-1998	Director Indio Mtn Res Sta	University of Texas at El Paso
1992-1996	Senior Research Scientist	Colorado State University
1991-1992	Research Scientist	Colorado State University
1989-1991	Post-doctoral Research Fellow	Colorado State University
1982-1989	Ecological Consultant	Kingsville, Texas
1981-1982	Associate Research Scientist	Texas A&M University
1975-1981	Assistant Professor	Texas A&M University
1973-1975	Graduate Research Assistant	Texas Tech University
1971-1973	Graduate Research Assistant	Colorado State University
1970-1971	Student Research Assistant	Texas Tech University

Potential Effects of Change in Depth to Water on Vegetation in Spring Valley, Nevada

PRESENTATION TO THE OFFICE OF THE NEVADA STATE ENGINEER

Prepared for
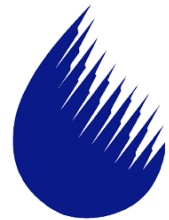
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Prepared by

June 2011

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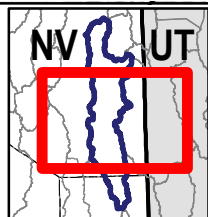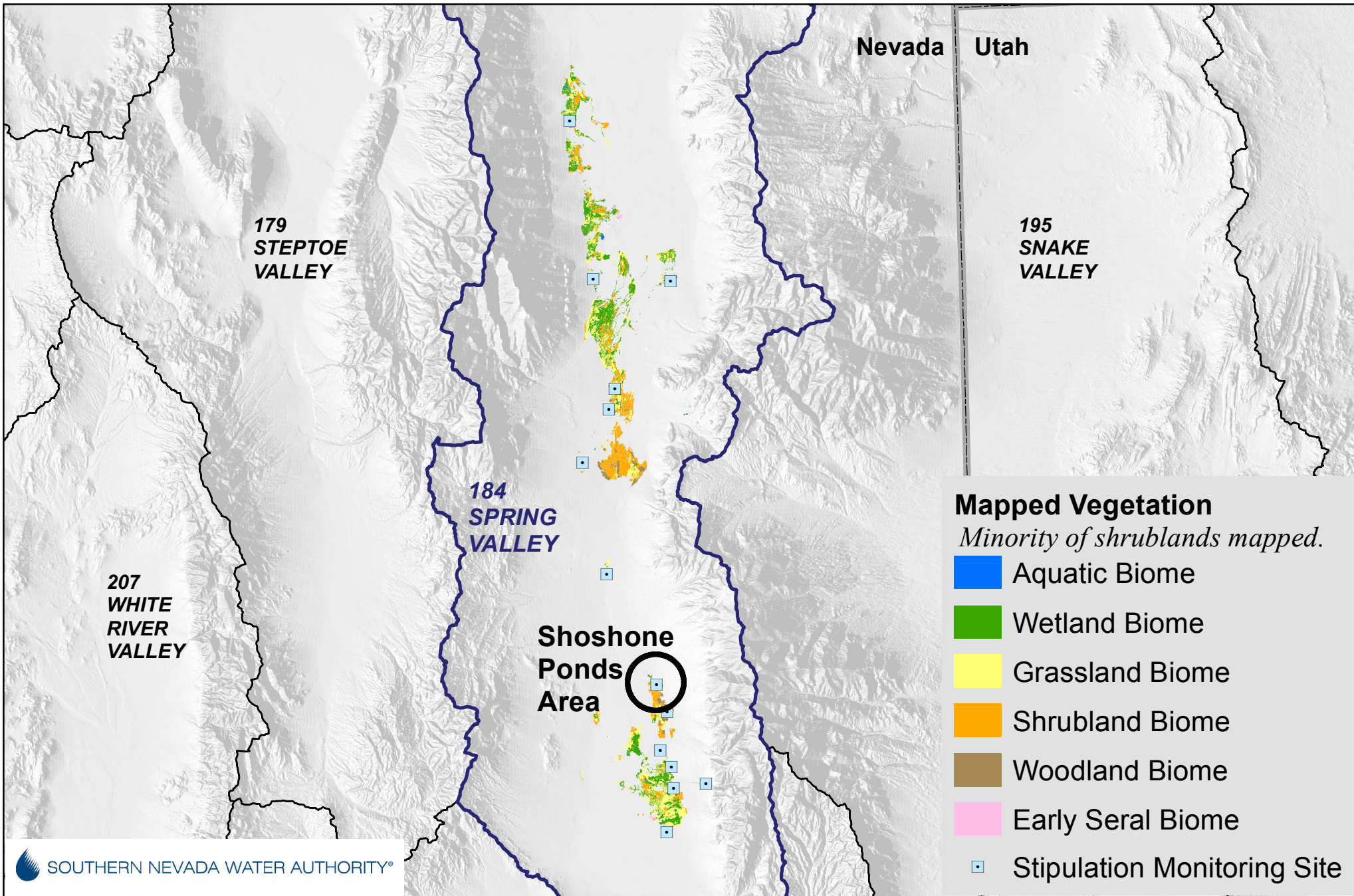
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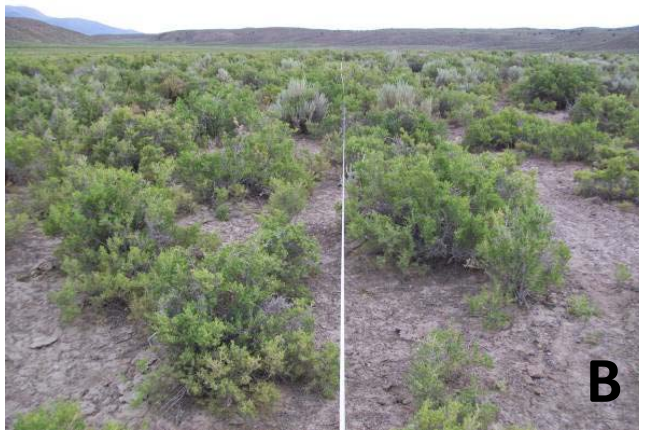
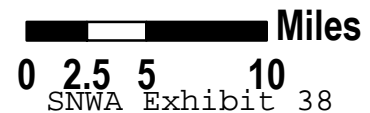Note: (A) woodland, (B) shrubland, (C) grassland, (D) wetland, (E) aquatic, (F) early-seral

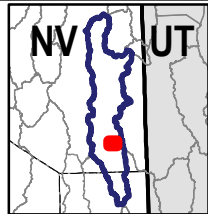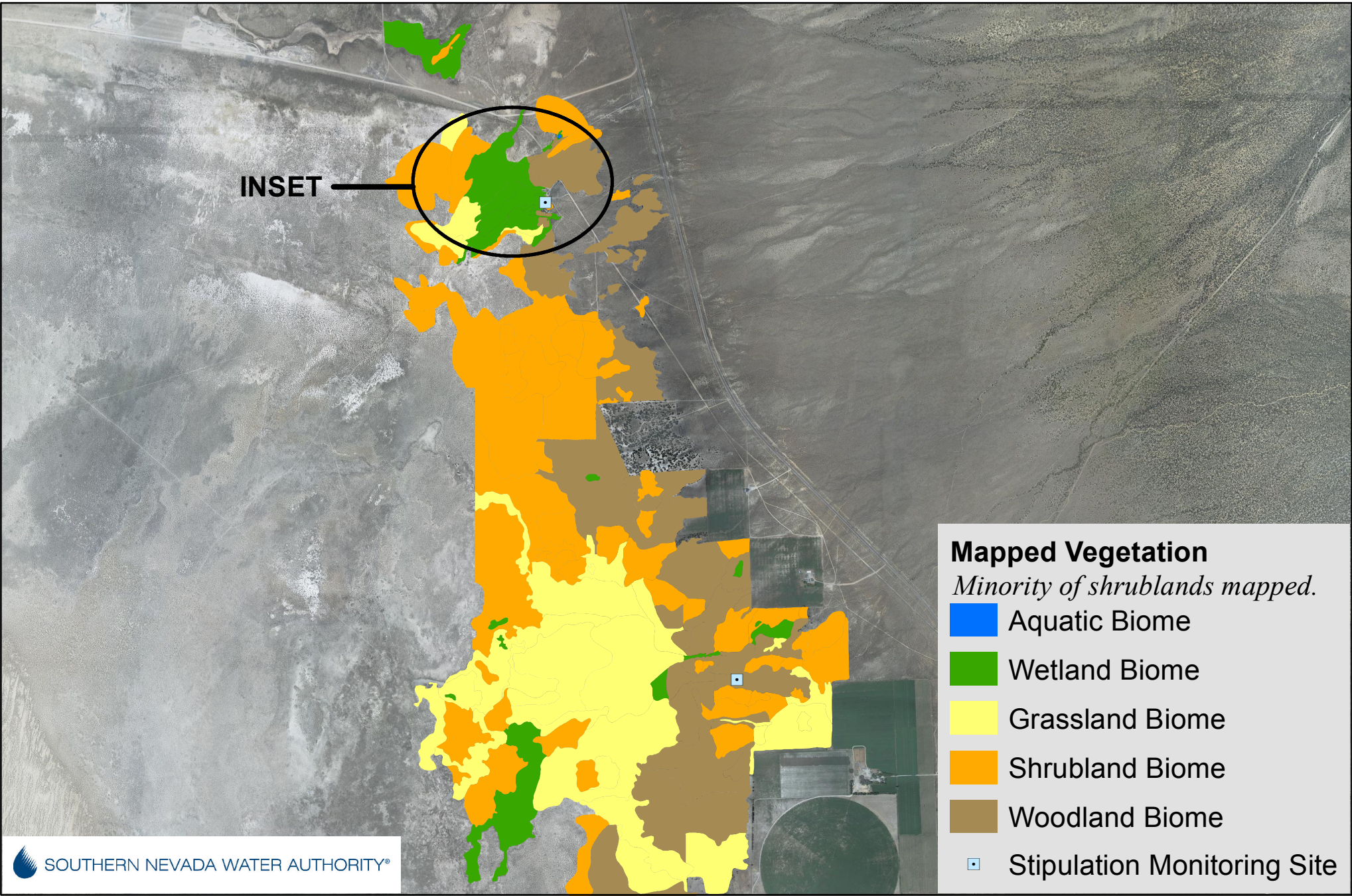**Figure 2-1**
Spring Valley Examples of the Six Biomes

Mapped Vegetation in Spring Valley (2008, 2009)

Northern Spring Valley not shown.

MAP 18627-3652 06/21/2011 NB

SNWA Exhibit 38

INSET

Mapped Vegetation
Minority of shrublands mapped.

Aquatic Biome

Wetland Biome

Grassland Biome

Shrubland Biome

Woodland Biome

◻ Stipulation Monitoring Site

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MAP 18628-3652 06/21/2011 NB

Mapped Vegetation, Shoshone Ponds Area (2008)

Miles

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SNWA Exhibit 38

Mapped Vegetation

Minority of shrublands mapped.

- Aquatic Biome
- Wetland Biome
- Grassland Biome
- Shrubland Biome
- Woodland Biome

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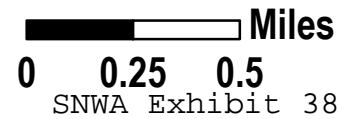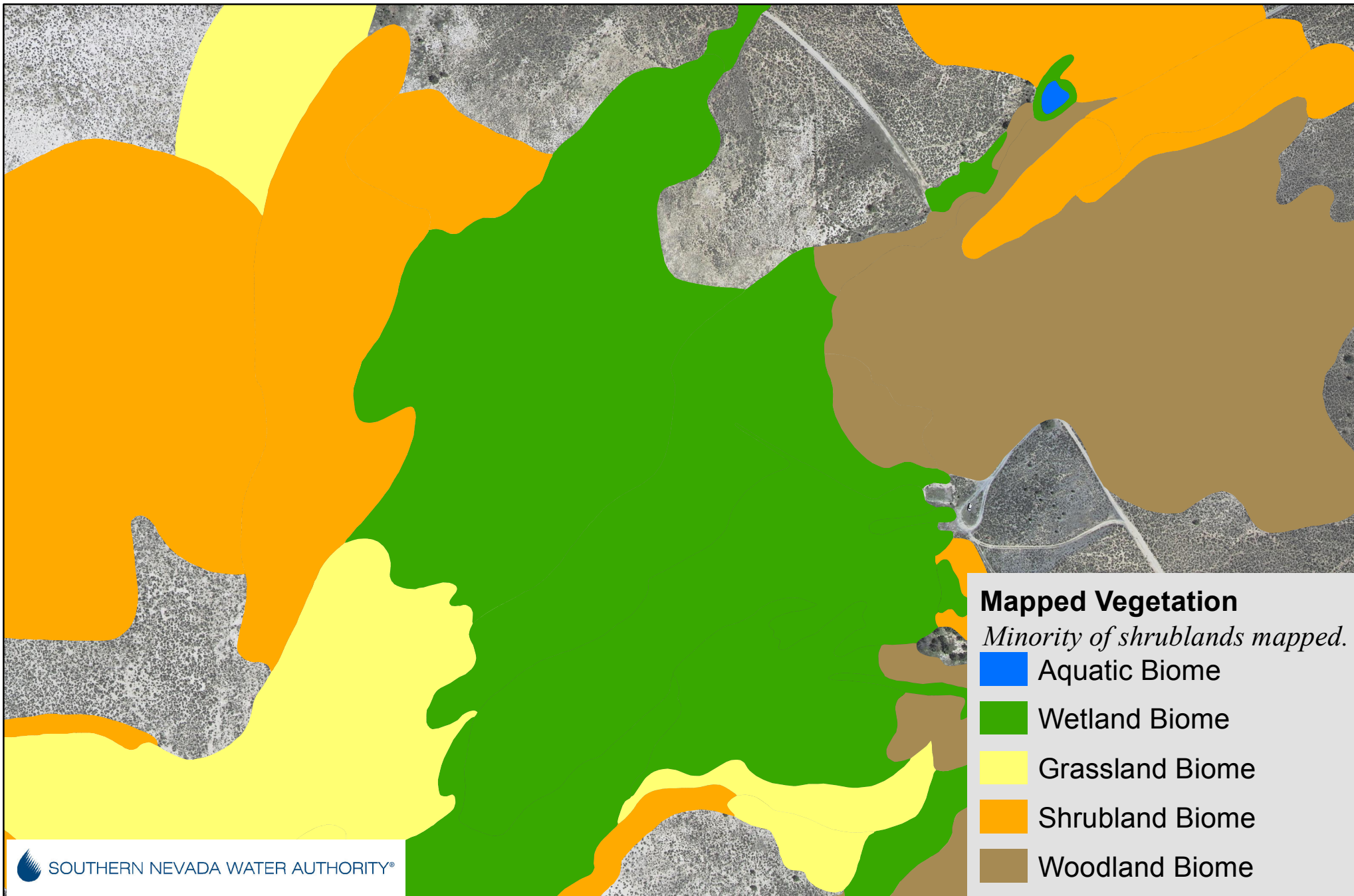
MAP 18630-3652 06/21/2011 NB

Vegetation Mapping, Shoshone Ponds Area (2008)

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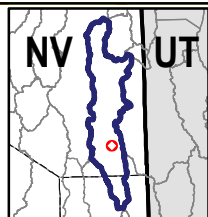
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SNWA Exhibit 38

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Vegetation Mapping, Shoshone Ponds Area (2008)

High Resolution (6 inch) Aerial Imagery
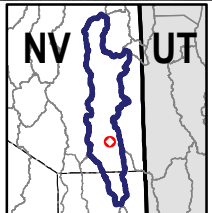
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SNWA Exhibit 38

Vegetation Mapping, Shoshone Ponds Area (2008)

Field Map of Vegetation Communities on Aerial Imagery
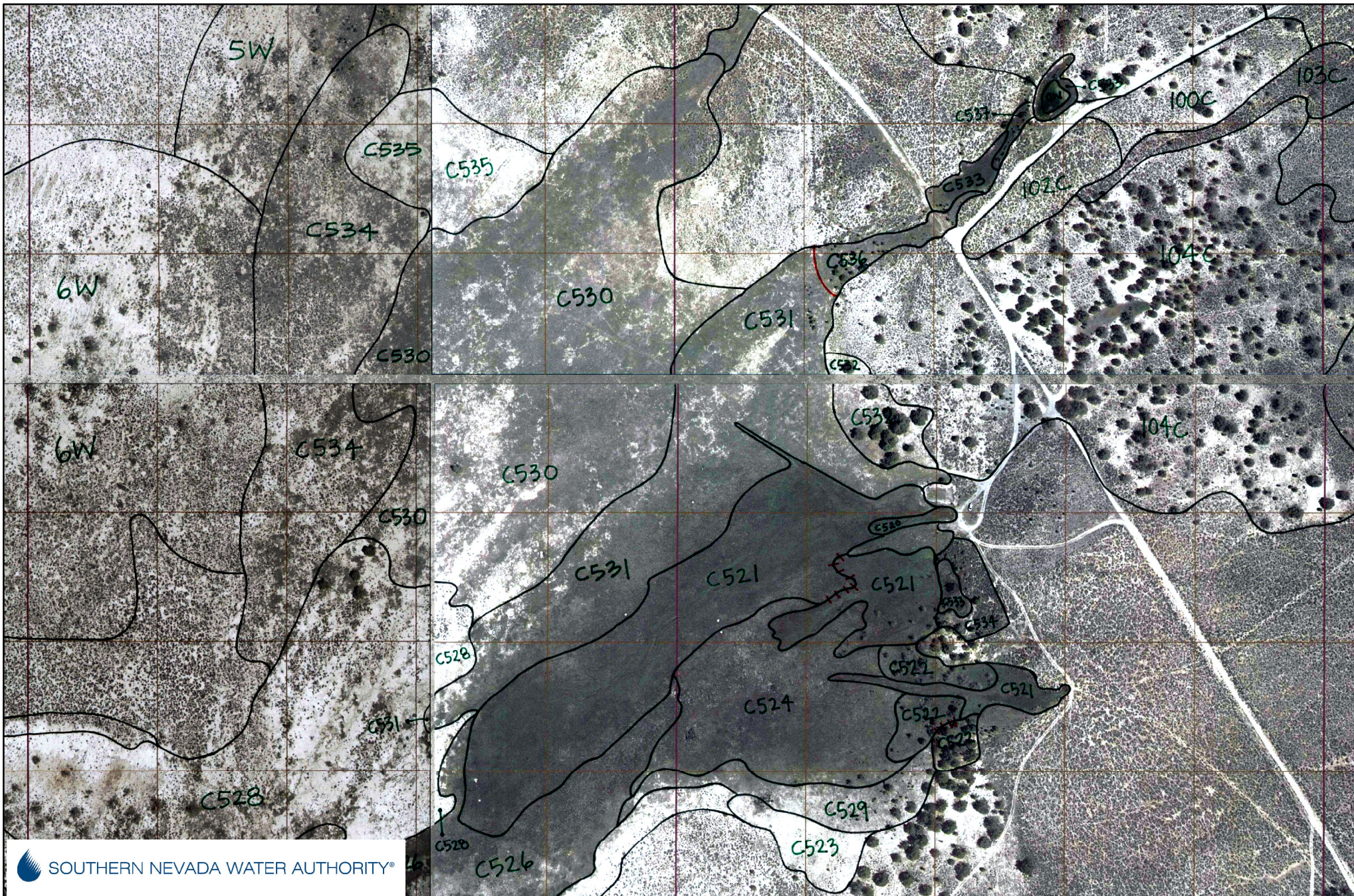
MAP 18631-3652 06/21/2011 NB

SNWA Exhibit 38

Meters
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Vegetation Mapping, Shoshone Ponds Area (2008)

Biome Designation for Vegetation Communities

Mapped Vegetation
Minority of shrublands mapped.
- ☐ Vegetation Communities
- ▦ Aquatic Biome
- ▦ Wetland Biome
- ▦ Grassland Biome
- ▦ Shrubland Biome
- ▦ Woodland Biome

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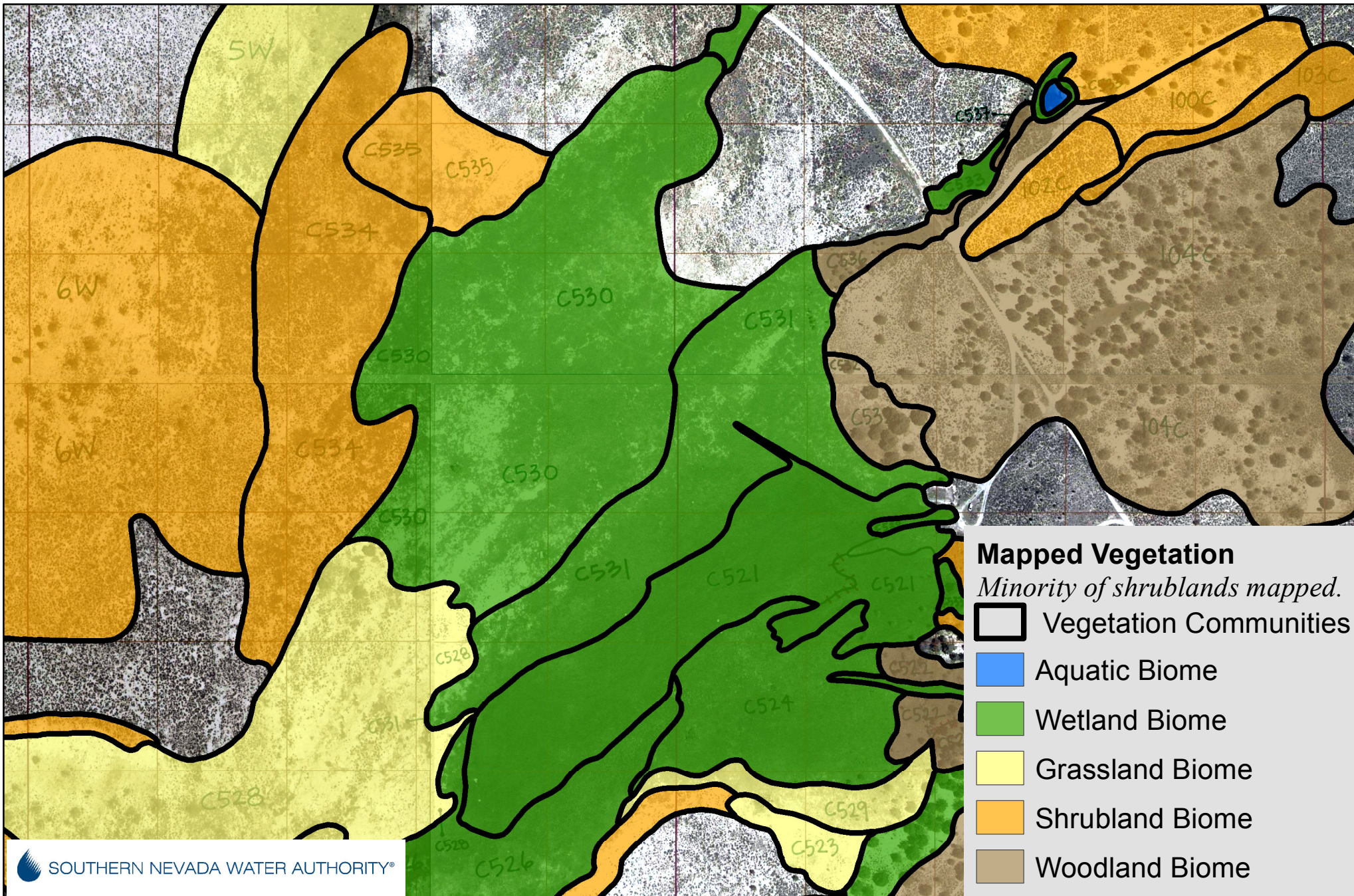
MAP 18629-3652 06/21/2011 NB

SNWA Exhibit 38

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Meters
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Table 2-1
Definitions of Biomes Used to Classify Vegetation Units
and Amount of Area Mapped in Spring Valley (2008-2009)

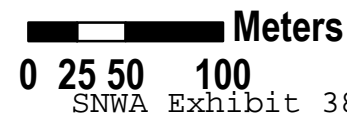| Biome	Definition	Mapped Area (ha)	Mapped Area (ac)
Woodland	Area where trees (woody plants greater than 3 m tall) are the dominant or subdominant species.	460	1,136
Shrubland	Area where shrubs (woody plants less than 3 m tall) are the dominant or subdominant species.	2,990	7,385
Grassland	Area dominated by grasses and not perennially covered by water.	2,798	6,911
Wetland	Area where the soil is saturated for most of the year, but not perennially covered by water, and not dominated by grasses.	3,175	7,842
Aquatic	Area perennially covered by water and supporting plants.	28	69
Early-seral	Area devoid of plant cover or supporting plants characteristic of early stages of succession[a].	77	190

[a]The term succession is used throughout this document. Succession can be defined as the progressive replacement of one plant community by another, generally terminating in a relatively stable community (Smith, 1992). In its simplest terms it is change in vegetation composition at a given location over time (Billings, 1970). The community progression that defines a specific succession (i.e., a sere) is commonly divided into early-, mid-, and late-stages (i.e., seral stages), with early-seral communities generally dominated by annual or short-lived perennial species and late-seral stages dominated by relatively long-lived perennials. As pointed out 350 years ago by Spinoza, "nature abhors a vacuum," and bare ground seldom remains bare for long because of succession (Kormondy, 1996, p. 299). Bare ground represents unutilized resources and plants will exploit these resources over time.
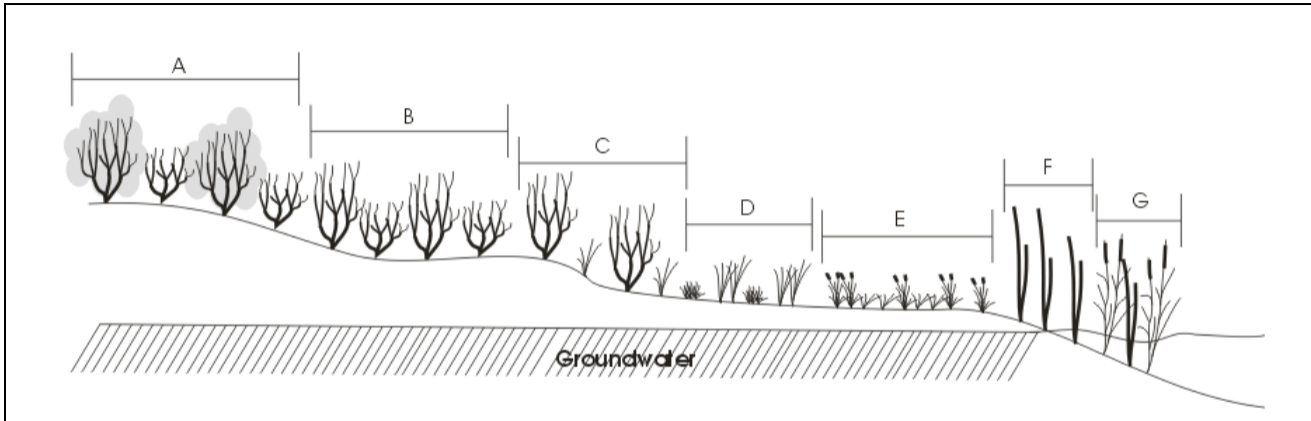
Note: A = big sagebrush-rabbitbrush, B = greasewood-rabbitbrush, C = greasewood-sacaton, D = sacaton-saltgrass, E = Baltic rush-Nebraska sedge, F = bulrush, G = cattail-bulrush.

Figure 3-1
Typical Toposequence of Plant Communities in Spring Valley in Relation to DTW

4.0 SUMMARY OF POTENTIAL SUCCESSIONAL PATTERNS

The patterns and rates of vegetation change will depend on a number of factors. Factors of key importance include (1) initial species composition, (2) rate of groundwater decline, and (3) amount of precipitation received during the transition period. Additional factors that will affect vegetation change include (1) level of livestock grazing, (2) irrigation practices, (3) possible climate change, and (4) frequency and intensity of disturbance factors such as fire.

Plant communities are dynamic over time (Clapham, 1973, p. 123; Veblen, 1992). Their species composition and productivity vary in response to fluctuations and changes in the environmental factors affecting the community. These community changes include both fluctuations (nonsuccessional) and directional (successional) change (Smith, 1992, p. 330). Fluctuations around a long-term average occur because of seasonal, annual, and decadal fluctuations in the levels of the various environmental factors. In dry years for example, productivity decreases and the relative importance of more xeric species within the community increases. In wet years, productivity increases as does the relative importance of more mesic species. Directional change in the community occurs when either (1) the long-term average level of one or more environmental factor affecting community composition shifts or (2) a major disturbance occurs that substantially alters the composition of the community. In both cases, the ecosystem readjusts to the altered conditions through the process of succession.

Succession is the ecological process of vegetation change over time (Billings, 1970) resulting from various species being replaced by other species as ecological conditions at the site change over time (Odum, 1971, p. 251). Primary succession occurs when the substrate has not been significantly affected previously by plants. An example would be a landslide that removed the plant community and supporting soil from a slope, exposing bedrock or rock debris. Secondary succession occurs when the disturbance is of sufficient magnitude to change the plant community but the soil remains. In some cases the disturbance factor can eliminate the existing plant community entirely. Examples include cultivation and very hot fires. In other cases, the disturbance alters the composition and structure of the plant community, but some species remain. Examples of this include sustained over-grazing, severe and long-term drought, and relatively cool fires.

Two major factors causing succession are competitive displacement and stress tolerance (McLendon and Redente, 1992, 1994; Smith, 1992, p. 323). No ecosystems exist that have all environmental factors at optimum levels at all times for all species present. One or more required resources (e.g., nutrients, water, sunlight, temperature, space) or stressors (e.g., fire, grazing, disease) are always suboptimal for each species. However, they are not equally suboptimal for all species nor are all species equally able to tolerate the conditions that exist at the site. As the levels of each of the resources and stressors change, there are corresponding changes in ability of each species to tolerate, or to thrive under, those conditions. These changes affect the ability of each species to secure its necessary resources relative to its associated species (McLendon and Redente, 1991, 1994; Smith

Ecosystem rooting depth determined with caves and DNA

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*Department of Botany and Nicholas School of the Environment, Duke University, Durham, NC 27708; and ‡Section of Integrative Biology, University of Texas, Austin, TX 78713

ABSTRACT Belowground vertical community composition and maximum rooting depth of the Edwards Plateau of central Texas were determined by using DNA sequence variation to identify roots from caves 5–65 m deep. Roots from caves were identified by comparing their DNA sequences for the internal transcribed spacer (ITS) region of the 18S–26S ribosomal DNA repeat against a reference ITS database developed for woody plants of the region. Sequencing the ITS provides, to our knowledge, the first universal method for identifying plant roots. At least six tree species in the system grew roots deeper than 5 m, but only the evergreen oak, *Quercus fusiformis*, was found below 10 m. The maximum rooting depth for the ecosystem was ≈25 m. ^{18}O isotopic signatures for stem water of *Q. fusiformis* confirmed water uptake from 18 m underground. The availability of resources at depth, coupled with small surface pools of water and nutrients, may explain the occurrence of deep roots in this and other systems.

Plant rooting depth influences the hydrology, biogeochemistry, and primary productivity of terrestrial ecosystems (1–7). Progress in determining the maximum rooting depth of species and in identifying the resources taken up at depth is limited by several factors. Access to the soil is difficult, particularly in rocky soils and in deeper layers. In addition, no universal method exists for identifying roots obtained from the soil, especially when only fine roots are available (8–10). There is considerable variation in maximum rooting depth and root biomass distributions, which affects the functioning of ecosystems (11–15). For example, in eastern Amazonia, water uptake from 2- to 8-m soil depths contributes to more than three-fourths of the transpiration of evergreen forest in the dry season and helps maintain an evergreen canopy on >1 million km² of tropical forest (1, 16). Characteristics of roots and the soil are also needed in models of biosphere–atmosphere interactions (17). A comparison of 14 land surface parameterizations concluded that rooting depth and vertical soil characteristics were the most important factors explaining scatter among models for simulated transpiration (18, 19), determining the amount of water available to plants and partitioning its uptake from different layers. Conclusions were similar for global soil-moisture dynamics (20, 21). Global simulations of net primary productivity and transpiration increased 16% and 18%, respectively, when optimized rooting depths incorporated soil water deeper than 1 m (22).

We developed a method for identifying roots based on DNA sequence variation and applied this method to roots collected from caves 5–65 m deep to determine the belowground community structure and maximum rooting depth of the 100,000-km² Edwards Plateau of central Texas. The Edwards Plateau and other karst regions in Texas cover one-fifth of the state, with >3,000 caves identified to date (23, 24). Karst systems, in general, cover 7–10% of land surface area globally and supply a quarter of the earth's population with drinking water (25). For the Edwards Plateau, we also examined the functional importance of roots at depth. We used stable isotopic signatures of water from plants, the soil, and an underground stream to examine the depth of water uptake. We also compared the concentration and potential pool of nutrients at depth and their relationship to fine-root biomass.

METHODS

The Edwards Plateau has shallow, calcareous soils overlaying fractured Cretaceous limestone (23, 24). Precipitation in the region ranges from ≈400 mm to 800 mm west to east, with a narrower range from 600 mm to 800 mm across our sites. The vegetation is primarily savanna and woodland dominated by trees in the genera *Quercus, Juniperus, Ulmus, Celtis*, and, farther to the west, *Prosopis* (26). We sampled 21 caves across the central and eastern Edwards Plateau (see Table 1 and its legend for the depths and locations of each cave). Fine roots were obtained from soil in the floor of the caves or, in a few cases, from underground streams. Most of the caves were smaller than 3 m across, and many were only 1 m in diameter or less.

To identify the roots obtained from the caves, we compared root DNA sequences of the ITS region of the 18S–26S nuclear ribosomal DNA repeat with an ITS reference database we developed for woody plants of the Edwards Plateau. The ITS evolves rapidly and is easily amplified in plants, allowing transgeneric and usually congeneric species to be readily identified (refs. 27–29; Fig. 1). Root and leaf DNA were extracted by using the techniques of Doyle and Doyle (30), except for a modified extraction buffer [3% (wt/vol) cetyltrimethylammonium bromide/1.4 M NaCl/20 mM EDTA/1.0 M Tris·HCl, pH 8.0/0.2% (vol/vol) 2-mercaptoethanol; see ref. 31] and the use of chloroform-phenol for removing proteins (32). Extracted DNA was gel purified (QIAquick Gel Extraction Kit, Qiagen, Chatsworth, CA) and amplified (27–29) for the entire ITS region (ITS1, ITS2, and the 5.8S ribosomal RNA gene). PCR products were purified (QIAquick PCR Purification Kit, Qiagen) and sequenced by using an ABI 377 Prism automated sequencer with dichloro-rhodamine dye terminators and other standard reagents and protocols (Perkin–Elmer). Electropherograms were proofread by eye. Both strands of the complete ITS were sequenced for all reference sequences; for root samples, the ITS was sequenced only

Facility for Environmental Research at the University of Utah (Salt Lake City, UT).

To estimate total soil N and organic C concentrations in cave soil as well as fine-root biomass and densities, we placed random 0.25-m² plots on the floors of the caves. The plots were excavated to depths of 20 cm. Fine roots (<2 mm in diameter) were separated from the soil, and the roots were dried at 60°C and weighed. Total N and organic C determinations of the soil were made with a CE Elantech NC 2100 Soil Analyzer (Lakewood, NJ). The six caves sampled were Spyglass, Cotterell, Turtle Shell, Sweet, Cicurina, and Powell's (see Table 1 for the location, depth, and species present in each cave). Surface-soil nutrient concentrations were estimated from random samples to bedrock (between 10 and 20 cm deep) above the caves at the same sites.

RESULTS AND DISCUSSION

Six tree species common to the Edwards Plateau were found with roots below 5 m (Table 1). These six species in the genera *Celtis, Juniperus, Quercus,* and *Ulmus* represent three-fourths of woody plants on the plateau, as determined by importance values, with *J. ashei* and *Q. fusiformis* comprising over half that total (26). Roots were observed above 20 m in every cave sampled with one exception, a 13-m-deep cave above which the surface vegetation had been cleared previously (data not shown). Despite the diversity of species found between 5 and 10 m, only one species was found below 10 m: the live oak *Q. fusiformis* from four caves between 10 and 25 m in depth (Table 1). Five caves deeper than 25 m had abundant *Q. fusiformis* populations at the surface, and three had permanent underground streams. Nonetheless, no roots of any species were found below 25 m, which we estimate to be the maximum rooting depth for the ecosystem.

A hierarchy of rooting depth for woody species emerges from the data (Table 1). Of the species present at the surface above five or more caves, *C. laevigata* was apparently the shallowest rooted. It was found at seven sites but was detected in only one cave at a depth of 6 m. *J. ashei*, the most common tree, occurred at 15 sites overall; it was found in three of nine caves shallower than 10 m (at 6, 7, and 8 m). *U. crassifolia*, though less abundant than *J. ashei*, was more likely to be found in caves when present at the surface (roots at 5, 7, and 9 m in three of five shallow caves). *Q. fusiformis*, the deepest of the species, was observed dependably in eight caves to depths of ≈20-m when present at the surface (Table 1).

We examined the functional importance of deep roots in the system by using ¹⁸O signatures of water in plants, soil, and a permanent underground stream at the Powell's Cave site. (We also used the ¹⁸O data as a check of the ITS results.) Live oaks at the site had ¹⁸O signatures that closely matched the signature of the underground stream water (Fig. 2), indicating that the trees apparently were using this water as their primary source. Stem water in a subshrub (*Guttierezia dracunculoides*), a forb (*Abutilon fructicosum*), and a grass (*Aristida purpurea*) had progressively heavier ¹⁸O signatures that reflected the uptake of evaporatively enriched water from the surface soil layer (and, most likely, increasingly shallow rooting depths from subshrub to grass; Fig. 2).

Although root biomass generally decreases with depth in the soil (34–36), plants show great flexibility in allocating roots and adjusting resource uptake in layers with high resource availability (37–40). Such flexibility may help capture belowground resources that vary with depth through time. For example, the availability of water in surface and deeper soil layers may vary depending on a site's hydrology and the seasonal pattern of precipitation and plant water use. We estimated a rough lower bound on the pool of water available to deep roots in our system based on data from the 11,400-km² drainage area of the Edwards aquifer. Average annual recharge from 1970–1997 was 1.08 km³ in the drainage area (41). Aquifer recharge across the zone is therefore 90 mm/year, the average amount of water that percolates beyond the rooting depth of plants and more than 10% of annual precipitation. Basing the calculation on the 3,900-km² recharge zone increases the estimated percolation from 90 mm/year to 260 mm/year in that smaller area. Five of our caves were in the aquifer drainage area, and three were in the recharge zone. Evidence for the presence of deep soil water also comes from the slow but observable trickle of water from the ceilings of caves we visited during the severe drought of 1998. Such slowly percolating water is the resource deep roots most likely exploit.

In addition to taking up water, the plants may also take up nutrients at depth. The relatively low nutrient concentrations and the shallow soils of the Edwards Plateau result in surface nutrient pools that are small. Organic matter in cracks and fissures and in cave soils may be the source of additional nutrients for plants across the region. Cave soils at six sites had total N concentrations ranging from 0.1% to 1.3% N compared with 0.3% to 1.4% in surface soils at the same sites (Fig. 3). Expressed as a ratio, N concentrations in cave soils were 17% to 92% of those in surface soils, and organic C contents were 16% to 77% of those at the surface (Fig. 3). The N in cave soils may come partly from bat guano [total N concentrations below bat roosts in Powell's Cave were 19.4% ± 0.81% (SEM)]. However, only a few caves had bat colonies, and Cotterell
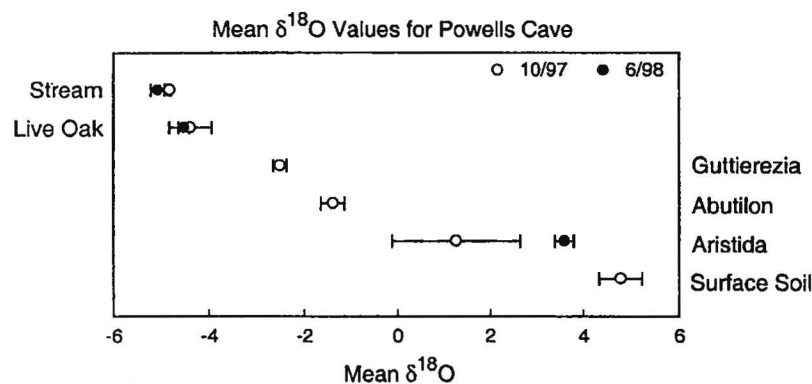

FIG. 2.   Comparison of ¹⁸O isotopic signatures on two dates for stem water of plants at the surface of the Powell's Cave site with the signatures of water from surface soil (surface to bedrock) and from an 18-m-deep underground stream (mean ± SEM; *n* = 2–5). The species sampled were *Abutilon fructicosum* (a forb), *Aristida purpurea* (a grass), *Guttierezia dracunculoides* (a subshrub), and *Q. fusiformis* Small (live oak tree), and the two sampling dates were October 25, 1997 and June 27, 1998 (the cave is open only on the last weekends of February, June, and October). Isotopic analyses were run at the Stable Isotope Research Facility of the University of Utah. Water in the stems of live oaks at the surface had an ¹⁸O signature that closely matched the underground stream water, evidence that the trees are likely using this water as a primary source.

Ecosystem effects of groundwater depth in Owens Valley, California

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ABSTRACT

Owens Valley, California, USA, is an important source of water for the city of Los Angeles; however, recent studies have documented losses of grass cover coinciding with decreased watertable depths in many locations. These changes in community composition are assumed to be associated with shallower rooting depths and greater vulnerability to declining watertable depths in grasses compared to neighbouring shrubs. However, the hydraulic properties and water stress resistance of most species in Owens Valley have not been measured. In addition, the relationships between groundwater depth and other aspects of ecosystem function such as nutrient cycling are not well understood. In this study, we measured grass and shrub cover, vulnerability to cavitation, and plant and soil isotopic and chemical composition at 9 sites along a depth to watertable gradient of 0·3–5·7 m in Owens Valley. Contrary to expectations, the grass species was more resistant to water stress-induced cavitation than either shrub species. However, grass cover declined in sites with deeper watertables while shrub cover remained constant. Water isotopes indicated shallower rooting depths in grasses than in shrubs, although the phreatophytic shrub *Ericameria nauseosa* had enriched leaf water isotopes at deep groundwater sites, indicating water stress. Sites with lower grass cover contained less soil nitrogen (N) that was also more isotopically enriched, which is indicative of greater ecosystem N losses. These results show that groundwater depth is correlated with a number of ecosystem traits in these Great Basin Desert ecosystems and should be considered when evaluating future changes in groundwater depth. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS   depth to watertable; grass cover; nitrogen; nitrogen isotopes; Owens Valley; vulnerability to cavitation; water isotopes

INTRODUCTION

Population growth in many regions of the world has necessitated water imports and redistribution from natural ecosystems, often resulting in loss of vegetative cover and changes in community composition, particularly in areas where species are dependent on groundwater sources (Muñoz-Reinoso, 2001; Lamontagne *et al.*, 2005; Cooper *et al.*, 2006; Hao *et al.*, 2010). In California, Owens Valley has been an important source of water for the city of Los Angeles for nearly 100 years. Located between the Sierra Nevada and White Mountains in central California, this semi-arid area receives a majority of its water in the form of runoff from the adjacent mountains, resulting in relatively shallow watertables in many areas. Therefore, phreatophytic—or groundwater-dependent—plant communities are common in Owens Valley, and include both shrubs and grasses. Since the completion of the Los Angeles aqueduct in 1913, groundwater has been pumped, diverted, and transported to Los Angeles for the city's water supply. Within the last 30 years, studies have documented changes in vegetation, with trends of both decreased live plant cover and replacement of grasslands by shrubs in Owens

Valley (Griepentrog and Groeneveld, 1981; Elmore *et al.*, 2003, 2006). The extent to which changes in community composition are attributable to hydrologic change is widely debated; in addition, the consequences of changes in grass and shrub cover for ecosystem function are poorly understood.

The ability of plants to withstand water stress-induced cavitation is a major determinant of their ability to cope with changes in watertable depth. However, the cavitation resistance of many plants in Owens Valley has not yet been measured. Grasses in Owens Valley are assumed to have shallower rooting depths than neighbouring shrubs (Elmore *et al.*, 2003, 2006), which is thought to limit their distribution and to make them more vulnerable to declining watertable depths. Many shrub species in Owens Valley are phreatophytic, and species with greater groundwater dependence tend to be more vulnerable to cavitation (Hacke *et al.*, 2000b; Pockman and Sperry, 2000). Therefore, grass species with shallower root systems may be generally more vulnerable to cavitation than shrubs, although this assumption has seldom been tested. In addition, plants have been shown to experience changes in hydraulic function with greater water stress, with populations in drier environments exhibiting greater resistance to cavitation than populations of the same species in wetter environments. Increased resistance to cavitation in environments of greater water stress is

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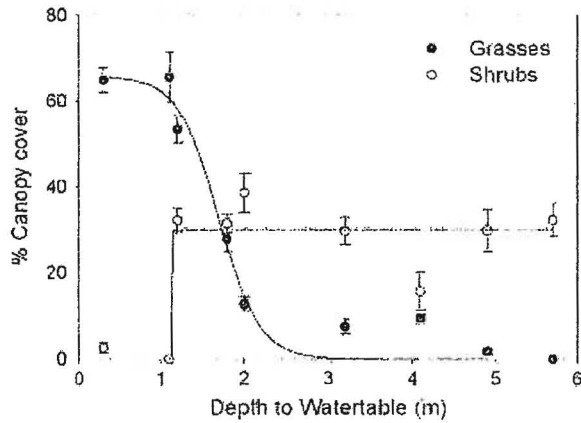E-mail: cgoedhar@uci.edu

Figure 5. Shrub and grass canopy cover (%) in sites varying with DTW (metres). Data were fit with a three-parameter sigmoidal curve (grasses: $R^2 = 0.96$, $p < 0.0001$; shrubs: $R^2 = 0.75$, $p < 0.01$). Error bars show one standard error ($n = 5$).
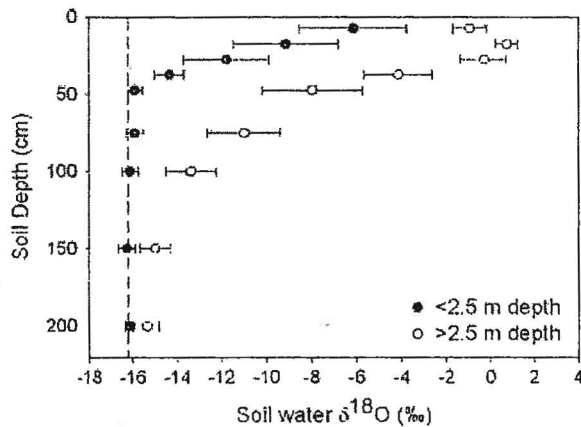

Figure 6. The average oxygen isotopic composition ($\delta^{18}O$) of soil water with depth for sites with DTW <2·5 m (closed circles) and >2·5 m (open circles). The dotted line shows the isotopic average composition of groundwater. Error bars show one standard error (n varies from 3 to 5).

Figure 7. Soil nitrogen isotope ratio ($\delta^{15}N$) (‰, $R^2 = 0.50$, $p < 0.05$) and soil organic nitrogen (%, $R^2 = 0.75$, $p < 0.01$) in sites varying in grass cover (percent). Error bars show one standard error (n varies between 3 and 5 samples for soil N characteristics and $n = 5$ for grass cover).

utilized shallower soil water than shrubs as indicated by water isotope measurements (Figure 1), and grass cover declined sharply with declining DTW (Figure 5). In addition, soil N declined with decreasing grass cover (Figure 7) as expected. However, contrary to our initial hypotheses, grasses were more resistant to cavitation than shrubs (Figure 3). Unexpectedly, vulnerability to cavitation was not correlated with lignin content (Table I); instead, lignin : N ratios declined with increasing DTW in *A. torreyi* (Figure 4). Our results show that many community, ecosystem, and plant traits vary with DTW, but there is still some uncertainty in the mechanisms linking groundwater depth with plant and ecosystem function.

Plant water sources

Plant species in the Great Basin Desert are known to utilize a variety of soil water sources (Ehleringer *et al.*, 1991; Donovan and Ehleringer, 1994; Pataki *et al.*, 2008; Goedhart *et al.*, 2010). In general, herbaceous species tend to utilize shallower sources of soil water, while
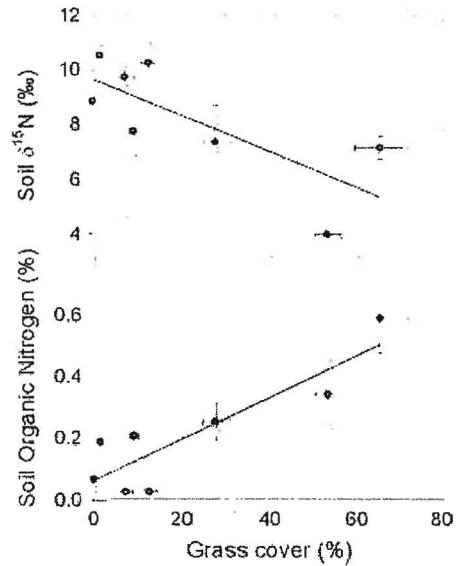
woody perennial species tend to utilize deeper soil water (Ehleringer *et al.*, 1991). We found this same trend in this study, as well as in our previous work in Owens Valley, where the grass species *D. spicata* had rhizome water isotopes that were more similar to shallow soil water isotopes, and the shrub species *A. torreyi* and *E. nauseosa* had stem water isotopes that were more similar to groundwater isotopes at sites with DTW of 1·5–2 m (Pataki *et al.*, 2008; Goedhart *et al.*, 2010). Great Basin species are also known to have varying responses to summer rain events (Ehleringer *et al.*, 1991; Flanagan *et al.*, 1992; Donovan and Ehleringer, 1994; Pataki *et al.*, 2008; Goedhart *et al.*, 2010), where grasses and shallowly rooted drought deciduous species tend to utilize summer precipitation to a greater degree than deeply rooted woody species. Additionally, DTW has been shown to play a role in the extent to which plants utilize precipitation, with greater use of precipitation in sites with greater DTW (McLendon *et al.*, 2008). In this study, we sampled plant water of all species in all sites following a rain event in September. *A. torreyi* and *D. spicata* showed variation in the amount of deep soil water utilization among sites. This variation was not correlated with DTW in *A. torreyi*, but the large decreases in deep water utilization in *D. spicata* at the deepest DTW site indicates that this species was either utilizing a shallower source of soil water or water from recent precipitation (Figure 1). *E. nauseosa*, a known phreatophyte, has consistently been found to utilize deep sources of water, even following precipitation events (Ehleringer *et al.*, 1991; Donovan and Ehleringer 1994; Pataki *et al.*, 2008; Goedhart *et al.*, 2010). In this study, *E. nauseosa* utilized deep soil water at all sites (Figure 1). However, bulk leaf $\delta^{13}C$, which is an
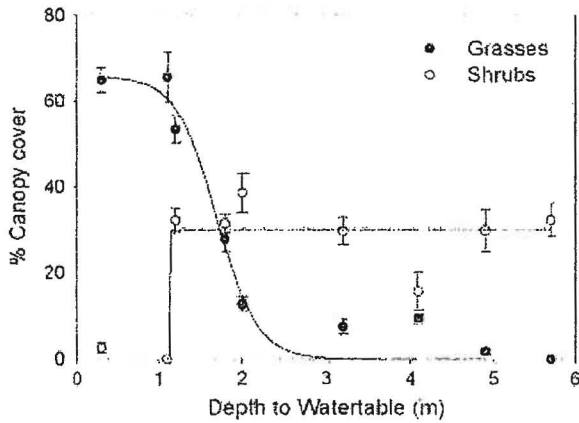
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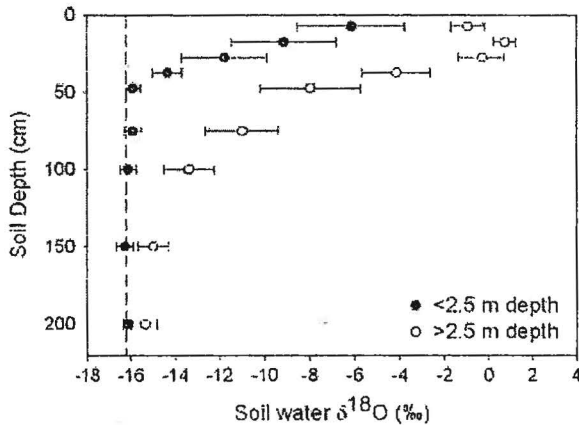

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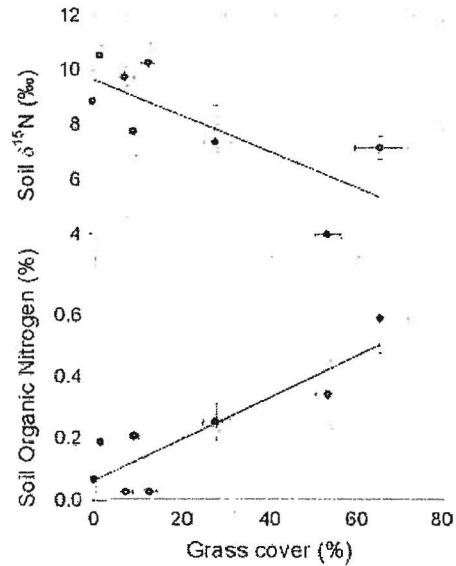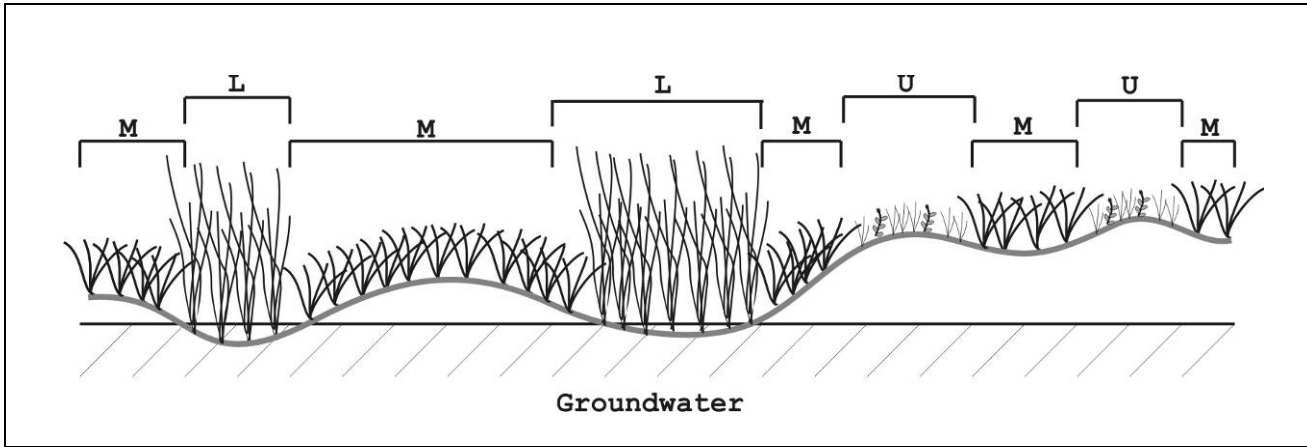

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woody perennial species tend to utilize deeper soil water (Ehleringer *et al.*, 1991). We found this same trend in this study, as well as in our previous work in Owens Valley, where the grass species *D. spicata* had rhizome water isotopes that were more similar to shallow soil water isotopes, and the shrub species *A. torreyi* and *E. nauseosa* had stem water isotopes that were more similar to groundwater isotopes at sites with DTW of 1.5–2 m (Pataki *et al.*, 2008; Goedhart *et al.*, 2010). Great Basin species are also known to have varying responses to summer rain events (Ehleringer *et al.*, 1991; Flanagan *et al.*, 1992; Donovan and Ehleringer, 1994; Pataki *et al.*, 2008; Goedhart *et al.*, 2010), where grasses and shallowly rooted drought deciduous species tend to utilize summer precipitation to a greater degree than deeply rooted woody species. Additionally, DTW has been shown to play a role in the extent to which plants utilize precipitation, with greater use of precipitation in sites with greater DTW (McLendon *et al.*, 2008). In this study, we sampled plant water of all species in all sites following a rain event in September. *A. torreyi* and *D. spicata* showed variation in the amount of deep soil water utilization among sites. This variation was not correlated with DTW in *A. torreyi*, but the large decreases in deep water utilization in *D. spicata* at the deepest DTW site indicates that this species was either utilizing a shallower source of soil water or water from recent precipitation (Figure 1). *E. nauseosa*, a known phreatophyte, has consistently been found to utilize deep sources of water, even following precipitation events (Ehleringer *et al.*, 1991; Donovan and Ehleringer, 1994; Pataki *et al.*, 2008; Goedhart *et al.*, 2010). In this study, *E. nauseosa* utilized deep soil water at all sites (Figure 1). However, bulk leaf $\delta^{13}C$, which is an

Note: (L = lower topographic group, standing water usually present; M = middle topographic group, saturated soil near the soil surface, standing water often present; U = upper topographic group, saturated soil near the soil surface, standing water occasionally present).

Figure 3-2
Typical Distribution of Plant Communities on Wetland Sites
in Spring Valley in Response to Microtopography

Table 3-2
Estimated Change in Plant Cover (%) in a
Typical Greasewood Communities in Spring Valley, Nevada
in Relation to Increase in DTW in Years of Average Precipitation

Mean DTW (m)																	
1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	>9
30	35	28	28	28	28	25	22	22	20	20	15	15	10	10	5	5	5

Soil Water and Vegetation Responses to Precipitation and Changes in Depth to Ground Water in Owens Valley, California

United States
Geological
Survey
Water-Supply
Paper 2370–G

Much of the bare soil, which covers from 20 to 40 percent of the transects at this site, is characterized by smooth areas or slicks between low vegetated mounds. The smooth surface of the slicks, combined with low infiltration rates, facilitates runoff and decreased infiltration.

In 1983, relatively abundant precipitation was evenly distributed over the winter months. In 1986, much of the precipitation fell during a few intense storms (more than 40 percent of the total annual precipitation fell during a single storm in February). The small but frequent
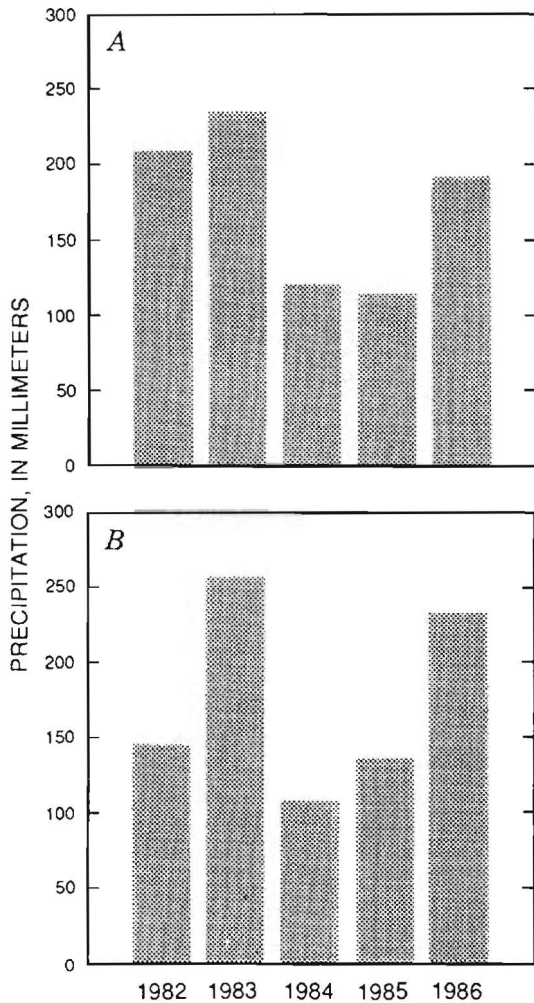
Table 2. Correlation coefficients for cover repetition and precipitation for phreatophytic shrubs and grasses for each transect at sites K and D

[--, no data]

Transect	Shrubs	Grasses
K1	0.19	--
K2	.62	--
K3	.55	--
K4	.42	--
K5	.36	--
K combined	.50	0.46
D1	.51	.48
D2	.58	.45
D3	.84	.90
D4	.80	.56
D5	.98	.68
D6	.65	.51
D combined	.88	.69

amounts of precipitation occurring in 1983 allowed greater infiltration at site D than in 1986, when more water may have been lost to runoff at site K than at site D because of differences in topography, soil type, and rainfall intensity. This would result in less recharge to the upper soil levels and less soil moisture available to plants.

Plant-cover measurements at slow-drawdown sites H and B (fig. 17) began in 1984. At site H, transects H1 and H2 show a decrease in plant cover from 1984 to 1985. In 1986, cover repetition increased following that season's increased precipitation.

Plant cover also decreased from 1984 to 1985 at transects B1 and B2. Cover repetition in 1986 increased at transect B2, but not at B1. As a group, phreatophytic shrubs at transect B1 showed no change in cover repetition between 1985 and 1986.

Response to Changes in Depth to Ground Water

In order to evaluate the effect of water-table drawdown on plant cover, the measurement of changes in plant cover induced by water-table drawdown must be separated from those changes induced by precipitation. The close proximity of each site's transects should result in equal distribution of precipitation among the transects. If one assumes that the effect of precipitation on plant cover also is uniform at each site, differences in the variation between transects may be the result of changes in the depth to the water table. This assumption is reasonable at all sites except site K, where the presence of the largely impervious slick areas alternating with mounds occupied by plants means that infiltration of precipita-

Figure 16. Seasonal precipitation at (A) Bishop and (B) Independence during each growing season, 1982–86. Values are combined monthly totals from November of the preceding year through October of the year indicated. From National Oceanic and Atmospheric Administration monthly summaries.

Table 1. Percentage cover of plant species, bare soil, and mulch measured at each transect, September 1984

Cover	Transect														
	K1	K2	K3	K4	K5	D1	D2	D3	D4	D5	D6	H1	H2	B1	B2
Artemisia tridentata	0	0	0	0	0	0.4	0.8	3.2	0	0	0	0	0	0	0
Atriplex confertifolia	0	0	0	0	0	1.2	0	.8	0	0	1.6	0	0	0	0
Atriplex torreyi	31.6	19.2	10.4	17.2	22.0	0	0	0	0	0	0	23.6	36.4	3.6	6.4
Chrysothamnus nauseosus	0	3.6	5.2	4.4	6.4	2.8	0	.4	4.0	6.4	6.0	.8	0	5.6	17.6
Distichlis spicata	.4	0	0	0	.4	2.4	10.4	.8	6.8	6.0	5.6	3.6	27.2	18.0	12.8
Glycyrrhiza lepidota	9.2	0	2.0	4.4	8.4	0	0	0	0	0	0	.4	1.2	0	0
Sarcobatus vermiculatus	0	1.6	.8	.4	1.2	6.0	3.2	0	.8	1.6	1.6	0	0	7.6	12.4
Sporobolus airoides	0	0	0	0	0	0	0	0	11.6	8.8	3.6	0	0	6.4	6.0
Other plant species	0	2.4	1.6	0	1.6	.4	.4	0	0	0	.4	.4	.4	0	1.6
Bare soil	20.0	39.6	41.6	22.8	26.0	62.4	54.8	62.8	50.0	47.2	58.8	55.6	6.0	22.8	8.0
Mulch	38.8	33.6	38.4	50.8	34.0	24.4	30.4	32.0	26.8	30.0	22.4	15.6	28.8	36.0	35.2

to leaf area and biomass and is a more sensitive measurement of changes in the plant canopy. Although the plant community at each site is qualitatively uniform as to species composition and character over the period of this study, quantitative differences between transects preclude direct comparison of the percentage cover or cover repetition measurements from one transect to another. This difference can be seen from the variability in percentage cover at each transect for each plant species, mulch (dead plant material), and bare soil in table 1. To allow comparisons between transects, measurements of cover repetition at each transect were normalized to initial, prepumping conditions (September 1983 measurement). Normalized cover repetition was calculated using the following equation:

$$\text{Normalized cover repetition} = \frac{\text{Current cover repetition}}{\text{Initial cover repetition}} - 1. \quad (2)$$

As a result of this normalization, the initial values for cover repetition at all transects are equal. Differences between normalized measurements at any single transect are a measure of change in cover repetition relative or proportional to initial conditions rather than a difference in actual cover repetition. At each transect, normalized cover repetition is zero for the first measurement. Subsequent measurements are positive for increases and negative for decreases in cover. Multiplying normalized cover repetition by 100 gives the percentage difference between a measurement and initial conditions at the transect.

Response to Precipitation

In the first 2 years of this study, a widespread decline in plant cover occurred at the study sites (fig. 14).

Measurements made in 1986 show a slight recovery but were still below initial levels. During the 1984 and 1985 growing seasons, a substantial decrease in cover was measured at all transects regardless of differences in water-table drawdown (fig. 15). Plant-productivity measurements made in 1983 and 1984 at Haiwee Reservoir at the southern end of the valley by Los Angeles Department of Water and Power also show a decline in 1984 (Los Angeles Department of Water and Power, written commun., 1986). The widespread decrease in plant cover is evidence that a valleywide factor affected plant cover.

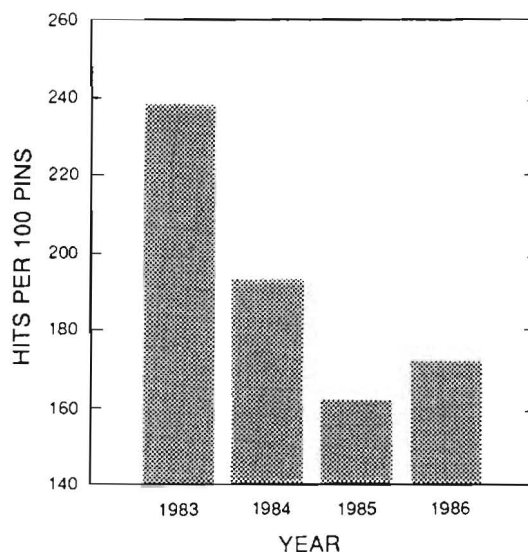Changes in plant cover closely corresponded to changes in total yearly precipitation as measured from

Figure 14. Combined measurements of cover repetition for all sites and species measured in September, 1983–86.

Table 3-3
Estimated Change in Plant Cover (%) in a
Typical Rabbitbrush Communities in Spring Valley, Nevada
in Relation to Increase in DTW in Years of Average Precipitation

Mean DTW (m)																
1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
20	25	30	40	45	60	40	30	25	22	20	20	20	18	17	16	15

Table 3-4
Understory Vegetation at the Rocky Mountain Juniper (JUSC)
Sample Locations, Spring Valley, Nevada, 2009

Vegetation Type	Numbers of Sites	Mean Cover of JUSC (%)	Major Understory Species
Wetland	1	86.7	Field clustered sedge-redtop-Woods rose
Wet Meadow	8	55.6	Creeping wildrye-alkali cordgrass-alkaligrass
Dry Meadow	11	44.6	Sacaton-alkaligrass-rabbitbrush
Rabbitbrush	10	41.0	Rabbitbrush-sacaton-big sagebrush
Sagebrush	1	34.6	Big sagebrush-greasewood-sacaton

4.0 SUMMARY OF POTENTIAL SUCCESSIONAL PATTERNS

The patterns and rates of vegetation change will depend on a number of factors. Factors of key importance include (1) initial species composition, (2) rate of groundwater decline, and (3) amount of precipitation received during the transition period. Additional factors that will affect vegetation change include (1) level of livestock grazing, (2) irrigation practices, (3) possible climate change, and (4) frequency and intensity of disturbance factors such as fire.

Plant communities are dynamic over time (Clapham, 1973, p. 123; Veblen, 1992). Their species composition and productivity vary in response to fluctuations and changes in the environmental factors affecting the community. These community changes include both fluctuations (nonsuccessional) and directional (successional) change (Smith, 1992, p. 330). Fluctuations around a long-term average occur because of seasonal, annual, and decadal fluctuations in the levels of the various environmental factors. In dry years for example, productivity decreases and the relative importance of more xeric species within the community increases. In wet years, productivity increases as does the relative importance of more mesic species. Directional change in the community occurs when either (1) the long-term average level of one or more environmental factor affecting community composition shifts or (2) a major disturbance occurs that substantially alters the composition of the community. In both cases, the ecosystem readjusts to the altered conditions through the process of succession.

Succession is the ecological process of vegetation change over time (Billings, 1970) resulting from various species being replaced by other species as ecological conditions at the site change over time (Odum, 1971, p. 251). Primary succession occurs when the substrate has not been significantly affected previously by plants. An example would be a landslide that removed the plant community and supporting soil from a slope, exposing bedrock or rock debris. Secondary succession occurs when the disturbance is of sufficient magnitude to change the plant community but the soil remains. In some cases the disturbance factor can eliminate the existing plant community entirely. Examples include cultivation and very hot fires. In other cases, the disturbance alters the composition and structure of the plant community, but some species remain. Examples of this include sustained over-grazing, severe and long-term drought, and relatively cool fires.

Two major factors causing succession are competitive displacement and stress tolerance (McLendon and Redente, 1992, 1994; Smith, 1992, p. 323). No ecosystems exist that have all environmental factors at optimum levels at all times for all species present. One or more required resources (e.g., nutrients, water, sunlight, temperature, space) or stressors (e.g., fire, grazing, disease) are always suboptimal for each species. However, they are not equally suboptimal for all species nor are all species equally able to tolerate the conditions that exist at the site. As the levels of each of the resources and stressors change, there are corresponding changes in ability of each species to tolerate, or to thrive under, those conditions. These changes affect the ability of each species to secure its necessary resources relative to its associated species (McLendon and Redente, 1991, 1994; Smith

Note: A = grass meadow, B = grass-shrub meadow, C = shrubland

Figure 4-1
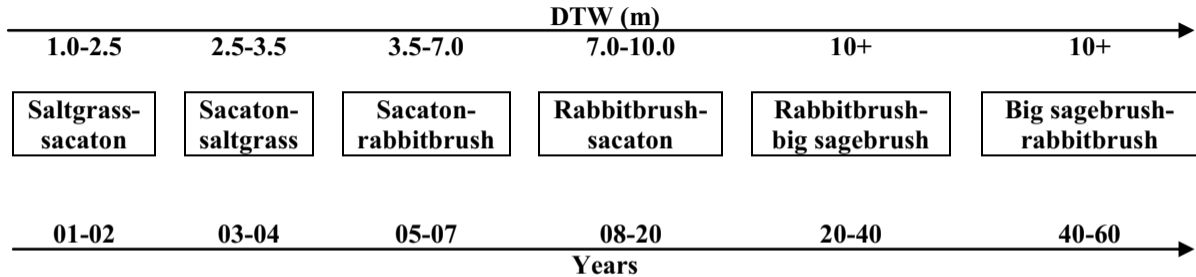**Successional Changes on Meadow (Grassland) Sites as DTW Increases**

Figure 4-3
Conceptual Diagram of a Transition from Saltgrass-Sacaton
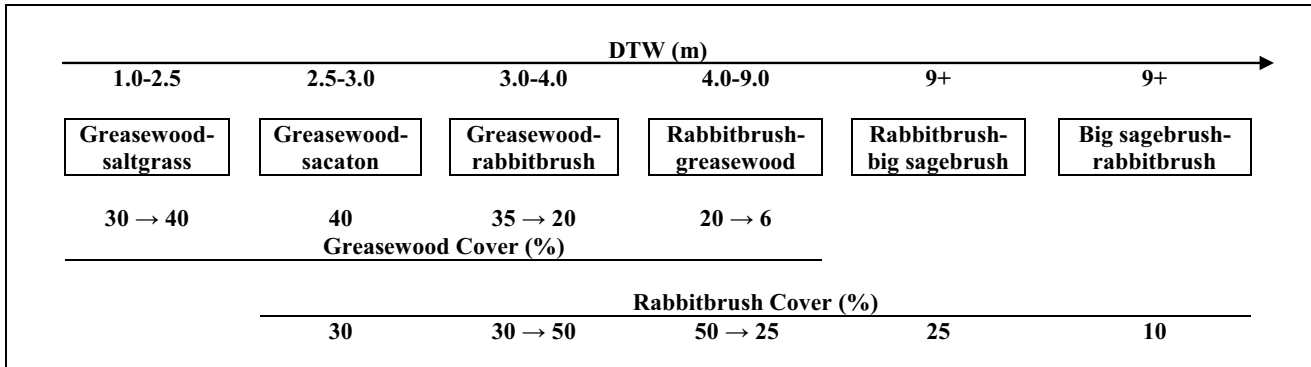**Dry Meadow to Shrubland Resulting from an Increase in DTW Over Time**

Figure 4-4
Conceptual Diagram of a Transition from Greasewood-Saltgrass Community to Big Sagebrush-Rabbitbrush Communities Resulting from an Increase in DTW

Natural Resources and Environmental Issues

January 2009

Dust emission at Franklin Lake Playa, Mojave Desert (USA): Response to meteorological and hydrologic changes 2005-2008

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saline minerals at the surface and within sediment between the surface and ground water table (the capillary fringe zone). Wet playas may thus be closely related to saline lakes, representing conditions that span alternating states of lake expansion and drying to long-term desiccation. Surfaces of wet playas are commonly dynamic, changing over very short time spans (on the order of weeks to months) between soft and hard, having relatively thick (approximately > 5 mm) crusts. When soft and dry in the upper few cm, wet-playa surfaces may be vulnerable to wind erosion and dust emission (Saint-Amand et al. 1986; Gill & Gillette 1991; Cahill et al. 1996; Gill et al. 2002). In contrast, dry playas are characterized by greater depths to the saturated zone (> 4 m depth) and lack of evaporation of ground water at the surface, all of which lead to hard, stable surfaces of clastic sediment. Typically, dry playas do not produce much dust unless disturbed.
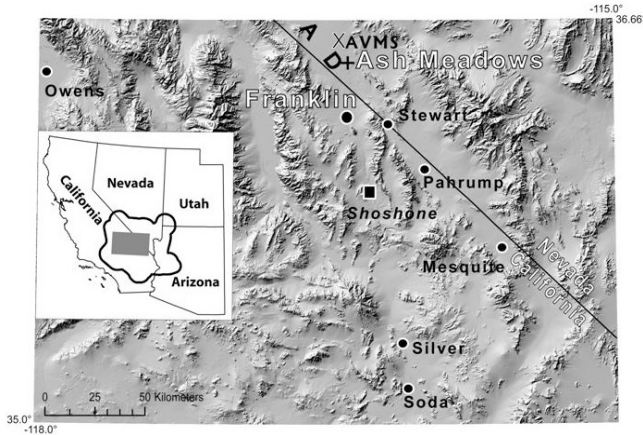

Figure 1–Location map of part of the Mojave Desert, which is indicated by the heavy line in the inset map. The map shows playas (filled circles), town (filled square), Amargosa Valley meteorological station (AVMS, denoted by X), and Ash Meadows (+). AD denote Amargosa Desert.

Many studies have characterized natural conditions of wind erosion at playas with respect to crust type, crust thickness, water content, and wind shear stress. In one set of approaches, wind erosion of natural surfaces is measured using wind tunnels or eolian sediment collectors with monitored meteorological conditions (e.g., Gillette et al. 1980, 1982, 2001; Reid et al. 1994; Cahill et al. 1996). Wind-tunnels and penetrometer tests have also been applied to samples collected in the field or prepared in the laboratory to simulate natural conditions, including varying concentrations of different salts (Nickling & Ecclestone 1981; Nickling 1984; Rice et al. 1996; Argaman et al. 2006).

Despite detailed understanding about eolian particle movement at playa surfaces, there are still gaps in understanding the many factors that promote or retard dust emission. This paper builds on previous studies, especially at nearby Owens (dry) Lake (Figure 1; Saint-Amand et al. 1986; Reid et al. 1994; Cahill et al. 1996; Gillette et al. 2001; Gill et al. 2002) and at FLP (Czarnecki 1990, 1997), to address some of the conditions that influence dust emission from FLP and their underlying causes.

Earlier work indicated that, at any one time, FLP supports many different types of surfaces varying greatly in mineral-crust properties (Czarnecki 1997; Reynolds et al. 2007). Moreover, some areas of the playa change rapidly in these properties, at times having high dust-emission potential and at other times low potential. Observations from our work (Reynolds et al. 2007) suggested important hydrologic influences on dust emission, leading to a hypothesis that relatively wet conditions, caused by high local or regional rainfall, promoted dust emission and that long-term dry conditions impeded emission. To test this hypothesis, we chose to examine the possible influences of precipitation and ground-water-depth levels on the frequency of dust emission. Precipitation and perhaps local flooding of the playa surface might enhance dust emissivity by providing new dust sources, such as clastic flood-sediment, or by temporarily removing saline-mineral crusts, thereby rendering the surface vulnerable to wind erosion before or as mineral crusts begin to re-form. A higher potentiometric surface might additionally promote development of wind-erodible saline-mineral fluff. We also considered variations in seasonal wind strength and temperature as factors that might influence dust emission (cf. Saint-Amand et al. 1986; Reid et al. 1994; Cahill et al. 1996).

SETTING

Franklin Lake playa is centered at 36.252° N, 116.375° W in the Mojave Desert of southeastern California (Figure 1). The playa covers 14.2 km^2 at about 610 m above mean sea level (Figure 2). The Mojave Desert receives most of its precipitation (50-125 mm annually) from winter frontal storms from the Pacific Ocean (Hastings & Turner 1965). Nevertheless, the frequency, seasonality, and amount of precipitation in the low-elevation parts of the Mojave Desert may vary considerably partly related to ENSO (El Nino-Southern Oscillation) states, monsoon strength, as well as tracks of winter frontal and tropical low-pressure systems.

2

Franklin Lake playa contrasts with some globally significant dry-lake dust sources in basin size and in its incapacity to accumulate large amounts of flood sediment. Nevertheless, FLP provides an example of a dust-producing playa where a large proportion of the total dust load is composed of evaporite minerals. At FLP, sustained aridity impedes dust emission, probably by development of salt-crusted surfaces that resist wind erosion. Local and regional moisture, either through rapid effects of direct rainfall on the playa surface or longer-term (months) effects of decreasing depth to the ground-water table, seems to promote dust emission at almost any time of year by creating relatively soft surfaces vulnerable to wind erosion.

ACKNOWLEDGMENTS

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Spring, Cave, Dry Lake and Delamar Valleys

SOUTHERN NEVADA
WATER AUTHORITY