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

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

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Pertaining to:
Groundwater Applications 54003 through 54021 in
Spring Valley
and
Groundwater Applications 53987 through 53992 in
Cave, Dry Lake, and Delamar Valleys

June 2011

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CONTENTS

CONTENTS (CONTINUED)

FIGURES

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TABLES

NUMBER **TITLE** **PAGE**

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ACRONYMS

DTW	depth to water
NRS	Nevada Revised Statutes
NSE	Nevada State Engineer

ABBREVIATIONS

ac	acre
cm	centimeter
g	gram
ha	hectares
m	meter
m^2	square meter
mm	millimeter

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1.0 INTRODUCTION

This report concerns the standard set forth in Nevada Revised Statutes (NRS) §533.370(6)(c), which provides that in determining whether an application for an interbasin transfer of groundwater must be rejected, the Nevada State Engineer (NSE) shall consider whether the proposed action is environmentally sound as it relates to the basin from which the water is exported.

This report will explain how plant communities are always in a natural state of fluctuation given naturally occurring environmental conditions. Well pumping often results in an increase in depth to water (DTW). Declines in the groundwater table often result in a change in the existing groundwater-dependent plant community.

This report distinguishes groundwater-dependence[1], groundwater use, and precipitation use among plant species, and discusses how transitions can occur from groundwater-dependent communities to precipitation-sustained communities while maintaining productive native plant communities. This report provides a scientific basis for assessing the types of changes one might expect in existing groundwater-dependent and groundwater-influenced plant communities, depending on various changes in DTW.

1. In this document, groundwater-dependent vegetation is defined as vegetation that requires groundwater or surface water for its existence at a site. As such, the term is synonymous with obligate phreatophyte (Section 3.3). Groundwater-influenced vegetation is vegetation that utilizes some groundwater when it is present, but can exist without groundwater. As such, the term is synonymous with facultative phreatophyte. The term precipitation-sustained is used to refer to the condition where the soil moisture used by vegetation at a site derives solely from precipitation, either as direct infiltration or as runoff.

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2.0 DESCRIPTION OF VEGETATION IN AREAS POTENTIALLY IMPACTED BY GROUNDWATER WITHDRAWAL

The spatial distribution of segments of groundwater-influenced vegetation in Spring Valley were mapped in 2008-2009 (McLendon et al., 2011). The areas mapped were those expected to be most sensitive to changes in DTW. Field mapping was conducted by visual inspection, with vegetation mapped to the community level (relative amounts of cover[1] of the three most abundant species, with order of species being important). Areas of relatively homogeneous composition were identified in the field and corresponding polygons were delineated on aerial photographs. A polygon was the mapping unit that included the contiguous area of relatively homogeneous vegetation that was identified in the field. A total of 9,332 polygons were mapped.

A hierarchical classification system was used that divided the polygons into 6 biomes, 107 alliances, 752 associations, and 2,671 communities. A biome was the highest level of the classification and included all vegetation of a specific structural category of the dominant species (Whittaker, 1975, p. 135) or on a major environmental characteristic of the ecosystem (e.g., wetland). Six biomes were included: woodland, shrubland, grassland, wetland, aquatic, and early-seral. The first three were classified on the basis of structural type and the last three on the basis of major environmental characteristic (Table 2-1). An alliance was the highest-order subdivision of a biome and was based on the dominant species, or in some cases the dominant genus, and included all associations with the same dominant species. An association included all communities with common dominant and subdominant species. A community was a contiguous area with the same three most-abundant species, with order of abundance of the three species considered. Each polygon was mapped at the community-level.

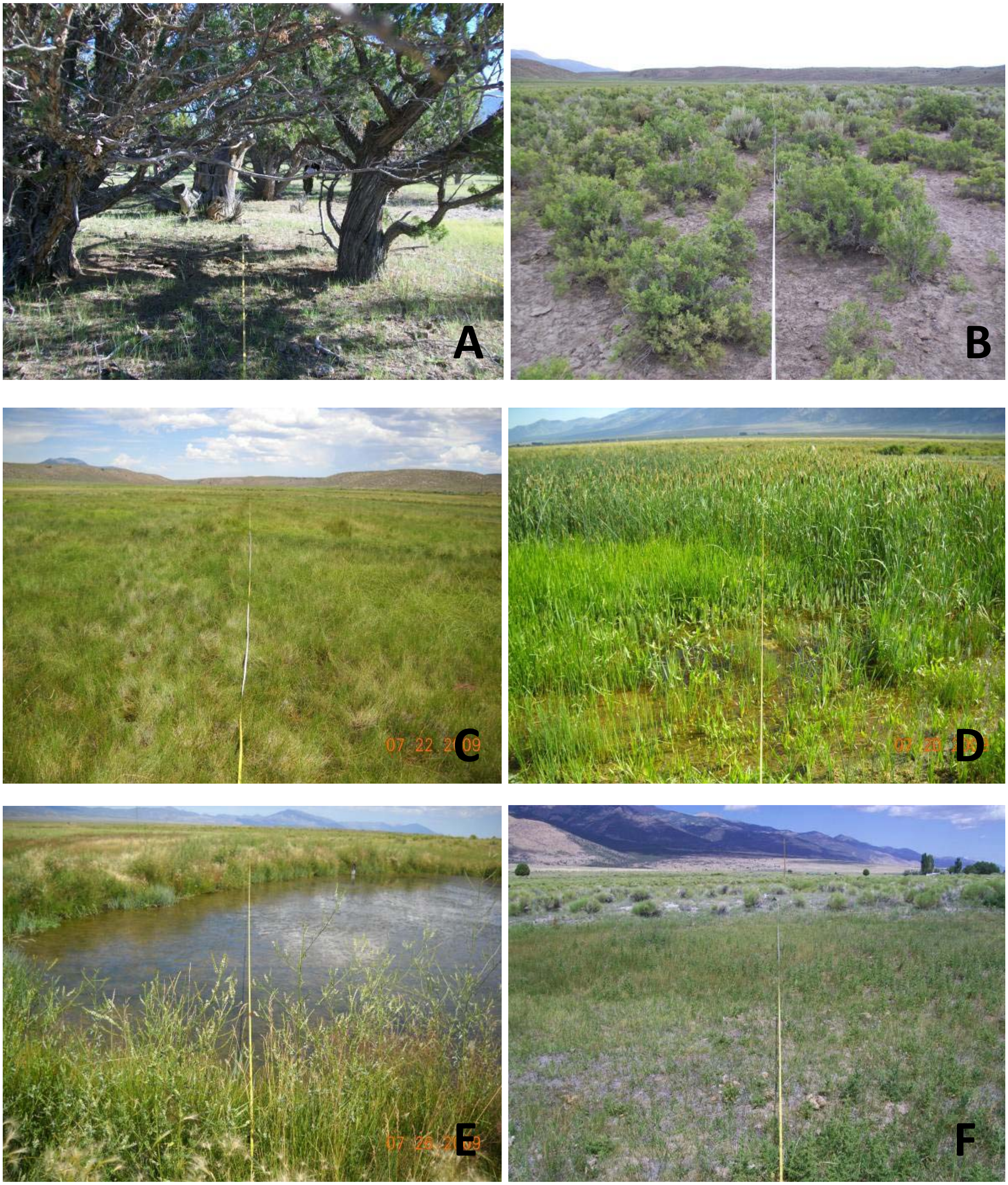
In this document, estimations of probable impacts of change in DTW on vegetation are presented first at the biome level and then for key species within biomes. Some plant communities can be assigned to more than one biome, depending on how the hierarchical rules are defined. For example, some wetlands are dominated by grasses. These communities could therefore be classified into either the wetland biome or the grassland biome. In this document, vegetation units are classified into biomes based on the definitions in Table 2-1. Examples of the six biomes occurring in Spring Valley are presented in Figure 2-1.

1. Cover refers to canopy cover, i.e., the vertical projection to the ground surface of the overlying portion of the vegetation, expressed as a percent of the soil surface.

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

Figure 2-1
Spring Valley Examples of the Six Biomes

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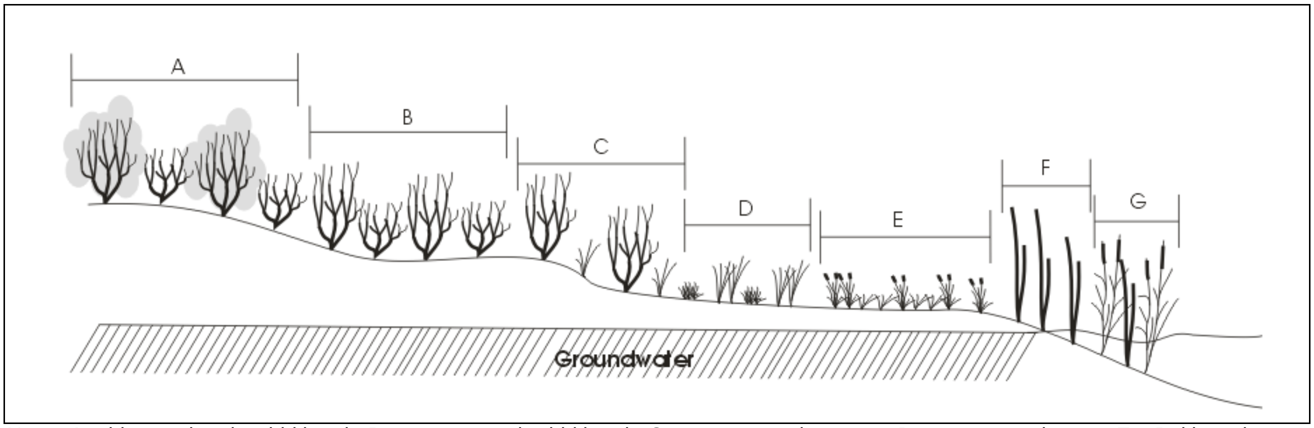
3.0 POTENTIAL VEGETATION CHANGES RESULTING FROM CHANGES IN DEPTH TO WATER IN SPRING VALLEY

Topography is a major factor affecting the distribution of vegetation in Spring Valley, in part because of its effect on availability of water. Aquatic and wetland communities occur in lower-elevation areas where water accumulates at and above the soil surface (Figure 3-1). As elevation increases, DTW also tends to increase and the vegetation generally shifts to grassland and then shrubland types in response to increasing DTW.



Note: A = big sagebrush-rabbitbrush, B = greasewood-rabbitbrush, C = greasewood-sacaton, D = sacaton-saltgrass, E = Baltic rush-Nebraska sedge, F = bulrush, G = cattail-bulrush.

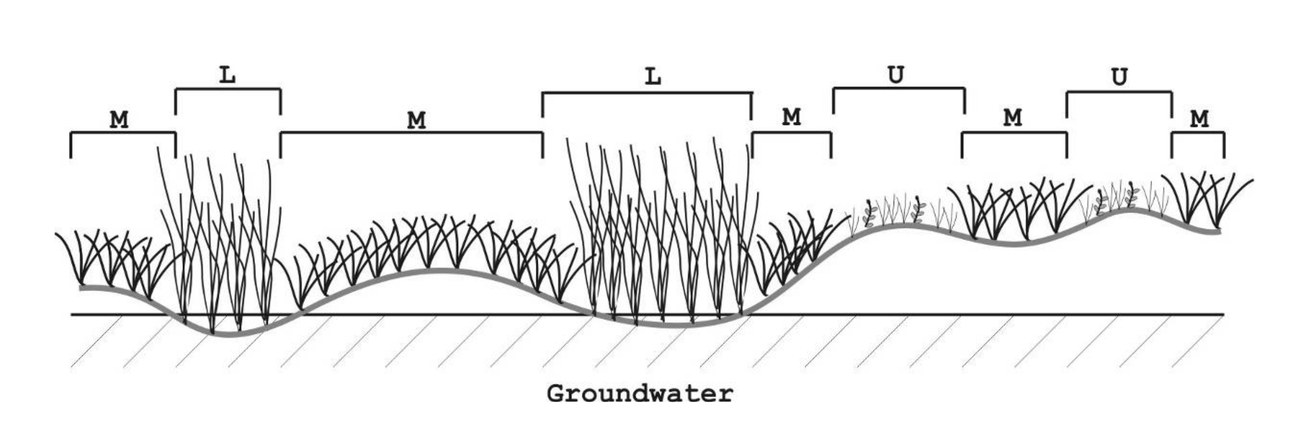
Figure 3-1
Typical Toposequence of Plant Communities in Spring Valley in Relation to DTW

3.1 Aquatic and Wetland Biomes

The most groundwater-sensitive biomes are the aquatic and wetland. Aquatic communities are dependent on standing water, with depth of standing water important for most of them. Aquatic communities in Spring Valley occur because of one of four factors: (1) outflow from springs, (2) overland flow from spring runoff, or (3) flow from irrigation structures, or (4) depth to water. Any substantial decrease in depth of standing water from any of these sources is likely to adversely affect these communities.

Wetland communities in Spring Valley area are primarily associated with the same four factors that create and sustain the aquatic communities. In most cases, the wetland communities exist because of outflow, both surface and subsurface, from the spring pools, spring channels, irrigation structures, and margins of ponds that result from spring or irrigation flows. Some wetlands do occur as a result of shallow groundwater that rises to the soil surface. This third set of wetlands, i.e., those sustained by shallow groundwater, are the wetlands likely to be most susceptible to an increase in DTW.

There are 3,569 wetland polygons mapped in Spring Valley. Micro-topography is a major factor affecting the distribution of associations and communities within the wetland biome. These wetland areas can be divided into three general categories: (1) those occurring on areas of slightly higher elevation (upper), (2) those occurring in intermediate zones, and (3) those occurring on sites of slightly lower elevation (lower). Micro-topography affects the supply of water to the various wetland communities. The lower sites have a more or less continually saturated soil surface whereas the higher elevation sites have saturated soil near, but not at, the soil surface at most times (Figure 3-2).



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

The upper micro-topographic wetlands have lower cover values and the species are of a lower successional status than the intermediate or lower wetlands because their surface soils tend to dry out during the summer and livestock tend to concentrate on them more heavily because of their higher elevation. These upper wetlands contain about 14 percent of the mapped wetland polygons and the most frequent dominant species were sliver cinquefoil (*Argentina anserina*) and various sedges (*Carex* spp.).

Intermediate wetlands are the most numerous in Spring Valley, containing 71 percent of all wetland polygons. Most of these are dominated by either Baltic rush (*Juncus arcticus*) or Nebraska sedge (*Carex nebrascensis*). The lower elevation wetlands contain 15 percent of the wetland polygons and the most frequent dominants are creeping spikerush (*Eleocharis palustris*), tule bulrush (*Schoenoplectus acutus*), and cattail (*Typha* sp.).

These wetland communities are very sensitive to variations in supply of water. Depth of surface water, depth to saturated soil, and duration of soil saturation are all important factors in determining the sustainability and productivity of these wetlands. If depth and duration of inundation increase, the wetlands will shift towards aquatic communities. If depth and duration of inundation decrease or depth to saturated soil increases, these communities will shift toward wet meadows.

Cattails require standing water up to 1 m deep for most of the growing season (Daubenmire, 1988). Baltic rush can tolerate standing water (0-30 cm deep) for much of the growing season (Daubenmire, 1988), but is often found on sites where DTW is as much as 1.5-2.5 m (Miller et al., 1982; Castelli et al. 2000; Chambers et al., 2004; Jewett et al., 2004). It tends to be most productive when DTW is 25 cm (Stromberg et al., 1996) to about 1 m (Weixelman et al., 1997; Mata-Gonzalez et al., in press). Nebraska sedge commonly occurs in association with Baltic rush, but tends to be more productive at shallower DTW (0-20 cm) than Baltic rush (Manning et al., 1989; Chambers et al., 1999; Castelli et al., 2000; Martin and Chambers, 2001a; Jewett et al., 2004).

3.2 Grassland Biome

Water availability (DTW, amount and frequency of seasonal flooding, and irrigation) is also the primary factor accounting for the distribution of the grassland communities in Spring Valley. Salinity and land use are important secondary factors. The grasslands in Spring Valley can be divided into wet meadows or dry meadows, based on the amount of water available and indicated by species composition. Although the separation into these two groups is clear in most cases, there are cases where the placement into wet or dry meadow is somewhat arbitrary. Moisture availability across these grasslands is a gradient and, as with all ecological gradients, there can be ambiguity as to where to establish a boundary.

Meadows are grasslands that have saturated soil within the rooting zone in most or all months of the year. If standing water occurs, it is for only part of the growing season. Micro-topography is important in determining the spatial structure of these meadows, with lower microsites being wetter and higher microsites being drier. If surface runoff is a major source of water to the meadow, the soils may be saline, with highest salt accumulations in the lower portions of the meadow. The high salinity results from the concentration of salts in runoff water which accumulates in the depressions and then evaporates, leaving the salts in the soil.

Much of Spring Valley is currently used, and has been historically, for livestock grazing. The livestock commonly found in Spring Valley (cattle, sheep, horses) are heavy users of grasses and grass-like plants (e.g., sedges). Consequently, the grassland communities have been impacted by livestock grazing and the degree of these impacts varies across the valley. These grazing impacts have had an impact on species composition, productivity, and distribution of the grassland communities. At some sites, these communities have also been affected by establishment of non-native species, either purposely or as a result of grazing practices. Land impacts other than grazing have also affected species composition at some sites. A common example is the placement of irrigation ditches and their history of usage. Some of the wet meadows in Spring Valley are the direct result of these irrigation practices.

3.2.1 Wet Meadows

Wet meadows occur on sites where the upper portion (0-50 cm) of the soil profile remains saturated for most of the growing season. They mostly occur in Spring Valley on outflow areas around and downstream from springs and along irrigation ditches. Species composition varies among sites, but the most common dominant and subdominant species are redtop (*Agrostis gigantea*), Baltic rush

(*Juncus arcticus*), meadow fescue (*Schedonorus pratensis*), and creeping wildrye (*Leymus triticoides*). Nebraska sedge (*Carex nebrascensis*) increases in importance as the wet meadows transition to true wetlands and saltgrass (*Distichlis spicata*) increases in importance as the wet meadows transition to dry meadows.

A total of 588 polygons in Spring Valley were mapped as wet meadow. These covered about 474 ha (1,171 ac). Most of the wet meadows in Spring Valley are watered either by outflow from springs or from irrigation ditches or ponds receiving irrigation water. This water is supplied both as surface flow and as subsurface drainage. Therefore, most of these wet meadows are not sustained by groundwater. Consequently, an increase in DTW caused by groundwater withdrawal is not likely to substantially affect the wet meadows unless it reduces outflow from the springs.

However, those sites where the wet meadows are supplied primarily by high groundwater will be susceptible to increases in DTW from groundwater withdrawal. At these sites, increases in DTW of 50 cm or more will reduce the productivity of the wet meadows (Martin and Chambers, 2001a and b) and increases on the order of 1 m will likely cause shifts in species composition, probably resulting in sufficient changes to shift from wet meadows to dry meadows.

Redtop is the most common dominant species on wet meadows in Spring Valley. Its high productivity is dependent on abundant soil moisture at or near the soil surface. An increase in DTW of 50 cm would likely decrease its productivity by 50 percent and an increase in DTW of 1 m or more would likely eliminate it as a dominant species. The same is true of meadow fescue. Creeping wildrye would likely remain a major species as long as DTW remained less than 1.5 m. Baltic rush is adapted to a wider range in DTW and would likely increase in abundance as the other three major wet meadow species decreased. Productivity of Baltic rush would likely decrease as DTW increased between 0.5-1.5 m (Castelli et al., 2000; Jewett et al., 2004; Mata-Gonzalez et al., in press), and would begin to be replaced by dry meadow species, primarily saltgrass, if DTW increased below 2 m (Miller et al., 1982; Chambers et al., 2004). Baltic rush would likely remain in the plant community, but at low cover values (1-3%) until DTW increased below 3 m.

In summary, those wet meadows that are dependent on shallow groundwater for their water requirements would be affected by declines in groundwater of 50 cm or more. If DTW increased by 50-100 cm, species composition would likely change, with redtop and meadow fescue decreasing and creeping wildrye and Baltic rush increasing, but the sites would remain wet meadows. Productivity of the plant communities would likely be half of their current levels with a 1-m increase in DTW. If DTW increased to 1-2 m, the wet meadows would likely shift to dry meadows although there would still be a strong Baltic rush component with some creeping wildrye. Saltgrass is a common secondary species in many of the wet meadows and would likely become the site dominant in most wet meadows that transitioned into dry meadows.

3.2.2 Dry Meadows

Dry meadows occur where the soil surface is periodically flooded but where the top 50-100 cm of the soil remains unsaturated for most of the growing season, or where the soil surface typically remains dry but the DTW is within about 50 cm of the soil surface at least some of the time during the growing season in most years. Dry meadows typically occur where the surface soils (0-50 cm) remain too dry for too much of the growing season or are too saline for wet meadow species to dominate the site but where too much of the soil profile is saturated each season for most shrub species to dominate. If the upper soil profile becomes wetter for longer periods of time, dry meadows transition to wet meadows, provided that the site is not too saline. If the upper soil profile becomes drier for longer periods of time, dry meadows transition to shrub-meadows.

A total of 2,350 polygons, covering 2,324 ha (5,740 ac) in Spring Valley were mapped as dry meadows. The most common dominant species on these dry meadows were saltgrass and alkali sacaton (*Sporobolus airoides*). Because of the frequency of occurrence of these two species as dominants in the dry meadows in Spring Valley and the abundance of ecological data on these two species in the Great Basin Region, they are used as the primary indicators of potential dry meadow response to shifts in DTW. Saltgrass will be considered the key species in discussions about sites where DTW is shallower or more saline and sacaton the key species on sites where DTW is deeper.

3.2.2.1 Saltgrass (Distichlis spicata)

Saltgrass is widely distributed throughout the Great Basin Region and much of the western United States. It is commonly found in saline meadows and marshes, often as the dominant species. On many dry meadow sites it forms almost monoculture stands. Although characteristic of saline sites, it also occurs on non-saline sites, including wet meadows.

Saltgrass typically occurs on sites where DTW is 2.5 m or less, but can be found where DTW is as much as 4.3 m (Meinzer, 1927; Robinson, 1958; Nichols, 1994). When it occurs on sites with deeper DTW, the sites generally receive additional water from other sources such as surface runoff or outflow from springs. Dry meadows dominated by saltgrass typically have DTW of 0.7-1.2 m and cover and productivity of saltgrass decreases as DTW increases to about 2.5 m (Lee, 1912; Grosz, 1972; McLendon et al., 2008). Between about 2.5 and 3.5 m, saltgrass cover is not affected by increasing DTW (Duell, 1990; Sorenson et al., 1991). Saltgrass cover then decreases rapidly as DTW increases below about 3.5 m.

Saltgrass is strongly affected by the amount of precipitation received (Sorenson et al., 1991; Goedhart and Pataki, 2010). When there is adequate soil moisture from precipitation, saltgrass utilizes little groundwater. In wet years (more than 20 cm precipitation), saltgrass is largely unaffected by change in DTW. The relationship between saltgrass cover and DTW becomes stronger in drier years.

Saltgrass cover is negatively affected by high groundwater (Groeneveld and Or, 1994). When DTW decreases to less than 0.7-0.8 m, saltgrass cover typically begins to decrease, probably because too much of the soil profile is saturated for too long during the growing season (Seliskar, 1983, 1987). This partially explains why saltgrass typically does not dominate wet meadow sites, although it is often present.

3.2.2.2 Alkali Sacaton (Sporobolus airoides)

Sacaton is a much deeper-rooted species than saltgrass, potentially rooting to over 6 m (ICWD/ LADWP, 1989). As such, it typically is the dominant species on dry meadows where DTW is greater than on those sites dominated by saltgrass. The two species are often found growing together, especially in the transition areas between shallower DTW sites dominated by saltgrass and deeper DTW sites dominated by sacaton or by a combination of sacaton and shrubs. Extensive dry meadows dominated by sacaton were once common in the Great Basin, but have now decreased in extent because of overgrazing by livestock and increased abundance of shrubs.

Sacaton has been reported on sites with DTW ranging from 1.2 to 13.7 m (Meinzer, 1927). Sacaton utilizes both precipitation- and groundwater-derived soil moisture (McLendon et al., 2008). On sites dominated by sacaton, the amount of sacaton cover supported by groundwater averages about 20 percent at 1.5 m DTW and decreases by about 1 percentage point for each 0.5-m increase in DTW to about 3.0 m. This rate approximately triples (3 percentage points per 0.5-m increase in DTW) between 3.0 and 5.5 m. Between 6.0 and 7.0 m DTW, sacaton cover supported by groundwater averages about 1 percent cover, and becomes zero below about 7.5 m. In addition to sacaton cover supported by groundwater, precipitation-derived soil moisture supports about 0.9 percent sacaton cover per centimeter of annual precipitation when precipitation is in the range of about 20-25 cm.

3.2.2.3 Effect of Increased DTW on Dry Meadows

If DTW increased from about 1.2 m to 2.5 m, cover of saltgrass in dry meadows would decrease by about 30 percent. A typical cover value at 1.2 m DTW might be 50 percent, with a value at 2.5 m DTW of 35 percent. Saltgrass cover would not likely decrease much more, when averaged over years, as DTW decreased between 2.5 to about 3.5 m DTW. Saltgrass cover would likely vary substantially during those years, but the fluctuations would be in response to precipitation fluctuations and not change in DTW. As DTW increased past 3.5 m, saltgrass cover would rapidly decrease. Typical values might be 30 percent at 3.5 m DTW, 10 percent at 4.5 m DTW, and 5 percent at 5.5 m DTW.

Sacaton cover would likely increase as saltgrass cover decreased because of more precipitation-derived soil moisture being available to sacaton and the ability of sacaton to access deeper soil moisture. At a DTW of 2.5 m and in years receiving average precipitation (24 cm), sacaton cover would likely be about 40 percent, 18 percentage points of which would be from groundwater. At 3.5 m DTW, sacaton cover would likely decrease to 37 percent (22% from precipitation + 15% from groundwater) and to about 23 percent at 6.0 m DTW (22% from precipitation + 1% from groundwater). Below about 7.5 m DTW, sacaton cover would be totally precipitation-dependent and would average about 20 percent in years of average precipitation.

Likely changes in plant cover in dry meadows as DTW increased are presented in Table 3-1. These estimates are based on average precipitation and light grazing by livestock.

3.2.2.4 Shifts in Species Composition in Grasslands

The scenario presented in Table 3-1 assumes that the original dry meadow was dominated by saltgrass, with sacaton as the sub-dominant species. If DTW increased, saltgrass would decrease in cover and sacaton would increase. At about 3.0 m DTW, competitive dynamics would likely shift in favor of sacaton and saltgrass would become sub-dominant, and then become only a minor species

Table 3-1
Estimated Change in Plant Cover (%) in a Typical Dry Meadow Corresponding to Increase in DTW in Spring Valley, Nevada

	Mean DTW (m)													
Component	**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**	**>7.5**
Saltgrass	45	40	35	32	30	20	10	7	5	1	0	0	0	0
Sacaton	20	30	35	38	37	34	31	28	25	23	23	23	21	20
Total	65	70	70	70	67	54	41	35	30	24	23	23	21	20

when DTW reached about 5.5-6.0 m DTW (ICWD/LADWP, 2010). A series of dry years would increase the rate of this transition from saltgrass to sacaton dominance and wet years would slow the rate.

As total grass cover decreased to less than 50 percent, shrubs would likely increase on the site. Under average precipitation, shrubs would likely require 15-30 years to increase sufficiently to shift the site to a shrub-meadow community. If DTW remained below about 4-5 m, the site would likely shift to a shrub community, with sacaton cover decreasing to less than 20 percent and 2-3 shrub species having higher cover values than sacaton. Grazing by livestock will increase the rate of this transition from a sacaton-dominated dry meadow to a shrub-dominated community. Conversely, a rise in water table or periodic fire would likely shift the successional dynamics back in the direction of a sacaton meadow.

The species composition of the resulting shrub community would depend on composition in adjacent shrub communities, the salinity level of the site, and the eventual DTW. Greasewood (*Sarcobatus vermiculatus*) and rabbitbrush (*Ericameria nauseosa*) are two shrub species that would likely establish on the dry meadows. Rabbitbrush would establish more rapidly and dominate the site unless salinity levels are particularly high, in which case greasewood would likely become the dominant shrub. If salinity levels are not excessive, big sagebrush (*Artemisia tridentata*) would likely eventually (50-100 years) replace rabbitbrush.

3.3 Shrubland Biome

Much of the vegetation of Spring Valley is shrubland. Many of these species, and most of the major ones, are facultative phreatophytes. The term phreatophyte is commonly used to denote a plant that utilizes groundwater. However, when used without a modifier, the term has little meaning because most plants will use some groundwater if their roots are in contact with the water table. An obligate phreatophyte is a plant that uses groundwater almost exclusively at all times (Lamontagne et al., 2005) and occurs only where groundwater (or surface water) is available. Examples include cottonwood (*Populus* sp.), willow (*Salix* sp.), saltcedar (*Tamarix* sp.), common reed (*Phragmites australis*), and Nebraska sedge (*Carex nebrascensis*). These species generally have some roots in unsaturated soil near the surface, but also have portions of their root system extending into saturated soil (Gary, 1963; Manning et al., 1989; Amlin and Rood, 2002). Their high productivity in arid environments is dependent on the continued supply of abundant water from a high water table.

In contrast, facultative phreatophytes are species that utilize groundwater when it is available, but also exist on sites where groundwater is not available. Many perennial species of arid environments fit into this category, including many of the shrubs and perennial grasses in Spring Valley. The productivity of facultative phreatophytes is increased by access to groundwater, but lack of groundwater within their rooting zones does not, in of itself, cause the elimination of the species. For this reason, facultative phreatophytes can be considered groundwater-sensitive species rather than groundwater-dependent species.

The shrubland biome contains 113 of the 752 mapped associations in Spring Valley and they cover a total of 28 percent of the mapped area (Table 2-1). Five species are the most common dominant species, comprising 87 of the 113 shrubland associations in Spring Valley. One of these species, coyote willow (*Salix exigua*) is an obligate phreatophyte. The dynamics of the communities dominated by this species are similar to those of the wetland biome. If DTW increases to about 4 m or more, this species would disappear from the site. Another of the five, Wood's rose (*Rosa woodsii*), becomes a dominant species only under conditions of high groundwater. Like coyote willow, an increase in DTW to about 4 m would eliminate it as a dominant species. The remaining three species are facultative phreatophytes and therefore their response to an increase in DTW is more complex. The dynamics of each of these three will be discussed in the following subsections.

3.3.1 Greasewood (Sarcobatus vermiculatus)

Greasewood is a species widely distributed throughout the Great Basin and southern warm desert regions, typically occurring on the edges of salt playas, saline flats with shallow water tables, and near saline seeps over a wide range of elevations, temperatures, and seasonal rainfall patterns (Shantz and Piemeisel, 1940; Miller et al., 1982; Comstock and Ehleringer, 1992). It is generally considered to be phreatophytic (Robinson, 1958; Dileanis and Groeneveld, 1989) and is often considered to be an obligate phreatophyte. However, the species can be found on sites where the water table is deep and should therefore be considered a facultative phreatophyte, although it is one of the most groundwater-sensitive facultative phreatophytic shrubs in the Great Basin Region. On sites where groundwater is deep, greasewood is found where there is moisture in excess of precipitation, often from an accumulation of surface runoff.

3.3.1.1 Effect of DTW on Greasewood

Maximum rooting depth of greasewood has been reported at various sites ranging from 4.5 to 6.1 m (Meinzer, 1927; ICWD/LADWP, 1989; Donovan et al., 1996; Chimner and Cooper, 2004), with one report of a maximum depth of 17.4 m (Meinzer, 1927). DTW varies substantially at sites supporting greasewood. Greasewood has been reported as most abundant in Steptoe Valley, Nevada where DTW was 3.7-6.1 m, but also was found in Alkali Spring Valley, Nevada where DTW was 14.5 m (Meinzer, 1927). In Big Smokey Valley, Nevada greasewood was found on sites with DTW varying from 0.8 to 18.3 m (Meinzer, 1927). In Ruby Valley, Nevada, greasewood is most abundant on sites where DTW is 0.9-1.6 m (Miller et al., 1982) and in Grass Valley, Nevada on sites where DTW is 2.1-3.2 m (Young et al., 1986). In the Owens Valley, California, greasewood occurs on sites with DTW varying between 2.6 to 6.7 m (ICWD/LADWP, 2010) and around Mono Lake, California on sites with DTW of 3.4-5.7 m (Donovan et al., 1996; Toft and Elliott-Fisk, 2002). Greasewood stands in the San Luis

Valley, Colorado are most dense when DTW is less than 3 m, but vigorous stands occur on sites with DTW as deep as 10 m (Charles et al., 1987).

Greasewood cover is highest when DTW is 1-2 m, but greasewood cover is only weakly correlated with DTW between 2 and 6 m. Cover of greasewood-dominated plant communities in central Nevada and eastern California typically average 30-35 percent when DTW is 1.0-1.5 m, in years with average precipitation (Nichols, 1994; ICWD/LADWP, 2010; Mata-Gonzalez et al., in press). At 1.5-4.0 m DTW, cover decreases to about 25-30 percent and about 15-25 percent between 4.0 and 6.0 m DTW (Table 3-2). Within each of these two ranges in DTW, greasewood is largely unaffected by changes in DTW. Between 6-8 m DTW, cover averages 10-15 percent and decreases to about 5 percent at DTW greater than 8 m.

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

Greasewood is sensitive to shallow groundwater. Greasewood cover decreases as DTW decreases above about 1 m (Shantz and Piemeisel, 1940; Sorenson et al., 1991; Nichols 1994) and greasewood plants do not tolerate flooding for extended periods (1-6 months) (Ganskopp, 1986; Groeneveld and Crowley, 1988).

Precipitation has a strong effect on greasewood, even when DTW is well within the rooting zone (Rickard, 1967; Branson et al., 1976; Rickard and Warren, 1981; Sorenson et al., 1991; Chimner and Cooper, 2004). Greasewood cover is about 50 percent higher when annual precipitation is more than about 20 cm than when it is less than 20 cm. In dry years (less than 10 cm), greasewood cover decreases by only about 10-20 percent compared to moderate precipitation years (10-20 cm). This relatively small decrease in cover is the result of increased use of groundwater during dry years. The interaction between precipitation and groundwater use by greasewood is an important factor to consider when attempting to quantify the effect of change in DTW on greasewood (Sorenson et al., 1991; McLendon et al., 2008).

3.3.1.2 Soil Texture and Soil Salinity

Greasewood is adapted to a variety of soil textures[1] but is often associated with finer-textured soils. This may be the result of additional moisture being present on these soils because they are often located in lower topographic sites and hence may receive more surface runoff than coarser-textured soils typically found on adjacent upland sites. It may also be true that greasewood is not directly favored by these fine-textured soils but instead can tolerate conditions on them more than competing species. Greasewood tends to have shallower roots on finer-textured soils than on coarser-textured soils, and this can have both beneficial and detrimental ecological effects (Sperry and Hacke, 2002).

Greasewood is generally considered to be a salt-tolerant species, adapted to saline conditions, but it is not confined to saline soils nor is its presence necessarily indicative of saline soils (Shantz and Piemeisel, 1940; Robinson, 1958). On some sites, greasewood is among the most salt-tolerant shrubs present (Blank et al., 1992; Toft and Elliott-Fisk, 2002), indicating that it can tolerate saline conditions. However, greasewood cover tends to be higher when it occurs on low-salinity sites than on nearby high-salinity sites (Sorenson et al., 1991), indicating that highly-saline conditions are not optimum for its growth.

3.3.2 Rabbitbrush (Ericameria nauseosa)

Rabbitbrush is the common name applied to several species of the genera *Chrysothamnus* and *Ericameria*. In this document, rabbitbrush will be used to refer to *Ericameria nauseosa* (formerly *Chrysothamnus nauseosus*), often referred to as rubber rabbitbrush.

Rabbitbrush is a widely-distributed shrub in western North America and the species includes at least 22 subspecies (Anderson, 1984a; Bhat et al., 1990). Because of the number of subspecies, many of which are co-occurring, water relations of the species are complex. Over most of its range, rabbitbrush is commonly found on sites with relatively deep groundwater (Meinzer, 1927; Robinson, 1958). On these deep groundwater sites, it is dependent on precipitation for its water supply. Rabbitbrush also occurs on sites with shallow groundwater, often as the subspecies *consimilis* (Robinson, 1958; Anderson, 1984b, Goedhart and Pataki, 2010). On these shallow groundwater sites, rabbitbrush has groundwater potentially available for its use in addition to precipitation-derived moisture. When growing on these shallow groundwater sites, rabbitbrush functions as a facultative phreatophyte. Otherwise, rabbitbrush is a non-phreatophytic species.

3.3.2.1 Effect of DTW on Rabbitbrush

Rabbitbrush is a deep-rooted species, with maximum reported rooting depths of 5.0-6.2 m (ICWD/ LADWP, 1989; Donovan et al., 1996). Rabbitbrush often has a dimorphic root system, with most of its fine roots in the upper soil profile (0-50 cm) but with woody tap roots extending to near the water

1. Texture is a physical property of a soil, based on the relative amounts of three soil particle classes: sand, silt, and clay. Sand particles are the largest and clay particles are the smallest. Coarse-textured soils contain a high portion of sand and fine-textured soils contain a high portion of silt or clay particles. Soils with intermediate amounts of sand and clay are termed loams. Based on these proportions, a particular soil is classified as a sand, loam, or clay. Adjectives are often used to denote variations, e.g., a sandy loam is a loam with a relatively high portion of sand.

table at greater than 4 m depths with some fine roots at the top of the water table (Branson et al., 1976; Donovan et al., 1996; Chimner and Cooper, 2004). Under conditions of flooding resulting from a rising water table, these deeper roots die and live rabbitbrush roots survive only in the unsaturated surface layers of the soil (Groeneveld and Crowley, 1988).

In the valleys of Nevada and eastern California, rabbitbrush communities have been reported occurring on sites with DTW ranging from 0.5 to 14.6 m. In Big Smokey Valley Nevada, they were reported on sites with 0.6-4.3 m DTW, but cover decreased when DTW was less than 2.4 m (Meinzer, 1927). In Steptoe Valley, Nevada the range in DTW was 2.4-3.4 m (Meinzer, 1927) and in Ruby Valley, Nevada rabbitbrush is dominant on sites with DTW of 0.9-1.6 m and co-dominant with big sagebrush on sites with DTW of 3.8-4.1 m (Miller et al., 1982). The subspecies *consimilis* occurs on sites in Grass Valley, Nevada where DTW is as shallow as 0.5-1.0 m (Young et al., 1986). In the Owens Valley, California, rabbitbrush communities are common where DTW is 1-4 m (Lee, 1912; Sorenson et al., 1991; McLendon et al., 2008) and rabbitbrush is dominant near Mono Lake, California on sites with DTW of 3.6-6.0 m (Toft, 1995).

Rabbitbrush cover on sites where DTW is within the rooting zone is at its maximum when DTW is about 3-4 m (Sorenson et al., 1991; McLendon et al., 2008) and cover decreases as DTW decreases (becomes shallower) from 2.5 m (Meinzer, 1927; Grosz, 1972; Mata-Gonzalez et al., in press). A decline in rabbitbrush cover also occurs with ssp. *consimilis* at DTW less than about 1.5 m (Groeneveld and Or, 1994) and rabbitbrush (ssp. *consimilis*) is replaced as the site dominant when DTW decreases to about 1.2 m (Groeneveld and Or, 1994; Goedhart and Pataki, 2010). Rabbitbrush cover begins to decrease at a DTW of about 4-5 m (Charles et al., 1987; Sorenson et al., 1991; McLendon et al., 2008) (Table 3-3).

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

Rabbitbrush utilizes groundwater at depths down to about 6 m (McLendon et al., 2008; Goedhart and Pataki, 2010). It makes maximum use of groundwater when DTW is 3-5 m (Steinwand et al., 2006; McLendon et al., 2008) and groundwater use at 6.0-6.5 m is only about 25 percent as much as at DTW of 4-5 m (McLendon et al., 2008). Groundwater usage increases as DTW decreases above 2.5 m but productivity decreases (Grosz, 1972), indicating that rabbitbrush is negatively affected by high water tables.

3.3.2.2 Soil Texture and Soil Salinity

The response of rabbitbrush to change in DTW is affected by soil texture. It is stressed more on sandy-textured soils than on fine-textured soils as DTW increases, as long as soil moisture remains adequate on the fine-textured soils (Sorenson et al., 1991). However, under drought conditions, rabbitbrush is more vulnerable to summer drought on fine-textured than on coarse-textured soils (Sperry and Hacke, 2002).

Rabbitbrush is a moderately salt-tolerant species, although its salt tolerance is somewhat dependent on subspecies (Anderson, 1984b). Soil salinity values on sites supporting rabbitbrush in Ruby Valley, Nevada, Big Smokey Valley, Nevada, and Owens Valley, California are about as saline, or slightly more saline, than those supporting greasewood (Meinzer, 1927; Miller et al., 1982; Branson et al., 1988; Sorenson et al., 1991). Around Mono Lake California, rabbitbrush is also salinity-tolerant, but less so than greasewood (Toft and Elliott-Fisk, 2002).

3.3.3 Big Sagebrush (Artemisia tridentata)

Big sagebrush is one of the most wide-spread shrubs in the Great Basin Region. It is not generally considered to be a phreatophyte. However when growing on lower elevation sites where groundwater is near the surface, big sagebrush does utilize groundwater (Dileanis and Groeneveld, 1989; Naumburg et al., 2005), provided the water table is not too near the soil surface. This is particularly evident at locations near streams and rivers where big sagebrush plants attain much larger heights and trunk diameters than sagebrush plants on adjacent sites with deeper groundwater. One example growing at the base of a drainage in Inyo County, California had a 39-cm diameter trunk (ground level) and was 4.6 m tall (Schneegas and Nord, 1967).

3.3.4 Shifts in Species Composition in Shrublands

3.3.4.1 Greasewood Communities

Greasewood communities covered 608 of the polygons that were mapped in Spring Valley in 2008-09 (McLendon et al., 2011). Of these polygons, 18 (3%) were almost monocultures of greasewood, 341 (56%) were greasewood-saltgrass associations, 51 (8%) were greasewood-sacaton associations, and 137 (23%) were greasewood-rabbitbrush associations. Potential changes to these greasewood communities, resulting from change in DTW or from other factors, would differ somewhat depending on the associated subdominant species.

The typical greasewood-saltgrass association supports an open overstory[2] of greasewood shrubs with a patchy understory of saltgrass. Typical cover values are about 30-35 percent for greasewood and 25-30 percent for saltgrass, assuming a DTW of about 1.5 m (Table 3-2). In most of these communities, there are smaller amounts of other shrubs and grasses. Rabbitbrush, big sagebrush, and shadscale (*Atriplex confertifolia*) are common associated shrubs and sacaton, alkaligrass (*Puccinellia* spp.), and creeping wildrye are other common grasses. On the wetter sites, Baltic rush is a common species in the greasewood communities.

2. Overstory and understory are terms related to vertical stratification within a plant community. Overstory species are taller species that form the upper-most layer of the vegetation. In shrublands, these are the taller shrubs. Understory species are shorter and exist beneath the canopies of the overstory species or in spaces between the overstory species. In most plant communities, the dominant species are the overstory species.

If DTW began to increase (become deeper), the first change in composition would be a decrease in cover of saltgrass. Saltgrass cover would be reduced by half if DTW increased to 4 m and would largely disappear from the community if DTW reached 6-7 m (Table 3-1). Sacaton would likely increase as saltgrass decreased, with the total cover of grasses not decreasing until DTW increased below about 4 m. Between 4-7 m, sacaton cover would decrease to about 10-15 percent, a level that it is likely to maintain utilizing precipitation-derived moisture only (i.e., decoupled from groundwater).

Greasewood cover would likely decrease if DTW increases between 1.5 and 6.0 m, but only slightly. Sorenson et al. (1991) found that a 2-m drawdown in water table had no adverse effect on greasewood but a 5-m drawdown did have an adverse effect, and ET from greasewood communities has been found to be substantially the same at DTW of 1.5 and 4.5 m (Charles et al., 1987). Over 20 years of monitoring data in the Owens Valley support these findings. Between 2.0-4.0 greasewood cover fluctuates annually in response to precipitation, but not to change in DTW, and cover remains largely independent of DTW between 4-8 m (ICWD/LADWP, 2010).

At a 6 m DTW, greasewood cover would likely remain about 20 percent (Table 3-2). Total cover at this DTW would likely be about 35 percent (20% greasewood + 15% sacaton) in years receiving average precipitation. In wet years, greasewood cover would likely increase by 50 percent and sacaton cover would likely double. In dry years, greasewood cover would likely decrease to about 15 percent and sacaton to 5-10 percent. Heavy grazing by livestock will largely eliminate the grass cover if DTW remains at 6 m or more.

If DTW increased to greater than about 9 m, greasewood cover would decrease to about 5 percent and sacaton cover would remain at about 15 percent. Once DTW reaches 9-10 m, any further increases in DTW would not affect the community because it would be effectively decoupled from groundwater. It would then be totally dependent on precipitation and runoff.

If greasewood cover decreased below about 20 percent (DTW = 5-6 m, Table 3-2), other shrubs would likely increase in cover. The species most likely to increase first is rabbitbrush. It is already present in many of the greasewood communities in Spring Valley (McLendon et al., 2011) and it is a rapid and aggressive colonizer, often becoming the first shrub to dominate a site following disturbance (McArthur and Welch, 1984; Young et al., 1984; Webb et al., 1987; McLendon and Redente, 1991; Tisdale, 1994; Bilbrough and Caldwell, 1997; Bagstad et al., 2005). Rabbitbrush can tolerate salinity at about the levels of greasewood and rabbitbrush is most favored by DTW deeper than that most favorable to greasewood (3.5 m and 1.5 m, respectively; Tables 3-2 and 3-3). Therefore, as DTW increases, rabbitbrush should have an advantage over greasewood.

Dominance of greasewood over rabbitbrush in greasewood communities does not occur because rabbitbrush cannot tolerate the environmental conditions or because greasewood out-competes rabbitbrush (Donovan and Richards, 2000). Instead, greasewood likely dominates certain sites because in colonized the site first (Blank et al., 1992, 1998; Toft and Elliott-Fisk, 2002) or it tolerated higher water tables (Grosz, 1972) or more frequent burial of plant parts by wind-blown material (Brown, 1997). Rabbitbrush is also less stressed by rapid fluctuations in DTW than is greasewood (Charles et al., 1987), perhaps because rabbitbrush utilizes more groundwater from deeper depths (Sorenson et al., 1991; McLendon et al., 2008) and because rabbitbrush has rapid root growth rates

(Donovan and Richards, 2000). Rabbitbrush maintains a higher level of productivity during summer months than most associated species in the Great Basin (Comstock and Ehleringer, 1992; Bilbrough and Caldwell, 1997), likely facilitated by its ability to utilize deeper soil moisture than some associated species (Huxman et al., 2004; Leffler et al., 2004). As DTW increases, shifting the zone of groundwater availability deeper, rabbitbrush would have the advantage over greasewood during the longer summer growing season.

Therefore if greasewood cover declines following an increase in DTW, rabbitbrush is likely to increase. The result is that the dominant species would likely change, but the site would remain a shrubland with a grass understory. Shrub cover may likely increase as DTW increases because rabbitbrush cover tends to maximize at about 3.5 m DTW (Table 3-2). Evapotranspiration (ET = evaporation from the soil surface plus transpiration through plants) would also likely increase until DTW reached about 6 m. Typical ET rates for greasewood communities (20-25% cover) at about 2.5 m DTW in Nevada and eastern California are 25-40 cm per year (Grosz, 1972; Miller et al., 1982; Duell, 1990; Steinwand et al., 2001). This compares to 45-50 cm for rabbitbrush communities at DTW of 3.0-3.5 m (Duell, 1990; Steinwand et al., 2001).

Even on drastically disturbed sites (e.g., abandonment of cultivation, bulldozing), rabbitbrush establishes rapidly. Under mesic conditions, rabbitbrush becomes site-dominant or co-dominant in 5-7 years (McLendon and Redente, 1991; Stevenson et al., 2000). Even under dry conditions (15 cm annual PPT), rabbitbrush establishes communities with 25 percent cover in less than 30 years (McLendon et al., submitted).

Rabbitbrush can successfully establish in the presence of cheatgrass (*Bromus tectorum*)(Young et al., 1984; McLendon and Redente, 1991) and cheatgrass production is reduced under rabbitbrush canopies (Young et al., 1984). During secondary succession, rabbitbrush replaces cheatgrass as a seral dominant, but does not totally exclude cheatgrass (McLendon and Redente, 1994).

The greasewood-sacaton associations would likely respond to increases in DTW in a similar manner as the greasewood-saltgrass associations, except that the starting DTW is likely to be deeper at the greasewood-sacaton sites. Similarly, the greasewood-rabbitbrush associations would respond in a manner similar to the later stages of change in the greasewood-saltgrass associations.

3.3.4.2 Rabbitbrush Communities

Rabbitbrush communities were the most frequent shrubland communities mapped in Spring Valley in 2008-09, covering 1,190 (54%) of the 2,196 shrubland polygons (McLendon et al., 2011). Of these 1,190 rabbitbrush-dominated polygons, 75 (6%) were almost monocultures of rabbitbrush, 677 (57%) were rabbitbrush-sacaton associations, 255 (21%) were rabbitbrush-saltgrass associations, 27 (2%) were rabbitbrush-alkaligrass associations, and 86 (7%) were shrubland-wet meadow associations with rabbitbrush and either sedges or Baltic rush.

These associations have rabbitbrush as the overstory dominant and the associated herbaceous species as the understory subdominant species. The associations form a DTW gradient, with the rabbitbrush-sacaton associations occurring on sites with deepest DTW and the rabbitbrush-sedge and rabbitbrush-Baltic rush associations occurring on sites with shallowest DTW. The response of these rabbitbrush associations to increasing DTW would follow a reverse pattern along this DTW gradient. If DTW increased, the sedges and Baltic rush would decrease in cover and would be replaced as understory species first by saltgrass and then, if DTW continued to increase, by sacaton. Saltgrass would begin to replace Baltic rush if DTW increased past about 1 m and saltgrass cover would exceed that of Baltic rush as DTW increased past about 2 m. Between 2-3 m DTW, saltgrass would begin to decrease in cover and sacaton would increase. Although there would be shifts in understory species composition, total herbaceous cover would remain high (50-70%) until DTW increased past about 4 m (Table 3-1).

Rabbitbrush cover would likely increase as DTW increased until DTW reached about 3.5 m, at which point rabbitbrush cover would be about 50-60 percent (Table 3-3). If DTW increased to 5-7 m, rabbitbrush cover would likely decrease to 20-25 percent and sacaton to about 10-15 percent. Both species would be decoupled from groundwater, including capillary fringe, if DTW increased to 8-9 m. Once decoupling occurred, the plant community would be precipitation-dependent and total cover would be on the order of 15-20 percent, with half to two-thirds being rabbitbrush. In wet years, cover might double and in dry years it might decrease to 10-15 percent.

If DTW increased below about 3-4 m, the grass component of the community would become more sensitive to livestock grazing. Heavy grazing would decrease the amount of perennial grasses present in the community, and shrubs would increase correspondingly. Even moderate grazing would put stress on these perennial grasses in dry years if DTW increased past about 3-4 m. Drought effects would also increase at deeper DTW, compared to when DTW is less than about 3 m. The dry meadow grasses and associated shrubs tend to rely heavily on precipitation, increasing their utilization of groundwater when precipitation-derived soil moisture is depleted (Sorenson et al., 1991; Goedhart and Pataki, 2010; Goedhart et al., 2010). Therefore if groundwater became less available, there would be less to utilize during dry periods. Depending on species, the threshold DTW is about 3-4 m (McLendon et al., 2008). Above that DTW, groundwater is sufficient in most years. Below that DTW, cover decreases because of lack of groundwater during dry periods.

Over time, big sagebrush would likely increase on the sites where DTW increased and remained below about 3-4 m, provided that salinity levels were not high in the upper soil layers. Throughout the Great Basin Region, rabbitbrush is generally a mid-successional species. On most of the rabbitbrush-dominated sites, big sagebrush is the late-successional dominant species. Of the Spring Valley shrubland sites mapped in 2008-09, 7 percent were dominated by big sagebrush with much more big sagebrush dominated area on the unmapped uplands. The most common sub-dominant species in the valley-floor big sagebrush communities were rabbitbrush (37%), greasewood (25%), and sacaton (14%).

In the eastern areas of the Great Basin, big sagebrush replaces rabbitbrush in 30-50 years. In the Owens Valley, California, which is drier than Spring Valley, abandoned cropland sites become dominated by rabbitbrush within 30-40 years and dominated by big sagebrush within an average of 75 years following abandonment (McLendon et al., submitted). Once rabbitbrush-sagebrush and sagebrush-rabbitbrush communities become established, the sites would have relatively stable and productive communities that are not groundwater dependent. These mid- and late-successional precipitation-supported communities are productive (100-200 g/m^2 annual aboveground productivity), long-term stable, and species diverse.

3.4 Woodland Biome

Woodlands are infrequent on the floor of Spring Valley. There are 24 locations that support trees associated specifically with high groundwater (McLendon et al., 2011). Of these 24 locations, 18 are dominated by Russian olive (*Elaeagnus angustifolia*), a non-native species. The remaining six are dominated by cottonwoods (*Populus* ssp.). The cottonwoods are dependent on a high water table (2-4 m). If DTW increased below this level, these trees would decrease in productivity and eventually die, and the site would transition to another community, most likely a shrub-meadow community.

The most extensive woodlands on the lower elevations of Spring Valley are those dominated by Rocky Mountain juniper (*Juniperus scopulorum*). Rocky Mountain juniper mostly occurs in Spring Valley on upland sites, but in two locations the populations extend from the uplands down to the valley floor. The trees in the valley floor locations are known locally as swamp cedars (Robinson, 1958). These lowland trees occur at the low end of a topographic gradient in close proximity to Rocky Mountain junipers on the upper slopes.

At both sites, the trees vary in density along the topographic gradient from valley floor to uplands, with density generally increasing as elevation decreases. Size of trees however, does not change substantially along the gradient. The juniper dominate sites varying from wetland sites with groundwater at or near the soil surface to dry upland sites, and at both locations these wetland-to-dry upland juniper-dominated sites form continuous gradients. There were 22 Rocky Mountain juniper associations mapped and these differed in relation to understory species. Understory species varied from typical wetland species such as redtop, Nebraska sedge, spikerush, and Baltic rush at the lower elevation wetland locations to typical dryland species such as big sagebrush and rabbitbrush at the upper elevation portions of the gradient. Intermediate sites had understory subdominants such as sacaton, greasewood, saltgrass, and alkali cordgrass (*Spartina gracilis*).

Because of their location at the edges of the wetlands, assumptions have been made that these lowland trees are an ecotype or sub-species of Rocky Mountain juniper that is sufficiently different genetically from the adjacent upland population to be uniquely adapted to the wetland conditions. However, to date no genetic or ecophysiological data have been presented to support this assumption. The fact that Rocky Mountain juniper is present on a large number of restricted and often isolated and highly selective environments throughout its range argues that ecotypes of the species may exist (van Haverbeke, 1980). But until they are shown to exist on the wetland sites in Spring Valley, “swamp cedar” ecotypes or varieties in Spring Valley remain a speculation.

Juvenile trees are present all along the topographic gradient, indicating that successful reproduction is not dependent on high groundwater. In fact, a high water table (0-50 cm DTW) appears to be detrimental to the species as evidenced by a large number of dead trees in areas that now have high groundwater.

Regardless of whether or not these lowland trees form a distinct wetland ecotype or subspecies, they do occur at low elevations and provide rare woodland habitats on the valley floor. For this reason alone, they should be considered as a valuable resource in Spring Valley and therefore possible impacts from changes in DTW on these trees should be considered.

Rocky Mountain juniper is more widely distributed than any other tree-sized juniper in the United States (Fowells, 1965; van Haverbeke, 1980) and is adapted to both dry and wet extremes within this wide range. It is found in the high-rainfall area of Puget Sound and in many areas it develops best along ravines and canyons, a characteristic that has given rise to one of its common names “river juniper” (Fowells, 1965). In the southern portion of its current range, Rocky Mountain juniper is common on areas of shallow groundwater (Adams, 1983). Currently, the western-most populations of Rocky Mountain juniper in the central Great Basin Region occur in central Nevada (Fowells, 1965). However, it occurred in the Owens Valley, California 16,000 years ago at a time when that area was wetter and had large areas of high groundwater (Koehler and Anderson, 1994). This occurrence of Rocky Mountain juniper at high groundwater sites along its southern (current) and western (past) boundaries indicates an adaptation of the species to shallow groundwater conditions over a long period of time.

3.4.1 Effect of DTW on Rocky Mountain Juniper

As a species, Rocky Mountain juniper is not groundwater-dependent. Over its range it is found on dry sites such as lava beds, limestone cliffs, exposed bluffs, low-moisture retention soils derived from shales, shallow stony soils with cemented subsoils (Fowells, 1965), and tops of mesas (Madany and West, 1983). However, when additional moisture is available, such as along waterways and drainages, it exploits the increased moisture resulting in higher productivity (Fowells, 1965). Therefore the species appears to function as a facultative phreatophyte.

Although Rocky Mountain juniper is widely distributed, little ecophysiological and especially water-use data have been published for this species. Because of the lack of species-specific data, data on other juniper species will be used to make estimates of ecological responses by Rocky Mountain juniper until species-specific data become available, especially data for the species in the Spring Valley area.

Utah juniper (*J. osteosperma*) is a common species co-occurring with Rocky Mountain juniper in much of the Great Basin Region. Utah juniper utilizes over 80 percent of its water from precipitation (Williams and Ehleringer, 2000), using precipitation-derived soil moisture from the upper soil profile as long as such moisture is available and shifting to deep soil moisture when the supply in the upper soil profile is depleted (Flanagan et al., 1992a and b; Williams and Ehleringer, 2000). Most studies on upland sites dominated by juniper indicate that most (68-99%) of annual precipitation is utilized as ET, when averaged over years (Huxman et al., 2005). This suggests that these species are primarily dependent on precipitation for their water source. However, when available, groundwater can contribute a significant amount to water use by juniper. In the fractured limestone ecosystems on the Edwards Plateau of Texas, groundwater supplies as much as 24 percent of the water use by Ashe juniper (*J. ashei*), even at DTW of 8 m (Jackson et al., 1999, 2000).

In Spring Valley, mean cover of Rocky Mountain juniper was 47 percent, averaged over 31 sample locations in 2009. Juniper cover averaged 54 percent on high-groundwater sites, as indicated by the understory vegetation, and 40 percent on the drier sites. This suggests that (1) the trees are benefited by higher groundwater, having 35 percent higher cover on the lowland sites, and (2) the species is not dependent on high groundwater because upland sites have relatively high cover values and support large mature trees and substantial numbers of juvenile trees. On the wet sites, juniper cover ranged from 32-87 percent among the 16 belt transects and from 21-54 percent among the 15 belt transects on the dry sites. These data indicate that the highest extreme cover values were on the wet sites and the lowest extreme values were on the dry sites, but that there was substantial overlap between the wet and dry sites. Ten of the 16 (63%) wet-site transects had juniper coverage within the range of coverage on the dry sites and 12 of the 15 (80%) dry-site transects had values within the range of coverage on the wet sites.

3.4.2 Effect of Change in DTW on Rocky Mountain Juniper

In the absence of DTW measurements, species composition of the understory vegetation provides a useful estimate of relative DTW. The understory vegetation at the 31 juniper sample locations varied from that typical of wetlands in Spring Valley to that typical of dry uplands (Table 3-4). Standing water was at the surface at numerous locations adjacent to the wetland juniper site and this location had average juniper cover of 87 percent. The surface soils at the wet meadow juniper sites were moist, but standing water was not common. DTW was probably 0.5-1.0 m on average at these 8 sites and average juniper cover was 56 percent. Surface soils were dry at the dry meadow juniper sites and the understory species composition would suggest that average DTW might be 2-4 m at these 11 sites and average juniper cover was 45 percent. Typical DTW at sites supporting rabbitbrush-sacaton shrub meadow communities, with some creeping wildrye and saltgrass, in central Nevada and eastern California is about 3-5 m. Average juniper cover on these 10 sites was 41.0 percent. Typical DTW at sites supporting big sagebrush-greasewood communities in the Great Basin is 5-10 m, or more. The average juniper cover at this site was 35 percent.

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

These estimates of the relationship between DTW and juniper cover provide reasonable approximations to expected changes in cover of Rocky Mountain juniper as DTW increases. At very shallow DTW (less than 1.0 m), juniper cover will likely be 60-90 percent. At 2-5 m DTW, cover would likely decrease to 40-50 percent. Juniper roots can extend as much as 8-10 m deep (one-seeded juniper trees in New Mexico are known to root to greater than 20 m; Tierney and Foxx, 1987), therefore juniper cover at these DTW should remain at about 40 percent. At DTW greater than 10 m, the trees might become decoupled from groundwater and cover would stabilize at about 30-40 percent.

Although the cover of Rocky Mountain juniper in the two lowland populations in Spring Valley is influenced by DTW, the water supply to these trees appears to be from a combination of spring outflow (the wetland and wet meadow locations, Table 3-4) and shallow water tables that may be perched (dry meadow and rabbitbrush locations, Table 3-4). The lowest elevation sites are associated with wetlands supported by spring outflows. The juniper communities occurring on sites immediately upslope from these wetland and wet meadow sites appear to receive subsurface moisture from some source, but it seems unlikely that this would be from the valley-floor water table because of the increase in elevation. A more likely explanation would be that these trees receive additional moisture from subsurface flows down the base of the adjacent mountains, caused by upslope percolation encountering impervious layers and then flowing laterally. If this assumption is correct, then groundwater withdrawal from deep valley-floor strata would not likely affect the water supply to these juniper populations.

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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.

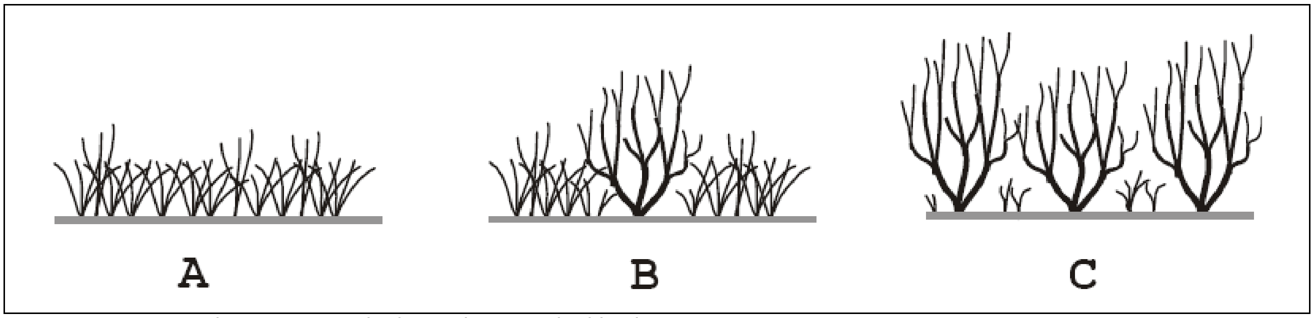
Succession is the ecological process of vegetation change over time (Billings, 1970) resulting from various species being replaced by other species as ecological conditions at the site change over time (Odum, 1971, p. 251). Primary succession occurs when the substrate has not been significantly affected 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

1992, p. 324). As one species becomes more successful in acquiring the limited resources under the changing conditions, it begins to replace less successful species. This is competitive displacement.

If the resource and stressor levels fluctuate within the limits associated with the dominant species of that community, the community will remain relatively stable. However, if one or more important resource or stressor level increases or decreases beyond these limits, competitive advantage will shift to other species and changes in species composition and productivity will occur. If these changes are relatively short-term and not extreme in their magnitude, the previous community is likely to re-establish itself in a fairly short period of time. This often happens during a drought sequence or following release from short-term overgrazing. Conversely, if the changes are long-term or extreme (e.g., climate change, re-occurring fire, sustained overgrazing), the composition of the community will change for an extended period of time, with those species better adapted to the changed conditions replacing those which are less adapted.

Lowering of the water table resulting from groundwater withdrawal is an example of a change in resource availability with an associated increase in ecological stress. Species adapted to conditions of higher available water will be replaced over time by species adapted to conditions of lower available water. Both aspects, changes in resource availability and ecological stress, are important in explaining the change in species composition as DTW increases. A general characteristic of succession is that aboveground structure increases as succession progresses (Odum, 1971, p. 252; Whittaker, 1975, p. 178; Smith, 1992, p. 324). Typical secondary succession in mesic regions passes consecutively through the following seral stages: annuals, short-lived herbaceous perennials, perennial grasses, shrubs, mid-seral trees, and late-seral trees (Odum, 1971, p. 261; Whittaker, 1975; Smith, 1992, p. 325). In most arid and semiarid regions, the lack of sufficient soil moisture prevents succession from progressing to the tree stages. Instead, the shrub stage is often the last stage of most successions. On wet sites in arid regions, such as the wetlands and meadows in Spring Valley, the saturated surface or near-surface soils prevents most shrubs from dominating the sites (Naumburg et al., 2005) and therefore succession stops with grass or other herbaceous wetland species being dominant. The most frequent dominant shrub species in Spring Valley (greasewood, rabbitbrush, and big sagebrush) do not tolerate high water tables (Shantz and Piemeisel, 1940; Ganskopp, 1986; Sorenson et al., 1991; Groeneveld and Or, 1994; Nichols, 1994; Goedhart and Pataki, 2010). Therefore if DTW increased, the resource (water) would become less available to the wetland and grass species and they would undergo greater stress while the shrubs would now be able to tolerate conditions at these sites. Succession would then proceed to the shrub stage (Figure 4-1).



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

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

How much of a change in species composition and productivity occurs would depend in part on how much of a drawdown occurs and how fast it occurs. In the following subsections, discussions of patterns and rates that are likely to occur in response to a lowering of the water table for major vegetation types are presented. Variations in species composition within each type will result in corresponding variations in rates and patterns.

Change in DTW is not the only factor that will cause changes to occur in the composition of these plant communities in Spring Valley. The potential impacts of some of these other factors (fluctuations in precipitation, climate change, livestock grazing, fire regime, and irrigation practices) are discussed in Section 5.0.

4.1 Aquatic and Wetland Communities

These communities are dependent on standing water at the surface at all times (aquatic) or occasional standing water and groundwater at or near (within about 20 cm) the soil surface most of the growing season (wetlands). If standing water becomes occasional, the aquatic communities would convert to wetlands. If DTW increases to about 50 cm, species composition in the wetlands would shift, with obligate wetland species such as cattail, bulrush, spikerush, Nebraska sedge, and redtop largely replaced by wetland and wet meadow species adapted to drier conditions, such as Baltic rush, Kentucky bluegrass (*Poa pratensis*), creeping wildrye, and saltgrass. Community plant cover would decrease somewhat, but would remain high at about 60-80 percent.

If DTW increases to 1-2 m, the wetland/wet meadow vegetation would shift to that of dry meadows. Cover of Baltic rush, Kentucky bluegrass, and creeping wildrye, for example, would decrease and cover of saltgrass would increase. Other dry meadow grasses, such as sacaton, alkaligrass, and alkali cordgrass would likely establish on the site, and shrubs adapted to relatively high groundwater, such as greasewood and rabbitbrush, would begin to establish. Plant cover would remain high, at about 50-75 percent. If DTW continued to increase past 1-2 m, the dynamics of the vegetation would follow the patterns discussed in Sections 4.2 and 4.3.

4.2 Wet Meadow

Three common dominant species in the wet meadows of Spring Valley are Nebraska sedge, Baltic rush, and creeping wildrye. These three species typically dominate sites where DTW is 1 m or less and form a gradient with Nebraska sedge most often dominant on the wettest sites and creeping wildrye on the driest (Figure 4-2).

In central Nevada, Nebraska sedge typically is dominant on sites where average DTW is 0-20 cm (Chambers et al., 1999; Castelli et al., 2000; Martin and Chambers, 2001a). Redtop and meadow fescue are also major species on these shallow DTW wetlands in Spring Valley (McLendon et al., 2011). Baltic rush can be found on sites with DTW as deep as 2.5 m (Miller et al., 1982; Chambers et al., 2004) but is most productive when DTW is less than 1.5 m (Castelli et al., 2000; Jewett et al., 2004; Mata-Gonzalez et al., in press). Creeping wildrye is highly productive when DTW is around 1 m. Saltgrass tends to become a major species on wetland sites when DTW becomes 1.0-1.5 m.

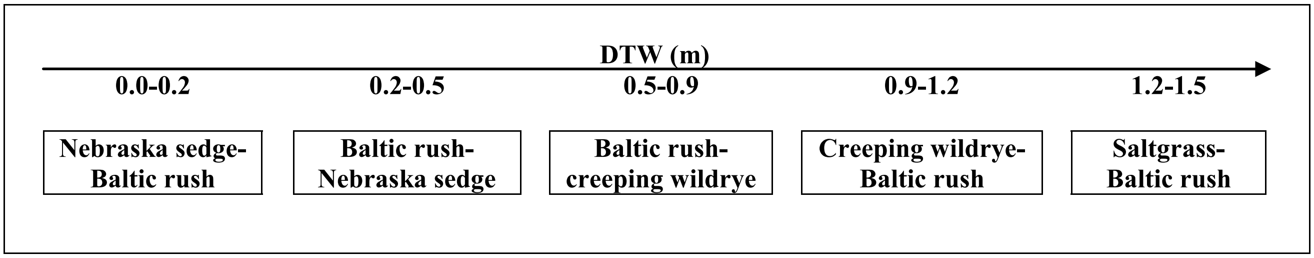


Figure 4-2
Conceptual Diagram of a Transition in Wetland Communities Caused by an Increase in DTW

If an increase in DTW occurred slowly (e.g., 10-20 cm per year), the transition would likely occur as depicted in Figure 4-1, with other wetland species included in each stage. If the increase in DTW occurred more rapidly (e.g., 0.5-1.0 m per year), Baltic rush would likely be the dominant species until replaced by saltgrass (Figure 4-2) and then sacaton because there would not be enough time for creeping wildrye to increase sufficiently to become a dominant species. When DTW is about 1 m, creeping wildrye can double in cover in one year but this growth rate would be much less if DTW was 1.5-2.0 m. Kentucky bluegrass would also likely be an important component of these communities when DTW is 1.0-1.5 m. Plant cover would remain high (60-80%).

If DTW increased to 1.5-3 m, wet meadow species such as Baltic rush, creeping wildrye, and Kentucky bluegrass would decrease in abundance and dry meadow species such as saltgrass, sacaton, alkaligrass, and alkali cordgrass would increase in abundance. Shrubs, particularly greasewood or rabbitbrush, would likely establish on the site if DTW increased past about 2 m. Plant cover would remain high (50-70%). Depending on grazing intensity and amount of precipitation received the sites would vary between mostly dry meadow (Section 4.3) to a mix of shrub-meadow. Heavier grazing and lower precipitation would favor shrubs and lighter grazing and higher precipitation would favor the grasses.

4.3 Dry Meadow

The most common dry meadow dominant species in Spring Valley are saltgrass and sacaton. These two species are dominant or subdominant on 60 percent of the areas mapped as dry meadow in 2008-09 (McLendon et al., 2011). Vegetation changes resulting from groundwater withdrawal would likely be similar on the other dry meadow associations.

For purposes of illustration, it is assumed that the initial DTW is 1.5 m and that DTW increases (water table declines) at a rate of 1 m per year. Rates of downward root growth in grasses are typically on the order of 10-15 mm per day (Kramer, 1969, p. 127; Mahoney and Rood, 1992; Armstrong et al., 1996; Dunbabin et al., 2002). At 12-mm per day growth rate, roots would require 80-85 days of growth to follow a 1-m decline in water table. Therefore, if DTW were to increase by 1 m per year, downward root growth would likely keep pace down to the maximum effective rooting depth of the species.

Sacaton has a deep root system (6 m, ICWD/LADWP, 1989), whereas saltgrass is a relatively shallow-rooted species (Cluff et al., 1983; Dahlgren et al., 1997) generally occurring where DTW is

2.5 m or less (Robinson, 1958; Nichols, 1994). Therefore, sacaton would become more abundant as DTW increased and saltgrass would become less abundant. Although saltgrass is found on some sites where DTW is as much as 3-4 m (Meinzer, 1927; Nichols, 1994; Mata-Gonzalez et al., in press), cover of saltgrass generally decreases when DTW increases past 1.5-2.0 m (McLendon et al., 2008). In comparison, sacaton is found on sites with DTW of 1-8 m but has its highest cover when DTW is 1.5-4.5 m (Meinzer, 1927; Duell, 1990). Sacaton cover is unaffected by change in DTW between 2-4 m (Sorenson et al., 1991; McLendon et al., 2008). Between about 4 and 7 m, sacaton cover averages about 60-70 percent of its value at 2-4 m.

Even under conditions of low annual precipitation (less than 10 cm) sacaton is able to tolerate increases in DTW of 2-3 m per year for at least two consecutive years (ICWD/LADWP, 2010). Under these harsh conditions, sacaton cover decreases by about 50 percent per year during the decline in groundwater. Upon restoration of average annual precipitation, sacaton cover stabilizes. At 7-8 m DTW, sacaton cover averages 10-15 percent in years receiving 10-20 cm of precipitation on sites that averaged 40-50 percent sacaton cover prior to drawdown (DTW = 2-3 m). In years receiving 20-35 cm of precipitation, sacaton cover averages 15-25 percent at 7-8 m DTW on these same sites.

Most dry meadow sites also have some shrubs present, often rabbitbrush but also including greasewood, shadscale (*Atriplex confertifolia*), and big sagebrush. These shrubs tend to increase in size and density as DTW increases below about 2 m. The specific successional pattern following a long-term increase in DTW depends on which shrubs are initially present, or present on adjacent sites, and how much DTW increases. Rabbitbrush will be used as the shrub in this example because it is the most abundant shrub on most of the dry meadow sites.

If DTW increased from 1.5 m to about 2.5 m, cover of saltgrass would decrease and cover of sacaton would increase, shifting the dry meadow from a saltgrass-sacaton community to a sacaton-saltgrass community. Cover of both of these species can increase relatively rapidly (on average, about 10 percentage points per year). Saltgrass increases cover primarily by spreading of rhizomes, from which new shoots emerge. Cover of sacaton increases by both expansion of the existing basal crowns and from new seedlings, sacaton being a relatively high seed producer. Therefore, the dynamics of the shift from saltgrass- to sacaton-dominated meadows are determined more by the change in DTW than in the colonization rate of the two species, except in dry years when increases in sacaton are negligible. When dry years are followed by years with moderate to high precipitation, sacaton cover typically increases 2-4 times over its value in the dry year. These increases are in response to precipitation and are largely independent of DTW. DTW is most important in affecting sacaton cover in dry years whereas precipitation is the primary control factor in years with average or above average precipitation.

Between 2.5 and about 4.5 m DTW, sacaton cover is not substantially affected by changes in DTW, with annual precipitation largely determining the cover value in a particular year. At these DTW levels, shrub cover gradually increases at a rate of about 3-4 percentage points per year in average years, with faster increases occurring in wet years and slower increases in dry years.

Sacaton cover would decrease to about 15-20 percent in average years if DTW increased to about 10 m, after which sacaton would utilize very little groundwater and its annual cover value would be determined almost exclusively by the amount of precipitation received. Further increases in DTW would have no measurable effect on sacaton because sacaton roots would be decoupled from groundwater.

Shrub cover, most likely primarily rabbitbrush for the first 10-15 years, would slowly increase at the rate of about 3-4 percentage points per year, on average. Maximum cover of rabbitbrush (50-60%) occurs when DTW is about 3-4 m. However, if there was only a small amount of rabbitbrush present when the increase in DTW began, it is unlikely to increase fast enough to reach this level at a rate of DTW increase of 1-m per year. If rabbitbrush cover was low initially (e.g., 1-2%), it would take 10-15 years for rabbitbrush to attain 50-60 percent cover under conditions of average precipitation. Rabbitbrush roots to about 6 m (ICWD/LADWP, 1989; Donovan et al., 1996) and rabbitbrush utilizes little groundwater below about 4.5 m DTW. Therefore, below 4.5 m DTW, rabbitbrush is largely decoupled from groundwater and its cover is determined by precipitation. At 20-25 cm annual precipitation, rabbitbrush cover would eventually average about 20-25 percent.

When DTW becomes sufficiently deep that roots of the major species are no longer in contact with groundwater or its capillary fringe, the plant community is decoupled from groundwater and it becomes an upland (i.e., not groundwater-influenced) plant community. In such cases, what was a dry meadow becomes a grass-shrubland or a shrubland community. Sacaton can remain an important component of the community in the absence of groundwater if livestock grazing is light or there is no grazing. Over time, other perennial grasses that are characteristic of upland communities in the Great Basin will likely establish on the site, provided that livestock grazing is not excessive. Examples include Sandberg bluegrass (*Poa secunda*), desert needlegrass (*Stipa speciosa*), Indian ricegrass (*Achnatherum hymenoides*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and western wheatgrass (*Pascopyrum smithii*). If livestock grazing is too heavy, establishment of these perennial grasses would be limited and the likelihood of establishment of extensive amounts of cheatgrass (*Bromus tectorum*) would increase. In either case, a shrub-dominated overstory would likely remain because of the presence of shrubs in the early stages of the increase in DTW.

Rabbitbrush would likely be the dominant shrub species for 20-40 years until replaced by big sagebrush (*Artemisia tridentata*) (Harniss and Murray, 1973; Young and Evans, 1974, 1978; McLendon and Redente, 1990; McLendon et al., submitted). Rabbitbrush is the common mid-seral shrub species on similar sites throughout the Great Basin and big sagebrush is the common late-seral species (McLendon and Redente, 1990; Tisdale, 1994). Big sagebrush generally establishes on disturbed sites within about 5 years but remains in low densities for another 5-10 years (McLendon and Redente, 1991; Stevenson et al., 2000), then increases in cover at an average annual rate of about 1 percentage point per year. In general, it takes about 40-60 years for big sagebrush to become site dominant (Mata-Gonzalez et al., 2007; McLendon et al., submitted). Once big sagebrush becomes the dominant species, rabbitbrush and other shrubs become minor species. The overstory is then almost totally dominated by big sagebrush, with the understory a mixture of perennial grasses and forbs.

A conceptual diagram of the transition from dry meadow to shrubland in response to an increase in DTW is presented in Figure 4-3. The two factors controlling the transition are DTW and time. The community changes early in the transition (left half of Figure 4-3) are controlled primarily by DTW. The changes later in the transition (right half of Figure 4-3) are controlled primarily by time. If DTW increases below 3-4 m, rabbitbrush would increase. How fast it would increases, and therefore the

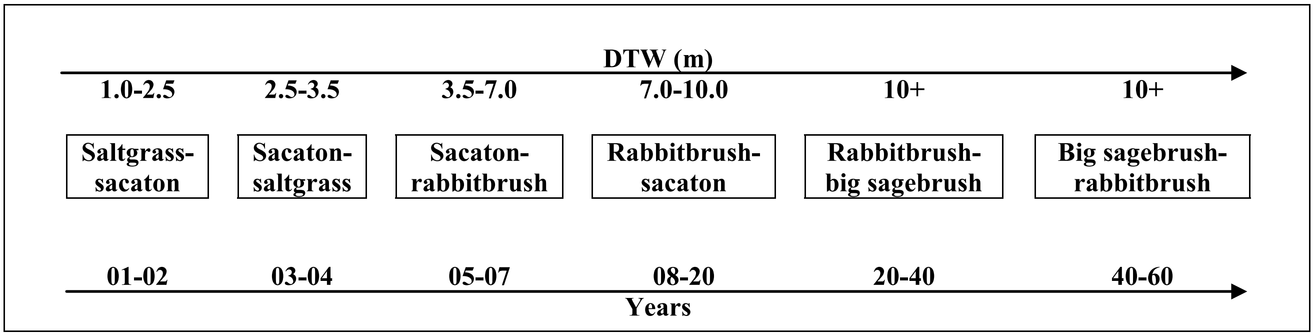


Figure 4-3
Conceptual Diagram of a Transition from Saltgrass-Sacaton Dry Meadow to Shrubland Resulting from an Increase in DTW Over Time

transition rate of sacaton to rabbitbrush, depends on the growth and colonizing rate of rabbitbrush. Likewise, the rate of the transition to big sagebrush is determined by the growth rate of big sagebrush.

For simplicity, the fourth community in Figure 4-3 is defined as a rabbitbrush-sacaton community. More likely, sacaton would be the major perennial grass during the initial phase of this community but could be replaced by other perennial grasses over time. Rabbitbrush is the most likely shrub to initially dominate these dry meadow sites as they shift to grass-shrublands and then shrublands because of its ability to rapidly colonize sites. However, if the soil texture at the site is clay-loam or finer, greasewood could become the dominant species. If that were the case, vegetation dynamics could then follow the pattern presented in Section 4.4.

4.4 Greasewood Shrubland

Greasewood shrublands tend to occur on sites with some combination of at least two of three factors: (1) moderately high groundwater (1-4 m), (2) fine-textured surface soils (loams to clays), and (3) moderately saline surface soils. Greasewood does occur on some sites with only one of these three factors but greasewood-dominated sites generally are characterized by at least two of the three.

Greasewood cover is generally highest when DTW is 1-3 m (Miller et al., 1982; Young et al., 1986) but vigorous stands occur on some sites with DTW as deep as 10 m (Meinzer, 1927; Charles et al., 1987; Chimner and Cooper, 2004). Greasewood cover decreases as DTW decreases above about 1 m (Shantz and Piemeisel, 1940; Sorenson et al., 1991; Nichols, 1994) and as DTW increases below 4-6 m.

In Spring Valley, greasewood does occur in near-monoculture stands but these sites are infrequent. Only 18 of the 608 polygons mapped as greasewood-dominated sites were monocultures or near monocultures (McLendon et al., 2011). The most frequent greasewood associations were greasewood-saltgrass (341 polygons), greasewood-sacaton (51 polygons), and greasewood-rabbitbrush (137 polygons). Of these three associations, greasewood-saltgrass generally occurs on sites with the shallowest groundwater and greasewood-rabbitbrush the deepest (Figure 4-4).

If DTW increases from 1-2 m initially to about 3 m, the primary result would be a shift in understory vegetation from saltgrass to sacaton. Greasewood cover would remain at about the same level or

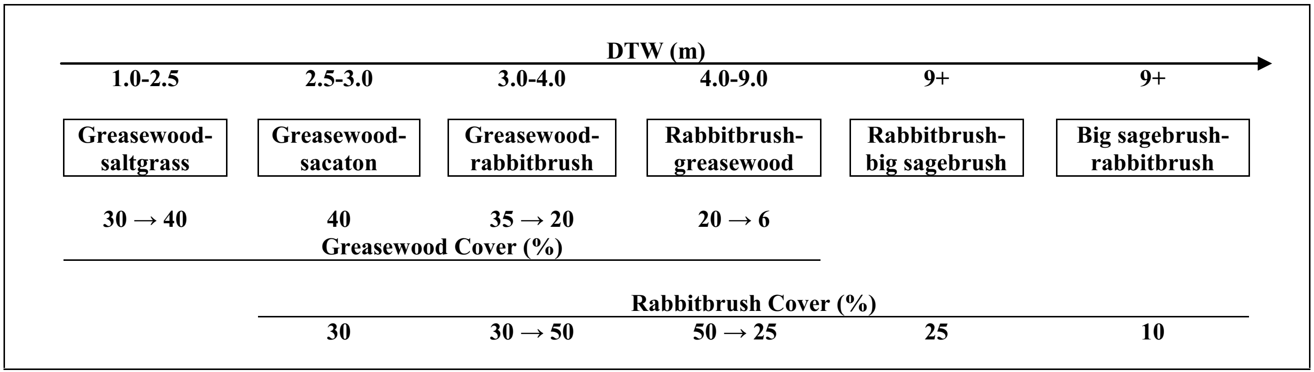


Figure 4-4
Conceptual Diagram of a Transition from Greasewood-Saltgrass Community to Big Sagebrush-Rabbitbrush Communities Resulting from an Increase in DTW

increase slightly and rabbitbrush would begin to increase (Figure 4-4). Between about 3-6 m, sacaton would remain abundant, greasewood cover would gradually decrease to about 20 percent in average years, and rabbitbrush would increase to about 50 percent at about 4 m DTW and then gradually decrease to 20-25 percent. At 6 m DTW, these sites would remain grass-shrublands, with sacaton as the major grass species and a rabbitbrush-greasewood complex as the shrub component.

Should DTW continue to increase below 6 m, greasewood would gradually be replaced by rabbitbrush, followed by big sagebrush (Figure 4-3). Below 6-8 m DTW, vegetation changes on most of these sites would likely follow the same pathway as the later stages of the dry meadow sequence (Figure 4-3). On sites with particularly high clay content, rabbitbrush might remain the dominant shrub when DTW increases below 8-10 m rather than being replaced by big sagebrush, although big sagebrush commonly occurs with greasewood in Spring Valley. Of the 153 polygons mapped as big sagebrush associations, big sagebrush-greasewood was the second-most frequent (38 polygons), second only to the big sagebrush-rabbitbrush association (56 polygons). This suggests that big sagebrush would likely eventually dominate many of the current greasewood sites should DTW increase sufficiently.

Soil salinity can affect the dynamics between greasewood and rabbitbrush, but greasewood-dominated sites in Spring Valley do not appear to have salinity levels that high, based on associated species. On some sites in the Great Basin Region, greasewood dominates sites higher in salinity than adjacent sites dominated by rabbitbrush (e.g., Mono Lake, California; Toft and Elliott-Fisk, 2002) but at other locales (e.g., Ruby Valley, Nevada, Big Smokey Valley, Nevada, Owens Valley, California), soil salinity values on sites supporting rabbitbrush are about the same or higher than those supporting greasewood (Meinzer, 1927; Miller et al., 1982; Branson et al., 1988; Sorenson et al., 1991). If some greasewood sites in Spring Valley have particularly high salinity levels, the current cover of greasewood is likely lower than on greasewood sites with more moderate salinity (Sorenson et al., 1991). Rabbitbrush would still likely replace greasewood over time if DTW increased, with the cover of rabbitbrush somewhat less than on less-saline sites. These higher saline sites might eventually develop saltbush-dominated communities, e.g., *Atriplex torreyi*, *A. canescens*, (McLendon et al., submitted), although saltbushes are not as abundant in Spring Valley as they are in other valleys in the Great Basin.

4.5 Woodland Communities: Cottonwood and Rocky Mountain Juniper

Cottonwood communities are very limited in Spring Valley, but they would be sensitive to increases in DTW. Cottonwoods would begin to be stressed in dry years if DTW decreases below about 2 m and seedling establishment would be severely limited at this DTW. Mature trees would not likely be strongly affected unless DTW increased past about 4 m.

The lowland stands of Rocky Mountain juniper in Spring Valley occur on sites that appear to have a wide-range of DTW. However, these trees do require more moisture than is normally supplied by the precipitation received on the valley floor. Therefore, regardless of location on the landscape, they likely receive some supplemental moisture. Those at the lowest elevation sites appear to receive this supplemental moisture from high groundwater or as outflow from adjacent springs. On more upland sites, the trees most likely receive supplemental moisture from perched water tables, although some sites appear (based on visual evidence of surface water flow) to receive substantial amounts of surface runoff. In each case, these sources of supplemental water are not likely to be affected by withdrawal of deep groundwater.

Juniper cover on the wettest sites averages 85-90 percent and cover on the driest sites averages about 35-40 percent. The drier sites have understory vegetation typical of dry meadow, shrub-meadow, or sites independent of groundwater. Based on these differences in juniper cover among sites, if DTW increased on the wetter sites, juniper cover would decrease to perhaps half its current level but the sites would likely remain dominated by Rocky Mountain juniper. If all supplemental moisture (groundwater, outflow from springs, overland surface flow, perched water tables) were eliminated, the trees would not likely survive for more than a few decades.

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5.0 EFFECTS OF OTHER FACTORS

The discussion to this point has emphasized the effect of change in DTW on groundwater-influenced vegetation in Spring Valley. This is the primary factor of concern because of groundwater withdrawal. However, there are a number of other factors that affect vegetation change and would influence vegetation response to change in DTW.

5.1 Amount of Annual Precipitation

The effect of amount of precipitation received has been mentioned. Vegetation in general and individual species in particular are strongly affected by amount of precipitation received and this amount varies substantially annually. In addition, there are recurring patterns of dry years (drought) and wet years. Of importance are both frequency of occurrence and magnitude of deviation from average. These variations are typical of arid and semiarid environments and substantially affect the cover values of species. In years of below average precipitation, the effects of increased DTW would be intensified, whereas in years of above average precipitation, vegetation cover values are often unaffected by an increase in DTW. These effects are the result of preferential use of precipitation-derived soil moisture instead of groundwater, when both are available (Flanagan and Ehleringer, 1991; Donovan and Ehleringer, 1994; Lin et al., 1996; Gebauer and Ehleringer, 2000; Schwinning et al., 2002, 2005; Chimner and Cooper, 2004; Goedhart et al., 2010). In years with above average precipitation, there is sufficient soil moisture derived from the high precipitation to meet the requirements of the plants and therefore they utilize little or no groundwater. However, in dry years there is insufficient precipitation-derived soil moisture to meet maximum use requirements of the vegetation, hence the plants utilize more groundwater if available or reduce their level of production if the supplemental groundwater is not available. Sorenson et al. (1991) reported that the shallow (1-2 m) water table in the Owens Valley, California supplied some water to the vegetation in most years, but its primary function was as a reserve supply of water for periods when precipitation-derived soil moisture, which is their primary water source, is inadequate to supply the requirements of the vegetation.

5.2 Climate Change

Climate is not static, it changes over time. Some of these changes are short-term fluctuations around a relatively stable long-term mean. These short-term changes may be annual variations (as described in Section 5.1) or series of below- or above-average precipitation years, generally lasting 2-5 years but sometimes lasting a decade or so. Precipitation patterns in the southwestern United States also have longer cycles, usually on the order of 40-60 years, and are correlated with both the Pacific Decadal Oscillation and Atlantic Multidecadal Oscillation (Hidalgo, 2004).

In addition to these annual and decadal fluctuations, precipitation and temperature change over longer periods of time, e.g., centuries and millennia. For example, the Great Basin Region, as well as much of the rest of the western United States, underwent a 2000-year period of increasing aridity beginning about 2,600 years ago during which woodlands in the Great Basin Region declined and shrubs such as greasewood increased (Tausch et al., 2004). Then about 650 years ago the Little Ice Age began and conditions became cooler. Pinyon-juniper woodlands, grasslands, and wetlands increased in extent. Vegetation patterns were very different during this period compared to current patterns, especially in relation to pinyon-juniper and sagebrush types (Tausch et al., 2004). The Little Ice Age conditions lasted until about 150 years ago, and then climate shifted again, with aridity once again increasing.

Climatic patterns may be relatively stable for periods on the order of centuries and then relatively rapidly (e.g., decades) change sufficiently to cause major changes in the vegetation of the region. The distinction between fluctuations with a relatively stable climatic pattern and climate change may be difficult to determine at the time it is occurring, except when comparing recent conditions to long-term patterns. For example, the drought that occurred in many parts of the western United States since about 2000 is the most severe within the observed period (1923 to present) for the Upper Colorado River Basin, but is only about the tenth most severe in the past 500 years based on reconstructed precipitation patterns (Timilsena et al., 2007).

There is no basis to believe that these types of climatic change that have occurred in the past are no longer occurring. What is less clear, and what is a major source of debate, is how these typical climate change patterns may be affected by industrial-age human activities. Regardless of the cause, we are in a period of global climate change. Temperatures in some areas are warming and precipitation patterns in many regions may be shifting. Of equal ecological importance may be the facts that (1) the variability in both temperature and precipitation is increasing in many regions (Chambers and Pellant, 2008) and (2) combinations of changes in temperature and precipitation are likely to cause nonlinear responses in ecosystems (Ibanez et al., 2007; Zhou et al., 2008).

There is a great amount of uncertainty associated with what the effects of climate change may be on specific ecosystems (Ibanez et al., 2007; Brown and Thorpe, 2008a; West et al., 2008) and the effects may not be what is expected (Adler and HilleRisLambers, 2008; Zhou et al., 2008). But there will be effects and the combination of long-term directional shifts, increased short-term variability, and expected and unexpected interactions among factors may be sufficient to change the fundamental properties of many ecosystems (Prentice, 1992; Brown and Thorpe, 2008b).

5.3 Livestock Grazing

Livestock grazing would have a major affect on some stages of vegetation change associated with an increase in DTW. Cattle, sheep, and horses are the major livestock types in Spring Valley and each of these types consume high proportions of grasses. Consequently, high livestock stocking rates over a sustained period would have a major impact on grasses. Because livestock preferentially utilize most grasses over shrubs in most seasons, these grasses undergo additional physiological stress compared to un-utilized or lightly-utilized shrubs. This in turn gives shrubs additional competitive advantage over grasses during stress periods. As stocking rates are reduced, this disadvantage to grasses decreases and they become more competitive.

Wet and dry meadows with relatively high groundwater are dominated by perennial grasses and grass-like species. Many of these species (e.g., Nebraska sedge, Baltic rush, saltgrass) are tolerant of heavy grazing use, especially seasonally (Martin and Chambers, 2001b). Other species (e.g., creeping wildrye, sacaton) can tolerate heavy grazing for short periods of time, but tend to decrease when heavy grazing in sustained over long periods each year. If DTW increases and vegetation shifts from wet to dry meadow or from dry meadow to grass-shrubland (Figures 4-2 and 4-3), shrubs would begin to increase in density and cover and perennial grasses become more stressed. If livestock grazing was excessive during these transitions, the grasses would decrease in cover more rapidly than indicated in Figure 4-4. A reduction in the grass component would increase the establishment and growth of shrubs. However, the major effect of lack of perennial grasses would likely be an increase in cheatgrass (Daubenmire, 1988).

Cheatgrass does not establish extensively in communities with well-developed perennials, but rapidly establishes in bare areas. Once established, cheatgrass is only slowly replaced by perennials (Daubenmire, 1988; Paschke et al., 2000). The rate of its replacement is correlated with the amount of summer precipitation received (Paschke et al., 2000). Cheatgrass is a cool-season annual, beginning growth early in the spring, or in some cases late in the autumn, before seedlings of most perennial species begin growth. Cheatgrass grows rapidly, depleting the available soil moisture before perennial seedlings can access this moisture (Harris, 1967). However, cheatgrass plants mature and die by early summer with seeds not germinating until the autumn or following spring. Therefore, moisture received during the summer becomes available to perennials or warm-seasoned annuals. Where there are regular amounts of summer precipitation, cheatgrass dominates disturbed sites for less than 10 years, with perennials, often rabbitbrush and perennial grasses, establishing by the third year (McLendon and Redente, 1991, 1994; Hosten and West, 1994; Stevenson et al., 2000). Where summer precipitation occurs irregularly (e.g, SE Washington), as in wet years only, cheatgrass dominates sites for as much as 50-75 years (Daubenmire, 1988), until there is sufficient establishment of perennials. In intermediate regions (e.g., S Idaho), cheatgrass begins to be replaced by perennials in 10-20 years (Piemeisel, 1951). Once established, perennials have a competitive advantage over cheatgrass (Daubenmire, 1988; Stevenson et al., 2000) because perennials do not have to re-establish from seed each year. Their perennial root system can extract moisture from deeper layers before the growing roots of cheatgrass can reach this moisture.

5.4 Fire Regime

Fire can have the opposite effect on vegetation change as does grazing. Fire has a more detrimental effect on woody plants than on perennial grasses because of the location of perennial tissues. Most aboveground tissue in grasses is annual, i.e., it dies at the end of the growing season, whereas aboveground tissue in shrubs is perennial. Unless the fire is very hot, most perennial tissue in grasses is not harmed by fire, the fire only removing one-year growth. On the other hand, fire removes multi-year accumulated growth from shrubs. Fires are especially destructive to non-resprouting shrubs such as big sagebrush.

Throughout the Great Basin Region, as in most arid and semiarid regions, fire has been an important factor maintaining a balance between grasses and shrubs. Provided there is sufficient fuel to carry the fire, fire reduces the amount of shrubs present in grasslands, allowing the grasses to remain dominant. In the absence of fire, shrubs tend to increase over time, eventually reducing the amount of grasses present and shifting the vegetation from a grassland to a shrubland. Prior to European settlement, many tribes routinely burned meadows for game management. This, along with lightning-induced fires, was likely a major factor in maintaining many of the Great Basin meadows as grasslands. Without fire, or some other shrub management mechanism, many meadows will likely become shrublands, wet meadows becoming dominated by wetland shrubs such as willows (*Salix* spp.) and Woods rose (*Rosa woodsii*) and dry meadows becoming dominated by more xeric shrubs such as greasewood, rabbitbrush, saltbushes, and big sagebrush.

5.5 Irrigation Practices

A number of the wet meadows in Spring Valley exist because of irrigation practices, including both application of water and transport of water. A large amount of water is moved across the valley floor each year through a series of irrigation ditches. As water moves through these ditches, some moves laterally from the ditches, supplying large amounts of subsurface water to the vegetation adjacent to the ditches. Depending on how much water is conveyed through a particular ditch and for how long during the growing season, well-developed wetlands and wet meadows have formed and are maintained by the water flowing through the ditches. Should the amount or duration of these flows be altered, it will have an effect on the adjacent plant communities.

Most of the water flowing through the ditches is used to irrigate pastures in Spring Valley. These irrigation practices have also shifted dry meadow or even grass-shrubland sites into wet meadows, which are maintained by the irrigation water and not by groundwater. Like the wet meadows associated with the irrigation ditches, the wet meadows maintained by irrigation will be affected if the amount and timing of irrigation is modified.

6.0 CONCLUSION

Substantial increases in DTW would have an effect on the vegetation in portions of Spring Valley but the effect would be manageable. Depending on the magnitude of these increases, their location and other factors discussed through this report, the results would be changes in species composition and vegetation types. Affected wet meadows are likely to shift to dry meadows, dry meadows to grass-shrublands, and greasewood shrublands to rabbitbrush and big sagebrush shrublands. Productivity and plant cover may decrease but viable, self-sustaining, and productive native plant communities will remain. The rate and magnitude of groundwater decline can be managed such that successional processes will result in target plant communities associated with specific DTW and soil conditions. In order to achieve these target communities, groundwater management will need to be balanced with developing climatic conditions, proper levels of livestock grazing, irrigation practices, and disturbance factors such as fire.

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8.0 GLOSSARY

aquatic site – An area perennially covered by water and supporting plants.

biome – The highest level of vegetation classification. It is based on general structural category of the dominant species (e.g., woodland) or on a major environmental characteristic of the ecosystem (e.g., wetland).

capillary fringe – The moist zone in a soil directly above a saturated layer, resulting from upward movement of water by capillarity.

coarse-textured soil – One relatively high in sand or gravel.

community – An assemblage of populations living in a prescribed area or physical habitat (Odum 1971). In this document, referring to the assemblage of plant species existing in an area defined by a contiguous area with the same three plant species as dominant and sub-dominant species, with order of the three species considered, i.e., plant community.

cover – The ground or water surface area covered by a vertical projection of the leaves and stems of overlying vegetation; also termed canopy cover.

disturbance – An impact, natural or anthropogenic, to a plant community that results in the composition, structure, or function of the community to change beyond its usual range in variability.

dominant species – The species which has the greatest influence on the overall characteristics of the community; generally the most abundant species in a community or the species with the greatest amount of biomass, cover, or productivity.

early-seral – Relating to the first stages of succession. Early-seral communities are typically dominated by fast-growing and short-lived species.

ecotype – A subspecies whose genetic differentiation from other populations in the species is associated with one or more environmental factors.

evapotranspiration – The combined water loss from evaporation from the soil or water surface and transpiration through plants.

fine-textured soil – One relatively high in silt or clay particles.

grassland – An area where grasses are the dominant species and which is not perennially covered by water.

Great Basin – The ecological region in the western United States located broadly between the Sierra Nevada Mountains and the Rocky Mountains and north of the Mojave, Sonoran, and Chihuahuan Deserts.

groundwater – Water beneath the soil surface located in a zone of saturation, the zone of saturation usually being continuous to substantial depths.

groundwater-dependent – Condition where groundwater, or an equivalent amount of supplemental water, is required for the continued existence of the plants or plant community.

groundwater-influenced – Conditions where groundwater is utilized by plants, but is not required for their continued existence at that location.

late-successional – Relating to the later stages of an ecological succession where the plant communities are typically dominated by relatively slow-growing and long-lived species and relatively well-developed vegetation structure.

meadow – A plant community dominated by grasses or grass-like plants and that generally has relatively wet soil for at least part of the growing season. When standing water is present, it is for less than the entire growing season.

mid-successional – Relating to the intermediate stages of a succession.

monoculture – The occurrence of a single species in a specific area.

overstory – Relating to the topmost vegetation strata.

perched water table – Zone of saturated soil above unsaturated layers that is held in place by underlying dense materials.

phreatophyte – A plant that uses groundwater. An obligate phreatophyte is a species that is dependent on groundwater for its existence at a site. A facultative phreatophyte is a species that uses at least some groundwater when it is present but its existence at a site is not dependent on groundwater.

precipitation-sustained – A plant or plant community whose water supply is derived entirely, or almost entirely, from precipitation or precipitation plus surface runoff.

saturated soil – One where all pore spaces are filled with water.

shrubland – An area where shrubs (woody plants mostly less than 3 m tall) are the dominant or subdominant species.

soil texture – The physical property of a soil associated with the relative amounts of the three soil particle classes (sand, silt, clay) that the soil contains.

species composition – The proportion of a vegetation metric (e.g., cover or biomass) contributed by a particular plant species.

sub-dominant species – A species which has a major influence on the characteristics of the community and whose removal would result in substantial impacts to the community but the overall structure and function of the community would not be fundamentally altered.

succession – The progressive replacement of one plant community by another, generally terminating in a relatively stable community; change in vegetation composition at a given location over time. The community progression that defines a specific succession at a site is called a sere and is commonly divided into stages or sets of communities grouped temporally. These stages are termed seral stages and are commonly grouped as early-seral, mid-seral, and late-seral. Species or conditions typically associated with the respective stages are commonly referred to as early-successional, mid-successional, or late-successional.

understory – Existing beneath the canopy of taller plants.

unsaturated soil – One where the water content is at or below field capacity.

vegetation structure – Relating to the spatial arrangement of vegetation, including height, stratification, cover, and spatial pattern.

water table – The upper surface of groundwater.

wetland – An area where the soil is saturated for most of the year, but not perennially covered by water, and as used in this document, not dominated by grasses.

woodland – An area where trees (woody plants taller than 3 m) are the dominant or subdominant species.

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