Comments on Effects of Proposed Groundwater Withdrawal in Eastern Nevada on Desert Springs and Associated Ecosystems

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Summary: The increased demand for water in arid regions has resulted in proposed groundwater withdrawal from aquifers underlying these regions of the West, including eastern Nevada. Groundwater withdrawal is expected to alter the hydrology of these regions in turn affecting desert springs and the ecosystems they support. The purpose of this report is to address these possible effects, especially those changes that is likely to take place in the plant communities supported by the springs. Two possible hydrological changes will alter the plant communities. A reduction in spring discharge will reduce the amount of wetlands and riparian communities associated with the spring ecosystem. A lowering of the water table is expected to alter the composition of the plant communities which grade from wetlands, through wetland/upland transition (riparian) to uplands. Alteration and/or loss of these plant communities will, in turn, reduce or negate the ecosystem services they offer to this arid region.

Background: Overview of Great Basin Desert springs and their ecosystem services.

Wetlands, riparian areas and other types of freshwater ecosystems can be affected by off-site activities that alter the hydrologic cycle (Pringle 2000, 2001, Burk et al. 2005). Such activities include watershed land use changes that affect recharge and other surface water processes, and water extractions that affect subsurface flow paths and other groundwater processes. Maintaining the requisite connectivity between ground water and surface water resources to sustain freshwater biota is not only a difficult challenge legally but also politically.

Spring ecosystems are one type of wetland that increasingly are being affected by local and regional groundwater withdrawals (Brussard et al. 1999, Burk et al. 2005). Protection of such isolated wetlands, critical habitat for many endemic and threatened species, has become a key conservation issue (Tiner 2003) (see special issue of Wetlands on isolated wetlands, September 2003). In deserts, these spring environments are “island” ecosystems surrounded by xerophyte-dominated deserts and may be the sole source of water for most biota. The springs are dependent on a limited water source supplied by a complex hydrologic system of basin-fill and/or deep regional aquifers and local watershed recharge. Spring areas usually include the spring orifice area and outflow stream or springbrook. These two systems often support distinct and different assemblages of plants (Jackson and Allen-Diaz 2006), particularly where the spring orifice area is a pool or has been modified by human activity for agricultural or recreational purposes.

Anthropogenic alteration of the complex hydrology underlying desert areas is considered one of the greatest threats to long-term sustainability of aquatic ecosystems of many desert ecosystems (Shepard 1993, Grimm et al. 1997) including those in the Great Basin and Mojave

Deserts (Brussard et al. 1999, Tiner 2003). For example, groundwater withdrawal may significantly reduce the shallow water table, leading to a decline or eventual elimination of spring flow (Fiero and Maxey 1970, Dudley and Larson 1976, Hendrickson and Minckley 1985, Schaefer and Harrill 1995, Burk et al. 2005, Myers 2011c). This, in turn, will affect the aquatic, wetland, and phreatic biota dependent on the range of spring-associated water sources. The Draft BLM EIS (BLM 2011) agrees with this statement in that it states when using the 10-foot drawdown contour as a frame of reference to identify water dependent resources within the drawdown area, "Drawdowns of less than 10 feet could reduce flows in perennial springs or streams that are controlled by discharge from the regional groundwater flow system, which in turn could potentially cause declines in the diversity and abundance of associated riparian flora and fauna that may only be able to tolerate water declines on the order of a few feet."

Hydrologic alteration, along with other anthropogenic activities, has not only altered desert springs and associated biota in North America and other continents (Fairfax and Fensham 2003) but also wetland vegetation associated with desert lakes and playas, for example, Owens Valley in eastern California (Schultz 2001, Elmore et al. 2003). In Owens Valley, groundwater pumping near springs resulted in reduced species cover, lower species richness, and shifts from marsh vegetation to more drought tolerant species (Perkins et al. 1984). Pumping also caused a decrease in vegetation cover and increase in mortality of phreatophytic shrubs (Sorenson et al. 1991). Water table declines that follow from groundwater withdrawal also can affect riverine riparian vegetation in arid regions which may include riparian communities along spring outflow channels (Stromberg et al. 1992, Stromberg et al. 1996, Scott et al. 1999, Shafroth et al. 2000, Horton and Clark 2001). These riparian communities depend on a shallow alluvial water table that is dependent on stream water or shallow groundwater (Lite and Stromberg 2005)

The extent of impact by groundwater withdrawal on springs and other freshwater ecosystems depends on the cumulative effects of withdrawal activities relative to the magnitude of groundwater recharge (Winter 1988). For example, water tables and plant cover in the Owens Valley have fluctuated in tandem, in response to changes in annual groundwater extraction rate and weather patterns (Elmore et al. 2006). Groundwater levels rapidly declined in the Owens Valley in the 1970s, a result of increasing groundwater pumping and drought (LADWP/Inyo County 1990), causing mortality of phreatophytic vegetation. In the 1980s, groundwater levels rose, a result of increased recharge owing to wet weather and decreased pumping because of lower water demand (Schultz 2001). Water levels in Devils Hole, part of Death Valley National Park adjacent to Ash Meadows National Wildlife Refuge and habitat for an endangered desert pupfish species (*Cyprinidon nevadensis*), declined from 1969-1972 due to agricultural groundwater pumping from the regional aquifer (Dudley and Larson 1976, Minckley and Deacon 1991, Dunham and Minckley 1998). Adjudication by the Supreme Court finally settled this issue (*United State v. Cappaert* 1976) but now there is concern about the influence of pumping activities for municipal use on desert pupfish and other biota at the Refuge.

The Great Basin and adjacent Mojave deserts, a complex Basin and Range landscape with mountains interspersed with dry desert valleys, contains many isolated spring supported wetlands. There is limited literature on the ecology of these springs with the exception of that on pupfish, amphibians, and invertebrates (Dudley and Larson 1976, Anderson and Deacon 2001, Hershler and Sada 2002). Description of spring vegetation and environmental controls is limited; however, most studies reveal the importance of both water availability and water quality (salinity in particular) on vegetation. For example, Bolen (1964) found soil salinity to strongly influence vegetation zonation in salt marshes in Utah. Bradley (1970) found shifts in plant community zonation occur in response to shifting environments associated with water availability. He (Bradley 1972) also found water availability to be the decisive influence of standing crop in marsh vegetation in California. Minshall et al. (1989) identified several environmental factors (including salinity and water availability) as influences on saline wetlands and thermal springs. Naumberg et al. (2005) demonstrated the importance of water table fluctuation in conjunction with soil texture on productivity of several desert spring herbaceous species.

Patten et al. (2008a) analyzed the effects of groundwater decline on Great Basin and Mojave Desert spring plant communities. They found that often a groundwater table decline of no more than a meter or less might change the plant community from one characteristic of wetlands to one more commonly found in the upland transition zone. This change becomes crucial to the dynamics of the spring ecosystem as the wetland community usually supports a much broader array of species than the uplands, some species being endemic to particular spring areas.

I. Springs with Large to Small Discharge.

Springs in Nevada vary in flow rate and coverage of outflow water. Consequently, they support a diverse assemblage of plant communities including wetlands, riparian areas, wetland/upland transition zones and, where there is a connection between outflow water and shallow groundwater, phreatophytic upland communities. These plant communities in turn support a broad array of invertebrate and vertebrate populations.

Much of my research has included comparisons of small and moderately large springs (e.g., Patten et al. 2008a) as well as studies of ecosystem dynamics of arid land riparian systems (e.g., Patten 1998). In the following table (Table 1), I have added additional large springs to a list of our research springs in Nevada. The table shows the outflow discharge for each spring. Discharge of the larger springs is measured by USGS flow gages, while smaller spring discharge was measured using temporary flow constriction "dikes" and V-notch weirs.

The springs with large discharges (ca. 4 cfs or greater) tend to support extensive downstream riverine oriented plant communities (e.g., wetlands and riparian communities), while those with small discharges tend to support limited wetlands and some wetland/upland transition communities. Reduced flows and lowered water tables, to be discussed later, will alter the extent and composition of these communities.

Table 1. Study springs and a few additional large springs indicating their location and approximate discharge (Q cms/cfs).

Spring	Location	Q (cms/cfs)
Crystal	Near Hiko, NV	0.32/11.2
Big Springs	Near Baker, NV	0.10/3.7
N Channel		
Fairbanks[#]	Ash Meadows NWR	0.120/4.3
Collins[#]	Ash Meadows NWR	0.0016/0.05
Jackrabbit[#]	Ash Meadows NWR	0.05/1.77
Meriwether*[#]	Ash Meadows NWR	0.005/0.177
Rogers[#]	Lake Mead NRA	0.045/1.60
Corral[#]	Lake Mead NRA	0.0002/0.0071
Blue Point[#]	Lake Mead NRA	0.016/0.55
Scirpus[#]	Lake Mead NRA	0.0002/0.0071
Leopard Frog[#]*	Spring Valley, NV	0.0005/0.0177
Rose[#]*	Spring Valley, NV	0.00015/0.0053
4WD Spring+		
Thorne[#]	Railroad Valley, NV	0.0004/0.0141
Christian[#]	Railroad Valley, NV	0.0001/0.0035

[#] Research springs (Patten et al. 2008a)

* Names given to unnamed springs used in Patten et al. (2008a)

+ Name given by monitoring agency

II. Basic Landscape of Desert Springs Describing the Various Components of the Spring Ecosystem.

The following discussion of the vegetation and landscapes at various springs of different sizes in the Great Basin and northern Mojave Deserts is presented to offer a brief overview of the areas that may be affected by hydrological modifications in the area. A more comprehensive overview of some of these areas is offered by Charlet (2007) in his report titled: "Effects of Groundwater Transport from Cave, Delamar, and Dry Lake Valleys on Terrestrial Ecosystems of Lincoln and adjacent Nye and White Pine Counties, Nevada". In this report Charlet not only discusses the various components of these desert ecosytems including plants, wildlife, etc. but also mentions rare species that might be affected by modified hydrology. He emphasizes that groundwater withdrawal in these areas will have a ripple effect into areas like the Pahranagat Valley that are dependent on the groundwater from the adjacent valleys.

A. Orifice area (size, flows, etc.)

The orifice area of desert springs is normally associated with the rate of flow. For example, Crystal Spring near Hiko has a large ponded area surrounded by riparian vegetation. At a small spring like Rose in Spring Valley the orifice area is a pond that is about 5 m across. This spring orifice area pond, as for many small springs in areas where there is ranching, has been altered to collect water for stock watering. In some cases the actual orifice has been "tapped" and piped to watering troughs. Very few of the springs I have visited still maintain what probably was the original orifice pond or outflow area, most having been altered to gather water for livestock, agriculture, mining, or recreation and/or maintenance of downstream ponds or lakes.

Small springs often support wetlands within a saturated ground surface near the orifice, or when the orifice pond is deep, marginal wetlands and emergent plants such as reeds and cattails.

B. Outflow stream (size, flows, distance from orifice, etc.)

The length of the outflow stream or springbrook is dependent on the amount of discharge and the density of wetland and riparian vegetation along the spring outlet. Large springs, using Crystal Spring near Hiko, NV as an example, flow along an outlet channel lined by riparian vegetation and then through the Pahranagat Valley (now covered with sparse forests and grassland), which is also fed by Hiko and Ash Springs. It supports two lakes at the upper end of the valley (Nesbitt and Frenchies), and ends in Upper and Lower Pahranagat Lakes at the south end of the valley which are part of the Pahranagat National Wildlife Refuge. Fairbanks Spring in Ash Meadows has an outflow stream that extends several miles into a large slough. Rogers Spring in Lake Mead NRA flows all the way to the Colorado River. In contrast to these three relatively large desert springs, Rose Spring in Spring Valley flows about 150 m from the orifice, the length of this flow dependent on season (ET loss) and cattle intrusion into the outflow wetlands where they puncture an impervious clay layer below the wetland vegetation causing seepage into the soil below the clay layer.

III. Vegetation Associated with Large to Small Springs.

A. Wetlands

Small springs such as Rose Spring in Spring Valley support a wetland in both the orifice area and outflow channel (even though it is short). Immediately at the orifice the wetland may be dominated by watercress (*Rorippa nasturtium-aquatica*), whereas elsewhere the wetland community is composed of an extensive array of herbaceous species such as *Eleocharis palustris, Berula erecta, Carex nebrascensis,Veronica anagallis, Mimulus guttatus, Carex nebrascensis, Carex stenophylla, Juncus balticus,and Puccinellia lemmonii.*

Large springs such as Crystal may also have watercress (*Rorippa nasturtium-aquatica*) near the orifice area as well as many of the same wetland herbaceous species found in small springs in the same climatic zone (desert type).

B. Riparian and wetland/upland transition areas

Small springs, for example Rose spring in Spring Valley, often do not have a distinct riparian plant community but rather a wetland/upland transition community. This transition plant community often does not include herbaceous species beyond the wetland border. Woody species are limited and may include Woods Rose (*Rosa woodsii)* and Big Sagebrush (*Artemisia tridentata).* These two species are not phreatophytic nor halophytic but depend on shallow fresh water from the outflow stream. Swamp cedar (*Juniperus scopularum)* may also be found in this transition area but more often in the phreatophytic zone. The species is a "unique" ecotype of the Rocky Mountain juniper (Billings 1954) found only in White River Valley and Spring Valley. It grows where there is a shallow water table, quite different than the typical habitat of this species as a semi-arid upland species. The location where swamp cedar is found in Spring Valley is now a Natural Area Park based on the almost unique nature of the location of this ecotype. It was evaluated for possible registered landmark designation in 1970 (McLane 1970) and Bostick et al. (1975) included this in an inventory of natural landmarks for the Great Basin for the National Park Service. Charlet (2007) in his report on effects of groundwater withdrawal in this area also mentions the importance of this ecotype and its location.

Large springs, for example Crystal Spring near Hiko, NV and Fairbanks Spring at Ash Meadows NWR support distinct riparian communities around the orifice pond as well as along the outflow channel. Although outflow from Crystal is greatly modified, there is still some riparian vegetation. The upper portion of Pahranagat Creek has a border of ash trees (*Fraxinus* sp.) and cottonwood (*Populus fremontii*). At Fairbanks, the channel and adjacent floodplain support stands of mesquite (*Prosopis pubescens),* Goodings and sandbar willow *(Salix gooddingii and Salix exigua),* and Salt Cedar *(Tamarix ramosissima).*

C. Adjacent uplands (phreatophytic and non-phreatophytic; halophytes and non-halophytes)

Small springs such as Rose Spring and neighboring springs in Spring Valley occur in a landscape dominated by phreatophytic and upland species. The phreatophytes may be linked to the same water source that creates shallow groundwater, possibly creating the spring flow. The pheatophytic communities include herbaceous salt grass (*Distichlis spicata)* and a woody community composed of swamp cedar (*Juniperus scopularum),* greasewood *(Sacrobatus vermiculatus),* and rabbit bush *(Chrysothamnus nauseosus, Chrysothamanus albidus).* In some locations the non-phreatophytic shrub big sagebrush *(Artemisia tridentata)* is common. Geasewood, one of the more common phreatophytes in the Great Basin is also one of the main sources of evapotranspiration from the shallow groundwater. Nichols calculated the transpiration discharge from shallow groundwater (Nichols 1993) and determined that this discharge was related to the depth to groundwater (Nichols 1994).

Large springs such as Crystal Spring near Hiko often dominate the valley they flow through, supporting riparian communities which may quickly grade into upland plant communities. The upland plant community in the Pahranagat Valley is typical of the Mojave Desert dominated by creosote bush (*Larrea tridentata*) and burroweed (*Ambrosia dumosa*). These are species common in the warmer deserts unlike the desert species found in Spring Valley which is in the Great Basin Desert.

IV. Water Sources for Springs

<u>Groundwater systems of eastern Nevada</u>. Most groundwater systems that are being targeted to satisfy projected future water needs of urban Nevada are located in eastern Nevada and western Utah. Most of eastern Nevada is part of the Basin and Range province (Hunt 1967) in which groundwater flow systems occur in individual basins or in two or more hydraulically connected basins (Plume 1996, USGS 1997). One main aquifer type in eastern Nevada is Cenozoic valley or basin-fill (Fenelon and Moreo 2002). Much of the ground water in this region flows through these basin-fill deposits, with mountains serving as boundaries of some of the flow systems. Another aquifer type is Paleozoic carbonate rock which commonly underlies the basins and provides hydraulic connections under mountains between basins (Dettinger 1969, Plume 1996). Groundwater in this aquifer either flows from east-central Nevada and western Utah near Spring

Valley south toward Ash Meadows, Death Valley and Lake Mead (Dudley and Larson 1976, Dettinger, et al. 1995, Prudic et al. 1995, Laczniak et al. 1996, Plume 1996, Thomas et al. 1996) or to Snake Valley and thence to the Great Salt Lake Basin (Welch et al. 2007). Approximately two-thirds of the flow south towards Death Valley is discharged into the Muddy River Springs north of Lake Mead NRA, and about one-third to springs in Ash Meadows NWR (Dettinger 1969). None of it discharges at Lake Mead NRA springs. However, groundwater in the Virgin River subflow system in southeastern Nevada and southwestern Utah, a subsystem of the Colorado River regional flow system, apparently discharges at some springs in Lake Mead NRA (Prudic et al. 1995). Many springs are sustained, at least proximately, by the basin-fill aquifer. The carbonate aquifer, however, is considered the ultimate water source for regional springs, through its replenishment of the basin-fill aquifer. It also directly supports some springs.

Elliot et al. (2006) in characterizing the water sources of Great Basin National Park also discussed their susceptibility to groundwater withdrawal in neighboring Spring Valley. Myers (2011a, b) has evaluated water sources for springs in the Spring Valley and Snake Valley areas. In his evaluation of these water sources he has used models to project possible groundwater withdrawal effects in these areas (Myers 2011c) . The amount of water table decline is relative to location of wells and length of water withdrawal. For evaluation of effects of groundwater withdrawal on spring plant communities, the decline in water table (i.e., drawdown) is most relevant. Basing his projections on several time scenarios (e.g., 75 and 200 years of pumping), Myers shows that drawdown may exceed 100 ft (ca. 30m) in areas near the wells but may also be about 5 ft (ca. 1.5 m) some distance away (e.g., as far as Snake Valley). For this discussion, consideration of the minimal drawdown should be considered (as the models showing changes in plant communities with water table decline later in this report indicate that small changes in water table may relate to distinct changes in plant composition).

V. Response of Plant Communities to Changes in Flows and Groundwater Depths.

Spring flows directly support wetlands and also contribute to shallow groundwater along the outflow stream necessary for riparian plant communities. Each of these plant communities has characteristic species as described earlier. However, because they are dependent on some component of the hydrology of the spring location, any change in that hydrological component is likely to result in a response of the associated plant community. The two primary alterations in the hydrology of a spring location are a reduction or cessation in flow at the spring orifice and a decline in the local water table resulting from reduction in spring flow or withdrawal of groundwater from the aquifer that supports the spring flow and phreatophytic vegetation in the area.

The following diagram (Figure 1) shows some of the plant species that compose the plant communities across the gradients from wetland to upland for small desert springs. These have been explained earlier. In the diagram below, woody species are bolded. The diagram also shows the changes in plant associations that are likely to take place as water resource changes (i.e., groundwater declines and/or spring flow terminates) influence the response of various species.

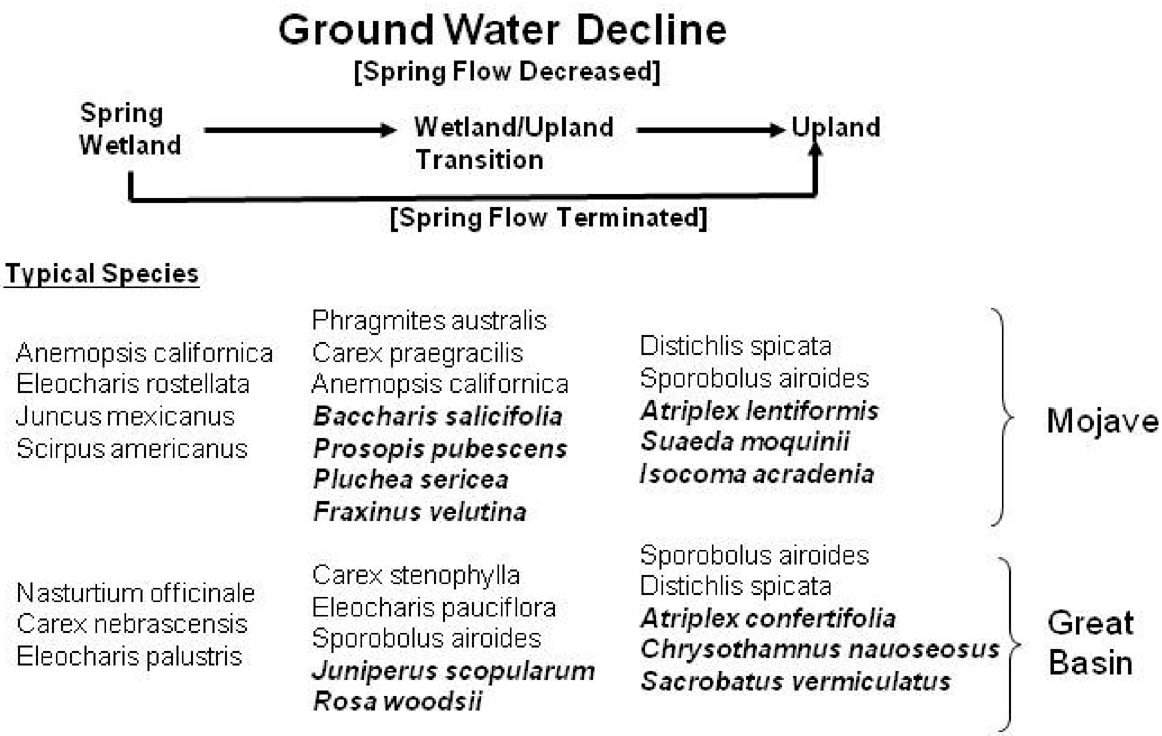

Figure 1. Diagram showing the gradient of plant communities from wetland to upland and thus potential changes in vegetation resulting from groundwater decline. If spring flow is terminated vegetation will change to upland; however, if spring flow is reduced wetland/transition vegetation may replace wetland. Typical species found at each vegetation zone are listed for Great Basin and Mojave Desert springs. Woody species are bold italics (From Patten et al. 2008a).

In addition to addressing changes in associations of plants at different zones across the spring landscape as shown in the above figure, I looked at changes in wetland community status using a Wetland Indicator Score (WIS) across the spring landscape. Obligate wetland species have a wetland status of 1, while facultative wetland species are 2, facultative species are 3, facultative upland species 4 and upland species 5. A plant community is often a mix of these different types and thus has a WIS status ranging from 1 to 5. A plant community composed solely of wetland plants has a WIS of 1, whereas most communities are a mix of species with WIS values ranging from 1 to 5. As the plant community is exposed to a changing hydrology (e.g., declining water table), the WIS will shift as the plant association changes. Table 2 demonstrates the potential for these changes across WIS levels for Spring Valley springs.

Using the WIS concept and relating plant community WIS scores to associated groundwater levels measured with groundwater monitoring wells, we found we could develop a model that indicates that with a certain amount of decline in groundwater there was a potential associated change in WIS. For example, the model for herbaceous communities at Spring Valley was:

Herb WIS = 0.786 + 1.085 Water Table Depth [$n=17$, $R^2= 0.427$, $p \leq 0.01$]

Using the above model, we find that the WIS will increase by about one unit with each meter decline in water table. For example, a wetland/upland transition zone herbaceous community with a WIS of 2 at the Spring Valley study springs includes species of *Carex, Juncus, Puccinella, Sporobulus* and *Distichlis.* Following a 2-meter water level decline, this community might shift to one with a WIS of 4, equivalent to a phreatophytic-upland community vegetated by species such as those of *Descurainia, Distichlis* and *Puccinellia* (Table 2).

BLM in its EIS (BLM 2011) supports this concept of change when it states that a decline of less than 10 feet (ca. 3 m) could reduce flows in perennial springs or streams that are controlled by discharge from the regional groundwater flow system, which in turn could potentially cause declines in the diversity and abundance of associated riparian flora and fauna that may only be able to tolerate water declines on the order of a few feet.

Table 2. Herbaceous and woody plant species characteristic of community types at Spring Valley, Nevada with wetland indicator status for each species and wetland indicator score range for each community type. Wetland indicator status: Obligate Wetland (OBL), Facultative Wetland (FACW), Facultative (FAC), Facultative Upland (FACU), Upland (UPL).					
			Community Type		
		Wetland	**Wetland/ Upland Transition**	**Phreatophytic Upland**	**Upland**
Community Wetland Indicator Score Range		**1-2**	**2-3**	**3-5**	**3-5**
Herbaceous Species	**Wetland Indicator Status**				
Berula erecta (Huds.) Coville	OBL	X			
Carex nebrascensis Dewey	OBL	X			
Eleocharis palustris (L.) Roemer & J.A. Schultes	OBL	X			
Eleocharis pauciflora (Lightf.) Link	OBL	X			
Nasturtium officinale Ait. f.	OBL	X			
Poa pratensis L.	FACU	X			
Juncus balticus Willd.	FACW	X	X		
Carex stenophylla Wahlenb.	UPL	X	X		
Sporobolus airoides (Torr.) Torr.	FAC		X	X	
Ivesia kingii S. Watts.	UPL		X	X	
Puccinellia lemmonii (Vasey) Scribn.	FAC		X	X	
Distichlis spicata (L.) Greene	FAC		X	X	X
Descurainia sophia (L.) Webb ex Prantl	UPL			X	X
Lappula redowskii (Hornem.) Greene	UPL				X
Woody Species					
Rosa woodsii Lindl.	FAC		X		
Juniperus scopulorum Sarg.	UPL		X		
Artemisia tridentata Nutt.	UPL		X	X	X
Chrysothamnus albidus (M.E. Jones ex Gray) Greene	UPL			X	
Chrysothamnus nauseosus (Pallas ex Pursh) Britt	UPL			X	
Atriplex confertifolia (Torr. & Frem.) S. Wats.	UPL			X	X
Sarcobatus vermiculatus (Hook.) Torr.	UPL			X	X

From Patten et al. 2008a.

VI. Potential Short Term and Long Term Effects of Groundwater Withdrawal.

Using Figure 2 below, one can visualize what may happen to the various plant communities associated with springs in a Great Basin valley when groundwater withdrawal occurs. Figure 2 illustrates the dependency of many of the plant communities on either or both available spring outflow and shallow groundwater.

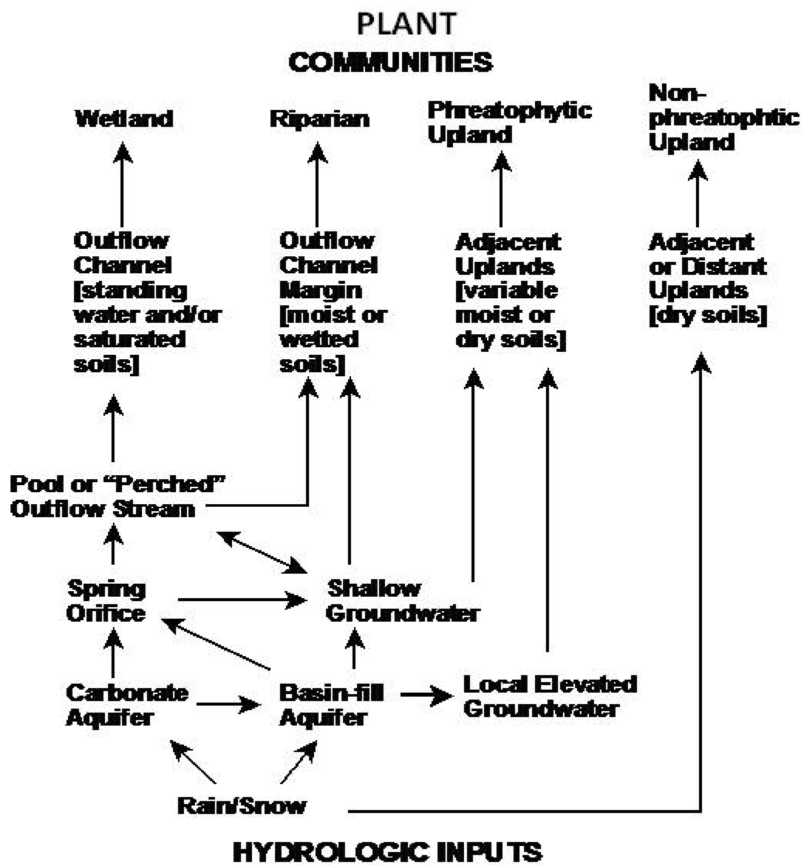

Figure 2. Model of dynamics of Great Basin springs showing hydrological inputs, connections among several flow paths and resulting vegetation types (see text for descriptions of the vegetation types). The diagram can be used to illustrate the potential impacts of groundwater withdrawal from the deep carbonate layer. Connections (or flows) between it and the basin-fill aquifer and spring orifice would decline or terminate depending on the magnitude of the groundwater withdrawal. Most vegetation types dependent on water from the deep aquifer would change to upland type communities (from Patten et al. 2008b).

A. Wetlands

The wetland communities at most springs are dependent on an inundated area which occurs in the spring orifice area or outflow stream. Reductions in spring flows may maintain the ponding at the orifice area, albeit, the area may be reduce. Reduced flows will truncate the length of the outflow stream. Consequently, any reduction in flow will reduce the amount of wetland, an ecosystem that is habitat for many species. Groundwater withdrawal over time may cause the spring flow to cease. With no surface water, all wetlands will be lost. Although there are few examples of this phenomenon, some springs in the Great Basin that supported springs in the early 1900s no longer exist because of long-term groundwater withdrawal by agriculture in the area. Figure 3 shows a spring area that no longer supports a wetland because of flow termination.

Figure 3. Gotchell Spring at Lake Mead NRA where flows have terminated and upland vegetation grows in spring outflow channel.

B. Riparian and/or Wetland/Upland Transition

The riparian areas on the edges of spring orifice ponds and along outflow streams are dependent on the shallow water table supported by the outflow stream and also, perhaps, by shallow groundwater associated with the basin fill. Both of these hydrological sources are dependent on the aquifers within the deeper carbonate layer and basin fill. As pointed out above in the discussion on groundwater systems of eastern Nevada, these two water sources may be connected through upward movement of water from carbonate aquifer into the basin fill . There are thresholds below which many riparian species can no longer survive (Lite and Stromberg 2005). Herbaceous riparian species will not survive if the water table they are dependent on declines only a few cm, whereas large woody riparian species such as cottonwood or mesquite may tolerate water table drawdown of several meters (5-7 meter depth is about the maximum these species can tolerate, although mesquite has been found with much deeper roots in non-riparian situations. Only large springs support large woody riparian species along their outflow streams, consequently, changes in volume and length of outflow may directly affect the footprint of these species as the water table declines with distance from the channel.

C. Phreatophytic uplands

Phreatophytic upland species are found throughout much of the Great Basin in areas where there is relatively shallow groundwater either within the valley fill or perched on impervious substrate layers away from water sources other than natural precipitation and shallow recharge flows from adjacent mountains. A disruption of this available shallow water, potentially a consequence of lowering the local water table following groundwater withdrawal, will reduce the amount of water available to a level below that which is required by the phreatophytic plant community and thus reduce plant cover of phreatophytes. Patten et al. (2008a) projected that, over many decades a loss of phreatophytic plant cover will be followed by invasion of non-phreatophytic species (both grass and shrubs). Some of the phreatophytes are also halophytes and we project that with a declining water table and loss of its associated capillary lift of salts to the soil surface, the halophytes may also be lost over time as natural precipitation leaches the salts from the surface soils, depositing them at some layer (sometimes referred to as a caliche layer) below the root distribution of non-halophytic plants.

D. Non-phreatophytic uplands

The non-phreatophytic plant communities of the Great Basin and northern Mojave Deserts have established on soils with only natural precipitation as a water source that has been present for millennia. Consequently, there is little likelihood that the non-phreatophytic plant community will change as a result of groundwater withdrawal and the associated groundwater level decline.

Table 3 summarizes some of the possible changes that may occur at large and small springs following groundwater withdrawal in the spring locations. Althought this summary primarily relates to effects near groundwater withdrawal locations, some of these effects are expected to also take place in the "downslope" region of a deep aquifer as deep groundwater is withdrawn in the "upslope" region of that deep aquifer. The White River Flow System and the Great Salt Lake Regional Flow System are two examples of extensive deep aquifers that, if affected by groundwater withdrawal at the "upper end", will affect availability of groundwater at the "downslope end". Myer's (2011 a,b,c) and BLM (2011) discussions of several aquifers in Nevada and how they support regional springs are good examples of this potential phenomenon.

Table 3 has two primary components. One deals with changes in hydrology, for example, reduced discharge, declining water table and reduced wetting of spring and outflow areas. These hydrological changes, important as water sources for wildlife and livestock, become of greater importance when they are related to changes in spring associated plant communities, that is, wetlands and wetland/upland transtion (riparian) communities. These two plant community types are considered some of the most valuable and threatened plant communities in the United States (Patten 1998, Zedler and S.Kercher 2005, Heinz Center 2008). In arid regions, these communities support over 75% of animals species at some stage in their life cycle (Naiman et al.

1993, Patten 1998). Consequently, a significant alteration in regional hydrology has a cascading effect on plant communities and associated animal populations.

Table 3. Consequences of hydrological changes at Great Basin and Mojave Desert springs. Comparison of large and small springs.

Change	Primary Consequences	Secondary Consequences	Large Spring Change	Small Spring Change
Groundwater decline	Reduced discharge	Reduced outflow length and width	Potential great loss of wetland and wetland/upland transition communities	Small loss of wetland and wetland/upland transition communities
	Lowered capillary fringe	Wetland to wetland/upland transition or wetland/upland transition to upland shift	Extensive loss of wetland area	Small loss of wetland area
		Reduced "wicking" of salts by capillarity	Upland shift from halophytes to non-halophytes	Upland shift to non-halophytes
Discharge increase or decrease	Outflow stream length change	Altered extent of wetland/upland transition community	Potential great change in wetland/upland transition community	Small change in wetland/upland transition community
	Wetted area width change	Altered extent of wetlands	Potential extensive wetland area change	Small wetland area change, but a high percent of total
Discharge terminated	No pool or outflow stream	Loss of wetlands and wetland/upland transition communities	Conversion from wetland to upland species and community	Conversion to upland species and communities

From Patten et al. (2008a)

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