Ecological Departure of TNC-Mapped Groundwater Dependent Ecosystems

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Introduction

As the driest state within the United States, Nevada's groundwater dependent ecosystems (GDEs) play an important role in supporting the state's biodiversity. In addition to being critical habitat for many of Nevada's endemic and native species, GDEs provide numerous benefits to people and nature, including forage for livestock, improving water quality, soil conservation, storing carbon, reducing flood risk, and providing recreational opportunities (Aldous and Bach 2014; Brown et al. 2011; Kath et al. 2018).

The Nature Conservancy (TNC) in Nevada has mapped more than 1,600,000 hectares (4 million acres) across the major ecoregions in Nevada: Sierra Nevada, Columbia Plateau, Great Basin, and Mojave (Figure 1). These landscapes were included in the Nevada Indicators of Groundwater Dependent Ecosystems (iGDE) database that was recently completed. Data for the landscapes were first collected in 2003 (Mt. Grant), and the latest was 2016 (Truckee Watershed). Spatial resolution of the satellite imagery was 5-m or less, except for Wassuck which was 10-m resolution (Table 1). Mapped area ranged from 5,077 ha to over 404,685 ha in the Spring Mountains. While GDEs were mapped in each landscape, generally the goals of the original work were related to management planning in the surrounding upland systems. Several of the projects were conducted to assess fire risk while others were oriented toward improving habitat for species of concern. The goals of the analysis presented here were to use these eleven previously mapped landscapes to 1) describe the condition of GDEs across the mapped areas, 2) identify causes of degradations among the landscapes and GDE types, and 3) identify management actions that may be used to improve GDE condition.

Background on approach used

Successful restoration of natural communities is dependent on understanding the natural dynamics, the current condition, and the trajectory of those communities. State-and-transition simulation models (STSMs) have been a useful tool to understand these ecological processes and have been used for a variety of ecosystems across the globe (Daniel et al. 2016; Carlson et al. 2019). Traditional state-and-transition models define natural communities with states (i.e., phases of vegetation composition and structure) and transitions (i.e., ecological and anthropogenic processes that cause change among the states). STSMs expand the traditional models by assigning probabilities to the transitions and employing a Monte Carlo simulation framework (Daniel et al. 2016). As such, STSMs allow users to explore how communities might change in the future as well as reconstruct past communities without anthropogenic transitions (Keane et al. 2009). By running multiple simulations over hundreds of simulated years without the anthropogenic inputs, the natural range of variation (NRV) can be defined for communities.

Increased access to satellite imagery has improved the ability to assess vegetation condition on large landscapes. Images can provide many different types of variables for a landscape depending on the spatial and spectral resolution of the image and its intended application. Higher resolution data can provide detailed maps of the current dominant vegetation types and structures. Two types of maps were created for each of our study landscapes from the satellite imagery to use with STSMs. The first map describes the *vegetation system* for each pixel. The vegetation system describes the site potential based on dominant vegetation type and abiotic factors. The second map type is the *vegetation class*, which describes the current composition and structure of the vegetation. Each *vegetation system* has its own STSM, with *vegetation classes* being the various states within that STSM.

If current conditions are known for a landscape, the NRV can be a helpful standard to understand where the landscape deviates from historical condition and what actions may be taken to improve degraded areas (Keane et al. 2009). Ecological departure (ED) was developed as a metric to measure how much a system varies from the expected NRV conditions (Barrett et al. 2006). ED is a standardized departure metric so lower scores indicate systems that are closer to NRV. Often, ED is categorized into three tiers: low departure, moderate departure, and high departure. For a given landscape, ED is calculated for each vegetation system (not across them).

Mathematically, ED is calculated as:

$$ED = 100\% - \sum_{i=1}^{n} \min\{Current_i, NRV_i\}$$

Where:

$Current_i$ = current percentage of landscape in a given vegetation class

NRV_i = expected percentage of the landscape in a given vegetation class

As ED is comparing current condition to NRV, the presence of some vegetation classes that are acceptable to managers may increase the ED score. Vegetation classes for GDEs are often highly managed classes, such as pastures or seeded areas, where the goal may not be to restore a site to NRV. While these classes can provide beneficial services (e.g., livestock forage, wildlife habitat, fuel breaks, etc.), these benefits are not accounted for in ED. Another important facet to note is that ED is a less meaningful metric for systems with small areas due to small sample size.

The ED of a given system is determined not only by the distribution of reference classes (or classes included in NRV simulations), but also the relative abundance of non-reference classes (also termed uncharacteristic classes). We grouped the uncharacteristic classes found on the landscapes into five categories based on the root cause of the issues associated with that vegetation class: fire suppression, inappropriate grazing, lowered water table, presence of non-native plant species, and miscellaneous. Fire suppression is the exclusion of fire as an ecological process; among GDEs, this was mainly observed in aspen woodland and aspen-mixed conifer systems. In the aspen systems and conifer riparian systems the removal of fire contributes to a poor distribution of reference classes during succession. Inappropriate grazing is the historic or contemporary overutilization of vegetation by non-native ungulates (e.g., cattle, horses, etc.). Lowered water table refers to changes in the hydrogeomorphology that causes a drop of the water table in the surrounding area. This can change the site potential from wetland obligate species to more upland associated species. The presence of non-natives includes forbs and woody species that have been introduced (e.g., tall whitetop, tamarisk, etc.). The miscellaneous category included classes where a cause is hard to determine (e.g., bare ground) or an uncharacteristic but not undesirable class is present. For example, pasture is a common uncharacteristic class in many wet meadows that is not a reference class, but pastures are not undesirable or likely to be managed toward a different condition.

It is important to note that the sources of degradation interact. For example, a meadow may develop a channel due to heavy grazing pressure. Then the channel deepens, lowering the water table. Once the water table drops, upland non-natives such as cheatgrass invade the site. In this case, “change in hydrogeomorphology” was chosen because restoration to raise the water table would allow for the establishment of wetland species back at the site. Understanding the root cause of degradation or departure is an important component in understanding the restoration opportunity and potential.

Description of ecological systems and TNC mapped landscapes

Across all the mapped areas, the ecological systems and vegetation classes were translated into a common terminology. This was an important step because more recent projects tended to have higher resolution in the number of classes identified within the landscape. Additionally, this common terminology allowed easier comparison of the ED of a system across mapped landscapes. Twelve vegetation systems were identified as being GDEs and were included in this analysis. Identified GDE systems were those systems where the site potential suggests phreatophytes (i.e., plants that can tap into groundwater) would dominate, whether the site is currently occupied by a phreatophyte or not. For example, a site currently dominated by non-native cheatgrass (*Bromus tectorum* L.), a non-phreatophyte, is still considered a GDE if the system is classified as greasewood, which is phreatophytic. The STSMs used to model the GDE systems were developed over time and parameterized using data from literature and input subject matter experts. Below is a brief description of the ecological systems.

<u>Aspen Woodland</u>

This system is dominated by quaking aspen (*Populus tremuloides* Michx.), where the expected climax state is dominated by aspen without the presence of conifers. In natural states, the understory is generally lush and comprised of a mix of shrubs and perennial forbs and grasses as subsurface flow is great enough to support high productivity. While aspen may be associated with riparian systems, subsurface flow is what allows the woodland to persist. Frequent fires were historically important to maintain the dynamics of this system. Grazing by livestock and native ungulates and fire suppression are often the cause of degradation and reduced stand recovery. Altered patterns of precipitation due to climate change may further threaten aspen woodland.

<u>Aspen-Mixed Conifer</u>

This system differs from the aspen woodland in that conifers become a more important canopy component in later seral classes, with conifer cover greater than 25%. Similar dynamics and threats occur in this system as in the aspen woodland system; however, aspen-mixed conifer has a more variable fire return interval than aspen woodland.

<u>Greasewood</u>

This system is dominated by greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.) in its climax classes. It usually occupies valley bottoms on the alluvial flats or adjacent to playas where the water table is relatively close to the soil surface. Soils are often saline or sodic. Other notable native plant species in this system include: basin big sagebrush (*Artemisia tridentata* spp. *tridentata* Nutt.), shadscale (*Atriplex confertifolia* (Torr. & Frém.) S. Watson), basin wildrye, (*Leymus cinereus* (Scribn. & Merr.) Á. Löve), and inland saltgrass (*Distichlis spicata* (L.) Greene). These sites are susceptible to non-native species such as cheatgrass and halogeton (*Halogeton glomeratus* (M. Bieb.) C.A. Mey.). In addition to threats from declining water tables, poor livestock management and fire, which was historically absent, contribute to degradation of the greasewood system.

Jeffrey Pine Riparian

This system is unique to the Sierra Nevada ecoregion and is relatively restricted in its landscape position, where it is found along channels where intermittent flow can occur. It is dominated by Jeffrey pine (*Pinus jeffreyi* Balf.). Due to the increased moisture, individual trees are often considerably larger than similar aged trees in the drier, adjacent forest. The canopy is generally closed. This system is often more productive than adjacent forest and may have species more associated with riparian communities in the understory. Like all Jeffrey pine forests, relatively frequent fires were a historically important ecological process.

Lodgepole Pine-Wet

This system is characterized by the dominance of Sierran lodgepole pine (*Pinus. contorta* spp. *murrayana* (Balf.) Engelm.) on seasonally saturated soils. These tend to be on flat to gentle slopes and adjacent to wet meadows. Generally, tree density and canopy cover are high, unlike the stands of lodgepole pines on upland, drier soils. Natural wet and dry climate cycles were important factors in the dynamics of these forests as was infrequent fire.

Mesquite

The mesquite system (also referred to as mesquite bosques) are found throughout low elevation in warm deserts. As the name suggests, the dominant vegetation are mesquite species, either screwbean mesquite (*Prosopis pubescens* Benth.) or honey mesquite (*Prosopis glandulosa* Torr.). This system is generally found on sandy dunes or loamy bottomland and can be found adjacent to playas as well. Other associated species are: Indian ricegrass (*Achnatherum hymenoides* (Roem. & Schult.) Barkworth, desert needlegrass (*Achnatherum speciosum* (Trin. & Rupr.) Barkworth, alkali sacaton (*Sporobolus airoides* (Torr.) Torr.), and big galleta (*Pleuraphis rigida* Thurb.). Historically, flooding, variation in precipitation, and freezing events were important ecological processes.

Montane Riparian

This is the vegetation community associated with intermittent or perennial streams/rivers, usually above 1,220 m (4,000 ft) in elevation. System sites range from low to high gradient streams and along a similar wide range in substrate composition. Sites with steeper slopes are often dominated by willow (*Salix* spp.), whereas shallow slopes may have more cottonwood, generally Fremont cottonwood (*Populus fremontii* S. Watson) at lower elevations and black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa* (Torr. & A. Gray ex Hook.) Brayshaw) at higher elevations. A variety of shrubs and tree species may be present as well. Flooding is the main ecological driver of system dynamics, though drought, fire, and grazing can play roles as well.

Ponderosa Pine Riparian

This system is similar to the Jeffrey pine riparian system, but with ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) replacing Jeffrey pine as the dominant canopy species. The system is primarily found in eastern Nevada close to the Utah border and in higher ranges of the Mojave Desert.

Saline Meadow

This system occurs in valley bottoms or alluvial flats. Soils are generally saline or sodic and often are seasonally saturated to the soil surface. While the presence of shrubs is not uncommon, sites are generally dominated by salt tolerant graminoids such as alkali sacaton, alkali muhly (*Muhlenbergia asperifolia* (Nees & Meyen ex Trin.) Parodi), and inland saltgrass. The cyclical patterns of above and below average precipitation, or the wet/dry cycle, is an important dynamic governing plant composition. Non-native grazing (e.g. cattle, horses, etc.) and invasion by non-native plants are current threats.

Wet Meadow-Bottomland

This system is generally found below 1,524 m (5,000 ft) and is fed by adjacent streams or springs. As the soil is usually saturated, vegetation is dominated by graminoids, such as tufted hairgrass (*Deschampsia cespitosa* (L.) P. Beauv), Nevada bluegrass (*Poa nevadensis* Vasey ex Scribn.), inland saltgrass, Baltic or mountain rush (*Juncus arcticus* Willd. ssp. littoralis (Engelm.) Hultén), and various sedges (*Carex* spp.). Soils may be saline, though rarely to the same extent as the saline meadow. The presence of shrubs is governed by drought dynamics, where woody species infill during below average precipitation. Development of well-established stream channels (i.e., headcuts, channelization, etc.) can lower the water table and shift the plant community from phreatophytes to more upland species. Hummocking caused by non-native grazing is another issue as well as non-native plants.

Wet Meadow-Montane

This system is similar to wet meadow-bottomland but occurs at higher elevation and in a greater range of slopes. In addition to willow and other shrubs that may be present, lodgepole pine may be present in the Sierra Nevada ecoregion. The relative cover of woody species is governed by wet/dry cycles and infrequent fires.

Wetland

Vegetation in this system is dominated by helophytes like cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and tule (*Schoenoplectus* spp.). Generally, wetlands are found in lacustrine sites or those with slow flows and are inundated throughout most of the year. Non-native grazing and non-native plants are likely the causes of degradation as well as water diversions.

GDE systems accounted for approximately 4% of the total mapped area, though the coverage of GDE systems varied from <1% at Spring Mountains to 25.8% at 7H (Table 1). The greatest representation of GDEs was found at TS-Horseshoe with 7 of the 12 GDE systems. The lowest number of GDE systems found on a single landscape was 2 at Mt. Grant. Despite being found on less than half of the landscapes, greasewood had the greatest total acreage (Table 1). The smallest system by area was wet meadow-bottomland with only 95 acres. Only two systems were found across all landscapes: montane riparian and wet meadow-montane. Five GDE systems were unique to one landscape.

NRV/Ecological systems/classes

For each ecological system, a common NRV was determined unless the system behaved uniquely in the given landscape (i.e., wet meadow-montane in Truckee Watershed). As mentioned previously, the NRV distribution of classes within a system is the determined by simulating vegetation dynamics without anthropogenic transitions or “un-natural” classes such as non-native dominance. For NRV determination, the STSMs were run non-spatially in the software ST-Sim^{TM} (ApexRMS 2018). Functionally, this was accomplished by artificially setting all GDE systems to their earliest successional class. The STSMs are then allowed to run long enough for natural processes to occur across the landscape and the systems’ dynamics to stabilize, generally 500-750 years. Transitions were simulated according to ecological parameters such as the likelihood that an aspen woodland system will experience a successional class transition or disturbance from fire in any one year. The simulation was replicated several times and the mean values of the resulting class distributions were then used to calculate the NRV (Table 2). The NRVs used in this analysis tended to be based on the most recent simulation run.

Ecological Departure

We used a weighted average to assess overall condition of each GDE across landscapes to account for the variation in each GDE systems’ area in different landscapes. The contribution of each system’s ED to the weighted average was based on total area for each landscape. The montane riparian system had, on average, the highest ED (i.e., it was less similar to NRV conditions), was the only system classified in the highest departure category (i.e., greater than an ED of 67, Table 3), and was moderately to highly departed in each landscape. Wet meadows-montane, the only other system found on all the landscapes, varied greatly in its ED. While the weighted average indicated low departure across all landscapes, the ED scores ranged from 7.5 (low departure) to 98.4 (high departure). Among the rest of the GDEs, 5 were in low departure (i.e., less than an ED of 33) and 6 were in moderate departure (i.e., ED between 33 and 66, Table 3).

We used a similar weighted average approach to assess GDE condition within landscapes as well. ED varied from a low of 16.7 (low departure) to a high of 78.1 (high departure) at Cortez and Mt. Grant, respectively (Table 3). Greasewood, which was largely intact at Cortez, accounted for approximately 80% of the GDEs in that landscape (Table 1). The landscape with the highest ED, Mt. Grant, only had a total of 116 ha of GDE, suggesting potential skew due to low sampling size. Two landscapes were highly departed, 6 were moderately departed, and 3 were highly departed.

At the time that these landscapes were mapped, the majority of the GDEs were classified in a reference class (Table 4). This indicates that the ED scores were mostly driven by the differences in the distribution of reference classes compared to NRV, as opposed to high occurrence of uncharacteristic classes. Among the ecological systems, mesquite had the highest percentage of uncharacteristic classes (Table 4); this was due to the high amounts of bare ground that were mostly likely caused by excessive off-highway vehicle use. Higher elevation systems (e.g., aspen woodland, aspen-mixed conifer, Jeffrey pine riparian, ponderosa pine riparian, and lodgepole pine-wet) tended to have lower proportions of uncharacteristic classes. Higher elevation systems are generally thought to be more resistant to non-native invasion (Guo et al. 2018). Non-native plant species were the most common cause of departure, being found in 6 of the ecological systems (Table 4). While inappropriate grazing was listed as the root cause of degradation in only 3 ecological systems, grazing interacts with many of the other issues (e.g., lowered water table, non-native plants, and fire suppression).

Restoring Nevada's GDEs

Among the uncharacteristic classes observed across the mapped landscapes, the opportunity and cost of restoration varies depending on the ecological system, type of degradation, severity of degradation, and location. Potential restoration actions are discussed for each category of uncharacteristic class, along with estimated costs (Table 5). The costs of treatments are based on workshops with managers to determine common and preferred restoration practices. In our experience costs of treatments may vary depending on site conditions and regional location of the site. As with any natural resource decision, restoration planning requires understanding of the specific site conditions.

Fire suppression

In fire-adapted systems, the removal of fire can help shift the system away from the historically dominant plant species. Among GDEs, this is especially true for aspen-mixed conifer and the conifer riparian systems. In the aspen systems, fire removes non-fire-adapted competitive species and rejuvenates the clone (Bailey and Whitham 2002). Similarly, the Jeffrey and ponderosa pine of the conifer riparian systems are adapted to frequent fires with adults possessing thick bark to insulate against fire (McCune 1988). In the Sierra Nevada wet meadows, fire, or the absence of fire, may have played a role in the infilling of fire intolerant lodgepole pine, though wet/dry cycles are also important to those dynamics (Ratliff 1985).

Prescribed fire or the mechanical thinning of forests can achieve similar results as natural fire. Broadcast fire can be used to indiscriminately remove biomass from the stand including fire intolerant species. However, if fuel loading is too high, mechanical thinning can be done to reduce escape risk of the negative effects of higher intensity fire.

Inappropriate grazing

Mismanagement of domestic livestock in GDEs can have several outcomes. Cattle can trample vegetation and, if extensive, can cause hummocking in saturated soils. Hummocked areas often have higher cover of bare ground. When flowing water is present, hummocking can lead to head cuts and increased channelization. This process can then further lower the water table if left unchecked. For areas of hummocking, rest from grazing is often prescribed. This can be achieved through exclusion of livestock by fencing the impacted areas. To prevent livestock pressure from being simply transferred to different portions of the GDE, livestock may have to be supplied water away from the GDE (e.g., pipe water to a stock tank). The type of fence needed depends on the species of animal being excluded. Areas with heavy feral horse pressure will require sturdier fences, such as pipe rail fencing. To reduce wildlife impacts, fence markers can be used to reduce wildlife collision, and wildlife fencing is available to allow for greater wildlife access. An alternative to fencing is more intensive management of livestock in impaired GDEs. Ranch managers employ staff to frequently move livestock off affected areas to minimize utilization and impact. In addition to lower grazing pressure, hummocking can be treated by distributing water over that area if a channel has formed. Small dams from local material (i.e., rocks, wood debris, etc.) can be used to pool water and slow flows over the impaired area.

Livestock will selectively graze more palatable species. If overutilized, grazing can shift the vegetation composition and structure away from the NRV as the seed source for the palatable species is reduced. Open niches left by the removal of palatable species are then filled by less desirable species, such as native shrubs (e.g., rabbitbrush and Woods' rose), native forbs (e.g., irises and mule's ear), and non-natives. On drier sites, non-natives are generally annual species (e.g., cheatgrass, Tansey mustard, etc.), while wetter sites may have tall whitetop, whitetop/hoary cress, knapweed, thistles, etc. If palatable species are still present, rest from grazing may be enough to allow for establishment. However, if seed sources are absent, seeding will have to occur to re-establish desired plants. If sites are dominated by less desirable natives or non-natives, removal of these species is required. Mechanical removal can be used, but herbicide application is likely the most effectives means of removal (e.g., 2,4-D for rabbitbrush species). It is important to note that due to historic overutilization, rest from grazing is rarely enough to restore a site and more active restoration is needed (Courtois et al. 2004).

Lowered water table

Reduction in the water table elevation can shift dominant vegetation from wetland species to upland species. The drop in water table can be caused by pumping of groundwater or deepening of channels, the latter being the most common cause found in our mapping areas. The change in vegetation may lead to increased non-natives; however, treating the non-natives without addressing the root cause of a lowered water table is unlikely to achieve long-term restoration success.

To be successful, the scale of restoration must match the scale of degradation. As with hummocking, small rock or wood dams can be used to slow flows and increase sedimentation of the stream channel. Larger incised channels may require significant engineering or earth moving to reconnect the historic floodplain and raise the water table.

Another option gaining interest is the reintroduction of beaver (*Castor canadensis*) or use of beaver dam analogs (BDAs, Pollock et al. 2014, Clothier and Zeedik 2014). Successful reintroduction of beaver has been used in many impaired streams across the west, including Maggie Creek in central Nevada (Charnley 2019). As a tool, beaver dams tend to be most successful when the stream channel has widened enough to create an inset floodplain and streamflows are lowered. BDAs, on the other hand, can be positioned at greater densities than naturally occurring beaver dams. As such, construction of BDAs can reduce the need for inset floodplain creation.

Non-native plants

In GDEs, non-natives present a continuing issue that can reduce plant diversity, lower habitat value, change soil characteristics, and impact other ecosystem services (Pejchar and Mooney 2009). Successful control of non-natives often requires both the removal of the biomass and seeding desirable species post-treatment to ensure non-natives do not reestablish. Common control methods in GDEs include: chemical, biological, and mechanical. Chemical control using herbicides is often the most cost-effective method, especially when the occurrence of non-natives is in a large area. Small patches can be efficiently controlled with backpack sprayers, while larger patches may require larger machinery to deliver the herbicide. The type of herbicide is dependent on the species of non-native. Biological control includes using pathogens, species specific herbivores (e.g., tamarix beetle), or generalist herbivores, (e.g., goats). Mechanical removal is the physical removal of biomass via machinery or human power (i.e., handpulling). Mechanical removal is often the most expensive form of control, though it may have less harmful side effects.

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Table 1. The 11 landscapes used in this analysis, their satellite image resolution, hectares within each ecological system, and percent of the landscape classified as a groundwater dependent ecosystem (GDE). "% GDE" represents the percent of the landscape that was GDE across the entire mapped area.

Landscape	Resolution (m)	AW	AMC	GW	JPR	LPW	Mes	MR	PPR	SM	WMB	WMM	Wet	% GDE
7H Ranch	1.5	54	0	<1	0	0	0	5	0	628	0	469	154	26%
Cortez	1.5	278	0	17,868	0	0	0	427	0	2,870	0	541	2	7%
Great Basin NP	2	229	3,285	0	0	0	0	183	69	0	0	35	0	12%
IL Ranch	5	784	122	0	0	0	0	580	0	0	0	785	0	1%
Mt. Grant	4	0	0	0	0	0	0	95	0	0	0	21	0	1%
Spring Mountains	2.4	0	205	0	0	0	1,259	69	0	0	0	52	0	<1%
Truckee Watershed	1.5	0	1,520	0	42	149	0	740	0	0	0	248	1	6%
TS-Horseshoe	5	250	0	23,808	0	0	0	350	0	2,874	38	225	448	13%
Tumbling JR	1.5	36	0	2,059	0	0	0	24	0	1,892	0	1,288	83	7%
Ward Mt.	2	239	905	0	0	0	0	68	0	0	0	5	0	3%
Wassuk	10	16	0	127	0	0	0	1,371	0	0	0	26	0	1%
Total	**--**	**1,887**	**6,037**	**43,862**	**42**	**149**	**1,259**	**3,911**	**69**	**8,265**	**38**	**3,697**	**688**	**4%**

Abbreviations: AW= Aspen Woodland, AMC = Aspen-Mixed Conifer, GW = Greasewood, JPR = Jeffrey Pine Riparian, LPW = Lodgepole Pine-Wet, Mes = Mesquite, MR = Montane Riparian, PPR = Ponderosa Pine Riparian, SM = Saline Meadow, WMB = Wet Meadow-Bottomland, WMM = Wet Meadow-Montane, Wet = Wetland

Table 2. The Natural Range in Variation (NRV) used to calculate ecological departure across the 12 ecological systems. The successional classes represent the vegetation classes expected in pre-European settlement conditions. The values represent the mean percentage found among the replicated NRV simulations. The source indicates which project area was used to determine the NRV, which was then applied to the other landscapes.

		Successional Class							
Ecological System	**Source**	**A**	**A2**	**B**	**B2**	**C**	**C2**	**D**	**E**
Aspen Woodland	Cortez	9%	--	26%	--	38%	--	27%	--
Aspen-Mixed Conifer	Truckee Watershed	9%	--	39%	--	35%	--	6%	11%
Greasewood	Cortez	1%	--	99%	--	--	--	--	--
Jeffrey Pine Riparian	Truckee Watershed	3%	--	25%	--	72%	--	--	--
Lodgepole Pine-Wet	Truckee Watershed	6%	--	6%	25	56%	7%	--	--
Mesquite	Spring Mountains	30%	-	20%	--	50%	--	--	--
Montane Riparian	Cortez	2%	5%	3%	17	8%	65%	--	--
Ponderosa Pine Riparian	Great Basin NP	26%	--	9%	47	17%	1%	--	--
Saline Meadow	Cortez	1%	--	91%	--	8%	--	--	--
Wet Meadow-bottomland	Cortez	2%	--	95%	--	3%	--	--	--
Wet Meadow-montane	Cortez	7%	--	92%	--	1%	--	--	--
Wet Meadow-Montane (Sierra)	Truckee Watershed	1%	--	96%	--	1%	--	2%	--
Wetland	Cortez	1%	1%	98%	--	--	--	--	--

Table 3. Ecological departure (ED) for the groundwater dependent ecosystems (GDEs) found across the 11 mapped landscapes. Lower ED values indicate the system is closer to the estimated natural range of variation for that system. Green, yellow, and red colors indicate the categories of “low departure” (0-33), “moderate departure” (34-66), and “high departure (67-100), respectively. The weighted average was based on the relative area of a given ecological system within a landscape compared to the total area for that ecological system. An asterisk (*) indicates ecological systems with small total areas (i.e., less than 100 ha) that have more uncertain system weighted average ED estimates due to the low sample size.

	GDE System												
Landscape	**AW**	**AMC**	**GW**	**JPR**	**LPW**	**Mes**	**MR**	**PPR**	**SM**	**WMB**	**WMM**	**Wet**	**Landscape Weighted Avg.**
7H	27.7	--	100.0	--	--	--	68.9	--	17.2	--	76.0	27.4	40.1
Cortez	25.1	--	10.9	--	--	--	75.3	--	39.3	--	37.5	4.1	16.7
Great Basin NP	37.6	63.2	--	--	--	--	70.0	34.2	--	--	12.0	--	61.0
IL Ranch	21.4	53.7	--	--	--	--	59.1	--	--	--	27.1	--	34.7
Mt. Grant	--	--	--	--	--	--	91.4	--	--	--	18.1	--	78.1
Spring Mountains	--	39.9	--	--	--	58.3	81.4	--	--	--	88.7	--	58.0
Truckee Watershed	--	18.0	--	26.7	53.5	--	55.1	--	--	--	22.0	0.7	30.6
TS-Horseshoe	37.6	--	38.9	--	--	--	66.3	--	61.8	24.3	25.1	59.5	41.8
Tumbling JR	21.5	--	10.9	--	--	--	82.7	--	27.5	--	9.1	20.1	16.8
Ward Mt.	57.1	47.4	--	--	--	--	77.7	--	--	--	7.5	--	50.8
Wassuk	34.6	--	10.8	--	--	--	73.4	--	--	--	98.4	--	68.2
System Weighted Average	**30.9**	**48.5**	**26.1**	**26.7***	**53.5**	**58.3**	**67.9**	**34.2***	**42.8**	**24.3***	**29.2**	**47.3**	

Abbreviations: AW= Aspen Woodland, AMC = Aspen-Mixed Conifer, GW = Greasewood, JPR = Jeffrey Pine Riparian, LPW = Lodgepole Pine-Wet, Mes = Mesquite, MR = Montane Riparian, PPR = Ponderosa Pine Riparian, SM = Saline Meadow, WMB = Wet Meadow-Bottomland, WMM = Wet Meadow-Montane, Wet = Wetland

Table 4. The distribution of uncharacteristic vegetation classes at the time of mapping grouped by the cause of degradation. "Fire suppression" indicates where the natural fire regime has been interrupted. "Inappropriate grazing" is the historic or contemporary degradation due to non-native ungulates. "Lowered water table" indicates where changes to hydrogeomorphology have caused the water table to drop. "Non-native plants" is the presence or dominance of exotic plant species. "Misc." are unknown or hard to identify causes of degradation. "Reference classes" are those expected in the natural range of variation. Note that causes of degradation can interact and that the relative distribution of reference classes, not just the occurrence, is an important component of ecological departure.

Ecological System	Fire Suppression	Inappropriate Grazing	Lowered water table	Non-native plants	Misc.	Reference classes
Aspen Woodland	7%	0%	0%	0%	0%	93%
Aspen-Mixed Conifer	4%	0%	0%	0%	0%	96%
Greasewood	0%	0%	0%	24%	2%	74%
Jeffrey Pine Riparian	0%	0%	0%	0%	0%	100%
Lodgepole Pine-Wet	0%	0%	0%	0%	0%	100%
Mesquite	0%	0%	0%	0%	32%	68%
Montane Riparian	0%	1%	11%	1%	7%	79%
Ponderosa Pine Riparian	0%	0%	0%	0%	0%	100%
Saline Meadow	0%	17%	0%	5%	0%	78%
Wet Meadow-bottomland	0%	0%	0%	24%	0%	76%
Wet Meadow-montane	0%	8%	6%	1%	5%	81%
Wetland	0%	0%	0%	24%	0%	76%
Average	**1%**	**2%**	**1%**	**15%**	**3%**	**79%**

Table 5. Select restoration actions, the issue they address, and their associated cost range. Cost are listed in cost per acre; "* " are actions for whole project, not by acre.

Restoration Action	Issue Addressing	Cost/Acre Range
Prescribed fire	Fire suppression	$500-$700
Canopy thinning-chainsaw	Fire suppression	$810-$1,500
Herbicide	Non-native species	$150-$260
Fence and water delivery	Inappropriate grazing	$2,100
Small dam	Lowered water table	$50*
Beaver dam analog	Lowered water table	$500-$5,000*
Sheep/Goat grazing for exotics	Non-native species	$25-$100

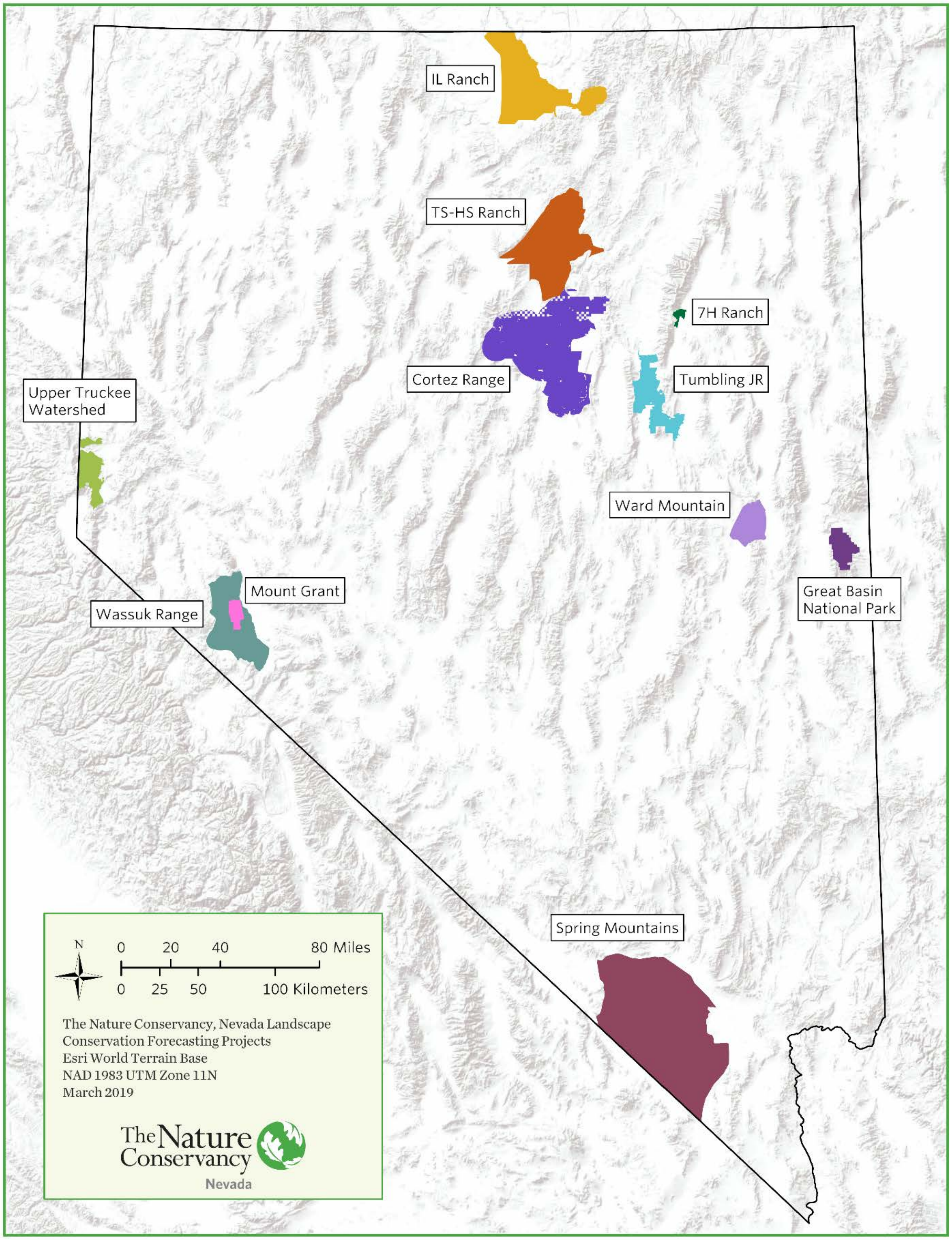

Figure 1. Location of the mapped landscapes used to identify and assess ecological departure for groundwater dependent ecosystems (GDEs).