Characterizing Condition in At-Risk Wetlands of Western Utah: Phase I

by Jennifer Jones, Rich Emerson, and Toby Hooker

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
2013

A contract deliverable for the US Environmental Protection Agency Wetland Program Development Grant #CD97847201-2

Characterizing Condition in At-Risk Wetlands of Western Utah: Phase I

by Jennifer Jones, Rich Emerson, and Toby Hooker

Cover:

Leland-Harris Wetland in Snake Valley, Juab County, Utah

DISCLAIMER

CONTENTS

FIGURES

TABLES

ABSTRACT

This report represents the first phase in development of a rapid wetland condition assessment tool for Utah wetlands and an extension of baseline data collection and analysis for spring-fed wetlands in the Snake Valley of Utah's West Desert. This initial phase of sampling and reporting had three main objectives: 1) test wetland mapping methodologies, 2) evaluate the efficacy of two rapid condition assessment methods, and 3) develop a simple conceptual model relating hydrology to biota.

We gathered all available spatial layers pertinent to wetland condition that could be used in a quantitative landscape-scale condition assessment to provide a first look at land use and stressors in the watersheds contributing to target wetland resources. We found that the surrounding uplands and wetlands are predominantly used for ranching and agriculture with a combination of private and public ownership across the entire study area. We tested two distinct mapping methods based on an existing vegetation map to evaluate automated schemes and proof of concept for a previously developed crosswalk from National Wetland Inventory standard classes to modified hydrogeomorphic classes. These additional mapping methods were both very accurate and efficient and will be useful tools in future mapping projects. We assessed two existing rapid assessment methods for use in Snake Valley, spring-fed wetlands: 1) the Utah Wetland Ambient Assessment Method, which was developed for wetlands around Great Salt Lake, and 2) USA-RAM, which was developed in conjunction with the National Wetland Condition Assessment program for wetlands at the national scale. The two methods generally indicated that wetlands in the northern reach of the study area are in good condition with a few notable exceptions. The limited condition gradient detected made it difficult to quantitatively assess the sensitivity of metrics. Condition assessment sampling will be expanded into the southern reach of the study area to capture a broader gradient for metric calibration. Finally, we developed a simple conceptual model relating hydrology to extant vegetation. This model represents the foundation of our understanding of how changes in hydrology may impact wetland biota and will be used to test relationships between hydrology, wetland condition, and wildlife habitat in future research. The second phase of sampling and reporting will expand on the objectives initiated in this report with additional data, specifically focusing on assessing metric sensitivity to condition in wetlands in the study area.

INTRODUCTION

Wetlands occupy approximately 1% of the landscape in the state of Utah (Dahl, 1990). This relatively uncommon resource occurs in all ecosystems, creating a number of distinct wetland types including marshes, wet meadows, fens, and playas. Though wetlands constitute a minor component of the landscape, they provide diverse ecosystem services including flood attenuation, water quality enhancement, sediment storage, and nutrient cycling, as well as providing critical habitat for biota (Costanza, 1997; Grimm and others, 1997; Mitsch and Gosselink, 2000). Researchers have estimated that Utah has lost approximately 30% of its wetland acreage and many of the remaining wetlands are at risk to loss and degradation due to a diverse number of human activities, making the task of monitoring and assessment of these critical habitats very important (Dahl, 1990; Dahl and Johnson, 1991; Sutula and others, 2006).

Springs and associated wetlands are an important component of desert ecosystems, where they often contribute a disproportionate amount to biodiversity compared to surrounding uplands (Sada and Pohlmann, 2002). In western Utah, these wetlands are located in valley bottoms where groundwater discharges to the surface, forming isolated pockets of highly productive zones in a mosaic of cold-desert uplands. In Snake Valley of the West Desert, the source water for these systems is derived predominantly from regional basin-fill aquifers that are recharged in adjacent mountain ranges (Kirby and Hurlow, 2005; Welch and others, 2007; Hooker and others, 2011). Spring wetlands in the valley serve as critical habitat for two sensitive species, Least Chub (*Iotichthys phlegothontis*) and Columbia Spotted Frog (*Rana luteiventris*), as well as other wetland-associated Species of Concern, including several endemic mollusks (Bailey and others, 2005; Sutter and others, 2005; Bailey and others, 2006). These wetlands are also important cultural and agricultural resources for the rural population, supporting the only land suitable for grazing and agriculture. The most significant potential stress proposed for this area is the development of an interstate groundwater withdraw network to supply water to southern Nevada (U.S. Bureau of Land Management, 2012).

Utah Wetland Program

The Utah Geological Survey (UGS) has partnered with the Utah Division of Water Quality (UDWQ) to coordinate strategies for the monitoring and assessment of wetland resources that correspond with state environmental plans (Hooker and Gardberg, 2010). As part of the state Wetland Program Plan, UGS and partner organizations have begun collecting extensive baseline data in Snake Valley to determine the type and extent of wetland resources in the valley and evaluate ambient condition. These baseline data will help managers assess the impacts of groundwater drawdown and potential changes in climate in the region. Phase I of this project, presented herein, represents a preliminary assessment of condition, area, and type of spring-fed wetlands in the Snake Valley of Utah's Western Desert.

Project Objectives

This project is intended to provide baseline data intended to enhance our understanding of how historical and contemporary changes in groundwater consumption might impact Utah's wetland resources. Objectives stated here will be expanded in Phase II of this project, *Developing Tools to Assess Condition of Great Salt Lake and West Desert Wetlands* (CD-96811101-0).

Objective 1. Characterize the current quantity (abundance) and quality (condition) of wetlands within the project area.

- Task 1. *Compile existing spatial data for the study area into a GIS.* Compile existing spatial data for vegetation, land use and land cover, soils, aerial photography, and high-resolution elevation data (LiDAR) to aid in wetland mapping and landscape/resource profiling.
- Task 2. *Perform intensive site survey of wetland vegetation, soils, and hydrology*. Utilize recently collected data to the extent possible, and augment this data with intensive site soil and vegetation field surveys, including a wetland hydrology monitoring network associated with targeted wetland sites.
- Task 3. *Map extent of wetland occurrence by wetland class.* Create wetland map and mapping scheme centered on a modified hydrogeomorphic (HGM) classification system

based on previously developed vegetation maps, and available high resolution imagery (Brinson, 1993; Smith and others, 1995).

- Task 4. *Evaluate wetland rapid assessment methodology for use in spring-fed wetlands, and assess wetland condition at targeted wetland sites*. Evaluate the utility of two rapid assessment methods (USA-RAM and UWAAM) to describe wetland condition.

Objective 2. Describe and quantify wetland hydrologic functions that support wetland condition, wetland-associated wildlife habitat, and other ecosystem services.

- Task 5. *Develop a simple conceptual model that correlates hydrologic metrics to wetland ecological condition and wildlife habitat quality*. Use key measures of wetland hydrology (e.g. annual and seasonal mean water levels, and temporal pattern of water level) to discern relationships to wetland type, condition, and habitat quality.

Research in Snake Valley

Snake Valley has recently been the focal area for a variety of studies addressing hydrologeology and groundwater as well as wetland and wildlife resources in response to groundwater development pressures in the region. Here we summarize a few of the more recent and pertinent projects conducted and ongoing in Snake Valley. A more extensive list and description of research on the hydrogeology in the region can be found in Hurlow (in preparation).

The Utah Geological Survey has established a groundwater monitoring network in western Millard and Juab Counties (UGS Groundwater Monitoring Data Portal, http://geology.utah.gov/databases/groundwater/projects.php). The study found that groundwater levels are gradually declining in areas of current agricultural pumping, and that recharge rates in most parts of the region are slow. Consequently, increasing groundwater pumping would substantially affect groundwater conditions in Snake Valley and adjacent parts of the West Desert. Recently published groundwater-flow models (Southern Nevada Water Authority, 2009; Halford and Plume, 2011; U.S. Bureau of Land Management, 2012) predict decline in groundwater levels and reductions in spring discharge that would adversely affect wetland resources in much of the study area, if future groundwater development occurs at the maximum quantities allowed under an agreement for management of Snake Valley groundwater resources between Nevada and Utah (currently unsigned by Utah) (Utah Division of Water Rights, 2010). Though limited reductions in discharge were predicted at springs being assessed in the current study, it is unclear how even small changes in spring discharge would alter physical aspects and biotic components of wetland resources associated with spring-fed wetlands. It is likely that reduction in discharge from springs resulting from anthropogenic or natural stressors would result in changes in species composition and habitat quality and a measureable decrease in wetland extent (Patten and others, 2007).

Three Parameters Plus (3PP) conducted extensive surveys of vegetation and in conjunction with the UGS, installed 60 shallow groundwater monitoring wells in the northern section of the Snake Valley study area (Three Parameters Plus, 2010). Staff ecologists collected vegetation data at over 600 points in the study area. 3PP (2010) used these data to classify vegetation types occurring in the study area, develop a vegetation map, and graphically compare mean depth to water between vegetation types. We used these data to develop an additional map based on a modified hydrogeomorphic classification system as well as conduct additional assessments of vegetation with extended hydrologic records.

The U.S. Bureau of Land Management produced the Environmental Impact Statement (EIS) concerning right of way for groundwater development requested by the SNWA (U.S. Bureau of Land Management, 2012). In this document, the BLM suggests an alternative in which all pumping will come from those areas in which SNWA already holds water rights and will not extend withdraw into additional areas including Snake Valley. The EIS also requires that SNWA implement a program to monitor, mitigate, and manage the impacts of groundwater withdraw.

The Utah Division of Wildlife Resources has been monitoring wildlife populations in the valley and surrounding valleys since the mid 1990s, providing a valuable source of data on wildlife populations and reproduction for *Iotichthys phlegethontis* (Least chub) and *Rana luteiventris* (Columbia spotted frog). Researchers at Oregon State University in the Oregon Cooperative Fish and Wildlife Research Unit are using these data to build predictive models of changes in populations in relation to possible hydrologic alterations (Jim Peterson, Oregon Coorperative Fish and Wildlife Research Unit, verbal communication, March 2013).

STUDY AREA

Geography

Snake Valley is located in Utah's West Desert, situated in the eastern half of the Great Basin and the northeastern extent of the Basin and Range physiographic province. The Great Basin extends from the eastern flank of the Sierra Nevada to the Wasatch and Uinta Mountains, and accounts for roughly the western third of Utah. The region is characterized by a series of north-south trending mountain ranges separated by broad, low-angle valleys. Below the valley floors lie deep accumulations of sediment derived from mountain weathering and lake-bed deposits from a series of large, prehistoric pluvial lakes that were trapped in this endorheic basin (Parsons, 1995). These materials, referred to as basin fill, form a mantel over a complex assortment of geologic strata that have been repeatedly folded and faulted over millions of years (Plume, 1996). Snake Valley straddles the Utah-Nevada border, approximately 60% of the valley lies in Utah (Figure 1).

Climate and Hydrology

Utah's West Desert is considered to have a cold desert climate with the majority of precipitation falling during the winter in the form of snow (Barbour, 1999). Though the area experiences hot summers, mean temperatures are not as hot as the Mojave and Sonoran Deserts and winters are cooler (California Academy of Sciences, 2013). West Desert wetlands are predominantly located in the topographically low centers of the valleys and receive very little precipitation. The lower elevation Snake Valley basin averages 196 mm (7.7 inches) annually, however, the ranges surrounding the basin receive much higher precipitation, with up to 900 mm (36 inches) in the Snake Range (PRISM Climate Group, 2007). These ranges recharge the valley aquifers which contain large stores of groundwater, the majority of which is over a thousand years old indicating slow recharge rates and long water travel paths through the aquifer (Kirby, 2011). This groundwater is located in two main aquifers: an extensive system within Paleozoic

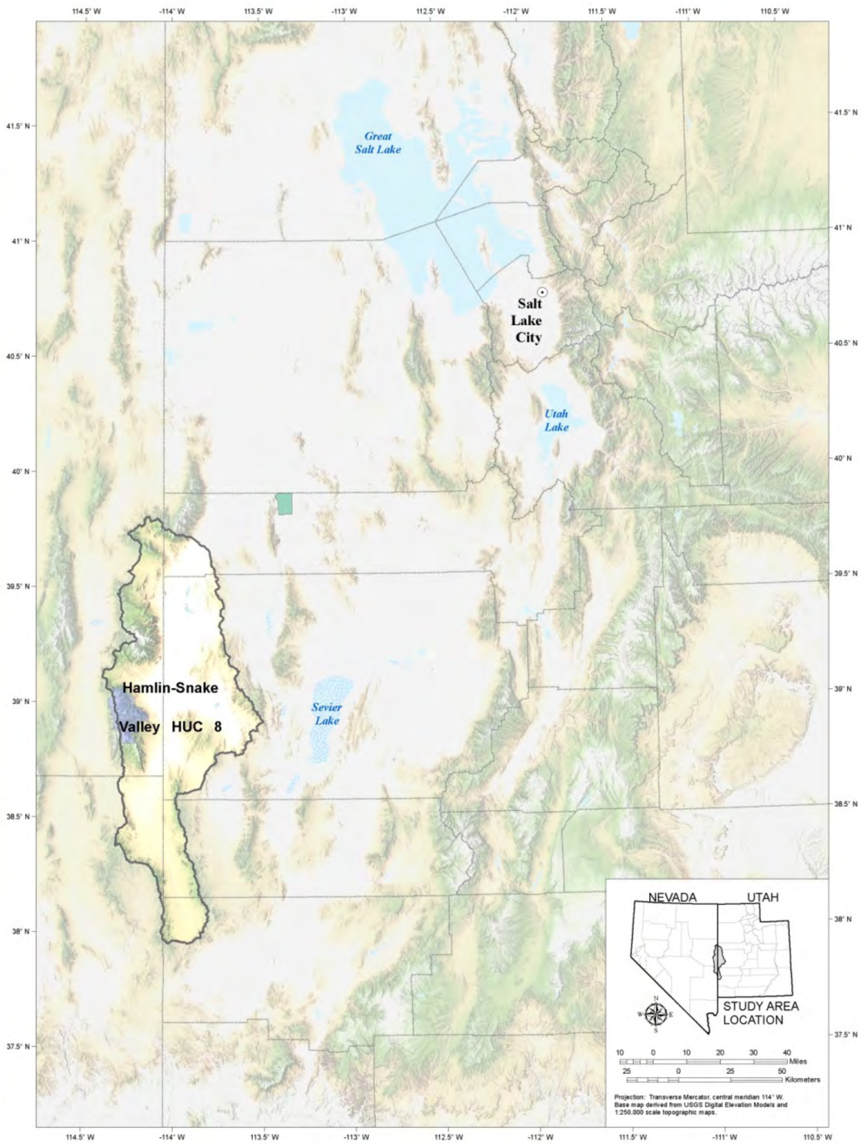


Figure 1. *Hamlin and Snake Valleys, located in Utah's West Desert.*

carbonate bedrock, and local systems of basin fill in lower portions of the valleys (Kirby and Hurlow, 2005). Water is youngest, and most plentiful, in areas where precipitation infiltrates the soil and recharges the aquifer. Recharge is greatest at upper elevations of mountain ranges (where most precipitation falls), and along perennial streams where the mountain flank meets the valley floor. Water flows through pores or fractures in the bedrock, and some of this water enters basin-fill deposits. In general, groundwater flow through the bedrock aquifer is from the south/southwest toward the northeast and Great Salt Lake, based on groundwater potential elevation data derived from the aquifer monitoring network in Snake Valley (Gardner and others, 2011).

Predominant sources of depletion of groundwater include inter-basin flow to adjacent watersheds (towards Great Salt Lake), evapotranspiration where water table elevations are within reach of plant roots, spring flow, and well withdrawal. Areas of groundwater discharge to the surface as springs are common within valleys throughout the West Desert. These springs often support extensive and unique wetland complexes. One well known area is Fish Springs National Wildlife Refuge, where discharge has been impounded to create over 4,000 hectares of marsh and other wetlands (U.S. Fish and Wildlife Service, 2013).

Biota and Wetland Resources

Snake Valley is part of the Central Basin and Range Ecoregion (Omernik and others, 2009). Valleys are dominated by xeric sagebrush or saltbush-greasewood communities with woodland, forest, and subalpine plant communities ascending into the montane elevations. Wetlands represent isolated pockets of highly productive ecosystems embedded within a mosaic of harsh desert uplands. In Snake Valley and other isolated valleys of the Great Basin, these wetlands serve as vital habitat for many species of wildlife and plants, including dominant hydrophytic (water-tolerant) plant species such as sedges (*Carex* spp.), rushes (*Juncus* spp.), and spikerushes (*Eleocharis* spp.) in extensive wet meadows, as well as bulrush (*Schoenoplectus* spp.) and cattails (*Typha* sp.) in seasonally or semi-permanently flooded marshes (Rocchio, 2006c, b, a; Three Parameters Plus, 2010). One interesting aspect of these wetland types in Snake Valley is that water sources are primarily derived from older, deeper, regional aquifer systems. As such, there is less seasonal variation in the quantity, temperature, and chemical composition of water feeding the wetlands compared to montane springs or riverine systems which rely on local aquifers (Sada and Pohlmann, 2002). These conditions provide a stable environment for many wetland species to persist within the context of an inhospitable climate.

Many of these wetlands are home to isolated wildlife populations that have endured since Lake Bonneville receded over 10,000 years ago. For example, a spring survey recorded 58 species of previously undescribed hydrobiid snails; 22 species are endemic to (only found in) single locations (Herschler, 1994). These wetlands also serve as critical habitat for wildlife Species of Concern, such as the Least Chub (*Iotichthys phlegothontis*) and Columbia Spotted Frog (*Rana luteiventris*), among others. Species of Concern are those at risk of being listed as Threatened or Endangered following protocols outlined by the Endangered Species Act (Utah Administrative Code, R657-48; see (Bailey and others, 2005, 2006). These species are then targets of Conservation Agreements, where threats to species are identified and conservation actions are prioritized to eliminate or ameliorate the threats as a result of state, federal, and local landowner cooperation (Sutter and others, 2005).

Spring Complexes

In the Snake Valley study area, wetlands are supported by both valley-margin and valley-floor springs (Hurlow, in preparation). A few warm and hot springs occur in the area, the majority of springs are considered cold with temperatures less than 21.2°C. Water sources vary from local to regional-scale groundwater. Sources will have direct impacts on flow rates and all components of the hydroperiod in the shallow groundwater table which in turn will affect wetland resources and habitat on the surface. We divided the Snake Valley study area into two separate, northern and southern reaches (Figures 2, 3, and 4) because these areas function independently of one another, are subject to different stresses, and support dissimilar wildlife and wetland resources. The locations of the possibly hundreds of spring heads in the two reaches have not been mapped in detail, but a series of major spring complexes having discrete water sources were targeted for sampling; Bishop Springs, Gandy Salt Marsh, Leland-Harris Spring, Miller Springs, Big Springs, Dearden Springs, and Clay Springs. Below we describe the independent springs that have been targeted for hydrologic monitoring and wetland condition assessment in this study. They are described in the order of issuance from upgradient to downgradient. See appendix A for figures of each spring complex.

Northern Study Area

Bishop Springs

Bishop Springs refers to a large wetland complex fed by three discrete high-flow springs: Foote Spring, Twin Springs, and Central Spring. The complex also includes many indistinct seeps and springs located along the western toeslope contributing an unknown quantity of water to the wetlands. During high water periods, water flows from Bishop Springs into Salt Marsh Lake to the north. This 540 hectare (1335 acre) lake forms a large playa east of Gandy Salt Marsh which, in some years, dries in late summer. Twenty-six piezometers were placed in the Bishop Springs area to capture hydrologic conditions.

Twin Springs

Two spring pools approximately 1.5 km (1 mile) southeast of Foote Reservoir are each monitored by a flume gage. Three shallow wells in the alluvial aquifer monitor the groundwater gradient associated with these two springs. Water flow from two spring pools supplies approximately 77 L/s (2.6 cfs) to the wetlands where we have placed seven piezometers in line with the outflow of Twin Springs (Hurlow, in preparation).

Foote Spring

Water from Foote Spring is collected in a 0.75 hectare (1.8 acre) reservoir capturing approximately 79 L/s (2.8 cfs) of water for agricultural use as measured by a flume gage installed by the UGS in 2009 (Hurlow, in preparation). Irrigation has been recently changed from flood irrigation to sprinkler irrigation. Periodic irrigation diverted all of the water from Foote Spring prior to the sprinkler installation which cut water usage by approximately half, allowing more water to flow into the wetlands during summer irrigation months. The effects of this increase in water supply has yet to be determined, but is suspected to be changing vegetation within the wetlands downgradient of Foote Spring. We have placed ten piezometers in this area.

Central Spring

Central Spring is a relatively large spring pool where water surfaces near the confluence of surface water from Foote Spring and Twin Springs. Six piezometers are situated around Central Spring.

Gandy Salt Marsh

Despite its name, the springs supplying Gandy Salt Marsh are not saline. The name likely derives from Salt Marsh Lake, the mineral playa that occupies the basin to the east of the complex of springs and seeps here. Gandy Salt Marsh has over 50 individual spring heads, making monitoring of this complex hydrologic system difficult (Golden and others, 2007). The UGS installed three shallow wells upgradient of the seeps in the alluvial deposits to monitor groundwater feeding these wetlands. Ten piezometers to monitor water within the wetlands were also installed here. This area is home to populations of Columbia spotted frog and Northern leopard frog (*Rana pipiens*) which are monitored by the Utah Division of Wildlife Resources (Wheeler and others, 2005).

Leland-Harris Springs

Leland-Harris Springs refers to a complex network of seeps and springs emanating from alluvial deposits approximately 3 kilometers southwest of Miller Spring. The UGS installed four shallow wells monitoring the groundwater supplying these springs in the alluvial deposits. Ten piezometers were installed to monitor the springs and outflow areas within the wetlands. Water from these springs flows into small pools providing habitat for Utah least chub (*Iotichthys plegethontis*) where the Utah Division of Wildlife Resources has aggressively monitored the species (Mills and others, 2004). Water flows overland until it reaches a playa to the east of Leland-Harris. When filled, the playa drains through a ditch to the west of Miller Spring eventually reaching a playa at the northern reach of the mapped wetlands area.

Miller Spring

Miller Spring is the northern-most area we monitor. In 2010, the UGS and the Utah Division of Water Rights repaired the earthen dam that pooled water at the spring and installed a discharge monitoring flume to monitor outflow, averaging 9.9 L/s (0.35 cfs) from 2010 to 2012 (Hurlow, in preparation). From the reservoir, water flows in a semi-natural channel for approximately 100 meters where it then disperses into wet meadow and marsh wetlands. Several seeps exist within this dispersion area. We installed 10 piezometers transecting the wetlands at three locations to monitor wetland hydrology downgradient from the spring head. Populations of Columbia spotted frog and northern leopard frog at Miller Spring are monitored by the Utah Division of Wildlife Resources (Mills and others, 2004).

Southern Study Area

Big Springs

Big Springs originates at the southeastern toeslope of the Snake Range in Nevada. The USGS installed a gage on this spring in 2006, which has averaged 108 L/s (3.8 cfs) yearly since monitoring began (USGS, 2013). This is the source of water for Big Springs Creek which is named Lake Creek at the Utah-Nevada border. Water is diverted from the spring to ditches that irrigate pastures to the north of the spring. Two piezometers have been installed in these pastures to capture the hydrologic effects of this irrigation.

Dearden Springs

Dearden Springs, also known as State Line Springs, is a series of springs issuing directly into Lake Creek and Big Springs Creek at the Utah-Nevada border. The two ditches that bound the Pruess Lake wetlands to the east and west capture water downstream from these springs. Monitoring flumes installed by the UGS in the ditches and one flume upstream of the springs monitor the water usage and attempt to quantify the volume of water issuing from the Dearden Springs complex which averaged 179 L/s (6.3 cfs) from 2009 to 2011 (Hurlow, in preparation). No piezometers have been installed in association with these springs though this area will be a focal area in Phase II of this study.

Clay Spring

Clay Spring is the final spring to issue into Lake Creek before Pruess Lake and is on the eastern margin of the wetlands. A weir flume monitors discharge from Clay Spring which averages 9.3 L/s (0.33 cfs) (Hurlow, in preparation). We have installed two piezometers in the wetlands associated with Clay Spring.

LANDSCAPE PROFILE

Introduction

At the onset of this project, wetlands in Snake Valley had not been mapped or assessed at the local or landscape-scale for condition. We determined that a landscape-scale assessment of land use and stressors in the watersheds contributing to target wetlands would be a useful tool and first step in developing local-scale assessments of wetland condition and evaluating relationships between hydrology, vegetation, and wildlife habitat. The landscape profile presented here represents a simplified Level 1 assessment which is a landscape-scale assessment of stressors. The Wetland Condition Assessment section below describes how Level 1 assessments fit in with the EPA Monitoring and Assessment framework (U.S. Environmental Protection Agency, 2006). Though developing a quantitative index of landscape-scale disturbance was outside of the scope of this project, we compiled potential stressors that would be used to develop such an index.

Key threats to critical habitat for wildlife species and spring-fed wetlands in general, include the loss or degradation of habitat and ecosystem function as a consequence of declining water table levels resulting from excessive groundwater development and inter-basin water transfer (Bailey and others, 2005, 2006). The importance of these key threats has been heightened by the proposed development of water supply wells and an interconnecting pipeline system within the far western portion of Snake Valley in eastern Nevada by the SNWA (Southern Nevada Water Authority, 2009, 2011). Their current plan involves pumping and removal of approximately 176,000 acre-feet per year of groundwater from the eastern Great Basin to the Las Vegas metropolitan area, including over 50,000 acre-feet per year from Snake Valley. The SNWA project, if developed, would likely represent an acute impact to groundwater resources in Snake Valley. It is anticipated that under this level of withdrawal, groundwater levels will decline, with substantial reductions in spring discharge (Schaefer and Harrill, 1995; Kirby and Hurlow, 2005). However, additional threats to spring-fed wetlands and groundwater resources exist, involving increased agricultural consumption of groundwater both within and beyond Snake Valley's hydrographic boundaries. These projects could move forward before the SNWA project in Snake Valley is activated. As such, cumulative groundwater removal could be greater than anticipated. At the present time, it remains unclear whether and how further development of Snake Valley's groundwater resources would affect water table elevations and ultimately spring-fed wetlands in the valley.

Methods

We compiled all available land use and stressor layers that we considered relevant to wetland and groundwater resources in the study area (see appendix B for description of data sources). We assessed an area within the Snake-Hamlin Valley hydrologic unit code (HUC) 8, which is divided into 15 HUC 10 units and 85 HUC 12 units. Each smaller unit represents a smaller hydrologic catchment, with HUC 12 representing 'watershed' units or the smallest unit available in the USGS system. To assess landscape-scale disturbance, we selected those HUC 10 level watersheds contiguous with wetlands in the study area. Those watersheds removed for the analysis are uninhabited, contain no known wetlands, and do not directly contribute to wetland hydrologic resources. Although this report focuses on the northern reach of the study area, ongoing research in the southern reach will be featured in Phase II of this study, and profiling the landscape in both areas provides landscape-scale information for both reporting phases. The landscape profile components were analyzed separately between these two areas to evaluate how stressors may account for differences observed in wetland condition.

Results

Within the context of the current project, a landscape profile was used to provide an initial picture of land use in the study area, compare the differences between the northern and southern reaches, and support a qualitative description of landscape-scale disturbances at the watershed level. Table 1 outlines ownership and land uses identified in the study area. Because significant differences in management exist between the northern and southern reaches, stressors and land use were analyzed independently for each reach.

Table 1. *Land use in relation to land ownership in the study area.*

	Total Land Area					Wetland Area				
	Hectares	% of study area	% Natural	% Agriculture	% Developed	Hectares	% of study area	% Natural	% Agriculture	% Developed
Bureau of Land Management	392,238	77.4%	99.8%	0.12%	0.04%	1234	50.7%	80.4%	10.1%	9.5%
US Forest Service	41,274	8.1%	100.0%	-	-	0	-	-	-	-
National Park Service	27,042	5.3%	100.0%	-	0.03%	0	-	-	-	-
Utah Trust Lands (SITLA)	25,035	4.9%	99.9%	0.09%	-	166	6.8%	87.5%	12.5%	0.0%
Bureau of Indian Affairs	1819	0.4%	100.0%	-	-	0	-	-	-	-
Private	19,152	3.8%	64.6%	34.3%	1.1%	1032	42.4%	11.1%	88.4%	0.5%

Land ownership in Snake Valley is predominantly public, administered by the Bureau of Land Management and the US Forest Service (Figure 2). Great Basin National Park in Nevada, two wilderness areas and two wilderness study areas comprise the additional public land area. Public lands are mostly managed as open range for sheep and cattle grazing, with the exception of Great Basin National Park.

Land ownership in wetlands is mostly public (9% private) in the northern reach and mostly private in the southern reach (73% private). In the southern reach, pastures are flood or sub-irrigated by two ditches that bound the wetlands to the west and east. This may contribute to the higher ratio of wet meadow in the south than the north where 87% and 34% of the wetlands mapped fall into the wet meadow class, respectively. Approximately 98% of the southern reach is influenced by irrigation as opposed to only 10% being irrigated in the northern reach, all near Miller Springs (Figure 3 and 4).

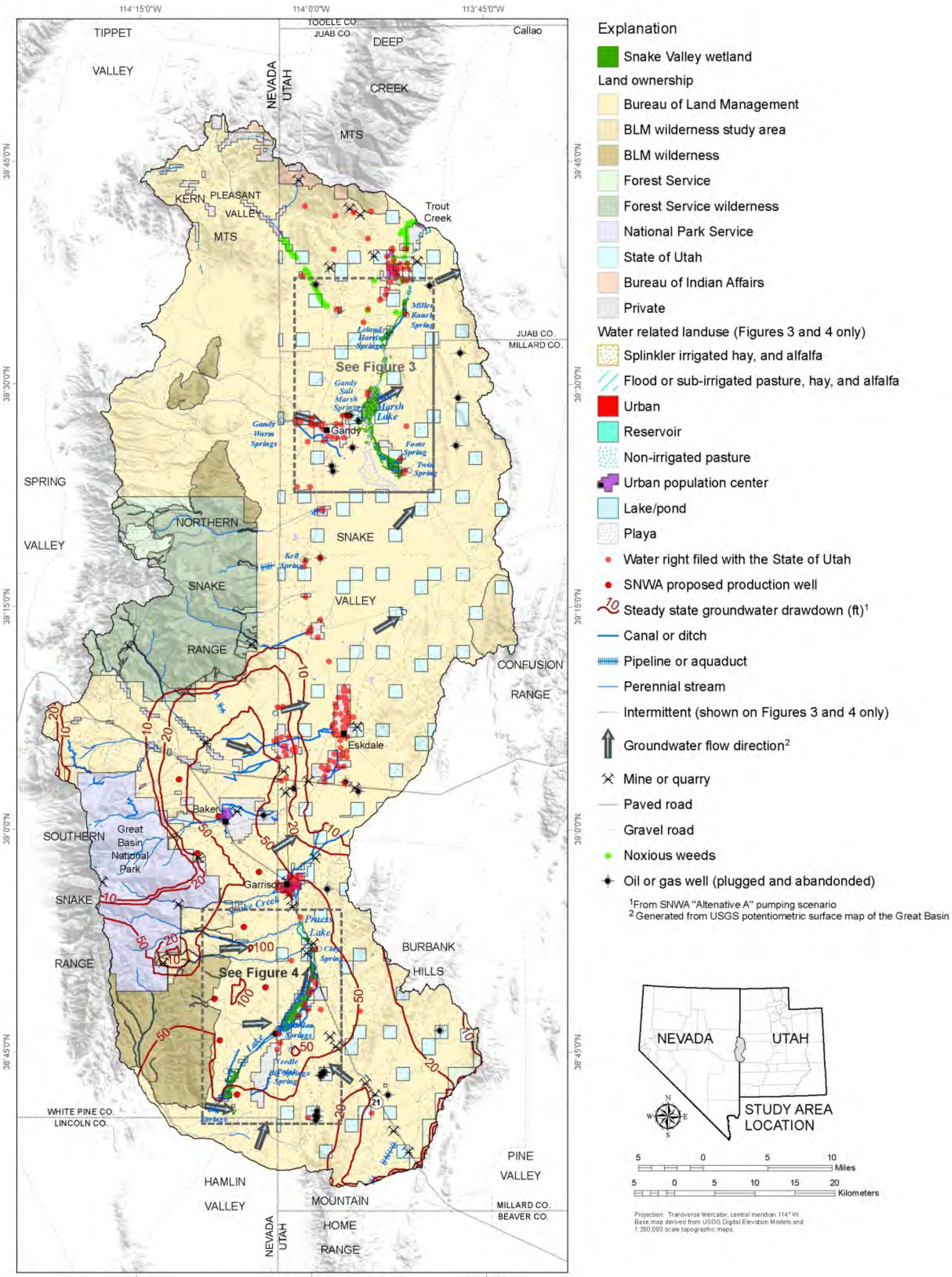


Figure 2. *Landscape-scale use and stressor data for the Snake Valley study area, see expanded inset areas, 3 and 4 figures below.*

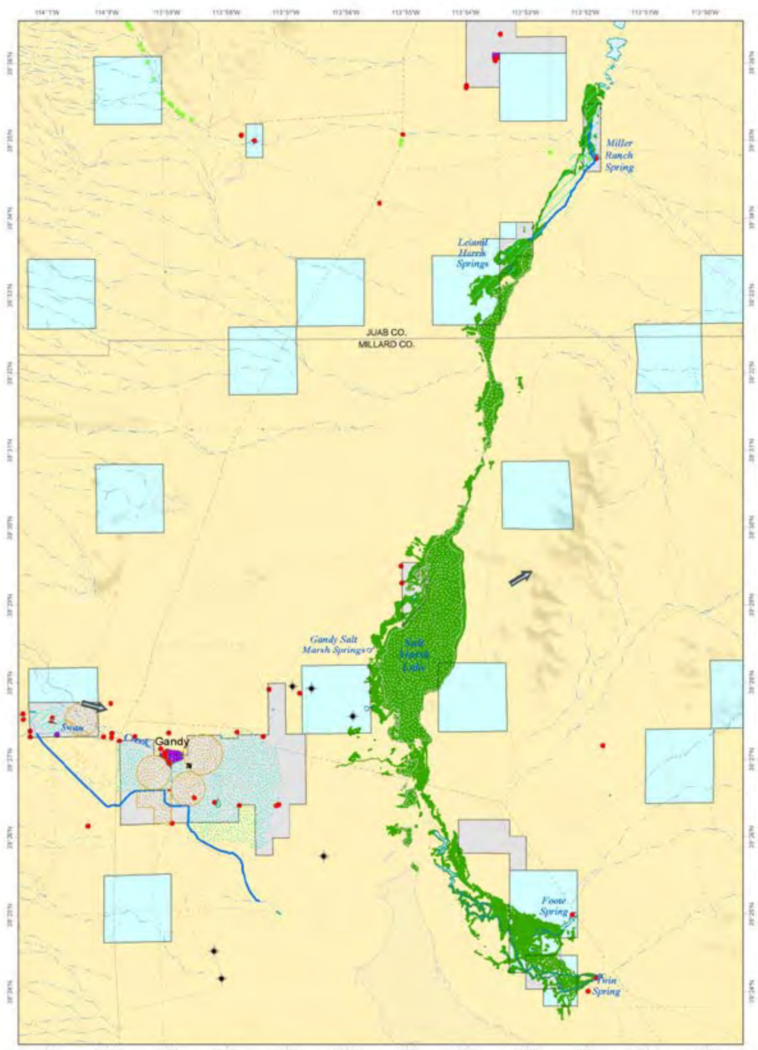


Figure 3. *Landscape assessment for the northern reach of the Snake Valley Study Area. See Figure 2 for explanation.*

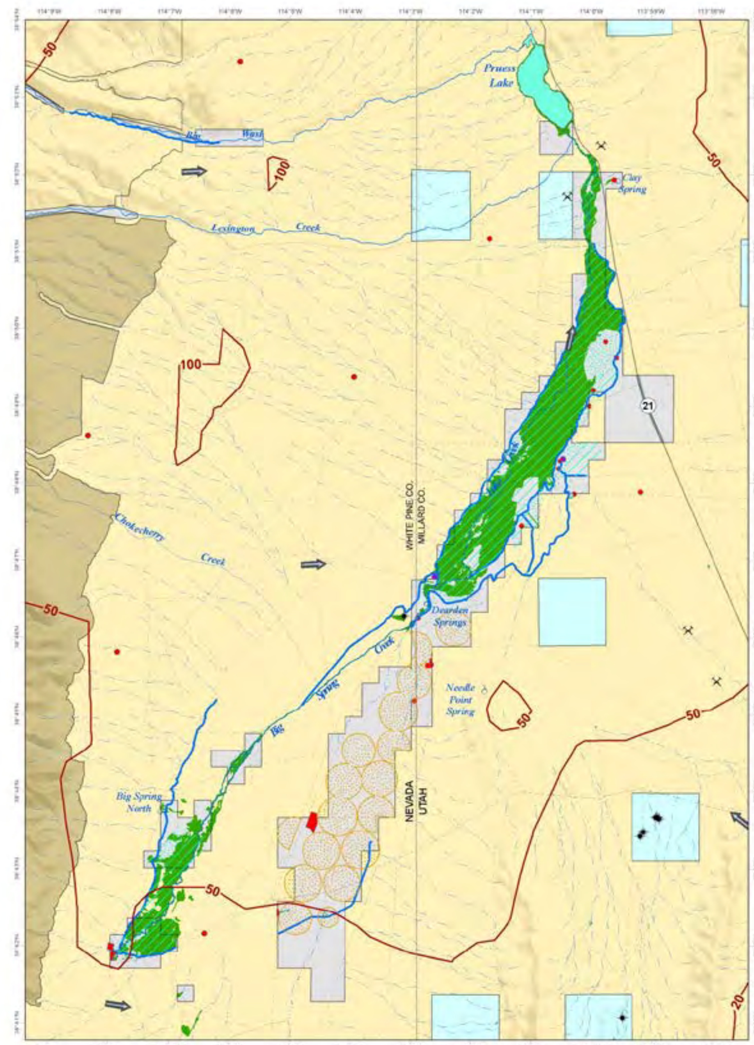
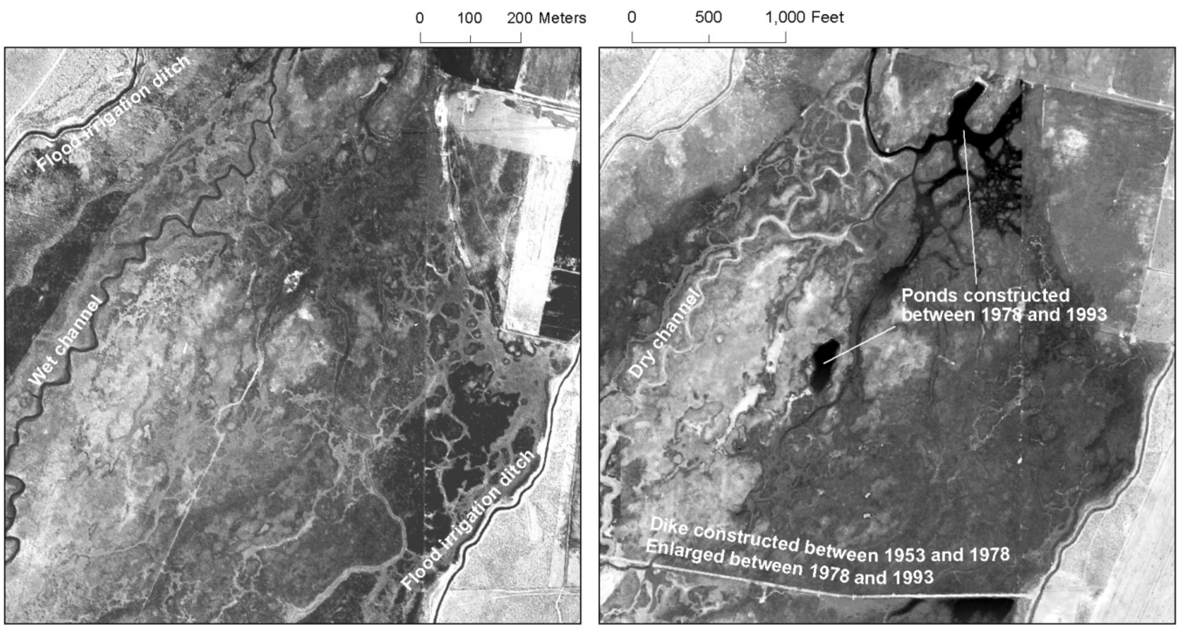


Figure 4. *Landscape assessment for the southern reach of the Snake Valley Study Area. See Figure 2 for explanation.*

The southern wetlands have also been altered to create ponds and water diversion structures. No record of dredging, channeling or tiling exists for the area. To roughly determine the timing of any hydrologic alteration to this area, historical images were compared for the following years: 1948, 1953, 1978, 1993, 2004, 2006, 2009, and 2011.

The most significant alterations occurred between 1953 and 1978 related to construction of ponds, ditches, and dikes. The two main ditches that bound the wetlands on the west and east were both constructed prior to 1953. The diversion of water to these ditches appears to dry the natural channel for at least a portion of the summer months. Water storage in constructed ponds has likely decreased water to the marsh ecologic systems which are now under a regulated hydrologic regime that has decreased the ecological system variability to mostly homogenous wet meadow systems compared to a more heterogeneous marsh/wet meadow mosaic pattern seen in the 1953 aerial photos (Figure 5).



A. *August 30, 1953 image* ***B.*** *August 6, 2006 image*

Figure 5. *Aerial photos comparing an area of southern Snake Valley wetlands for A. 1953 showing a heterogeneous wetland mosaic, and B. the same area as a more homogeneous wetland in 2006.*

Hydrologic alteration in the northern reach is limited to the construction of two reservoirs, Miller Spring and Foote Reservoir. Foote Reservoir provides water to a pivot sprinkler for a 40-hectare alfalfa field which prior to 2008 was watered by flood irrigation from Foote Reservoir which resulted in all of the water being diverted from the wetlands to alfalfa fields. This change in water management has resulted in the loss of most of the cottonwood trees that lined the abandoned ditch as well as some changes in the wetland vegetation as an increase in water has allowed more water-tolerant plants such as *Typha spp.* to pioneer into areas previously dominated by herbs and sedges.

Discussion

Snake Valley encompasses an area of approximately 8000 km^2 (3100 mi^2), with less than 250 people (U.S. Census Bureau, 2010; Utah Automated Geographic Reference Center, 2010). The primary industries in the valley are cattle and sheep ranching, with some tourism. Great Basin National Park in the Snake Range brings an average of 82,000 visitors each year (National Park Service, 2008). Ranching operations primarily occupy the valley floor, using water from the local aquifer to irrigate approximately 3060 hectares (7560 acres) of alfalfa and hay for cattle feed and utilizing wetland resources for pasture throughout the year. These operations occur mostly on privately owned parcels while the remainder of the valley is used for open range grazing on public lands.

The remoteness of Snake Valley and lack of urban development in the valley has left the wetlands relatively undisturbed, particularly in the northern reach. Most of the Snake-Hamlin Valley HUC is federal and state-owned, and managed for range to graze both sheep and cattle, while the montane recharge areas are largely protected by wilderness, wilderness study areas, and Great Basin National Park. Wetland land use is limited to agriculture, with some hydrologic modifications to springs and surface flows on private lands. To date, all hydrologic modifications, both in and out of the wetland areas, have kept water consumption within Snake Valley. Modifications to the southern reach may have created more extensive wetlands than what would naturally occur here due to flood irrigation practices. Wet meadows have likely been artificially expanded to upland areas and in some cases may have replaced marsh ecosystems where water is diverted from marshes and most likely regulated to a more consistent level throughout the wetland. We expect that the differences in management strategies between the northern and southern areas will be reflected in condition between the two reaches and provide for a broader disturbance gradient to inform development of rapid condition assessment tools during Phase II of this project.

MAPPING

Introduction

Assessment of the impacts of landscape and local-scale stressors to wetland condition requires mapping of wetland area and type. In 2009, the Utah Division of Wildlife Resources contracted Three Parameters Plus, Inc. (3PP) to provide a baseline vegetation and habitat survey of Snake Valley wetlands and provide a wetland map for the US Fish and Wildlife Service's National Wetlands Inventory (NWI) (Three Parameters Plus, 2010). We used the resulting data from this effort to further develop our NWI-to-functional crosswalk and work extensively on developing streamlined functional wetland mapping models (Three Parameters Plus, 2010). We proposed a model to map wetlands to a scale appropriate for landscape and local-scale condition assessments using standard remote sensing techniques and the best available aerial imagery.

Methods

Three classification schemes were used to map wetlands in the northern study area of Snake Valley. The initial method was implemented by 3PP (2010) while collecting baseline physical habitat data in the valley as part of a project funded by the Utah Department of Natural Resources. The two subsequent methods were implemented by the Utah Geological Survey. The initial method performed by the UGS utilized the results from a classification tree (CART) to develop a predictive surface with a model in ArcGIS. The final method was accomplished in R using the ModelMap package (Freeman and Frescino, 2012; R Development Core Team, 2012). All three methods used supervised classification techniques based on a subset of the field data to train a classification that would inform a predictive surface that would be assessed in a GIS. The key difference between the methods are the data used for prediction: the initial method utilizes only spectral imagery while subsequent methods used both spectral and ancillary data with the hopes of improving on the existing map and developing an automated method to be used in future projects. Each method is described in more detail below.

3PP Classification and Mapping

The initial classification of wetland area in Snake Valley was performed by 3PP (2010). As part of their baseline vegetation model, they collected detailed vegetation data at 640 plots in the northern study area for use as training points for their classification process. Their method utilized USDA National Agriculture Imagery Program (NAIP) 2006 Color Infrared (CIR) as the spectral imagery. Imagery for the study area was segmented and smoothed in SPRING 5.0.4 and then supervised classification was implemented using a small subset of field data producing seven broad habitat types. Polygons were manually edited and attributed in GIS based on adjacent polygon values and best professional judgment, making this a robust, yet time consuming method. Mapping units were classified based on the Cowardin Classification System and National Wetlands Inventory (NWI) classification standards (Cowardin and NWI). The map produced included an attribute of ecological communities to the Alliance and Association level based on the National Vegetation Classification System developed by NatureServe (Comer and others, 2003; Peterson, 2008). Mapping methods are described in more detail in the report submitted to the Utah DNR, Endangered Species Mitigation Fund, Baseline Physical Habitat Conditions of Wetlands in Snake Valley, Utah, Final Report: Volume 1 (Three Parameters Plus, 2010).

UGS Mapping

We used the results from the 3PP (2010) mapping effort as a proof of concept for two purposes: (1) assess reliability of our previously developed crosswalk of NWI-to-functional wetland classification for Great Salt Lake wetlands, and (2) develop an automated wetland classification model using NAIP imagery and LiDAR. We used two classification tree methods, CART and ModalMap, to test and automate the two mapping processes.

CART

The initial UGS mapping procedure used classification trees ‘grown’ in the tree package in R to inform development of a predictive surface in a GIS model (R Development Core Team, 2012; Ripley, 2012). Classification trees are a multivariate method of recursive partitioning that allow for prediction of a categorical variable response based on a series of decisions. Classification trees were built using field data collected by 3PP for baseline assessment at 640 sites with wetland classes as the categorical response variable and raster values as the explanatory variables (Three Parameters Plus, 2010). We withheld 30% of the data as test data, using 70% as the training data set for the model.

ModelMap

We used Random Forest classification trees within the ModelMap framework to develop a third classification of the northern Snake Valley study area (Freeman and Frescino, 2012; R Development Core Team, 2012). This approach was tested in hopes of developing an automated process that can be used in future landscape-scale mapping and classification projects. The map can be developed in an interactive graphical user interface (GUI) platform or in the main R console. ModelMap produces an independent probability raster of each categorical response (class) in a GIS format. These rasters can be combined by highest probability or weighted to prioritize classes which the user determines are more likely. We withheld 25% of the data as test data, using 75% as the training data set for the model. The same predictor data was used for this classification as was used for the CT classification.

Automated Classification

Statistics were collected from the model variables (predictors) to include all cells in a 5 meter radius from the 640 3PP detailed vegetation plots (Three Parameters Plus, 2010). Maximum, minimum, mean, median, and standard deviation statistics were tabulated and used to inform the models. Accuracy was checked by holding back a designated number of points (25-30%) stratified across the seven "response" wetland classes from the crosswalk. Results and accuracy assessments can be seen in the Mapping Results section below.

Crosswalk

We applied a NWI functional crosswalk established for Great Salt Lake wetlands which was developed to simplify ambiguous vegetation and Cowardin water regimes to the following six wetland classes (Sumner and others, 2010; Emerson and Hooker, 2011): Emergent, Open water, Playa, Scrub/Shrub, Lacustrine fringe, and Woodland.

The crosswalk was applied to the 640 vegetation plots collect by 3PP with very accurate results (>90% overall model accuracy); however, we did not find the new classifications particularly useful because the emergent class was too broad to provide meaningful information regarding wetland function. We found that NWI classification descriptions by themselves lacked the detail necessary to accurately classify wet meadow and marsh classes, providing only an emergent wetland category. NatureServe Ecological Classifications provided by 3PP to the Alliance and Association level provide the information needed to further the development of an NWI-to-functional crosswalk in the study area (Three Parameters Plus, 2010). When Alliance and Association data are coupled with NWI classes, a more descriptive functional crosswalk could be achieved (Figure 6). The classes used were determined by the available data and the amount of detail desired in the final model. A more detailed map was outside of the scope of this project, but this method can be used to develop comprehensive maps based on specific vegetation types.

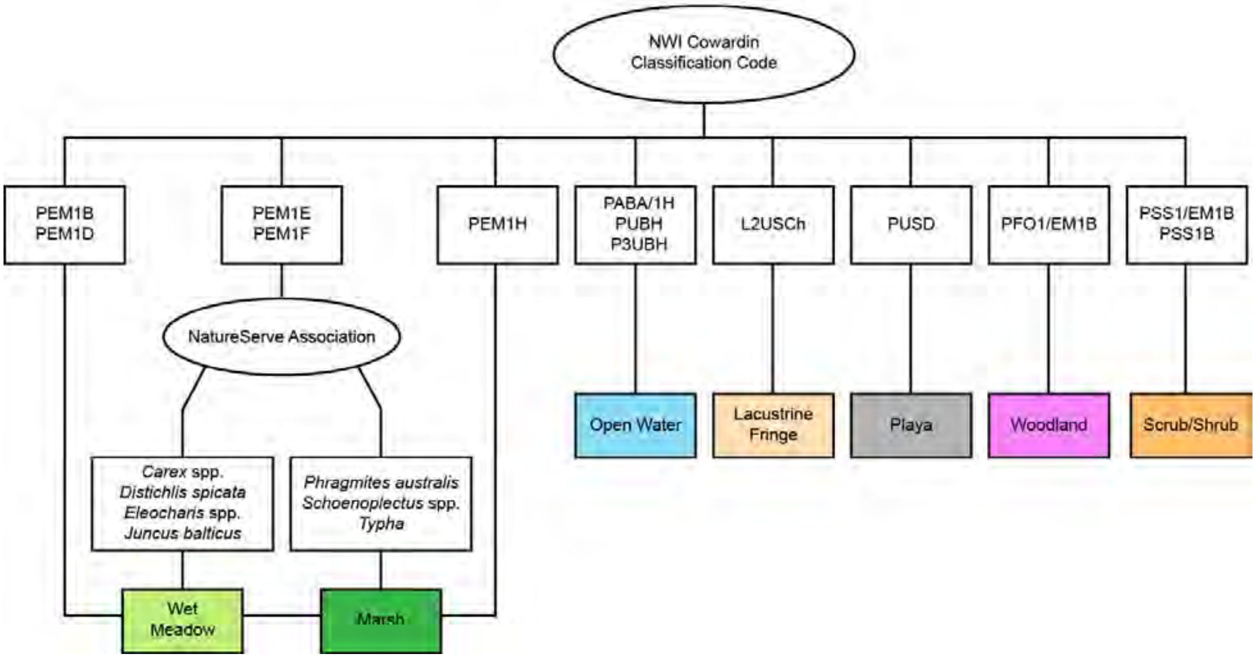


Figure 6. *Flow chart of crosswalk from NWI classes to classes used in CART and ModelMap mapping procedures.*

While this crosswalk offers an improvement over existing methods used in the area, it still lacks the ability to discern some classes and is not associated with any existing, tested, or described classification scheme. Future classification work will utilize existing classification schemes to create map products that may be more useful to a broader group of users, providing both detailed classification as well as crosswalks for multiple, existing classification schemes.

Model Variables

To further enhance the wetland classification model, we used both spectral and generated ancillary data to inform the predictive surface. Spectral imagery included all four bands of the 2009 NAIP imagery. Ancillary data included a normalized difference vegetation index (NDVI), a geomorphologic profile, and minimum vegetation height based on LiDAR, described below (Table 2).

NDVI

A normalized difference vegetation index (NDVI) is derived from the mathematical normalization of the red band and near infrared-band (NIR) using the following formula:

$$\frac{(\mathbf{NIR} - \mathbf{Red})}{(\mathbf{NIR} + \mathbf{Red})}$$

The results are a normalized raster with values between -1 and +1, representing the ‘greenness’ of vegetation. The more positive values represent healthy, dense vegetation and negative values represent open water and bare earth devoid of vegetation (Jensen, 2005). NDVI was derived using 1 meter, 4 band 2009 NAIP imagery collected by the US Department of Agriculture (U.S. Department of Agriculture, 2009).

Table 2. *Variables used in classification tree analysis and map building.*

	Variable	Description	Source
Predictor	NAIPB1MN	NAIP Band 1 (Red)	USDA
	NAIPB2MN	NAIP Band 2 (Green)	USDA
	NAIPB3MN	NAIP Band 3 (Blue)	USDA
	NAIPB4MN	NAIP Band 4 (NIR)	USDA
	NDVIMN	Normalized Difference Vegetation Index (NIR -Red)/(NIR+Red)	UGS
	SHCMED	Landscape Profile Classification (Depression or Hill)	UGS
	VEGHmMN	Vegetation Height (LiDAR first return - LiDAR DEM)	UGS
Response	Wetland Class	Marsh, Open Water, Playa, Salt Scrub, Saltgrass, Upland Grass, Wet Meadow, and Woodland wetland types	UDWR 2009-2011 inventory

Geomorphology

A geomorphological profile was created for the study area using 1 meter LiDAR data collected during the 3PP study in 2009. This process entailed creating a landscape position raster by determining depressions and hills using ArcGIS hydrology tools. We used the fill tool in the ArcGIS hydrology toolbox to fill the bare earth digital elevation model (DEM) so that any depression was filled to the point of outflow. The resulting raster was then subtracted from the original bare earth DEM to produce a raster with values ranging between 0 and -2.56. The negative numbers represent areas of depression. Conversely, to determine hills, the same process was accomplished on the inverse of the bare earth raster. The resulting raster values ranged between 0 and 8.57. The two rasters were then combined to produce a seamless raster representing hills and depressions in the study. All units represent depression depth or hill height in meters, accurate to 0.1 meter.

Vegetation Height

In addition to the bare earth DEM, a first return digital surface model (DSM), which represents a vegetation surface, was also provided as part of the LiDAR product. LiDAR is reflected by vegetation, and where canopy density allows, will also reach the ground surface so that multiple elevation values for a point can be determined. The first return DSM can be subtracted from the bare earth DEM to calculate vegetation height.

Data Management

We compiled and generated spatial data using ArcMap 10.1. Spatial data were collected in a variety of formats and converted to ESRI File Geodatabase format in order to store all data in a central database for ease of access and distribution. Data were organized into three feature datasets:

1. **Classification** - Contains data related to the three wetland classifications accomplished by 3PP (2010) and UGS;
2. **Features** - Contains non-analytical data such as geographic basemap features, annotation, cartographic masks, and ancillary data such as piezometer spatial locations and attributes;
3. **Level I Assessment** - Contains all data generated by the Level I regional assessment.

Geodatabases automatically manage projection information which was set to NAD 83 Zone 12 North. Because Snake Valley straddles UTM zones 12 and 11 the central meridian for the maps in this report was changed from 111º W to 114º W for display purposes only in order to display the maps with a "true north" orientation. The underlying projection information was not changed. Raw piezometer data and imagery files can be found at the following links:

- Current and historical National Agricultural Imagery Program natural color and color infrared photos (1993-2011) -*http://datagateway.nrcs.usda.gov/GDGOrder.aspx*
- Historical imagery (pre-1993) - *http://geology.utah.gov/databases/imagery/index.php*

Results

The three mapping procedures utilized different source data and classification schemes with widely disparate time requirements. Consequently there were discernible differences in the resulting products, though product accuracies were similar. All mapping efforts aimed to map at a 0.04 hectare (0.1 acre) minimum mapping unit. Because of the complexity of the wetland/upland matrix in the study area, all three maps have units smaller than this specified area. The map developed by 3PP (2010) is an intensive vegetation-specific map requiring multiple years to complete. The 3PP (2010) mapping effort utilized only the 2006 3-band CIR imagery. We felt that the available LiDAR and 4-band CIR imagery could potentially yield more accurate results by incorporating additional vegetation information and geomorphology to the models. UGS mapping procedures used the more current 2009 CIR imagery, which was collected in the same year as the LiDAR data for the CART and ModelMap classification models and a simplified functional classification scheme. This simplified scheme does not require vegetation-specific information, which resulted in a streamlined automated process that provided results comparable to the more time-consuming and resource-intensive 3PP (2010) mapping procedure. Although, the results provide less detail, we felt that broader classes may be more easily linked to wildlife habitat and wetland-scale responses to stress, providing a more broadly accessible tool for use in a variety of management applications.

3PP Mapping

3PP mapped 6488 hectares in the study area including 3731 hectares in the northern reach and 2757 hectares in the southern reach (Three Parameters Plus, 2010). Vegetation mapping resulted in approximately 83% accuracy. See 3PP (2010) report for more result details and specific accuracies for each of the targeted dominant vegetation types.

CART

The CART model mapped 6260 hectares in the northern study area. CART produces a decision tree model of results of the predictive surface, but does not produce a spatial result ready for input into a GIS. The resulting decision tree was manually entered into ArcGIS piecewise to create a spatial dataset that could be analyzed in GIS and independently verified. This process was time consuming and introduced an opportunity for error as the decision tree resulted in 37 nodes and 74 independent rasters to be processed.

The initial classification was designed to map uplands as three classes: saltgrass, upland grasses, and salt scrub. However, we found that the high-resolution LiDAR data may actually provide too much detail to make this a useful classification as it mapped individual shrubs as salt scrub and the space between the shrub cover as grasses. While there are GIS-based algorithms available to clump, merge or smooth this result to a desired mapping unit, the time involved for such analysis was deemed too costly considering this study is focused on wetland resources in the study area. We chose to merge all three upland classes into a single upland category. Standard smoothing and filtering algorithms run across the classes generated an acceptable mapping unit.

The final wetland classification resulted in over 300,000 individual wetland polygons as small as 1 square meter. We attempted to generate a standard mapping unit size of 0.04 hectares (0.1 acres), however the mosaic nature of Snake Valley wetlands made it necessary to simplify to units of 100 square meters in an automated process. This resulted in approximately 6000 individual units. We manually inspected polygons smaller than 400 square meters (0.04 hectares) to determine if they were critical units for an effective wetland model. Examples of a critical unit would be a small upland swale surrounded by wet meadow, or a small marsh associated with a spring in the uplands. The final simplified classification resulted in 1554 individual polygons with an overall accuracy of 71.5% for this method (Table 3).

Table 3. *CART map error matrix. Shaded cells indicate the number of accurately assigned test points.*

CART Results						Overall	71.5%
	Upland	Wet Meadow	Marsh	Open Water	Playa	Woodland	Total
Upland	49	1					50
Wet meadow	12	37	32				81
Marsh	3	7	43				53
Open Water				4			4
Playa					4		4
Woodland	1	1				6	8
Total	65	46	75	4	4	6	200

	Users Accuracy	Producers Accuracy	Omission Error	Commission Error
Upland	75.4%	98.0%	2.0%	24.6%
Wet meadow	80.4%	45.7%	54.3%	19.6%
Marsh	57.3%	81.1%	18.9%	42.7%
Open Water	100%	100%	0.0%	0.0%
Playa	100%	100.0%	0.0%	0.0%
Woodland	100%	75.0%	25.0%	0.0%

ModelMap

The resulting model from this automated method is a collection of probability rasters for each wetland class that can be used for analysis independently or can be combined into a single classification raster by assigning a class to the highest probability. For the final classification, the rasters were combined by highest probability down to a 0.60 probability. We determined that the validity of assigned cells below 0.60 was uncertain in the automated process and that by overlaying the data with the imagery, judgment-based criteria could be used to set thresholds for the classification. This resulted in increased accuracy for all individual classes of 3-33% and a 9% overall accuracy increase compared to the automated highest probability method. The finalized raster data underwent the same process as outlined for the CART classification except we withheld 25% of the vegetation plots for the accuracy assessment. The final simplified classification resulted in 1404 individual polygons with an overall classification accuracy of 79.4% (Table 4).

Table 4. *ModelMap error matrix. Shaded cells indicate the number of accurately assigned test points.*

ModelMap Threshold Results						Overall	79.4%
	Upland	Wet Meadow	Marsh	Open Water	Playa	Woodland	Total
Upland	43	1					44
Wet meadow	4	51	10				65
Marsh		16	27				43
Open Water				2			2
Playa	2				3		5
Woodland						1	1
Total	49	68	37	2	3	1	160

	Users Accuracy	Producers Accuracy	Omission Error	Commission Error
Upland	87.8%	97.7%	2.3%	12.2%
Wet meadow	75.0%	78.5%	21.5%	25.0%
Marsh	73.0%	62.8%	37.2%	27.0%
Open Water	100%	100%	0.0%	0.0%
Playa	100%	60.0%	40.0%	0.0%
Woodland	100%	100.0%	0.0%	0.0%

Discussion

To compare the results of the three methods, we looked at the area assigned to each of three Ecological System wetland classes that are dominant in the northern reach of the study area: North American Arid West Emergent Marsh (Marsh), Rocky Mountain Alpine-Montane Wet Meadow (Wet Meadow), and Intermountain Basin Playa/Alkaline Closed Depression (Playa) as well as Open Water (Comer and others, 2003). Since the UGS models mapped approximately double the spatial extent, the results were clipped to the same spatial extent as the 3PP (2010) mapping for direct comparison. There are marked differences in the amount of area assigned to each specific Ecological System by each method (Figure 7). The 3PP (2010) method designated more area to wet meadow and playa and less area to marsh, while the CART method designated the most marsh area out of all of the methods. The ModelMap method designated the most open water, the least marsh and wet meadow. Playa designation was comparable between the two UGS methods.

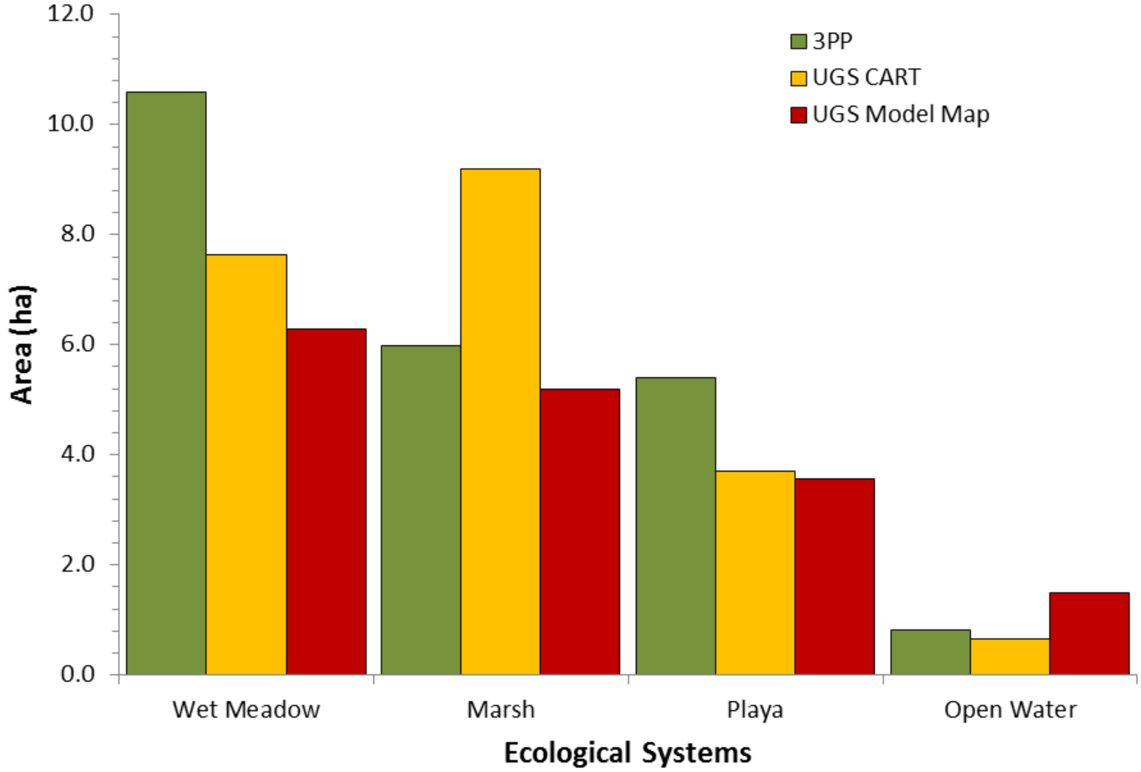


Figure 7. *Area of Ecological System types mapped by the three different mapping procedures.*

Aside from differences in overall mapping methods, the crosswalking schemes used may be the cause for some of the differences in ecological systems mapped. One specific group that varied between the methods includes three species in the genus *Eleocharis* found in the study area. The three species sampled dominate vegetation types that occur in both marsh and wet meadow hydrologic regimes. In the 3PP (2010) classification, all *Eleocharis*-dominated vegetation types were lumped into one class. Consequently, *Eleocharis* Seasonally Flooded Alliance could fall into either the wet meadow or marsh ecosystem type. *Eleocharis* accounts for approximately 6% of the emergent wetlands in Snake Valley, so while small, it is an important class as it is often associated with the transition between wet meadow and marsh ecotypes. Lacking species information, we chose to lump this class into wet meadow but did not run the classification models with this class lumped into marsh. The current schema of lumping *Eleocharis* into wet meadow likely contributed to the 3PP (2010) crosswalk resulting in more wet meadow and less marsh than the classification models developed by the UGS (Figure 8). UGS models used 2009 NAIP 4-band infrared imagery collected in June compared to the 3-band CIR imagery collected in August of 2006 used by 3PP (2010). Obvious differences in surface water between the two time periods associated with seasonal water fluctuations in the wetlands due to evapotranspiration accounts for more open water in UGS models, and may partially be responsible for the increase in marsh areas as the plants will not be fully developed in the marsh areas earlier in the growing season.

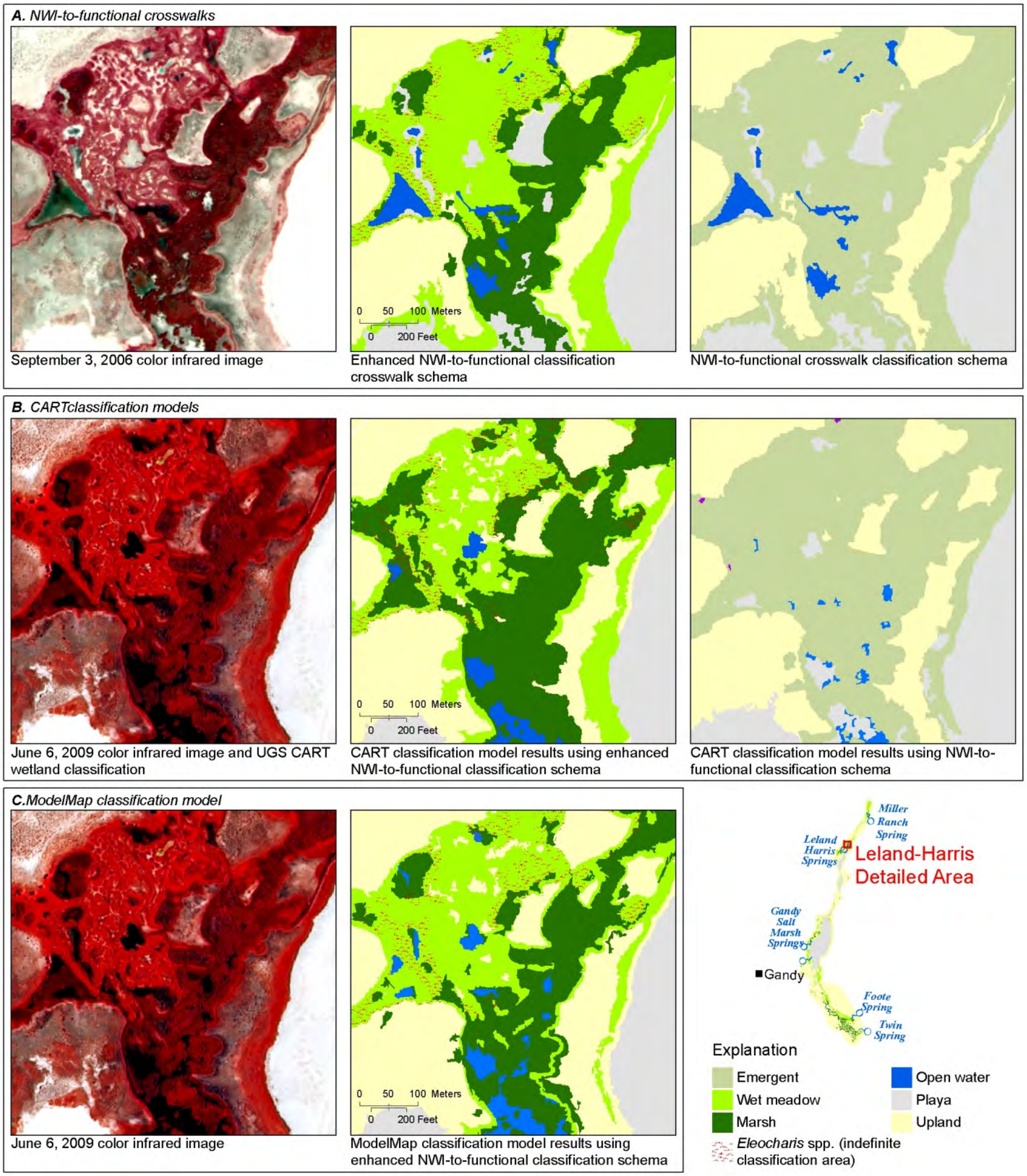
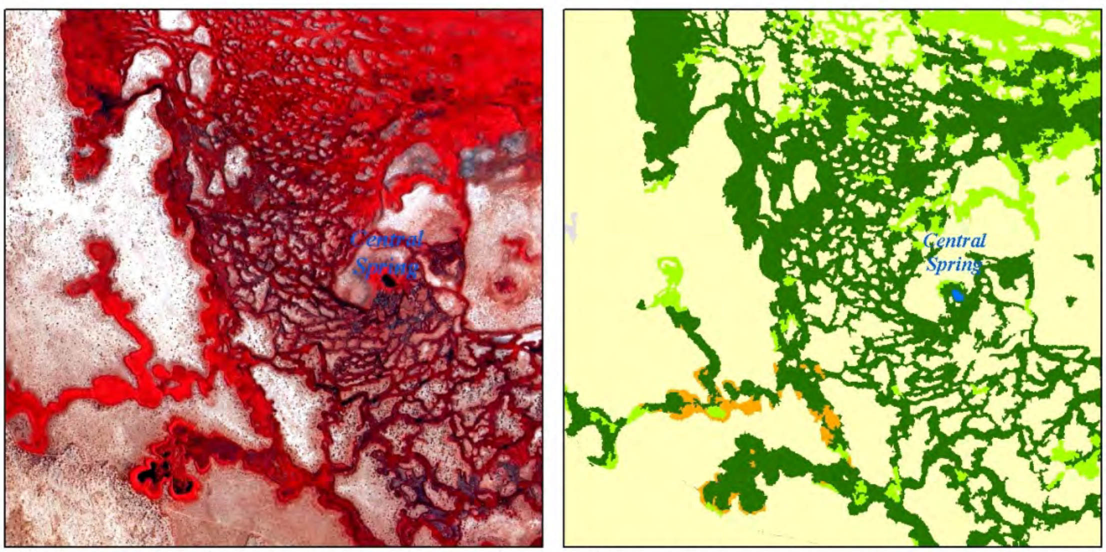


Figure 8. *Subset of three mapping efforts in northern Snake Valley at Leland-Harris spring complex. A. 3PP (2010) NWI crosswalk results, B. UGS CART classification model showing both the enhanced NatureServe classification and our first model attempt showing the NWI-to-functional classification, and C. UGS ModelMap classification model.*

An unexpected result of this mapping effort is that we were able to verify and map in detail, stands of *Phragmites* using the automated CART model (Figure 9). *Phragmites* grows taller and in denser stands than native Snake Valley vegetation, which the LiDAR data were able to differentiate through the vegetation height calculation. We believe this could be a beneficial tool that could be applied around the Great Salt Lake where *Phragmites* invasion is a more serious problem. In the current context, the observation and mapping of these populations will be used to call attention to occurrences of this species and highlight where mitigation efforts will need to focus to avoid further spread of the species in the valley. Though there are ongoing mitigation efforts in the valley being implemented for populations of *Elaeagnus angustifolia* (Russian Olive) by the BLM west district office and *Lythrum salicaria* (Purple loosestrife) in the valley managed by the Utah DWR central district office, there are currently no efforts being directed toward *Phragmites*. This is partly due to the fact that the nativity status of *Phragmites* has yet to be determined. Samples will be collected during the 2013 field season and sent to local experts to determine if mitigation efforts should also be directly toward this species.



2009 color infrared image of Phragmites invasion near central spring | *Phragmites (orange) mapped near central spring*

Figure 9. *Wetland profile at Leland-Harris springs highlighting* Phragmites *occurrences.*

ModelMap results were the most accurate as well as the most efficient with customizable inputs and easy to interpret results. This model will be tested further for Great Salt Lake wetlands as part of our Wetland Program Development Grants, *Developing Tools to Assess Condition of Great Salt Lake and West Desert Wetlands* (CD-96811101-0), and *Prioritization of Wetlands in a Managed Agricultural Landscape - Upper Bear River Watershed, Utah* (CD-96811801-0).

WETLAND CONDITION ASSESSMENT

Introduction

The EPA has developed a Core Elements Framework (CEF) to guide state and tribal wetland program development (U.S. Environmental Protection Agency, 2012). Within this framework, the core elements, Monitoring and Assessment, Regulatory Activities, Voluntary Restoration and Protection, and Water Quality Standards are suggested as the foundation for states and tribes to define components in their wetland programs. Monitoring and assessment is an essential component of a wetland program, providing baseline data that can inform other components in a wetlands program including regulatory and restoration activities (U.S. Environmental Protection Agency, 2006). Partners in the Wetland Program planning and implementation in Utah, the UGS and the Utah Division of Water Quality, have placed emphasis on developing tools for monitoring and assessment of the diverse wetland resources across the state.

Within the CEF, the EPA suggests a three-tiered approach for wetland monitoring and assessment, representing three scales at which wetland resources are evaluated (U.S. Environmental Protection Agency, 2012). Level 1 assessments provide a coarse measure of wetland condition based on existing GIS data. These assessments are typically evaluated at the landscape scale using characteristics of adjacent lands to apply general values of wetland condition and can be used to guide more specified, site-scale assessments. Level 2 or rapid assessment methods (RAM) are site-scale assessments that rely on readily observable indicators of wetland condition that can be easily collected in a short period of time. These assessments often result in a single value or used to compare wetlands across a disturbance gradient. Level 3 assessments are the most intensive assessments and require the collection of quantitative data by expert field crews. These intensive surveys provide the most detailed level of condition assessment. Lower levels (1 and 2) can be used to direct sampling for higher level assessments while higher levels (2 and 3) can be used to validate lower level assessments (Fennessy and others, 2007). Because of the limited expertise and time needed to apply RAM, these assessments can provide an essential tool for assessing a large number of wetlands at a regional scale and can be a complimentary component of other wetland surveys. As such, many programs have embraced RAMs as a focal and central tool in the Monitoring and Assessment component of their wetland programs.

The ultimate goal of wetland condition assessment methods is to utilize a suite of observable indicators to estimate relative ambient condition by class (Stein and others, 2009). Figure 10 shows the ecological features that define wetlands and components of refining a RAM.

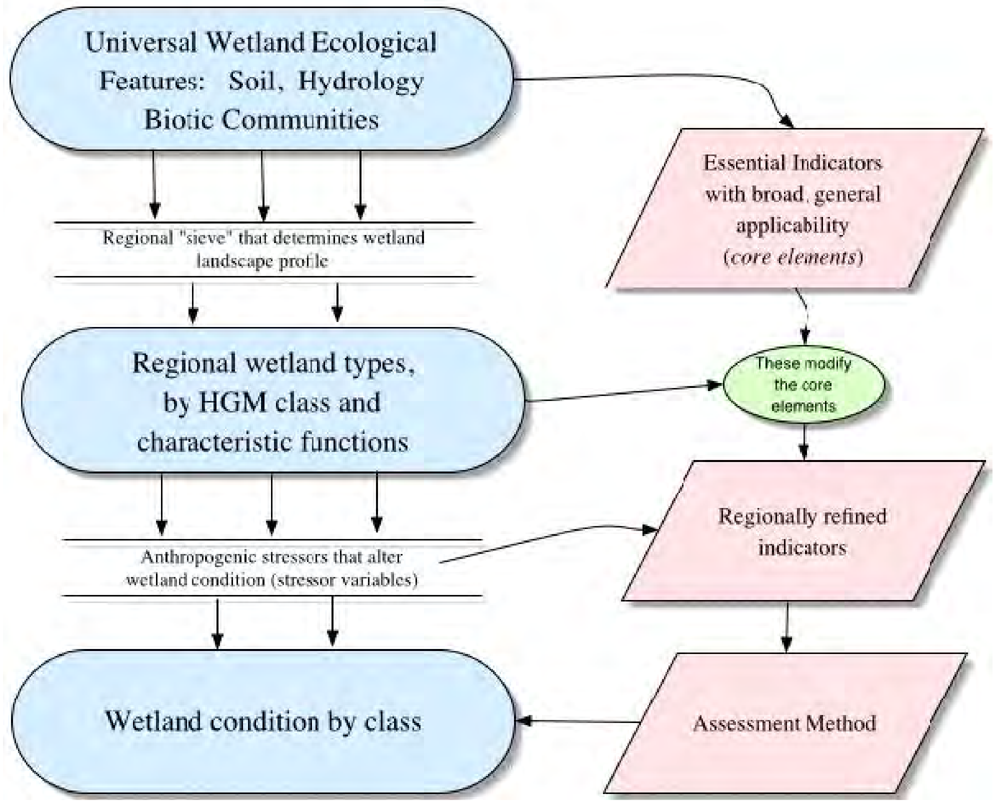


Figure 10. *Conceptual model of the relationships between evaluated wetlands and the components of a rapid assessment method, with characteristic ecological features of wetlands on the left and hierarchy of refining a method to local use on the right (Fennessy and others, 2007).*

A key component of the method development process includes the characterization of a reference standard or gradient along which sites will be compared, more specifically, a gradient of conditions that can be related to stressors appropriate for specific wetland classes (Sutula and others, 2006). This can be accomplished by establishing a reference network, or group of sites representing the range of anthropogenic disturbance which can be sampled to refine metrics based on this known disturbance gradient. A reference network can help to determine the characteristics that define different levels of condition as well as establish a range of responses to specific stressors. During rapid assessment development, there would preferably be a Level 3 or intensive quantitative assessment developed and used concurrently to validate rapid methods. Quantitative tool use and development are outside of the scope of this project. Validation of the methods being assessed will be addressed in future projects using intensive vegetation data and independently collected monitoring data from the study area.

Utah does not currently have a successfully tested RAM to evaluate ambient wetland condition. Considerable time and effort has been put into developing RAM's in other states, in specific regions of Utah, and at the national scale (Collins and others, 2007; Hoven and Paul, 2010; U.S. Environmental Protection Agency, 2011). Rather than developing a new RAM for statewide condition assessment, we chose to test two existing methods for their applicability to spring-fed wetlands of the West Desert. The methods, UWAAM and USA-RAM, represent two approaches with very different focal scope. UWAAM, Utah Wetlands Ambient Assessment Method, was developed specifically for wetlands associated with the Great Salt Lake (Hoven and Paul, 2010). USARAM was developed by the EPA for use in the National Wetland Condition Assessment (NWCA), a method encompassing both Level 2 and 3 assessments for wetlands at the national scale (U.S. Environmental Protection Agency, 2011). Both rapid assessment methods are broadly based on a previously developed and successfully applied model, the California Rapid Assessment Method (CRAM) (Collins and others, 2007), and include four common response attributes or major elements: landscape context and buffer, hydrologic structure, physical structure, and biotic (vegetation) structure (Fennessy and others, 2007). Response attributes in both methods rely on a number of metrics used to target key components of each attribute. Both methods also largely rely on checklists when evaluating metrics rather than collecting quantitative data, as used during Level 3 intensive wetland assessments. However, the two RAMs differ in the scope and specificity of their metrics, and it is not known which approach would best assess the condition of spring-fed wetlands within Snake Valley. USA-RAM employs separate metrics for evaluating wetland condition and wetland stress, while UWAAM includes metrics for wetland condition, some aspects of wetland stressors, and a metric evaluating wildlife habitat.

Assumptions that underlie assessment tool methodology drive the development process and aid in interpretation of resulting scores, so stating these assumptions is an important part of building defensible methodologies (Collins and others, 2007). Consideration must be made for how these assumptions align with assumptions about target wetlands when adopting metrics from an existing assessment method. The two methods being tested here have similar assumptions, and have been detailed as part of the NWCA Program (U.S. Environmental Protection Agency, 2011):

- The overall condition of a wetland is its capacity or potential to provide its full suite of functions and services, relative to reference sites.
- The overall condition of a wetland can be assessed in terms of the complexity of its visible form and structure, relative to reference sites.
- The overall stress on a wetland is the sum total and extent of human-caused processes and events that are likely to degrade wetland form and structure.
- The overall stress on a wetland can be assessed as the number of evident stressors and their cumulative extent. As the number and extent of stressors accumulates, wetland overall condition declines, regardless of wetland type or vegetation community composition.
- Indicators are visible representations of wetland form, structure, or stress. Suitable indicators can be identified using conceptual models that relate wetland form and structure to wetland processes, functions, and stress.
- For any wetland type or class, larger wetlands with more intact structure and less stress tend to have greater levels of characteristic functions and services. This can be represented by Condition Profiles and Stress Profiles.

Developing a specific set of assumptions based on these will guide which metrics will be used and adapted from the methods being assessed.

Methods

Field Surveys

This study employs intensive surveys of targeted sites to characterize distinct wetland types and evaluate wetland condition assessment tools. Targeted sites included a combination of the three most common wetland types: freshwater marsh, wet meadow, and saltgrass meadow. The sites were focal areas for intensive surveys of wetland hydrology, as described in the Hydrologic Monitoring Network section below. Targeted sampling is often used when a study question does not require a representative sample of the population but a focused sample of specific resources. Seven of the twelve identified springs in the survey area were selected for detailed groundwater, spring flow, and wetland studies by the UGS. Sample sites were selected to capture the represented hydrologic and vegetation types in a 2.5 hectare area for both methods being tested. Surveyed sites contained known populations of Least Chub and Columbia Spotted Frog based on previous UDWR surveys.

Vegetation surveys are often an important component of condition assessments as vegetation responses such as species richness and cover can be good indicators of both wetland function and condition. In addition to structural vegetation metrics measured as part of the rapid assessments, we conducted quantitative surveys of vegetation composition to support qualitative assessments and inform additional analyses that will be presented in Phase II of this report.

Data Management

Condition Assessment Data

We linked rapid assessment data from each site to a spreadsheet used to calculate RAM metric and indicator scores. We entered all data and implemented quality control measures to inspect data for inaccuracies. A Microsoft Access database is under development to house data from the wetland condition assessment work from this project and future Wetland Program Development Grant projects focused on developing rapid assessment tools in Utah wetlands. This database will contain all Level 2 condition assessment metric data as well as Level 3 vegetation data being collected in project study areas. The database built for Snake Valley will also house any additional data collected that can be used to characterize the study area (i.e. soils and vegetation data).

Piezometer Data

We processed raw data files of piezometer transducers and barologgers using R (R Development Core Team, 2012) and Microsoft Excel software packages. Raw data were appended to previous text files (comma delimited [*.csv]) for each transducer in R, and opened in Excel. We used barometric pressure data from barologgers closest to each site to correct for atmospheric pressure variations. We calculated relative difference in water level for each time-period from which field measurements were taken. These values were then adjusted for the difference in observed minus expected water levels, and instrumental drift over the measurement period. Finally, we subtracted these values from the piezometer elevation to yield absolute water table elevation, subsequently referred to as depth to water table. A compiled Microsoft Access database of all piezometer data can be requested from our FTP site by contacting the Utah Geological Survey at (801) 537-3300 - *http://geology.utah.gov/databases/groundwater/map.php?proj_id=1*.

Data Analysis

Initial evaluation of two rapid assessment methods entailed scoring results based on method-suggested criteria, identifying comparable metrics, describing the differences between the results of comparable metrics, and describing general differences between the two methods. We converted numerical UWAAM scores scaled from 0 to 100 to a 1-4 rating so that they could be more easily compared to USA-RAM scores (A-D). We made qualitative comparisons between similar metrics to initiate rapid assessment evaluation. Phase II of this project will investigate additional methods of comparing metrics using data from a broader disturbance gradient.

Results

Results presented here include a qualitative evaluation and initial step in determining which component metrics should be retained and examined for development of rapid assessment methodology for springs in the West Desert and wetlands at the state scale. We present herein a comparison between the components of each response attribute, which constituent metrics are redundant and unique between the methods, and suggestions on why scores varied between similar metrics.

One of the most pronounced structural differences in the two methods is that USA-RAM distinguishes between and separates out stress metrics from condition metrics, while UWAAM predominantly assesses condition. Condition metrics are those measured variables that evaluate components of wetland integrity and may signal reduced condition in a wetland (i.e. erosion, altered hydrologic regime, or bare ground). Stress metrics are aimed at evaluating elements in a wetland or the surrounding landscape that may impact wetland integrity (i.e. roads, diversions, or grazing). USA-RAM includes five stressor metrics evaluating observed stress factors that may impact the buffer, water quality, hydroperiod, habitat and substrate, and vegetation attributes. Assessing stressor metrics during condition assessment provides data that can be used to correlate estimated condition to observed stressors. Though the stressor metrics included in the USA-RAM method were made to conform to all wetlands types at the national level, in future work, we will focus metric development on those stressors observed explicitly in Utah wetlands.

Another structural difference between the methods is the inclusion of a separate indicator class for habitat in the UWAAM method, specifically intended to evaluate wildlife habitat. The habitat indicator is composed of three metrics: presence of water, ecological services, and threats. Because high-profile wetlands in the state, such as Great Salt Lake and West Desert wetlands, support unique and important wetland resources for wildlife, this group of metrics may be an important component in some Utah wetlands, while being less important in others. In UWAAM, habitat metrics are included as part of the overall score, though some wetlands in the state may not support habitat for the suggested wildlife species. Retaining these as value-added metrics may be the most appropriate use in a statewide method.

Another distinction between the methods is the predominant use of narrative ratings in UWAAM versus semi-quantitative tabulations based on checklists in USA-RAM. The use of narrative ratings may allow for some subjectivity in the results unless use of each metric is well-described during training or in a very detailed manual for the method. Intended users of the method being developed will drive what methods are used to evaluate component metrics. The most simple and transparent method is likely most appropriate when developing a tool having utility for a broad range of users.

Assessment Area

The size of the assessment area may have important implications on results in relation to the assumption that complexity and resilience of a wetland increases with size. The two methods under consideration suggest very different methods for determining the assessment area. UWAAM follows the model suggested by CRAM in that assessment areas should be comparable between sites that will be compared with the resulting scores (i.e. wetland types). CRAM suggests a maximum and minimum size for each wetland type. In contrast, current USA-RAM methodology follows a systematic sampling method based on a random point and 40-m radius (0.5 ha) circular plot (U.S. Environmental Protection Agency, 2011). This method was likely used to standardize sampling for use at the national scale by a broad range of users. Sampling for both methods during this survey assessed the same area and therefore we cannot make a comparison of how the two methods may differ in evaluating condition based on differences in assessment area at this time.

Response Attributes

There are pronounced differences in how the two methods evaluate their component response attributes or major elements: landscape context, hydrology, physical structure, and biological structure. With no direct comparison between individual metrics, we compared the most similar metrics to one another to provide a general understanding of the differences between the two methods. Most notably, there are distinct differences in how the two methods evaluate hydrology and plant communities, while the methods generally assessed buffer/landscape context and physical structure metrics similarly. Below, we detail how the methods vary and where metrics are redundant or where they may be complimentary.

Buffer/Landscape Context

The buffer/landscape context attribute is broadly focused on land cover conditions at the margin of the wetland or assessment area. The two main metrics are Buffer Extent and Buffer Width. There are minimal differences between these two metrics of the methods, the most pronounced being the radial distance of the buffer zone evaluated (UWAAM = 250 m, USA-RAM = 100 m). A third metric evaluates the *quality* or *condition* of the land covers that represent suitable wetland buffers, referred to as Buffer Quality or Stress to Buffer Zone. The two methods address buffer quality in distinct ways. In USA-RAM, the entire buffer area is evaluated for stressors, while in UWAAM, only the area identified as 'suitable' buffer is evaluated for quality. This is an important distinction as those areas not considered 'suitable' buffer may contain stressors that impact the assessment area. An additional difference in the methods is the use of a checklist (USA-RAM) versus a narrative rating (UWAAM). In USA-RAM, a checklist is constructed to identify stressors to the wetland buffer, rather than evaluating the condition of the buffer. Narrative categories in UWAAM are focused on the relative importance of native versus non-native vegetation, soil disturbance, and the degree of human visitation, an approach similar to that used by CRAM (v. 5.0.2). Given that the differences in the narrative categories of UWAAM (and CRAM) are qualitative, developing specific criteria for the intensity (or severity) of impacts to the wetland buffer would be beneficial for the long-term applicability of this metric. Retaining both a metric targeting buffer condition as well as a separate checklist to document buffer stresses may be the most appropriate way to assess wetland buffer condition while allowing users to examine correlations between condition and stressors (Collins and others, 2007).

Table 5. *Metric scores for the Buffer and Landscape Context attribute in northern Snake Valley spring-fed wetlands.*

			Site						
Metric	**Description**	**Method**	**Miller**	**Leland-Harris**	**Gandy**	**Foote Reservoir**	**Central Spring**	**Twin Springs**	**Pruess Marsh**
Buffer Extent	% of AA perimeter with suitable buffer	USA-RAM-1	A	A	A	A	A	A	B
		UWAAM-1A	A	A	A	A	A	A	A
Buffer Width	Width of suitable buffer	USA-RAM-2	A	A	A	A	A	A	A
		UWAAM-1B	A	A	A	A	A	A	B
Buffer Quality	Buffer Stress	USA-RAM-3	C	A	A	B	A	A	C
	Buffer Condition	UWAAM-1C	B	A	B	B	A	A	A

Condition metrics from both models indicate that wetland buffers were in good overall condition (Table 5). Suitable buffer land cover types dominated the perimeter of assessment areas (AA), and the width of suitable buffers was excellent at distances of 100 and 250 meters from margin of the AA. One exception is that of Pruess Marsh, where the eastern portion of the wetland lies adjacent to a paved two-lane highway (within 46 m). The proximity of this road may increase sediment and erosion in the area and serve as an opportunity for weedy plant species invasion as well as being an impediment to wildlife movement.

Metrics that examined the *stress* to or *quality* of wetland buffers suggest that these areas are healthy for four out of seven wetland sites. Both models indicate appreciable stress or moderate amounts of degradation to wetland buffers at the Miller Spring and Foote Reservoir sites. These impacts are likely due to active cattle grazing and the presence of drainage ditches; grazing intensity was estimated to be low to moderate at these sites at the time of field sampling (late August). The UWAAM model also indicated a moderate amount of buffer degradation at the Gandy site as a result of grazing impacts to wet-meadow and marsh communities, while the USA-RAM model indicated that the buffer at Pruess Marsh had moderately high levels of stress due to intense grazing at the time of sampling as well as the proximity to the highway.

Physical Structure

Both methods include metrics for surface and topographic complexity as well as a stressor checklist to address physical alterations. Surface complexity refers to horizontal or plan view complexity of the patch mosaic. The main difference between the methods is that USA-RAM includes substrate and vegetation patches while UWAAM only assesses vegetation patches. As well, playas and flats are treated separately in UWAAM due to their typical lack of vegetation patches, often supporting a single patch or band of vegetation at the edge of open water or hard pan.

Topographic complexity refers to richness of vertical structural patches in the assessment area and is treated by both models with a checklist. UWAAM distinguishes between wetland types and calculates a score based on the observed patch types in relation to those possible in the wetland types observed, while USA-RAM has a single list that applies to all wetland types. This distinction may be very important in some wetland types that have an inherently simple vertical structure.

Habitat and physical alterations are addressed by each method with a checklist. In UWAAM, the list is used to draw the user's attention to stressors, but depends on a narrative rating based on the qualitative significance of each of the observed stressors. USA-RAM strictly scores based on stressors and severity of stressors.

Table 6. *Metric scores for the Physical Structure attribute in northern Snake Valley spring-fed wetlands.*

			Site						
Metric	**Description**	**Method**	**Miller**	**Leland-Harris**	**Gandy**	**Foote Reservoir**	**Central Spring**	**Twin Springs**	**Pruess Marsh**
Surface Complexity	Patch Mosaic Complexity	USA-RAM-7	A	A	A	A	A	A	B
	Horizontal Interspersion	UWAAM-3A	A	A	A	A	A	A	B
Topographic Complexity	Topographic Complexity	USA-RAM-6	C	A	A	A	A	A	C
	Structural Patch Richness	UWAAM-3C	A	A	A	A	A	A	B
Habitat/Substrate Alterations	Substrate Alteration	USA-RAM-12	A	A	A	A	A	A	A
	Physical Alteration	UWAAM-3D	B	B	B	A	A	A	C

In general, the physical structure of the wetlands contributed to high condition scores for most of the sites (Table 6). For USA-RAM, both Miller Spring and Pruess Marsh scored lower in Topographic Complexity (USA-RAM-6, Table 6) than the other sites, mainly due to the limited number of indicators of micro- and macro-topographic relief; for example, there was little coverage of bare ground, abrupt slope breaks, shallow depressions, or physical components typically observed in wetlands with more dynamic hydrology. This is an example of how the two methods differ in assessing specific wetland types (UWAAM) versus assessing all wetland types (USA-RAM) for the same features. For UWAAM, Pruess Marsh had the lowest scores for all four metrics, due to the lower complexity of vegetation types, fewer vertical layers of vegetation and detritus, fewer structural microsites, and soil disturbance due to grazing.

Hydrology

The two methods evaluate hydrologic condition in significantly different ways. USA-RAM consists of one stressor checklist and two condition metrics, evaluating extreme high or low water levels, general hydrologic connectivity, and indicators of an altered hydroperiod. The altered hydroperiod metric here includes multiple stressors and is treated as a stressor checklist as most of the submetrics are structures or physical alterations to the landscape that would likely impact hydroperiod in the assessment area. In contrast, UWAAM employs five separate condition metrics to evaluate hydrologic condition, with three metrics devoted to hydrologic connectivity.

Table 7. *Metric scores for the Hydrology attribute in northern Snake Valley spring-fed wetlands.*

			Site						
Metric	**Description**	**Method**	**Miller**	**Leland-Harris**	**Gandy**	**Foote Reservoir**	**Central Spring**	**Twin Springs**	**Pruess Marsh**
Hydroperiod	Alterations to Hydroperiod	USA-RAM-11	B	A	A	A	A	A	A
	Hydroperiod	UWAAM-2B	A	A	A	A	A	A	A
Water Source	Water Source	UWAAM-2A	B	A	A	A	A	A	A
Water Level Fluctuation	Water Level Fluctuation	USA-RAM-4	B	D	D	D	D	D	D
Hydrologic Connectivity	Upstream Connectivity	UWAAM-2C	B	B	B	B	B	B	B
	Downstream Connectivity	UWAAM-2D	A	A	A	A	A	A	A
	Landscape Connectivity	UWAAM-2E	A	A	A	A	A	A	A
	Hydrologic Connectivity	USA-RAM-5	C	C	C	C	C	C	C

Sites scored poorly for hydrologic condition metrics under USA-RAM, but had very high scores under UWAAM (Table 7). Poor scores under USA-RAM were largely due to the general lack of indicators of high water levels compared to indicators of low water level (USA-RAM-4, Table 7), and the lack of indicators of a fluvial zone, a vadose zone or lacustrine connections (USA-RAM-5, Table 7). In contrast to the USA-RAM results, UWAAM indicates that the hydrology of project sites was dominated by natural water sources, with unaltered hydroperiods, well integrated within a mosaic of natural wetlands and uplands, and water outflow was unrestricted. Both condition metrics in the USA-RAM method may be more suitable for wetland types that exhibit dynamic hydrologic regimes, regimes less likely to be observed in groundwater-dependent wetlands. The alterations-to-hydroperiod checklist scored all sites as having few stressors, suggesting that hydrologic stressors are not correlated with the hydrologic condition metrics in USA-RAM and that the metrics in the UWAAM methods may be more suited to assessing condition in groundwater-dependent wetlands.

With the aim of developing a hydrologic attribute appropriate for all wetland types in the state, a narrative rating similar to that used in UWAAM may be more suitable in conjunction with a stressor checklist of alterations to hydroperiod and connectivity. If the USA-RAM metrics are retained in the model, we may need to include an additional group of indicators for wetlands supported by groundwater discharge or have a suite of metrics appropriate for wetland types with less visible hydroperiod fluctuations.

Plant Community

Plant community and structure metrics varied in some respects between the two methods. Invasive species are scored based on presence in UWAAM and co-dominance in USA-RAM, which accounts for the generally lower scores in UWAAM for this metric, due to low cover of a few species of non-native or introduced grass—an expected result to the long-term history of grazing in this valley (Table 8). Because cover of non-native species was low in all sites, USA-RAM scored at the highest level.

Table 8. *Metric scores for the Plant Community attribute in northern Snake Valley spring-fed wetlands.*

			Site						
Metric	**Description**	**Method**	**Miller**	**Leland-Harris**	**Gandy**	**Foote Reservoir**	**Central Spring**	**Twin Springs**	**Pruess Marsh**
Vegetation Community/Invasive Species	% Cover Invasive Species	USA-RAM-13	A	A	A	A	A	A	A
	% Cover Native versus Non-native	UWAAM-4A	B	B	B	B	B	B	B
Community Structure	Vertical Complexity	USA-RAM-8	D	D	D	D	D	D	D
	Vertical Biotic Structure	UWAAM-3B	A	A	A	A	A	A	B
	Plant Layers & Species Richness	UWAAM-4B	A	A	A	D	A	A	D
	Plant Community Complexity	USA-RAM-9	A	B	B	B	B	A	B

Within the community structure attribute, USA-RAM scored poorly due to limited vertical structure, an expected result in wetlands dominated by herbaceous species that lack additional strata common in other wetland types (e.g., forested swamps, subalpine wet meadows). Interestingly, the richness of co-dominant species (USA-RAM-9) among the vegetation types (*quasi*-beta diversity) was sufficient to yield high condition scores in at least two sites. Co-dominant species richness averaged 10 to 15 species among short- and tall-emergent vegetation layers.

Overall, plant community structure scores under UWAAM were indicative of good condition. Most of these wetlands had numbers of plant layers and species richness values within the expected range, 4-5 layers and 10-21 species for freshwater, spring-fed wetlands. However, Foote Reservoir had more species than expected and Pruess Marsh had fewer plant layers than expected (no submerged aquatic vegetation). In the Plant Layers and Species Richness metric in UWAAM, sites are devalued for having more or fewer species than a given range per wetland type, indicating that some wetlands with more species and more strata than given in this range are in worse condition, presumably due to the addition of exotic species. Though basis for this distinction is not made in the manual, we will need to ensure that the ranges used are appropriate for wetlands being assessed in order to avoid devaluing sites for increased species richness or heterogeneity.

There is also a distinct difference in the method's assessment of vertical biological structure. Where UWAAM recognizes all strata no matter how much cover they comprise, USA-RAM only recognizes those strata with at least 25% cover in the AA. This could greatly reduce number of strata detected by this method.

Habitat and Additional Stressors

Only UWAAM included explicit features of wetland-associated wildlife habitat. As these wetland sites are known for their excellent habitat features for sensitive species such as Columbia spotted frogs, endemic mollusks, and least chub, it is expected that these sites will score well. The main biological threats to wildlife at these sites were invasion from Western Mosquitofish (at all sites) and common carp observed at Pruess Marsh.

Stressor metrics were explicitly described in the USA-RAM model, while UWAAM includes at least one implicit stressor metric that is not directly comparable to a similar metric of USA-RAM; these results are summarized below (Table 9). There was little evidence for severe stress to wetland water quality, surface soils, or vegetation based on the models (Tables 5, 6, 7, and 9, shaded metrics).

Table 9. *Metric scores for the Habitat and Stressor attributes in northern Snake Valley spring-fed wetlands.*

			Site						
Metric	**Description**	**Method**	**Miller**	**Leland-Harris**	**Gandy**	**Foote Reservoir**	**Central Spring**	**Twin Springs**	**Pruess Marsh**
Habitat	Presence of Water Features	UWAAM-5A	A	A	A	A	A	A	A
	Ecological Services	UWAAM-5B	A	A	A	A	A	A	B
	Threats to Habitat	UWAAM-5C	-	-	-	-	-	-	-
Water Quality Disturbance	Stressors to Water Quality	USA-RAM-10	A	A	A	A	A	A	A
Vegetation Disturbance	Stressors to Vegetation Quality	USA-RAM-14	A	A	A	A	A	A	B

Both habitat and stressor metrics will be investigated in further detail in Phase II of this project. Habitat metrics will be discussed with wildlife biologists who have been monitoring least chub and Columbia spotted frog populations in the area for almost two decades. We will use their input to reassess if habitat metrics are capturing the important variables that may determine quality in wetland habitat. Stressor metrics will also be reassessed to determine sensitivity to the most significant stresses in the study area. Both groups of metrics were found to be valuable components to condition assessment.

Discussion

Overall, both UWAAM and USA-RAM indicate that wetlands sampled in the northern Snake Valley survey area are in good condition. The principal indicators of compromised condition observed were related to grazing pressures. These indicators were modest at all sites except for Pruess Marsh, where grazing had a moderate impact on vegetation structure and species composition (e.g., more forbs than grasses). Predictably, the principal stressor observed was also grazing. Other notable stressors included some habitat and hydrologic alterations within assessment areas and in buffer zones including ditches and roads.

Though sites scored generally high in most categories and there was a general lack of stressors in the study area, there were some metrics that scored low at some or all sites. Metrics that scored low often did so because metrics did not account for properties like hydrologic regime or vegetation structure inherent in the focal wetland system. These results have given us a good indication of which metrics will need to be evaluated for their suitability for use in these and other target wetlands in the region.

There was a limited gradient of wetland condition captured during this initial sample; as such we are unable to determine which metrics are sensitive to human disturbance at this time. Capturing a broader disturbance gradient and having a larger sample size will help us better determine the ratio of signal to noise in specific metrics and further understand which metrics may be most appropriate for a final rapid assessment model for wetland condition in Utah. We will be initiating Phase II of this project in Snake Valley with the expressed focus of capturing a broader condition gradient in spring-fed wetland resources. This work will begin during the 2013 field season and will expand sampling into a southern study area along the Utah-Nevada border. This area was included in our Level 1 assessment as a first look at differences in stressors between the two study areas. As indicated in the Level 1 assessment, the southern study area encompasses more landscape and local-scale stressors than the northern area. If condition scores from Pruess Marsh, located at the northern end of the southern assessment area, are any indication of the conditions we will encounter in this area, sampling will significantly expand our gradient.

CONCEPTUAL MODEL

Wetlands are characterized by their hydrology, vegetation, and soils (Mitsch and Gosselink, 2000). In groundwater-dependent ecosystems like springs, hydrology is often the primary driver of wetland form and function (Figure 11). Understanding the interaction between elements of a wetland’s hydrologic regime with biotic and biogeochemical components is a key factor in understanding how changes in groundwater may impact wetland ecology and condition.

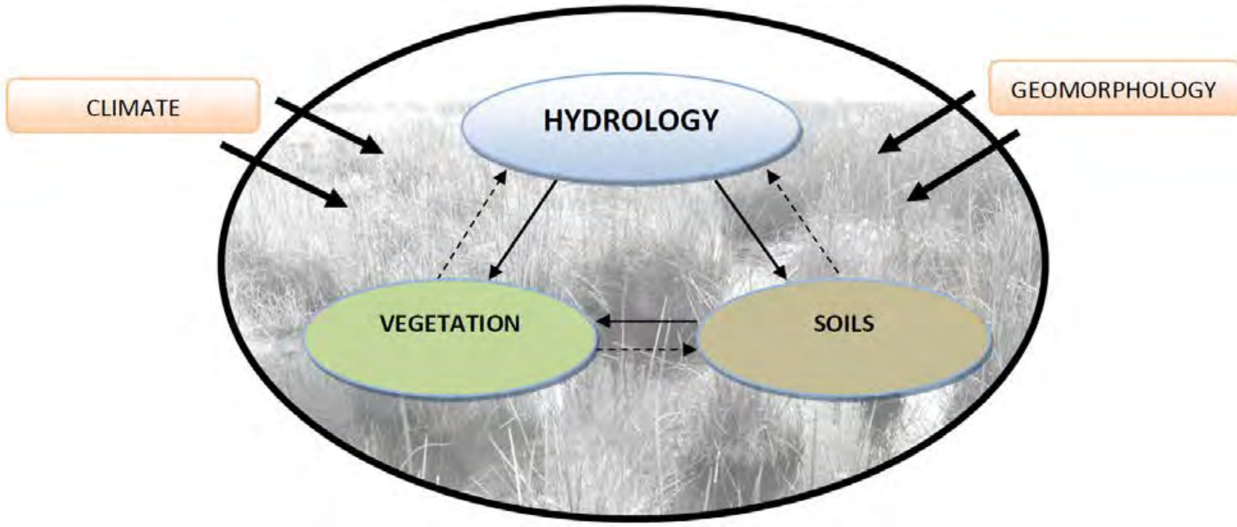


Figure 11. *Simplified conceptual model of the components of wetland ecosystems with hydrology as a principal factor directly influencing vegetation and soils with some feedback from each, adapted from Lewis (Lewis, 1995).*

Conceptual models are a fundamental component of monitoring natural resources (Gross, 2003). They are based on existing knowledge about the dynamics of a focal system and can help guide the development of tools used to assess condition and monitor trends. Specifically, stress models in ecology are intended to examine the relationship of stressors to potential responses of the components of the focal ecological system. The initial focus in creating a conceptual model for this project was to form hypotheses about the relationships between hydrologic regime and wetland types, wetland condition, and habitat quality. At this time there are insufficient data available to conceptualize components of wetland condition and habitat quality in the study area, so we focus here on the association between wetland vegetation types and hydrologic metrics. We developed a stressor model based on alternative futures of hydrologic regime and how hydrology may link to changes in vegetation, in turn altering habitat and occupancy of target wildlife species in the study area. Future work will utilize hydrologic and spatial data to develop a potentiometric surface for the study area. This surface will be used to further modeling efforts relating vegetation and habitat to hydrologic metrics.

Methods

Field Surveys

Hydrologic Monitoring Network

UGS and 3PP staff installed a network of nested piezometers to transect wetlands in 2009 and 2010, progressing downgradient from the point of groundwater discharge. Wetland piezometer locations were selected to best capture the seasonal and inter-annual patterns of water levels across the distribution of wetland types observed at a given site. Generally, we positioned two to four piezometers at similar distances from the spring, located in a distinct vegetation type and hydrologic regime. We installed 7 to 10 piezometers per site; see appendix A for locations of all piezometers. We installed each piezometer according to NRCS standard protocols described in Sprecher (2008). We surveyed each piezometer using a Trimble model 5800 base station unit accurate to ± 1.0 cm elevation. The stick-up height of each well was recorded to aid in water table elevation calculations. Each piezometer received a Solinst Levelogger Junior pressure transducer programmed to record hourly temperature and water level. Data from all pressure transducers (including Barologgers) were uploaded at least three times a year. During upload periods, water levels within the well were measured directly using a sounding meter (Heron, Conductivity PlµS) before the pressure transducer was removed, and the height of the piezometer pipe above ground was recorded to ensure that the well height had not been affected by frost heave, soil swelling, or disturbance by livestock. After the transducer was removed, we made water temperature, specific conductance (25 °C), and pH measurements on water within the piezometer using a YSI-30 multi-parameter probe. We have collected three full water years of data from October 2009 to September 2012. We used head values relative to the ground surface for all analyses. Because there were no evident confining layers found while installing each of the piezometers and the surface of the water outside of the piezometers was always very close to that being measured inside of the piezometer wells, we assume here that we are measuring the open aquifer. The surface of the water in relation to the ground surface is hereafter referred to as depth to water or water table.

Vegetation

We used vegetation data collected at the 60 hydrologic monitoring well sites to evaluate associations between vegetation and hydrology. Vegetation surveys conducted by 3PP (2010) included cover of all vascular plant species in 0.04-hectare circular plots. Cover of bryophytes and algae were measured separately as distinct strata. Nomenclature follows the USDA PLANTS Database (Natural Resources Conservation Service, 2013). Field crews measured depth to water table, electrical conductivity, and thickness of organic horizons and assigned a plant community type at each location based on a list of possible NatureServe Ecological Communities (Peterson, 2008). Additional vegetation, soils, and environmental data were collected throughout the study area. These data will be used in Phase II of this project to expand condition analyses and understanding of hydrologic links to soils and vegetation in the study area.

Data Analysis

Hydrology

We classified the hydrologic regime at each monitoring well based on patterns observed in mean daily water table depth across the three available water years (October 1, 2009 to September 30, 3012). We used hierarchical, agglomerative, cluster analysis to group wells by mean daily depth to water based on Euclidean distance and Ward's linkage method in PC-ORD version 6 (McCune and Mefford, 2011). We filled gaps in the record using linear interpolation if values were available before and after the missing period. Missing values at the beginning and end of records were left blank. Significant differences in hydrologic regime between vegetation types and sites will be assessed in more detail in Phase II of this project.

Vegetation

Multivariate analyses are often used to reveal patterns and relationships in vegetation community data and related environmental variables (Clarke, 1993). We used Nonmetric Multidimensional Scaling (NMS) ordination to evaluate the relationship between wetland vegetation, hydrology, water chemistry and available soil metrics at sites with groundwater monitoring wells. The analysis consisted of vascular plants occurring in more than one plot at each of the sampled monitoring sites (56 sites, 50 species). We performed the ordination in PC-ORD using the Sorenson distance measure and the thorough 'autopilot' procedure which performs 500 iterations on 250 real runs with random starts to find the lowest stress solution having the lowest dimensionality (McCune and Mefford, 2011). We used a graphical rotation based on the most highly correlated variable in the second matrix, which allows for easier interpretation of the first two resulting axes.

Results

Data from all 60 wells across the three-year monitoring period (October 1, 2009 to September 30, 2012) were used for analysis. The lowest depth to water observed at any point in the period was 155 cm below the ground surface. This value was measured at Gandy Spring in August of 2010 in an area supporting *Distichlis spicata* mixed herbaceous vegetation. The highest water depth observed was 70 cm above the surface. This value was measured at Gandy Spring in January of 2010 in an area supporting *Schoenoplectus acutus* herbaceous vegetation.

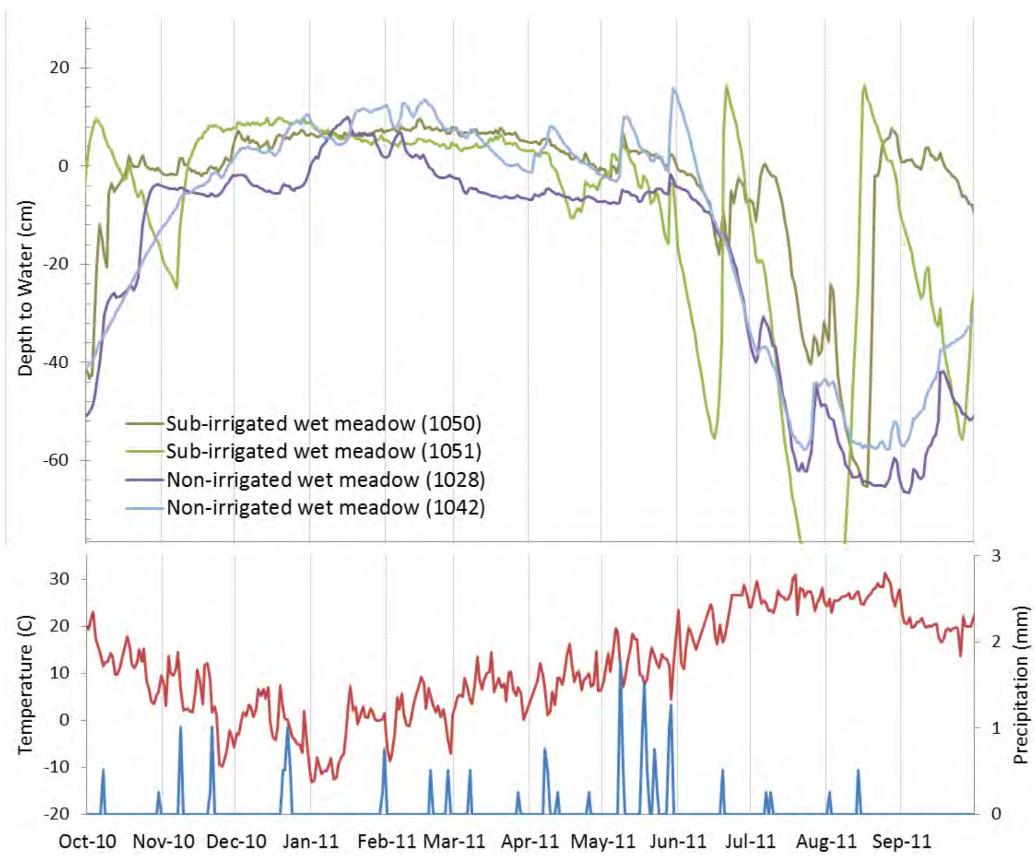


Figure 12. *Comparison of irrigated and non-irrigated wet meadows showing the effects of periodic release of water from ditches on the water levels.*

Another monitoring area supporting *Schoenoplectus acutus* herbaceous vegetation at Leland-Harris had the highest mean water table of +20 cm across all three years. The site with the lowest mean water depth across all three years (-95 cm) is located at Bishop Springs in *Distichlis spicata* mixed herbaceous vegetation.

When all wells are considered together, groundwater on average was lowest in August and highest in January and February for all three water years. Water levels exhibited responses to precipitation events, irrigation events, and vegetation senescence at the end of the growing season (Figure 12). Some wells exhibit marked responses to irrigation, with extreme variability in water levels throughout the growing season. Plant communities occurring in irrigated areas will be much more susceptible to changes in both local and regional water management and climate. Hydrographs also showed a marked response to senescence during October and November, indicating that evapotranspiration is an important component of the water budget of wetlands in the study area.

Cluster analysis of mean daily depth to water resulted in five groups (Figure 13). The groups are described by the pattern observed in the water table depth across the three hydrologic years. We pruned the resulting dendrogram at approximately 83% similarity to optimize the information retained at that level and provide homogenous, interpretable groups (see Appendix C for dendrogram of cluster analysis results).

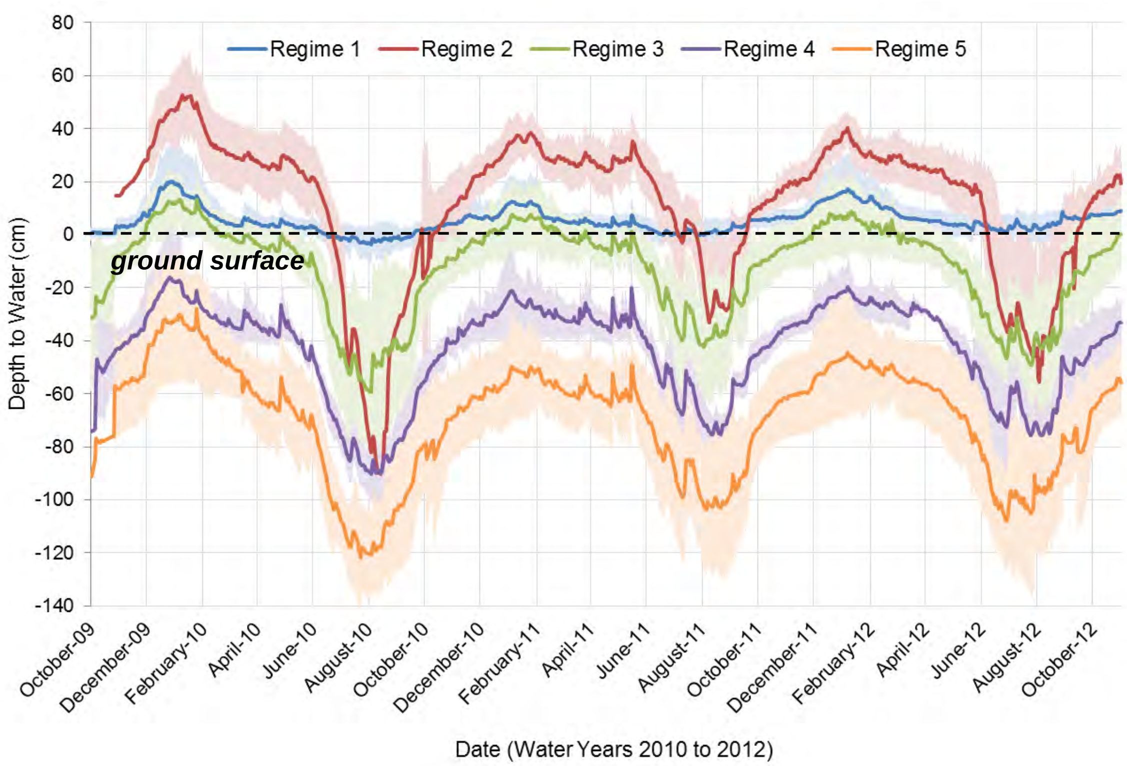


Figure 13. *Cluster analysis of depth to water table for three hydrologic years from October 2009 to September 2012. Sites grouped by Ecological System.*

Cluster analysis of sites based on hydrologic regime showed that a priori groups of vegetation type and ecological system generally reflect hydrologic regimes observed in groundwater monitoring sites, with some notable exceptions. Drier sites (Regimes 3, 4, and 5 below) had the most consistent vegetation, occurring in wetland-upland transitional areas, with vegetation types dominated by *Distichlis spicata* and wet meadows dominated by *Juncus balticus*. The two wetter hydrologic regimes (Regime 1 and 2 below) supported the most inconsistent vegetation cover, with all six vegetation types. *Typha latifolia*, *Juncus balticus*, and *Eleocharis* spp. dominated vegetation types were the most versatile, being found in three or more hydrologic regimes. This variability in vegetation within hydrologic regimes may reflect ongoing shifts in vegetation in response to existing stressors or changes in water management in the area. One site dominated by the transitional species *Distichlis spicata* experienced a water table that never fell below the surface across all three water years (2010-2012).

We describe groups below based on the hydroperiod observed on Figure 13, minimum and maximum values across the three water years, and the results of an indicator species analysis:

- **Regime 1** – These areas are characterized by a consistent hydroperiod, with a water table that remains close to, at, or above the surface throughout the year. Soils are typically waterlogged, with multiple hydric indicators including organic horizons and gleying. Plant communities in these areas are dominated by obligate wetland species that are adapted to tolerate extended inundation. *Schoenoplectus americanus* is the dominant species in most sites and algae was common.
- **Regime 2** – Seven sites corresponded to the unique hydroperiod exhibited at these monitoring sites, which had very high winter and spring water tables that dipped well below the ground surface in the late summer. Dominant vegetation was variable across the sites in this regime, with some sites dominated by *Schoenoplectus acutus* and others by *Typha latifolia*, *Carex simulata*, *Juncus balticus* and *Eleocharis* sp. Four of the sites are located near the Gandy Spring complex, a valley-margin spring, which is connected to local-scale flows causing it to show more annual variability (Hurlow, in preparation). Two of the other sites are located more than 2 kilometers from any of the major spring heads, but are in the main outflow areas from two springheads, so their hydrology may be more susceptible to high variability due to location. A longer record of hydrology and vegetation changes in these areas may give us a better understanding of the interactions between plant composition and hydrology at these sites and ascertain if the sites are responding to changes in hydrology.
- **Regime 3** – Hydroperiod at these sites is characterized by seasonally saturated soils, with a water table that is near the surface during the winter and spring that dips in the later summer, but stays well within a meter of the surface. Sites are typified by wet meadow vegetation dominated by *Juncus balticus* or a species of *Eleocharis*. *Typha latifolia*, *Populus angustifolia*, and *Elymus triticoides* are common at multiple sites.
- **Regimes 4 and 5** – These two hydrologic regimes are both distinct, in that water tables typically do not reach the surface at any time during the year. They are distinguished from each other by the degree of distance from the surface that the

water table remains, with Regime 4 typically staying within a meter of the surface and Regime 5 often showing a dip below a meter during most summer seasons. All sites in these two groups are dominated by *Distichlis spicata*, a common halophytic, perennial grass in playas and alkaline flats of closed basins where capillary action from the shallow water table and high rates of evaporation cause salt accumulations at the surface. These areas constitute a transition from wetland to upland. Other common species in these areas include *Juncus balticus*, *Sporobolus airoides*, *Spartina gracilis*, *Suaeda calceoliformis*, *Carduus nutans*, and *Elymus triticoides*.

Non-metric Multidimensional Scaling (NMS) ordination of vascular plant species in plots sampled near monitoring wells resulted in a three-dimensional solution representing 72% of the variance in vegetation composition (Figure 14). The first axis was highly positively (r > 0.4, r < -0.4) correlated with mean, minimum and maximum depth to water, water pH, and organic soil thickness and negatively correlated with bare ground and water temperature. The second was negatively correlated with herbaceous cover and standard deviation in water table depth. The third axis had no significant correlations, representing only 18% of the variance in composition. See appendix D for correlation of all variables with ordination axes.

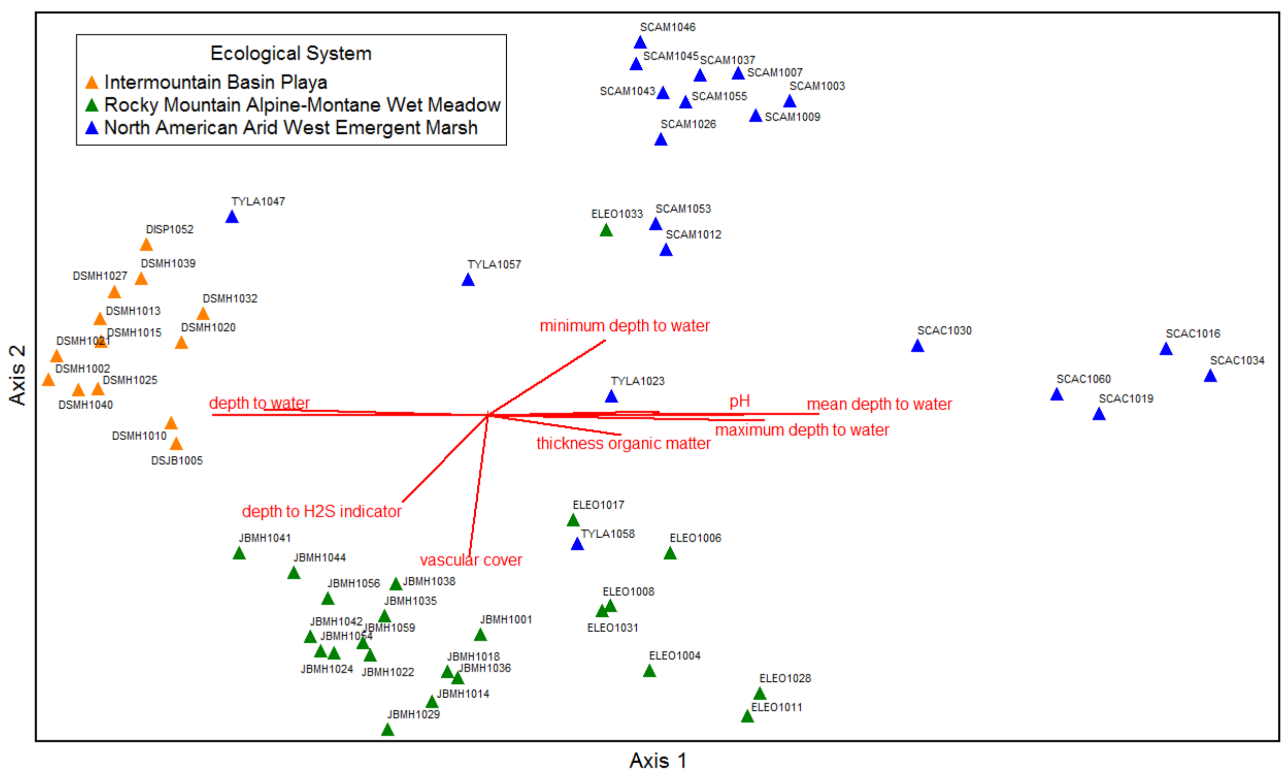


Figure 14. *Non-metric Multidimensional Scaling (NMS) ordination of all vascular species in transects rotated by mean depth to water table. Groups are ISOPAM cluster groups, if we decide a cluster analysis is warranted, I can provide more detail here.*

Vegetation types clustered in ordination space, with a few exceptions, suggesting that vegetation type assignment does reflect composition. The *Typha latifolia* vegetation type did not cluster in ordination space, indicating that composition at these sites is highly variable and the sites could be experiencing vegetation shifts due to hydrologic or other physical alterations.

Model

The resulting stressor model examines two scenarios of hydrologic changes determined by existing and potential stressors and how these stressors may alter vegetation and habitat in focal wetlands (Figure 15). The first scenario suggests that existing stressors to hydrology in the region including agriculture and climate change may result in persistence of habitat within the natural range of variability, shifts, or reduction/loss of habitat. The second scenario suggests that new stressors will cause shifts in wetland habitat or reduction/loss. There is the chance that moderate to severe drawdown in surrounding valleys would have limited impact on wetlands in the study area and that existing hydrologic models have not accurately captured inter-basin connectivity. However, we felt that addressing worst-case scenarios would be the best approach to instigate development of management tools for monitoring wetland resources that will target negative responses to changes in hydrology.

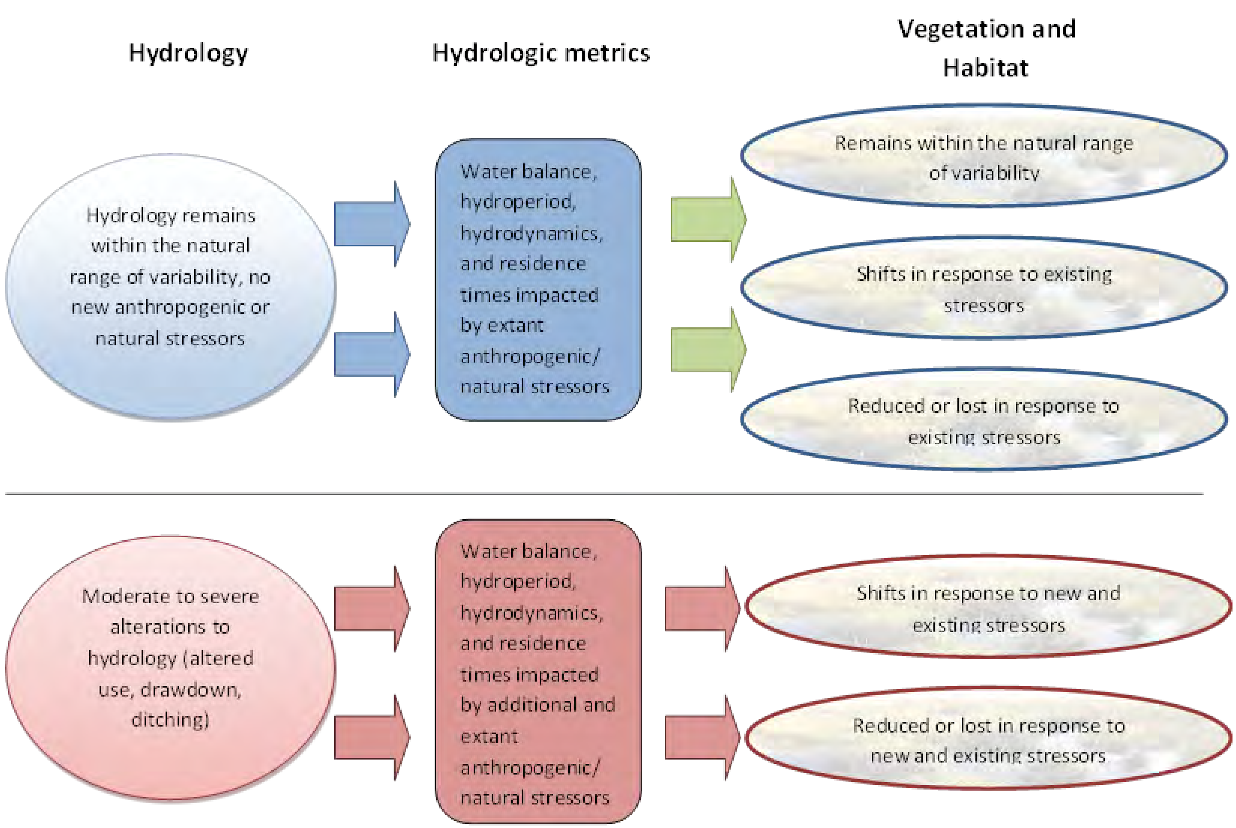


Figure 15. *Conceptual model of alternative futures for wildlife habitat in Snake Valley in relation to hydrologic stressors.*

Discussion

Hydrologic regime is reflected at the surface by biogeochemical properties in soils and by biota inhabiting an area. Though biota, specifically vegetation, is often used as an indicator of hydrologic regime, plant communities may not be precise indicators of hydrology on short temporal scales. It may take multiple seasons of sustained changes to a regime to reflect in vegetation due to rates of colonization by new species and broad tolerances by extant species. Though still a short record, resampling vegetation at monitoring wells for Phase II of this project will provide a better idea of the relationship between vegetation and hydrology and if those areas that do not follow predicted patterns based on vegetation are in the process of transitioning to different vegetation types.

This model in conjunction with the above analyses of hydrology and vegetation provides preliminary insight into how hydrologic changes may be exhibited in target wildlife resources. Using this model, we can take additional steps toward understanding how specific hydrologic metrics such as seasonal highs and lows, duration of high or low water table, and mean annual depth to water may relate to condition, specific vegetation types, and habitat for target wildlife species.

Researchers at Oregon State University (OSU) are using least chub population data to model occupancy in potential habitat patches in the study area. Additional work based on populations of Columbia spotted frog is addressing how changes in hydrology may impact vegetation and in turn alter populations. Both modeling efforts are directed at developing effective decision-making tools for managers. Future data collection and analysis to be conducted during Phase II of this project will target the relationship between hydrology, habitat, and condition. We hope to incorporate the results from the OSU modeling efforts into our analyses to provide a better understanding of the importance of hydrology and wetland condition to sensitive wildlife populations in the region.

SUMMARY AND RECOMMENDATIONS

The results of this study present a continuation of baseline data analyses in the Snake Valley study area and a foundation for future work on developing a rapid assessment tool for the region and state. We have addressed our main objectives: compile existing spatial data and use those data to assess new mapping methodologies; begin the process of collecting detailed vegetation, soils, and hydrologic data; evaluate the utility of rapid condition assessment methods; and develop a simple conceptual model relating hydrologic futures to extant biota in the study area.

Here we provide recommendations for future work in Snake Valley wetlands that will enhance our knowledge of ambient condition, shallow groundwater hydrology, vegetation, and wildlife habitat. Though providing management recommendations is outside of the scope of this project, our recommendations identify multiple tasks to be considered in Phase II of this project and as part of future work in Snake Valley.

In relation to development of condition assessment tools:

- Assess sensitivity of metrics to condition.
- Combine metrics into a single method based on most sensitive metrics.
- Reassess species-specific, value-added metrics.
- Validate metrics based on quantitative data.

In relation to other aspects of this study:

- Conduct a spatial assessment of population and reproduction data being collected on Columbia spotted frog and least chub in the study area.
- Collect more detailed environmental information for wetland resources across the two study areas (i.e., mean and range of water quality values, mean and range of organic matter depth, other physical variables, mean and range of slope values).
- Examine relationships between regional groundwater and local groundwater in study area wetlands.
- Develop potentiometric surface model as close to the years of vegetation data collection as possible to develop a better understanding of the relationships between vegetation and hydrology.

ACKNOWLEDGEMENTS

This work was made possible through funding by an Environmental Protection Agency, Region 8, Wetlands Program Development Grant and Endangered Species Mitigation Fund (ESMF) grants from the Utah Department of Natural Resources (UDNR) Recovery Programs Office to the Utah Geological Survey (UGS). We worked collaboratively with several UGS geological scientists involved in monitoring groundwater aquifer dynamics in Snake Valley, as well as ESMF personnel, Utah Division of Wildlife Resources Wildlife biologists, and a Bureau of Land Management Riparian Program manager during field sampling and while interpreting the results. Specifically, we thank Justin Minter and Mark Rains of 3PP, Heidi Hoven of the Institute for Watershed Sciences, and Becka Downard of Utah State University for their help in implementing the field component of this work. We also thank Chris Keleher, Deputy Program Director of the Utah DNR Recovery Programs for logistical, technical, and financial support. UGS reviewers provided invaluable suggestions and help with editing. Special thanks go to Jill Minter and Rich Sumner from EPA whose input has been invaluable in moving development of the Utah Wetland Program forward. This work represents a first step towards developing a better understanding of spring-fed wetlands in Utah’s West Desert, and how to best conserve these resources for the current and future enjoyment by all Utah’s residents. The help of every individual involved is essential in increasing our understanding and preservation of these unique resources.

REFERENCES

Bailey, C., Wilson, K.W., and Anderson, M.E., 2005, Conservation Agreement and Strategy for Least Chub (*Iotichthys phlegethontis*) in the State of Utah Utah Division of Wildlife Resources Publication, 05-24, p. 47.

Bailey, C., Wilson, K.W., and Anderson, M.E., 2006, Conservation Agreement and Strategy for Columbia Spotted Frog (*Rana lutieventris*) in the State of Utah: Utah Division of Wildlife Resources Publication 06-01, p. 50.

Barbour, M.G., J. H. Burk, W. D. Pitts, F. S. Gilliam, M. W. Schwartz., 1999, Terrestrial Plant Ecology (Third Edition ed.): Menlo Park, California, USA., Benjamin Cummings, 649 p.

Brinson, M., 1993, A hydrogeomorphic classification for wetlands:: U.S. Army Engineer Waterways Experiment Station U.S. Army Corps of Engineers, Washington, DC., Wetlands Research Program Tech. Report, WRP-DE-4.

California Academy of Sciences, 2013, The Desert Biome: Cold, Online, http://www.ucmp.berkeley.edu/exhibits/biomes/deserts.php, accessed January 2013.

Clarke, K.R., 1993, Non-parametric multivariate analyses of changes in community structure: Australian Journal of Ecology, v. 18, no. 1, p. 117-143.

Collins, J., Stein, E., Sutula, M., Clark, R., Fetscher, A., Grenier, L., Grosso, C., and Wiskind, A., 2007, California Rapid Assessment Method (CRAM) for Wetlands, v. 5.0.1., 151 pp.

Comer, P., Faber-Langendoen, D., Evans, R., Gawler, S., Josse, C., Kittel, G., Menard, S., Pyne, M., Reid, M., Schulz, K., Snow, K., and Teague, J., 2003, Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems.

Costanza, R., 1997, The value of the world's ecosystem services and natural capital: Nature, v. 387, no. 6630, p. 253.

Dahl, T.E., 1990, Wetlands losses in the United States 1780's to 1980's. : U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/wetlands/wetloss/index.htm (Version 16JUL97).

Dahl, T.E., and Johnson, C.E., 1991, Wetland Status and Trends in the Conterminous United States Mid-1970's to Mid-1980's, *in* U. S Dept. of Interior, F.a.W.S., Washington, D. C.

Emerson, R.E., and Hooker, T., 2011, Utah Wetland Functional Classification and Landscape Profile Generation Within Bear River Bay, Great Salt Lake, Utah: Utah Geological Survey Contract Deliverable for U.S. EPA, 9 p.

Fennessy, M.S., Jacobs, A.D., and Kentula, M.E., 2007, An evaluation of rapid methods for assessing the ecological condition of wetlands: Wetlands, v. 27, p. 543-560.

Freeman, E., and Frescino, T., 2012, Modeling and Map production using Random Forest and Stochastic Gradient Boosting: Package 'ModelMap', Online, http://cran.r-project.org/web/packages/ModelMap/index.html, accessed December, 2012.

Gardner, P.M., Masbruch, M.D., Plume, R.W., and Buto, S.G., 2011, Regional potentiometric surface map of the Great Basin carbonate and alluvial aquifer system in Snake Valley and surrounding areas, Juab, Millard, and Beaver Counties, Utah and White Pine and Lincoln Counties, Nevada: U.S. Geological Survey Scientific Investigations Map 3193.

Golden, M., Oborny, E., Albrecht, B., Norman, N., Webster, J., Ripple, S., Robertson, M., and Herstein, S., 2007, Ecological Evaluation of Selected Aquatic Ecosystems in the Biological Resources Study Area for the Southern Nevada Water Authority's Proposed Clark, Lincoln, and White Pine Counties Groundwater Development Project Volume 1: Logan, Utah, unpublished consultant's report for Southern Nevada Water Authority, 255 p.

Grimm, N.B., Chacon, A., Dahm, C.N., Hostetler, S.W., Lind, O.T., Starkweather, P.L., and Wurtsbaugh, W.W., 1997, Sensitivity of aquatic ecosystems to climatic and anthropogenic changes: The Basin and Range, American Southwest and Mexico: Hydrological Processes, v. 11, no. 8, p. 1023-1041.

Gross, J.E., 2003, Developing Conceptual Models for Monitoring Programs: Fort Collins, Colorado, National Park Service.

Halford, K.J., and Plume, R.W., 2011, Potential effects of groundwater pumping on water levels, phreatophytes, and spring discharges in Spring and Snake Valleys, White Pine County, Nevada, and adjacent areas in Nevada and Utah, *in* Report, U.S.G.S.S.I., no. 2011-5032, p. 52.

Herschler, R., 1994, A systematic review of the North American freshwater snail genus, Pyrgulopsis (Hydrobiidae): Smithsonian Contributions to Zoology, v. 554, p. 1-115.

Hooker, T.D., and Gardberg, J., 2010, Utah's Wetland Program Plan, 2011- 2016: Prpared for the EPA by the Utah Geological Survey and Utah Division of Water Quality.

Hooker, T.D., Jordan, J.L., and Emerson, R.E., 2011, Intensive Monitoring of Spring Discharge and Wetland Hydrology to Understand Aquifer Dynamics and the Consequences for Excessive Groundwater Withdrawal [abs. and poster], *in* Geological Society of America, Rocky Mountain/Cordilleran Section Meeting Abstracts, Logan, Utah.

Hoven, H.M., and Paul, D.S., 2010, Utah Wetlands Ambient Assessment Method Version 1.1, Kamas Utah, The Institute for Watershed Sciences.

Hurlow, H.A., ed., in preparation, Hydrogeologic studies and groundwater monitoring in Snake Valley and adjacent hydrographic areas, west-central Utah and east-central Nevada, in preparation: Utah Geological Survey, 500 p.

Jensen, J.R., 2005, Introductory Digital Image Processing: A Remote Sensing Perspective: Upper Saddle River New Jersey, Pearson Prentice Hall, p. 460.

Kirby, S., 2011, What Do Environmental Tracers Tell Us About Groundwater In Snake Valley: Utah Geological Survey Survey Notes, v. 46, no. 3, p. 6-8.

Kirby, S., and Hurlow, H., 2005, Hydrogeologic setting of the Snake Valley hydrologic basin, Millard County, Utah, and White Pine and Lincoln Counties, Nevada – implications of possible effects of proposed water wells, *in* Utah Geological Survey Report of Investigation 254, p. 39.

Lewis, W.M., National Research Council, Committee on Characterization of Wetlands,, 1995, Wetlands: Characteristics and Boundaries: Washington, DC, National Academy Press.

McCune, B., and Mefford, M.J., 2011, PC-ORD. Multivariate Analysis of Ecological Data: Version 6. MjM Software, Gleneden Beach, Oregon, U.S.A.

Mills, M.D., DuRoss, E.M., and Wilson, K.W., 2004, Columbia Spotted Frog (Rana luteiventris) Monitoring Summary: Utah Division of Wildlife Resources Publication 05-23, 28 p.

Mitsch, W.J., and Gosselink, J.G., 2000, Wetlands (3rd ed.), John Wiley & Sons.

National Park Service, 2008, Annual Recreation Visits Report for: 2007 to 2012: Online, https://irma.nps.gov/Stats/SSRSReports/System%20Wide%20Reports/5%20Year%20Annual%20Report%20By%20Park, accessed, September 5, 2011.

Natural Resources Conservation Service, 2013, The PLANTS Database. : US Department of Agriculture, National Plant Data Team, http://plants.usda.gov.

Omernik, J.M., Griffith, G.E., and McGinley, M., 2009, Ecoregions of Utah, Environmental Protection Agency Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment, Online, http://www.eoearth.org/article/Ecoregions_of_Utah_(EPA), accessed March, 2013.

Parsons, T., 1995, The Basin and Range Province, in Continental Rifts: Evolution, Structure and Tectonics, Olsen, K., editor, Amsterdam, Elsevier, ISBN 044489-566-3, p. 277-324.

Patten, D.T., Rouse, L., and Stromberg, J.C., 2007, Isolated spring wetlands in the Great Basin and Mojave Deserts, USA – Potential response of vegetation to groundwater withdrawal: Environmental Management, DOI 10.1007/s00267-007-9035-9.

Peterson, E.B., 2008, International Vegetation Classification Alliances and Associations Occurring in Nevada with Proposed Additions. Nevada Natural Heritage Program, Carson City, Nevada.

Plume, R.W., 1996, Hydrogeologic framework of aquifer systems in the Great Basin region of Nevada, Utah and adjacent states: U.S. Geological Survey Professional Paper 1409-B, 64 p.

PRISM Climate Group, 2007, Prism Climatology Normals, Prism Group, Oregon State University, Online http://www.prism.oregonstate.edu/products/ Accessed January, 2011.

R Development Core Team, 2012, R: A Language and Environment for Statistical Computing: R Foundation for Statistical Computing. R Foundation for Statistical Computing, http://www.R-project.org.

Ripley, B., 2012, Classification and regression trees: Package 'tree', Online, http://cran.r-project.org/web/packages/tree/index.html, accessed January, 2011.

Rocchio, J., 2006a, Intermountain Basin Playa ecological system: Ecological Integrity Assessment: Colorado State University, Fort Collins, CO.

Rocchio, J., 2006b, North American Arid West Freshwater Marsh Ecological System: Ecological Integrity Assessment Colorado State University, Fort Collins, CO.

Rocchio, J., 2006c, Rocky Mountain Alpine-Montane Wet Meadow ecological system: Ecological Integrity Assessment: Colorado State University, Fort Collins, CO.

Sada, D.W., and Pohlmann, K.F., 2002, Spring Inventory and Monitoring Protocols Conference Proceedings. Spring-fed Wetlands: Important Scientific and Cultural Resources of the Intermountain Region, 2002, http://www.wetlands.dri.edu.

Schaefer, D.H., and Harrill, J.R., 1995, Simulated effects of proposed ground-water pumping in 17 basins of east-central and southern Nevada: U.S. Geological Survey Water-Resources Investigations Report 95-4173, 71 p.

Smith, R.D., Ammann, A., Bartoldus, C., and Brinson, M., 1995, An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices: : U.S. Army Engineer Waterways Experiment Station U.S. Army Corps of Engineers, Washington, DC., Wetlands Research Program Technical Report

Southern Nevada Water Authority, 2009, Conceptual model of groundwater flow for the central carbonate-rock province – Clark, Lincoln, and White Pine Counties groundwater development project, in U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project Final Environmental Impact Statement: FES 12-33, Document BLM/NV/NV/ES/11-17+1793, includes Supplements CD.

Southern Nevada Water Authority, 2011, Clark, Lincoln, and White Pine Counties Groundwater Development Project - Conceptual Plan of Development: Online, snwa.com/assets/pdf/gdp_concept_plan_2011.pdf, accessed 24 May, 2011.

Sprecher, S.W., 2008, Installing monitoring wells in soils (Version 1.0): National Soil Survey Center, Natural Resources Conservation Service, USDA. Lincoln, NE.

Stein, E., Fetscher, A.E., Clark, R., Wiskind, A., Grenier, J.L., Sutula, M., Collins, J., and Grosso, C., 2009, Validation of a wetland Rapid Assessment Method: Use of EPA's level 1-2-3 framework for method testing and refinement: Wetlands, v. 29, no. 2, p. 648-665.

Sumner, R., Shubauer-Berigan, J., Mulcahy, T., Minter, J., Dyson, B., Godfrey, C., and Blue, J., 2010, Alternative futures analysis of Farmington Bay wetlands in the Great Salt Lake ecosystem: U. S. Environmental Protection Agency, Cincinnati, OH, EPA/600/R-10/032, 106 p.

Sutter, J.V., Andersen, M.E., Bunnell, K.D., Canning, M.F., Clark, A.G., Dolson, D.E., and Howe, F.P., 2005, Utah Comprehensive Wildlife Conservation Strategy: Utah Division of Wildlife Resources Publication 05-19: Utah Division of Wildlife Resources, p. 281.

Sutula, M.A., Stein, E.D., Collins, J.N., Fetscher, A.E., and Clark, R., 2006, A practical guide for the development of a wetland assessment method: The California experience: Journal Of The American Water Resources Association, v. 42, no. 1, p. 157-175.

Three Parameters Plus, 2010, Baseline Physical Habitat Conditions of Wetlands in Snake Valley, Utah, Final Report: Volume 1: unpublished consultant's report for Utah Department of Natural Resources, Endangered Species Mitigation Fund, 55 p.

U.S. Bureau of Land Management, 2012, Clark, Lincoln, and White Pine Counties groundwater development project final environmental impact statement FES 12-33: Document BLM/NV/NV/ES/13-2+1793.

U.S. Census Bureau, 2010, Data Access Tools: Online, http://www.census.gov/easystats/, Accessed December 5, 2012.

U.S. Department of Agriculture, 2009, 2009 National Agriculture Imagery Program (NAIP) Aerial Photography Mosaic: Salt Lake City, Utah, USDA-FSA Aerial Photography Field Office.

U.S. Environmental Protection Agency, 2006, Application of Elements of a State Water Monitoring and Assessment Program for Wetlands: Online, http://water.epa.gov/type/wetlands/assessment/index.cfm, accessed October 2013.

U.S. Environmental Protection Agency, 2011, National Wetland Condition Assessment: Field Operations Manual: EPA-843-R-10-001. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency, 2012, Core Elements of an Effective State and Tribal Wetlands Program: Online, http://water.epa.gov/grants_funding/wetlands/cef_full.cfm, accessed October 2013.

U.S. Fish and Wildlife Service, 2013, Fish Springs National Wildlife Refuge, Online, http://www.fws.gov/fishsprings/Description.html, accessed March, 2013.

Utah Automated Geographic Reference Center, 2010, 2010 Demographic Data: Online, http://gis.utah.gov/data/demographic/2010-census-data/, accessed February 19, 2012.

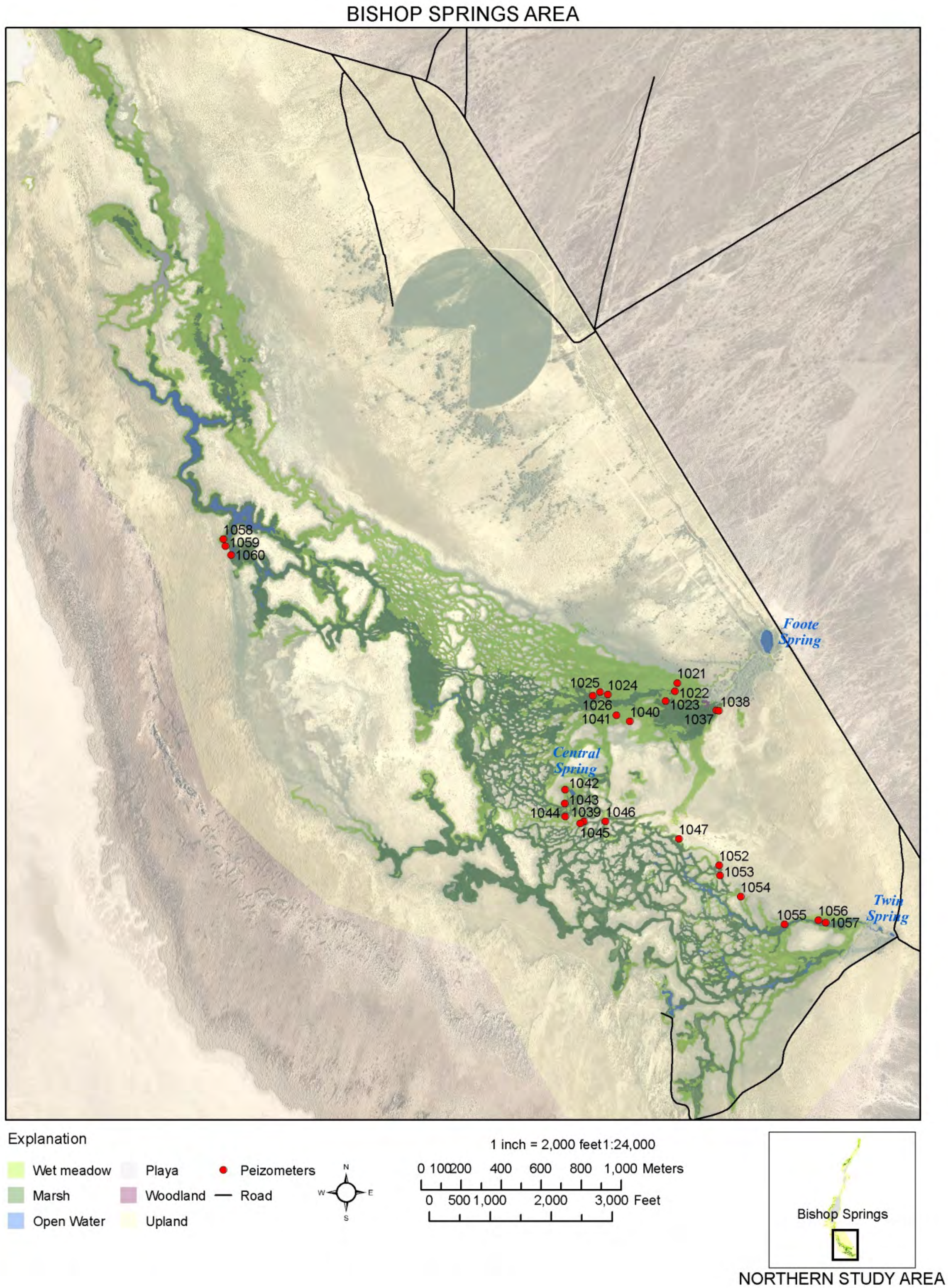
Utah Division of Water Rights, 2010, Snake Valley Agreement, Online, http://waterrights.utah.gov/snakeValleyAgreement/default.asp, accessed March 23, 2010.

Welch, A.H., Bright, D.J., and Knochenmus, L.A., eds., 2007, Water Resources of the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah, U.S. Geological Survey Scientific Investigations Report 2007–5261,, 96 p.

Wheeler, K.K., Fridell, R.A., and Doyle, M.C., 2005, Columbia Spotted Frog (Rana luteiventris) Population Monitoring Summary: Bishop Springs, Tule Valley: Utah Division of Wildlife Resources Publication 05-41, 31 p.

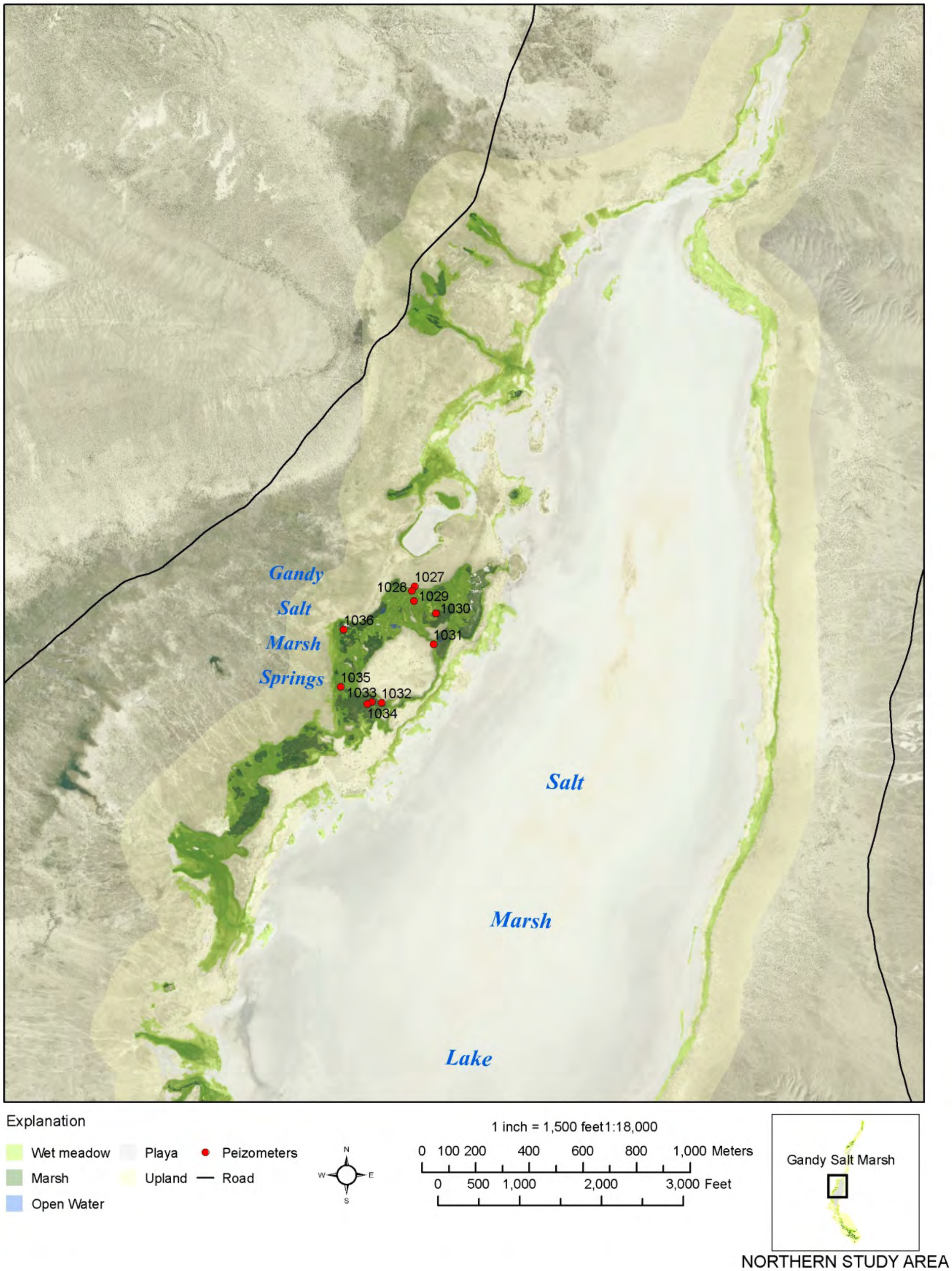
APPENDICES

APPENDIX A: SPRING AND PIEZOMETER NETWORK MAPS

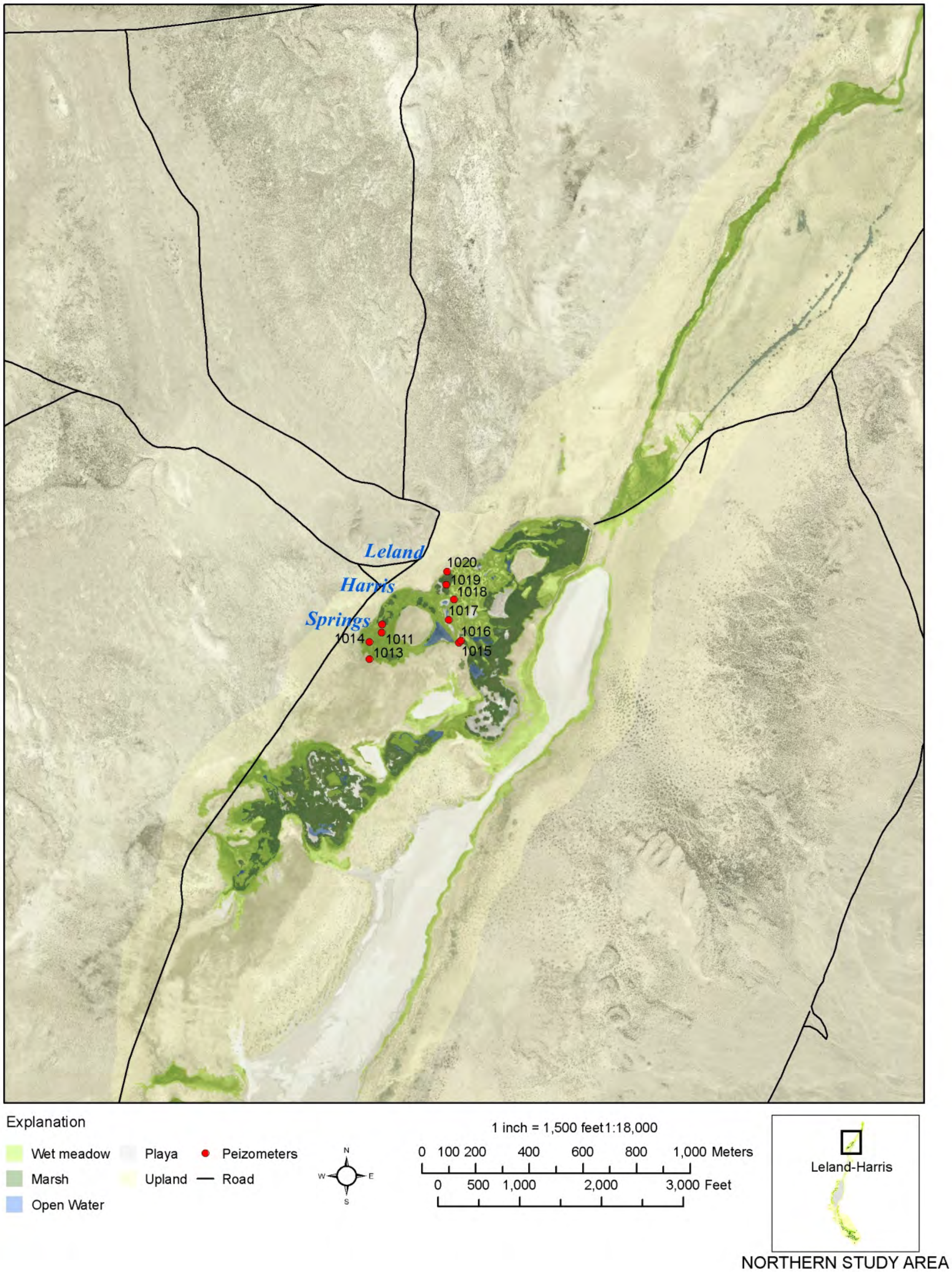


BISHOP SPRINGS AREA
1058
1059
1060
Foote Spring
1021
1025
1024
1022
1026
1023
1038
1040
1041
1037
Central Spring
1042
1043
1044
1039
1046
1045
1047
1052
1053
1054
1055
1056
1057
Twin Spring
Explanation
Wet meadow
Marsh
Open Water
Playa
Woodland
Upland
Peizometers
Road
N
W
E
S
1 inch = 2,000 feet 1:24,000
0 100 200 400 600 800 1,000 Meters
0 500 1,000 2,000 3,000 Feet
Bishop Springs
NORTHERN STUDY AREA

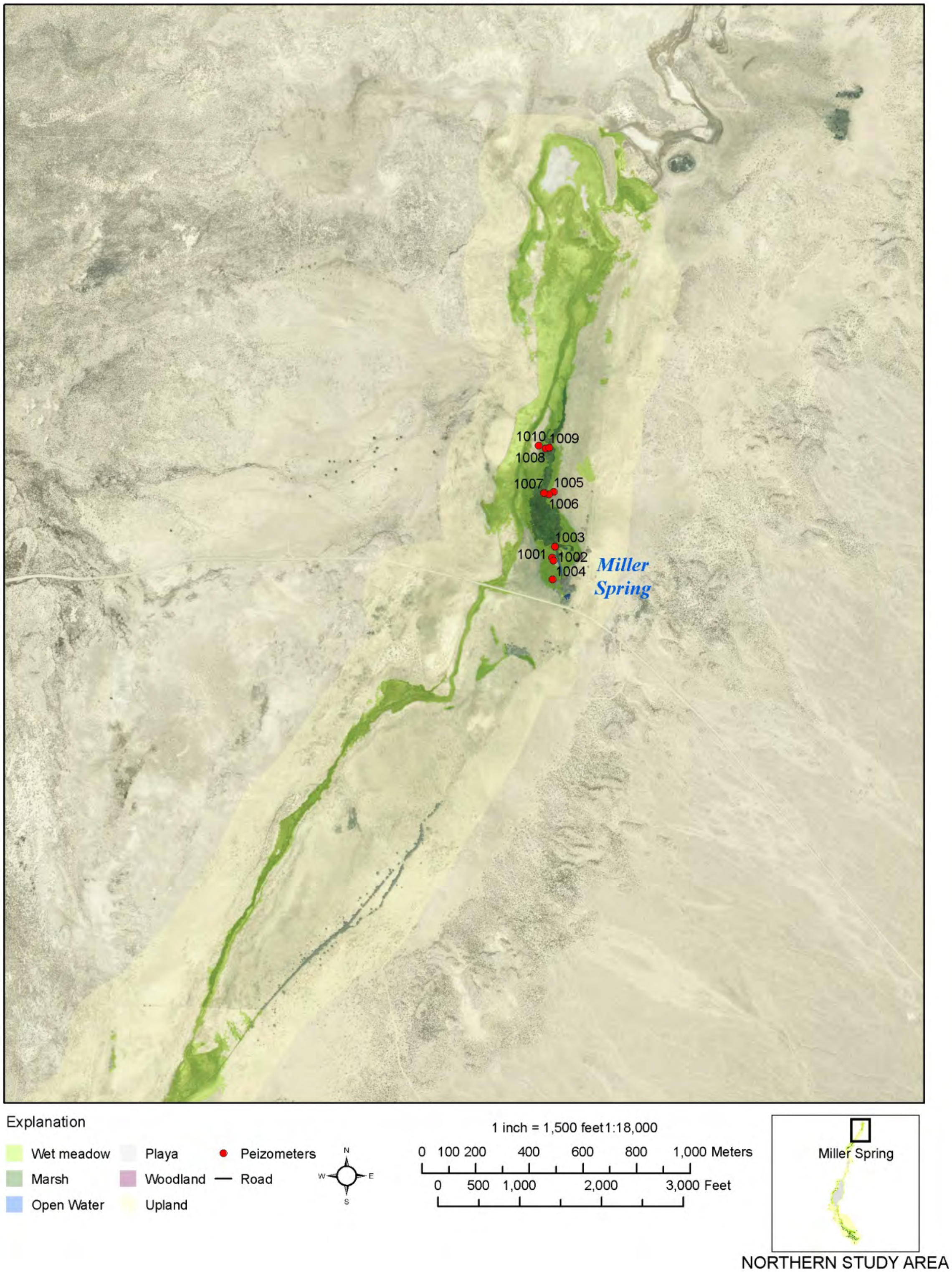
GANDY SALT MARSH AREA



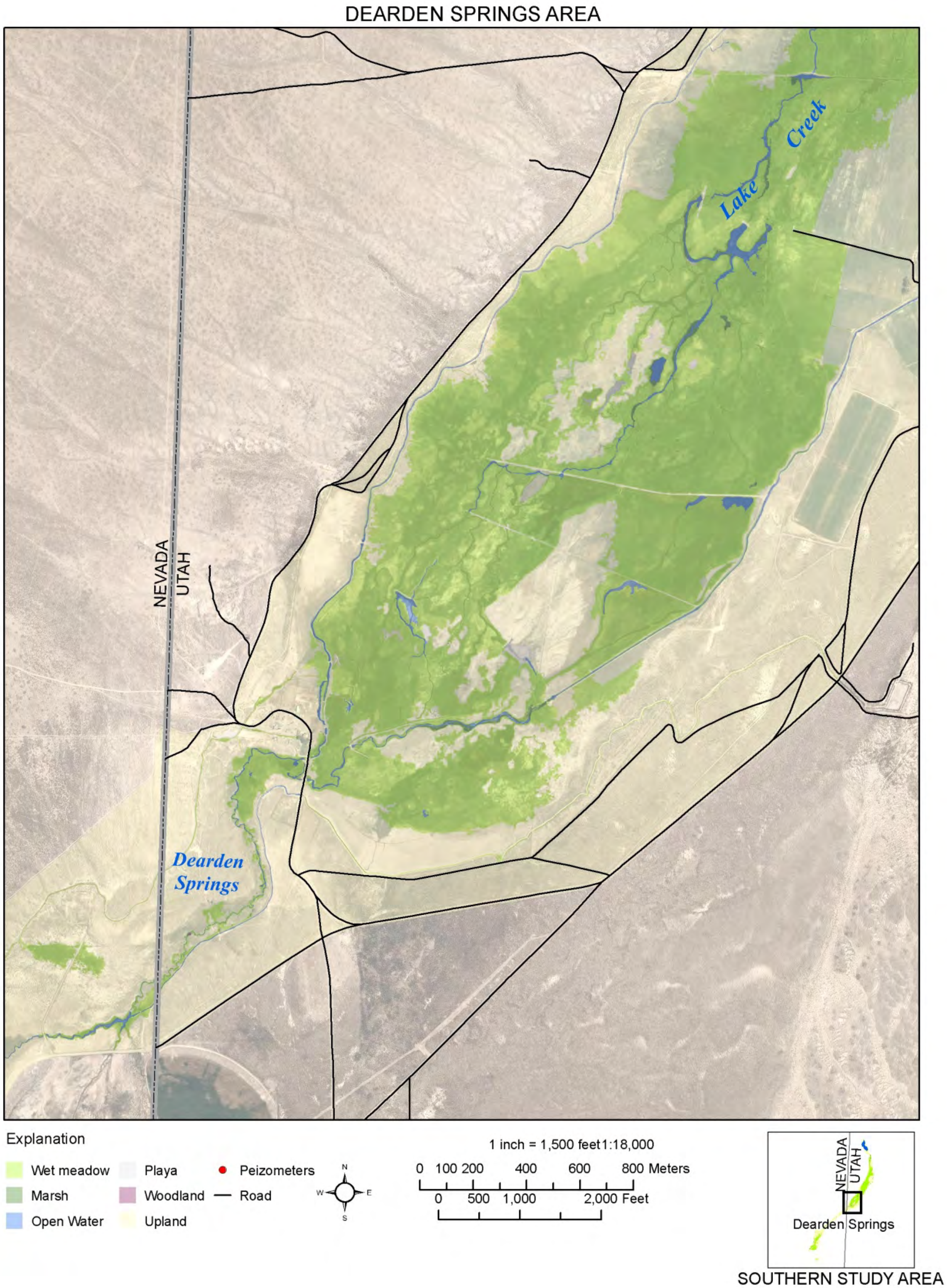
LELAND-HARRIS SPRING COMPLEX AREA

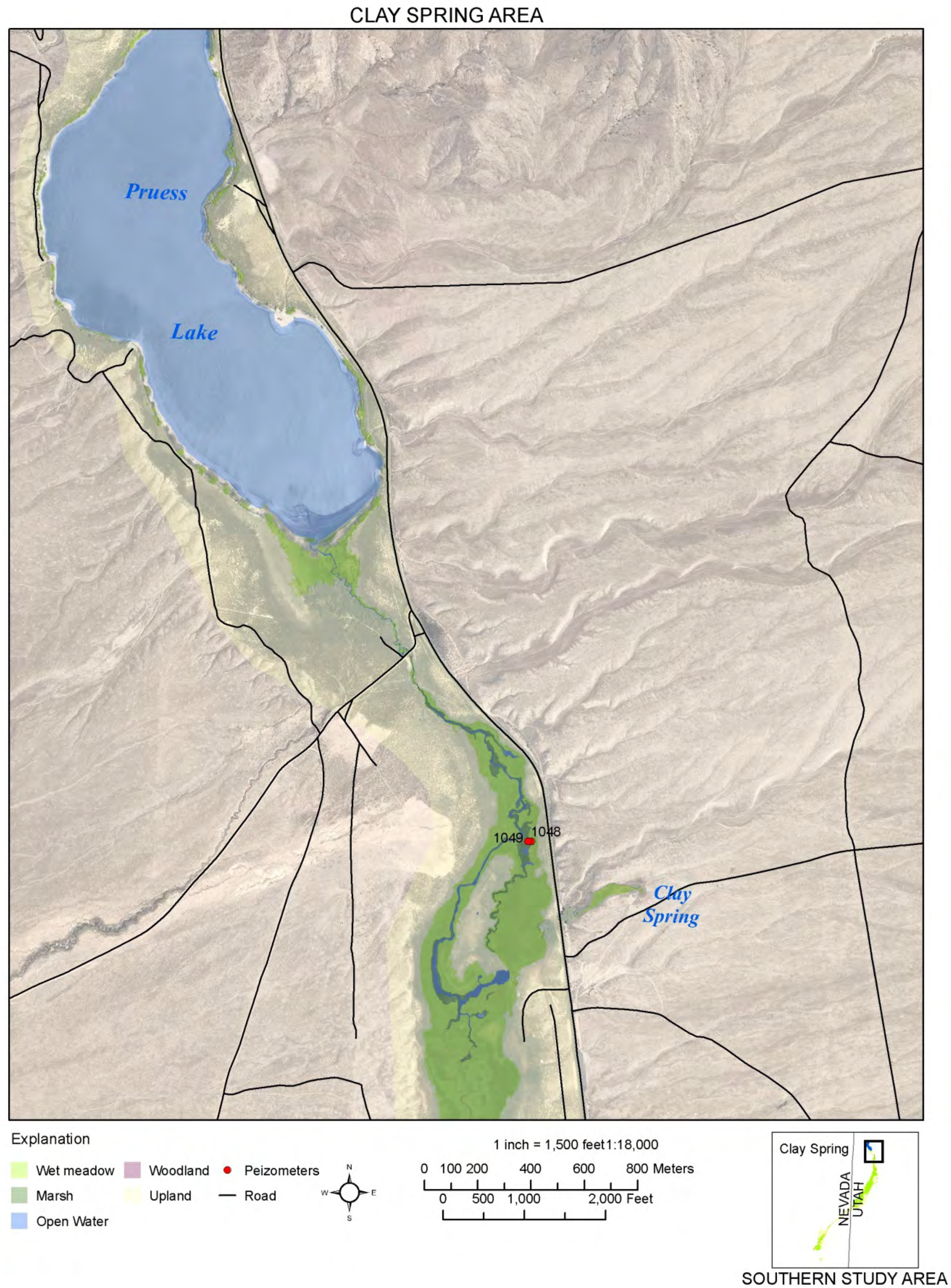


MILLER SPRING AREA



BIG SPRINGS AREA


DEARDEN SPRINGS AREA
Lake Creek
NEVADA
UTAH
Dearden Springs
Explanation
Wet meadow
Marsh
Open Water
Playa
Woodland
Upland
Peizometers
Road
N
W
E
S
1 inch = 1,500 feet 1:18,000
0 100 200 400 600 800 Meters
0 500 1,000 2,000 Feet
NEVADA
UTAH
Dearden Springs
SOUTHERN STUDY AREA


CLAY SPRING AREA
Pruess
Lake
1049
1048
Clay
Spring
Explanation
Wet meadow
Marsh
Open Water
Woodland
Upland
Peizometers
Road
N
W
E
S
1 inch = 1,500 feet1:18,000
0 100 200 400 600 800 Meters
0 500 1,000 2,000 Feet
Clay Spring
NEVADA
UTAH
SOUTHERN STUDY AREA

APPENDIX B: LANDSCAPE PROFILE DATA SOURCES

Table B1. *Data sources used in landscape profile and watershed assessment*

Category	Dataset	Description	Source	Scale
Land Use and Development				
	Water related land use*	Agricultural and urban water use, polygon	Utah Division of Water Resources, 2005, 2012	1:24,000
	Populated location	Urban centers or rural ranches, point/polygon	U.S. Census Bureau, 2010	1:12,000
	Roads	Roads, line	Utah AGRC, 2012	1:12,000
	Land ownership	Land ownership rights, polygon	Bureau of Land Management, 2012	1:12,000
Resource Extraction				
	Oil wells	Water production wells, points	Compiled from Utah Division of Oil, Gas, and Mining and Nevada Bureau of Mines and Geology, 2012	1:24,000
	Mines and quarries	Active and abandoned mines and gravel quarries, point	Compiled from Utah Division of Oil, Gas, and Mining, Utah Department of Transportation, and Nevada Bureau of Mines and Geology, 2012	1:24,000
Hydrological modifications				
	Reservoir	Surface water storage, polygon	National Hydrography Dataset, USGS, 2012	1:24,000
	Canals/ditches/pipelines	Surface drainage network, line	National Hydrography Dataset, USGS, 2012	1:24,000
	Water right	Wells and points of diversion from water rights applications, point	Utah Division of Water Rights, Points of Diversion, Southern Nevada Water Authority**, 2012, 2009	1:100,000
	Future groundwater drawdown	"Alternative A" groundwater model proposed by Southern Nevada Water Authority; steady state achieved by year 2250	Southern Nevada Water Authority, 2009	1:2,000,000
Biota				
	Noxious weeds	Invasive plant species, point	Compiled by Utah AGRC, 2012	1:12,000
	Endangered species	Plant and animal threatened or endangered species listed by 7.5' quadrangle, polygon	Utah Division of Wildlife Resources, 2012	1:24,000
*Nevada data digitized using 2012 ESRI imagery data				
**SNWA proposed high volume production wells only, local use water rights not available unavailable for the state of Nevada				

APPENDIX C: CLUSTER ANALYSIS RESULTS

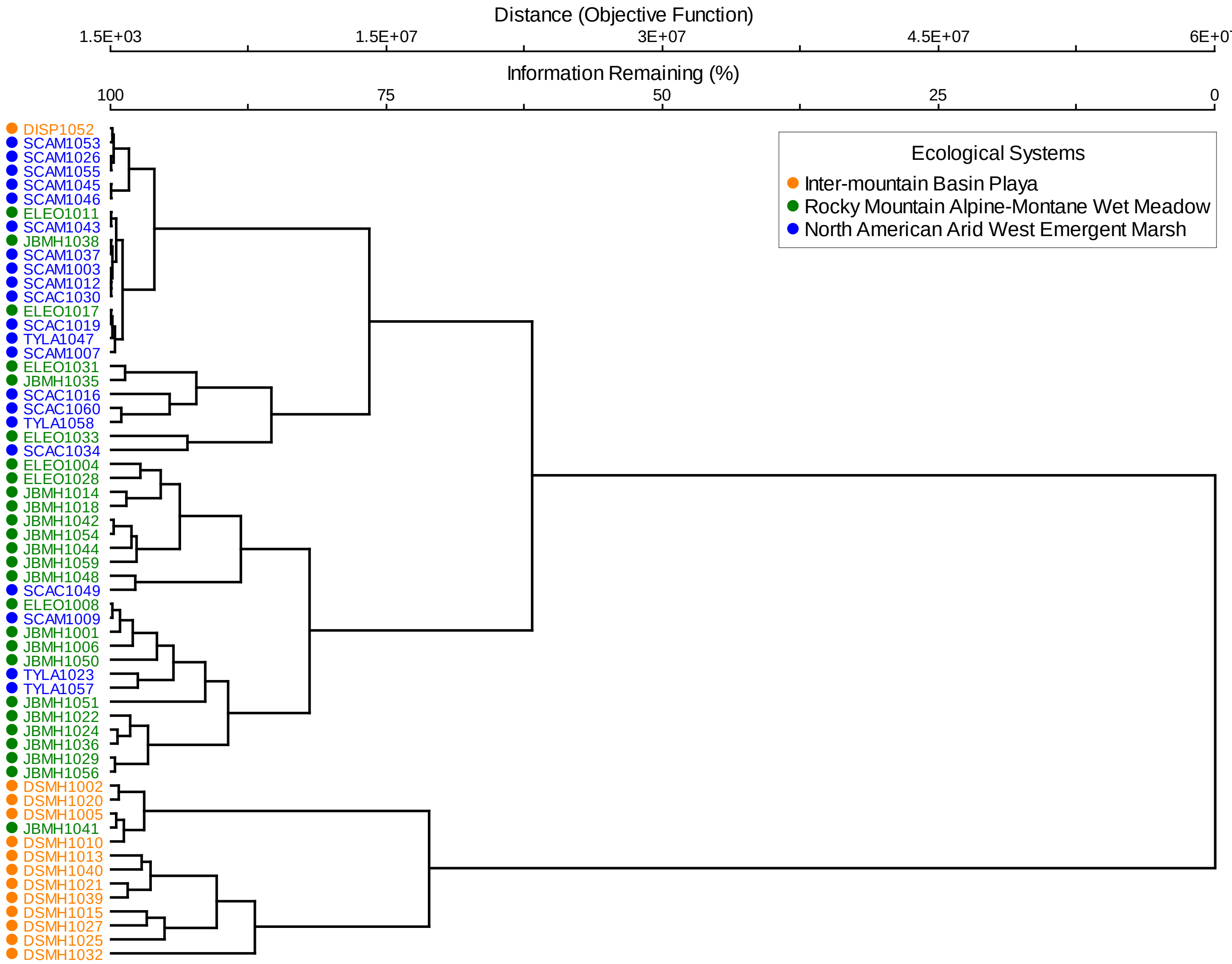


Figure C1. *Cluster analysis of depth to water table for three hydrologic years from October 2009 to September 2012. Sites grouped by Ecological System using hierarchical agglomerative clustering in PC-ORD software (McCune and Mefford, 2011).*

APPENDIX D: ORDINATION RESULTS

Table D1. *Correlation of measured variables with axes from ordination of vegetation collected at groundwater monitoring sites.*

		Axis 1	Axis 2	Axis 3
Percent Variance Represented by Axis (R^2)		**31%**	**23%**	**18%**
Vegetation and Ground Cover	Herbaceous Cover	-0.178	**-0.492**	0.187
	Open Water	0.231	0.254	-0.323
	Bare Ground	**-0.427**	0.153	-0.322
Water Chemistry	Salinity (ppm)	-0.113	-0.077	0.051
	Electrical Conductivity	-0.09	-0.057	0.021
	Temperature (°C)	**-0.408**	0.119	-0.088
	pH	**0.69**	-0.099	0.385
Soils	Depth to H2S Hydric Soil Indicator	-0.384	-0.385	-0.205
	Organic Soil Thickness	**0.478**	-0.185	0.248
Hydrologic Metrics (across three water years)	Depth of Surface Water	**-0.689**	0.018	-0.33
	Mean Depth to Water	**0.755**	0.066	0.311
	Standard Deviation	-0.152	**-0.422**	-0.224
	Minimum Depth to Water	**0.45**	0.36	0.318
	Maximum Depth to Water	**0.664**	-0.024	0.195
	Magnitude of change (range)	-0.033	**-0.402**	-0.209