December 2015

Ecological Characteristics of Potential Reference Standard Sites for Great Salt Lake Impounded Wetlands: 2014 & 2015 Survey

Purpose: FY2011-WPDG :: Characterize Reference Standard Sites for GSL Impounded Wetlands

Contract: CD96812201

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1.0 Introduction

1.1 Project Background

Impounded wetlands (IWs) associated with Great Salt Lake (GSL) occur predominantly along the eastern periphery of the lake as a series of shallow, irregularly shaped ponds. These impoundments are concentrated near major surface water inflows to GSL, such as the deltas of the Bear, Weber, and Jordan rivers, where dikes, berms, ditches and culverts have been constructed to control the inflow and outflow of water through the wetlands. As such, all impounded wetlands associated with GSL are man-made. GSL-IWs encompass approximately 100,000 acres around the lake and are actively managed by state and federal agencies and private conservation clubs as prime waterfowl habitat.

Utah Division of Water Quality (DWQ) has been working with public and private-sector partners to characterize the chemical, biological, and ecological features of these working wetlands since 2004, with an eye on developing appropriate and protective standards for these waterbodies. Early work focused on a network of targeted sites to better understand which features of these shallow ponds appeared to be most sensitive to chemical, physical, or biological stressors (Miller and Hoven, 2007; DWQ, 2009). More recently, DWQ sampled an extensive set of 50 sites to evaluate the relative health of impounded wetlands among the three main contributing watersheds to GSL based on previously established indicators (DWQ, 2012; CH2M, 2014). Results describing the relative health of three key IW indicators (submerged aquatic vegetation (SAV) persistence, diverse and abundance benthic macroinvertebrate communities, and lack of extensive algal mats) were reported as part of DWQs statutory requirements (DWQ, 2014).

DWQ's evaluation of relative health was useful in describing the single-year (2012) variation among ponds within and across the three watersheds. For example, we found that the proportion of impounded wetlands in poor ecological condition within both the Lower Bear and Lower Jordan river watersheds was lower than for the Lower Weber watershed. This result identified a focus area where possible changes to pond management techniques, or a more detailed look at surface water inflows to these ponds, could improve water quality and support waterfowl habitat. However, relative comparisons of ecosystem health as defined in the 2014 *Integrated Report* (DWQ, 2014; *Wetlands Chapter*) were based on *Best Attainable Condition* (BAC; Stoddard, 2006), where the best 25% of sites (12-13 sites) represented 'Good' ecological condition, and the worst 25% represented 'Poor' condition.

There are two important limitations to this approach. First, as extensive surveys of GSL wetlands continue, it will be difficult to evaluate changes in ecosystem health over time. For example, if wetland management techniques improve, or there is a period of greater than average water availability to the ponds (a common physical stress to many impounded wetlands), or if the water quality of surface water inflows improves, the next survey would reveal, again, that 25% of the sites are in 'Good' ecological condition and 25% of the sites are in 'Poor' condition. There would be no way to know if there were true improvements (or degradations) in ecological health within and among watersheds unless all the data were completely reanalyzed for each analysis.

A second limitation stems from DWQs goal of developing appropriate and protective water quality standards for these wetlands. Systematic development of clear and reproducible water quality standards that are protective of the designated uses (i.e. protect the ponds as waterfowl habitat, including providing sufficient food and foraging areas) requires that there is some absolute scale against which the indicators of ecosystem health can be compared, and that clear relationships between specific stressors (e.g. pesticides or toxic metals) and appropriate ecological (or biological) responses (e.g. SAV growth or macroinvertebrate survival) can be obtained. For example, the aquatic wildlife designated use is protected against exceedingly high concentrations of toxic metals by application of numeric criteria as laid out in Administrative Rule (UAC R317-2-7). While development of protective numeric criteria, similar to those for toxic metals, cannot yet be reliably obtained for measures of ecological health for the wide variety of wetland types, it may be possible to identify similar ecosystems that have very low amounts of stress (little developed land use, including agriculture, industry, or urban environments), and use these ecosystems as benchmarks that define our expectations for 'Good' ecological condition. This approach is widely used for both streams and lakes (e.g. see EPA National Aquatic Resource Surveys[1]), where low-stress ecosystems represent 'Reference Standard Sites'.

1.2 Reference Standard Sites

Unlike most of Utah's lakes and streams, wetlands associated with Great Salt Lake have been intensively managed, and even created, for a variety of purposes over the last century. In addition, upland areas adjacent to GSL are some of the most densely populated areas in the intermountain west where urban stormwater runoff, treated effluent from industrial and wastewater treatment plants (WWTPs), and a legacy of historical mining activity contributes to a high degree of cumulative stress on local water bodies. As such, we have little information on what characteristics represent the highest degree of ecological integrity for the dominant wetland types associated with Great Salt Lake. Another option is to investigate wetlands farther afield, away from specific activities or discharges that may have degraded wetlands within the GSL assessment area, but where ecosystems with comparable structure and function (i.e. shallow ponds), and management goals (waterfowl production) occur.

Through preliminary field work as well as continuing collaboration with scientists from Utah Geological Survey (UGS), DWQ identified areas in Utah's West Desert where wetlands have likely received a lower level of historic and contemporary disturbances: wetlands associated with Fish Springs National Wildlife Refuge (NWR), Clear Lake Waterfowl Management Area (WMA), and wetlands within Snake Valley. Both of these areas are within the historic extent of Lake Bonneville, have broadly similar plant communities, and contain a similar range of water salinity as wetlands more closely associated with Great Salt Lake. One main difference is that water in the West Desert wetlands are derived mostly from groundwater discharge, while surface water inflows (both natural and man-made) are the predominant water sources for most (but not all) GSL wetlands. It is likely that the reliance on groundwater vs. surface water for potential reference standard wetlands will be an important element in limiting historical nutrient and toxic metal loads compared to GSL wetlands. In addition, the extent and dominance of the invasive wetland weed, *Phragmites australis*, is much lower in the West Desert than within the GSL basin. Thus, there are two excellent reasons to expect a greater degree of ecological integrity compared to GSL.

This report describes the results of two years of surveys (2014 and 2015) examining the ecological health of IWs located at Fish Springs National Wildlife Refuge (FS) and the Clear Lake WMA (CL), located in Utah's West Desert (Figures 1 to 3). The main objective was to characterize variation in biological responses and physical and chemical stressors for a set of potential impounded wetland reference standard sites through collection of field data from remote areas. Following the sampling approach developed for other Great Salt Lake impounded wetlands, West Desert IWs were sampled during two index periods in each year (DWQ, 2012). Additional work on fringe wetlands (shallow marsh) in the West Desert will accompany an upcoming report on that ecosystem type in early 2016.

[1] www.epa.gov/national-aquatic-resource-surveys

1.3 Water Quality Regulatory Protections for GSL Wetlands

Water quality regulations for Utah's waters have been developed iteratively over the past four decades, resulting in five distinct use classes with different regulatory protections. Many wetlands, such as marshes and springs are not explicitly identified but are included in Utah's definition of "waters of the state[2]" and are protected by narrative standards that protect aquatic wildlife through designated uses (Utah Administrative Code [UAC] R317-2-6[3]; Environmental Law Institute, 2008). Wetlands associated with GSL have distinct use classes based on land ownership and geographic location (i.e., relative to the historically defined high lake level elevation, 4,208 feet above sea level). For example, wetlands associated with the Bear River Migratory Bird Refuge (operated by the US Fish & Wildlife Service (USFWS)) as well as state waterfowl management areas (WMAs; operated by Utah Division of Wildlife Resources) are provided specific beneficial use classes (see UAC R317-2-6 [4]) that include numeric criteria to protect aquatic life uses (Classes 3B and 3D) in addition to the narrative standard (UAC R317-2-7.2 [5]).

Utah's water quality standards also define transitional wetlands (Class 5E), as those from the historically defined high lake level elevation (4,208 feet above sea level; an historical representation of the ordinary high watermark for GSL) to the current edge of the open waters of GSL. As such, similarly situated wetlands around GSL with similar ecological characteristics can be protected by different designated use classes. Clearly, if criteria are intended to protect the biological and recreational uses of these waters, they should be based on their ecological characteristics, as opposed to management boundaries.

Current efforts by DWQ's Wetlands Program include identification and evaluation of appropriate biological and ecological characteristics that can be used to refine (or establish) numeric and narrative criteria, and develop assessment methods for narrative standards that are appropriately protective to people and wetland biota. Once established, DWQ can assess the chemical and physical conditions that are most strongly associated with healthy versus degraded wetlands, which ultimately can be used to define water quality goals that are specific to these ecosystems.

As described above, this project supports DWQ's efforts to protect wetland health by collecting environmental data on the natural variation (including temporal variability) of wetlands that occur in remote areas of Utah, where environmental stresses are expected to be low. These data will support the development of reference standard sites for GSL impounded wetlands and will help DWQ establish benchmarks that distinguish 'GOOD' versus 'FAIR' ecological condition for this ecosystem type.

1.4 Historical Summary

The Utah Division of Water Quality (DWQ) initiated its Wetlands Program in 2004 with a focus on evaluating whether wetlands associated with Great Salt Lake (GSL) were fully supporting their broadly defined beneficial use: habitat support for waterfowl and shorebirds and the necessary aquatic life in their food chain. Early efforts focused on shallow ponded areas, or impounded wetlands (IWs), where dikes, berms, and ditches have been constructed to control water flow. DWQ's interest began in response to stakeholder concern that nutrient loads from water treatment facilities and other surface water inflows adjacent to GSL may have deleterious impacts on these productive and highly valued ecosystems. Initial work focused on wetlands adjacent to Farmington Bay,

[2] waterquality.utah.gov/lawsrules.htm
[3] http://www.rules.utah.gov/publicat/code/r317/r317-002.htm
[4] http://www.rules.utah.gov/publicat/code/r317/r317-002.htm#T8
[5] http://www.rules.utah.gov/publicat/code/r317/r317-002.htm

where wetland managers and conservation groups observed the occasional dominance of cyanobacterial mats (Miller and Hoven, 2007), a common indicator of phosphorus-induced eutrophication (Reddy and DeLaune, 2008).

An early concern was that these mats could negatively impact the health and vigor of extensive swards (i.e., an expanse of short grass or meadow) of submerged aquatic vegetation (SAV) (e.g., sago pondweed, *Stuckenia* sp.) or could alter the species composition and abundance of aquatic macroinvertebrate communities. Both SAV and benthic macroinvertebrates are key food resources for migrant waterfowl species (Miller and Hoven, 2007) and important ecological components of shallow ponds (Keddy, 2010).

Current efforts to protect and conserve Utah's wetlands revolve around the development of water quality standards for wetlands and management of habitat for wetland-associated wildlife. The success of these efforts relies on a rigorous and responsive wetland monitoring and assessment program. Up to now, there were few monitoring and assessment data describing and/or quantifying the condition of Utah's wetlands (Sumner et al., 2010). DWQ is continuing collaborative work with Utah Geological Survey (UGS) (a division of Utah Department of Natural Resources) to address the lack of information on wetland extent and condition. The key goals in developing a wetland monitoring and assessment program, as exemplified in Utah's Wetland Program Plan 2011-2016 (Hooker and Jones, 2013) are to 1) inform decision making for the derivation and implementation of statewide wetland water quality standards, 2) develop evidenced-based priorities for wetland conservation, 3) track progress of wetland management and conservation activities, and 4) assess the ecological condition of wetlands over time.

These wetlands provide essential ecosystem services, including moderation of surface water and ground water flows, and removal of nutrients and other pollutants. In addition, plant productivity in desert wetlands commonly exceeds that of adjacent uplands, which provides valuable forage for wildlife and cattle grazing (Schlesinger, 1997; Reddy and DeLaune, 2008). There continues to be an essential need to maintain the health and extent of these ecologically critical wetlands, especially in the face of severe and persistent threats from population growth (most Utah citizens reside within the GSL watershed), industrial and urban development, excessive surface water and ground water withdrawal, invasive species, and relatively high rates of nutrient loading (Millennium Ecosystem Assessment, 2005; Dahl, 2006).

1.5 Wetland Health and Assessment Methods

To assess IWs associated with GSL, DWQ developed a preliminary assessment tool based on a multimetric index tool (MMI; see Karr and Chu, 1997) that integrates measures of physical, chemical, and biological aspects of wetland condition (DWQ, 2009). Several specific biological responses are expected to reflect the health of these waters, including a focus on SAV, aquatic benthic macroinvertebrates, and floating surface mats as potential biological indicators. A probabilistic survey was developed from previously mapped GSL IWs (Emerson and Hooker, 2011) so that the results could be generalized across IWs in the GSL basin. To evaluate sensitivity to stress, data were obtained for a range of potential physical and chemical stressors within both water column and sediments (Table 1). Analysis of potential stressor-response relationships for these IWs is ongoing. Additional details describing wetland measurements and the probabilistic sampling design can be found in the IW *Sampling and Analysis Plan* (DWQ, 2012).

Biological assessments of aquatic resources, including wetlands, rely primarily on three key components. The first component entails development of integrated measures of biological integrity, most commonly derived from the taxonomic composition of aquatic assemblages, such as algae (phytoplankton, periphyton or diatoms), amphibians, macroinvertebrates, or plants. The second component most commonly involves identification and characterization of a collection of reference standard sites (i.e., unaltered or least disturbed sites) that are used as a benchmark for site comparisons within a given ecosystem type. The third component consists of an appropriate probabilistic survey design that allows for generalization of wetland health at the watershed scale (Stevens and Jensen, 2007). However, given that all IWs associated with GSL are human-made, and most of these systems are actively managed for waterfowl and other waterbirds, there is no *a priori* set of reference standard sites to use for comparison.

Results reported here, from the two-year survey of IWs in Utah's West Desert, will be used as a first approximation of IW reference standard sites.

1.5.1 Development of an Impounded Wetland Assessment

The target population for IWs consists of ponded wetlands that are primarily managed for production of a variety of habitats supporting waterfowl and shorebird populations (USFWS, 2009; DWQ, 2012). Industrial ponds (i.e., evaporation ponds) and ponds managed for non-waterfowl or waterbird wildlife were excluded from the target population. The minimum size of IWs was 5 acres (approximately 2.0 hectares). Field reconnaissance was performed to confirm that sites fit target criteria, including water depths that support healthy SAV growth and waterfowl habitat (25–100 centimeters) (USFWS, 2009; USFWS, 2004), with sufficient water depth for water chemistry sampling throughout the growing season. Measurements were collected over two index periods (IP): IP-1, June through July (35 days; summer); and IP-2, late-August through mid-September (20 days; early autumn).

The condition of IWs was characterized by three main indicators of ecological health:

- Persistent cover of SAV between index periods
- (Lack of) occurrence of surface mats
- Composition of benthic macroinvertebrate communities.

These indicators are linked to both wetland management goals and beneficial use classes (DWQ, 2009). High-quality IWs (i.e., best ecological condition) are assumed to provide excellent habitat for waterfowl and the necessary food chain and support Utah's narrative water quality standard (UAC R317-2-7.2[6]) by supporting extensive beds of SAV, low incidence of surface mats, and diverse macroinvertebrate communities. In contrast, poor ecological conditions may include a combination of sparse cover or early senescence of SAV, extensive surface mats, or simple macroinvertebrate communities.

2.0 Methods

2.1 Study Area

New data collected as part of this project were obtained from wetland sites in Utah's West Desert region (see Figure 1). Springs and associated wetlands are common in valley bottoms throughout the West Desert, where discharge of groundwater supports isolated areas of highly productive wetlands in the midst of sparse, cold-desert uplands (Jones et al., 2013). The source waters for many of these systems are derived from regional aquifers that are recharged in adjacent mountain ranges (Kirby and Hurlow, 2005; Welch et al., 2007). These isolated wetlands serve as critical habitat for two sensitive species (Least Chub (*Iotichthys phlegothontis*) and Columbia Spotted Frog (*Rana luteiventris*)) and several other species of concern, including several endemic mollusks (Bailey and others,

[6] http://www.rules.utah.gov/publicat/code/r317/r317-002.htm#T9

2005; Sutter and others, 2005; Bailey and others, 2006) and a wide range of migratory waterfowl and shorebirds (FWS, 2004).

A brief description of the general project area is provided below. For additional details on the geography, hydrology, and ecology of Utah's West Desert, the reader is directed to two recent reports by the Utah Geological Survey (Jones, et al., 2014; and Hurlow, 2014 [ed.]).

2.1.1 Geography

Utah's West Desert occupies more than one-third of the state, and is situated within the eastern Great Basin where the Basin and Range physiographic province meets the Wasatch Mountains. This region is dominated by a series of prominent north to south trending mountain ranges separating extensive, broad alluvial valleys (Jones, et al., 2014). Hydrologically, the West Desert and the Great Salt Lake basin have no current outlet to the sea, and have been hydrologically isolated (i.e. endorheic) for several thousand years. The project area includes portions of Juab and Millard counties, Utah.

2.1.2 Ecological Context

The predominant climate is cold desert, where precipitation is nearly evenly distributed throughout the year, often falling during the winter as snow (Flowers, 1934; Bolen, 1964). Wetlands in the West Desert commonly occur within broad valleys, surrounded by desert-scrub vegetation, where groundwater discharge from regional aquifers reaches the land surface (Kirby, 2011; Hurlow [ed], 2014; Jones et al., 2014). As such, spring discharge rates, chemical composition, and temperatures of surface waters are relatively constant throughout the year.

The dominant vegetation of valley uplands ranges from xeric sagebrush and saltbrush-greasewood communities to sparsely vegetated zones adjacent to hypersaline mudflats and relict playas. Common wetland vegetation ranges from emergent, hydrophytic plants such as sedges (*Carex* spp.), rushes (*Juncus* spp.), and saltgrass (*Distichlis spicata*) in seasonally-saturated wet-meadows, to bulrush (*Schoenoplectus* spp.) and cattails (*Typha* spp.) in seasonally flooded marshes (Rocchio, 2006; Jones et al., 2014). In addition, areas that are flooded or ponded for longer periods, including areas purposely impounded for open water habitat by land managers, are often dominated by a variety of plant species adapted to either a facultative and obligate submerged aquatic habit. These taxa are collectively described here as submerged aquatic vegetation (SAV), and may include the macroalgae *Chara* sp., facultatively aquatic forbs such as *Ranunculus* spp., *Berula* spp., and *Mimulus* spp., and obligate submerged aquatic monocots such as *Stuckenia* spp. and *Ruppia* spp. These common plant species of West Desert wetlands are also well represented within the flora of Great Salt Lake wetlands (Flowers, 1934; Bolen, 1964). One notable exception to the similarity in flora between GSL and West Desert wetlands is a general lack of extensive stands of the invasive grass *Phragmites australis* within areas of freshwater marsh.

2.2 Site Selection

2.2.1 Targeted Sampling Sites

Sites were identified via GIS-based reconnaissance and discussions with scientists and resource managers knowledgeable about the area (Figure 2 and 3). Environmental data collections were made during the summer and early-autumn of 2014 and 2015, approximately July to late-September. The specific objective was to collect data from sites that, because of their remoteness, were expected to exhibit a high degree of ecological integrity and a low magnitude of stress.

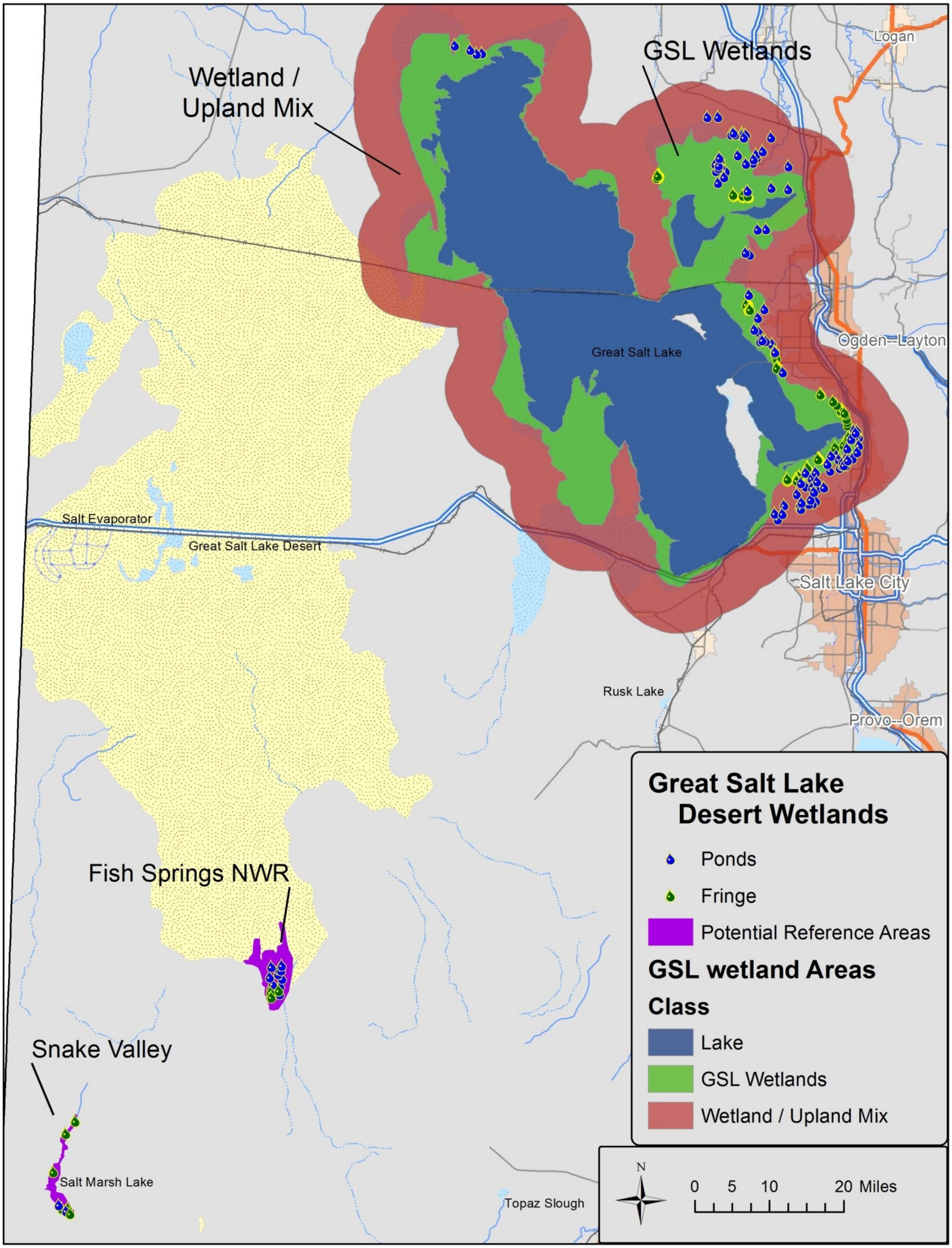

Figure 1. Major wetland classes associated with Great Salt Lake.

2.2.2 Target Population (Wetland Type)

While we use a targeted sample design to identify potential reference standard sites for IWs, the Sample Target – or specific wetland type to be examined – follows the Sampling and Analysis Plan for the 2012 IW survey (DWQ, 2012). Not all wetland areas in the West Desert had been mapped by the start of this project, however, where data were available, appropriate wetland targets included:

- NWI System = Lacustrine (L) or Palustrine (P)
- NWI Class = Aquatic Bed (AB), Unconsolidated Shore (US), or Unconsolidated Bottom (UB)
- NWI Water Regime = Permanently Flooded (H), Intermittently Exposed (G), or Semi-permanently Flooded (F)
- NWI Special = Diked or Impounded (*including visual evidence to confirm*)
- Water-related Landuse ≠ Evaporation Pond
- Area > 5.0 ac (2.0 ha)

2.2.3 Project Boundaries

Impounded wetlands represent an important and unique component of ecosystems throughout the West Desert. While the physical boundaries of impounded wetlands are entirely created by human efforts, high-quality impounded wetlands are prized for their ability to support large and diverse populations of waterfowl and other waterbirds. Many IWs are hydrologically connected to one another through extensive series of dikes, ditches and canals. Moreover, these systems are highly sensitive to the *quantity* of water they receive during the growing season. As such, it was necessary to define where IWs occur in the landscape, geographically and hydrologically, to identify comparable IWs across the broad project area. In addition, temporal boundaries were set by two distinct index periods during the growing season to account for seasonal changes in biological response measures.

2.2.3.1 Geographic Boundaries

As shown in Figure 1, the project area includes wetlands along the eastern and southeastern shores of Great Salt Lake as well as more remote areas in the West Desert (see also Figures 2 and 3). While the GSL-IW survey included a target elevation band (< 4218 feet above sea level [asl]), this boundary was relaxed to account for increasing valley floor elevations across the West Desert.

2.2.3.1 Hydrologic Boundaries

Impounded wetlands are essentially shallow, steep-sided ponds, and their principal source of water is from surface water delivered via extensive networks of canals, ditches and head gates. The relative importance of terrestrial vs. aquatic features within these wetlands can change markedly from year to year and across the growing season.

In order to provide for maximum waterfowl habitat, wetland managers utilize a variety of tools to maintain water depths at the desired levels throughout the year. Current WMA goals for waterfowl production are to provide IWs with approximately 46 cm water depth for maximum growth of submerged aquatic vegetation (Hoven and Miller, 2009); however, this goal may not always be attained by WMA’s when water supplies are limited.

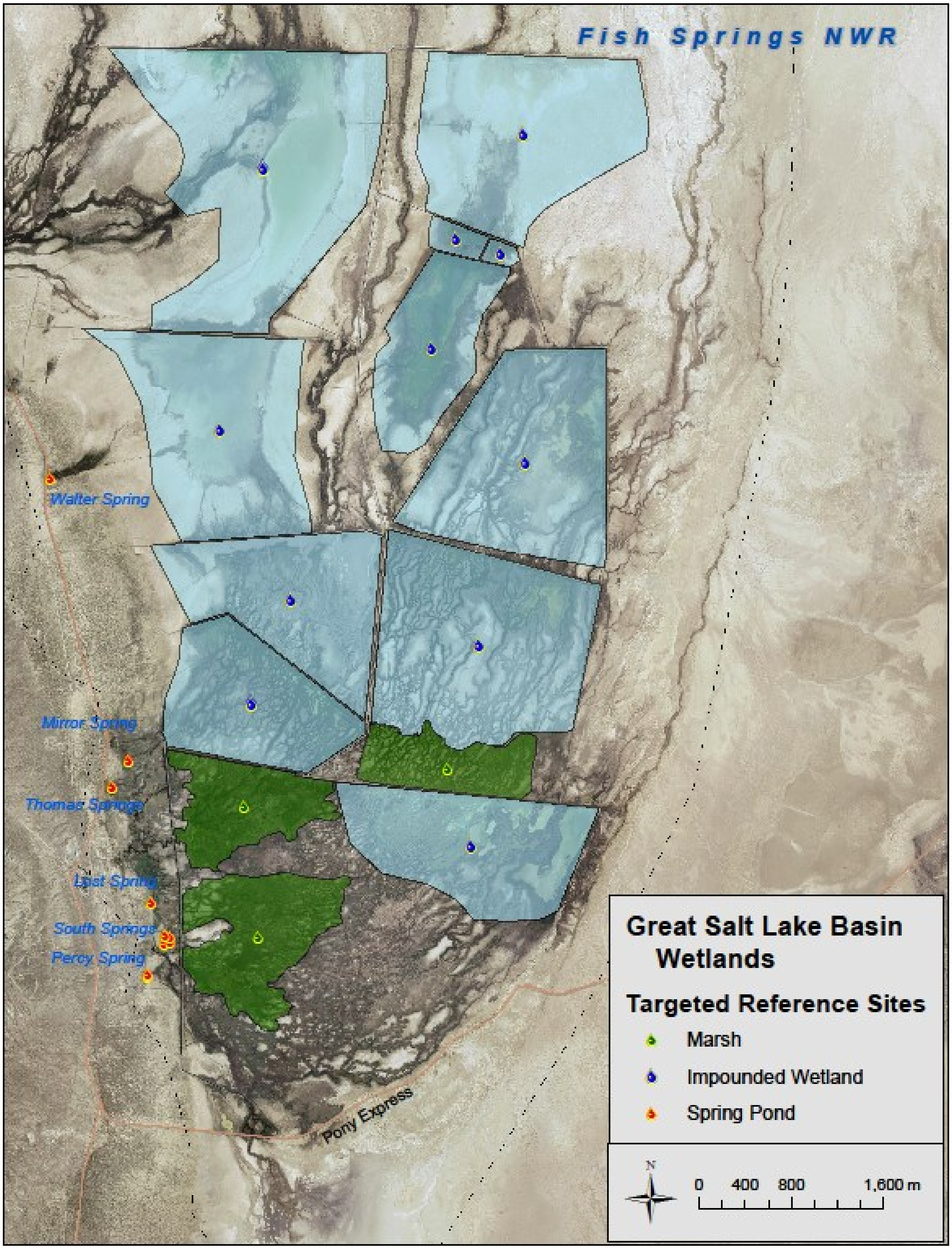

Figure 2. Impounded Wetlands at Fish Springs National Wildlife Refuge

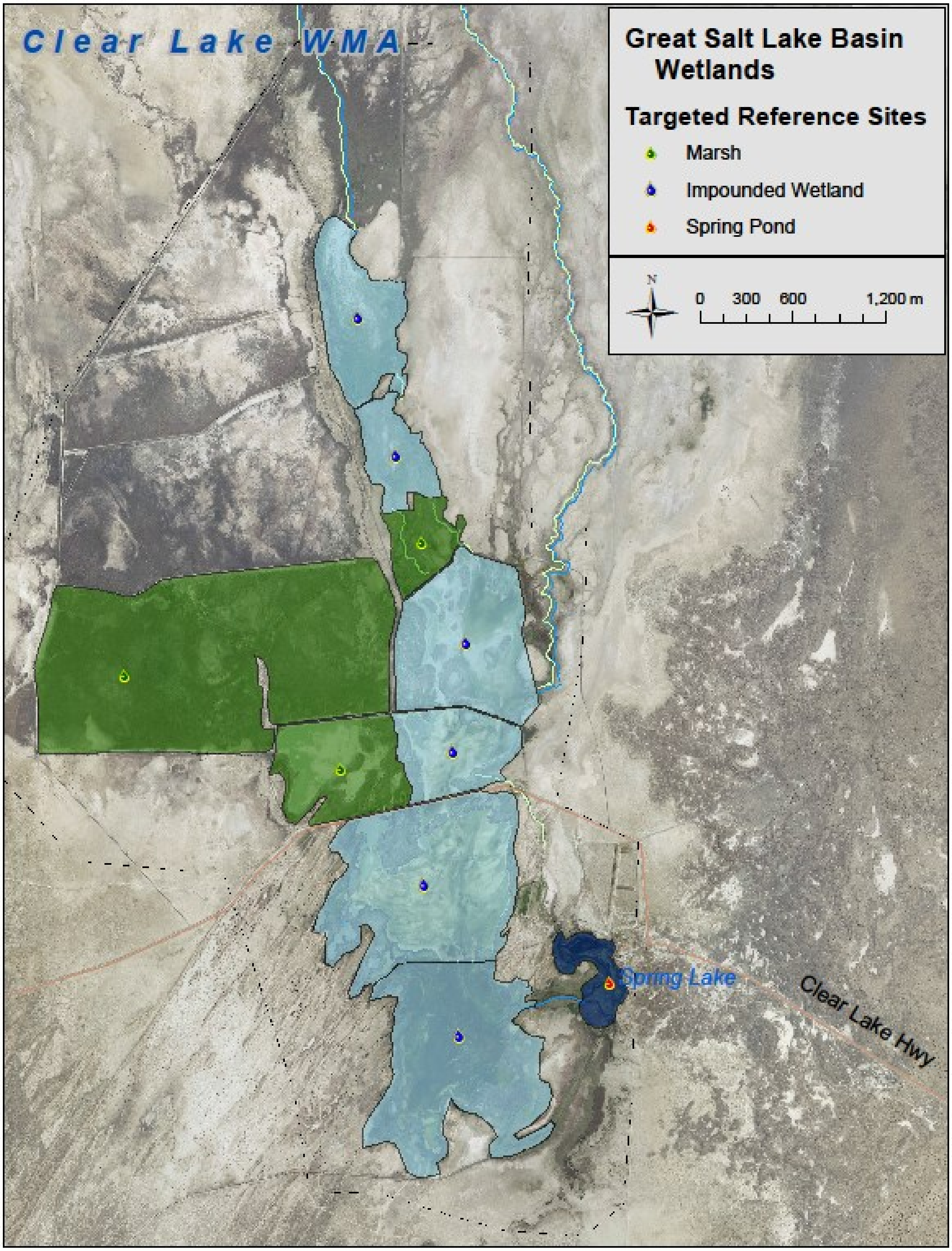

Figure 3. Impounded Wetlands at Clear Lake Waterfowl Management Area.

Two important measurement parameters of the IW assessment are water chemistry and the cover of submerged aquatic vegetation (SAV) (see below). Water depth exerts a strong influence of these parameters, above and beyond any potential effects of water quality, per se. Previous work suggests that optimal water depths for healthy SAV growth within IWs ranges from approximately 25 to 100 cm; the former water level is also roughly the minimum water depth desirable for collection of water chemistry samples. As such, specific efforts were made during site reconnaissance to identify areas within each IW where these depth conditions could be met.

2.2.3.2 Temporal Boundaries (Index Period)

Previous work evaluating the ecological characteristics of impounded wetlands and their biological response to nutrient loading has identified seasonal changes in SAV cover as a potentially powerful measure of wetland condition (Hoven and Miller, 2009; DWQ, 2009). Early senescence of SAV was observed in some nutrient-enriched ponds in late summer, while SAV persisted through autumn in more oligotrophic ponds (DWQ, 2009). While this pattern was observed for only a limited number of sites, early SAV senescence could negatively impact some species of migratory waterfowl who rely on SAV tubers as one component of their autumnal food source.

The seasonal change in SAV cover between summer and autumn was a useful element of the preliminary IW-MMI (DWQ, 2009; see also DWQ, 2014). The index periods for this project are June through July (summer), and September through October (early-autumn). Index periods are commonly used in biological assessments because they help minimize temporal variation in biological parameters and optimize the information gained from measures of community composition.

2.3 Parameters to be measured

Previous work was based on four main sample collections within each pond:

1) Surface Mat Cover
2) Submerged Aquatic Vegetation Cover
3) Benthic Macroinvertebrate Community
4) Water Chemistry

These data have been collected from IWs since approximately 2004, using generally similar methods (DWQ, 2009; DWQ, 2012; CH2M, 2014). Supplemental measurements added since 2012 include:

5) Sediment Available (extractable) Nutrients
6) Sediment Metals

Samples for these parameters (four main collections plus the two soils) were collected at all Reference Standard Sites, where applicable, using sample collection SOPs developed for DWQ's wetlands program (On the web[7]). A brief description of each measured parameter is provided in Table 1 below.

Table 1. Parameters to be measured at Impounded Wetland sites

Description	Field Method *	Details
Aquatic Vegetation	Visual Observation	Five 1 m^2 quadrats along 100-m transect % Submerged Aquatic Vegetation (SAV), % Filamentous Algae, and % Floating Aquatic Vegetation

[7] DWQ Wetlands Program website: http://www.deq.utah.gov/ProgramsServices/programs/water/wetlands/monitoring.htm

Description		Field Method *	Details
Benthic Macroinvertebrates		Sample Collection using D-net	Five x 1-m sweeps with 500 µm D-net along 100-m transect One wide-mouth polyethylene quart jar *Sent to Gray Lab*
Zooplankton		Sample Collection using Wisconsin Net	Five x 5-m tows (radial) with Wisconsin Net One 50-mL centrifuge tube *Sent to Gray Lab*
Water Chemistry	Field Parameters	Multi-Parameter Probe	Temperature, Specific Conductance, pH, Dissolved Oxygen
	Total (unfiltered) Nutrients	Grab Sample Collection	NH_4^+, NO_3^-/NO_2^-, Total Kjeldahl Nitrogen (TKN), Total P, *TOC* One 500 mL bottle with H_2SO_4 preservative *Sent to State Water Lab*
	Dissolved (filtered) Nutrients	Grab Sample Collection and Field Filtering	NH_4^+, NO_3^-/NO_2^-, Total N (dissolved), Dissolved P, DOC One 500 mL bottle with H_2SO_4 preservative *Sent to State Water Lab*
	Dissolved (filtered) Metals	Grab Sample Collection and Field Filtering	Aluminum, Arsenic, Barium, Cadmium, ~~Cobalt~~, Copper, Iron, Mercury, ~~Lithium~~, Manganese, Nickel, Lead, Selenium, Zinc, and *Hardness* One 250 mL bottle, preserved with HNO_3 *Sent to State Water Lab*
	General Chemistry	Grab Sample Collection	Alkalinity, Total Suspended Solids, Total Volatile Solids, Total Dissolved Solids, Sulfate ($SO_4^=$) One 1000 mL bottle *Sent to State Water Lab*
	Sulfide	Grab Sample Collection	Hydrogen sulfide as Total sulfide One 120 mL bottle with ZnoAc and NaOH preservative *Sent to State Water Lab*
	Chlorophyll-*a*	Grab Sample Collection and Field Filtering	0.7 µm filter residue *Sent to State Water Lab*
	~~Oxygen Demand~~	Grab Sample Collection	~~5-day Biochemical Oxygen Demand (BOD_5)~~ One 2000 mL bottle *Sent to State Water Lab {Discontinued in 2013 due to low signal:noise}*
Sediment Available Nutrients		Sample Collection using a Corer *Index Period #1 ONLY*	Composite of five 0-10 cm cores along 100- transect Stored in separate 1-quart zip bags (Nutrient Extracts: NH4, NO3/NO2, PO4); Total N, Total and Organic C *Sent to USU Analytical Lab*
Sediment Total Metals		Sample Collection using a Corer *Index Period #1 ONLY*	Composite of five 0-10 cm cores along 100- transect Stored in 1-gallon zip bag Aluminum, Arsenic, Barium, Cadmium, Cobalt, Copper, Iron, Mercury, Lithium, Manganese, Nickel, Lead, Selenium, and Zinc *Receiving Lab being negotiated (6/8/2012)*

2.4 Field Methods

Sample collections included:

1) Water column chemistry (general chemistry, total nutrients, total metals, sulfide, chlorophyll-a, and carbonaceous BOD_5 (*this parameter was replaced w/ DOC (and TOC) in 2013*))
2) Sediment metals (Al, As, Ba, Cd, Cu, Fe, Hg [total], Mn, Ni, Pb, Se, Zn)

3) Sediment nutrients (extractable-NH_4^+, NO_3^-, $PO_4^{\equiv}$; total N, C, P, and organic matter; pH and EC_{25} from saturated pastes; and natural abundance $\delta^{15}N$ stable isotope signatures)
4) Vegetation nutrients (total C, N, P, and $\delta^{13}C$ and $\delta^{15}N$ signatures)
5) Aquatic benthic macroinvertebrates (identification, enumeration and biomass estimation)

In addition, measurements were taken with a multi-parameter probe (Hydrolab or YSI) for water temperature, pH, dissolved oxygen concentration, and EC.

Benthic macroinvertebrate community composition observations were collected to help characterize the importance of different feeding groups and functional classes in the processing of organic materials in the wetlands.

Water chemistry (nutrients, major ions, and metals) data were collected to characterize the basic constituents available as building blocks for vegetation, macroinvertebrates, and other biological processes. Metal data were used to determine if any potentially toxic conditions were present in the wetlands.

Sediment extractable nutrients and metals data were collected to help determine if any historical inputs to the wetlands may have deposited nutrients, such as P, or toxic contaminants, such as Hg, that may continue to affect the condition of the wetlands.

Leaf CNP concentrations and $\delta^{15}N$ isotope ratios of dominant emergent plant species were collected to assess the potential sources of nutrients for plant growth in the wetlands.

2.4.1 Environmental Sampling – Vegetation

Cover of aquatic vegetation was sampled by visual estimation of aerial cover along 100-m transects. Procedures are described in the SOP (Note[8]). Briefly, five values from a random numbers table (range of 0 to 100) provide the distance along a transect where the cover of SAV and/or surface mats within a 0.5 x 2.0 m quadrat are recorded. This data, along with other pertinent observations are recorded on a field sheet. No collections were made for historical samples (2004 through 2012 (IW Survey)), however, in 2013 DWQ began collecting samples of dominant SAV for nutrient and metal analyses.

2.4.2 Environmental Sampling – Macroinvertebrates and Zooplankton

Benthic macroinvertebrates were collected from an undisturbed area using a D-net along a 100-m transect. Procedures are described in the SOP (Note[9]). Briefly, five random numbers (ranging from 0 to 100) were used to identify sampling points along a transect. This transect should be at least 5 m ‘upstream’ (towards the interior of the IW) from the SAV transect described above. At each sampling location, the D-net is tapped along the sediment/soil surface while performing a figure-eight type motion along a 1-m length. Three figure eights over the same area constitute a ‘sweep’, and one ‘sweep’ is performed at each sampling location along the transect.

Zooplankton sampling was performed using a tow net to collect large plankton within the upper portion of surface waters. Procedures are described in the SOP (Note[10]). Briefly, an undisturbed area was selected and the tow net cast and recovered for a total of five 5-meter tows over an approximate 120° path. Contents were rinsed into a sample container (typically a 50 mL centrifuge type), carefully to avoid to sediment/soil materials and surface mats in the sample container. Best results were obtained when the top of the tow net is oriented horizontally, just below the water surface, while the net is being recovered; this maximizes the collection of plankton per tow.

[8] See: www.deq.utah.gov/ProgramsServices/programs/water/wetlands/docs/2014/05May/SOP_SAVeg_09092011_WetL.pdf
[9] See: www.deq.utah.gov/ProgramsServices/programs/water/wetlands/docs/2014/05May/SOP_Macroinvert_09092011_WetL.pdf
[10] See: www.deq.utah.gov/ProgramsServices/programs/water/wetlands/docs/2014/05May/SOP_Zooplankton_09092011_WetL.pdf

Because these data were not included in previous IW-MMI reports, and have not yet been summarized for other applicable datasets, zooplankton abundance and community composition are not reported at this time.

2.4.3 Environmental Sampling – Water Chemistry

Sampling of water chemistry parameters involved two separate activities, as shown in Table 3. Field parameters were measured using a multi-parameter probe (Hydrolab or similar.); typically one of the first activities performed during a site visit. Procedures for (daily) calibration and use of the multi-parameter probe are provided in the SOP (Note[11]). This project used temperature, specific conductance, pH, and DO probes. Multi-parameter probe data was recorded on field sheets once results were verified as acceptable by the field crew and stored on the instrument; field sheets also included notes about site conditions observed during the measurement.

Field collection of water samples for chemical analysis was next. Specific procedures for collection of water grab samples are described in the SOP (Note[12]). Several volumes of surface water were collected for different types of analysis. Four bottles were filled for Total Nutrients, General Chemistry, Sulfide, and BOD5. One or more 'transfer bottles' were also be filled and then filtered for Dissolved Nutrients and Dissolved Metals. Additional water was filtered separately and the residue collected for Chlorophyll-α analysis (Note[13]).

2.4.4 Environmental Sampling – Soils

Sediment available nutrients and total metals were sampled from 5 sediment cores along a 100-m transect; again, at least 5 m away from another transect or other disturbed area. This procedure is slightly modified from that described in the SOP (Note[14]).

Briefly, the goal was to sample the top 10 cm of loose sediment (or mucky soil) at five random locations along the transect. Each core was split in the field, using a soil spatula, and each half of the sediment core placed in separate sample bags: one-half of the core will be placed in a labeled plastic 1-quart zip bag for nutrients, the other half of the core will be placed in a labeled zip bag for total metals. This process was repeated for all five samples collected per site. All soil / sediment samples were composited.

2.5 Laboratory Methods

All chemical analyses were performed in accordance with standard laboratory methods by contracted laboratories. Specific details for each method and laboratory are located in the project SAP (DWQ, 2012; DWQ, 2014). A summary of analytical methods and associated QC limits is presented in Table 3.

2.6 Data Quality Objectives

Data quality objectives were derived from a systematic planning process that was intended to clarify the study objective, determine the most appropriate types of data to collect, determine the most appropriate conditions from which to collect data, and specify the level of uncertainty allowed in the collected monitoring data while still meeting project objectives (EPA, 2006). Project specific information is summarized in Table 2 below.

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[11] See: www.deq.utah.gov/ProgramsServices/programs/water/wetlands/docs/2014/05May/SOP_Hydrolabs_09092011_WetL.pdf
[12] See: www.deq.utah.gov/ProgramsServices/programs/water/wetlands/docs/2014/05May/SOP_WaterChem-SampleCollection_091011_WetL.pdf
[13] See: www.deq.utah.gov/ProgramsServices/programs/water/wetlands/docs/2014/05May/SOP_Chlorophyll-a_09092011_WetL.pdf
[14] See: www.deq.utah.gov/ProgramsServices/programs/water/wetlands/docs/2014/05May/SOP_Sediment_09102011_WetL.pdf

Table 2. Data Quality Objectives

Step	DQOs for West Desert Reference Standard Site Survey (2014 and 2015)
Problem Statement	Wetland resource managers and engaged stakeholders had previously observed algal mats within GSL wetlands and expressed concern that this could be an indicator of poor wetland health resulting from high N and P loading from wastewater treatment facilities, possibly impacting the food sources of waterfowl and shorebirds using these areas. It was suspected that wetlands with high nutrient loads may not be supporting their beneficial use of waterfowl habitat and necessary food chain. In response, DWQ initiated the development of a framework to assess the relative condition of impounded and fringe wetlands of GSL. The assessment framework for impounded wetlands has been refined through a probabilistic survey of IWs. However, collection of empirical data from IWs representing potential Reference Standard Sites is needed to define appropriate ecological endpoints for the Best Attainable Condition (BAC) reference standard.
Goal of Study / Decision Statements	*Key Question[s]* Q0: What key variables define the function, characteristics, and condition of GSL fringe wetlands? Q1: What stressors are impacting the condition of GSL's fringe wetlands? Q2: What metrics are most useful for evaluating wetland condition and stress with respect to beneficial use classes? Q3: What are appropriate benchmarks for establishing GOOD / FAIR / POOR reporting classes for both biological responses and environmental stressors? Q4: How do wetland biological response metrics and MMI scores from sites far from human disturbance compare with scores from sites associated with GSL? Q5: What is the range of natural variation in biological and chemical parameters (indicators), relative to data from more highly disturbed GSL wetlands? *Potential Outcomes* 1: Information is adequate to answer the key questions, resulting in a scoring system for response and stressor variables. 2: Information is inadequate to develop robust metrics of relative condition of fringe wetlands. DWQ will identify potential confounding factors, develop appropriate sampling and analytical methods, revise the sampling plan, and complete reporting as above.
Inputs to Decision	The following information was collected: Field sampling, including collection of water chemistry and biota samples, was conducted during two index periods in 2014 and 2015 at targeted wetland sites in Utah's West Desert. *Water chemistry parameters*: Total nutrients, total metals, chlorophyll a, general chemistry (major ions, suspended solids), and field measures (DO, temp, pH, salinity) using appropriate and documented methods. *Benthic macroinvertebrates*: Species composition of benthic macroinvertebrate communities using appropriate and documented methods. *Field measures of vegetation and surface mat* cover were collected using appropriate & documented methods. *Sediment metals and nutrient availability*: Total (digested) metals and exchangeable nutrient concentrations using appropriate & documented methods. *Field observations of stressors*, including soil and vegetation disturbance, altered hydrology, over grazing, and the establishment and dominance of invasive plant species. Supplemental Indicators: Leaf C, N, and P concentration, and δ15N and δ13C isotope ratios from dominant emergent plants along transect endpoints and open water sampling locations.
Study Boundaries	The study area for this project includes Impounded Wetlands within Farmington Bay, Ogden Bay, Bear River Bay, and Gilbert Bay portions of Great Salt Lake, and areas within Utah's West Desert. Spatial data identifying impounded wetlands was derived from reclassified National Wetland Inventory data and other sources as available. Sampling sites were field-checked to ensure that they: *Represent the sample target*—Fringe wetlands associated with and adjacent to the GSL. *Are accessible*—DWQ has received permission to visit wetlands on private property. Have sufficient water availability for sampling requirements. Weather conditions during the growing season were a constant source of concern, including high temperatures and unpredictable summer thunderstorms.

Step	DQOs for West Desert Reference Standard Site Survey (2014 and 2015)
Decision Rules	If information is adequate to answer the key questions, then these sites will be used as an initial set of Reference Standard Sites. These sites will then be sampled over multiple years to develop an understanding of the range of natural, interannual variation of biological response and stressor metrics. If information is inadequate to answer the key questions; DWQ will identify potential confounding factors, develop appropriate sampling and analytical methods, revise the sampling plan, and complete reporting as above.
Acceptance Criteria	PARCC elements for data *Precision*—Because of the low number of sampling sites, only one set of field replicates were collected in 2014 and 2015. *Preliminary results from water chemistry and macroinvertebrate analyses are within expected precision limits (see SAP).* *Accuracy*—Special efforts were made to minimize contamination of water chemistry samples through proper collection of field samples and use of appropriate laboratories for analysis. Field surveys were performed by a single monitoring crew trained in each method. Few species of vegetation occurred within the project area and were generally easily identified. *Representativeness*—The sampling locations have been well-defined. Site photos and field notes were collected at each site to describe any unusual conditions that may occur. *Data from other sources, but similar wetland types (e.g. IWs) are presented to compare against the West Desert site data.* *Completeness*—Sample completeness was within bounds of expectation, greater than 85% for all measurements. Completeness of historical data was somewhat less than expected, but results were evaluated at appropriate scales (e.g. seasonal or interannual vs. weekly). *Comparability*—All field sampling and analytical procedures were completed following both previously tested and newly developed SOPs for each metric and were performed by the same field crew throughout the sampling season. Measurement quality objectives for chemical measurements are specified in the SAP (DWQ, 2014). DWQ QAPP specifies the minimum QA/QC objectives for sample measurement.
Sampling Plan and Design	The baseline sampling program includes the following: Collection and analysis of water, macroinvertebrates, and surface sediments for chemical, physical, and taxonomic attributes, as appropriate Field observations of vegetation and algal mat cover Data were used to estimate baseline conditions of isolated impounded wetlands in Utah's West Desert. Forthcoming analyses will use these data to construct appropriate benchmarks for GOOD versus POOR conditions for each set of biological responses / indicators, following reasonable and convincing linkages to beneficial use of these wetlands. A key element of this methodology is the reliance on standard, repeatable measurements that area appropriate for use in a routine monitoring program.

Table 3. Analytical QC limits and reporting ranges

Sample Type	Parameter	Method #	MRL *	Units	Calibration Range	Precision	Accuracy	Recovery	Current Numeric Criteria **		
									2A/2B	3B/3C/3D	4
Water Chemistry (nutrients)	NH_4-N	350.1	0.05	mg/L	0.05 - 10.0	± 15%	± 15% †	± 15%		pH dependent	
	NO_2/NO_3-N	351.4	0.10	mg/L	0.10 - 10.0	± 15%	± 15%	± 15%	4	4 / 4 / na,	na
	TKN ††	353.2	0.10	mg/L	0.10 - 5.0	± 15%	± 15%	± 15%			
	TP	365.1	0.02	mg/L	0.01 - 1.0	± 15%	± 15%	± 15%	0.05	0.05 / na / na	na
	DOC	5310B	0.5 *est*	mg/L	0.5 - 20.0	± 15%	± 15%	± 15%			
Water Chemistry (metals)	Al	200.8	10	µg/L	10 - 100	± 15%	± 15%	± 15%		87 / 750	
	As	200.8	1	µg/L	10 - 100	± 15%	± 15%	± 15%			
	Ba	200.8	100	µg/L	10 - 100	± 15%	± 15%	± 15%			
	Cd	200.8	10	µg/L	10 - 100	± 15%	± 15%	± 15%			
	~~Co~~	~~200.8~~	~~?~~	~~µg/L~~	~~n.d~~	~~± 15%~~	~~± 15%~~	~~± 15%~~			
	Cu	200.8	1	µg/L	1 - 100	± 15%	± 15%	± 15%		9 / 13	200
	Fe	200.7	20	µg/L	4 - 4000	± 15%	± 15%	± 15%		1000 max	
	Hg	245.1	0.2	µg/L	0.2 - 10	± 15%	± 15%	± 15%		0.012 /	
	Mn	200.8	5	µg/L	5 - 100	± 15%	± 15%	± 15%			
	Ni	200.8	5	µg/L	5 - 100	± 15%	± 15%	± 15%		52 / 468	
	Pb	200.8	0.1	µg/L	0.1 - 100	± 15%	± 15%	± 15%		2.5 / 65	100
	Se	3114 C	1	µg/L	1 - 10	± 15%	± 15%	± 15%		4.6 / 18.4	50
	Zn	200.8	10	µg/L	10 - 100	± 15%	± 15%	± 15%		120 / 120	
	Hardness	200.7		--- calculated from D-Ca and D-Mg ---							
Sulfide	H_2S	376.2	0.1	mg/L	0.1 - 20	± 10% *est*	± 10%	± 15%			
Water Chemistry (general)	Alkalinity	2320 B	4	mg/L	4 - 1230	± 15%	± 10%	± 10%			
	TDS	2540 C	10	mg/L	10 +	± 15%	± 10%	± 10%			
	TSS	160.2	4	mg/L	4 +	± 15%	± 10%	± 10%			
	TVS	160.4	5	mg/L	5 +	± 15%	± 10%	± 10%			
	$SO_4^=$	375.2	20	mg/L	20 - 300	± 15%	± 10%	± 10%			
Water Chemistry (other)	Chl-a	10200 H	0.1	µg/L	0.1 - 20	± 15%	± 10%	± 10%			
	~~BOD_5~~	~~405.1~~	~~3~~	~~mg/L~~	~~24 - 240~~	~~± 10%~~	~~± 10%~~		~~5~~	~~5 / 5 / 5~~	~~5~~
Benthic Macro-invertebrates				Taxa	> 50 indiv	Genus or better	Reference collections				
Zooplankton				Taxa	> 200 indiv						

* Method Reporting Limit; ** Numeric Criteria for Beneficial Uses of State-managed wetlands (R317-2 Standards of Quality for Water). *Note that nutrients presented as Pollution Indicators; values for dissolved metals refer to chronic / acute values.* [na = not applicable]. † Matrix control samples are within ±20% (nutrients) & ±30% (metals), per State Lab QA Manual. †† Total N used to calculate organic N (filtered), for Total N: MRL = 0.2 mg/L, Range = 0.2-10; other QC values same as TKN. Note that this information was developing for the project Sampling and Analysis Plan; updated values for method-specific MRLS and/or numeric criteria can be found in the table in the Water Chemistry Section of this report. Lines with strikethrough text show parameters that are no longer collected.

3.0 Data Analysis

In an effort to take a comprehensive view of the variability of conditions within impounded wetlands, DWQ compiled all available data for IW and other, similar wetland types (e.g. shallow ponded wetlands) into datasets describing water chemistry, macroinvertebrate community composition, and SAV and site characteristics. These data were derived from four primary sources:

1) Historical data from DWQs wetland assessment surveys (2004 to 2011) (*targeted*);
2) Great Salt Lake Impounded Wetland Survey (2012) (*probabilistic*);
3) Impounded Wetland Reference Standard Sites (2014, 2015) (*targeted*); and
4) Willard Spur Water Quality Study (see: willardspur.utah.gov) (2011-2013) (*repeat monitoring*).

This required a long and tedious effort to compile the large amount of disparate data into a consistent dataset. The goal of this data assimilation is the allow for greater in-depth examination of spatial and temporal (seasonal and interannual) patterns for this wetland type. In this report, the aggregation of the first three datasets will be used as context for the newly acquired Reference Standard Site data.

Three distinct datasets make up the bulk of the IW data. The SAV dataset is derived from cover estimates collected across 100-m transects within ponds; there is some variation in the number of plant cover quadrats per transect, particularly in the earlier years of IW work as methods were being developed. This dataset also includes various aspects of surface cover of a pond, such as the cover of algal mats, benthic periphyton mats, and floating aquatic vegetation (notable Lemna spp.), and the depth of water in a pond. Because definitions and project goals varied over time, these data are the least complete. When comparisons are made among studies, we tried to ensure that variables were similar in spatial scale.

The macroinvertebrate dataset is derived from over a decade of work by Dr. Larry Gray (of Utah Valley University) processing DWQ sample collections, identifying taxa, and communicating the results back to DWQ. DWQs current wetland macroinvertebrate includes 76 distinct taxa. Dr. Gray has also guided the development of metrics describing the diversity of wetland macroinvertebrate communities, based on Simpson's diversity index (calculated as 1-D), as well as a metric termed 'Phytophilous (or Plant-associated) Macroinvertebrate Index' (PMI for short) designed to correspond to key macroinvertebrate food items of waterfowl. This dataset is reasonably complete (546 distinct sample collections, 4760 taxa occurrences).

Lastly, the water chemistry dataset includes laboratory and field-based measures of IW water chemistry (see Section 2.2 for greater detail), and is the most complete (1252 distinct sampling events, over 100 measured and derived chemical parameters). Additional data for nutrient and/or trace metal concentrations from wetland soils, plant biomass, and most recently surface algal mats, but these data are quite sparse and project specific.

The data in this report are presented in several ways: the most comment approach examines data over time (monthly) to highlight temporal / seasonal patterns within and among datasets. These figures highlight the magnitude of variation within and among sampling months, between years and across datasets. A second figure style highlight the data distribution among methods, displayed as either boxplots or empirical cumulative distribution functions (CDFs). For boxplots, the upper and lower bounds of the 'box' represent the 25th and 75th percentiles of the data, while the 'whiskers' extending beyond the box represent values less than 1.5 times the interquartile range (distance between the 25th and 75th percentiles) from the median; this is meant to reflect a 95% confidence interval around the difference between two medians (Note[15]). For CDFs, horizontal dashed lines identify the upper and lower quartiles for each dataset.

[15] Additional information available here: http://www.inside-r.org/r-doc/grDevices/boxplot.stats

An attempt was made to examine the multivariate nature of water chemistry data from all four datasets using PCA, however, the large proportion of missing values – even among a trimmed subset of variables – made this an unworkable goal over the near term. While methods are available for 'imputing' missing data values, and variables with poor completeness were removed from the dataset (e.g. DOC, TVS/TSS, and SE), 29 to 38% of the reduced dataset were missing, including up to 67% of observations for particular variables (water depth, several metals (> 50% missing), TN:TP ratios. Only a limited selection of sites (less than 118 of 1367 site-observations) had complete data for a trimmed list of 34 key variables. As such, confidence was low for even the best imputation methods under these circumstances. Going forward, as cohesive subsets of these data are developed, multivariate methods will continue to be applied.

4.0 Results

4.1 Site Characteristics

Potential reference standard sites for impounded wetlands were identified and sampled at two areas within the West Desert of Utah, Fish Springs National Wildlife Refuge (NWR) operated by the U.S. Fish and Wildlife Service (Figure 2), and Clear Lake Waterfowl Management Area (WMA) operated by the Utah Division of Wildlife Resources (Figure 3). The remote location of Fish Springs is clearly shown in Figure 1; Clear Lake is slightly more accessible (approximately 18 miles south of Delta, Utah; site is obscured in Figure 1, 25 miles south of Topaz Slough), but still remote in terms of adjacent land use and known pollutant sources.

The relative importance of dominant land cover classes and characteristics of known sources of pollutant inputs to watersheds adjacent to impounded wetlands associated with both Great Salt Lake and the West Desert are shown in Table 2. The first three watersheds (defined as the lowest HUC10 (Hydrologic Unit Code) within the major river subbasin) are associated with IWs found along the eastern shores of Great Salt Lake. The next two watersheds are associated with prospective reference sites located within Clear Lake WMA and Fish Springs NWR, respectively.

While the relative cover of eight general land use classes varies among watersheds, both Clear Lake and Fish Springs have much lower cover of developed land and intensive agriculture, including pasture and rangelands compared to the watersheds adjacent to GSL. This is clearly expected, given both the remoteness of the West Desert watersheds as well as considering the extreme physical and climatic conditions in these areas – expansive areas of salt desert scrub amidst rugged mountain ranges with low vegetation cover. Urban development and intensive agricultural use can contribute substantial physical, chemical and biological stresses to watersheds, including pollutant loads to surface waters through both point- and nonpoint sources and by direct (stormwater runoff from impervious surfaces) and indirect (greater density of paved roads with increasing urban development) means. GSL-watersheds also have higher numbers of UPDES (Utah Pollution Discharge Elimination System) discharge permits than the West Desert (Reference Standard) watersheds, across all permit categories (Table 4).

At a broad scale, we expect pollutant loads to increase with human-induced stress. Conversely, we expect low pollutant loads in watersheds with low stress from development. In this regard, West Desert wetlands should have much lower stress – all else being equal – than similar wetlands in watersheds associated with Great Salt Lake. This pattern appears to be borne out by the greater number and cumulative length of impaired surface waters (perennial streams, only) from GSL- versus West Desert watersheds, as reported in the 2012-2014 *Integrated Report* (DWQ, 2015).

Table 4. Land cover and characteristics of watersheds contributing to GSL and West Desert wetlands

	Lower Bear +	Lower Weber	Lower Jordan	Clear Lake *	Fish Springs *
HUC10 Code:	1601020405	1602010206	1602020404	1603000804	1602030604
Dominant Land Cover (%)					
Developed Land	4.5	33.1	25.9	0.3	0.8
Cultivated Crops	7.6	8.4	0.1	-	-
Pasture and Range	11.9	20.2	13.0	1.7	0.1
Forest	10.3	7.4	4.9	-	-
Shrub-Scrub	16.0	9.7	25.7	83.0	28.0
Open Water	21.0	5.0	9.8	3.1	3.2
Wetlands	15.3	12.2	12.3	0.6	18.4
Barren Land	13.4	3.9	8.2	11.3	49.6
Total Watershed Area (ha)	91,138	33,632	61,582	62,441	12,277
Number of UPDES Discharge Permits					
Biosolids	3	5	5	0	0
Construction related	3	32	51	0	0
Fish Hatcheries	1	1	0	0	0
Pesticides, General Permit	5	7	22	0	1
Industrial	3	7	9	0	0
Stormwater	35	170	377	0	1
Municipal (WWTPs)	5	9	9	0	0
Irrigation and Water Supply	0	7	10	0	0
Total UPDES Permits	55	238	485	0	2
Impaired Surface Waters (Perennial Streams)					
Number of Impaired Assessment Units	3	18	23	0	0
Impaired Stream miles	140.7	510.9	334.7	-	-

Notes: + Utah portion only. * For these closed basin watersheds, there are no 'pour points', and only data from the upstream portion of the watershed is reported. Results for Land Cover classes and UPDES Permits correspond to HUC10 units, while the results for Impaired Waters were summarized at the HUC8 scale. Results were extracted from the following datasets: National Land Cover Database (NLCD), Utah Pollution Discharge Elimination System (UPDES) discharge permits, Water-Related Land Use, and Impaired Surface Waters database; all available via the Automated Geographic Reference Center (AGRC[16]).

4.2 Biological Response Indicators

During the growing seasons of 2014 and 2015 DWQ collected field data and environmental soil, water and plant samples to characterize indicators of biological response and chemical stress from eight impounded wetlands and four springs (Section 2.2). As described in Section 3.0, we compare these data against an extensive set of previously collected IW data that had never before been compiled.

The remaining sections of this report highlight interesting or important differences in parameter values among datasets, with particular emphasis on how data from the reference standard sites (labeled below as 'West Desert IWs (2014-15)' compare against the 2012 GSL-IW survey (labeled as 'IW Survey (2012)'). Additional information on the 2012 IW survey can be found at DWQ's Wetland Program website[17]. Additional datasets include data compiled from DWQ's previous wetland surveys (2004 to 2011), though not all measurements were made over the entire timespan; these data are labeled as 'Historical (2007-2011)'. Finally, we include results from an extensive, multi-year monitoring project (2011 through 2013) within Willard Spur, a large (over 10,000 acres) shallow embayment of Bear River Bay that is currently dominated by extensive areas of SAV and provides habitat for large populations of both waterfowl and shorebirds. While Willard Spur is not an impounded wetland *per se* (i.e. bound

[16] See: http://gis.utah.gov/
[17] See: http://www.deq.utah.gov/ProgramsServices/programs/water/wetlands/monitoring.htm

by dikes and berms), and the hydrology is not actively managed for waterfowl production (Willard Spur website[18]), we include these data to gain a better understanding of the ecological breadth occupied by the shallow pond wetland type in northern Utah. Reports from the Willard Spur Water Quality Study suggest that the composition of plant (SAV and emergent vegetation) and benthic macroinvertebrate (Gray, 2015) communities are broadly similar to those of GSL Impounded Wetlands, however, it remains unclear whether the two ecosystem types also have similar functions and biological responses to stress.

The following analyses address the degree to which the West Desert reference standard sites support (or oppose) the expected conditions of healthy impounded wetlands (from Section 1.4.1):

- Persistent cover of SAV between index periods
- (Lack of) occurrence of surface mats
- Composition of benthic macroinvertebrate communities.

4.2.1 Surface Mats

Surface mats within GSL impounded wetlands represent accumulations of filamentous algae (*Cladophora* sp., *Spirogyra* sp.) or floating aquatic vegetation (as *Lemna* spp.) that occur on the surface or within the upper portions of the water column (see Figure 4). The timing and causes of surface mat development are not entirely clear for GSL wetlands. Some experimental work links increases in nutrient availability to extensive growth of epiphytic algae on submerged aquatic plants in estuaries (see citations in: Madden and Kemp, 1996) that may contribute to accumulation of surface mats. Large surface mats have also been reported previously in some GSL wetlands (Miller

Figure 4. Surface Mats observed in GSL impounded wetlands

and Hoven, 2007; Hoven and Miller, 2009). While low-level and ephemeral accumulations of algae occur in many water bodies, extensive development of these mats is currently considered an indication of degraded conditions with respect to recreation and aquatic wildlife designated uses (DWQ, 2009). A recent econometric survey of Utah waterfowl hunters reported that development of algal mats, invasive species encroachment, and water allocation away from wetlands were important environmental concerns of waterfowl hunters (Duffield et al., 2011).

Results from the compiled IW datasets display a wide range of surface mat cover over the growing season, particularly between June and September, for the Historical (top panel), IW Survey (second panel), and Willard Spur datasets (bottom, fourth panel) (Figure 5). Surface mats were not observed at the West Desert reference sites (third panel). There were insufficient repeat visits to impounded wetlands to identify any interannual patterns,

[18] See: http://www.willardspur.utah.gov/

however repeat monitoring of surface mats in Willard Spur suggest that large year to year differences in environmental conditions (e.g. water availability, temperature, nutrient loads) may be an important component of the observed seasonal variation.

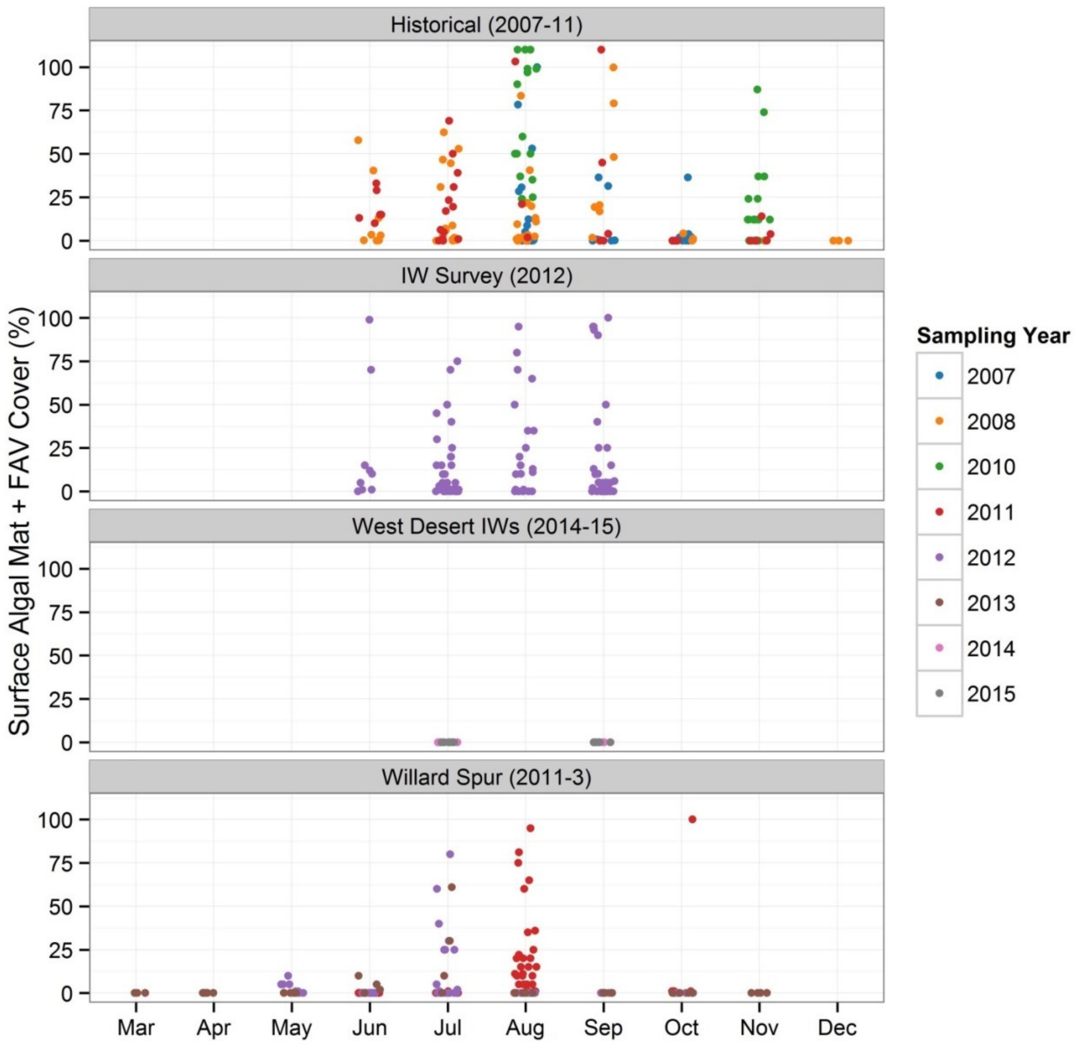

Figure 5. Seasonal patterns in Surface Mat cover

With the exception of no observed surface mats at the West Desert sites, the distribution of mats between the Historical and IW Survey datasets were similar; median surface mat covers were less than 5% for both datasets, upper quartiles (75th percentile) were around 25% (Figure 6). Extensive surface mats covering half or more of IW ponds were rare, occurring in 10% of site visits for the Historical and IW Surveys. These results also suggest that the occurrence of surface mats are not necessarily ubiquitous in all impounded wetlands (Figure 5).

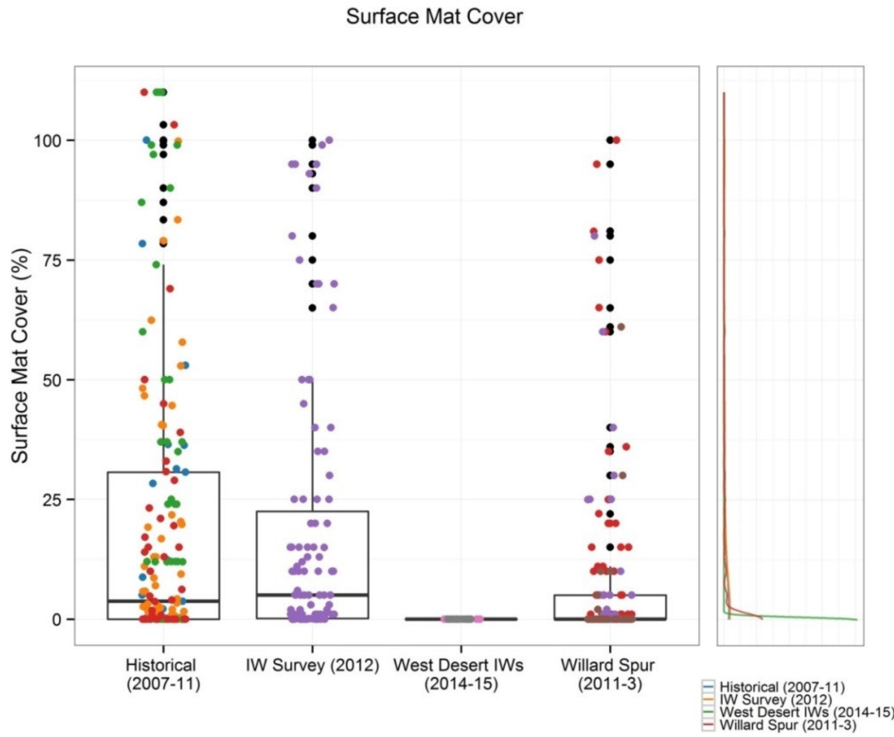

Figure 6. Distribution of Surface Mat cover values among IW datasets

In summary, the low cover of surface mats in West Desert reference sites is consistent with expected conditions for healthy impounded wetlands (Section 1.4.1). Unfortunately, the lack of any variation in surface mats within these potential reference standard sites (all site observations reported zero surface mat cover) does not provide sufficient information to establish any type of benchmark for IW surface mats. In addition, the econometric study of waterfowl hunter site preferences did not suggest a breakpoint in surface mat cover, above which hunters would choose to not recreate (i.e. wade in and hunt for waterfowl) at that pond. For the time being, a benchmark of 50 to 75% of pond area covered by surface mats is proposed as an appropriate and protective level for healthy impounded wetlands.

4.2.2 Submerged Aquatic Vegetation

Submerged aquatic vegetation (Figure 7) is an important element of shallow impounded ecosystems, particularly those with a management focus on waterfowl production (Miller and Hoven, 2007; DWQ, 2009; USFWS, 2009). Previous work on GSL wetlands has shown SAV to be sensitive to variations in water quality, which makes it a potentially valuable indicator of human-caused stress. Early work on GSL IWs was concerned with observations of early senescence (or decline in plant vigor) of SAV in some wetland ponds prior to the arrival of migratory waterfowl in early autumn; this was considered to be an important indicator of declining health of these wetlands, particularly for desirable plant species such as Stuckenia pectinata (sago pondweed)(Miller and Hoven, 2007). In this section we report on observations of total SAV cover among GSL and West Desert IW datasets and describe an index of SAV persistence that characterizes SAV cover across the summer to early-autumn index periods used in the 2012 IW Survey.

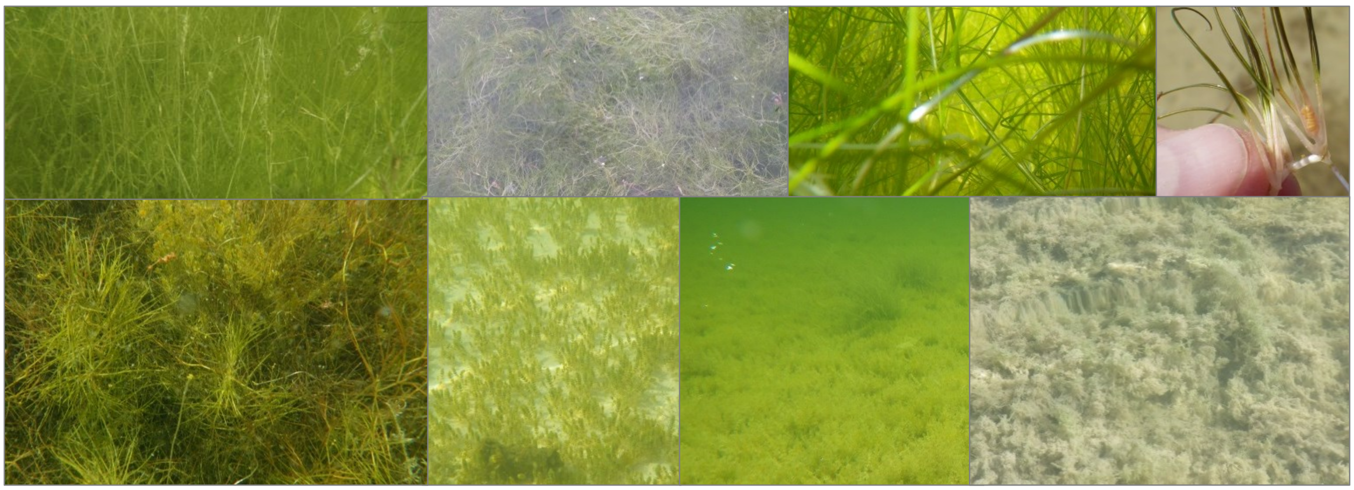

Figure 7. Submerged Aquatic Vegetation communities and representative species found in impounded wetlands adjacent to Great Salt Lake and the West Desert of Utah.

During the 2012 IW and the West Desert IW surveys, DWQ field crews collected data on SAV cover at the whole-pond scale as well as from 1-m^2 quadrats within the pond. These measurements were used as a check for representativeness of sampling locations and to evaluate whether there were detectable differences in the patchiness of SAV cover within ponds. For example, it could be that some ponds have extensive stands of low-density SAV cover, possibly due to low nutrient availability or differences in aquatic species growth forms; alternatively, some ponds may have only patches of dense SAV, possibly indicative of disturbances to pond sediments (e.g. by carp or other benthivorous fish).

For the sites that had data for both SAV measurements, we found close agreement between the more intensive quadrat-level measurements and estimates made for the pond as a whole (or at least the visible portion of the pond) (Figure 8). The data were readily described by a linear model with 1:1 slope and a y-intercept driven through the origin (n = 105), r^2 was 0.89 and model-p < 0.001. The reader should note that nearly 30% of all data points are focused at both extremities of the data range (i.e. many data pairs have coordinates (<5, <5) and (>95, >95)); when these data are removed (n=72), the slope is approximately 0.93 and r^2 decreases to 0.63.

As the development of IW assessment methods progresses, pond-scale SAV cover may be a useful measurement for extensive, more rapid surveys of IW health.

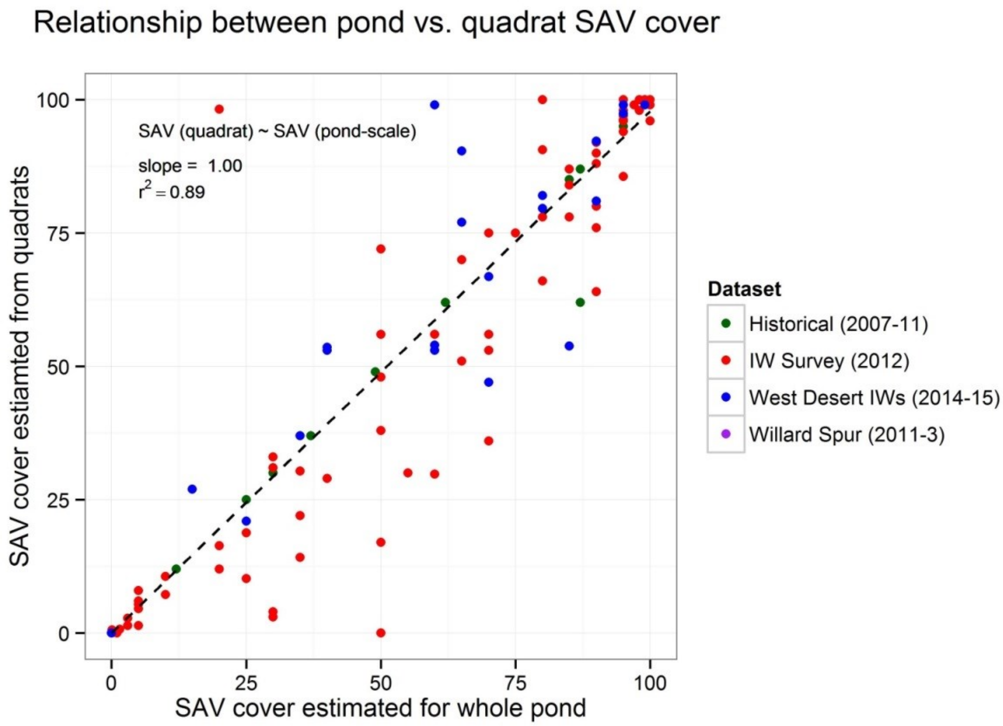

Figure 8. Correlation of SAV cover measurements at quadrat versus whole-pond scales

Seasonal patterns in SAV cover within sites were not widely available from the IW datasets, largely because repeat SAV data were not consistently collected across the growing season during most years of the Historical IW surveys. However, results from the Willard Spur study provide some site-specific data on the timing of SAV growth, where a year with high water inflows (2011) had a longer period of maximum SAV cover compared to two drier years (2012 and 2013) that had earlier but shorter peak in SAV cover (DWQ, 2015; *draft report not yet released*).

Where data were available, index periods (IPs) were calculated for the Historical and Willard Spur datasets in order to maintain a consistent basis for temporal comparisons among wetland surveys. IP dates were based on the range from the IW 2012 Survey. Index Period #1 (IP-1) included sampling dates from 6/21 to 8/8, and Index Period #2 (IP-2) included dates from 8/28 to 9/19. The sampling interval ranged from 36 to 70 days.

From a SAV cover dataset of 509 observations (across all four datasets), SAV cover over both IPs could be examined for 108 observations. Four distinct patterns of change in SAV between IPs were observed in the IW datasets (Figure 9), similar to those described previously for the IW Survey (DWQ, 2014):

(1) Extensive stands of SAV (> 65% cover) that persist across index periods;
(2) Pronounced decline in SAV prior to IP-2;
(3) Little to no SAV cover (< 20% cover); and
(4) Increasing SAV cover between index periods.

Previous work on GSL wetlands raised concerns about whether water quality-based stresses to impounded wetlands could affect SAV health and persistence, and possibly impact populations of migratory waterfowl arriving in autumn (Miller and Hoven, 2007; DWQ, 2009; USFWS, 2009). All four patterns of SAV growth were observed from GSL and West Desert IWs (top three panels in Figure 9), while results from Willard Spur predominantly show pronounced declines in SAV cover before early autumn.

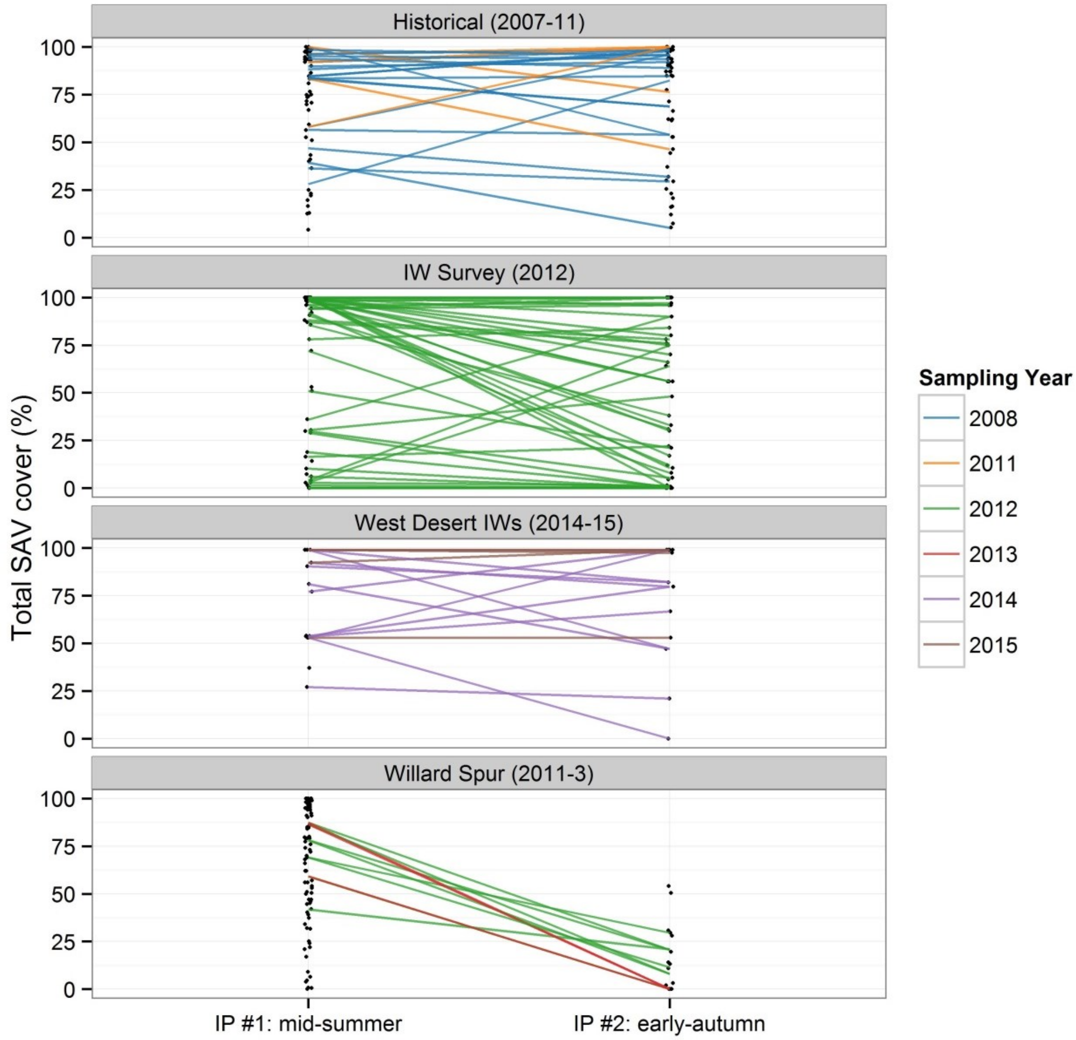

Figure 9. Seasonal change in SAV cover between Index Periods

This is not entirely unexpected, in that IW water management is directed toward maintaining healthy SAV stands through the early autumn period via stable to slightly increasing water depths, while water levels in Willard Spur decline throughout this time period. Around 50% of West Desert sites displayed persistent and high SAV cover, with a few sites increasing across IPs, consistent with the expectation that healthy IWs, with low amounts of external stress from urban or industrial development, should be able to maintain healthy stands of SAV through the summer and early-autumn periods.

A few West Desert sites displayed low or declining SAV cover – two are Clear Lake WMA sites, with shallow water depths and deep soft muck. Site records suggest that these ponds are wet all year long and managed more for winter goose than autumn 'tipping' or 'diving' ducks. Differences in management goals and techniques (e.g. lack of cold-season drawdown) could affect temporal patterns of SAV. Another West Desert site is located in Fish Springs NWR and is currently managed for early and late-season shorebird habitat. This site is undergoing a management transition where the pond may be drawn down in mid-summer, between the sampling index periods, such that very little SAV (mostly *Chara* sp. currently) persists into early autumn (i.e. only in the deepest portion of the pond). An alternative explanation for low and declining SAV cover could be nutrient limitation, particularly at the West Desert sites. Nutrient concentrations in the water column and surface soils are presented later in this report, however, the high SAV cover at these same locales casts some doubt on this mechanism for SAV decline.

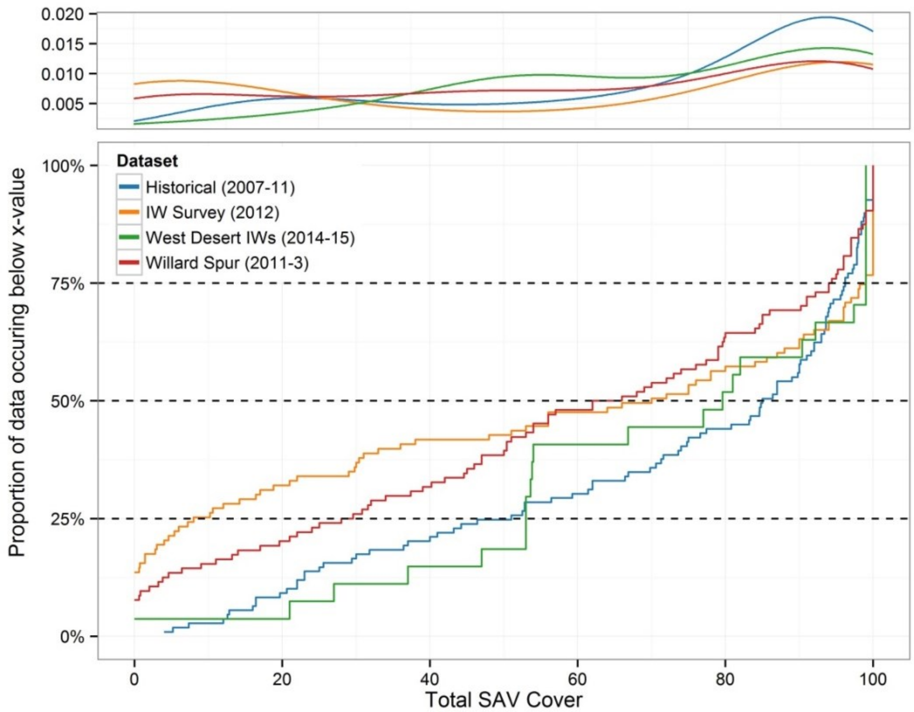

Figure 10. Cumulative distribution of Total SAV cover, among datasets

The prevalence of high vs. low SAV cover across datasets is shown in Figure 10. There was little difference among datasets at higher SAV cover (upper righthand corner of Figure 10); the upper quartile (highest 25% of sample visits) during the two index periods was greater than 75%, and median values ranged from ~ 80% cover (Historical data) to ~ 60% (IW Survey and Willard Spur). However, SAV cover for the lowest quartile of site observations ranged from approximately 50% for both the Historical and West Desert sites to 30% and < 10% cover for the Willard Spur and IW Survey data, respectively. The probabilistic 2012 IW Survey collected data over a wider gradient of SAV cover (and presumably SAV health / vigor) than the West Desert (potential reference standard) sites and the Historical IW sites.

To standardize changes in biological response metrics across the growing season, we calculated an 'Index of SAV Cover' to describe the observed change in SAV growth between index periods. The index is a weighted sum of SAV cover for both summer and early-autumn IPs, but the cover of SAV in early-autumn (IP-2) is given twice the weight of IP-1 to reflect the greater importance of high SAV cover for waterfowl use later in the growing season.

SAV Index = (SAV.cover[IP-1] + 2 * SAV.cover[IP-2]) [1]

The Index scores range from 0 to 300, but have been relativized to the maximum score (300) in the following figures. The highest scores reflect situations where extensive cover persists across index periods, moderate scores primarily reflect SAV cover that 'tanks' between IPs, and low scores reflect little to no SAV cover throughout the growing season (Figure 11). A second index score was developed, which incorporates an assessment of SAV vigor into the calculation, however, these results did not provide a clear improvement over the SAV Index described above (Eqn. 1)(*data not shown*), and may have some methodological limitations due to variations in SAV condition class that remain unresolved. Further work will examine this index, since measures of SAV canopy health appear to be a sensitive and useful response to elevated nutrient levels (Hoven et al., 2014).

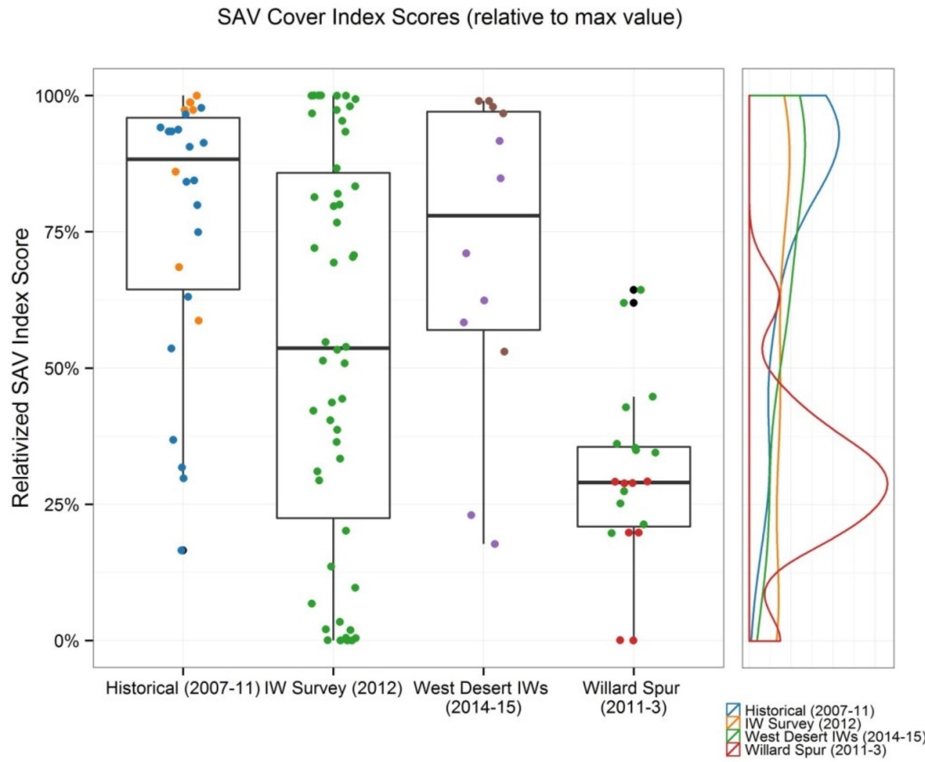

Figure 11. Distribution of SAV Index Score among datasets

Interestingly, the data from IW survey contain the greatest amount of variation in SAV cover (Figure 10) and SAV Index Scores among all datasets (Figure 11). This highlights the importance of probabilistic surveys in developing wetland assessment tools in addition to targeted surveys of sites along predicted disturbance gradients.

Among datasets, the Willard Spur data clearly have lower SAV Index Scores than the other datasets and have a narrow range of variation in Scores. In contrast, the Historical and the West Desert data have higher SAV Index Scores across the 25th and 50th percentiles than the 2012 Survey. The 2012 Survey appears to have a nearly uniform distribution of SAV scores (as evidenced by site-scores distributed across the full range of possible values).

If we apply the statistical definition of SAV health from the 2014 IR to these datasets, then nearly 50% of sites from the Historical and West Desert surveys had 'GOOD' SAV health. Similarly, approximately 25% of Willard Spur sites had 'POOR' SAV health, but less than 10% of Historical or West Desert sites were 'POOR'.

In summary, IWs from the West Desert survey generally have higher total SAV cover (> 50%) and higher SAV Index Scores than the 2012 IW Survey sites, consistent with our expectation that IWs situated in areas with lower stress from urban and industrial development would have higher SAV health. The lowest SAV Index Scores from West Desert sites (Clear Lake Unit 2 and Fish Springs Harrison Pool), with values less than 25% of maximum scores, may be a consequence of wetland water-management techniques that differ from the other sites (e.g. summer drawdown and persistent inundation during the cold season), suggesting that pond management may have a substantial effect on biological conditions within the ponds.

A preliminary breakpoint between 'GOOD' and 'FAIR' classes of SAV condition, based on the West Desert IW sites, is proposed at the 25th percentile, with an SAV Index Score of approximately 60% of the max (Index Score of ~ 180 out of 300)(Figure 11).

4.2.3 Wetland Macroinvertebrates

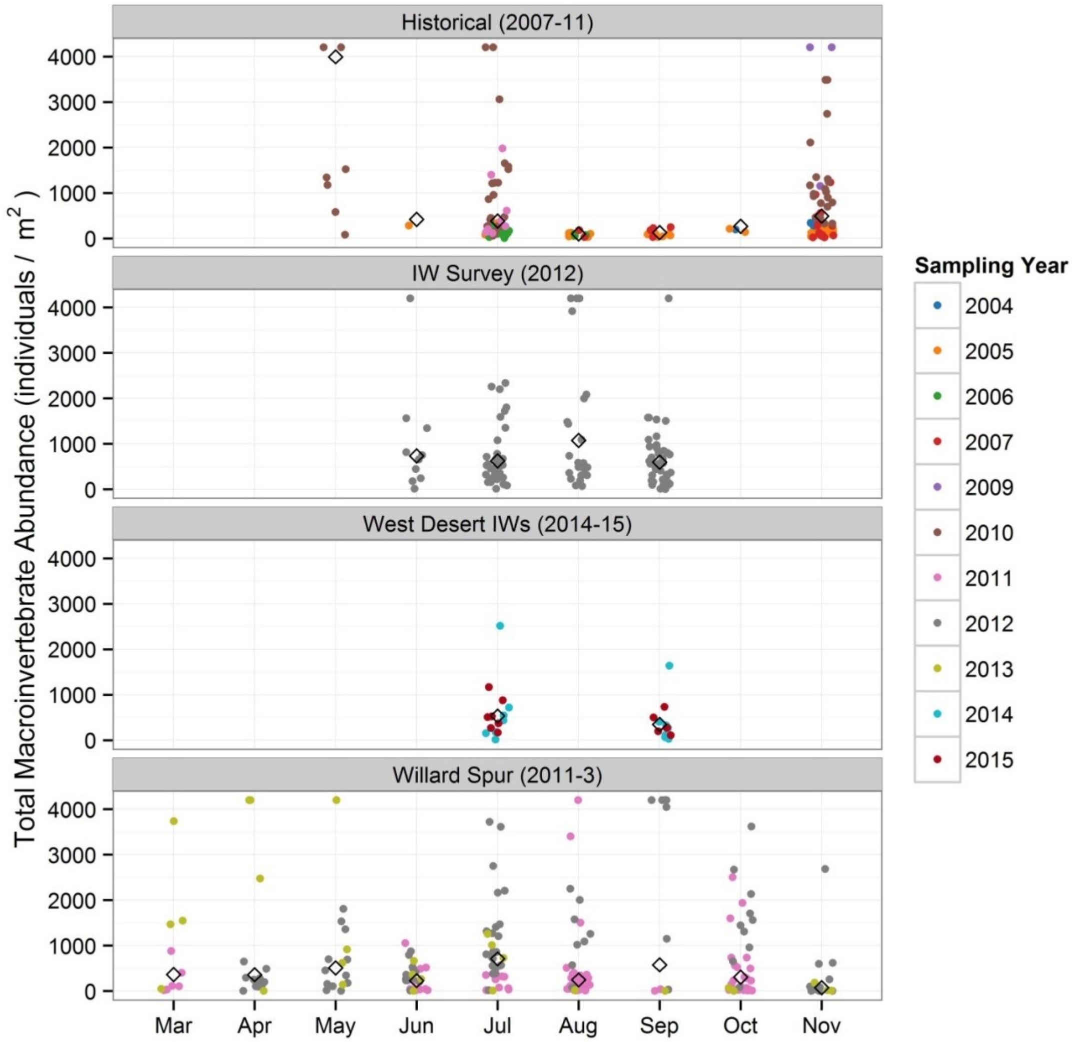

Figure 12. Seasonal patterns in macroinvertebrate abundance

The abundance of benthic macroinvertebrates varied by nearly two orders of magnitude among sample collections (Figure 12). These abundance estimates are based on an expected sampling intensity of five (5) sweeps (30 cm wide D-net x 100 cm swath) along 100-m transects adjacent to the sampling location. Across all datasets, benthic macroinvertebrate abundance was low (< 200 individuals / m^2) in approximately 35% of samples (192 of 546 sample collections); it remains unclear whether these observations reflect methodological issues (i.e. fewer sweeps performed) versus actual low abundance. Conversely, approximately 6% of sites had more than 2500 individuals / m^2, and taxa were typically dominated by either chironomids (75% of high-abundance samples) or snails (25%).

While it is possible that sampling protocols differed among datasets, this is most likely for the Historical data, since methods were rapidly being developed during that time. This is supported by the wide variation in invertebrate abundance from month to month for the Historical dataset, as well as the greater abundance in later versus earlier years (2010 / 2011 vs. 2004-2009)(Figure 12), compared to the other datasets. Because of this, broad temporal trends in abundance are difficult to identify across datasets.

Across datasets, it does appear that the abundance of invertebrates from the West Desert sites were generally lower than for sites from the IW 2012 Survey during the summer and early-autumn index periods (Figure 13).

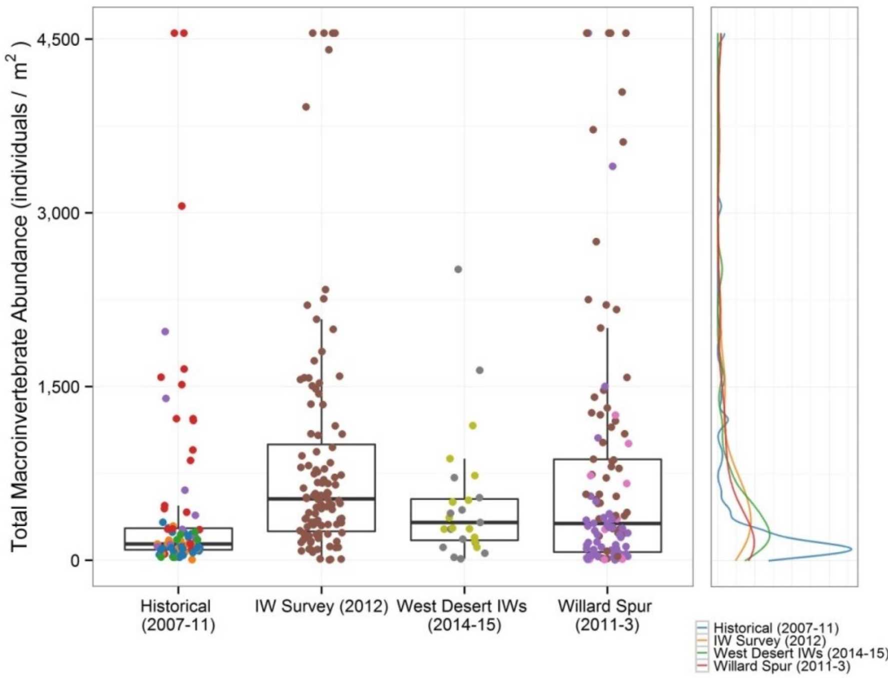

Figure 13. Distribution of macroinvertebrate abundance, among datasets

From these data, the next step would be to determine the biomass of benthic invertebrates within the wetlands. Recent work integrating Great Salt Lake wetlands into broader a spatial framework to support migratory waterfowl and shorebird conservation goals has begun to utilize avian energetic models as a way to link wetland quantity and quality with seasonal measures of bird abundance from broad-scale surveys (IWJV, 2013a; 2013b; 2013c). Since benthic macroinvertebrates commonly represent a key food resource for many waterfowl and shorebird species (Vest and Conover, 2011; Barber and Cavitt, 2012; Cavitt, 2013), there is a clear need for accurate and representative measurements of invertebrate biomass from GSL wetlands. DWQ recognizes the importance of this work and the need for timely and accurate data. Unfortunately, work remains to be completed on the IW macroinvertebrate datasets, in terms of completeness and consistency across datasets and over time, before IW invertebrate biomass data can be released. Once this work is completed, these data will be incorporated into DWQ Wetland Program planning documents and reports, and distributed to interested parties.

The number of macroinvertebrate taxa ranged from 1 to 18 across all four datasets (Figure 14). There was little evidence for a clear seasonal pattern in taxa richness (data not shown); except that the Willard Spur dataset showed peak richness in July compared to the other months (March through November).

Interestingly, taxa richness from the West Desert sites was not greater than for the other datasets, as might be expected for reference standard sites. This suggests that the number of taxa, in general, is not the most sensitive indicator of the relative health (i.e. condition) of impounded wetland macroinvertebrate communities. As seen for other biological response metrics, the IW Survey (2012) dataset spans the full range of the observed variation in macroinvertebrate abundance (Figure 13) and taxa richness (Figure 14).

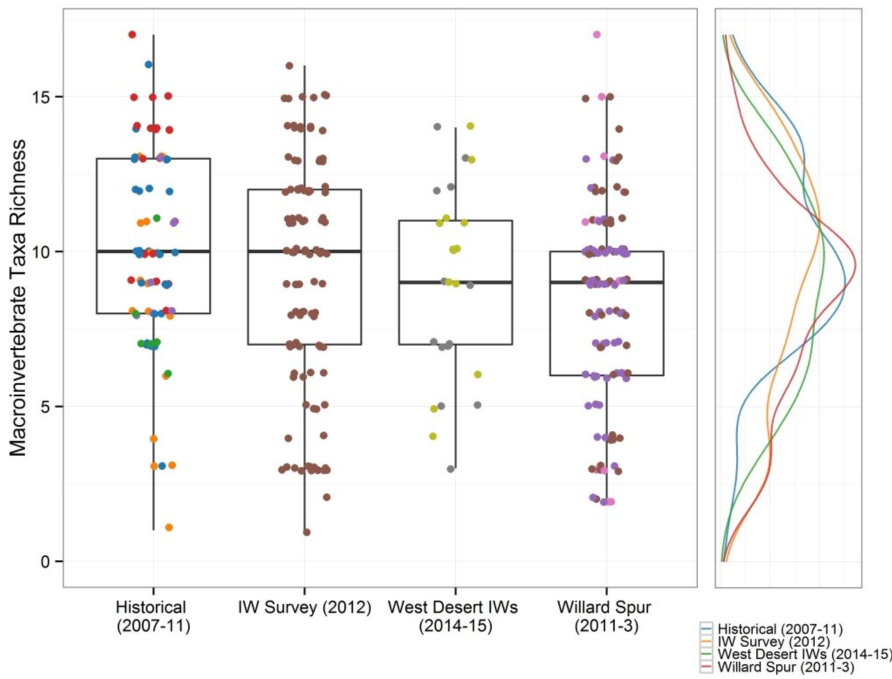

Figure 14. Distribution of macroinvertebrate taxa richness, among datasets

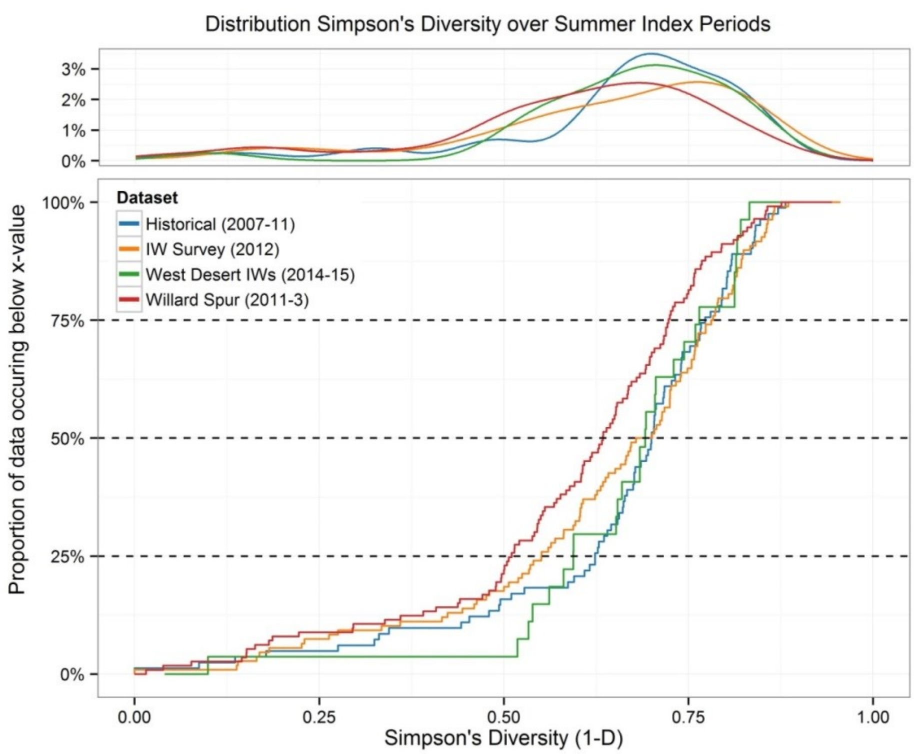

Figure 15. Cumulative distribution of a macroinvertebrate taxa diversity index (Simpson's, 1-D), among datasets

Simpson's diversity index (SI, calculated as the complement 1-D) represents the probability that any two randomly selected individuals from a sample below to different taxa. For two samples with the same taxa richness, one with a more even distribution of individuals per taxa has a higher SI than a sample where one (or a few) taxa are dominant.

The SI values range from 0 (samples with only 1 taxa were set to SI of 0) to 0.89 across all datasets (Figure 15). , while the effective range for SI values across all datasets is 0.50 to approximately 0.80, based on the 10th and 90th percentiles, respectively. There is little difference in the distribution of SI values among datasets. A report by Dr. Larry Gray (Gray, 2015) summarizing three years of macroinvertebrate data for the Willard Spur Water Quality Study shows that SI values vary seasonally and in response to water availability (inflows) to the wetland. The West Desert sites have SI values indicative of moderate levels of taxa diversity (as evenness; 75% of samples have SI greater than 0.63), and are not indicative of samples dominated by a great abundance of few taxa (e.g. either chironomids or snails). Additional analyses in this report and forthcoming work will look more closely at whether this aspect of macroinvertebrate diversity is closely associated with other biological response or physical/chemical aspects of the IWs.

Benthic macroinvertebrate communities of GSL-IWs, based on results from the 2012 IW Survey, were typically composed of six taxonomic groups: odonates, mayflies, hemipterans, chironomids, snails, and the amphipod *Hyalella*; and most taxa were generally quite tolerant of stressful aquatic conditions, including low dissolved oxygen, high pH, and warm temperatures (L. Gray, *unpublished discussion notes* [May 2013]). In addition, those preliminary analyses suggested little effect of SAV species (*Chara* versus *Stuckenia*) on invertebrate community composition, but the absence of SAV had a pronounced effect on the invertebrate community, particularly the dominance of chironomids (and occasionally snails) over other taxa.

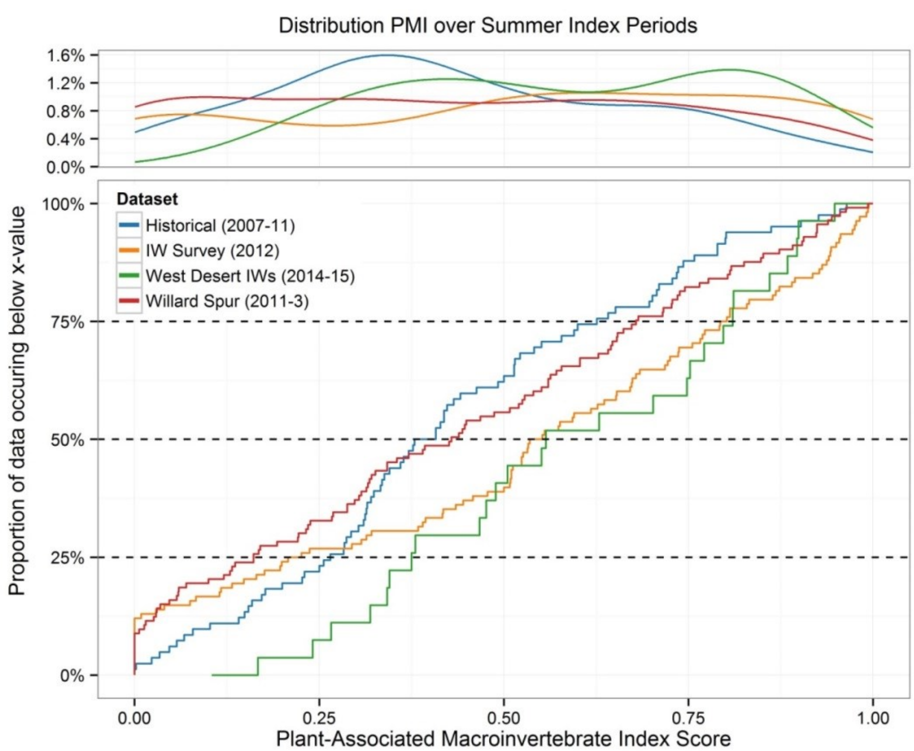

Figure 16. Cumulative distribution of Plant-associated Macroinvertebrate Index (PMI), among datasets

A second measure of macroinvertebrate community composition is the Plant-associated Macroinvertebrate Index (PMI, also as 'Phytophilous Macroinvertebrate Index' *sensu* Gray (2015)), which describes the relative abundance of taxa considered to be reliant on SAV for habitat and/or as a food source(Table 5). PMI values ranged from 0 to 1.0 across the datasets (Figure 16), with West Desert sites generally having higher PMI scores

Table 5. Macroinvertebrate Taxa used to calculate PMI Index Scores

Order	Family	Genus	Taxon Code	Feeding Group
Ephemeroptera	Baetidae	*Callibaetis*	273	GC
	Caenidae	*Caenis*	286	GC
Trichoptera	Leptoceridae	*Ylodes (Phryganea)*	432	SH
Odonata	Coenagrionidae	*Ischnura + Enallagma + Amphiagrion*	350	PR
	Lestidae	*Archilestes*	354	PR
	Libellulidae	*Erythemis + Sympetrum + Libellula*	356	PR
Hemiptera	Corixidae	*Hesperocorixa*	330	PH/PR
Coleoptera	Haliplidae	*Haliplus*	151	SH
	Chrysomelidae	(larvae)	none	SH
Mollusca: Gastropoda	Planorbidae	*Gyraulus*	505	SC

Feeding Groups correspond to: GC = Gatherer-Collector; PH = Piercer-Herbivore; PR = Predator; SC = Scraper; SH = Shredder

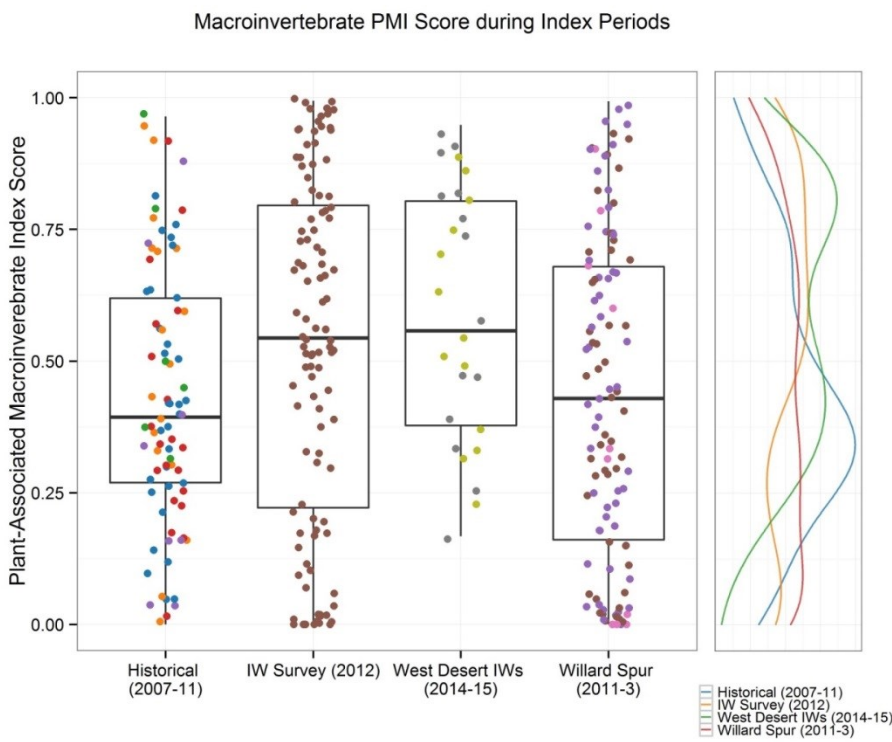

Figure 17. Distribution of macroinvertebrate PMI, by dataset

Across datasets, PMI values tended to be higher in the IW (2012) Survey and West Desert sites (Figure 17) compared to the Historical and Willard Spur datasets, and once again, samples from the IW Survey spanned the entire range of possible PMI values. Gray (2015) reported that high-water years in Willard Spur had similar seasonal patterns in PMI as IWs with high SAV cover, while low-water years in Willard Spur and IWs with low SAV cover both had low PMI values, but distinct seasonal patterns.

Previous reports that used macroinvertebrate communities to assess impounded wetland health combined several aspects of the community into an Index of Biotic Integrity (IBI) or a Multimetric Index (MMI) (DWQ, 2009; CH2MHill, 2014; DWQ, 2014). These efforts had varying degrees of success, but were generally not verified due to limitations in sample size or were difficult to tie to other measures of biological response (based on Historical data). Development and testing of potentially useful indices describing changes in macroinvertebrate community composition will be an important and ongoing effort and it one of the principal reasons these wetland datasets were compiled.

In summary, macroinvertebrate abundance was commonly on the order of 400 (median) to nearly 1000 individuals per m^2 (geometric means) across datasets, but very high densities (> 2500 individuals per m^2) were observed when either chironomids or snails were particularly abundant. Taxa richness ranged from 1 to 18 across datasets, with median values between 8 and 10 taxa per sample; the current taxa list for GSL and West Desert wetlands includes 76 individual taxa organized into 67 'Taxon Codes' (due to varying specificity of identification among datasets). Simpson's Diversity Index ranges from 0.5 to 0.89 across all datasets, and based on work from the Willard Spur project, may be sensitive to both seasonal and hydrologic variations. PMI index values appear to be sensitive to broad differences in SAV cover and water availability.

Macroinvertebrate communities from West Desert IW sites were not clearly more diverse or more abundant compared to either the Historical or the probabilistic (IW Survey) sites. As such, it is difficult to suggest any breakpoints for distinguishing 'GOOD' versus 'FAIR' condition classes using the West Desert sites as reference standards. However, based on two years of sampling the West Desert sites, we are starting to get a sense of the range of variation among IWs with very little external urban or industrial stress, compared to the GSL IWs. As a preliminary benchmark, applying the 25th percentile for taxa richness, SI, and PMI measurements to distinguish 'GOOD' versus 'FAIR' condition classes may be a useful approach and is consistent with the concepts behind Stoddard et al.'s (2006) '*Best Attainable Condition*'.

4.3 Physical and Chemical Characteristics

In this section, key temporal (seasonal) patterns and differences among datasets are described for general physical characteristics of the ponds, as well as for concentrations of major ions, toxic metals, and nutrients within the water column. The physical and chemical parameters of shallow ponds, such as water depth, temperature and salinity are major drivers of wetland structure and function, and serve as significant controls on the composition of biological communities. The major ions within the water column have important effects on the toxicity of some soluble metals and can be used to identify distinct water sources to wetlands. Concentrations of toxic metals were evaluated against aquatic life use numeric criteria, as benchmarks, while the distributions of nutrient concentrations (and nutrient ratios) were evaluated in terms of a fertility/eutrophication gradient among IWs.

Summary characteristics for water chemistry data from all impounded wetland sites (i.e. excluding Willard Spur data) are provided in Table 6. This table includes the units of measure for each parameter, a laboratory-generated minimum reporting level (MRL; generally synonymous with Practical Quantitation Limit [PQL]), number of samples below the MRL, and the number of observations. In addition, the distribution of each parameter is described by the 25th, 50th (median) and 75th percentiles of data, as well as the range of values observed. Lastly, when appropriate values were available, benchmarks were provided that describe important break points or numeric criteria for protection of aquatic life uses. When benchmark data were available, the number of samples exceeding the benchmark are listed as well. Some benchmarks can only be expressed as a function of other parameters, for example ammonia toxicity criteria are a function of both pH and temperature – for these cases, the benchmark listed in the table was calculated from the median of the independent variables, however, the number of exceedences was tallied using the appropriate calculation for each case.

4.3.1 Physical Parameters

4.3.1.1 Water Depth

Pond water depth is clearly a key element controlling all aspects of the physical and chemical structure, community composition, and functional aspects of impounded wetlands. Unfortunately, most of the water depth data from the Historical dataset could not be located from site observations before 2010 (only 62 of 1122 (5.5%) water chemistry observations included water depth). As such, no consistent temporal pattern within or among datasets emerges (Figure 18). However, there are two interesting details that appear from Figure 18. First, most water depths fall within the 25 to 75 cm target for IWs as set in the SAP for the 2012 survey (DWQ, 2012). Second, results from the Willard Spur dataset show that water levels within some GSL wetlands vary widely with differences in annual precipitation or surface water inflows. Continued monitoring of IWs over time will improve our understanding of the timing and magnitude of changes in water depth from these ponds and to what degree these changes affect other biological response and chemical characteristics.

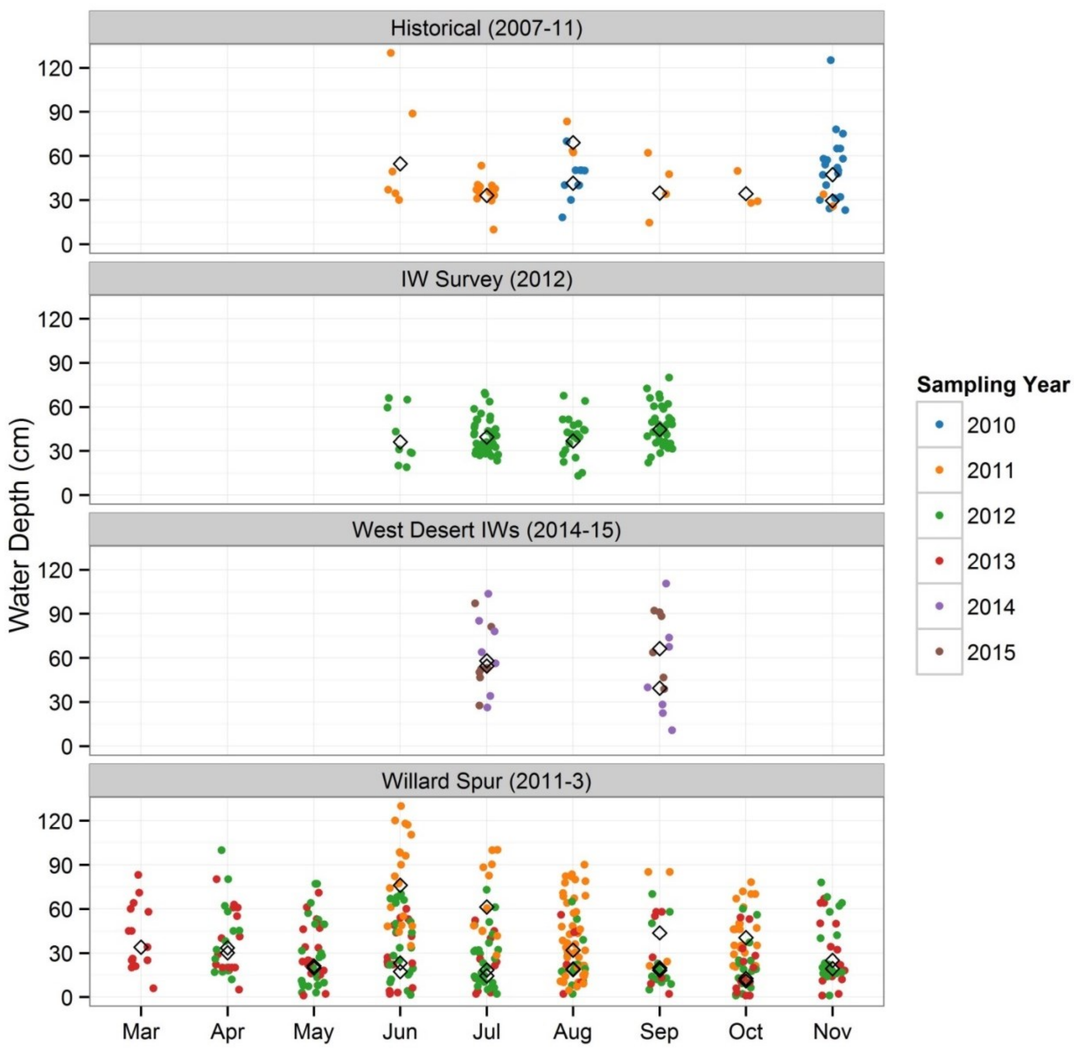

Figure 18. Seasonal patterns in water depth

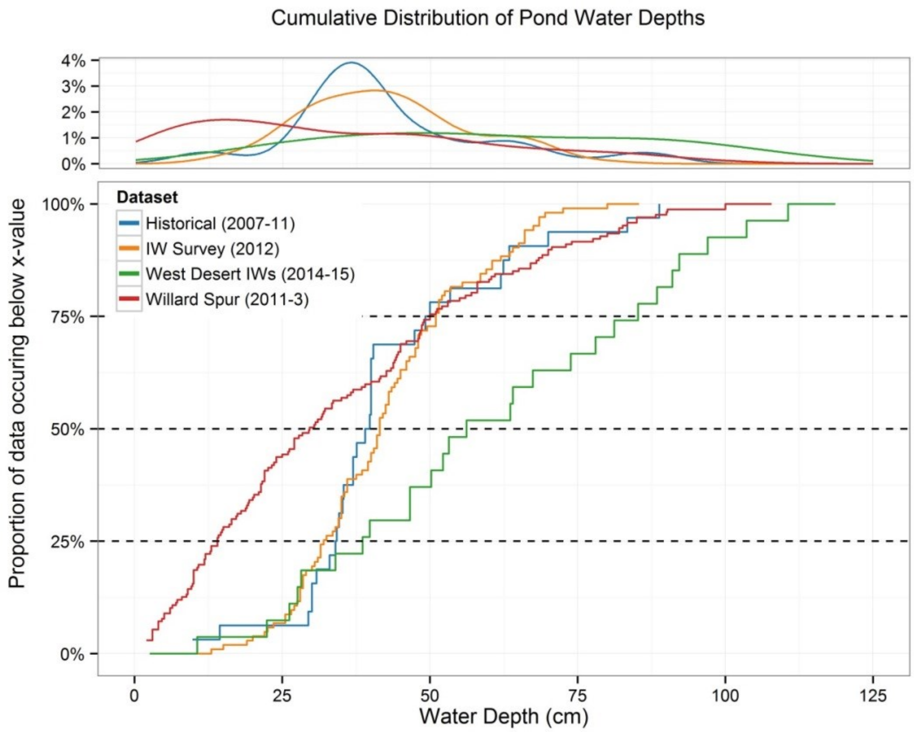

Figure 19. Cumulative distribution of water depth of impounded wetlands, by dataset

When the available data are restricted to the summer and early-autumn index periods we see that the Willard Spur dataset includes more sampling locations with shallow water depths, where the 25th percentile for Willard Spur data was approximately 12 cm (Figure 19), while the West Desert sites were generally deeper (median and 75th percentiles were approximately 55 and 80 cm, respectively).

4.3.1.2 Water Temperature

In contrast to the historical water depth data, observations of water temperature were compare across all datasets. Strong seasonal patterns of water temperature are shown in Figure 20, with peak pond temperatures in July and August, as expected. Strangely, the warm temperatures in January (> 10 °C) for the Historical dataset cannot be explained at this time (it is not known whether there is a sampling date error or a temperature-data transcription error). From both the Historical and the Willard Spur datasets, there appears to be an interannual range of roughly 5 °C during the summer.

As mentioned earlier in this report, many impounded wetlands associated with Great Salt lake have a water quality-based designated use class for aquatic wildlife, as provided for by the federal Clean Water Act and the Utah Water Quality Act (Title 19.5), protecting these waters as either warm-water fisheries (class 3B) or waterfowl and shorebirds (class 3D). Class 3B includes numeric criteria for maximum temperature (27 °C), but class 3D does not. This benchmark is shown as the horizontal dashed lines in Figure 20. These data show routine exceedance of the 3B temperature criterion in all datasets. As such, the application of this standard to impounded wetlands that are not expected to support the rearing of warm water fish should be may be inappropriate, since water temperatures > 27 °C can be observed even in remote IWs of the West Desert. However, this is not to say that warm temperatures do not matter for IW health, since hydrologic constraints (low inflows during summer irrigation season) and management techniques ('fill and hold' vs. 'flow through') could either alleviate or accentuate stress to sensitive organisms.

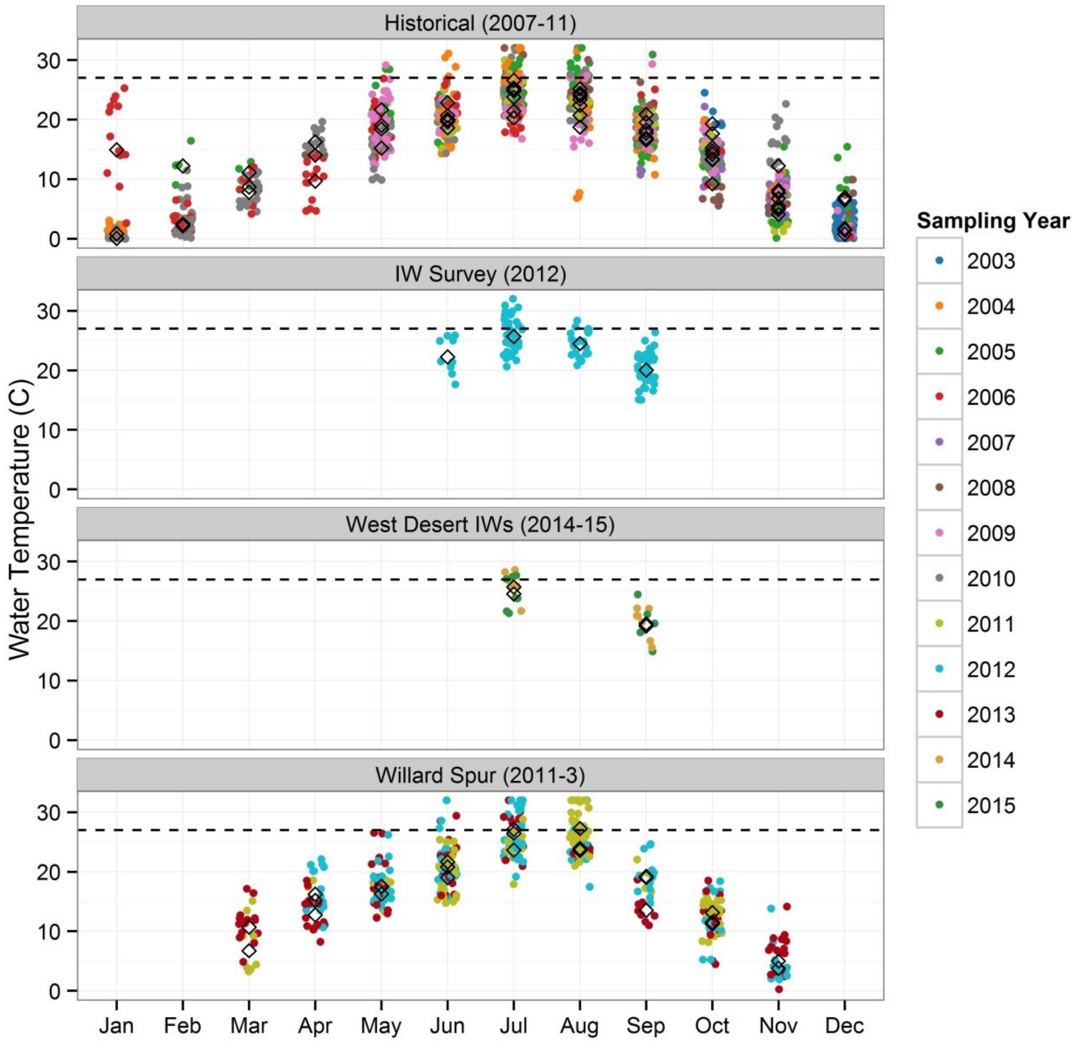

Figure 20. Seasonal patterns in water temperature

4.3.1.3 Water Salinity

The salinity of surface waters from wetlands associated with Great Salt Lake can vary widely, from fresh (< 500 µS/cm {Specific Conductance} or 270 mg/L {TDS}) to hypersaline (> 50,000 µS/cm or 30,000 mg/L). For a given waterbody, salinity typically varies as a function of inflows from typically fresh inflows, presence/absence of outflows, soil type, and the rate of evapotranspiration. Two measures of salinity are commonly reported for GSL wetland work: Specific Conductance, the electrical conductivity of water adjusted to a constant temperature (25 °C), denoted here as EC25; and Total Dissolved Solids (TDS), the weight of precipitatable salts after drying. Because specific conductance (EC25) is readily measured with DWQs field multiparameter probes, this value is used here. For GSL wetlands, EC25 is linearly related to TDS values (Figure 21).

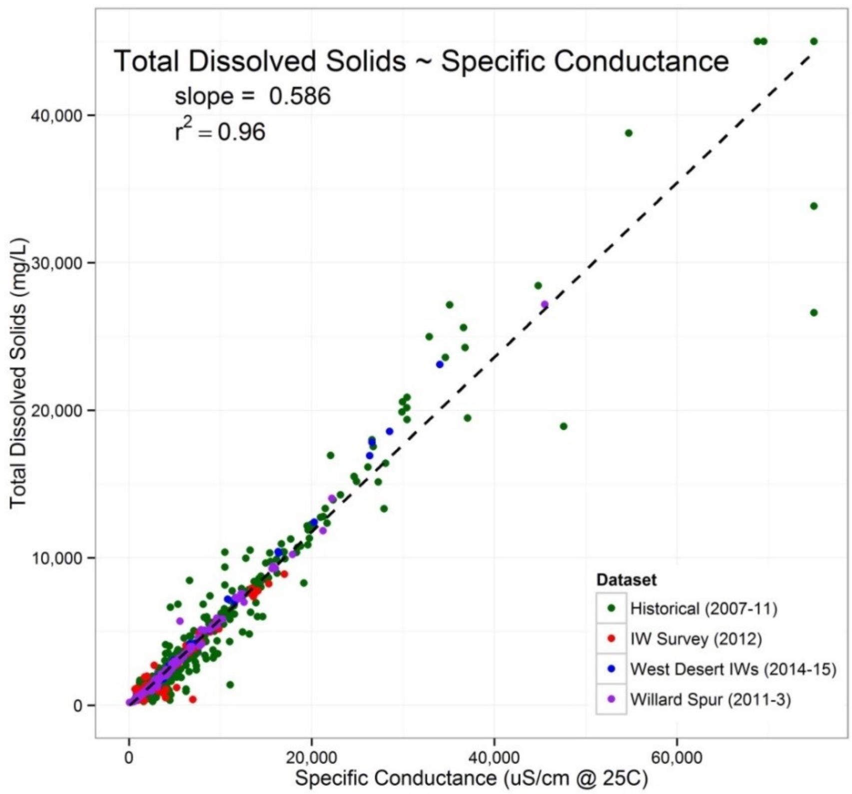

Figure 21. Relationship between Total Dissolved Solids and Specific Conductance for impounded wetlands

Previous work on GSL wetlands has found similar relationships between TDS and EC25, with the slope varying from 0.54 to 0.58. Among datasets, the slope of TDS-EC25 relationships varied from 0.542 (IW Survey) to 0.647 (West Desert), but these differences were not meaningful across the range of observed values.

Across datasets, there was little clear evidence seasonal patterns in the salinity of IWs (Figure 22). Ponds with the most saline waters (> 22,500 µS/cm) were generally uncommon (approximately the 97th percentile of all data) on the landscape (data not shown). While salinity plays an important and well-known role controlling the composition of aquatic communities, it is not year clear where the breakpoint lies between IW ponds that support waterfowl versus other aquatic life, such as shorebirds and their more saline food chain.

During the summer and early-autumn index periods, the West Desert sites had higher salinities than many of the other IW sites, largely because the springs that feed these ponds have salinities of approximately 3200 and 4450 µS/cm for Fish Springs and Clear Lake, respectively. We will continue to seek appropriate impounded wetland sites for use as potential reference standards, however, we suspect that spring discharge areas with low-salinity waters in a low-development landscape like the West Desert, that support shallow impoundments for waterfowl production, will be quite rare.

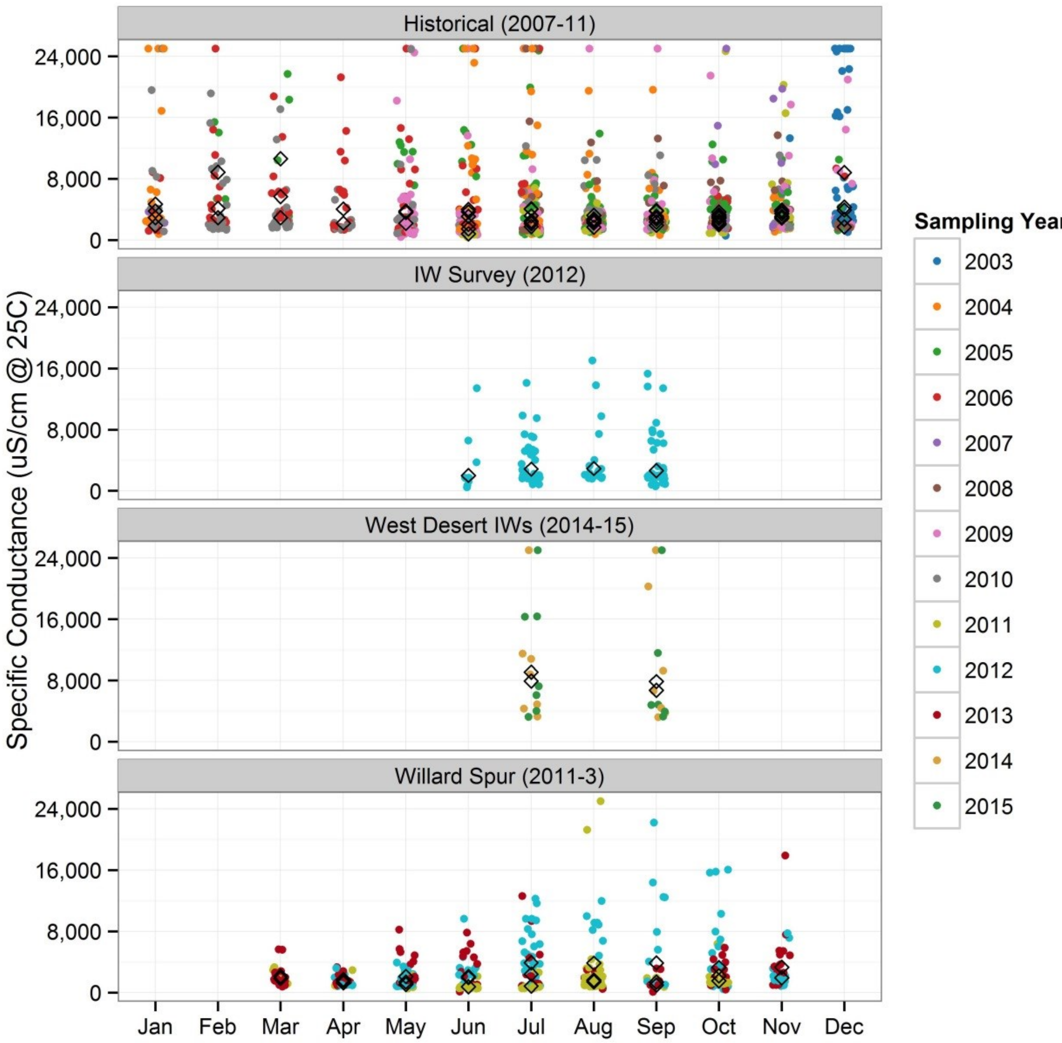

Figure 22. Seasonal patterns in Specific Conductance of impounded wetlands

4.3.2 Water Chemistry: Major Ions

The major ions present in IW surface waters are dominated by sodium (Na^+) and chloride (Cl^-) ions, accounting for 77% and 74% of cations and anions (molar basis), respectively, at waters near median salinity (TDS = 1030 mg/L). The remaining major cations are magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+), with 12, 7%, and 4% of cations, respectively. The relative importance of Na^+ increased with increasing TDS, K^+ remained constant, and Ca/Mg declined possibly as a result of Ca- and $MgCO_3$ precipitation at higher salinity. For the anions, bicarbonate (HCO_3^-) and sulfate ($SO_4^=$) accounted for most of the remainder, 13% and 13% respectively; carbonate ($CO_3^=$) concentrations were low in nearly all samples. The relative importance of Cl^- increased, while that of HCO_3^- decreased, with increasing TDS; interestingly, the relative importance of $SO_4^=$ was greatest at moderate (median) TDS.

Piper plots display the relative contribution of major cations (lower left triangle plot), anions (lower right triangle plot), and the most abundant cation-anion pairs (central diamond plot). These patterns are illustrated for all site means (n=141) in Figure 23, where the points represent the relative contribution of each ion on a per unit charge basis (i.e. units are meq/L, normalized to total cations and anions). Symbol sizes for all data points have been scaled by the range of TDS values, from approximately 300 to over 27,000 mg/L.

The composition of dominant cations (Figure 23, lower left) were reasonably well constrained across all datasets, where waters became more enriched in Na as TDS increased. The composition of dominant anions was more varied among datasets (Figure 23, lower right); while waters generally became more enriched in Cl^- at higher TDS, the West Desert sites tended to have slightly more $SO_4^=$ (approximately 25%) than other sites.

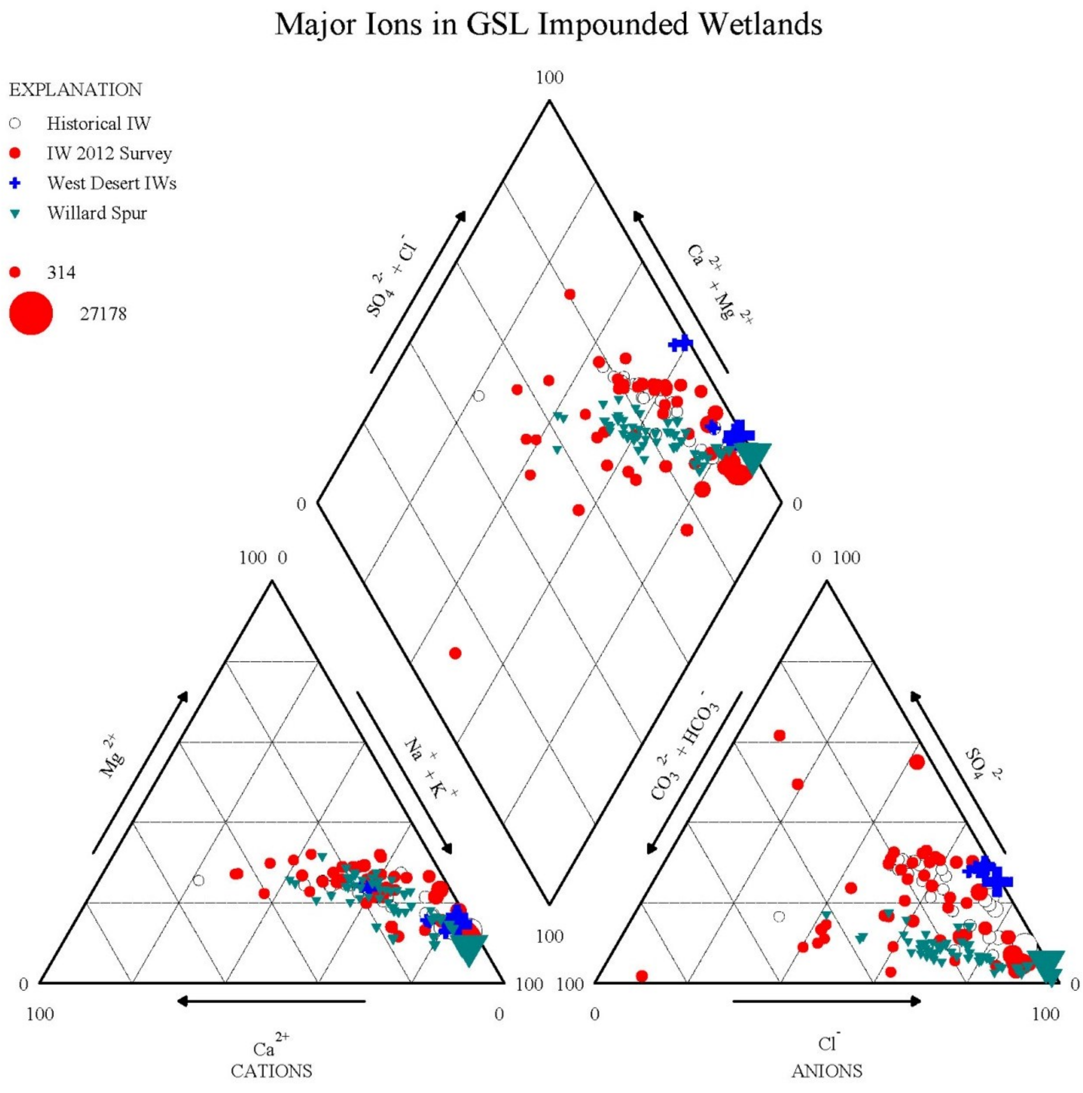

Figure 23. Piper plot of major ions in surface waters of impounded wetlands

Based on these results, it should come as no surprise that IW waters from GSL and West Desert areas have very high levels of Ca and Mg-based hardness (Table 6), with 25th and 75th percentiles of 294 and 486 mg $CaCO_3$/L, where aquatic pH levels can be strongly buffered between 7 and 9.

Table 6. Summary Characteristics of Water Chemistry Parameters for All Impounded Wetlands

Parameter	Units	MRL	Samples below MRL	Number of Observations	Percentiles *			Range	Samples Exceeding	Benchmark	Comments
					25th	Median	75th				
Standard Water Quality Parameters											
Temperature	° C			1252	9.01	17.75	26.15	35.83	86	27.0	Max. temperature for Utah Aquatic Wildlife Use 3B (warm water fish and necessary food chain) (see UAC R317-2-14)
pH	-			1242	8.50	8.93	9.37	4.29	550	<6.5 or >9.0	See Note [1]
Specific Conductance	µS/cm			1208	1,668	2,341	4,872	85,423	183	7,500	Tolerance for freshwater marsh (See Keate, 2005)
Total Dissolved Solutes (TDS)	mg/L	10		1113	983	1,324	2,655	49,344			
Dissolved O_2	mg O/L			1191	6.52	9.18	11.80	32.87	164 / 62	5.0 / 3.0	See Note [1]; Exceedance refers to DO concentrations *below* the benchmark.
Dissolved O_2	% saturation			1186	79.25	104.5	140.25	458.1			
Chlorophyll-a	µg/L			567	2.7	8.1	23.8	297.7			
Nutrient and Organic Matter Concentrations											
Ammonium (NH_4)-N, total	mg N/L	0.05	330	1062	0.025	0.100	0.210	26.59	189	0.367	See Notes [1] and [2]. Benchmark shown is based on the median values for pH and Temp (pH 8.93 and Temp 17.75 °C), for ammonia toxicity.
Nitrate + Nitrite (NO_3 + NO_2)-N, total	mg N/L	0.01	72	1064	0.020	0.038	0.076	4.198	22	[4.0]	See Note [3]. MRL values varied widely among the three IW datasets, from 0.002 to 0.10; value represents median.
Organic N, total	mg N/L			555	0.561	0.784	1.036	7.391			
Total N, total	mg N/L			559	0.775	1.080	1.840	25.278			
Phosphorus, total (digested)	mg P/L	0.02	44	801	0.061	0.187	0.494	7.205	638	[0.05]	See Note [4]
TN:TP ratio	-			288	3.50	8.06	21.21	349			
Organic Carbon, dissolved	mg C/L	0.5		130	8.05	11.45	16.65	48.64			
TOC:TON ratio	-			127	12.11	14.9	17.49	69.50			
Suspended Solids, total (TSS)	mg/L	4	118	1042	7.6	19.1	49.1	4,456			
Volatile Solids, total (TVS)	mg/L	5	66	130	2.5	2.5	11.05	87.68			
TVS:TSS ratio	-			130	0.24	0.37	0.68	0.93			
Major Anion and Cation Concentrations											
Sulfate (SO_4)	mg S/L	20		878	127.0	209.0	287.0	7,929			
Chloride (Cl)	mg Cl/L	1			251.2	478.5	934.7	1,536.4			
Flouride (F)	mg F/L	0.05	2		0.40	0.62	0.79	1.96			
Calcium (Ca)	mg Ca/L	1			66.67	75.70	93.02	271.60			
Magnesium (Mg)	mg Mg/L	1			38.52	49.35	71.27	137.60			
Potassium (K)	mg K/L	1			17.05	21.70	35.62	87.04			
Sodium (Na)	mg Na/L	1			168.2	337.5	583.7	2,433.2			
Iron (Fe)	µg Fe/L	20	450	595	10	10	12.5	3,284	9	1000	See Note [1]. MRLs varied with sample dilution, from 20 to 80 µg Fe/L.
Manganese (Mn)	µg Mn/L	5	314	598	2.5	2.5	12.5	243.6	31	80	See Note [7]. MRLs varied with sample dilution, from 5 to 50 µg Mn/L.
Hardness, total (as $CaCO_3$)	mg $CaCO_3$/L			598	293.7	387.8	485.8	4,702			
Trace Metal Concentrations											
Silver, dissolved (Ag)	µg Ag/L	0.5	296	468	0.25	0.25	1.0	49.75	2	33.1	See Note [6], acute criterion. Benchmarks shown are median of calculated site values.
Aluminum, dissolved (Al)	µg Al/L	10	351	596	5	5	15	295	0	750	See Note [1]; acute value for dissolved metal.
Arsenic, dissolved (As)	µg As/L	1		534	7.34	11.40	18.50	119.3	0 / 0	150 / 340	See Notes [1] and [6]; acute value for dissolved metal.
Boron, dissolved (B)	µg B/L	30	0	420	246	317	485	18,358	53	750	Benchmark is acute value for Agricultural Use class (4).
Barium, dissolved (Ba)	µg Ba/L	100	321	457	50	50	112.5	422	0	1000	See Note [5].
Cadmium, dissolved (Cd)	µg Cd/L	0.1	401	595	0.05	0.05	0.50	24.95	90	0.63 / 7.0	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Cobalt, dissolved (Co)	µg Co/L	30	14	14	15	15	15	0	14	3.0 *	See Note [7]. Note that screening level is 10x lower than MRL
Chromium, dissolved (Cr)	µg Cr/L	2	198	416	1.00	2.24	2.50	49.0	0 / 0	224.9 / 1729	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Copper, dissolved (Cu)	µg Cu/L	1	3	598	2.16	3.50	6.00	119.50	30 / 10	28.5 / 48.2	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Nickel, dissolved (Ni)	µg Ni/L	5	410	598	2.5	2.5	2.5	187.5	1 / 0	163.7 / 1474	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Lead, dissolved (Pb)	µg Pb/L	0.1	25	597	0.39	0.96	1.57	280.0	38 / 1	9.3 / 238.3	See Notes [1] and [6]. Benchmarks shown are median of calculated site values.
Selenium, dissolved (Se)	µg Se/L	1	419	688	0.50	0.5	1.42	50.0	34 / 4	4.6 / 18.4	See Note [1].
Mercury, dissolved (THg)	µg THg/L	0.2	530	533	0.1	0.1	0.1	0.21	533	0.012	See Note [1]. Note that screening level is 8x lower than MRL.
Zinc, dissolved (Zn)	µg Zn/L	10	308	597	5.0	5.0	15.0	295	0 / 0	372.5 / 369.5	See Notes [1] and [6] Benchmarks shown are median of calculated site values.
Toxic Ligands											
Hydrogen Sulfide, total (H_2S)	mg S/L	0.1	118	127	0.05	0.05	0.05	0.20	34	0.002	See Note [1]; value is a function of pH (see Note [8].

Notes: Samples were collected from representative, open water areas of impounded wetlands as specified in appropriate sampling and analysis plans. *Willard Spur results are not included in this table*.

[1] See R317.2, Table 2.14.2 for Aquatic Wildlife Use (3D).

[2] For ammonia toxicity, chronic criteria is a function of both pH and temperature, with parameters based on fish early life-stages present..

[3] Nitrate listed as a pollution indicator in R317.2, Table 2.14.2 for Aquatic Wildlife Use, but no value provided for use class 3D. Wildlife use classes 3B (warm water fish) and 3C (non-game fish) have value of 4.0.

[4] Total phosphorus listed as pollution indicator in R317.2, Table 2.14.2 for Aquatic Wildlife Use (3B) value of 0.05; value for lakes and reservoirs is 0.025.

[5] See R317.2, Table 2.14.1 for Human Health Use (1C); no value for Aquatic Wildlife.

[6] First value is for chronic criteria, corrected for hardness; second value is acute value (also corrected).

[7] Value is from Screening Quick Reference Tables (SQuiRT) for surface water (FW) (see: Link to NOAA).

[8] The proportion of undissociated $H_2S_{(aq)}$ from total hydrogen sulfide (measured value) was calculated from a thermodynamic model at 25 °C under freshwater conditions (ionic strength of 0.05 mM), and fitted to a sigmoidal curve: $H_2S_{(aq)}/H_2S_{total} = 1 - \left[1/\left(1 + e^{-\left((pH-\beta_0)/\beta_1\right)}\right)\right]$; where β_0 = 7.018, and β_1 = 0.434, estimates of the mean and standard deviation of 50 data points for pH from 4.0 to 10.0.

4.3.3 Water Chemistry: Trace Metals and Metalloids

Measurements of sixteen (16) trace metals and metalloids from the dissolved fraction (filtered < 0.45 μm) of water column samples were obtained over the course of the four wetland projects. Concentrations for many elements ranged from less than laboratory reporting limits to values that exceed acute benchmarks intended to protect aquatic wildlife uses (Table 6). DWQ continues to work with state- and university-led partner laboratories in an effort to optimize analytical sensitivity against sample analysis cost, particularly in waters where ambient factors, such as salinity of wetland surface waters, may degrade instrument sensitivity – either by sample dilution or measurement interference.

For cobalt (Co) and total mercury (THg), nearly all observations (14 of 14 for Co and 530 of 533 for THg) were below minimum reporting limits (MRLs), where constituents were positively detected but concentrations could not be quantified. While limited detection of toxic elements can mean that concentrations are low and therefore unlikely to affect sensitive aquatic organisms, this is not necessarily the case for Co and THg. Instead, because of instrument and/or methodological limitations, the MRLs are 10x and 8x higher than benchmark concentrations for Co and THg, respectively (Table 6). Until a suitable remedy for this issue can be found (either by improving analytical sensitivity or pursuing analytical services from alternative avenues), we recommend that monitoring for these elements be halted, or at least collected only sparingly.

For several elements, silver (Ag), aluminum (Al), arsenic (As), boron (B) and barium (Ba), chromium (Cr), nickel (Ni) and zinc (Zn), few samples exceeded benchmarks (Table 6), even when MRLs were far below benchmark concentrations (e.g. As and B). Note that the benchmark for B is not based on protection of aquatic life, but rather for agricultural irrigation and livestock watering uses; this value is presented for comparative purposes only, since there are no known agricultural withdrawals from impounded wetlands. Generally, these elements represent a low threat to the health of IWs.

Most soils within and adjacent to Great Salt Lake wetlands are dominated by limestone and other lacustrine deposits, where concentrations of iron (Fe) and manganese (Mn) (i.e. actively cycling forms of these elements) are typically low compared to areas with soils derived from more granitic or sandstone materials. Because the solubility of these elements is much greater under anoxic conditions, elevated concentrations of dissolved Fe and Mn above ambient levels are expected to highlight ponds with strongly reducing conditions within the water column or upstream source waters with high Fe/Mn levels. Concentrations of Fe and Mn were most often above ambient levels in the Historical and Willard Spur datasets (Figure 24), including 9 and 31 observations that exceeded the 1000 μg/L and 80 μg/L benchmarks for Fe and Mn, respectively (Table 6).

Eight metals (Ag, Al, Cd, Cr, Cu, Ni, Pb, Zn) have aquatic life benchmark criteria that are sensitive to the chemical conditions (as hardness or pH) of the surface water (Table 6). Aluminum is a special case, where a higher (acute) benchmark of 750 μg/L applies to alkaline waters (pH > 7.0) with greater than moderate levels of Ca-Mg hardness (> 50 mg $CaCO_3$/L). For Al, 10 of 351 samples were below detection and 0 samples exceeded the benchmark. For the remaining elements, the number of exceedances varied from 0 to 90 (Table 6). The effect of hardness on benchmark levels is illustrated for Ni and Cu (Figure 24), where differences in salinity and the relative importance of Ca and Mg as major ions drove variations in benchmarks within and among the datasets.

Distributions of observed concentrations of nine (9) dissolved metals are shown in (Figure 24), for all four datasets. There were no exceedances for Al or As, and only one for Ni. Concentrations above ambient (or baseline) were observed in the Historical, IW Survey, and Willard Spur datasets; concentrations from West Desert IW were very low for both Al and Ni. Cadmium, Cu, and Pb had multiple exceedances, mainly from the Historical samples; however the West Desert IW sites had a few exceedances of Cu, and generally higher background levels of both Cu and As. Lastly, 34 chronic and 3 acute exceedances were observed for Se, all but two were derived from the Historical dataset (the others were from West Desert sites).

Overall, there were 598 site observations that included metals analyses (excluding Willard Spur), and about 24% (137) of these observations included at least one benchmark that was exceeded. Nearly all of the exceedances were from the Historical dataset, with 7 from the West Desert sites and zero sites from the IW Survey. A total of 59 sampling events (site x date observations) had >1 metal exceedance, and these were most commonly observed in IWs within the Inland Sea Shorebird Reserve (ISSR; 3 sites), Public Shooting Grounds WMA (2 sites), Ambassador Duck Club (4 sites), and two sites within Farmington Bay WMA; exceedances for Cd and Cu were most common among these sites. Subsequent work on metal concentrations within GSL IWs will include spatial analysis of where and when these exceedances occur, whether they persist in more recent sampling events, and further analyses on what conditions foster or prevent high dissolved metals concentrations in GSL IWs.

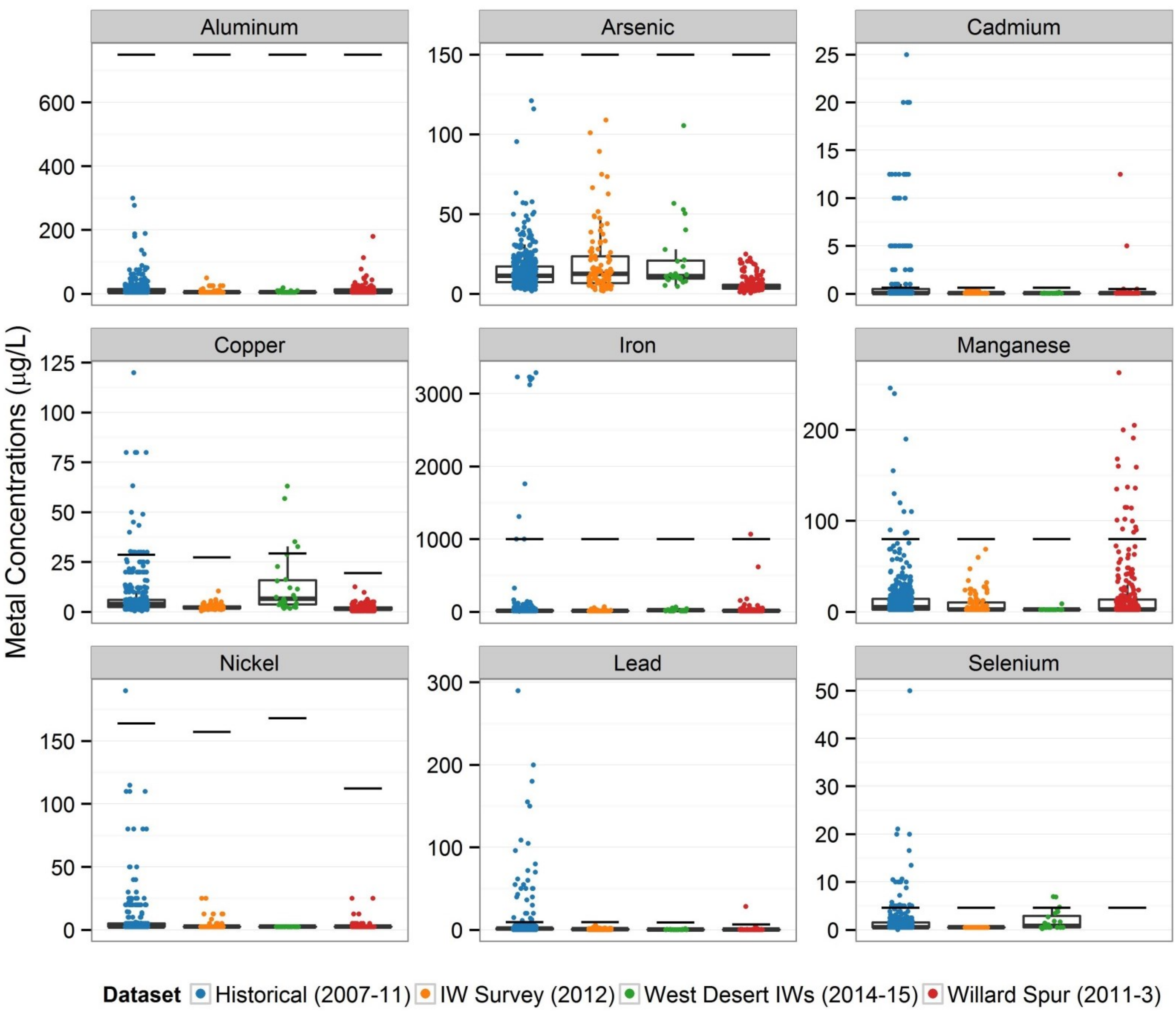

Figure 24. Distribution of nine Dissolved Metal concentrations, among datasets

4.3.4 Water Chemistry: Nutrients

Nutrient concentrations varied widely among open water wetlands. Total N concentrations (i.e. unfiltered) in the water column, particularly among sites in the Historical and Willard Spur datasets, ranged from <0.5 to well over 10 mg/L (Figure 25). There was little evidence of pronounced seasonal patterns in Total N concentrations, largely because of differences in which ponds were sampled for TN over time; however, some evidence from the Historical and Willard Spur datasets supports the idea of lower TN concentrations during the growing season, compared with

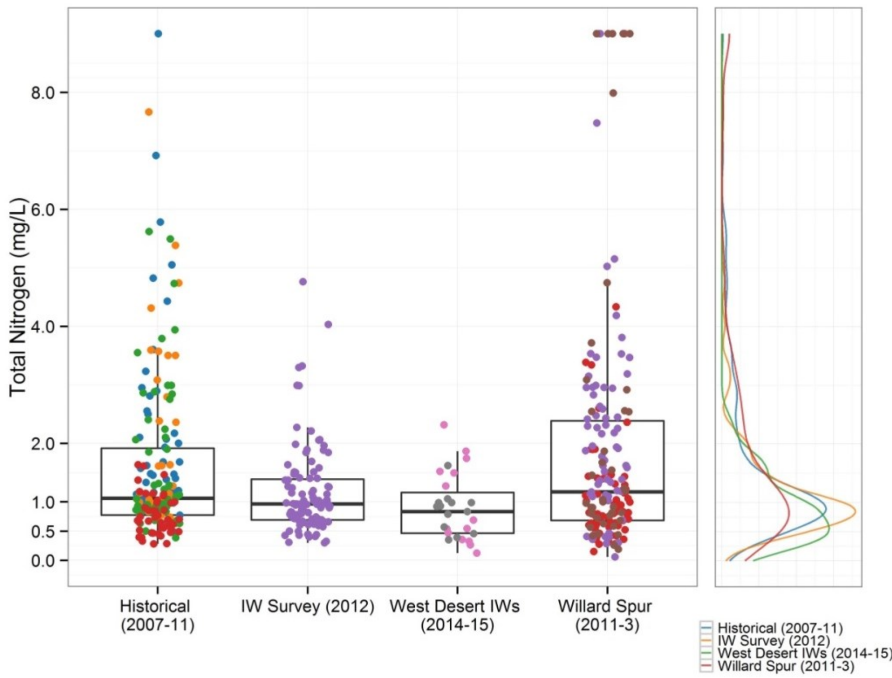

Figure 25. Distribution of water column Total N concentration, among datasets

the cool-season months (*data not shown*). Total N concentrations during the two index periods show little variation in median and lower quartile (25th percentile) values among datasets (Figure 25), but the upper quartile (75th percentile) concentrations were lower for the IW Survey and West Desert sites (approximately 1.25 mg N/L) compared to the Historical and Willard Spur datasets (approximately 2.0 and 2.2 mg N/L, respectively); the main difference in distributions is the size of the tails.

Total N pools within open water areas of wetlands include a wide variety of chemical constituents with differences in bioavailability and turnover rate. As such, higher TN concentrations in the water column may not necessarily alter the rate or capacity of photosynthetic growth within IWs over the short term, because a large proportion of TN can be in the form of organic N compounds, many of which are much more recalcitrant (i.e. slower cycling) than the readily available inorganic N forms (NH_4^+ and NO_3^-).

Across all datasets, NH_4^+ and NO_3^- were much more frequent measurements (> 1420 observations) than total N (961 observations across all datasets). Moreover, NO_3^- was most commonly the dominant form of inorganic N (Figure 26). As mentioned above, a modest seasonal pattern is evident – mainly from the Historical IW dataset – where total inorganic N (TIN) concentrations typically decline during spring to early-summer before increasing again. Given the wide variety of IW locations and the quantity and quality of inflows to these ponds, it is not yet clear whether or how much of these inorganic N pools are a consequence of internal cycling versus external inputs from other surface waters. However, given that NO_3^- pools can be sizable (> 2.5 mg N/L), the occurrence of anoxic or anaerobic conditions within the water column could provide an opportunity for high rates of N loss via denitrification from IW.

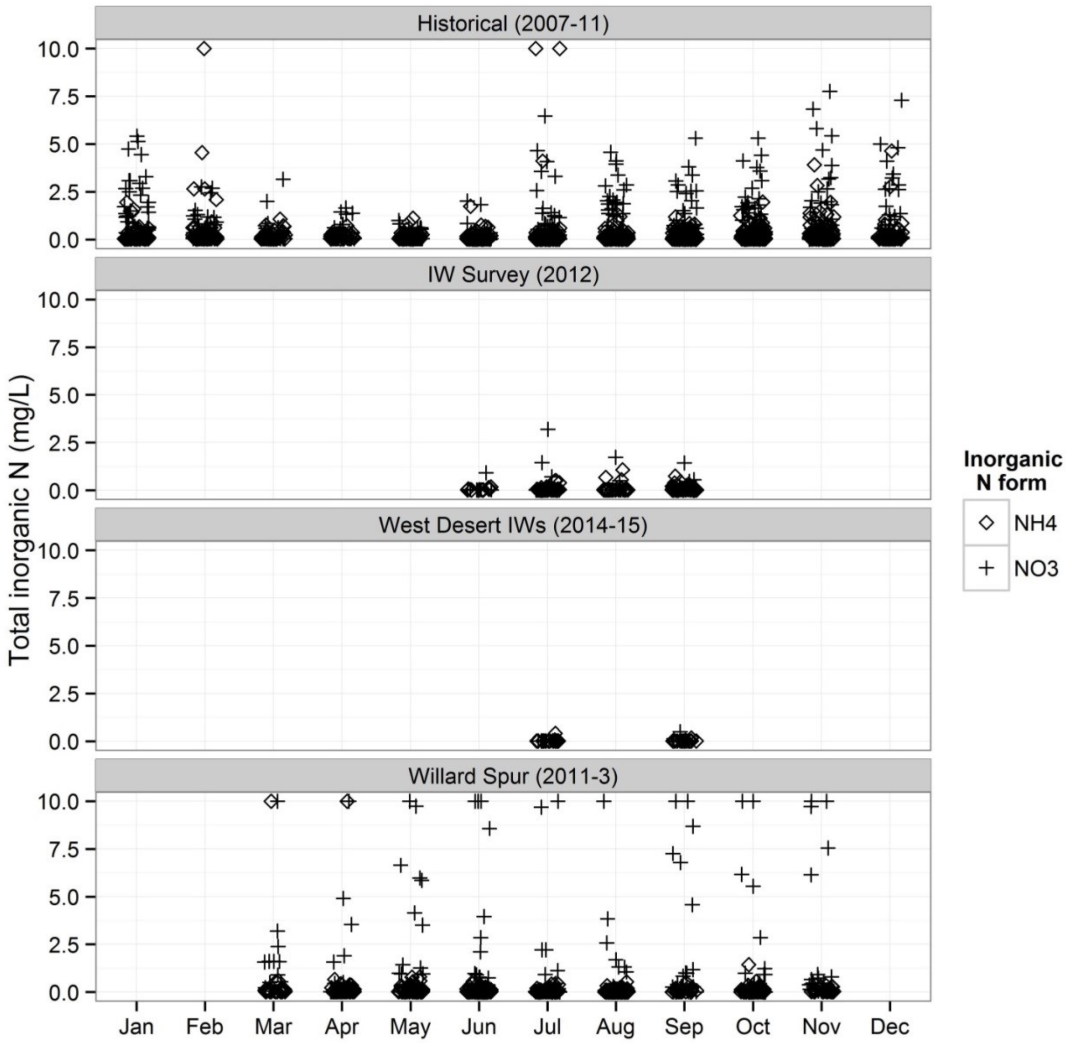

Figure 26. Seasonal patterns in water column Total Inorganic N species

A closer look at TIN vs. Total N concentrations revealed that TIN and TN concentrations were generally independent at lower TN concentrations (< 3 mg N/L), but pulses (or spikes) in TIN dominant TN pools when concentrations exceed 5 mg N/L. During the IW index periods, TIN accounts for 10 to 50% of Total N concentrations (25^{th} and 75^{th} percentiles) in the Historical data and 5 to 55% of Total N in the Willard Spur data, while TIN accounts for only 5-15% in the IW Survey and 2-7% in the West Desert data.

In general, inorganic N pools can – on occasion – reach high values (up to 10 mg N/L or more), and were mainly due to pulses of NO_3^-. Interestingly, inorganic N spikes were low (or uncommon) in both the West Desert and the IW (2012) Survey data, suggesting that these spikes are not a required element of healthy IWs.

Total phosphorus concentrations ranged from < 0.01 to over 2.0 mg P/L among all datasets (1203 observations). During index periods, lower & upper quartiles were 0.06 to 0.45, 0.05 to 0.3, 0.01 to 0.04, and 0.05 to 0.22 mg P/L for the Historical, IW Survey, West Desert, and Willard Spur datasets, respectively (Figure 27). While sizable Total

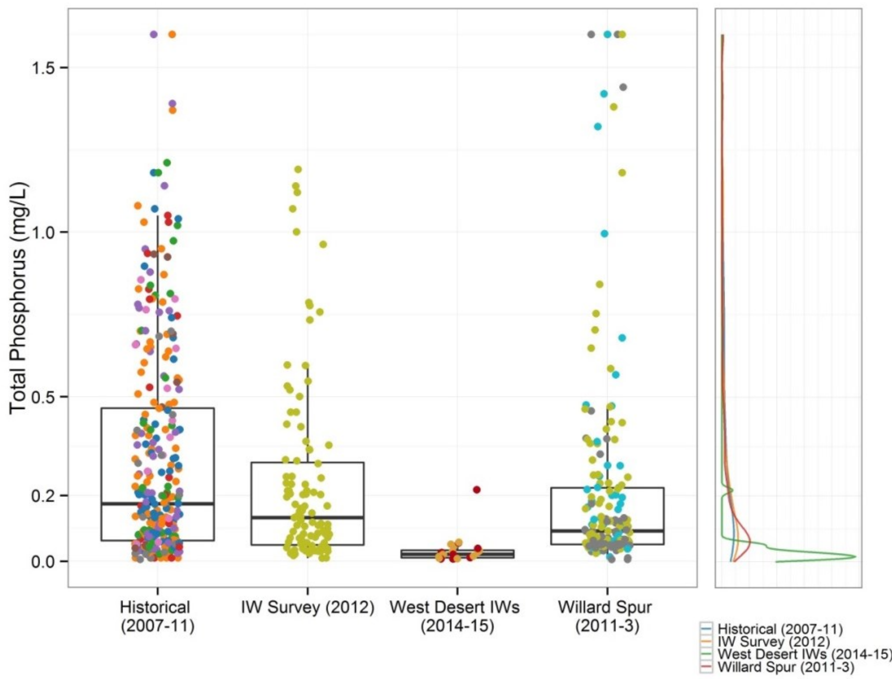

Figure 27. Distribution of water column Total Phosphorus concentrations, by dataset

P concentrations can be found within GSL ponded wetlands, concentrations within the West Desert sites were very low. This result is not unexpected, since the water sources for the West Desert sites is groundwater with very low levels of adjacent land use, while the other IW sites can receive surface water draining urban and agricultural watersheds as well as treated wastewater effluent.

Dissolved P concentrations were not routinely collected across all datasets; sample observations were n = 745 for DP, but n=287 site-observations were made for DP and TP pairs during the IW index periods. The available data suggest that dissolved P accounts for a large proportion (> 75%) of total P (median; 51 to 93% of total P using lower and upper quartiles).

There were modest seasonal patterns in TN:TP ratios, with geometric mean values ranging from < 5:1 (higher P concentrations, or N limitations) to around 15:1 (lower P vs. N, or P limitation) (Figure 28). A recent summary of observations from three years of monitoring within Willard Spur described a pattern of increasing TN:TP from early through late-summer as progressive P-limitation during the growing season (DWQ, 2015). This pattern is broadly similar to the Historical data, although a cool-season narrowing of TN:TP ratios is more readily apparent

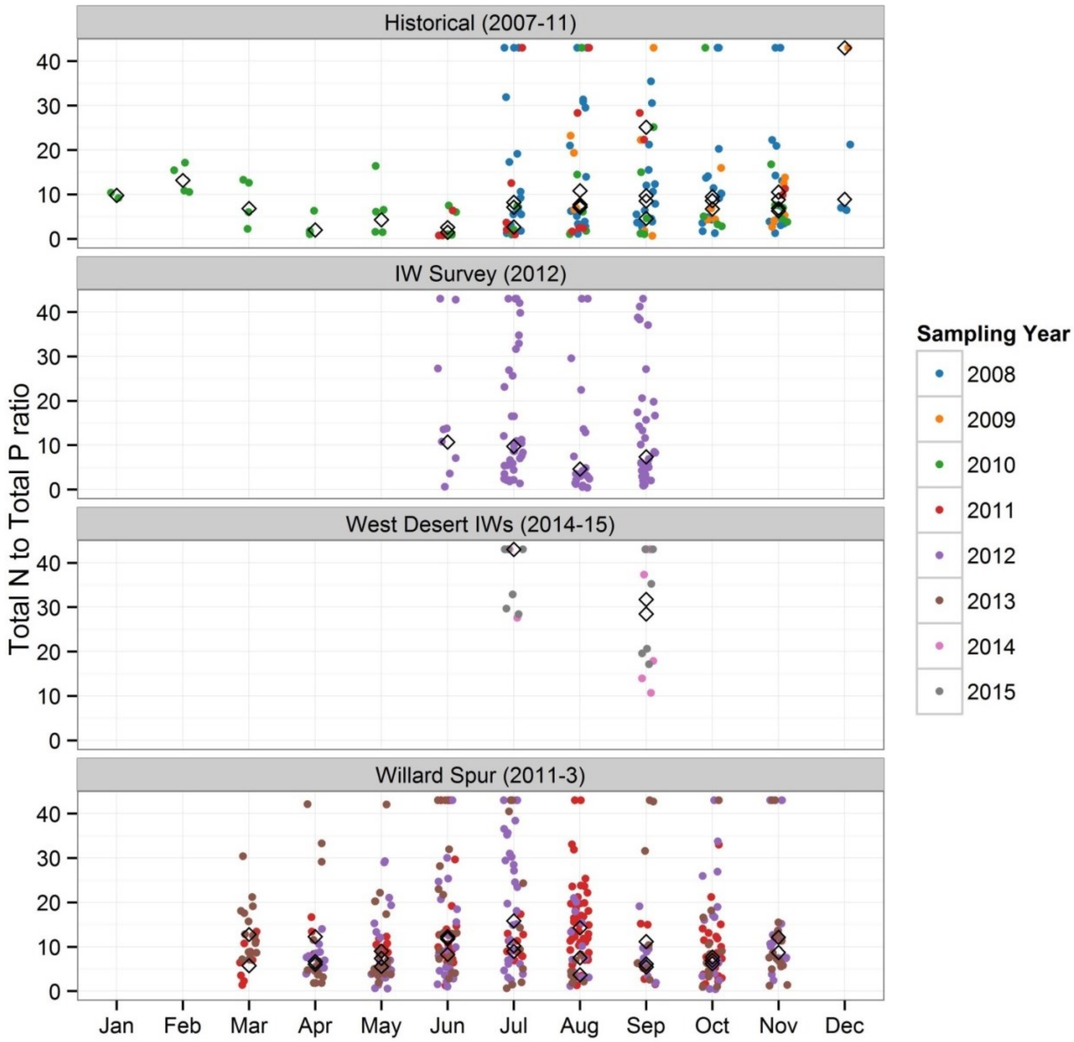

Figure 28. Seasonal patterns in water column TN:TP ratios

(Figure 28). While values range widely among sites in the IW Survey dataset, geometric means appear to decrease from IP-1 to IP-2; this pattern is also observed for the West Desert sites. Also notable are the much greater TN:TP ratios from the West Desert sites, a consequence of the much lower TP concentrations (Figure 27)(instead of higher TN).

In addition to general patterns among datasets, the wide range of TN:TP ratios among sites, particularly during the growing season, demonstrates a wide range in apparent N- versus P-limitations to photosynthetic growth. Reasonable breakpoints for N- versus P-limited growth (based on mass ratios) are TN:TP < 3.6 for N-limited growth (or excess P) and TN:TP > 13.6 for P-limited growth (Moss et al., 2013).

4.4 Indicators of Aquatic Metabolism

Key elements of aquatic metabolism that describe the balance between autotrophic photosynthesis and heterotrophic respiration in impounded wetlands include the abundance of photosynthetic organisms within the water column and temporal changes in dissolved oxygen concentration and pH. In impounded wetlands, high rates of photosynthesis can be associated with water column algae (phytoplankton), algae growing on bottom sediments (periphyton), submerged and emergent vegetation, as well as algae growing on the submerged tissues of higher plants (epiphytes). Photosynthetic organisms that are completely submerged have the largest effect on the chemistry of impounded wetlands, since the exchange of CO_2 and O_2 gases within plant leaves (or other photosynthetic tissues) must also be transported across the air-water interface via diffusion. In contrast, emergent plants can exchange gases directly with the atmosphere and thus have a much smaller effect on dissolved CO_2 and O_2 concentrations. In this section, we describe some key patterns in water column chlorophyll-a concentrations (a proxy for phytoplankton abundance), dissolved O_2 concentration (positively related to photosynthesis and negatively related to respiration), and pH (inversely related to photosynthetic C demand, via CO_2-$CO_3^{=}$ system).

A strong seasonal pattern in chlorophyll-a concentrations is evident from both the Historical and the Willard Spur datasets (Figure 29); *note that the y-axis is scaled to log-10 basis*. Seasonal peaks in chlorophyll-a occur in mid-spring (April) and mid-summer (July and August), with geometric mean concentrations of 20 to 40 µg/L and spikes among sampling locations > 100 µg/L. Both the IW Survey and West Desert sites display a slight increase in

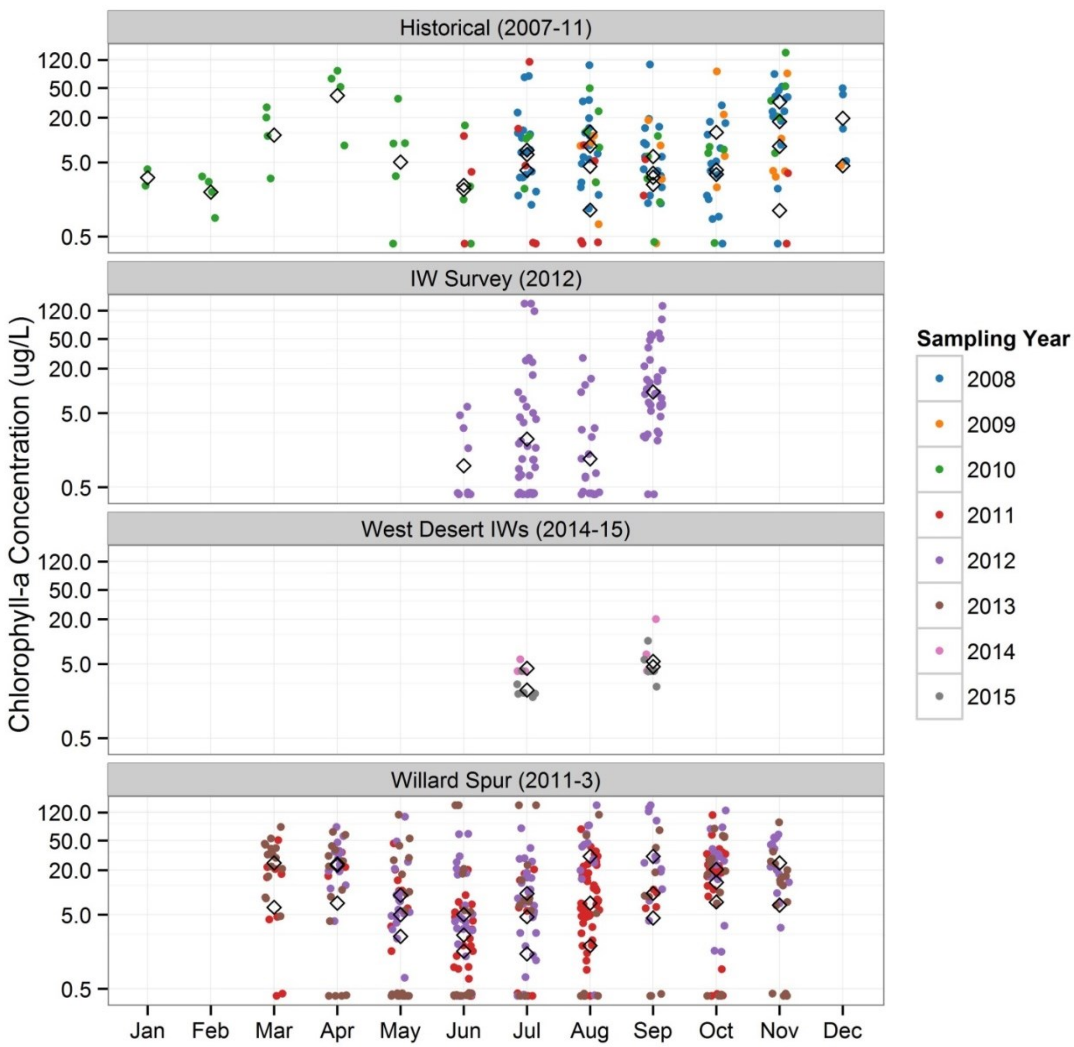

Figure 29. Seasonal patterns in water column Chlorophyll-a concentrations

chlorophyll-a between index periods. In addition, West Desert sites have very low chlorophyll-a concentrations (< 20 µg/L), but all other datasets display a wide range from below detection (< 0.7 µg/L) to over 120 µg/L.

Across datasets, the upper quartile of chlorophyll-a concentrations during the IW index periods range from approximately 5 to 20 µg/L (Figure 30).

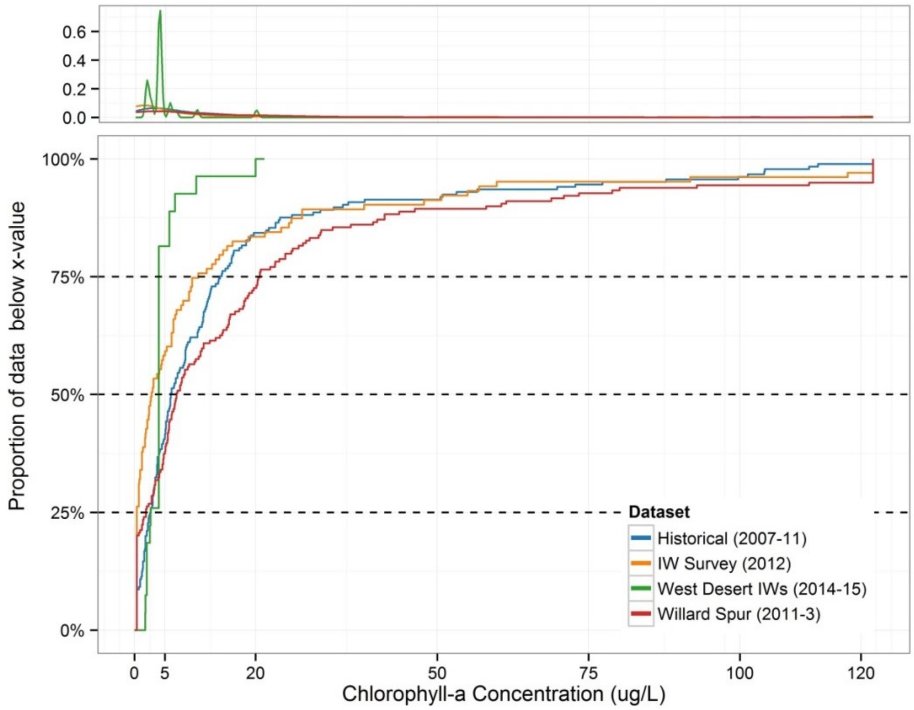

Figure 30. Cumulative distribution of Chlorophyll-a concentrations, by dataset

Many questions remain with regard to benchmarks for chlorophyll-a concentrations that describe that natural variability of health IWs and distinguish these from more heavily impacted sites. Based on the data presented in Figure 30 (above), less than 10% of all ponded wetland samples collected during the two index periods have chlorophyll-a concentrations >40 µg/L. However, our understanding of the relationships between chlorophyll-a concentrations and other desirable (e.g. SAV) and undesirable (e.g. surface mats) pools of photosynthetic organisms can be improved with more integrated monitoring and assessment of GSL and West Desert IWs, particularly with respect to how these pools change seasonally and relate to variations in overall pond conditions, water management, and water quality stressors.

Tightly coupled with chlorophyll-a concentrations are the well-known diel patterns of dissolved oxygen (DO) concentrations that illustrate how high rates of photosynthesis in the water column can generate large quantities of DO. Seasonal variation in DO concentrations is high among ponded wetlands, ranging from <1.0 to >20.0 mg/L (Figure 31). Note that all DO concentrations shown here are from grab samples collected during the daytime hours (between 0930 and 1500 h); samples collected at night would be expected to have even lower DO concentrations.

Benchmarks for DO concentrations are available for aquatic wildlife uses (3B and 3D), based work from streams and lakes, with 30-day average of 5.0 mg/L and minimum value of 3.0 mg/L (UAC R317-2-14 {*Link*}). These benchmarks, and those for pH (pH < 6.5 and pH > 9.0), are not applicable to GSL IWs (see footnote 2a in Table 2.14.2, {*Link*}), but are presented in Figure 31 for comparative purposes. GSL IWs are currently exempted from these criteria, largely because wetlands are widely known to support healthy ecosystems even under strongly anaerobic or anoxic conditions and the high rates of photosynthesis expected for this wetland type would commonly result in temporary periods of high pH (see below). As we develop a better understanding of reference standard conditions for IWs, high-frequency measurements of DO and pH can be used across a disturbance gradient to gain insight into what benchmarks for DO and pH are appropriate.

For at least some sites, DO concentrations measured during the daytime can be quite low – often below the 5.0 and 3.0 mg/L benchmarks – throughout the year. Interestingly, even some West Desert sites had DO concentrations near 5.0 mg/L, suggesting that anoxia in subsurface waters can occur in even low-stress IWs. Further analyses will examine whether variations in DO, and low DO concentration in particular, appear to be associated with biological responses. For sites evaluated during the index periods, approximately 15% of samples had DO < 5.0 mg/L and 6% of samples < 3.0 mg/L.

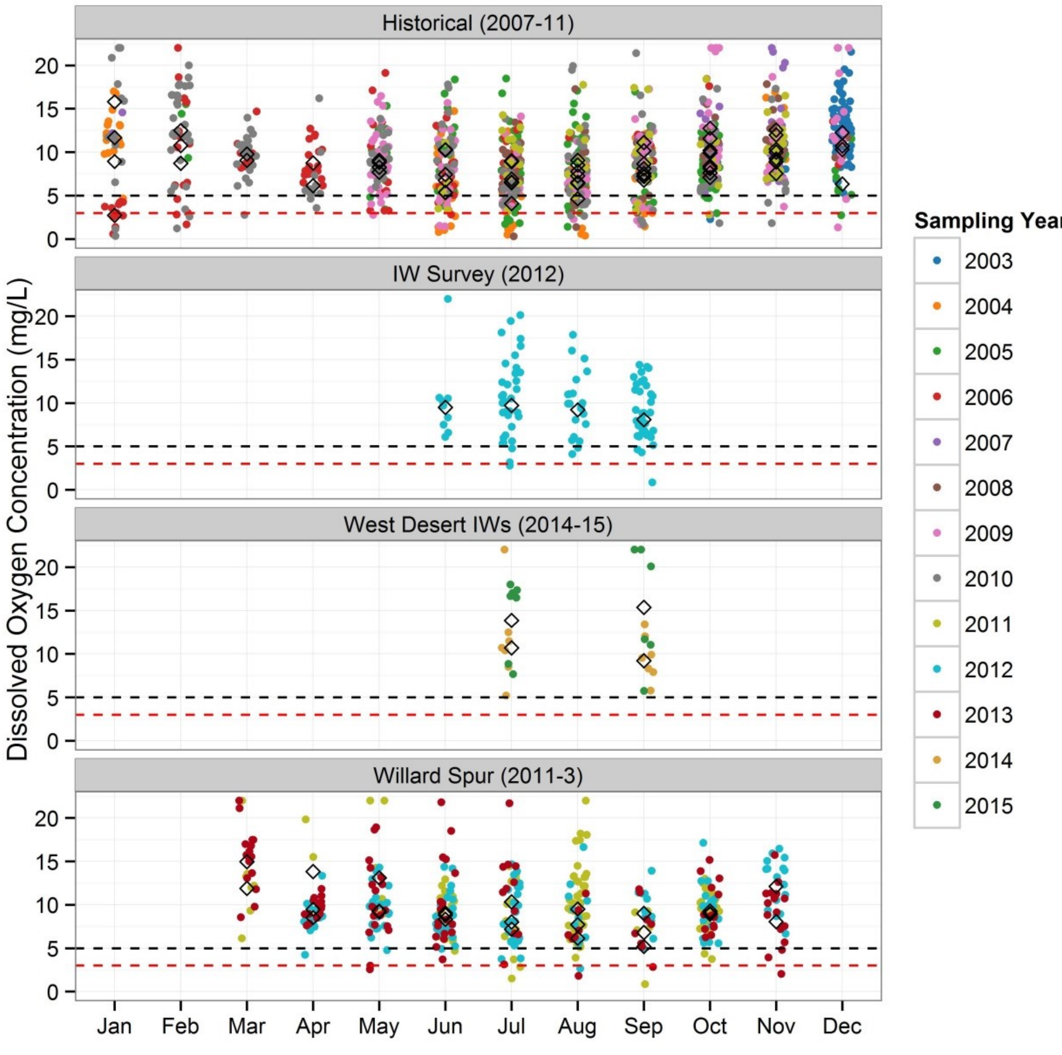

Figure 31. Seasonal patterns in water column dissolved oxygen concentration

As mentioned above, sizable variations in water column pH can be observed on daily and seasonal scales across all datasets (Figure 32). pH values range from slightly greater than 6.0 to well over 10.0, and the amplitude of pH on a monthly time-step was greatest in mid-summer (July), when rates of photosynthesis and respiration are likely to be greatest.

In addition, while the upper numeric criteria for pH for protection of aquatic wildlife (pH > 9.0) does not apply to GSL impounded wetlands, Figure 32 illustrates that even samples from the low-stress and purportedly nutrient limited West Desert sites commonly exceeded 9.0.

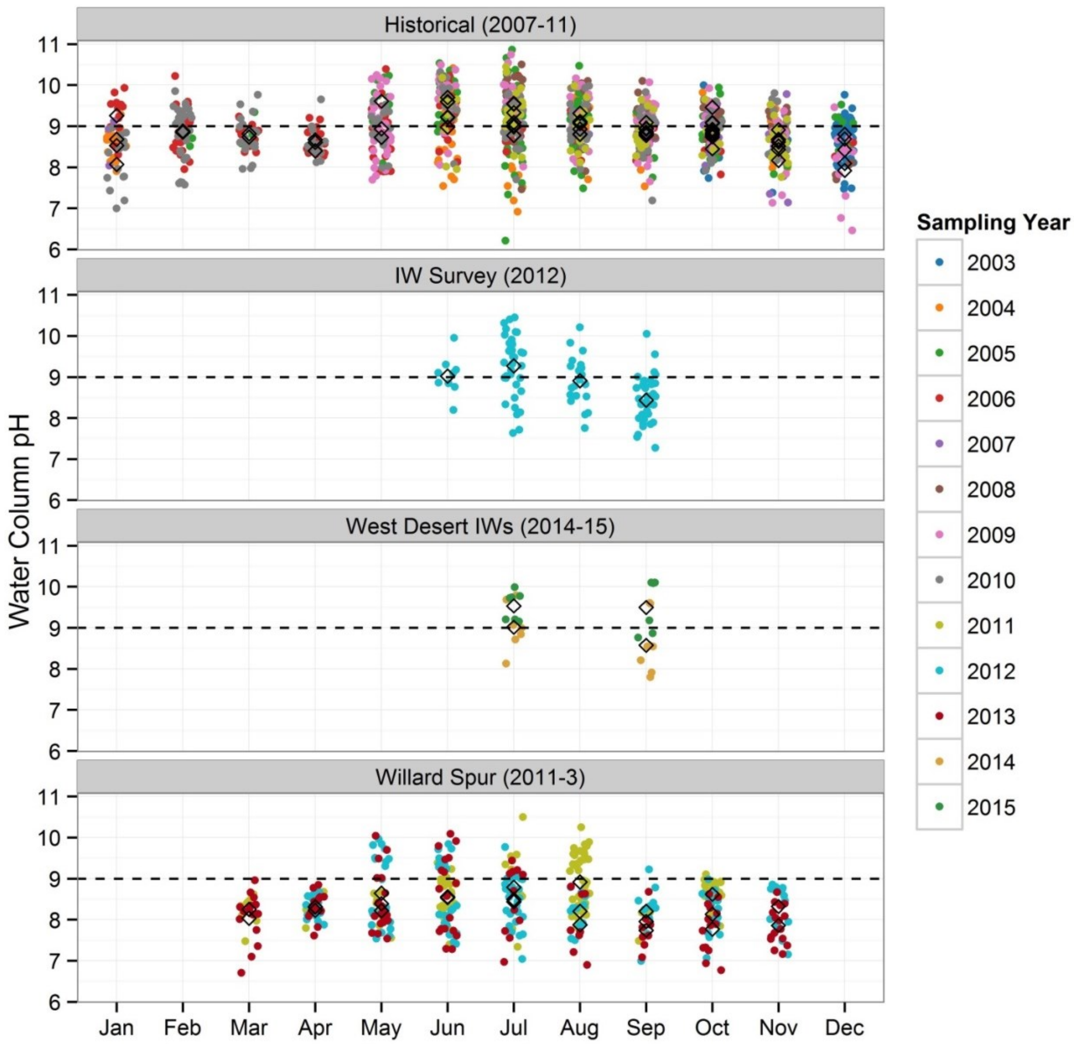

Figure 32. Seasonal patterns in water column pH

4.5 Supplemental Indicators

Starting in 2013, DWQ began collecting plant samples for nutrient and metal (a subset) concentrations to relate to similarly determined concentrations from water and wetland soils. In late December, 2015, T. Hooker identified problems with nutrient data, particularly the digestion efficiencies from total P of soils and plants. Since these samples are not part of this analysis (and the project is now closed), DWQ will identify alternative funding sources while the analytical problems are resolved.

4.5.1 Wetland Soils

DWQ is currently processing QC data for plant total and soil total and extractable nutrients and trace elemental analyses. Once these data have passed QC, they will be integrated with the IW Survey (2012) dataset and evaluated. A summary of trace metal concentrations in IW soils is shown in Table 7. Briefly, soil trace metal concentrations are described by 25th, median, and 75th percentiles of data from West Desert IWs, and compared to

Table 7. Summary Characteristics of Wetland Soil Trace Element Concentrations from West Desert Impounded Wetland Sites

Parameter	Units	Number of Observations	Percentiles *			Range	Background Level **	Benchmark (PEL) **	# Sites Exceeding §	Comments
			25th	Median	75th					
Trace Elements										
Aluminum (Al)	mg Al/kg	25	686	1765	2888	3738	2,600	18,000	0	
Arsenic (As)	mg As/kg	25	2.31	5.97	10.40	22.88	1.1	17.0	5	Associated with agricultural and industrial sources
Barium (Ba)	mg Ba/kg	25	79.7	102.2	128.6	302.6	67 ‡	130	1	See Note [1] for benchmark; Industrial sources
Cadmium (Cd)	mg Cd/kg	25	0.25	0.38	1.14	8.62	0.2	3.5	0	See Note [2] for benchmark; Agricultural sources
Cobalt (Co)	mg Co/kg	15	1.83	2.55	3.38	7.51	1.85 †	10	0	See Note [3] for benchmark; Industrial sources
Chromium (Cr)	mg Cr / kg	11	0.55	1.189	2.69	45.43	10	90	0	Associated with industrial sources
Copper (Cu)	mg Cu/kg	25	6.85	17.73	40.86	102.15	25	197	0	Associated with agriculture, industry, and road sources
Iron (Fe)	mg Fe/kg	25	2,663	4,194	6,128	13,392	2,950 †	40,000	0	See Note [4] for benchmark
Manganese (Mn)	mg Mn/kg	25	221.2	315.5	402.3	721.5	400	1,100	0	See Note [4] for benchmark
Nickel (Ni)	mg Ni/kg	25	3.91	5.28	7.88	19.79	9.9	36	0	Associated with agricultural and industrial sources
Lead (Pb)	mg Pb/kg	25	10.5	27.8	66.4	263.8	10.5	91	0	Associated with roads and industrial sources
Selenium (Se)	mg Se/kg	25	0.08	0.10	0.13	0.42	0.29	1.0	0	See Note [3] for benchmark
Mercury, total (THg)	µg THg/kg	25	24.2	46.2	124.4	534.2	27.5	486	0	See Note [5] for benchmark
Zinc (Zn)	mg Zn/kg	25	25.3	37.5	120.8	303.4	22.5	315	0	See Note [6] for benchmark; Associated with agriculture and industrial sources

* Percentiles calculated from all sample data for this wetland type (n=25 measurements from West Desert reference standard sites).
** Based on values from SQuiRT tables, unless specified otherwise.
§ Based on number of site observations.
‡ Background value from Alberta Environment (2009). † Background levels estimated from Johnson et al. (2012)
[1] Toxic effects level (TEL) from NOAA's Screening Quick Reference Table (SQuiRT) for marine sediments.
[2] Value for freshwater sediments given, marine sediment value is 4.2 mg/kg.
[3] Apparent effects threshold (AET) for marine sediments.
[4] Severe effects level (SEL) from SQuiRT tables.
[5] Value for freshwater sediments given, marine sediment value is 700 mg/kg.
[6] Value for freshwater sediments given, marine sediment value is 271 mg/kg.

literature values for background levels and benchmark criteria (as Probable Effects Levels, PEL). Five samples were observed to exceed the PEL benchmark for arsenic, and once sample exceeded PEL for barium, Note that these levels are presented for comparative purposes, since there are currently no acute or chronic numeric criteria for aquatic wildlife based on the concentrations of constituents in soils. For these West Desert sites, most constituents are near to below the background levels. Once these analyses are more fully integrated with soils data from the IW Survey (2012), DWQ will use these data to identify and characterize potential wetland stressors following the technical guidance laid out by EPA for the National Wetland Condition Assessment program (EPA, 2015).

4.6 Correlation Analysis (Spearman's ρ [rho])

Spearman rank correlation (also known as Spearman's ρ [rho]) describes the strength of monotonic relationships between pairs of variables. We used rank correlation instead of the more common Pearson correlation to evaluate potential associations between variables because many variables have highly skewed distributions (i.e. some variables have long tails of infrequent, but likely important information).

The following figures illustrate both the strength and direction of rank-correlations among pairs of variables. The color scale on the bottom of the figure (from dark red to dark blue) corresponds to a gradient from strongly negative (darker red) correlation (where the ranked observations of variable #2 *decreases* as the ranked observations of variable #1 *increases*) to strongly positive (darker blue) correlation (where the ranked observations of both variables increase together). The upper portion of the figure represents the lower half of the rank-correlation matrix for each pair of variables. Within each grid cell, the color and eccentricity of the ellipse describes the direction and strength of the rank correlation.

Because of the large number of pairwise correlations, a significance level (α) of 0.001 was used to screen against low-order, potentially spurious correlations. Only pairwise rank correlations with significance value of $p < 0.001$ are shown with an ellipse in the correlation charts.

The full dataset (n=1654 observations) was trimmed to be more directly applicable to further monitoring and assessment of Great Salt Lake and West Desert impounded wetlands. Sampling dates were restricted to the May through October time-period to include the IW index periods as well as providing a seasonal context for chemical or biological measurements that change over time. Observations from the Willard Spur dataset were omitted to narrow the range of hydrologic conditions to ponded wetlands managed for autumn waterfowl use. Finally, variables with poor representation in the dataset (e.g. missing from more recent survey work or only sporadically collected) were removed. The dataset used for correlation analyses includes 47 variables with 858 cases (sample sizes for individual variables range from 69 (SAV Index Score) to 858 (field chemistry: temperature, pH, etc.).

4.6.1 Spearman Rank Correlations among Water Chemistry variables

The water chemistry variables from all four datasets were trimmed to a working set of 21 variables describing the general chemical attributes (major ions, hardness, suspended solids), dissolved metals concentrations (including the total number of metals that exceeded a numeric benchmark, see Table 6), indicators of aquatic metabolism, and nutrients. In the following figures, all water chemistry variables are preceded by a chemical-group code, for example GEN_EC25 refers to the variable Specific Conductance in the General Chemistry group.

Across water chemistry variables, sample sizes for pairwise comparisons ranged from 243 to 858 observations. There were 11 'strong' positive rank-correlations, with $\rho > 0.50$, and 110 combinations with $p < 0.001$ (out of 210 total). Several sets of rank-correlations are apparent from the correlation matrix (Figure 33). The major ions and specific conductance were strongly positively correlated, while ambient water temperatures (GEN_W.TempC) were negatively correlated with total alkalinity (GEN_T.Alk). Arsenic (As) strongly increased with salinity and/or major ion concentrations. Distinct patterns of rank-correlation were found for aluminum (Al), As, copper (Cu), manganese (Mn), lead (Pb), selenium (Se) and zinc (Zn). The total number of metals exceeding numeric benchmarks (MET_MET_crit) was positively correlated Al and Cu concentrations ($\rho > 0.46$).

For metabolic variables, chlorophyll-a was strongly correlated with suspended solids (GEN_T_TSS, and turbidity). pH were negatively correlated with manganese (Mn) and total alkalinity (GEN_T.Talk), and modestly positively correlated with DO concentrations (and % saturation). For nutrients, informative and strong (|ρ| > 0.5) correlations include a positive correlation between TIN and TP (but not between TN and TP). Because of a large number of missing samples, TN:TP ratios were removed from this dataset.

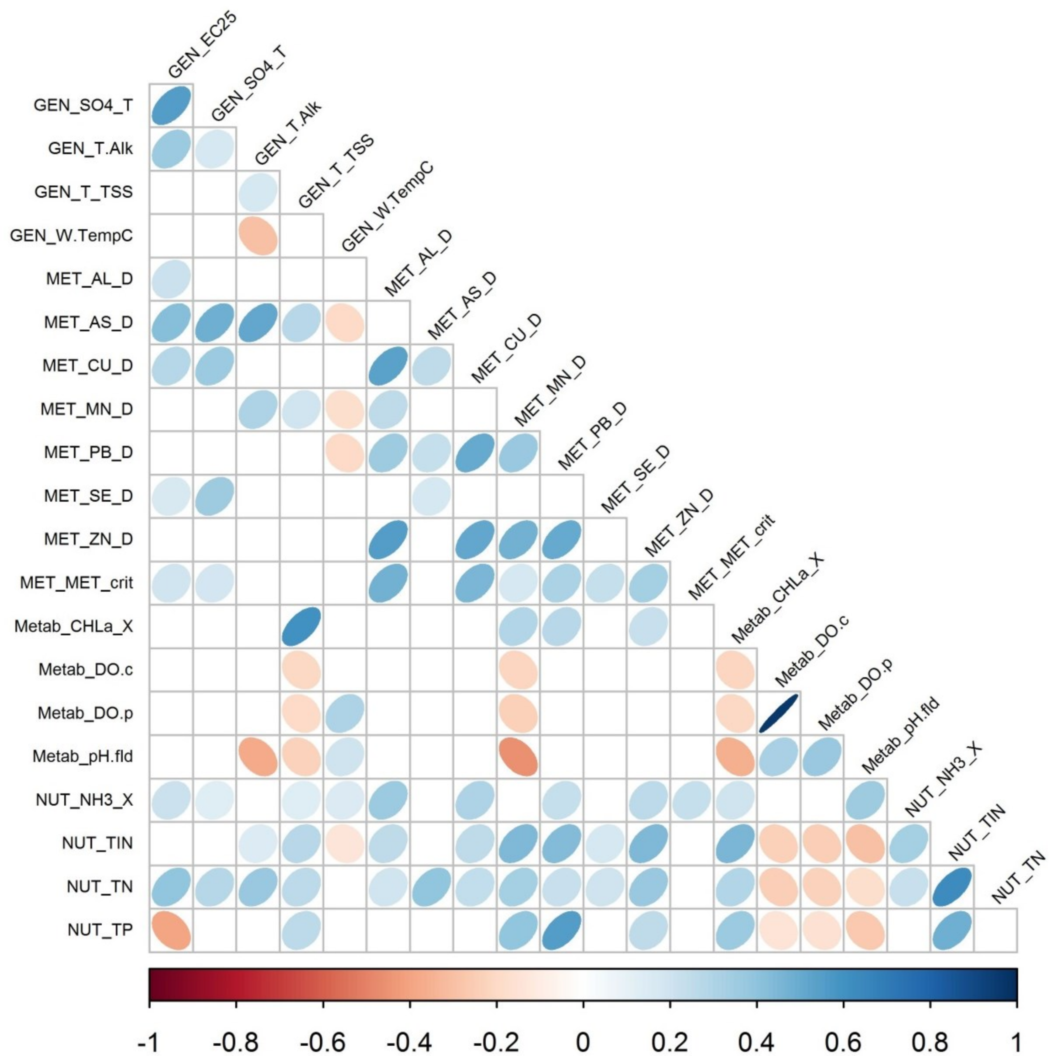

Figure 33. Spearman (rank) correlation among water chemistry variables

4.6.2 Spearman Correlations among Macroinvertebrate Taxa and Metrics

A subset of eighteen (18) invertebrate taxa and 4 invertebrate metrics were examined. Taxa with less than 25 occurrences (approximately 5% of 504 invertebrate sample collections) were omitted from rank-correlation analyses; this removed 55 uncommon or rare invertebrate taxa. Additional taxa that had less than 30 occurrences were removed (low information content). Our goal here was to examine whether the abundance of other (common) taxa could improve the sensitivity of invertebrate metrics to variations in water quality or stress. There were 11 'strong' (ρ > 0.50) positive rank-correlations (and 0 strong negative correlations), with 202 samples for all 231 variable pairs.

Correlations were generally lower among invertebrate metrics (Figure 34) than among water chemistry variables (Figure 33). The abundance of *Callibaetis* was strongly and positively correlated with *Ischnura* and %PMI (zPMI.f), while both *Chironomous* and Tanypodinae (two types of midge larva) increased with invertebrate abundance (zAbund). *Gyraulus* and *Physella*, both snails, were positively correlated (ρ > 0.50), while increases in taxa richness were strongly associated with greater abundance of *Caenis, Callibaetis, Hesperocorixa, Hyalella,* and *Physella*.

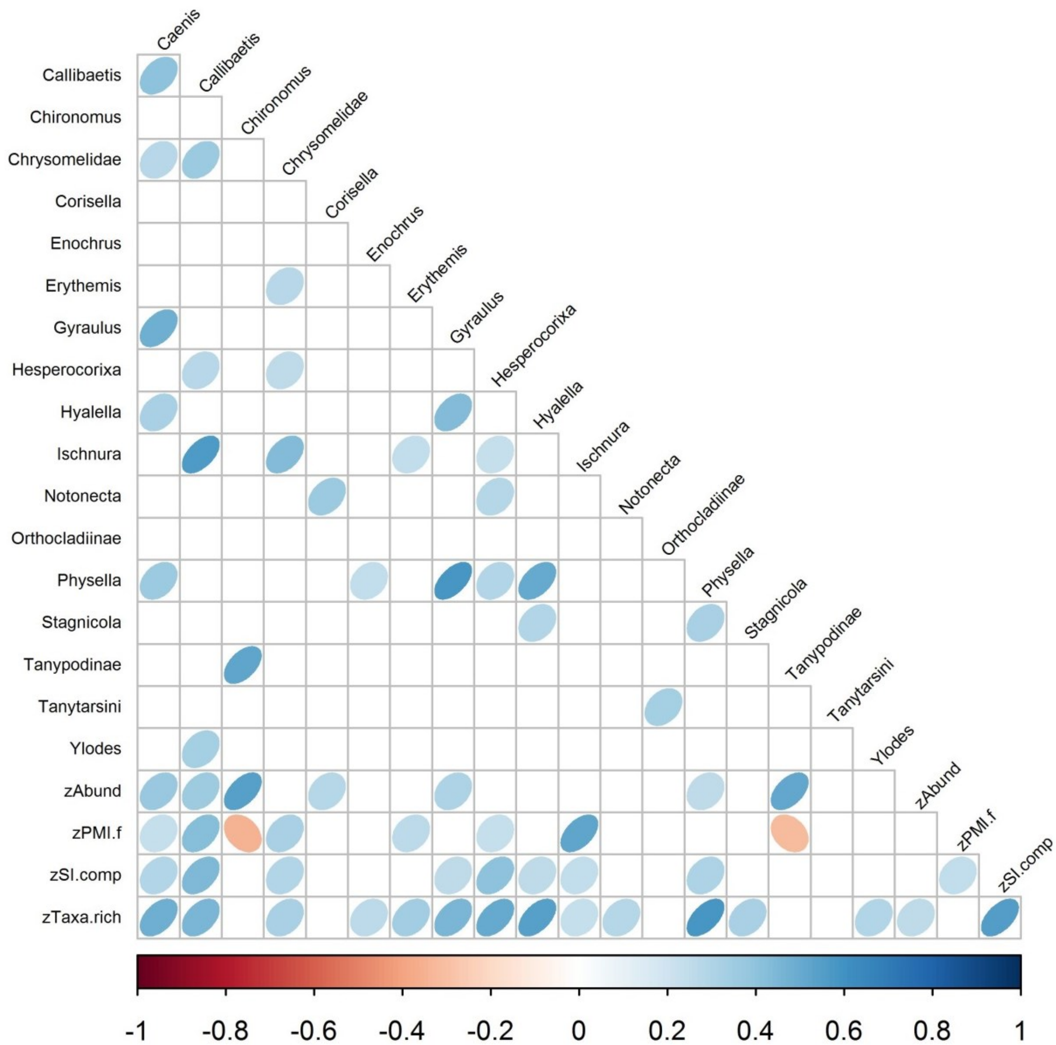

Figure 34. Spearman (rank) correlation among macroinvertebrate variables

4.6.3 Spearman Correlations among measures of Biological Response

Twenty seven (27) variables describing SAV and surface mat cover, invertebrate taxa, and measures of aquatic metabolism were examined. There were 21 'strong' (ρ > 0.50) positive correlations and 0 negative correlation among 351 variable pairs; sample sizes ranged from 56 (SAV index) to 412 (chlorophyll-a).

SAV metrics negatively correlated with chlorophyll-a (Figure 35). Surface mats of algae or floating aquatic vegetation (e.g. *Lemna* sp.) (as Pond_mat.x in Figure 35) were not significantly correlated with SAV cover or chlorophyll-a. However, surface mats were modestly correlated with a variety of invertebrates, including *Caenis*, Chrysomelidae, *Enochrus*, *Erythemis, Gyraulus, Hyalella, Physella* and *Stagnicola* (ρ 0.31 to 0.53), negatively correlated with Orthocladiinae and Tanytarsini (two subfamilies of midge) , positively correlated with invertebrate taxa richness. Invertebrate diversity indexes (zPMI.f, Simpson and taxa richness) displayed some distinct patterns

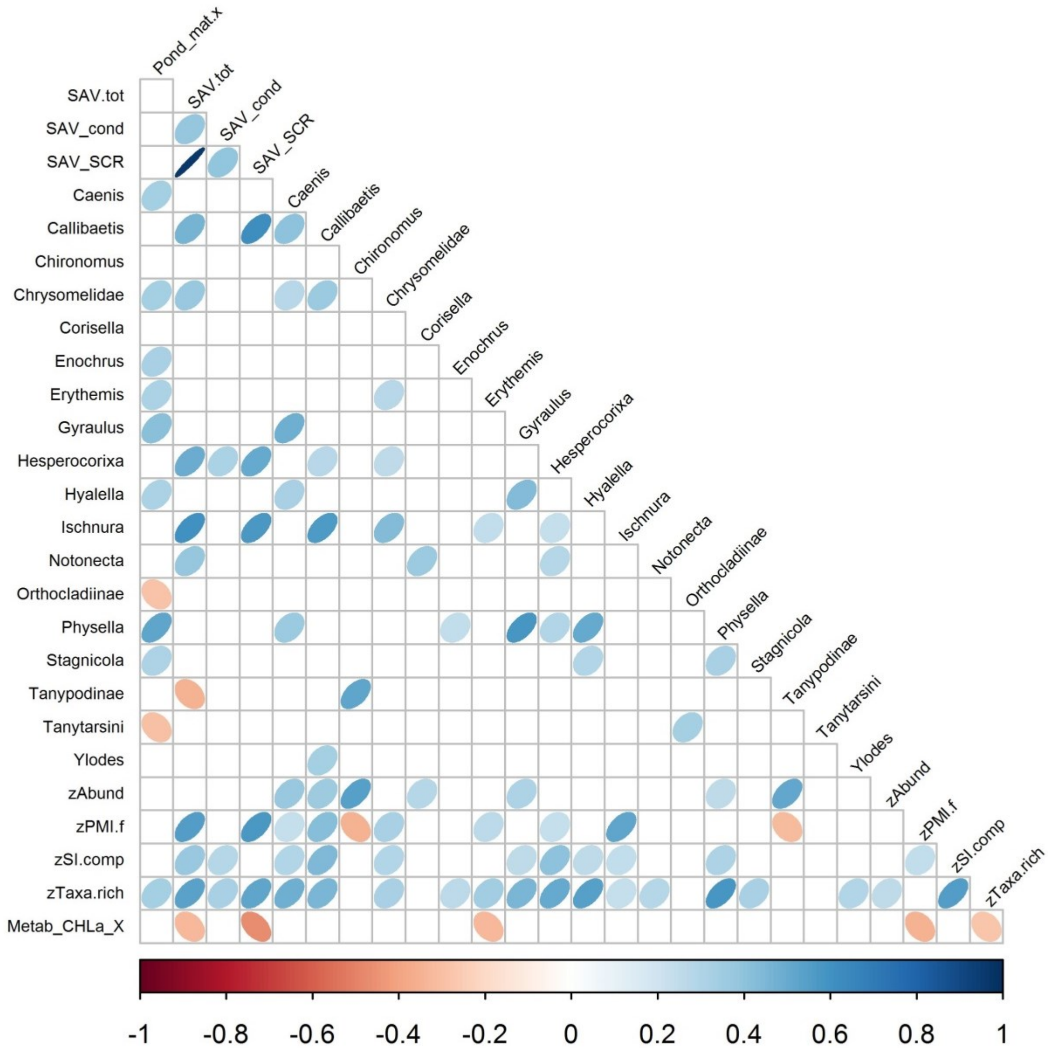

Figure 35. Spearman (rank) correlation among Biological Response variables

of rank-correlations with other biological response variables. Generally, these indexes increased with SAV cover and lower chlorophyll-a concentrations. PMI was negatively correlated with two midges (*Chironomous* and Tanypodinae) and positively correlated with *Ischnura*, while taxa richness increased with multiple taxa, including *Hesperocorixa, Hyalella* and *Physella*.

4.6.4 Spearman Correlations between Water Chemistry and key Biological Responses

A subset of 47 water chemistry and biological response variables were examined for rank correlations between response and stressor variables. There were 34 'strong' (ρ > 0.50) positive correlations and five (1) negative correlations among 1081 variable pairs; sample sizes ranged from < 56 (SAV Index) to 858 (Temp)(Figure 36).

Surface mats (Pond_mat.x) were modestly correlated with pond water salinity (EC25 and $SO_4^{=}$, ρ = 0.47 and 0.48, respectively), lead (ρ = 0.35) and total N (ρ = 0.43), and strongly correlated with the snail genus *Physella* (ρ = 0.53).

SAV cover (SAV.tot) was strongly correlated with water pH (ρ = 0.53) and negatively correlated with total suspended solids (TSS; ρ = -0.47). SAV Index was tightly linked with SAV cover (ρ = 0.96), but had lower sample size since it integrates data over two index periods (170 versus 79). Even so, SAV Index scores had strong correlations with TSS (ρ = -0.59), pH (ρ = 0.61), chlorophyll-a (ρ = -0.46), and DO (ρ = 0.43), and higher SAV scores were associated with greater abundance of *Callibaetis* (ρ = 0.61), *Hesperocorixa* (ρ = 0.50), and *Ischnura* (ρ = 0.58).

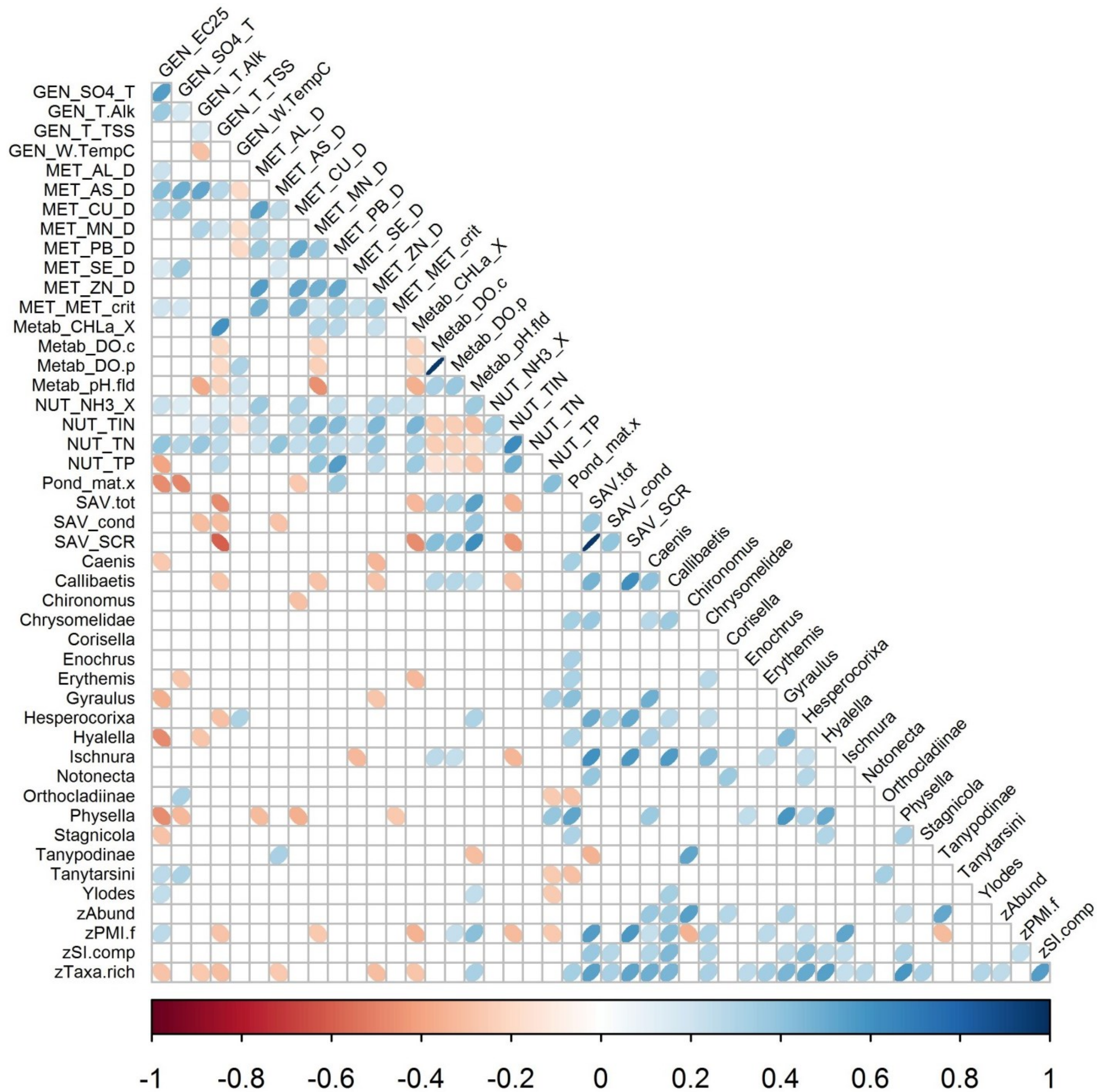

Figure 36. Spearman (rank) correlation among water chemistry and biological response variables

In general, nutrient concentrations were poorly correlated with indicators of aquatic metabolism, except for a positive correlation between chlorophyll-a and TIN (ρ = 0.45). Interestingly, chlorophyll-a increased with both TIN and TP (ρ = 0.37), while surface mats increased with TP (ρ = 0.43), and SAV cover (and index scores) decreased with TIN (ρ = -0.34 and -0.43 (for SAV Index Score)). The lack of positive associated between SAV and water column nutrients could be related to the ability of SAV species to take up nutrients from wetland soils and sediments; as mentioned previously, DWQ is addressing a technical QC issue with soil and plant nutrient analyses and will examine how SAV growth and health varies with soil nutrients when those data become available.

Notable correlations between the abundance of invertebrate taxa and other variables include: greater abundance of *Corisella* in shallower water depths (ρ = -0.52; not shown); and greater abundance of *Callibaetis* in sites with high SAV index scores (SAV_SCR; ρ = 0.61). The abundance of the damselfly *Ischnura* was positively correlated with SAV cover (and SAV index) and the abundance *Callibaetis*, and negatively correlated with dissolved selenium (MET_SE_D) and TIN concentrations. We see few strong correlations between the invertebrate taxa and environmental limiting factors that were anticipated based on previous work; for example the abundance of gastropod taxa (i.e. snails) versus low DO or high NH_3 concentrations, or *Hyalella* versus algal mats or declining SAV cover. Instead, *Hyalella* abundance decreased at higher salinities (EC25, ρ = -0.48), and was positively associated with *Physella* and total invertebrate richness (ρ = 0.50 and 0.55, respectively).

Lastly, invertebrate abundance and diversity metrics were only modestly correlated with a few environmental factors. Invertebrate abundance was not positively correlated with SAV cover . Invertebrate diversity metrics (i.e. PMI, SI and taxa richness) displayed little correlation with environmental variables, except that PMI was negatively correlated with chlorophyll-a and TIN concentrations, and positively correlated with water pH.

Because these data describe a wide range of environmental conditions, including over 10 years of measurements for some variables and samples collected from IW wetlands within Utah's Great Salt Lake and West Desert basins, the above correlation analyses are based on several conservative assumptions in an effort to limit the number of spurious associations among variables. As such, we applied a significance limit of 0.001 and qualitative evaluation of 'strong' (ρ > 0.50) vs. 'modest' (ρ < 0.49, and p < 0.001) correlations. Now that these data have been compiled and subjected to the introductory analyses reported here, subsequent work on this wetland type can explore more advanced approaches with more subtle parsing of the data than has been available in the past.

5.0 Summary and Integration

The primary objective of this work was to report on monitoring from a set of targeted sites that may be useful as reference standards for impounded wetlands associated with Great Salt Lake. The targeted sites were located in remote portions of Utah's West Desert and were monitored over two years in an effort to describe the natural variability of important biological response indicators and chemical stressors in these systems. These results are reported in a series of tables and figures that describe the distribution of values over time (i.e. seasonally) and the distribution of values within growing season index periods relative to other appropriate data.

Additional data from historical measurements of impounded wetlands, the 2012 IW Survey, and the Willard Spur Water Quality Study were compiled at the same time that these analyses were performed. Results from these datasets were used to provide context for results from the West Desert reference standard sites. The following section summarizes key findings from this report.

5.1 Summary of Key Findings

5.1.1 Biological Response Metrics

- Land cover and point-source discharge characteristics for local upstream catchments support the idea that West Desert wetlands (in Clear Lake WMA and Fish Springs NWR) have much lower levels of disturbance and fewer sources of pollution compared to Great Salt Lake wetlands (see Table 4)

- Surface mats of filamentous algae and floating aquatic vegetation were not observed in West Desert IWs. In other shallow ponded wetlands (e.g. IWs and Willard Spur open water waters), only 10% of site observations reported surface mat cover > 50%, and 25% of observations had mat cover > 25%. The previously developed breakpoint between 'FAIR' and 'POOR' condition was 25% surface mat cover in the 2nd index period, based on the *upper* quartile of IW Survey results. Based on results from this report, we propose the following *revised* breakpoints for surface mat cover:
  - GOOD: < 25% Surface Mats
  - FAIR: 25 to <50% Surface Mats
  - POOR: ≥ 50% Surface Mats
- Submerged aquatic vegetation of West Desert sites appear to be dominated by *Chara* (a macroalgae) and *Ruppia* (widgeon grass), while GSL IWs are commonly dominated by up to a few species of *Stuckenia*. We do not yet know if these differences in taxa matter with respect to other biological and chemical aspects of IWs
- Estimates of SAV cover made from quadrat measurements were in very close agreement with estimates made for the whole pond. *Reasonable estimates of total SAV cover could be incorporated into a rapid assessment method for IWs*
- A SAV Index Score was developed to describe the main patterns of SAV growth between mid-summer and early-autumn index periods (see equation 1 and Figure 9), where highest scores indicate persistent cover of SAV between index periods. Previous breakpoint between 'FAIR' and 'POOR' condition was a SAV Index Score of 25% (raw score of approximately 75 out of 300) based on the *lower* quartile of IW Survey results. West Desert sites had ~ 10% of observations (two sites) with score < 25% of max, while median and lower quartile values were approximately 75% and 50% of max SAV Index Scores, respectively. Revised breakpoints for SAV:
  - GOOD: >66% SAV Index Score (raw score > 200)
  - FAIR: 25 to 66% SAV Index Score
  - POOR: < 25% SAV Index Score (raw score < 75)
- Aquatic macroinvertebrates varied widely in abundance (# individuals/m^2) within and among datasets; samples with the greatest abundance tended to have low diversity but high dominance by either chironomids or snails. The richness (and composition) of macroinvertebrate taxa was broadly similar among all datasets, where lower and upper quartiles had 7 to 12 taxa; *this suggests that macroinvertebrate richness (alone) is of limited use in comparing IW condition between GSL and West Desert sites*
- Simpson's diversity index (SI, as 1-D) and Plant-associated Macroinvertebrate Index (PMI) had similar distributions among datasets (see Figure 15 and Figure 16), except that the lower quartiles from West Desert sites (0.60 and 0.37 for SI and PMI, respectively) were higher than from the other datasets. IW Survey results used a combined MMI for SI and PMI, with breakpoints of 35 and 70 for 'POOR' and 'GOOD' condition classes; breakpoints for PMI (alone) were 0.0 and 0.60 for 'POOR' and 'GOOD' condition classes. We propose the following *revised* breakpoints for both PMI and SI (separately) based on the median of West Desert sites for 'GOOD' vs 'FAIR' and lower quartile from all IW data for 'FAIR' vs 'POOR':
  - GOOD: > 0.70 Simpson's Index score and > 0.55 PMI
  - FAIR: 0.33 to 0.70 Simpson's Index score and 0.25 to 0.55 PMI
  - POOR: < 0.33 Simpson's Index score and < 0.25 PMI

5.1.2 Physical Parameters of Ponds

- Measurements of water depth were inconsistently collected during Historical surveys, but more recent work is collecting this and other measurements in an effort to understand how differences in pond hydrology (and wetland water management) affect biological and chemical aspects of IWs

- Water temperature measurements show a 10 to nearly 20 °C range by month, among ponds or other open water wetland sites (see Figure 20). As of yet, there is no indication that water temperatures that exceed the numeric criteria for designated use 3B (warm water fishery), 27 °C, have a deleterious effect on biological or chemical conditions of IWs. *It is recommended that use class 3B temperature criteria not be applied to IWs*
- Pond salinity ranges widely among sites, seasons and years, from approximately 400 to over 50,000 µS/cm. *It is not yet clear whether breakpoints exist, and where they might occur, for important differences in SAV or macroinvertebrate community composition*

5.1.3 Chemical Parameters of Ponds

- The major ions of IWs become more enriched in Na^+ and Cl^- as salinity increases over time (see Figure 23)
- Concentrations of trace metals and metalloids were commonly near or below analytical minimum reporting levels (MRLs). Exceedance of toxic metals criteria were most common for Cd, Cu, Pb and Se, and nearly all exceedances were from the Historical data; no IW Survey samples exceeded any toxic metals benchmarks, while West Desert sites accounted for 4 of 30 exceedances for Cu, and 3 of 34 exceedances for Se. *Further analyses of these data will examine spatial and temporal differences in the concentrations of metals relative to an ambient baseline in an effort to screen for metals within IWs more effectively*
- Two trace metal constituents Co and THg have analytical MRLs that are greater than the numeric criteria for aquatic wildlife uses. These analytes should not be collected from wetlands until analytical limits are improved or an alternative laboratory is used
- The total number of metal exceedances per sample (site x date combination) among sites ranged from 0 to 6; 144 of 598 samples (Willard Spur omitted) had at least 1 exceedance for dissolved metals concentrations and 137 of these were from the Historical dataset
- Total N concentrations varied widely among samples, from < 0.2 to > 8.0 mg N/L. Water column TN pools were dominated by organic N at lower concentrations, however, occasional spikes (or pulses) of inorganic N (mainly as NO_3^-) > 1.5 mg N/L were observed in approximately 10% of samples. Median TN concentrations were similar among datasets, while the lower quartile of TN values was slightly lower for West Desert sites compared to the other IWs
- Similarly, Total P concentrations varied from < 0.06 to > 0.5 mg P/L; however, nearly all TP samples from West Desert sites had concentrations lower than 90% of all other IW samples, *suggesting a potentially strong P-limitation in these sites*
- Water column TN:TP ratios (mass basis) ranged from < 2:1 (N-limited) to > 50:1 (P-limited) across all sites, with West Desert sites having higher TN:TP ratios than other IWs

5.1.4 Aquatic Metabolism

- Water column chlorophyll-a concentrations ranged from < 1.0 to > 60 µg/L. Samples from nearly all West Desert sites were less than 10 µg/L, lower than about 50% of all other IW samples
- Dissolved oxygen concentrations varied widely among ponds and over time, from < 3 to > 20 mg O_2/L (see Figure 31). DO concentrations less than 5.0 and 3.0 mg/L occurred in approximately 14% and 5% of samples from Historical and IW Survey sites.
- Water column pH values spanned a 3.0 range, or more, among sites, seasons, and years (see Figure 32). All datasets commonly exceeded the 9.0 numeric criterion for aquatic wildlife.
- The above two observations support the exception from the DO and pH criteria for GSL impounded wetlands (see footnote 2a in Table 2.14.2 at [UAC R317-2]).

5.1.5 Parameter Associations (Rank-Correlation Analysis)

- Trace metals and metalloids were trimmed from 16 analytes to a subset of 7 prior to correlation analysis, based on number of observations and values greater than analytical MRLs. Four of these were positively correlated with Zn: Al, Cu, Mn, Pb,; while the patterns for As and Se were distinct. *The total number of trace metal exceedances was positively correlated with Al and Cu concentrations and salinity (albeit weakly)*
- A few strong rank-correlations among macroinvertebrate taxa were observed from a subset of 18 taxa (with modestly frequent occurrence): *Callibaetis* and *Ischnura*, *Physella* with *Gyraulus* and *Hyalella,* and *Chironomous* and Tanypodinae. PMI was strongly correlated with *Ischnura*, *Callibaetis*, and negatively with *Chironomous* and Tanypodinae. SI was modestly correlated with *Callibaetis* and *Hesperocorixa*.
- Surface mats were most positively correlated with *Physella, Gyraulus* (both snails) and invertebrate taxa richness, and negatively correlated with Orthocladiinae and Tanytarsini (midges), water salinity (as EC25 and $SO_4^{=}$), and TP.
- Total SAV cover (and SAV Index Scores) was positively correlated with SAV condition class, *Callibaetis*, Chrysomedlidae (leaf beetles), *Hesperocorixa , Ischnura*, PMI, DO and pH, and negatively correlated with chlorophyll-a, TSS, and total inorganic N.
- Chlorophyll-a was positively correlated with TSS, total nutrients (TIN, TN, and TP), and negatively correlated with SAV cover, *Erythemis*, PMI and invertebrate taxa richness, but was not correlated with surface mats. *The poor association between water column chlorophyll-a and surface mats suggests an area for improvement of IW assessment methods, with the goal of appropriately describing the distribution of photosynthetic tissues within impounded wetlands*

5.2 Lessons learned and next steps

A wide variety of lessons have been learned over the course of 10 years of work in GSL IWs. Much of this knowledge has been incorporated into Standard Operating Procedures and sampling plans associated with DWQ's *Wetlands Program*. This project is the first to report on an integrated dataset of GSL IWs, and the first to report on similar IWs in Utah's West Desert that may serve as reference standard sites for further IW assessments. While the process of compiling all available data from IWs and other shallow open water wetlands (i.e. Willard Spur) was extremely cumbersome, several key lessons became apparent:

- There is a strong need to maintain a consistent approach while collecting baseline monitoring measurements over time. *This is especially true when trying to develop multivariate models*
- Addition of metrics or analytes collected infrequently are not highly useful for monitoring or assessment purposes – *if they cannot be related to some other, more routinely collected variable*
- Key physical parameters the describe the water body, for example water depth and flow, must be collected in order to control for variation in hydrologic properties of the ponds

More broadly, previous work developing an assessment framework for GSL IWs identified the need for a set of sites that can be used to define appropriate reference standards for this highly managed ecosystem type. Depending on available resources and DWQ wetland policy goals, next steps may include re-scaling of IW data collected during the 2012 probabilistic survey against the reference standard breakpoints described in this report. In addition, there is a strong need to identify and obtain continued funding for routine monitoring of GSL (and West Desert) impounded wetlands over time; unfortunately, resources have been limited and no monitoring of GSL IWs has taken place since the 2012 survey.

Now that the data have been compiled and a preliminary (and mostly univariate) analysis has been completed, an opportunity exists for finer-scale examination of physical, chemical, and biological characteristics of GSL IWs, including the sensitivities to various stressors, using more advanced spatial and multivariate analyses. Some examples include:

- Spatial descriptions of water chemistry and wetland soil nutrient and metal concentrations, to identify flow-path versus landscape-scale controls on these indicators
- Random Forest modeling to describe the dominant drivers of: surface mat development, SAV persistence or decline, macroinvertebrate community diversity and biomass, and exceedances of toxic metals criteria

While not explicitly addressed in these analyses, the effects of current wetland management techniques on IW characteristics remain poorly understood. If there continues to be a concern with regard to whether GSL IWs are supporting their intended beneficial use of providing forage and habitat for waterfowl and shorebirds, then the magnitude and direction of various management options must be addressed in addition to any hydrologic (inflow) issues resulting from point-source discharges or urbanized water sources. Lastly, where issues in beneficial use support do arise (e.g. some ponds may indeed be impaired), early steps should be taken to identify and implement ameliorative measures to reduce the severity, frequency or duration of the impact.

5.3 Linkages

This project was supported by technical assistance and funding from EPA's Wetland Program Development Grant program in Region 8. This project is based on the key elements of successful state wetland programs as identified from EPA's Core Elements Framework and Utah's Wetland Program Plan. This effort supports Utah's Wetland Program Plan, through development of wetland water quality standards, and by building scientific infrastructure to characterize wetland functions and biological / ecological responses to disturbance. This work also builds on EPAs Core Elements Framework for CE #1 Monitoring and Assessment (M&A) and CE #4 Water Quality Standards for wetlands, including: M&A Objective 1, *develop monitoring design to serve objectives* and *select core set of response indicators*; M&A Objective 2, *pilot projects to test methods, calibrate tools, and enhance reference network*, *establish reference condition (and define reference standard condition)*, and *develop/document data analysis procedures and assessment methods,* and *establish baseline wetland condition.* WQS Objective 2, *define wetland classes* and *establish reference conditions*, *support establishment of wetland-specific designated uses,* and *develop technical documents supporting development of both narrative and numeric criteria,* as appropriate.

6.0 Literature Cited

Albert, D.A., D.A. Wilcox, J.W. Ingram, and T.A. Thompson. 2005. Hydrogeomorphic classification of Great Lakes coastal wetlands. J. Great Lakes Res. 31(suppl. 1): 129-146.

Alloway, B.J. (Ed.). 2012. Heavy metals in soils: trace metals and metalloids in soils and their bioavailability. 3rd Edition. Environmental Pollution Series, vol. 22. Springer, Dordrecht. 614 pp.

Arnow, T. 1984. Water-level and water-quality changes in Great Salt Lake, Utah, 1847-1983. U.S. Department of Interior, U.S. Geological Survey, circular 913. 29 pp. Online, accessed 1 March, 2015 (Link).

Bolen, E.G. 1964. Plant ecology of spring-fed salt marshes in western Utah. Ecological Monographs 34(2): 143-166.

Brinson, M. 1996. Assessing wetland functions using HGM. National Wetlands Newsletter 18(1):10-16. Online, accessed 17 February, 2015 (Link)

CH2MHill. 2005. Statistical analyses of 2004 data on wetland plants and invertebrates in Farmington Bay, Great Salt Lake, Utah. Technical memo for Utah Division of Water Quality and Central Davis Sewer District. 62 pp. Online, accessed 19 February 2015, at: (Link).

CH2MHill. 2006. Analyses of 2005 data on wetland biota and water quality in Farmington Bay, Great Salt Lake, Utah. Technical memo for Central Davis Sewer District and Utah Division of Water Quality. 70 pp. Online, accessed 19 February 2015, at: (Link)

CH2MHill. 2012. A review: Farmington Bay hydrology and water management. Report to Utah Department of Natural Resources, Division of Forestry, Fire and State Lands. 60 pp. Online, accessed 18 February, 2015 at: (Link).

Cooper, M.J., G.A. Lamberti, and D.G. Uzarski. 2013. Spatial and temporal trends in invertebrate communities of Great Lakes coastal wetlands, with emphasis on Saginaw Bay of Lake Huron. J. Great Lakes Res. 40(suppl. 1): 168-182.

Cvetkovic, M., and P. Chow-Fraser. 2011. Use of ecological indicators to assess the quality of Great Lakes coastal wetlands. Ecological Indicators 11:1609-1622.

Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States, 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp. Online, accessed 10 Jan., 2015 at: (Link)

Ducks Unlimited. 2008. Great Salt Lake Wetlands Assessment Project. GIS database. Online, accessed June 5, 2012 (Link)

Division of Water Quality, Utah (DWQ). 2009. *Development of an Assessment Framework for Impounded Wetlands of Great Salt Lake*. Great Salt Lake Water Quality Studies, November 2009. Accessed May 1, 2012; (Link).

Division of Water Quality, Utah (DWQ). 2012. Great Salt Lake Impounded Wetlands: 2012 Probabilistic Survey of Wetland Condition, Sampling and Analysis Plan. Online, accessed 2 February, 2015: (Link)

Division of Water Quality, Utah (DWQ). 2013. Great Salt Lake Wetlands (2013): Preliminary Fringe Wetland Condition Assessment, Sampling and Analysis Plan. Online, accessed 13 February, 2015: (Link)

Division of Water Quality, Utah (DWQ). 2014. Validation of and enhancements to an assessment framework for impounded wetlands of Great Salt Lake. Final Technical Memo, prepared by CH2MHill for Utah Department of Environmental Quality, Division of Water Quality. 57 pp. Online, accessed November 15, 2014: (Link).

Division of Water Quality, Utah (DWQ). 2015. Great Salt Lake Paleolimnological Study. Series of project reports for DWQ. Online, accessed 17 March, 2015: (Link)

Emerson, R. and T.D. Hooker. 2011. *Utah Wetland Functional Classification and Landscape Profile Generation within Bear River Bay, Great Salt Lake, Utah*. Utah Geological Survey, Salt Lake City, UT. Contract deliverable for EPA, Region 8 Wetlands Program. 39 pp.

Environmental Law Institute. 2008. State Wetland Protection: Status, Trends, & Model Approaches. State Profiles: Utah. Online, available at: www.eli.org/sites/default/files/docs/core_states/Utah.pdf

Environmental Protection Agency (EPA). 2006. Guidance on systematic planning using the data quality objectives process. Office of Environmental Information. EPA/240/B-06/001: EPA QA/G-4. Online, accessed 1 March, 2015: (Link).

Environmental Protection Agency (EPA). 2015 [*in review*]. National Wetland Condition Assessment: 2011 Technical Report. EPA-843-R-15-006. US Environmental Protection Agency, Washington, DC. 243 pp. Online, accessed December 1, 2015: (Link).

Flowers, S. 1934. Vegetation of the Great Salt Lake region. Botanical Gazette 95(3): 353-418.

Gray, L.J. 2015. Macroinvertebrate and Zooplankton Communities of the Willard Spur Wetlands: Summary Results of 2011-2013 Sampling. Draft report to the Utah Division of Water Quality. September 30, 2015. 32 pp. Online, accessed 22 December, 2015: (Link).

Hoven, H.M., and T.G. Miller. 2009. Developing vegetation metrics for the assessment of beneficial uses of impounded wetlands surrounding Great Salt Lake, Utah, USA. Natural Resources and Environmental Issues, Vol. 15, no. 11. Online, digitalcommons.usu.edu /nrei/vol15/iss1/11, accessed May 15, 2012.

Hruby, T. 2001. Environmental Auditing: testing the basic assumption of the hydrogeomorphic approach to assessing wetland functions. Environmental Management 27(5): 749-761.

Intermountain West Joint Venture (IWJV). 2013a. Intermountain West Joint Venture 2013 Implementation Plan. Chapter Four: Waterfowl. 58 pp. Online, accessed 29 December, 2015: (Link).

Intermountain West Joint Venture (IWJV). 2013b. Intermountain West Joint Venture 2013 Implementation Plan. Chapter Five: Shorebirds. 30 pp. Online, accessed 29 December, 2015: (Link).

Intermountain West Joint Venture (IWJV). 2013c. Intermountain West Joint Venture 2013 Implementation Plan. Chapter Six: Waterbirds. 67 pp. Online, accessed 29 December, 2015: (Link).

Jacobs, A.D., M.E. Kentula, and A.T. Herlihy. 2010. Developing an index of wetland condition from ecological data: an example using HGM functional variables from the Nanticoke watershed, USA. Ecological Indicators 10(3): 703-12.

Johnston, C.A., B.L. Bedford, M. Bourdaghs, T. Brown, C. Frieswyk, M. Tulbure, L. Vaccaro, and J.B. Zedler. 2007. Plant species indicators of physical environment in Great Lakes coastal wetlands. J. Great Lakes Res. 33(Spec. Iss. 3): 106-124.

Kadlec, R.H., and S.D. Wallace. 2009. Treatment Wetlands. 2nd Ed. CRC Press, Boca Raton. 1016 pp.

Karr, J.R. and E.W. Chu. 1997. Biological Monitoring and Assessment: Using Multimetric Indexes Effectively. PEAK 235-R97-001. Seattle: University of Washington. Online, accessed 18 December, 2015: (Link).

Keddy, P.A. 2010. *Wetland Ecology: Principles and Conservation*. 2nd edition. Cambridge University Press: New York. 497 pp.

King, R.S., and C.J. Richardson. 2002. Evaluating subsampling approaches and macroinvertebrate taxonomic resolution for wetland Bioassessment. J. N. Am. Benth. Soc. 21(1): 150-171.

Lemly, J. and L. Gilligan. 2013. Ecological Integrity Assessment (EIA) for Colorado wetlands. Field Manual, Ver. 1.0. Colorado Natural Heritage Program. 101 pp. Online, accessed 17 February, 2015: (Link).

Lougheed, V.L., C.A. Parker, and R.J. Stevenson. 2007. Using non-linear responses of multiple taxonomic groups to establish criteria indicative of wetland biological condition. Wetlands 27(1): 96-109.

Madden, C.J., and W.M. Kemp. 1996. Ecosystem Model of an Estuarine Submersed Plant Community: Calibration and Simulation of Eutrophication Responses. Estuaries Vol. 19 No. 2B:457-474.

McCune, B., and M.J. Mefford. 2011. PC-ORD. Multivariate analysis of ecological data. Ver. 6.0. MjM Software, Gleneden Beach,Oregon, USA. URL: http://home.centurytel.net/~mjm/pcordwin.htm.

Menuz, D., R. Sempler, and J. Jones, 2014. Great Salt Lake Wetland Condition Assessment. Utah Geological Survey. Contract deliverable to U.S. EPA Wetland Program Development Grant. Online, accessed May, 2014 at: (Link).

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Wetlands and Water Synthesis*. World Resource Institute. Washington, D.C. 80 pp.

Miller, T.G., and H. M. Hoven. 2007. *Ecological and Beneficial Use Assessment of Farmington Bay wetlands: Assessment and Site-specific Nutrient Criteria Methods Development, Phase I*. Progress Report to EPA, Region 8, for Wetland Program Development Grant No: CD988706-03. Accessed May 2012: (Link).

Miller, T.G., H.M. Hoven, J. Cavitt, and L. Gray. 2012. *Research Compendium, Jordan River and Farmington Bay Water Quality Council, Utah*.

Mitsch, W.J. and J.G. Gosselink. 2007. *Wetlands*. 4th edition. Wiley & Sons: Hoboken, New Jersey. 582 pp.

National Wetlands Inventory (NWI). 2008. Wetlands Data for Utah (GIS data). United States Fish and Wildlife Service. Accessed March 2010: (Link).

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org/.

Reddy, K.R., and R.D. DeLaune. 2008. Biogeochemistry of Wetlands. CRC Press, Boca Raton. 774 pp.

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

Rocchio, F.J., and R.C. Crawford. 2013. Floristic quality assessment for Washington vegetation. Washington Natural Heritage Program. 55 pp. Online, accessed 17 February, 2015: (Link).

Smith, R.D., A. Ammann, C. Bartoldus, and M.M. Brinson. 1995. *An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices*. Technical Report WRP-DE-9, United States Army Engineer Waterways Experiment Station: Vicksburg, Mississippi. 90 pp.

Stein, E.D., A.E. Fetscher, R.P. Clark, A. Wiskind, J.L. Grenier, M. Sutula, J.N. Collins, and C. Grosso. 2009a. Validation of a wetland rapid assessment method – use of EPAs level 1-2-3 framework for method testing and refinement. Wetlands 29(2): 648-665.

Stein, E.D., M. Brinson, M.C. Rains, W. Kleindl, and F.R. Hauer. 2009b. Wetland Assessment Debate: Wetland assessment alphabet soup: how to choose (or not choose) the right assessment method. Wetland Science and Practice 26(4): 20-24. Online, accessed 17 February, 2015: (Link).

Steinman, A.D., M.E. Ogdahl, M. Weinart, and D.G. Uzarski. 2014. Influence of water-level fluctuation duration and magnitude on sediment-water nutrient exchange in coastal wetlands. Aquatic Ecology 48: 143-159.

Stevens, D.L., and S.F. Jensen. 2007. Sample design, execution, and analysis for wetland assessment. Wetlands 27(3):515–523.

Sumner, R., J. Schubauer-Berigan, T. Mulcahy, J. Minter, B. Dyson, C. Godfrey, and J. Blue. 2010. Alternative futures analysis of Farmington Bay wetlands in the Great Salt Lake ecosystem. EPA, Cincinnati, OH. EPA/600/R-10/032. 106 pp. Online, accessed 13 February, 2015: (Link).

U.S. Fish and Wildlife Service, U.S. (USFWS). 2004. Comprehensive Conservation Plan, Fish Springs National Wildlife Refuge. 103 pp. Online, accessed 20 December, 2015: (Link).

U.S. Fish and Wildlife Service, U.S. (USFWS). 2009. Annual Habitat Management Plan: 2009, Bear River Migratory Bird Refuge, Brigham City, Utah. Online, available at: (Link).

Wardrop, D.H., M.E. Kentula, S.F. Jensen, D.L. Stevens, K.C. Hychka, and R.P. Brooks. 2007. Assessment of wetlands in the upper Juniata watershed in Pennsylvania, USA using the hydrogeomorphic approach. Wetlands 27(3): 432-445.

Ye, R., A.L. Wright, W.H. Orem, and J.M. McCray. 2010. Sulfur distribution and transformations in Everglades Agricultural Area soil as influenced by sulfur amendment. Soil Science 176(6): 263-269.