



Summary of Willard Spur Investigations

Introduction

The Utah Division of Water Quality (DWQ) is convening a workshop to develop site-specific narrative criteria for the Willard Spur ecosystem. At this workshop the Conservation Action Planning (CAP) process will be used to frame the discussion of important ecological attributes that could potentially be included in these regulations (see <http://appliedconservation.com/resources/> for additional details on the process). Included among the CAP method elements are several steps that are particularly relevant to this discussion: 1) the identification of focal ecological systems, assemblages, species, or other ecosystem properties that require protection, 2) the identification of key threats to these focal targets, and 3) specific ecological characteristics or attributes that could be used to measure the health of condition of these conservation targets.

From 2010 through 2016 DWQ collaborated with numerous scientists on a number of investigations that could inform the CAP discussions. This document summarizes the results from well over 1000 pages of reports that were generated from these investigations. For regulatory context, the document also summarizes why these studies were initiated and reviews several water quality rules and regulations that may be relevant to the discussion.

Project Background

Willard Spur Description

Willard Spur is wetland that functions as a non-tidal estuary between the terminus of Bear and Ogden Rivers and the Bear River Bay of Great Salt Lake. The wetland is located north of Willard Bay Reservoir and South of the Bear River Migratory Bird Refuge (Figure 1). The closest communities, to the east, are the towns of Perry (population 4,846) and Willard (population 1,812). The Spur is located on sovereign state lands, but is

influenced influenced by water management conducted by the US Fish and Wildlife Service (USFWS) to the north at the Utah Department of Natural Resources' management of the Harold Crane Wildlife Refuge to the south, and less directly a multitude of water management agencies further upstream in the further upstream in the Bear River and Ogden River Watersheds. Recreation within the Willard Spur mostly consists of air boating, bird watching and hunting.

The unique habitat of Willard Spur varies dynamically throughout any given year and is directly linked to the hydrologic cycle of GSL's watershed. Willard Spur is where GSL's saline waters and fresh water entering from the Bear River and Weber River Basins begin to mix when lake levels exceed approximately 4,201.9 feet (CH2M HILL, 2014a). Fresh water entering Willard Spur from the Bear River and Weber River Basins makes up an average of 42 percent of the total annual inflow to GSL. When GSL water levels fall below an elevation of approximately 4,201.9 feet, Willard Spur no longer mingles with GSL's saline waters, and its habitat is then controlled largely by the freshwater inflows. Great Salt Lake was last at an elevation of 4,201.9 feet in July 2000; Willard Spur has since been transitioning into freshwater-dominated wetlands (U.S. Geological Survey (USGS), 2011). As inflows to Willard Spur decrease and water levels in Willard Spur drop, a natural rise in the lake bottom on the western boundary of Willard Spur (locally known as the "sand bar") disconnects the waters of Willard Spur from Bear River Bay and the waterbody becomes a natural impoundment. This can happen on an annual basis depending on available inflows.

While unique in terms of its large size and dynamic hydrology, ecologically Willard Spur is not too dissimilar from other wetlands that surround Great Salt Lake. The U.S. Fish and Wildlife Service (USFWS) has developed five management categories describing different habitat in the Willard Spur wetlands within the boundaries of the BRMBR (USFWS 2004). The areal extent of each of these categories is largely dependent on the hydrology in a given growing season:

- Deep submergent wetlands (18–24 inches of water, dominated by sago pondweed [*Stuckenia pectinata*] with very little emergent vegetation)
- Shallow submergent wetlands (4–18 inches of water, dominated by sago pondweed with sparse emergent vegetation)
- Mid-depth emergent wetlands (8–12 inches of water, 50 percent emergent vegetation with alkali bulrush [*Schoenoplectus maritimus*] largely in shallower areas and hardstem bulrush [*Schoenoplectus acutus*] in deeper areas, large stands of cattails [*Typha latifolia* and *T. angustifolia*] and phragmites [*Phragmites australis*] possible)

- Shallow emergent wetlands (2–8 inches of water, predominantly alkali bulrush, some stands of cattails, and phragmites)
- Vegetated mudflats (0–2 inches of surface water during high-inflow periods or large precipitation events, highly saline soils, often unvegetated, can support shallow-rooted vegetation such as pickleweed [*Salicornia rubra* and *S. utahensis*], saltgrass [*Distichlis spicata*], and seepweed [*Suaeda calceoliformis* and *S. moquini*])

The varied habitat that Willard Spur provides is a haven for birds and fish; the immense populations of birds are perhaps what Willard Spur is most well known for. USFWS has documented over 210 bird species that regularly use the adjacent BRMBR, at least 67 of which nest in the area. The vegetation, macroinvertebrates, and fish the wetlands of BRMBR and Willard Spur provide are ideally suited for these migrating populations of waterfowl, shorebirds, and other waterbirds from the Pacific Flyway and Central Flyway. These waters, in conjunction with other waters of GSL, were recognized for their importance to shorebirds as a Western Hemisphere Shorebird Reserve Network Site in 1992 (USFWS, 2004).

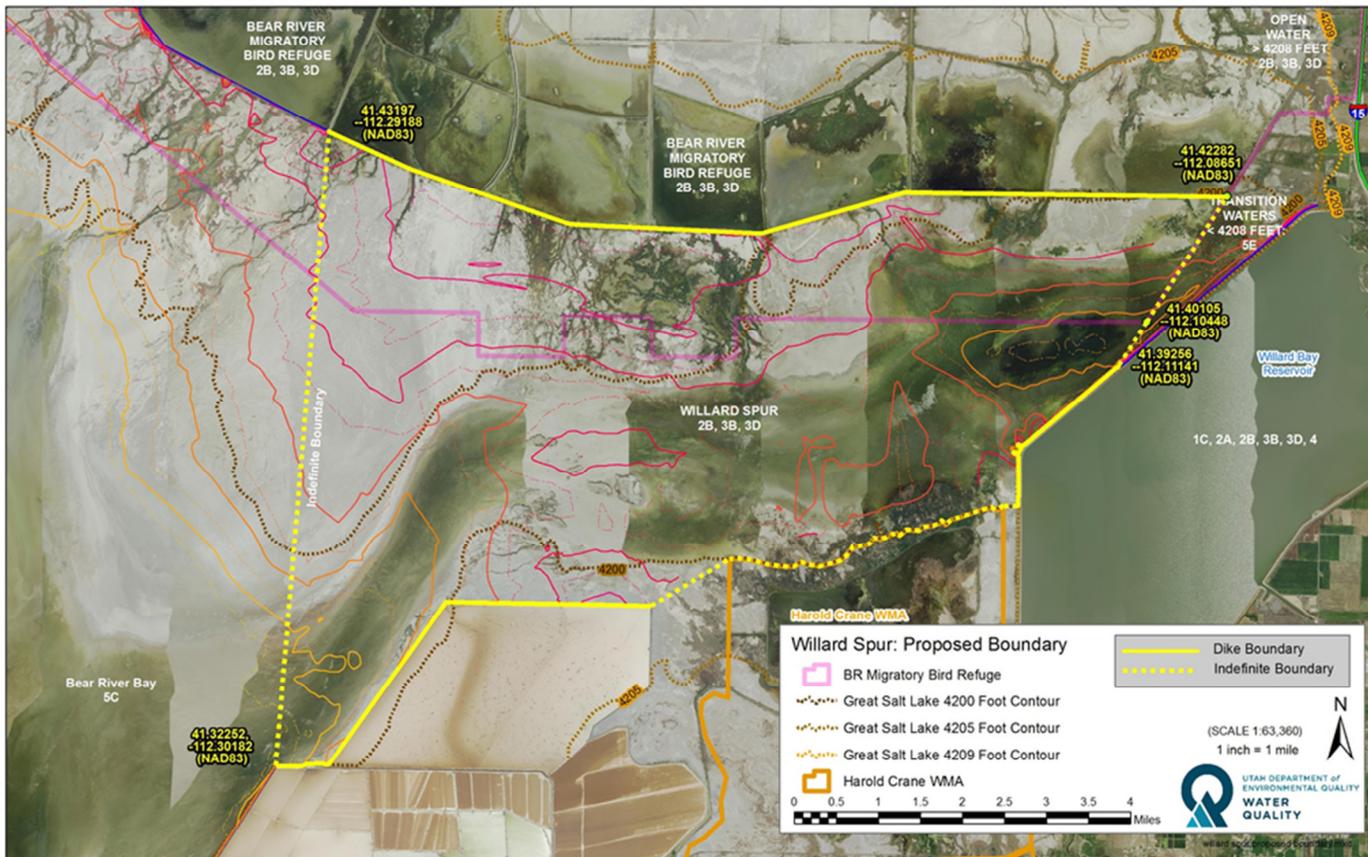


Figure 1. Map of Willard Spur, including proposed boundaries (yellow). Note the different use classes within and outside of the Bear River Migratory Bird Refuge boundary.

Political Backdrop

In 2010 the cities of Perry and Willard completed construction of \$28 million worth of sewer improvements, including a new regional wastewater treatment facility to be managed jointly by the two cities through an Interlocal Agreement—the Perry Willard Regional Wastewater Treatment Plant (PW-WWTP). In May 2010, as construction of the PW-WWTP neared completion, DWQ published a public-notice of the Utah Pollutant Discharge Elimination System (UPDES) permit for the discharge of treated effluent from the PW-WWTP into the Willard Spur of Great Salt Lake (GSL). In response to this solicitation, Western Resource Advocates —on behalf of the Utah Waterfowl Association—petitioned the Water Quality Board (WQB) to re-classify Willard Spur as a Category 1 waterbody, a classification reserved for waters of exceptional recreational or ecological significance that would prohibit all wastewater discharges to Willard Spur. If this was not possible the petitioners requested to reclassify Willard Spur to protect the wetlands and current uses of the water. This led to DWQ temporarily withholding the UPDES discharge permit.

The WQB denied the petition but directed DWQ staff to develop a study design to establish defensible protections (i.e., site-specific numeric criteria, antidegradation protection classes, and beneficial use changes) for the waterbody. In addition, DWQ was directed to work with stakeholders to identify a path forward to allow the PW-WWTP to operate while the studies were underway, with reasonable assurances that the effluent would not harm the ecosystem. The WQB also directed DWQ to work collaboratively with stakeholders to develop and implement a research program to obtain the data necessary to ensure that any regulatory changes that are ultimately proposed will be scientifically defensible.

In response to these directives, DWQ formed two workgroups. A Science Panel was established to oversee a research program aimed at collecting sufficient data to inform regulatory decisions. Specifically, the Science Panel was charged with the responsibility to identify and oversee the studies required to address the question: “*What water quality standards are fully protective of beneficial uses of Willard Spur waters as they relate to the proposed POTW (publicly owned treatment works) discharge?*” A Steering Committee, consisting of interested stakeholders was also formed. This committee was charged with the responsibility of guiding the process of water quality standards development. At the end of the process, this group was asked to come to consensus—via a supermajority vote— to the WQB on any regulatory changes that are necessary to resolve either of the two framing questions for the project:

1. *What are the potential impacts of the Perry Willard Regional Wastewater Treatment Plant on Willard Spur?*
2. *What changes to water quality standards will be required to provide long term protection of Willard Spur as they relate to the proposed POTW discharge?*

To provide answers to these questions, the three following key research areas were agreed upon:

1. *Define and understand the food web of Willard Spur*
2. *Define the water and nutrient budget for Willard Spur*
3. *Define responses to eutrophication within Willard Spur*

Once these groups were formed, the most immediate task was an agreement among challenging parties to drop their permit challenges, so the PW-WWTP could start operating while the research process was ongoing. To facilitate this compromise DWQ conducted an analysis that concluded, albeit with limited data, that the immediate (3-5 year) risk from the PW-WWTP discharge was minimal. To further minimize the risk the WQB funded chemical phosphorus removal, both the infrastructure and operation and maintenance expenses. This allowed the PW-WWTP to meet a phosphorus reduction target of 1 mg/L. Also, to alleviate concerns from Perry and Willard cities that hardship grant funds would be unavailable at the end of the project—should the research demonstrate that additional nutrient reductions, especially nitrogen, were necessary—the WQB set aside \$1M in contingency funding. Together, these agreements were successful in satisfying the challenging parties such that they were willing to drop protests to the UPDES permit, and also avoided another potential challenge in Federal Court. Investigations into the biological, physical, and chemical properties of the Willard Spur ecosystem were conducted for three years, from 2011 to 2013.

Relevant Water Quality Regulations

Clean Water Act Objectives

Under both state law (Utah Administrative Code (UAC) Title R317) and federal Clean Water Act (CWA) authority, DWQ is entrusted with the responsibility to maintain the chemical, physical, and biological integrity of Utah's surface waters, including Great Salt Lake. Three minimum water quality goals are specified in Section 101(a) of the CWA: 1) water quality that supports propagation of fish, shellfish, and wildlife; 2) water quality that supports recreation in and on the water, and; 3) no discharges of toxics in toxic amounts. Utah Water Quality Act and CWA requirements to meet these goals begins by first designating beneficial uses and then establishing and enforcing water quality criteria that define the specific water quality requirements needed to maintain these uses.

Willard Spur's Beneficial Uses

Beneficial uses are descriptions of how the water will be used by humans and other organisms, or, in other words, what the water quality is intended to support. The current beneficial uses assigned to the Willard Spur are based on management area/political boundaries and include those assigned to the Bear River Bay of Great Salt Lake (UAC R317-2-6.5) and those assigned to protect the Bear River Migratory Bird Refuge (BRMBR, UAC R317-2-13) (see Figure 1). Both of these designated uses protect infrequent primary and frequent

secondary contact recreation (Class 2B) and aquatic life. Areas within the BRMBR are designated to protect “warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain” (Class 3B, UAC R317-2-6.3) and “waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain” (Class 3D). Aquatic life protections for areas outside of the BRMBR boundaries are part of the beneficial uses established for Great Salt Lake, specifically: “waterfowl, shore birds and other water-oriented wildlife including their necessary food chain” (Category 5C or 5E). Qualitatively, these descriptions are obviously similar however, the distinction is important with respect to the associated numeric criteria (see discussion below).

All of the aquatic life designated uses established for Willard Spur include the implicit CWA assumption that these goals, if fully attained, would be protective of the biological integrity of these waters (CWA §101(a)). This is an important clarification because ecological attributes used to describe biological integrity can be used to inform appropriate biological attributes. While the CWA does not define biological integrity, several definitions have subsequently been proposed. Currently, the most widely accepted definition is one that was proposed by Karr (1981), after Frey (1977), who defined biological integrity as:

“the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region.”

Consideration of this definition in the context of Utah’s rules can be used to glean insight into what it means to be protective of organisms and their “necessary food chain”. Such considerations also help to conceptually integrate the subtle distinctions in Willard Spur’s designated aquatic life uses by contextualizing the intent behind Willard Spur’s designated uses. Similarly, this context helps mitigate confusion caused by political boundaries that artificially establish different water quality regulatory requirements for a single ecosystem.

Existing Water Quality Criteria

An important distinction with respect to the various designated uses for Willard Spur is that the designated uses within the BRMBR boundaries have associated numeric criteria for dissolved oxygen (DO), pH, and temperature, and toxic substances, whereas those that fall outside the boundaries do not. The current permit for the PW-WWTP reconciled this by basing the permit effluent limits on the assumption that Class 3B use criteria were applicable throughout the ecosystem. The variance request made by the PW-WWTP from the Technology Based Phosphorus Effluent Limit (TBPEL) (insert rule) made a similar assumption, comparing water quality observations associated with nutrient enrichment (e.g., DO, pH), against 3B use criteria. In addition, the variance used a similar approach that DWQ applies when conducting biological assessments (UAC 317-2-7.3) by examining several measurements of the current health of Willard Spur’s aquatic community and the potential for

the PW-WWTP to have any deleterious effects on the aquatic life uses that these standards ultimately seek to protect.

Utah's Narrative Criteria

Utah currently has narrative criteria that apply to all waters of the state (UAC R317-2-7.2), which reads as follows:

It shall be unlawful, and a violation of these rules, for any person to discharge or place any waste or other substance in such a way as will be or may become offensive such as unnatural deposits, floating debris, oil, scum or other nuisances such as color, odor or taste; or cause conditions which produce undesirable aquatic life or which produce objectionable tastes in edible aquatic organisms; or result in concentrations or combinations of substances which produce undesirable physiological responses in desirable resident fish, or other desirable aquatic life, or undesirable human health effects, as determined by bioassay or other tests performed in accordance with standard procedures; or determined by biological assessments in Subsection R317-2-7.3.

While the water quality objectives outlined in these criteria are qualitative in nature, DWQ has several programs that have developed numeric translations of these narrative statements into more objective measures that can then be used to identify circumstances where these criteria are not supported. The development and implementation of these numeric translators is specifically authorized in Utah's Water Quality Standards (UAC R317-2-7.3):

Waters of the State shall be free from human-induced stressors which will degrade the beneficial uses as prescribed by the biological assessment processes and biological criteria set forth below:

- a. Quantitative biological assessments may be used to assess whether the purposes and designated uses identified in R317-2-6 are supported.*
- b. The results of the quantitative biological assessments may be used for purposes of water quality assessment, including, but not limited to, those assessments required by 303(d) and 305(b) of the federal Clean Water Act (33 U.S.C. 1313(d) and 1315(b)).*
- c. Quantitative biological assessments shall use documented methods that have been subject to technical review and produce consistent, objective and repeatable results that account for methodological uncertainty and natural environmental variability.*
- d. If biological assessments reveal a biologically degraded water body, specific pollutants responsible for the degradation will not be formally published (i.e., Biennial Integrated Report, TMDL) until a thorough evaluation of potential causes, including nonchemical stressors (e.g., habitat degradation or hydrological modification or criteria described in 40 CFR 131.10 (g)(1 - 6) as defined by the Use Attainability Analysis process), has been conducted.*

Planned Updates to Willard Spur's Water Quality Regulations

DWQ is proposing to designate Willard Spur as a unique water body in Utah's water quality standards. This designation will likely also involve the promulgation of 3B numeric water quality standards, with the possible exception of pH and Dissolved Oxygen (DO), which are frequently violated in Willard Spur due to naturally occurring conditions. In addition, DWQ intends to work with stakeholders to collaboratively develop narrative criteria for this waterbody because the numeric criteria are primarily for toxic substances and do not fully capture several important ecological attributes that need to be protected to ensure the long-term protection of the Willard Spur ecosystem.

Scientific Investigations

Introduction

Numerous studies were conducted over the course of the Willard Spur investigations (2011-2013) and the combined results of these investigations were reviewed by the Science Panel and Steering Committee. Among their recommendations to the WQB was that the PW-WWTP be provided a variance from the TBPEL from October through June. Results from these investigations—particularly those that can be used to understand linkages between nutrient enrichment and aspects of Willard Spur's chemical, physical or biological integrity—are briefly summarized and include key findings. The studies are organized into two sections: 1) investigations focused on elements of Willard Spur's biological integrity because these data are integral to better understanding the designated uses of the Spur, and 2) investigations focused on underlying chemical and physical conditions because these data are needed to understand the potential influence of the threats with potential to degrade the biological integrity of the ecosystem. More detailed data and information that support the information provided in this research summary can be obtained from the project reports and constituent research citations, which are included in the appendices of this variance request rationale.

The hydrologic conditions in Willard Spur were different during each year of the study and had a profound impact on the biological and chemical attributes that were observed. The first year of the study, 2011, was an exceptionally wet year in Northern Utah and the Willard Spur saw deeper, more extensive, and longer flooding than in subsequent years. As a result of these larger water supplies, a hydrologic connection between Willard Spur and Bear River Bay was retained through the year. The study years of 2012 and 2013 coincided with a multi-year regional drought and low snow-packs and stream discharge meant less extensive and more temporary flooding through the study area. These lower water inputs resulted in Willard Spur becoming isolated from Bear

River Bay in the summer, and then continue to decrease in size until flows increased at the end of irrigation season upstream.

Biological Integrity: Willard Spur's Food Web

Several investigations and literature reviews have been conducted to better understand Willard Spur's food web and the potential for increases in nutrients from the PW-WWTP to degrade the structural components of biological integrity of several important assemblages of the wetland-dependent community within Willard Spur, including: birds, fish, macroinvertebrates, zooplankton, and vegetation. The latter three assemblages were selected because they are important elements of avian food webs, and are therefore explicitly protected components of the Spur's designated aquatic life uses.

While the specific methods differed among the investigations, they all had the same general objectives. First, each investigation aimed to evaluate the current health or condition of the wetland-dependent life in the Spur ecosystem. A second objective was to provide information on the potential for excess nutrients to degrade the condition of any of these uses. Finally, these investigations all attempted to identify measures that could be used to assess any changes to the biological integrity of the Spur, with an emphasis on those measures that have been demonstrated to respond to nutrient enrichment in wetlands elsewhere.

Birds (Avian Fauna)

Dr. John Cavitt and his team at Weber State University reviewed the literature to investigate bird use of the Willard Spur ecosystem. Nutrients are not known to directly degrade the health or condition of birds. Instead, any degradation to the birds resulting from excess enrichment would occur through alteration of habitat, including important food resources. As a result, these studies aimed to better understand the current condition of the avian assemblage in the Spur and the threats, if any, that excess nutrients on conditions found to be important to the condition of this assemblage (Cavitt 2013, Barber and Cavitt 2012).

Key Findings

A detailed review of Utah Division of Wildlife Resources' avian population database for 1999-2012 was completed by Dr. Cavitt to determine which species were using Willard Spur, an estimate of how many birds of each species were present throughout different seasons, and how these numbers fluctuated depending on various conditions, in particular, water level and inflows. Fifty-six species were recorded in the database and their populations illustrate how critical the Willard Spur habitat is within the Great Salt Lake (GSL) ecosystem. Changes in the relative abundance of most key bird species appear to be correlated with temporal changes in water elevations and flows, both within and among years. Shorebirds, which prefer mudflats and shallow waters, increase when flows are low into Willard Spur. Larger waterfowl that prefer deeper waters, more SAV, and possibly birds who have been pushed out of other areas of the GSL by rising water levels tend to increase in

quantity in Willard Spur during times of high flows and corresponding high water levels. This finding showcases how dynamic Willard Spur's ecology is throughout different seasons and conditions and why it attracts such a diversity of birds.

A couple of investigations aimed to evaluate the potential effects of additional nutrients from the discharge to either high- or low-water avian assemblages. First, a detailed literature review was completed to summarize dietary information for fifty-two bird species found to utilize Willard Spur. Diets among these species were diverse and included: fish, invertebrates, and vegetation. Diets for some of these species were relatively plastic, changing seasonally depending on the availability of food sources. Other species of birds had more specific feeding requirements (e.g., piscivores) or feeding behaviors that require specific habitat conditions (e.g., suitable water depth for shorebirds foraging). Those species with the most specific feeding requirements often exhibited the most pronounced changes in relative abundance among seasons.

A second study evaluated the diets of ducks feeding in Willard Spur to determine the most critical food sources needed to support waterfowl populations. While the diets of the various waterfowl species sampled varied as widely as the habitat they prefer, the diet of the ducks captured in the BRMBR area in 2009-2010 and the ducks captured in Willard Spur in November 2011 was almost entirely herbivorous. The relative importance of vegetation compared to other types of food observed in this study could be the result of the selection and quantity of vegetation in Willard Spur exceeded other locations on the GSL. Alternatively, it is also possible that these results were an artifact of when the investigations were conducted because vegetation preferred by the waterfowl was highly abundant during the periods of deeper water in 2011, whereas the density of macroinvertebrates was relatively low. Hence, this investigation was augmented with data for diets from birds sampled in other parts of the GSL to provide a more complete picture of the range of food items consumed by ducks in the area, and how their diets changed depending on season. Among all bird species present in Willard Spur, macroinvertebrates were the largest component of the diet (n=44), while other invertebrates (n=36), plants (n=29) and fish (n=23) form the next highest prey categories. Only ten species include vertebrates in their diet. At least eleven species consume brine flies, while a minimum of eight species prey on brine fly larvae and brine shrimp.

Potential Ecological Attributes (Indicators)

- Bird diversity or abundance of either species of concern or indicator species
- Abundance or health of important vegetative forage (e.g., SAV, bullrush)
- Macroinvertebrate abundance
- Threats to avian health (e.g., early SAV senescence)

Fish

While the protection of warm water fish in portions of the Spur is explicitly required by Utah's water quality standards, it was unknown at the inception of the investigation whether this aquatic life designation was appropriate because an evaluation of fish populations in the Spur had never been conducted. Also, it was impossible to estimate the threats, if any, of nutrient enrichment to this unknown assemblage because fish species differ in their sensitivity to changes caused by nutrient enrichment. Chris Penne at the Utah Division of Wildlife Resources completed a review of the available literature and conducted field studies to ascertain the presence, composition, and diversity of the fishery in Willard Spur (Penne 2012a, Penne 2012b). Once the fish species were identified Penne reviewed the literature to identify ways in which nutrients can potentially affect those species, with an emphasis on dissolved oxygen (DO) reductions and increases in pH, which are both consequences of excess enrichment that could potentially degrade the condition of this assemblage.

Key Findings

Although no investigations describing Willard Spur's fishery prior to 2011 were found, observational studies of migratory birds and reports from anglers suggested that there was a warm-water fishery dominated by invasive common carp. Two field studies (Moore 2011, Penne 2012b) confirmed that a warm water fishery does exist in Willard Spur. The fish species found consisted of common carp, gizzard chad, Utah chub, channel catfish, black bullhead, hybrid striped bass (also known as wiper), yellow perch, and black crappie. Although there is some recreational use of the fishery, the primary value of the fishery in the Willard Spur is thought to be as a food source for migratory birds such as the white pelican.

The two fisheries in adjacent waterbodies that are also a source of water to Willard Spur, the Bear River and Willard Bay Reservoir, have been extensively studied. The primary fish species found in these two fisheries, *names?*, were found in Willard Spur, indicating a strong link between the fisheries of Bear River, Willard Bay Reservoir and Willard Spur. The fish present in Willard Spur are capable of surviving and reproducing in varied conditions, including extremes of oxygen and temperature that are known to degrade the condition of other fish species. The dominant fish species found in Willard Spur (common carp, gizzard shad, Utah chub, and black bullhead) are all able to spawn in the ecology of Willard Spur and are generalist feeders capable of eating detritus, benthic invertebrates, plant material, and plankton, all of which are found in abundance within Willard Spur. Each of these four species are also more tolerant of the warm temperatures, low dissolved oxygen, and higher salinities found in shallow, fluctuating ecosystems like Willard Spur. Among other things, this broad tolerance means that changes in water quality caused by excess production (e.g., decreased DO, increased pH) are unlikely to affect the health or fecundity of fish in Willard Spur. Moreover, the broad tolerance and generalist feeding characteristics of these fish means that they are also unlikely to be affected from indirect changes caused by nutrients such as alteration of their food web.

The greatest threat to the Willard Spur fishery is thought to be the elimination of habitat through the absence of water. A significant loss of fish was observed in 2012 and 2013 as the open water in Willard Spur receded and eventually dried up in 2013. Some of these losses are likely the result of a reduction in the overall size of fish habitat, but indirect effects caused by water loss are also possible. In systems such as Willard Spur that have high densities of common carp, the collective feeding activity of these fish can degrade water quality and reduce habitat for other fish species. This becomes more important as water levels decrease and carp are concentrated in smaller areas.

Potential Ecological Attributes (Indicators)

- Health or abundance/biomass of fish
- Minimize carp density

Macroinvertebrates and Zooplankton

Dr. Larry Gray evaluated the macroinvertebrate assemblages of Willard Spur from samples collected by DWQ in 2011 – 2013 (Gray 2012, Gray 2013, Gray 2015a, Gray 2015b) and completed a review of the literature to understand the composition, characteristics, and tolerance of its resident macroinvertebrates fauna to nutrient enrichment.

Key Findings

Dr. Gray found that the macroinvertebrate taxa present in Willard Spur are representative of what are commonly found in other GSL wetlands. Abundance of major taxa shifted seasonally and likely in response to changing conditions in Willard Spur. Community composition appeared to be most sensitive to water level and the health of SAV. This observation was confirmed both through a comparison of taxonomic results among years, and also a comparison of central and peripheral Willard Spur sample sites. The literature review (Gray 2012) provided an important summary of major macroinvertebrate taxa found in Willard Spur, effects of salinity, water level, and nutrient enrichment on individual taxa, and community metrics and community responses to nutrient enrichment. Unlike condition metrics for other assemblages, some measures of the condition of macroinvertebrates were diminished in high water conditions. For instance, the abundance of macroinvertebrates and zooplankton was found to be lowest in 2011, the year when flow rates were highest and water temperatures were lowest (Gray 2012). Other compositional metrics of Willard Spur macroinvertebrates were similar to other GSL wetlands, declining in response to a decrease in SAV within Willard Spur. Perimeter and channel sites were found to contain a greater abundance of species such as snails, hemipterans, and aquatic beetles that are more tolerant of poor water quality.

Dr. Gray reported that the year 2012 had similar taxa as 2011, however the relative abundance of taxa shifted to a greater abundance of midges, rather than mayflies and damselflies, early in the drier year of 2012 (Gray 2013). Lower water levels and rapidly declining SAV condition in 2012 resulted in declining macroinvertebrate community metrics and a shift to a community of taxa adapted to stagnant conditions and low dissolved oxygen concentrations. Gray also completed an evaluation of the life cycles and trophic position of common macroinvertebrate taxa found in Willard Spur and noted that low water levels reduce the number of generations produced in a given year. Dr. Gray found that the community composition and response to low water levels and SAV condition were similar in 2013 as observed in 2012. The macroinvertebrate communities appeared to rebound even after the low water conditions observed in 2012. The overall density of macroinvertebrates was found to exhibit a high degree of resilience with sample counts actually higher in the spring of 2013 than the spring of 2012. Overall abundance, however, was lower in the fall of 2013 than in the fall of 2012, which may be natural variation or the result of repeated years of dry conditions.

Potential Ecological Attributes (Indicators)

- Relative abundance of sensitive or tolerant species
- Macroinvertebrate abundance or diversity
- Zooplankton abundance or diversity

Assessment of Emergent Wetland Vegetation

Dr. Karin Kettenring and her team at Utah State University completed a detailed review of the literature to understand the vegetation, invasive plants, and nutrients as a driver of emergent vegetation dynamics in Willard Spur (Downard et al. 2013).

Key Findings

Detailed studies of the vegetation and habitat specific to Willard Spur do not exist within the literature, however, the literature did confirm the important role that vegetation plays as part of the habitat and food web in ecosystems adjacent to and similar to Willard Spur. The literature indicates that the Willard Spur may have a higher diversity of plant species than other GSL locations due to freshwater inflows. Inflow and water level fluctuations are important in determining the location, extent, condition, and expansion of vegetation in systems similar to Willard Spur. Extreme fluctuations in water levels can stress vegetation by changing the salinity and other aspects of chemistry of water and sediments and create conditions opportune for invasive species. Numerous invasive plant species are likely located within Willard Spur; however, *Phragmites australis* is the most widespread. Monotypic stands of these invasive species displace native vegetation and the food sources they provide for migratory birds, fragment the marshes, affect nesting habitat, and generally reduce the quality of the habitat and ecosystem services provided by the wetlands. Several sources of GSL vegetation mapping were identified, however only the 2007 Ducks Unlimited and 2011 Utah State University GSL vegetation mapping

projects provided readily useful data for Willard Spur. A consistent difference between datasets was simply an observed increase in *Phragmites* distribution between 2007 and 2011. The more recent 2011 USU dataset is provided at a one meter resolution, whereas the 2007 Ducks Unlimited dataset was done at a much coarser resolution, making it difficult to precisely quantify the actual increase in *Phragmites* during this time period.

At the outset of this project, concern was voiced that a stand of *Phragmites* located adjacent to the old Outfall Ditch was a result of discharge from the (PW-WWTP). Through analysis of historical data in the form of satellite images of the site and first person accounts it was determined that the *Phragmites* stand was present in that location before the (PW-WWTP) began discharging to the Outfall Ditch in April of 2011. Nonetheless, the literature indicates that *Phragmites* is a high nutrient specialist and as such, performs particularly well in areas with elevated anthropogenic nutrient inputs that allow it to out-compete native species and spread more rapidly. There are findings that link nutrients to changes in the distribution of invasive species, however there are also other modifying factors that need to be better understood that also could impact the spread of invasive species, such as salinity, pH, natural inflows, temperature, etc.

Potential Ecological Attributes (Indicators)

- Abundance or aerial cover of *Phragmites*
- Abundance or aerial cover of indicators of healthy emergent vegetation

Submerged Aquatic Vegetation (SAV)

Early investigations in Willard Spur suggested that SAV were particularly important components of its food web and potentially to its ecosystem processes such as nutrient cycling. As documented throughout the food web investigations, SAV is important as a source of food and habitat for many different wetland assemblages. As a result, several studies were conducted to better understand the role of SAV in the Willard Spur Ecosystem and the linkages to nutrients. Dr. Heidi Hoven and University of Utah researchers conducted a series of nutrient enrichment experiments that evaluated the potential role of nutrient enrichment on various measures of macrophyte condition (Hoven et al. 2014, 2015). DWQ also evaluated SAV cover and condition throughout the growing seasons of 2011-2013 (Hooker et al. 2015).

Key Findings

Temporal Patterns in Macrophyte Condition and Abundance

In 2011, following a wet winter and spring, luxuriant macrophyte growth was observed starting from late spring and then continuing through autumn. In subsequent, much drier years (2012 and 2013), a macrophyte die off occurred in mid-late summer, followed by a subsequent greening of the water as periphyton densities increased. The transition of primary production from SAV to periphyton was concordant with changes in habitat (e.g., salinity, temperature) and community composition throughout the food web.

Healthy macrophyte assemblages contribute positive feedback to water quality by providing good filtration and removal of particulates, removal of water column phosphorus (P) that binds with particulates, and absorption of dissolved solids and other nutrients, resulting in improved water clarity and quality. In dense, healthy swards such as those observed in the Spur, P cycling is considered closed and water column P is readily taken up by the SAV or its associated periphyton and macroalgae. Also, SAV provides refugia for grazers such as zooplankton that further control periphyton. In Willard Spur, periphyton growth appeared to be repressed until SAV die-off occurs, releasing nutrients to the open water increasing light penetration.

In Willard Spur, the time-frame of SAV senescence was considered premature compared to that documented in impounded wetland systems around the GSL. Although premature die-off in Willard Spur may be chiefly driven by natural processes (e.g., high alkalinity and pH), an accelerated die-off was observed in the high nutrient-amended plots during both years of the nutrient enrichment experiments (2012 and 2013). SAV from high amendment plots died two to four weeks prior to those in control plots, and SAV in all amendment and control plots showed no significant sign of recovery after die-off both years.

Experimental Nutrient Additions

A series of experiments were conducted in 2012 and 2013 where nitrogen (N) and P were added at three different concentrations (high, medium and low). While the experimental design differed a little between the two years, the central objective was similar: to evaluate biological responses to nutrients, as opposed to other potential stressors, by comparing conditions observed in the experimental treatments with those observed in controls. In 2012, more SAV responses to nutrients were measured, including SAV condition metrics and changes in the composition and abundance of algae and macroinvertebrates. Relevant SAV-nutrient responses were narrowed to SAV condition and abundance in 2013 because these were found to be more sensitive measures of biological condition.

Water chemistry analyses were unable to detect changes in water column nutrient concentration in the experimental nutrient enrichment plots. Yet, other lines of evidence (e.g., $\delta^{15}\text{N}$, controlled release rate investigation, and plant tissue stoichiometry) clearly indicated that the experimental additions were successful. This observation, especially when considered in the context of the other experimentally induced responses to nutrient additions (see discussion below), is important because it suggests that water column nutrients may not be the best way to identify the influence of nutrient enrichment.

Statistically significant differences between treatments and controls were identified for several biological responses. A general measure of SAV condition showed that the condition of SAV declined as nutrient (most importantly, P) treatments increased; SAV abundance measured as %SAV responded similarly. However, neither of these broad measures of condition responded as early to treatments as the density of SAV branches, which

may be a good early indicator of change in SAV condition. Other significant responses included metrics that quantified the amount of biofilm (BDS) or algae on macrophyte tissue, which provides some insight into the mechanisms responsible for declines in SAV cover and condition. Observed changes in SAV condition in the nutrient enrichment treatments relative to controls demonstrated that increases in nutrients have the potential to affect SAV condition. However, these responses also occurred in the controls, albeit later in the growing season. This observation demonstrates that other, naturally-occurring physicochemical changes are important determinants of SAV condition. Responses to nutrients cannot be evaluated without also understanding the influence of important drivers in background physical and chemical conditions.

There are several important observations that can be gleaned from the experimentally induced responses to nutrient enrichment. Again, it is important to note that all statistically significant responses occurred despite the fact that changes in water column chemistry in the experimental treatment plots relative to controls were not detectable. This observation means that water column nutrient concentrations are not the best way to quantify the influence of nutrient enrichment on conditions in Willard Spur, and that stressor-response relationships based on water column nutrient concentrations may underestimate the effects of nutrient enrichment. On the other hand, in the low nutrient treatments even the most sensitive of these responses metrics were indistinguishable from controls, which means that even if nutrients were to start accumulating in Willard Spur over time—an unlikely outcome under current hydrologic conditions—small increases in nutrients would be unlikely to affect the health of SAV, which was among the most sensitive biological responses evaluated.

Potential Ecological Attributes (Indicators)

- Abundance or aerial cover of SAV
- SAV health (e.g., branch density, general condition)
- Extent of algae growth on SAV

Physical and Chemical Integrity

One common theme among all of the studies involving Willard Spur biota is that the physical and hydrological template is a critically important determinant of its biological integrity. As a result, these characteristics are also important considerations in understanding what ecological conditions need to be protected to ensure the long-term protection of the Willard Spur ecosystem. As a result, several studies attempted to better understand these important ecological attributes of Willard Spur.

Physical Integrity: Hydrology

Year-to-year and inter-annual changes in hydrology are important drivers of ambient conditions in Willard Spur. Periodic hydrologic disconnection of the Willard Spur from the open waters of GSL that occurs in dry years

corresponds with considerable changes throughout the Willard Spur's food web. During all but the wettest years, ongoing evaporation during the isolated state causes the Willard Spur to get smaller and smaller as the growing season progresses. As the flooded area of Willard Spur decreases, the condition, abundance and composition of every biological assemblage changes correspondingly, so any ecological attributes used to measure the condition of the Willard Spur ecosystem will require interpretation in the context of the hydrological conditions that were present at the time they were measured. To address this data requirement, an extensive investigation was conducted to quantify the amount, time and sources of water inputs to the Willard Spur ecosystem (CH2MHill 2016a).

Key Findings

Conditions within Willard Spur from 2011 through 2013 were extremely dynamic and driven by wide ranging inflows of surface water from the Bear River, Weber River, and a local east side drainage basin. The year 2011 was a wet year characterized by an almost complete inundation of Willard Spur, water depths of up to six feet (two meters), and continuous outflow to Bear River Bay throughout the year. The years 2012 and 2013, by contrast, were characterized by a significantly smaller volume of surface water inflow, a complete cutoff of outflow to Bear River Bay when spring runoff was complete, a rapidly shrinking and even disappearing footprint of open water, but then a restoration of outflow to Bear River Bay during the subsequent winter and spring seasons.

The range of flood and drought conditions observed during the project's study period provided a unique opportunity to understand this ecosystem. Surface water inflows were dominated by spring runoff, contributions from the Bear River basin, and in almost all respects the surface water inflows that were managed by water users at the fringes of Willard Spur. Water volumes contributed by the PW-WWTP were negligible compared to other surface water sources. Surface water inflows from all sources, but in particular from the PW-WWTP, often failed to reach the open water impoundment of Willard Spur observed during the summer months of 2012 and 2013, which may be explained by observed groundwater interactions.

The mudflats at the western edge of Willard Spur appear to serve as a natural weir that creates an impounded condition during summer months. Increasing surface water inflows, typically beginning at the end of the annual irrigation season (generally in mid-October), likely recharge the local groundwater table, raise the water level of the open water of Willard Spur, reconnect all surface water inflow sources directly to the open water, and then flow out to Bear River Bay through May or June of the subsequent year.

A review of historical aerial photography indicates that an impounded condition during summer months followed by outflows during the fall, winter, and spring months is likely a typical annual pattern for Willard Spur. The higher, flushing flows observed during the fall–spring months are likely the most significant factor in preserving Willard Spur's present condition. PW-WWTP effluent that reaches the impounded open water of Willard

Spur is likely retained until the higher, flushing flows return in the fall. PW-WWTP effluent that reaches the open water during a flowing condition is more likely to be diluted, dispersed, assimilated, and exported to Bear River Bay. A water balance completed for the PW-WWTP's effluent provides some perspective on how discharge operations can affect the frequency and volume of the effluent reaching the open water of Willard Spur.

Potential Ecological Attributes (Indicators)

- Water availability
- Length of isolation from or connection to Great Salt Lake
- Interpretation of numeric water quality criteria under low flow conditions

Ambient Nutrient Conditions

Any effort to ensure the long-term protection of Willard Spur's biological integrity needs to include an analysis of current, ambient nutrient concentrations. DWQ collected water column and sediment nutrient data from ~70 different locations throughout Willard Spur during the growing seasons of 2011-2013 (Hooker et al. 2015). Plant and algal tissue was also collected during both high and low water conditions and then analyzed to determine its Carbon (C), N and P concentration to evaluate nutrient limitation (Ostermiller et al, 2015).

Key Findings

Ambient nutrient concentrations in Willard Spur were generally low in comparison to other similar wetlands around GSL. Median concentrations for Total-P (TP) and Total-N (TN) were 0.048 and 0.081 mg/L, respectively. Elevated nutrient concentrations observed in TN and TP concentrations observed in tributary sources were generally not detectable in the closest open water sample location, which supports observations from other studies that Willard Spur's capacity for biogeochemical removal of TN and TP during the growing season is high.

Ambient nutrient concentrations exhibited wide temporal variation, both among and within years. In 2011, when Willard Spur remained connected to GSL throughout the growing season, nutrient concentrations remained low throughout the growing season. In contrast, TN and TP concentrations increased markedly during periods of SAV die-off during dry years; a trend that was particularly evident in 2013. Despite appreciable external loads to Willard Spur there was no evidence that nutrient concentrations within Willard Spur increased from one year to the next. The higher late-season nutrient concentrations observed in dry years returned to background concentrations prior to the onset of the growing season the subsequent year.

Tissue concentrations of photosynthetic organic matter standing stocks suggest that P is more limiting than N. P limitation is particularly strong for benthic algae (periphyton), especially during periods of active SAV growth. In contrast, evidence for P limitation in the seston (phytoplankton) is fairly weak until production shifts

from SAV to the water column when the evidence for P limitation becomes much stronger (Ostermiller et al. 2015).

Potential Ecological Attributes (Indicators)

- Nutrient loads to Willard Spur
- Pant tissue nutrient ratios

Nutrient Loading to Willard Spur

There are many sources of nutrients to Willard Spur and understanding the timing and distribution of these different sources is an important consideration for the evaluation of the this potential threat to the Willard Spur ecosystem. These loading data (CH2MHill 2016b) can also help better understand periods, if any, where external nutrient loads pose the greatest risk so that additional precautions can be taken in more sensitive periods that are identified.

Key Findings

Conditions within Willard Spur from 2011 through 2013 were extremely dynamic and driven by wide-ranging inflows of surface water from the Bear River Basin, a local East Side Drainage Basin, and Weber River Basin. The year 2011 was a wet one, with high inflows and nutrient loads. The years 2012 and 2013, by contrast, were characterized by a significantly smaller volume of surface water inflow and corresponding smaller nutrient load.

The Bear River Basin contributed the vast majority of the surface water nutrient load, representing more than 82 percent of the total phosphorus load and 71percent of the total nitrogen load during the months that were evaluated each year. On average, the PW-WWTP's "end-of-pipe" effluent represented a contribution of less than 5 percent of the total external surface water nutrient load to Willard Spur. As surface water inflows and nutrient loads decreased during dry summer months, the PW-WWTP's relative nutrient contribution increased. The PW-WWTP's relative end-of-pipe nutrient contribution increased to up to 33 percent of the total phosphorus surface water load and up to 25 percent of the total nitrogen surface water load during the summer months to Willard Spur. This change was a result of reductions in other sources of surface water inflow and nutrient loads observed during these months while the PW-WWTP's effluent flow rate remained consistent.

Much of the PW-WWTP's effluent was observed to be lost during the summers of 2012 and 2013 to evaporation and infiltration as the effluent traveled through and across the vegetation and mudflats on its way to the open water. Importantly, the PW-WWTP's effluent did not reach the open water of Willard Spur during most if not all of each month in the period of July–October for both 2012 and 2013; during the same period, Willard Spur was impounded, with no outflow to Bear River Bay.

The impounded condition is considered to be the critical condition for Willard Spur, one where the PW-WWTP has the potential to have the most impact upon water quality. Nutrients from PW-WWTP effluent that may reach the impounded open water are likely retained and assimilated until the higher, flushing flows return in the fall. Nutrients from PW-WWTP effluent that reach the open water during a flowing condition are more likely to be diluted, dispersed, assimilated, and exported to Bear River Bay.

Potential Ecological Attributes (Indicators)

- Nutrient loads to Willard Spur
- Plant tissue nutrient ratios

Nutrient Cycling in Willard Spur

The uptake experiments conducted by the University of Utah (Hoven et al. 2014, Hoven et al. 2015) linked nutrient enrichment to several measures of biological condition. These experiments provided useful data about the potential for excess nutrient inputs to degrade the biological integrity of the Willard Spur; however, the experiments did not capture the intervening ecosystem processes involved in the cycling of nutrients between the water column and wetland biota. The Willard Spur Science Panel believed that filling this data gap was important to better understand whether nutrient inputs from the PW-WWTP had the potential to increase ambient nutrient concentrations in the Willard Spur. As a result, DWQ conducted a series of mesocosm experiments to obtain empirical information about internal nutrient cycling rates and the amount of nutrient retention in the Willard Spur ecosystem (Ostermiller et al. 2015).

Key Findings

Like measures of biological composition and condition, ecological processes demonstrated marked differences between periods of vibrant SAV growth in comparison with periods of SAV senescence. The uptake experiments also demonstrated the importance of SAV in the ability of Willard Spur to process external sources of nutrients. Consistent among all experimental treatments was the finding that the capacity of Willard Spur, like many wetlands, to take up and process nutrients is considerable.

SAV plays an important role with respect to the ability of Willard Spur to process nutrients. This is especially true during periods when SAV is healthy, when nutrient uptake was about four times greater in experimental mesocosms that contained SAV than those with SAV removed. This means that not only are healthy SAV an important determinant of Willard Spur's biological integrity, they are also important with respect to the ability of the ecosystem to process nutrients—an important ecosystem service.

Nutrient cycling dynamics change later in the growing season of dry years—as the SAV senesce. Organic carbon concentrations in the standing stock reveal a shift in production from SAV to periphyton (water

column), with a corresponding increase in the importance of phosphorus as a determinant of primary production rates. The change from primary production dominated by SAV to one based on periphyton also affected nutrient uptake rates. In the daytime the differences between the mesocosms with and without SAV that were observed early in the year largely went away, with both treatments exhibiting similar uptake to the observations in experimental units with macrophytes earlier in the year. Rates among treatments were also similar in nighttime experiments, with the important exception that rates of N loss in treatments without SAV were about two times greater than those with actively senescing vegetation, which may signify an increasingly important role of denitrification under late season conditions.

Daily, ecosystem-scale comparisons of uptake rates with external nutrient inputs suggests that the capacity of Willard Spur to process nutrients far exceeds daily external inputs of N and P. However, the capacity of Willard Spur to process nutrients was much lower later in the season, largely due to its vastly smaller flooded area.

Potential Ecological Attributes (Indicators)

- Ecosystem service of nutrient processing
- Nutrient uptake rates

Other Chemical Constituents

The primary pollutants of concern for the Willard Spur investigations were the macronutrients N and P. However, other water chemistry parameters were also collected and these data warrant some discussion in this rationale for several reasons. First, as previously discussed, periods of hydrologic isolation and evaporation in Willard Spur resulted in the simultaneous changes in several parameters and observed biological responses cannot be attributed solely to any single stressor. Second, several parameters that were collected can be used to quantify changes in ecosystem metabolism, which is ultimately the ecological response to nutrient enrichment of principal concern. Finally, all observations throughout the three years of the Willard Spur investigation are limited to nutrient-related responses under contemporary ecological conditions and the interplay among nutrients, ecological responses and important covariates that alter these responses can potentially provide insight into future changes that have the potential to increase or decrease the sensitivity of Willard Spur to nutrient enrichment. All told, DWQ collected over 200 water chemistry samples in the open water of Willard Spur to help elucidate temporal and spatial trends in chemical composition from 2011-2013 (Hooker et al. 2015).

Key Findings

Changes in the physical characteristics of Willard Spur did not exhibit consistent changes over the growing season of 2011, whereas consistent and marked differences were observed prior and subsequent to hydrologic isolation in 2012 and 2013. After isolation, an increase in temperature, salinity and most major ions

was observed at all open water sample locations. These changes would generally all contribute to an increase in stress to resident biota during hydrologic isolation.

Turbidity (the ratio of Total Suspended Solids to Volatile Suspended Solids) peaked prior to SAV establishment and then declined rapidly throughout the remainder of the growing season. Water clarity markedly increased during periods of active SAV growth and then declined during SAV senescence, but the late season declines were caused by an increase in periphyton as opposed to high concentrations of inorganic matter that were observed during spring runoff.

Similarly water column nutrients did not vary consistently or systematically in 2011, whereas both N and P increased over the growing seasons of 2012 and 2013. During the drier years peaks of N and P corresponded with periods of SAV senescence and also periods where external inputs of nutrients were relatively low, which highlights the importance of internal nutrient cycling during periods of hydrologic isolation from GSL.

Measures of metabolism also exhibited temporal patterns over the growing seasons of 2012 and 2013. Primary production, as estimated by DO saturation and pH, peaked during periods of vibrant SAV growth and then slightly declined over the remainder of the growing season. Biological Oxygen Demand (BOD) peaked during SAV senescence, providing an additional line of evidence that the late season peaks in nutrients were caused by the mineralization of macrophytes.

Overall, the chemical integrity of Willard Spur was indicative of healthy conditions. No violations of Class 3B numeric metal water quality criteria were observed in the open water of the Willard Spur. We did record a handful of violations of pH, temperature and ammonia criteria. These limited violations all occurred during the latter stages of hydrologic isolation, and may be the result of naturally occurring conditions. Despite the marked changes in physical conditions following hydrologic isolation, ammonia water quality standard violations were rare (7 of 211 observations) and associated with atypically high pH and water temperature at the margins of Willard Spur as water levels receded. Violations in pH were far more common (56 of 209 observations), but the violations corresponded with periods of peak SAV growth and condition when all other indicators of biological integrity were highest. Violations of temperature were somewhat less frequent (27 of 209 observations) and were confined to the latter stages of hydrologic isolation and peak air temperature, which again are unavoidable natural conditions.

Potential Ecological Attributes (Indicators)

- Numeric water quality criteria

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