Draft Report

Great Salt Lake Wetlands

Great Salt Lake Water Quality Studies

Development of an Assessment Framework for Impounded Wetlands of Great Salt Lake

State of Utah

Department of Environmental Quality

Division of Water Quality

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Acronyms and Abbreviations

ADC	Ambassador Duck Club
B-IBI	Benthic Index of Biotic Integrity
BRMBR	Bear River Migratory Bird Refuge
CWA	Clean Water Act
DO	dissolved oxygen
EC	electrical conductance
EPA	U.S. Environmental Protection Agency
FBWMA	Farmington Bay Waterfowl Management Area
IBI	index of biotic integrity
ISSR	Inland Sea Shorebird Reserve
mg/L	milligram per liter
MMI	multimetric index
NDC	Newstate Duck Club
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetlands Inventory
PCA	principal components analysis
PDSI	Palmer Drought Severity Index
POTW	publicly owned treatment works
ppt	part per thousand
PSG	Public Shooting Grounds
RFM	random forests model
TDS	total dissolved solids
TSS	total suspended solids
UDWQ	Utah Division of Water Quality
U.S.	United States
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WMA	wildlife management area
WQI	water quality index

1.0 Introduction

The literature has long espoused Great Salt Lake's importance to resident and migratory birds, local recreation, and the brine shrimp and mineral industries (Gwynn, 1980 and 2002). More recently, research initiated by the State of Utah has focused on the wetlands surrounding Great Salt Lake and the direct connection they have with both the lake and surrounding watershed (Gray, 2005; CH2M HILL, 2005 and 2006; Rushforth and Rushforth, 2006a, 2006b, 2006c, 2006d, and 2007; Miller and Hoven, 2007). These studies have uncovered remarkable complexities that form the fabric of the wetlands' ecosystem and how they interrelate with Great Salt Lake and its watershed. This document summarizes the State's program to characterize the ecosystem of Great Salt Lake's wetlands and more specifically to develop a framework to assess the condition of one subset of those wetlands: impounded wetlands.

This section of the document describes the objective of this report, the physical setting of Great Salt Lake and its wetlands, the characteristics of impounded wetlands, and the document's organization.

1.1 Objective

The objective of this report is to summarize recent efforts to characterize the ecosystem of the wetlands of Great Salt Lake and develop the first draft of a preliminary assessment framework specifically for the impounded wetlands of Great Salt Lake. Research into the impounded wetlands class continues; however, this report describes the basis for and proposes a preliminary draft assessment framework that will be verified and augmented with subsequent data collection.

1.2 Physical Setting

Given the complex dynamics between the wetlands along Great Salt Lake and the lake itself, it is important to have an understanding of the physical characteristics of the wetlands and where they are located. The following is a cursory description of Great Salt Lake and the wetlands that were the focus of this program.

1.2.1 Great Salt Lake

Great Salt Lake is a uniquely dynamic terminal lake located adjacent to a rapidly growing metropolitan area in northern Utah (see Figure 1-1). Its approximate watershed area is 21,540 square miles, extending over three states, with an estimated population exceeding 1.9 million people in 2003. Population in the watershed is expected to increase by almost 75 percent by the year 2030 (Governor's Office of Planning and Budget, 2005). Changes in land use, hydrology, and water quality as a result of this population growth will add further dimensions of complexity to the lake's dynamic nature.

FIGURE 1-1
Project Area

Great Salt Lake is the largest remnant of the ancient Lake Bonneville, which existed from about 32,000 to 14,000 years ago and once covered about 20,000 square miles of western Utah, eastern Nevada, and southern Idaho. A natural dam gave way about 16,000 years ago, resulting in a large flood that drained much of Lake Bonneville. Increased evaporation over the following millennia has led to the present-day Great Salt Lake, occupying the lowest depression in the Great Basin. As is characteristic of terminal lakes, Great Salt Lake has no outlet; water that flows in can only evaporate or percolate into the substrate.

Great Salt Lake is the sixth-largest lake in the United States (U.S.) and the world's fourth-largest terminal lake. It varies significantly in size and depth as a result of changes in inflow from precipitation, tributaries, and groundwater, as well as from losses through evaporation. At a lake elevation of 4,200 feet, the lake is about 75 miles long and 30 miles wide and has about 335 miles of shoreline. It occupies more than 1,700 square miles and contains more than 15 million acre-feet (or almost 5 trillion gallons) of water. Great Salt Lake's shallow depths (its maximum depth is about 35 feet) and its gradually sloping shoreline result in dramatic surface area variations with any increase or decrease in lake level. Lake levels fluctuated more than 20 feet between 1873 and 1963, which had elevations of 4,211.5 and 4,191.35 feet, respectively. The lake's surface area fluctuated between 938 and 2,500 square miles in that same period (Hahl and Handy, 1969). The lake level rose 20.5 feet after 1963 to reach its record high level of 4,211.85 feet on June 3, 1986. The net rise between 1982 and 1986 alone was 12.2 feet (Arnow and Stephens, 1987).

On average, 2.9 million acre-feet of water and 2.2 million tons of salt enter Great Salt Lake each year. The vast majority of lake inflow typically comes from three drainages: the Jordan River (9 percent), Weber River (13 percent), and Bear River (39 percent). Additional inflow comes from groundwater (3 percent), direct precipitation (31 percent), and other minor east-side streams (5 percent) (Arnow and Stephens, 1987). Because the lake's only substantial water loss mechanism is evaporation, minerals, salts, and sediments from the watershed accumulate in Great Salt Lake. This results in lake water that is typically three to five times more salty than sea water and creates a unique habitat for Great Salt Lake wetlands that have adapted to and rely on this dynamic ecosystem.

1.2.2 Great Salt Lake Resources

Great Salt Lake's unique yet harsh conditions are significant to the ecology and economy of the region and the western hemisphere. Each of the lake's resources—including wetlands, bird habitat, people, the mineral industry, and brine shrimp harvesters—maintains a fragile balance with the ecology of Great Salt Lake, often dependent on the annual conditions of the lake for its scale, diversity, and economic value.

Millions of birds use the lake as they migrate from breeding grounds as far away as the Arctic to wintering areas as far away as Argentina. For example, up to 1 million Wilson's phalaropes (*Phalaropus tricolor*), or more than two-thirds of the world's population, annually migrate through Great Salt Lake as they travel from the near arctic to the high Andes (Jehl, 1988; Colwell and Jehl, 1994). The magnitude of the Wilson's phalarope population was a primary factor in the designation of Great Salt Lake as one of six sites within the western hemisphere's Shorebird Reserve Network in the U.S. (Aldrich and Paul, 2002). Over half of the world's population of eared grebes (*Podiceps nigricollis*) use Great Salt Lake for up to 4 months during fall migration (Jehl, 1988), and in 2007 their population on Great Salt Lake exceeded 2.5 million birds (Darnall, 2007). Great Salt Lake hosts the largest nesting colony of American white pelicans (*Pelecanus erythrorhynchos*) west of the continental divide (King and Anderson, 2005) and the largest breeding population of California gulls (*Larus californicus*) in the world (Aldrich and Paul, 2002).

Opportunities for recreation abound on and around Great Salt Lake. Thousands of people visit the lake annually to enjoy sailing, hiking, hunting, and watching the diverse bird life. Along the lake are two state parks, numerous state wildlife management areas, and one federal wildlife refuge. Waterfowl hunting alone was estimated to be almost an $8-million industry in 1998 (Isaacson et al., 2002).

As a result of the minerals left behind by evaporation, Great Salt Lake is home to a burgeoning mineral industry that is perhaps the Great Salt Lake industry with the greatest impact on Utah's economy (Isaacson et al., 2002). Several mineral extraction companies currently operating on Great Salt Lake generated a total of about 2.8 million tons of sodium chloride, potassium sulfate, magnesium chloride, magnesium metal, chlorine gas, and other products—all estimated to be worth about $300 million in 1995 (Gwynn, 1997). This represents about 16 percent of the annual value of all minerals produced in 1995 in Utah (U.S. Geological Survey [USGS], 1995).

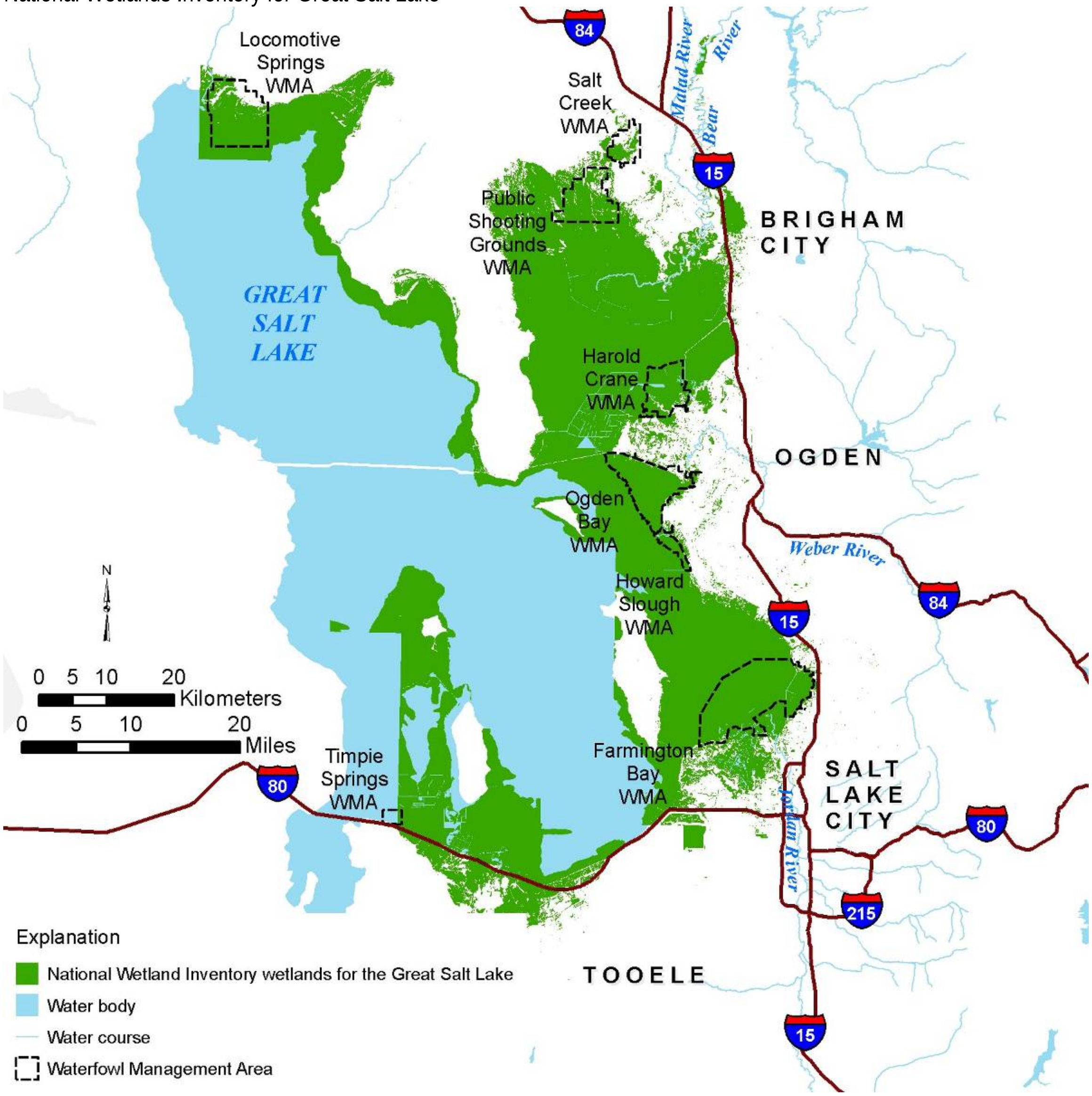
Great Salt Lake produces a significant portion of the world's supply of brine shrimp cysts. Commercial harvest on the lake began in 1952, and the lake has become an internationally renowned source of cysts for their quality as feed for the aquaculture and ornamental fish industry. The market value is estimated to average $8 to 11 million annually with an estimated peak value of $58 million in 1995. The annual harvest from Great Salt Lake is often limited by biological factors rather than market forces (Isaacson et al., 2002).

1.2.3 Great Salt Lake Wetlands

The dynamic nature of Great Salt Lake brings unique challenges to quantifying and classifying wetlands resources around Great Salt Lake. Jensen (1974) identified 474,139 acres of wetlands around Great Salt Lake. This represented approximately 85 percent of the wetlands located throughout the state of Utah. Other more recent publications estimate that Great Salt Lake wetlands include approximately 400,000 acres and represent 75 percent of Utah's wetlands. (Friends of Great Salt Lake, 2002; Utah Wetlands Interpretive Network, 2004). The updated *National Wetlands Inventory* (NWI) compiled by the U.S. Fish and Wildlife Service (USFWS) in 2008 estimated approximately 427,000 acres of wetlands along Great Salt Lake (Emerson, 2009) (see Figure 1-2). Regardless of the estimate used, it is clear that Great Salt Lake wetlands represent a significant resource in the state of Utah but also in the western U.S.

There are many factors that contribute to the characteristics of Great Salt Lake's wetlands; however, salinity in the water and sediments of the shoreline are a primary factor that determines the nature, location, and extent of wetlands around the lake. The level of salinity in these waters and sediments varies widely depending largely on the availability of freshwater and the water level of the lake. Thus the nature, location, and extent of the wetlands around Great Salt Lake can vary significantly depending upon location, year-to-year runoff levels, and the lake's water level (Aldrich and Paul, 2002).

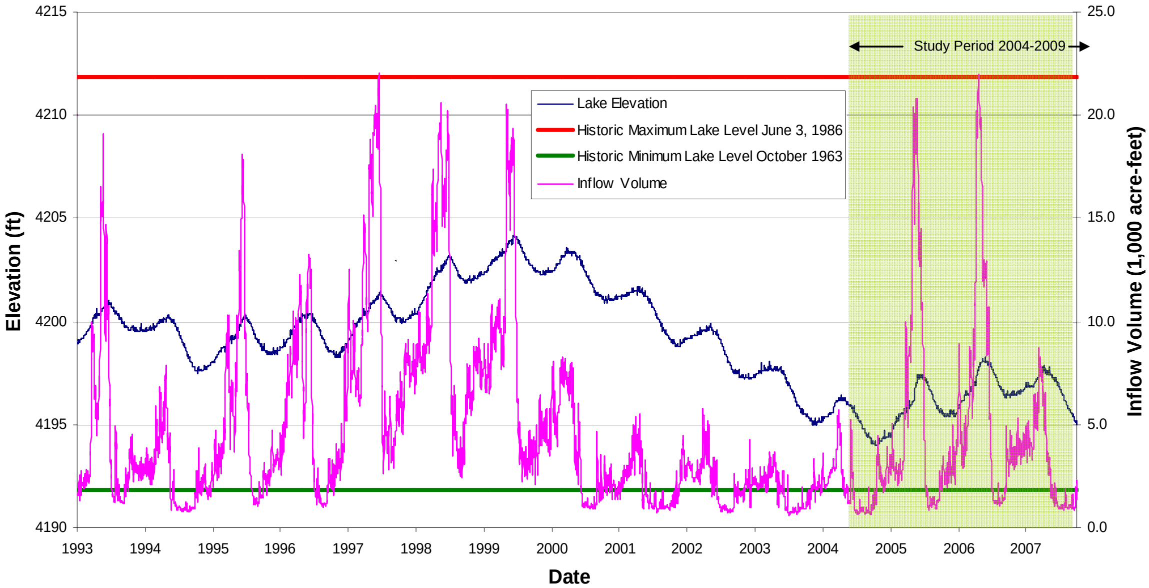
FIGURE 1-2
National Wetlands Inventory for Great Salt Lake



Source: Utah Geological Survey

The primary freshwater sources for Great Salt Lake are the Bear River, Weber River, and Jordan River. These rivers represent over 60 percent of the freshwater input to Great Salt Lake (Arnow and Stephens, 1987) and are the source for many of the wetlands around Great Salt Lake. Some of the freshwater from these sources flows unimpeded to Great Salt Lake, but much of it is impounded within dikes and other artificial structures. The quantity of freshwater flowing into the lake varies with seasonal and climatic changes. Figure 1-3 illustrates how freshwater volumes (from Jordan River, Weber River and Bear River) have varied between 1997 and 2007 and how these changes have corresponded to lake level.

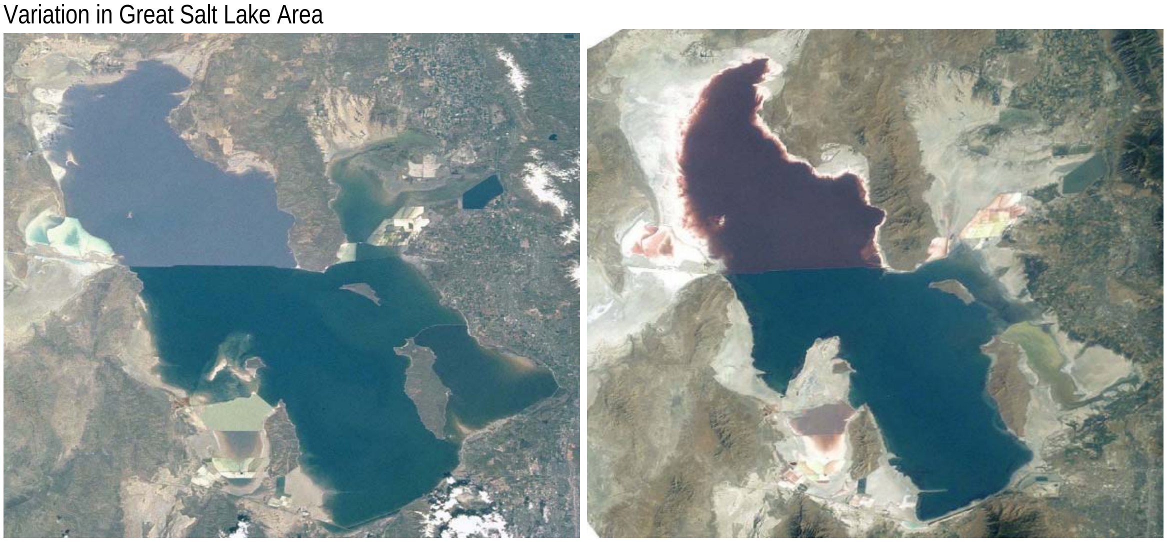
Figure 1-3
Lake Elevation and Inflow Volume 1993 – 2007.



Source: United States Geological Survey
Note: Inflow is characterized simply as sum of flows from Bear River, Weber River, and Jordan River. It does not include all inflow to Great Salt Lake.

As previously discussed, the lake's level has a profound impact on the areal extent of the lake surface but also on the areal extent of the mudflats and wetlands surrounding the lake (see Figure 1-4). It is estimated that for every 1 foot the lake rises or falls, approximately 44,000 acres of mudflats are inundated or exposed (Aldrich and Paul, 2002).

FIGURE 1-4
Variation in Great Salt Lake Area



1988 *2003*

Source: Miller and Hoven, 2007

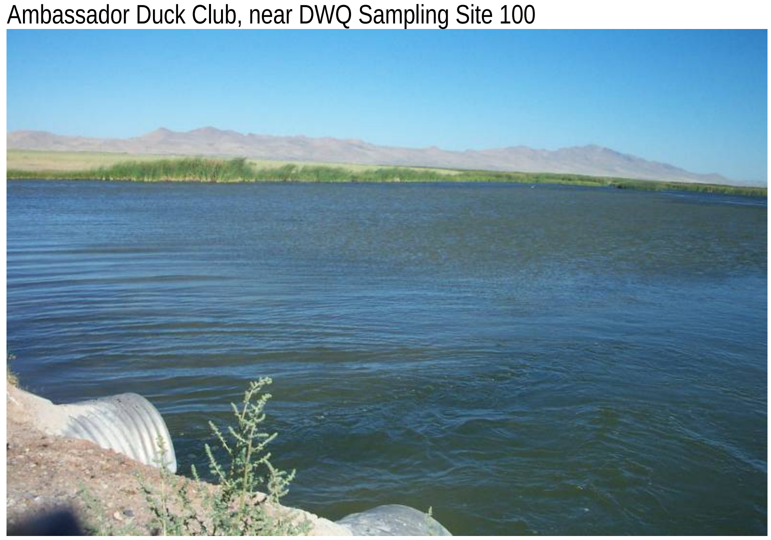
As lake levels rise, as they did in the period leading up to the most recent peak lake level in 1983, mudflats become open water and freshwater wetlands turn brackish and eventually become open waters of Great Salt Lake. High waters driven by winds gradually dissolve any dikes, berms, canals, or other features they cover (Gwynn, 2002). Salt coming out of solution is deposited in the sediments, thus creating a salt source for wetlands that begin to reestablish when the lake recedes. These processes radically change the landscape for years to come. As the lake recedes, freshwater from the lake's tributaries flows across the uncovered lakebed, slowly flushing salts back into Great Salt Lake. As the salinity of the soils changes so does the vegetation as it adapts to the changing conditions. It is estimated that up to 3 years of freshwater flushing may be required before plants can begin to germinate and the wetlands community can proliferate (Miller and Hoven, 2007). Natural lakebed and artificial features that remain after the lake recedes direct the waters across the lakebed. New, less-saline sediments from the inflows gradually deposit on the lakebed creating new habitat and features of the wetlands surrounding Great Salt Lake. Meanwhile, vegetation, macroinvertebrates, birds, and other organisms also adapt to the changing salinity and landscape. This dynamic pattern continues as the hydrology and lake level varies each year.

The majority of the wetlands around Great Salt Lake fall into at least four classes: impoundment, sheetflow (fringe), playa (shallow ephemeral ponds) and emergent marsh. Sheetflow wetlands are typically located along the fringe of Great Salt Lake's mudflats and typically form around water sources freely flowing across the mudflats (Miller and Hoven, 2007). These water sources may be from springs, upstream impounded wetlands or streams, or permitted discharges. Impounded wetlands are the focus of this report and are described in more detail in Section 1.3.

1.3 Impounded Wetlands

One characteristic of Great Salt Lake wetlands that dampens the impacts of the dynamic fluctuations of the lake is the presence of impoundments. These impoundments largely consist of wetlands where dikes, berms, ditches, and culverts have been constructed to control or constrict the inflow into or outflow of water from the wetlands (see Figure 1-5).

FIGURE 1-5
Ambassador Duck Club, near DWQ Sampling Site 100



Impounded wetlands have residence times ranging from a few days to weeks in length. Salinity levels often increase as waters move through successive impoundments toward Great Salt Lake. Outlet water from these wetlands flows through sheetflow wetlands and mudflats until it reaches the open waters of Great Salt Lake (Miller and Hoven, 2007).

Many of these facilities have been built and rebuilt since the 1920s to conserve habitat for conservation or recreation purposes. They vary in size from just a few acres to up to 500 acres (Miller and Hoven, 2007). There are currently seven wildlife management areas (WMAs), one federal bird refuge, and numerous private duck clubs that maintain impounded wetlands along Great Salt Lake (see Figure 1-6). Per the updated NWI completed by the USFWS in 2008, there are approximately 100,000 acres of such impounded wetlands in and along Great Salt Lake with approximately 24,000 acres of these impounded wetlands located in the WMAs (Emerson, 2009). The prevalence of this type of wetlands, along with the available information and particular issues that these wetlands face, are significant reasons as to why the Utah Division of Water Quality (UDWQ) has focused on these systems first. Note that impounded wetlands as defined in this report do not include those used for solar evaporation for the purpose of mineral extraction.

While almost all impounded wetlands along Great Salt Lake are managed facilities, the intensity of management practices in these impounded wetlands often varies widely. Actual management practices are most commonly a result of stated goals and objectives for the facility, available funding, and available water. For example, some impounded wetlands facilities are managed as mitigation sites, thus flows, water depths, and vegetation are optimized to the prescribed conditions for the desired and approved habitat. Some facilities are managed to optimize habitat for shorebirds, and thus flows, water depths, predators, and vegetation are managed to optimize conditions favorable to shorebirds. Most facilities, however, are managed to optimize habitat for waterfowl, and similarly, flows, water depths, predators, and vegetation are managed to optimize conditions favorable to waterfowl. Each of these facilities must use the quantity and quality of water that is available for use to create the wetlands conditions that meet their stated goals and objectives.

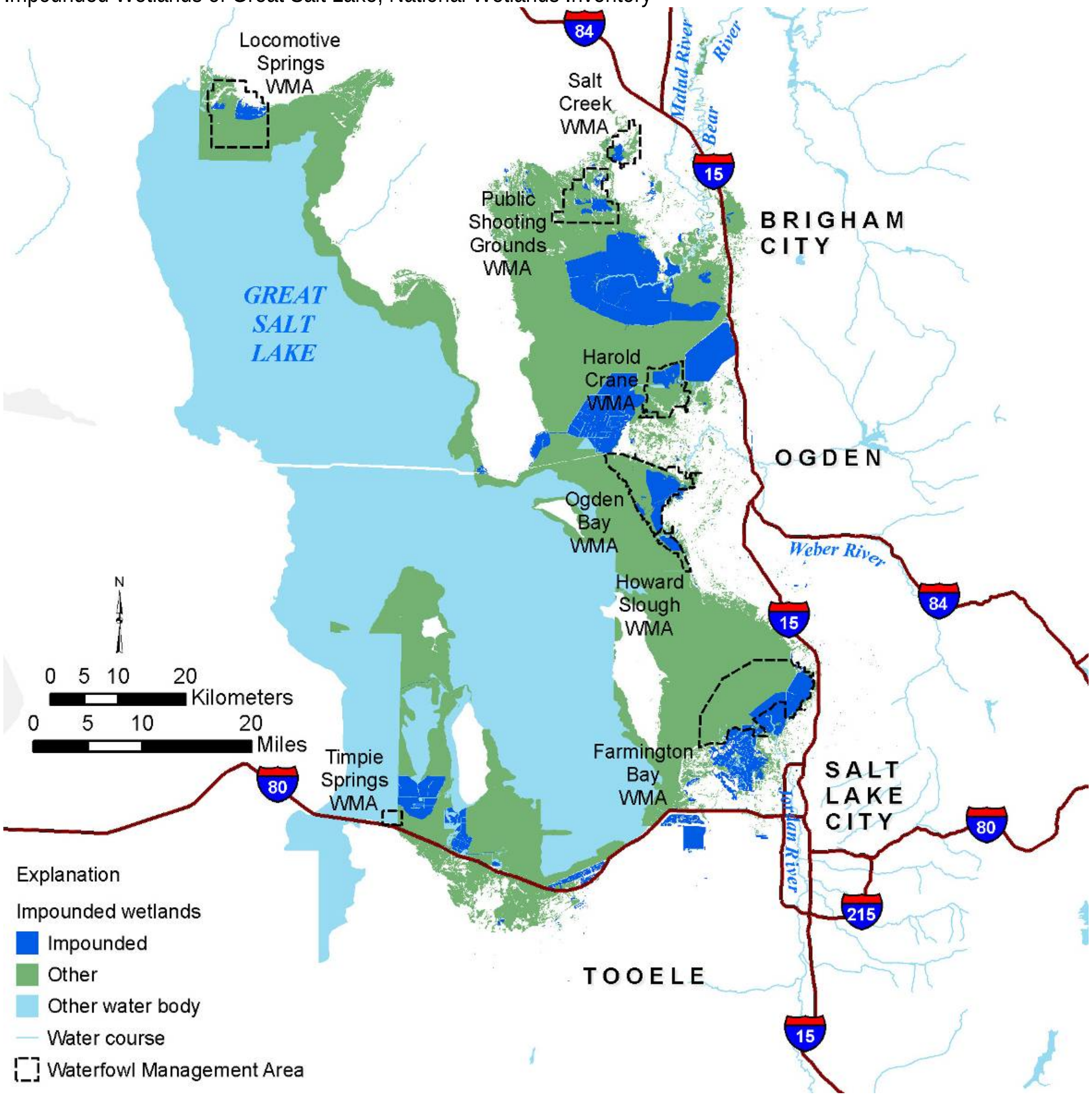
1.3.1 Characteristics of Impounded Wetlands

Impounded wetlands are generally defined as wetlands where the hydrology has been artificially modified through the use of berms, weirs, and culverts to create open water features. Though natural impounded wetlands exist, most of the impounded wetlands surrounding Great Salt Lake are man-made.

Impounded wetlands are a critical habitat element at Great Salt Lake. They have clear benefits in the storage of freshwater flows coming to Great Salt Lake. As such, they provide significant freshwater and brackish-water habitat for fish, shorebirds, and waterfowl that otherwise might not exist today at Great Salt Lake as a result of development along its shore (USFWS, 2004). The resulting use of these wetlands by fish and birds makes the wetlands of Great Salt Lake an invaluable wetlands habitat resource in the western hemisphere but also creates an important destination for recreational uses. As previously described, visitors to the wetlands of Great Salt Lake generate millions of dollars in revenue for the state of Utah as they enjoy hiking, birding, and hunting in this world-class resource.

Storage and the slowing of these incoming flows also have implications with regard to water quality. Wetlands often function to filter particulate-bound nutrients and contaminants from water (e.g., suspended sediment, most metals, phosphorus, organochlorine, and organophosphate pesticides) but may also contribute remineralized or

FIGURE 1-6
Impounded Wetlands of Great Salt Lake, National Wetlands Inventory



Source: Utah Geological Survey
Note: Impounded wetlands as defined in this report do not include those used for solar evaporation for the purpose of mineral extraction.

transformed pollutants (e.g., methylated mercury, organo-selenium, soluble phosphorus, ammonia, and biochemical oxygen demand). While these wetlands likely serve as a natural and beneficial treatment mechanism for Great Salt Lake, they also may create conditions that some may not consider beneficial. These implications make water quality an important consideration for management of these facilities.

Impounded wetlands are extremely productive and biologically diverse, particularly for those organisms at the base of the food web (algae, macrophytes, planktonic plants and animals, benthic macroinvertebrates, etc.). Understanding the characteristics and dynamics of this complex system has been a significant focus of UDWQ's research program. Describing how these factors interact with the water quality of the impounded wetlands is the goal of this report.

1.4 Document Organization

The remainder of this document is divided in the following sections:

Section 2.0 provides the historical background of the project, regulatory framework, and need for developing a preliminary assessment framework for Great Salt Lake impounded wetlands.

Section 3.0 summarizes the ongoing Great Salt Lake wetlands research program that serves as the foundation for the proposed preliminary assessment framework.

Section 4.0 describes the proposed preliminary assessment framework.

Section 5.0 describes UDWQ's plans for implementation and further development of the preliminary assessment framework.

2.0 Program Background

An understanding of past approaches to managing and protecting the wetlands of Great Salt Lake is necessary to understand how ongoing research of these wetlands and the proposed preliminary assessment framework contained herein achieve the objective of protecting the beneficial uses of these ecosystems. This section describes how the Great Salt Lake wetlands program has developed since 2004 and shaped the proposed wetlands assessment framework.

2.1 Historical Perspective

Great Salt Lake and its shores has been the subject of management deliberations arguably since the first Mormon pioneers settled near its shores in 1847. These deliberations historically centered primarily on resource use and allocation. Increasing development of those resources in the latter part of the 20th century shifted that focus toward defining the ecological resources of Great Salt Lake and protecting them. What was first considered a relatively simple ecosystem composed of algae, brine shrimp, brine flies, and bird life was discovered to be a very complex and dynamic ecosystem. It rapidly became apparent that the lack of a comprehensive database describing the complex ecosystem made it very difficult to make management decisions sufficiently protective of the lake's resources (Atwood et al., 1999).

State and federal agencies historically have collected a significant amount of information characterizing lake level fluctuations, water balance, and salt balance throughout Great Salt Lake. While appropriate for some management decisions, additional information was needed to understand the ramifications of those decisions on the Great Salt Lake ecosystem. The State of Utah completed the Great Salt Lake Comprehensive Management Plan in 1997 and updated it again in 2000 (Utah Department of Natural Resources, 2000). The State of Utah initiated the Great Salt Lake Ecosystem Project in 1994 to work towards understanding the ecology of Great Salt Lake (Stephens and Birdsey, 2002) and completed a research program in 2008 to understand cycling of selenium through the food web of Great Salt Lake (CH2M HILL, 2008).

The ecosystem project and other efforts have worked to understand the following:

- How the algal growth rate, competitive interactions, abundance, and species composition fluctuate as they relate to salinity, temperature, and nutrient influxes
- How brine shrimp survival and reproduction fluctuate with salinity, temperature, nutrient influxes, algal abundance and species composition, and predation from other zooplankton
- Great Salt Lake bird species—both their numbers and how they use lake resources
- The complex limnology of Great Salt Lake as it relates to salinity, temperature, lake levels, water balance and mixing, and contaminant and nutrient influxes and cycling

This research has revealed that key ecological processes do not operate independently but interact and seem to vary—sometimes significantly—from year to year (Atwood et al., 1999). Overall, these studies confirmed that Great Salt Lake's ecosystem is unique and much more complex than previously thought.

2.2 Existing Regulatory Framework

The federal Water Pollution Control Act Amendments of 1972—also known as the Clean Water Act (CWA)—established the institutional structure for the U.S. Environmental Protection Agency (EPA) to regulate discharges of pollutants into the waters of the U.S., establish water quality standards, conduct planning studies, and provide funding for specific grant projects. The CWA has been amended by Congress several times since 1972. The EPA has provided most states with the authority to administer many of the provisions of the CWA.

The UDWQ has specified appropriate beneficial uses for waters of the State (UAC R317-2) and achieves and protects those uses through the development and enforcement of water quality standards (40 *Code of Federal Regulations* §131.11). This section provides a summary of the current regulatory framework that affects how the water quality of Great Salt Lake wetlands is managed.

2.2.1 Designated Uses for Great Salt Lake

Table 2-1 summarizes the designated use classes for waters in the state of Utah as defined in Utah Administrative Code (UAC) R317-2-6 prior to 2008. The State of Utah reclassified the designated uses of Great Salt Lake (Class 5) in 2008 into five subclasses that more accurately reflect different salinity and hydrologic regimes and the unique ecosystems associated with each of the four major bays (Gilbert, Gunnison, Bear River, and Farmington) and surrounding wetlands. Classification of Great Salt Lake in this manner provides the UDWQ with the flexibility to develop scientifically defensible water quality criteria for each of these unique ecosystems. These distinct ecosystems were reclassified as follows:

- Open waters at or below approximately 4,208-foot elevation in Gilbert Bay as Class 5A
- Open water at or below approximately 4,208-foot elevation in Gunnison Bay as Class 5B
- Open waters at or below approximately 4,208-foot elevation in Bear River Bay as Class 5C
- Open waters below approximately 4,208-foot elevation in Farmington Bay as Class 5D
- The UDWQ assigned Class 5E to the mudflat or transitional wetlands of Great Salt Lake. These are defined as waters located in the area at or below an elevation of approximately 4,208 feet to the current lake elevation of the open water of Great Salt Lake. Class 5E recognizes the importance of freshwater tributary or discharge water, particularly to shorebirds, that flows across the mudflats during periods of low lake elevation. These shallow, sheet-flowing waters (referred to herein as "sheetflow" wetlands) provide optimal habitat for large populations of macroinvertebrates that, in turn, represent critical food resources for the nesting and migratory staging of hundreds of thousands to millions of shorebirds.

TABLE 2-1
Utah's Designated Uses for Water prior to 2008

6.1 Class 1—Protected for use as a raw water source for domestic water systems
a. Class 1A—Reserved
b. Class 1B—Reserved
c. Class 1C—Protected for domestic purposes with prior treatment by treatment processes as required by the Utah Division of Drinking Water
6.2 Class 2—Protected for recreational use and aesthetics.
a. Class 2A—Protected for primary contact recreation, such as swimming.
b. Class 2B—Protected for secondary contact recreation, such as boating, wading, or similar uses.
6.3 Class 3—Protected for use by aquatic wildlife.
a. Class 3A—Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food.
b. Class 3B—Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain.
c. Class 3C—Protected for nongame fish and other aquatic life, including the necessary aquatic organisms in their food chain.
d. Class 3D—Protected for 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.
e. Class 3E—Severely habitat-limited water. Narrative standards will be applied to protect these waters for aquatic wildlife.
6.4 Class 4—Protected for agriculture, including irrigation of crops and stock watering.
6.5 Class 5—The Great Salt Lake. Protected for primary and secondary contact recreation, waterfowl, shore birds, and other water-oriented wildlife, including their necessary aquatic organisms in their food chain, and mineral extraction.

All five of these Great Salt Lake subclasses are protected for infrequent primary and secondary contact recreation, waterfowl, shore birds, and other water-oriented wildlife, including their necessary food chain, with the exception of Class 5A, Gilbert Bay, which is also protected for frequent primary and secondary contact recreation.

Open waters that are not part of the open water of Great Salt Lake, occur above approximately 4,208-foot elevation, and extend to the mouth of the Bear River, Weber River, or Jordan River or associated delivery canals are currently protected for classes 2B, 3B, and 3D uses by default. All waters within the geographical boundaries associated with various state WMAs and the Bear River National Wildlife Refuge are protected for Classes 2B, 3B (or 3C), and 3D uses (UAC R317-2-6).

2.2.2 Water Quality Standards for Wetlands

Under the CWA, states are required to develop water quality standards for their surface waters, including wetlands. The EPA has established numeric standards (toxicity thresholds) for many toxic pollutants; these standards are refined and used by the states in conjunction with assessments of the beneficial uses for the various types of water bodies. As with other states, the UDWQ has protected the wetlands surrounding Great Salt Lake through its water quality standards program.

Due to the unique geochemistry of Great Salt Lake, the application of national freshwater quality criteria to Great Salt Lake is inappropriate. The open waters of Great Salt Lake (use Classes 5A, 5B, 5C, 5D, and 5E) have instead been protected for their beneficial uses through the application of the following narrative criteria clause (UAC R317-2-7):

> *7.2 Narrative Standards*
> *It shall be unlawful, and a violation of these regulations, 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.*

The only exception is that the UDWQ has also established a numeric water quality standard for selenium for Class 5A, Gilbert Bay (UAC R317-2-14).

Open waters along Great Salt Lake above an elevation of approximately 4,208 feet are protected for their aquatic wildlife beneficial uses (Classes 3B, 3C, and 3D) through the use of the narrative standard and numeric criteria as enumerated in Table 2.14.2 of UAC R317-2-14. These criteria currently include provisions for dissolved oxygen, temperature, pH, turbidity increase, metals, organics, and inorganics based upon national water quality standards. The current aquatic life use classifications were initially established in the 1970's because UDWQ acknowledged that ecosystems within the Wildlife Management Areas were ecologically significant and warranted express protection under the CWA. However, scientific investigations—those discussed in this report and elsewhere—continue to suggest that these standards are not appropriate to some of the diverse habitats located within these WMAs. Ultimately, UDWQ intends to subdivide ecosystems within the WMAs and develop a Use Attainability Analysis (UAA) to propose standards appropriate for the protection of biota within each biologically distinct class of waters that are delineated.

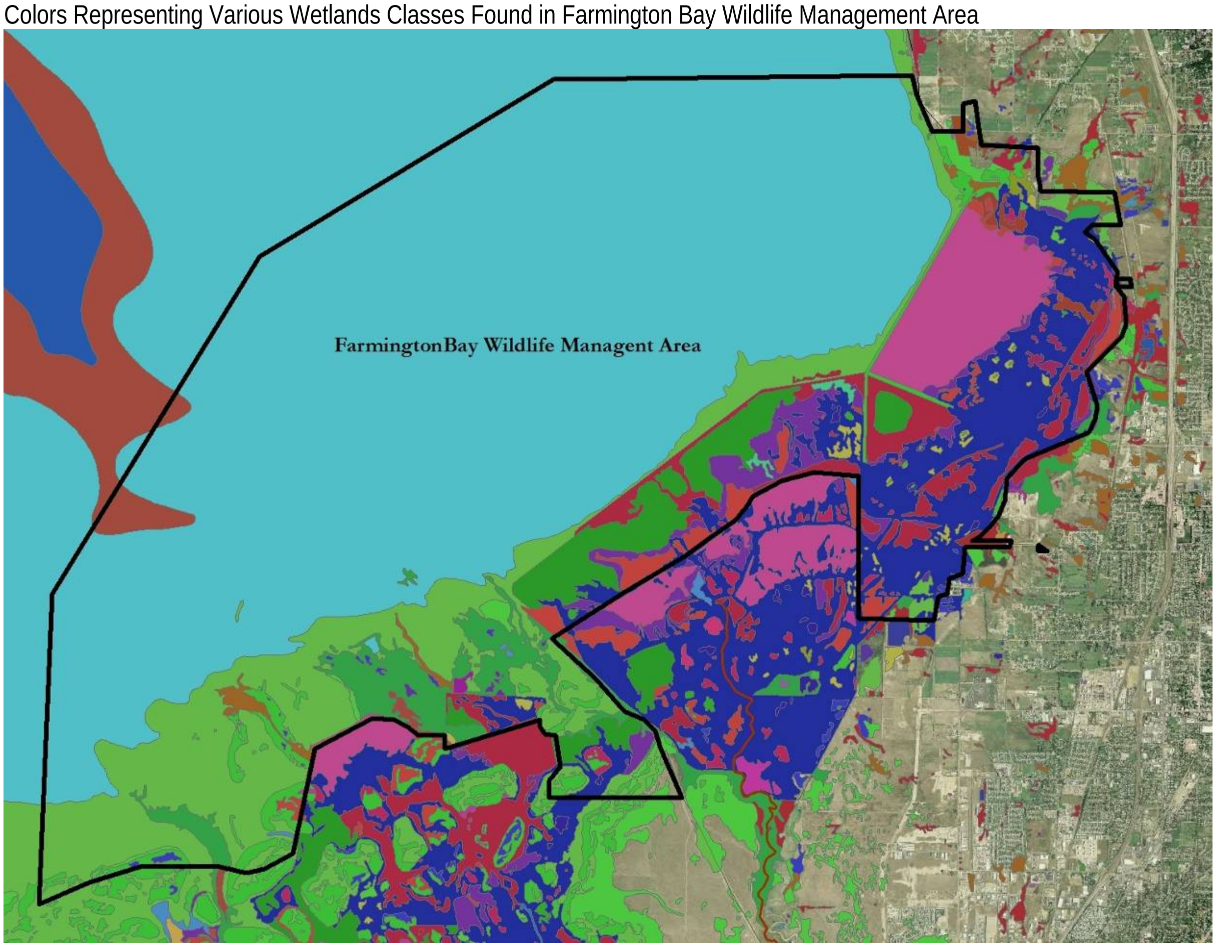
While EPA has developed nationwide numeric criteria for many pollutants, there are nontoxic pollutants, including nutrients (e.g., nitrogen and phosphorus), where the EPA has not established numeric criteria. This is largely because the response of ecosystems to these nontoxic pollutants, including nutrient loadings, is typically governed by multiple site-specific abiotic and biotic conditions. Thus, EPA allows states to develop criteria based on site-specific water quality and ecological studies that take into account local abiotic and biotic conditions and attainable beneficial uses. The UDWQ's goal is to collect site-specific data that can be used to validate and improve the water quality standards used to protect the beneficial uses of Great Salt Lake wetlands.

Use of Numeric Water Quality Standards

Various stakeholder groups in Utah including the public, government agencies, and academic community have expressed concerns that the Great Salt Lake ecosystem, including its wetlands, may be impaired by nutrients and that the past approach of applying existing water quality standards to the Great Salt Lake wetlands is problematic and may not be protecting their beneficial uses. There are two main reasons the implementation of water quality standards has been problematic:

1. First, the standards that are specifically applied to wetlands are based on the geographical location of the aquatic resource rather than their ecological characteristics. For example, a set of wetland-specific standards are attributed to state WMAs and the Bear River Migratory Bird Refuge (BRMBR). Numerous classes of wetland types are located within each of those areas (see Figure 2-1), each class with its own biota and distinct ecosystem processes. Water quality standards applicable to one area within a WMA, for example, may not be applicable in the area adjacent to it. The ecologically distinct character of each of those wetland classes and their respective beneficial uses needs to be considered when developing defensible standards, assessment methods, and protection practices. Also, the wetland areas described in current standards represent just a subset of the wetlands around Great Salt Lake. The quality of some wetlands outside of the described areas may actually be more at risk because they are not actively managed for wildlife conservation.

FIGURE 2-1
Colors Representing Various Wetlands Classes Found in Farmington Bay Wildlife Management Area



Source: 2001 NWI, USFWS

2. The second problem with current water quality standards lies in the types of criteria used to assess and protect the biological integrity or health of Great Salt Lake wetlands. For example, the current water quality standards have a numeric criterion for dissolved oxygen (DO). The criterion is exceeded within many impoundment class wetlands, even in non-impacted reference sites. Furthermore, there is evidence suggesting that most of these wetlands continue to support their designated uses (see Table 2-2 and discussion below). Conversely, lake "fringe" wetlands, also known as sheetflow wetlands, which are sometimes sustained by discharges from wastewater treatment facilities, rarely show a violation of DO criteria. Irrespective of both situations, wetland biota has adapted to environmental conditions with wide fluctuations in DO. These data suggest that measures of DO, by itself, are not a robust indicator of wetland condition.

TABLE 2-2
Summary of Sampling Sites That Exceeded Current Water Quality Standards of DO and pH

Sampling Site	DO	pH
GSL Wetlands Newstate Duck Club Pond 47	Yes	No
Farmington Wetlands Ambassador W 1	No	Yes
Farmington Wetlands FBWMA Unit 1 Outfall	Yes	Yes
Farmington Wetlands FBWMA Unit 2 Outfall	Yes	Yes
Farmington Wetlands West A Pond	Yes	Yes
GSL Wetlands Newstate Duck Club Unit 5-6	No	Yes
Farmington Wetlands Ambassador 100	No	Yes
Farmington Wetlands Ambassador W 5	Yes	Yes
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall	Yes	Yes
Newstate Duck Club Middle Unit	Yes	Yes
GSL Wetlands Newstate Duck Club Pond 20	Yes	Yes
Farmington Wetlands Ambassador W 2	Yes	Yes
Farmington Wetlands South B Pond	Yes	Yes
IMPC Conservation Easement	No	Yes
GSL Wetlands Public Shooting Ground Pintail Lake Outfall	No	Yes
Bear River National Wildlife Refuge Pond 4C Outfall	Yes	Yes

These observations have led the UDWQ to reconsider the use of some numeric water quality standards specifically for impounded wetlands, namely for pH and DO. Table 2-3 summarizes current pH and DO water quality standards for Classes 3B, 3C, and 3D uses in Utah.

Water Quality Standards for pH and DO

The UDWQ first reported values that exceeded Utah's classes 3B, 3C, and 3D numeric standards for pH and DO in Miller and Hoven (2007). The impetus for this study was not to explain the particular ramifications of extreme pH and DO, but to investigate the relationship between the aquatic community and high concentrations of nutrients associated with Jordan River water that was supplying the impounded wetlands in Farmington Bay (see Section 3.0 for a summary of this work). DO and pH are water quality parameters that are frequently used to quantify the effects of eutrophication in stream and lake ecosystems, thus these parameters were measured to more completely understand links between nutrient enrichment and biogeochemical processes.

TABLE 2-3
Numeric Criteria for Aquatic Wildlife for Classes 3B, 3C, and 3D Uses

Criteria	Measurements
pH range	6.5–9.0
Minimum DO (7-day)	3.0 mg/L

NOTES:
DO = dissolved oxygen
mg/L = milligrams per liter

Miller and Hoven (2007) selected study locations to capture the range of nutrient concentrations observed among Great Salt Lake's impounded wetlands. Reference sites were chosen on the basis of low concentrations of nutrients, and target sites were selected to encompass a gradient from relatively low to relatively high concentrations of nutrients. Both the reference (oligotrophic or low-nutrient) and target (nutrient-rich) impoundments exhibited large diel swings in pH, DO, and temperature with observations that frequently violated Utah's water quality standards (see Figures 2-2 and 2-3). The magnitude of pH exceednces of water quality standards was observed to be highest in reference impounded wetlands, whereas low DO criteria violations were most commonly observed to occur in nutrient-enriched impounded wetlands. Despite these differences, similar taxa occurred at both sites, indicating that such taxa are adapted to both elevated pH and depressed DO (Miller and Hoven, 2007). Furthermore, when UDWQ's assessment methods are used to evaluate pH and DO data collected at these wetlands nearly all of the wetlands evaluated would exceed the pH and DO numeric criteria.

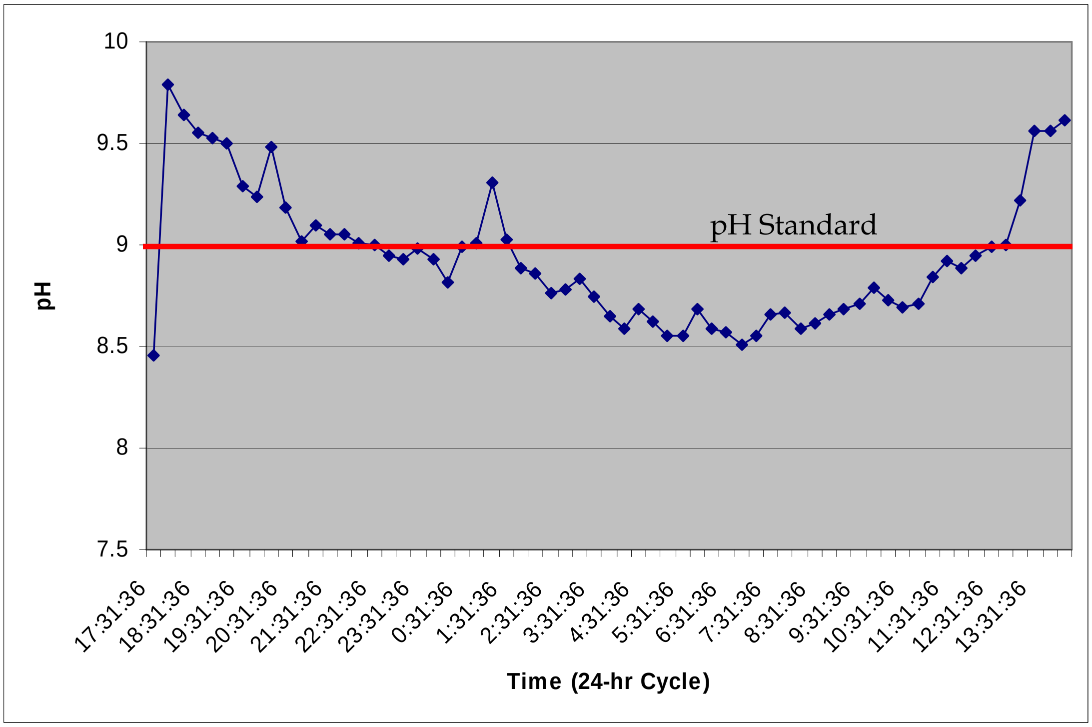
The evidence suggests that large swings in pH and DO may be due to the specific hydrological, biological, and chemical conditions found in shallow, impounded wetlands. Further, the macroinvertebrate community found in these wetlands appears to be adapted to the extremes and variability that has been observed in these parameters. Current numeric water quality standards for pH and DO may be too broad and excessively stringent when applied to impounded wetlands on Great Salt Lake for at least three reasons. First, diel fluctuations of pH and DO are typical for small wetland ponds, as evidenced by the fact that the reference impounded wetlands in this study exceeded water quality standards. Second, differences in composition among wetland pond biota are not related to observed differences in pH or DO data.

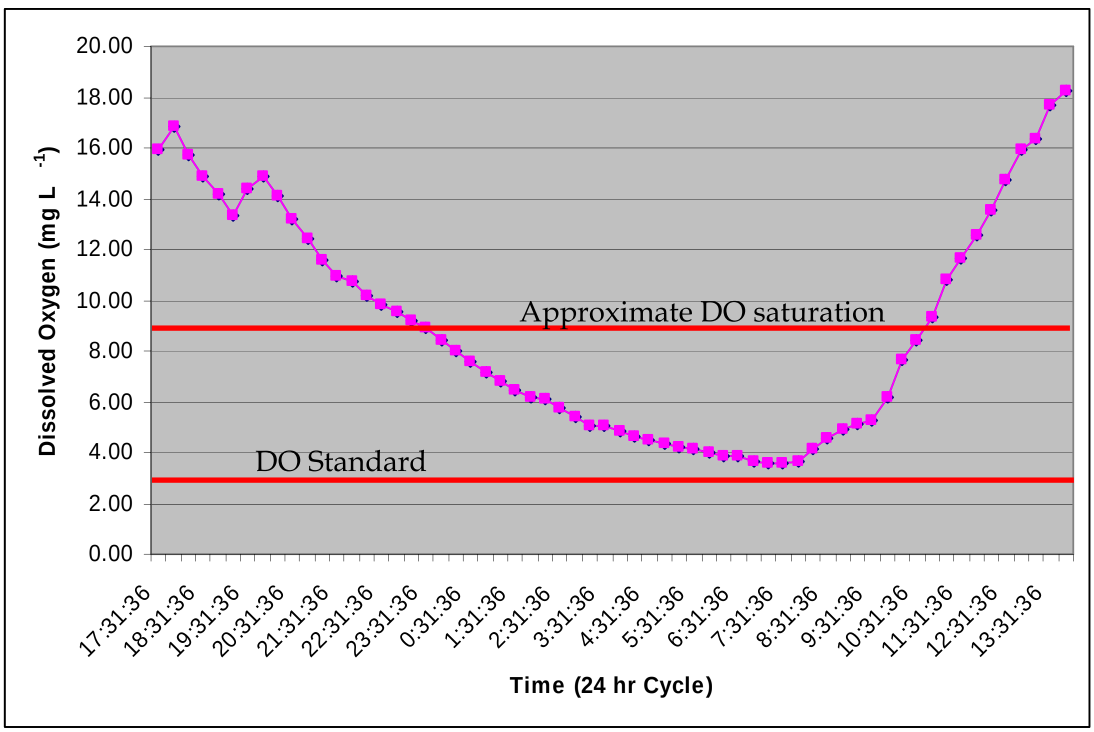
Variations in pH and DO Concentrations

The processes of photosynthesis and respiration within impounded wetlands are often responsible for large diurnal swings in DO and pH (Mitsch and Gosselink, 2007; Kadlec and Wallace, 2009). In the presence of sunlight, submerged aquatic vegetation (SAV) and algae in impounded wetlands photosynthesize within the water column, adding DO directly to the water, while removing carbon dioxide. During the daytime, the process of photosynthesis leads to peaks in DO. Use of carbon dioxide during photosynthesis also shifts the carbonate-bicarbonate-carbon dioxide equilibrium toward higher pH. During nighttime, plant and microbial respiration dominates, consuming oxygen and producing carbon dioxide, which creates a low-pH environment. These diurnal swings in DO and pH occur in both nutrient-enriched and relatively oligotrophic open-water wetlands, although nutrient enrichment tends to dampen the fluctuations in diurnal DO and generally decreases average DO levels (Bosserman, 1984; Mitsch, 1989; Gunderson, 1994; Rose and Crumpton, 1996; McCormick and Laing, 2003). Wetlands with shallow water depths and dense stands of emergent macrophytes (e.g., sheetflow wetlands of Great Salt Lake) typically do not exhibit large diurnal fluctuations in DO and pH because photosynthesis within the water column is regulated by shading from the emergent macrophytes. Rather, these wetlands often show depressed average DO, a decrease in the amplitude of the diurnal DO cycle, and no diurnal cycle in pH and circumneutral pH (Mitsch and Gosselink, 2007; Kadlec and Wallace, 2009).

Diurnal cycling of DO and pH is thus mediated by the photosynthetic-respiration activity of SAV and algae, and is a common phenomenon observed in a variety of impounded wetlands. These diurnal fluctuations in DO and pH can occur even in water bodies with relatively low levels of nutrients (Gunderson, 1994; McCormick and Laing, 2003), as observed in some of the reference impounded wetlands of Great Salt Lake. DO and pH standards proposed for other ecosystems (lakes, rivers) may not be applicable to wetland systems where these parameters show wider diurnal ranges (McCormick and Laing, 2003).

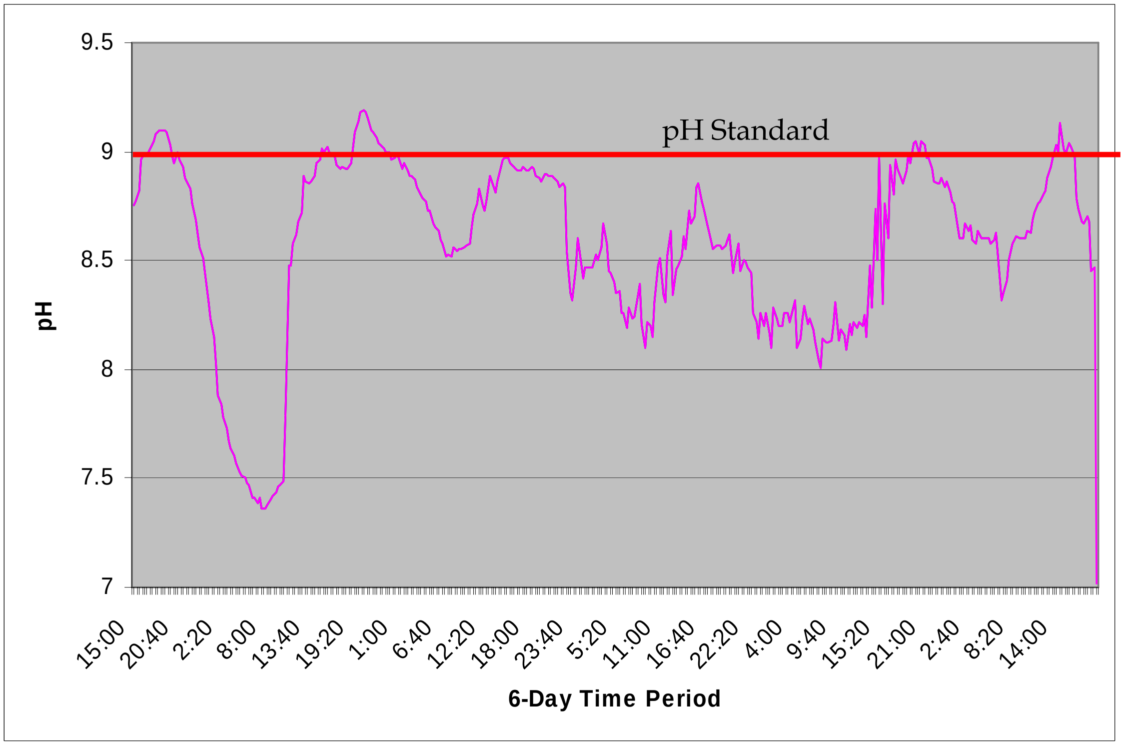
FIGURE 2-2
Diel pH (Upper) and DO (Lower) Concentrations
In a reference impounded wetland, Widgeon Pond, collected August 24 and 25, 2008; Utah's water quality standard for DO supersaturation is at 110 percent of the saturation value

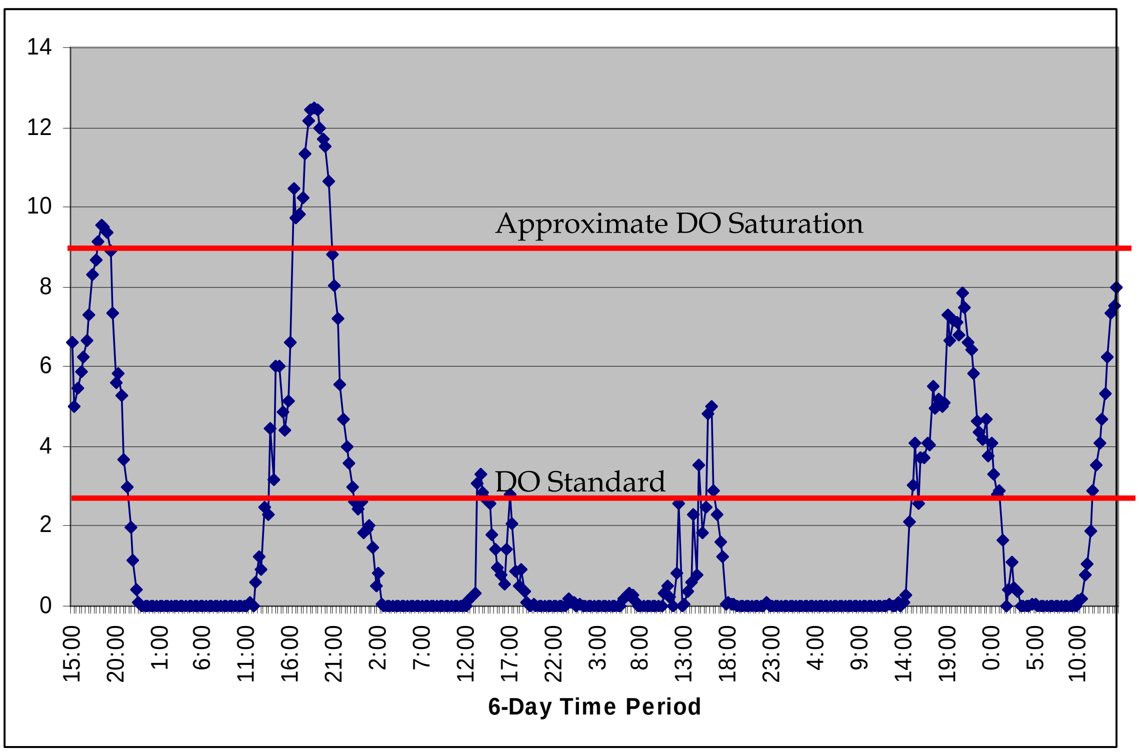




Source: Miller and Hoven, 2007

FIGURE 2-3
Diel pH (Upper) and DO (Lower) Concentrations
In a target (nutrient-rich) impounded wetland, Unit 1 of Farmington Bay WMA collected August 21-26, 2008; Utah's water quality standard for DO supersaturation is at 110 percent of the saturation value





Source: Miller and Hoven, 2007

Variations in the Sensitivity of Wetland Biota to pH and DO

The CWA requires states to develop water quality standards that ensure protection of the biological integrity of the nation's waters. Many methods have been developed to accomplish this goal. These methods all attempt to identify organisms that are sensitive to pollutants and pollutant concentrations that will ensure protection of aquatic life uses. Numerous biological assemblages depend upon impounded wetlands of the Great Salt Lake and the sensitivity of species within each assemblage will ultimately need to be considered. However, the relative sensitivity of macroinvertebrates that occupy these waters is discussed here for the purpose of illustrating the importance of directly relating potential threats of human-caused pollutants to the sensitivity of organism that currently or historically have occupied these wetlands.

Dominant macroinvertebrate taxa that are present in Great Salt Lake impounded wetlands are typical of many types of wetlands throughout the west (see Table 2-4), (e.g., Keeley and Zedler, 1996; Apfelback, 1999) and indeed throughout the world (e.g., Cheal et al., 1993; and others). Common wetland macroinvertebrates include snails (Gastropoda), waterboatman (Corixidae), midges (Chironomidae), damsel flies (Odonata), scuds (Amphipoda), and occasionally tolerant mayflies (Baetidae and Caenidae, Ephemoroptera) and leaches (Hirudinea). These dominant taxa are known to adapt to nutrients and the associated diurnal DO and pH, swings that are typically observed in eutrophic ecosystems (as indicated by Hillsenhoff, 1987 and 1998; Bode et al., 1991; and others). Further, these taxa dominate the macroinvertebrate assemblage in Great Salt Lake wetland reference sites and the nutrient-enriched target sites (Table 2-4). This suggests that, by nature, shallow wetlands, whether ephemeral or permanent, or eutrophic or oligotrophic, are dominated by taxa that, to an extent, can adapt to the natural large diel swings in basic water quality constituents such as temperature, pH, and DO.

Level III studies that involve intensive wetland site assessments are rare in the literature. However, one such study revealed similar characteristics. Heimann and Femmer (1998) studied three riparian wetlands in the relatively soft and low-alkalinity waters of Missouri. Their goal was to identify a reference condition for development of numeric standards for the Missouri Department of Natural Resources. The three wetlands were hydrologically linked to the adjacent streams or rivers and had direct connectivity during high-flow periods. Among the three wetlands, pH ranged from 7.6 to 8.9, and DO ranged from 0.0 to 26.8 milligram per liter (mg/L). Median total phosphorus ranged from 0.06 to 0.15 milligram per liter (mg/L), with the higher values measured during or immediately following periods of direct connectivity to the adjacent rivers. Macroinvertebrate taxa collected at these wetlands were dominated by Chironomidae (Diptera), Stratiomyidae (Diptera), Glossiphonidae, Hirudinea, Coenagrionidae (Odonata: Zygoptera), Caenidae (Ephemeroptera), Planorbidae (Gastropoda), and Palaemonidae (Decapoda). The macroinvertebrate taxa observed at these sites is similar to those observed in Great Salt Lake impounded wetlands as summarized by CH2M HILL (2006), Gray (2005), and Miller and Hoven (2007). While these taxa range from moderately sensitive (i.e., Caenidae) to tolerant to organic enrichment (Hilsenhoff 1987), the majority of taxa observed at wetlands with both high and low concentrations of nutrients are generally considered to be tolerant to anthropogenic stress.

Next Steps with pH and DO Water Quality Standards

While implementing the current pH and DO numeric water quality standards has been problematic, so is the development of new site-specific numeric water quality standard for pH and DO. A significant amount of data—and time and resources to collect that data—would be required to understand seasonal, spatial, and multiyear variability of pH and DO in these wetlands. The existing database is not sufficient at this time to provide defensible pH and DO numeric criteria. Moreover, even if these data were available, the application of pH and DO criteria would not be a practical way to ensure protection of biological uses because subsequent assessments would also need to be based on costly and time-consuming monitoring data.

Toxicological data on the effects of pH and DO on wetland taxa is also insufficient to determine whether background concentrations observed at these sites represents an appropriate threshold of impairment. Thus, the UDWQ has proposed an approach to eliminate the pH and DO numeric water quality standards for the classes 3B, 3C, and 3D impounded wetlands of Great Salt Lake. However, UDWQ acknowledges that federal rules and regulations require documentation that another mechanism exists to ensure protection of aquatic life uses following the removal of these numeric criteria for these waters. As a result, UDWQ has developed a quantitative and scientifically rigorous approach for measuring the biological integrity of wetlands. This approach will retain protections for wetlands biota and implement an assessment framework that documents how beneficial uses of these impounded wetlands are being protected. This report documents the development of a preliminary assessment framework.

TABLE 2-4
Most Abundant Taxa in Great Salt Lake Reference and Target Impounded Wetlands (2005)
The eight most abundant taxa in sweep-net samples collected from a reference site (Widgeon Pond) located in the PSG WMA, Bear River Bay, and from a target (nutrient-enriched) site (Unit 1) located in Farmington Bay WMA. Samples were collected in 2005.

Reference Pond (Widgeon)	#	Farmington Bay WMA (Unit 1)	#
Chironomus, Chironomidae	98	*Chironomus,* Chironomidae	9
Corisella, Corixidae	9	*Corisella,* Corixidae	60
Hesperocorixa, Corixidae	22	*Hesperocorixa,* Corixidae	13
Ischnura Odonata	14	*Ischnura,*–Odonata	110
Hyallela azteca, Hyallelidae, Amphipoda	105	*Hyallela azteca,* Hyallelidae, Amphipoda	140
Gyraulus, Gyraulidae, Gastropoda	8	*Physella,* Physellidae, Gastropoda	9
Tanypodinae, Chironomidae	4	*Gyraulus,* Gyraulidae, Gastropoda	7
Callibaetis, Baetidae, Ephemoroptera	6	*Callibaetis,* Baetidae, Ephemoroptera	8

NOTES:
PSG = Public Shooting Grounds
WMA = wildlife management area

2.3 Need for Assessment Protocol

Research to characterize the ecosystem of Great Salt Lake's wetlands has uncovered numerous new questions regarding how these wetlands may be best protected. Complexities in the biological, chemical, and ecological function of the wetlands makes determination of suitable numeric criteria for these wetlands difficult and time consuming. Discussion of using only narrative criteria to protect the wetlands meets with significant concern that narrative criteria alone may not adequately protect the beneficial uses. Regardless of the water quality standard that is implemented in the future, an assessment framework specific to the impounded wetlands of Great Salt Lake is vital to moving forward. This framework, and the science that defines it, will serve as the baseline for documenting if and how the beneficial uses of these impounded wetlands are protected. This framework will also serve as the foundation for a new, proposed approach to managing the wetlands of Great Salt Lake (see Section 5.0).

The following sections of this report describe the UDWQ's efforts to evaluate data collected during the period of 2004–2008 and to develop a preliminary draft assessment framework that can serve as a "straw man." Future data collected may then be used to validate and improve the assessment framework before it is adopted.

3.0 Ongoing Research

Concern about the potential impact nutrient loads may be having on the wetlands and open water of Farmington Bay prompted UDWQ and others to initiate a research program in 2004 to characterize the ecosystem of Farmington Bay. The goal of the program was to characterize the physical, chemical, and ecological processes that were critical to the integrity of Farmington Bay's ecosystem. This characterization would then serve as the basis for developing a sustainable plan for defining, evaluating, and protecting Farmington Bay's beneficial uses and resources.

As research progressed, funding became available for wetlands research, and the wetlands of Farmington Bay became the key area of focus. This was not to say that issues in the open waters of Farmington Bay were less important but was a matter of directing research toward where the resources to complete it were available. Miller and Hoven (2007) and the many individual reports prepared by principal investigators included in their report provide the seminal review of the work completed through 2007. Subsequent to this report, research was further focused upon impounded wetlands. It became apparent that the characteristics of impounded wetlands in Farmington Bay were not distinct to Farmington Bay but were applicable to impounded wetlands throughout Great Salt Lake. Ongoing research will continue to work to understand these complex systems so that management efforts may be better focused to protect their beneficial uses.

Additional reports summarizing ongoing research were being prepared by the principal investigators at the time of this draft publication. Updated data, evaluations, and interpretations will be compiled and included in the final version of this report. This section compiles key observations from ongoing research efforts to characterize the condition of Great Salt Lake's impounded wetlands and presents some of the measures recommended for inclusion in the preliminary assessment framework. The reader is directed to Miller and Hoven (2007) for details and complete summary regarding this work.

3.1 Program Objectives

Wetlands studies completed as part of the research program were designed to (1) identify thresholds of adverse biological or ecological changes in nutrients and other parameters, such as extreme swings in pH and dissolved oxygen (DO), that are typically associated with hypereutrophy and (2) identify sensitive and ecologically important responses to nutrient enrichment in the wetlands. Information gathered from these studies would be incorporated into an assessment framework that quantifies scores and various ecological functions against a gradient in nutrients. Ultimately, thresholds along this scoring range would then be used to establish beneficial use support status and potentially to establish site-specific water quality standards for nutrients (Miller and Hoven, 2007).

Studies were designed to capture information for five assemblages: (1) water quality, (2) macroinvertebrates, (3) SAV and soils, (4) algae, and (5) birds. Table 3-1 summarizes the studies undertaken as part of this program along with the sampling period, principal investigators, and methods used. Note that only water quality, SAV and macroinvertebrates were selected for inclusion in the preliminary assessment framework and thus are summarized in this section. See Section 4.0 for further discussion.

TABLE 3-1
Summary of Studies Undertaken as Part of Great Salt Lake Wetlands Research Program

Activity	Schedule	Responsible Agency	Methods
Water quality parameters include field (pH, DO, temperature) nutrients and metals	Monthly except winter months	UDEQ/UDWQ	UDEQ/UDWQ's SOPs
Macroinvertebrates	Early July, late August and November 2005; November 2007	UDEQ/UDWQ and Dr. Larry Gray, Utah Valley University	UDEQ/UDWQ's SOPs and Dr. Gray SOPs for Analysis of Aquatic Macroinvertebrate Samples
Algal (phytoplankton, periphyton, and epiphytes)	Early July and late August, 2005; early August, 2006; fall 2007; July 2008	UDEQ/UDWQ and Dr. Rushforth, Utah Valley University	UDEQ/UDWQ's SOPs and Rushforth Phycology, LLC, Protocols and Procedures: Analysis of Algae Samples
Submerged aquatic vegetation and soils	Early summer, late summer, and fall 2005; summer, fall 2007; Early summer, late summer, fall 2008	Dr. Heidi, Hoven, Institute for Watershed Sciences	EPA Wetlands Assessment Module 10 and 16, IWS QAPP, BYU Plant Laboratory, Timpview Analytical Laboratories
Shorebird nesting success, foraging ranges, and prey selection	Spring and summer 2005	Dr. John Cavitt, Weber State University	EPA Wetland Assessment Module 13 (Biological Assessment Methods for Birds), and Cavitt QAPP

NOTES:
BYU = Brigham Young University
EPA = U.S. Environmental Protection Agency
SOP = standard operating procedure
UDEA = Utah Department of Environmental Quality
UDWQ = Utah Division of Water Quality

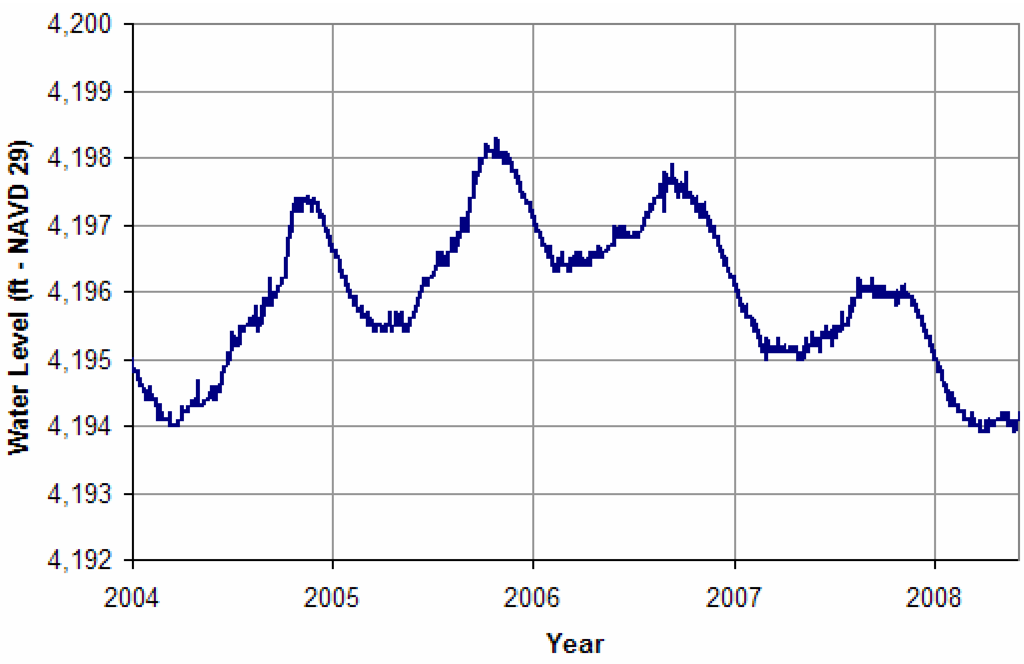
3.2 Lake Conditions during the Study Period

As described in Section 1.0, Great Salt Lake is a uniquely dynamic water body dependent on a wide variety of variables that affect the physical characteristics of the lake but also its adjacent wetlands. While an objective of this research program was to characterize the ecosystem of Great Salt Lake's impounded wetlands, it is important to understand the context of the research in terms of the historic variability of the lake and its watershed. Field studies for this program began in August 2004 and continued through August 2009.

3.2.1 Lake Level

The lake elevation for the study period, as measured at the U.S. Geological Survey station at Saltair (USGS 10010000 Great Salt Lake at Saltair Boat Harbor, Utah), varied from 4,194.9 feet on August 1, 2004, to 4,194.1 feet on December 31, 2008 (see Figure 3-1). The maximum lake elevation in the study period was 4,198.3 feet (May 27, 2006), and the minimum elevation was 4,193.9 feet (October 24, 2008).

FIGURE 3-1
Great Salt Lake Elevation for the Study Period



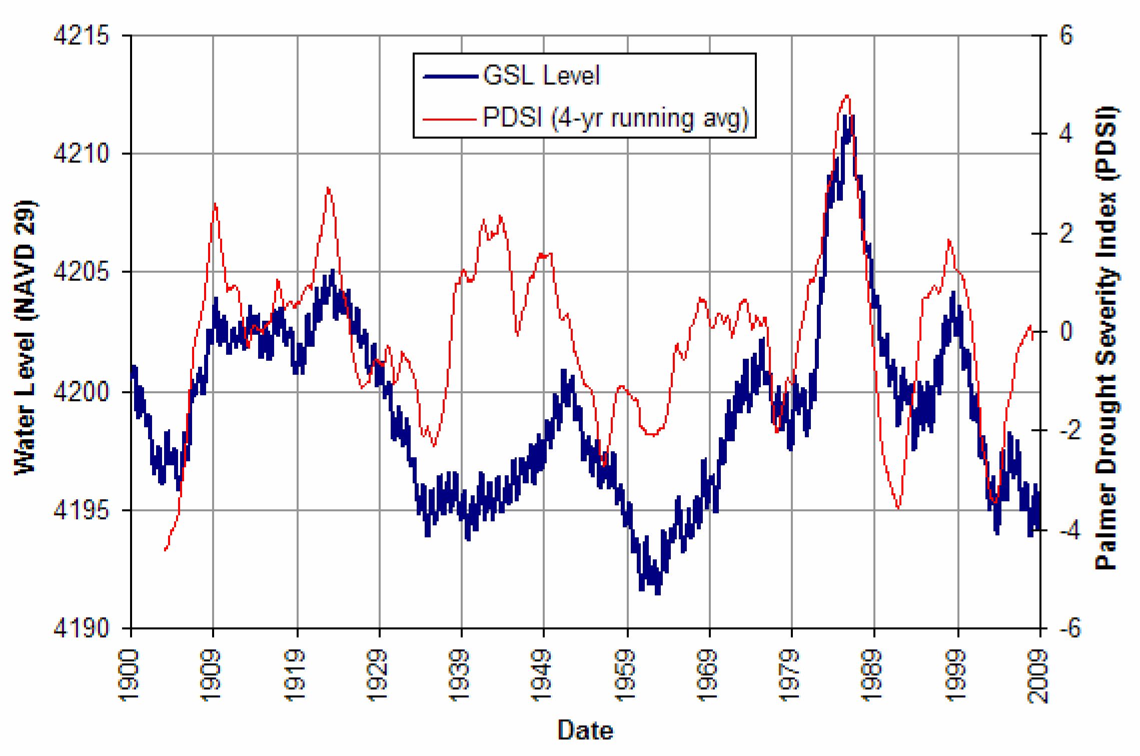
As noted in Section 1.0, during the period of record available, the lake elevation has historically fluctuated more than 20 feet with a maximum elevation of 4,211.6 feet in 1986 and in the early 1870s and a minimum elevation of 4,191.4 feet in 1963.

3.2.2 Hydrology

The elevation and size of Great Salt Lake and, as a result, conditions in Great Salt Lake's wetlands vary largely as a result of changes in inflow from precipitation, tributaries, and groundwater, as well as from losses through evaporation. Understanding the watershed's historic hydrologic regime helps to place the lake's response during the study period in context.

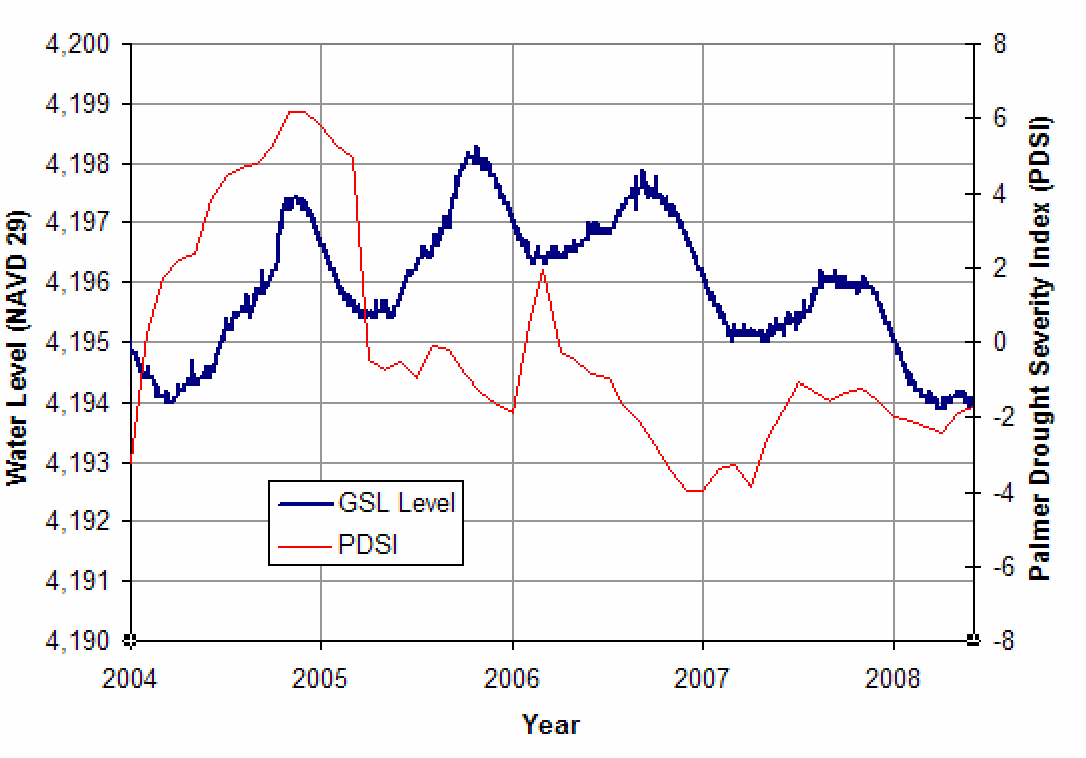
A common measure of meteorological drought across the country is the Palmer Drought Severity Index (PDSI). The PDSI, although not a true measure of meteorological drought in the strictest sense, adequately describes it. The PDSI is the monthly value (index) that is generated indicating the severity of a wet or dry spell. This index is based on the principles of a balance between moisture supply and demand (National Oceanic and Atmospheric Administration [NOAA], 2009). The 4-year running average of PDSI values somewhat correlates with historic Great Salt Lake levels, as seen in Figure 3-2.

FIGURE 3-2
Great Salt Lake Elevations Compared with 4-year Running Average PDSI during the Past Century



The study period provided a unique opportunity to understand the dynamics of Great Salt Lake during a wet and dry period of the hydrologic cycle. The PDSI indicates that the watershed moved into a drought condition during the study period (Utah Division of Water Resources, 2007), as shown in Figure 3-3. Great Salt Lake's watershed had a PDSI in June 2005 of greater than 6, indicating wetter than normal conditions. Following this wet period, the watershed's condition changed to severe drought (PDSI value of nearly -4) by late 2007 (NOAA, 2009). The effects of the dry cycle can also be observed in Figure 3-1; lake levels generally decreased during the study period as inflow volumes decreased.

FIGURE 3-3
Great Salt Lake Elevations Compared with PDSI during the Study Period



3.3 Summary of Methods and Results

The initial research design focused on measuring nutrient attenuation along a longitudinal gradient established by water passing through successive impoundments from publicly owned treatment works (POTW) discharges. Total nitrogen was found to not exceed Utah's narrative criterion of 5 mg/L, and it was often below instrument detection limits of 0.05 mg/L. Therefore, attention largely focused upon the impacts of phosphorus. Four POTWs discharge to the Jordan River, and the effluent from these facilities alters the biogeochemistry of the Jordan River and potentially on the wetlands at the terminus of the river. For instance, the location just upstream of the wetlands on the Jordan river has mean total phosphorous concentrations that range from 0.43 and 1.4 mg/L over the period of 1995 to 2008 (Jordan River TMDL Phase II, 2009). The Jordan River itself is currently on Utah's 303(d) list for low DO and high levels of phosphorus.

Reference (least-disturbed) as well as target (nutrient-enriched) sampling sites were identified and included in the study design (see Figure 3-4). Numerous biotic parameters were collected at each site including: macrophytes (percent cover, stem height, species composition, tissue nutrient concentrations and ratios, and biomass), phytoplankton and periphyton community structure, macroinvertebrate community composition, and shorebird nesting success and forage preference studies. Abiotic factors collected at the sites primarily focused on water chemistry and included parameters such as: phosphorus, nitrate-nitrite, ammonia, metal concentrations, pH, electrical conductance (EC), DO, and temperature, sediment nutrient concentrations, organic carbon, and pH.

Miller and Hoven (2007) provide a detailed summary of study methods and results as well as a compendium of individual reports prepared by individual principal investigators. The following summary of Miller and Hoven's 2007 report only briefly describes the wealth of information contained in this report and focuses only on results for impounded wetlands and those used in the development of the assessment framework. The reader is directed to the original report for further information and discussion. A discussion of data used from these studies is described in Section 4.0.

3.3.1 Sampling Sites

Reference conditions for impounded wetlands were identified at the Public Shooting Grounds (PSG) WMA and Bear River Migratory Bird Refuge (BRMBR). Targeted (nutrient-enriched) sites were identified in the delta area of Jordan River and included Farmington Bay WMA, the New state and Ambassador duck clubs, and the Inland Sea Shorebird Reserve (ISSR). See Figure 3-4 for sampling site locations. The following provides a brief description of each of the sampling sites.

Public Shooting Grounds Waterfowl Management Area

The Public Shooting Grounds (PSG) Waterfowl Management Area is managed by the State of Utah, Division of Wildlife Resources, and is open to the public once a year during the hunting season. It is located on the northern shore of Bear River Bay on Great Salt Lake and about 10 miles west of Corrine, Utah. The primary source of water to the PSG is Salt Creek. There are no industrial or municipal facilities discharging to the creek, but it does receive some agricultural return flows. Total phosphorus levels were found to be between 0.02 and 0.05 mg/L. Because it is minimally influenced by anthropogenic sources, the PSG was chosen as a reference wetland site for the project.

Pintail Lake is the first and most northern pond in the complex and the least saline of the ponds. The outflow of Pintail Lake discharges to Widgeon Pond. Water exiting Widgeon Pond discharges into a large shallow marsh that is used by a variety of birds that prefer emergent vegetation and shallow water. Two of the impoundments within the refuge were selected for sampling and are labeled as Public Shooting Grounds Widgeon Lake 01 Outfall and Public Shooting Grounds Pintail Lake Outfall.

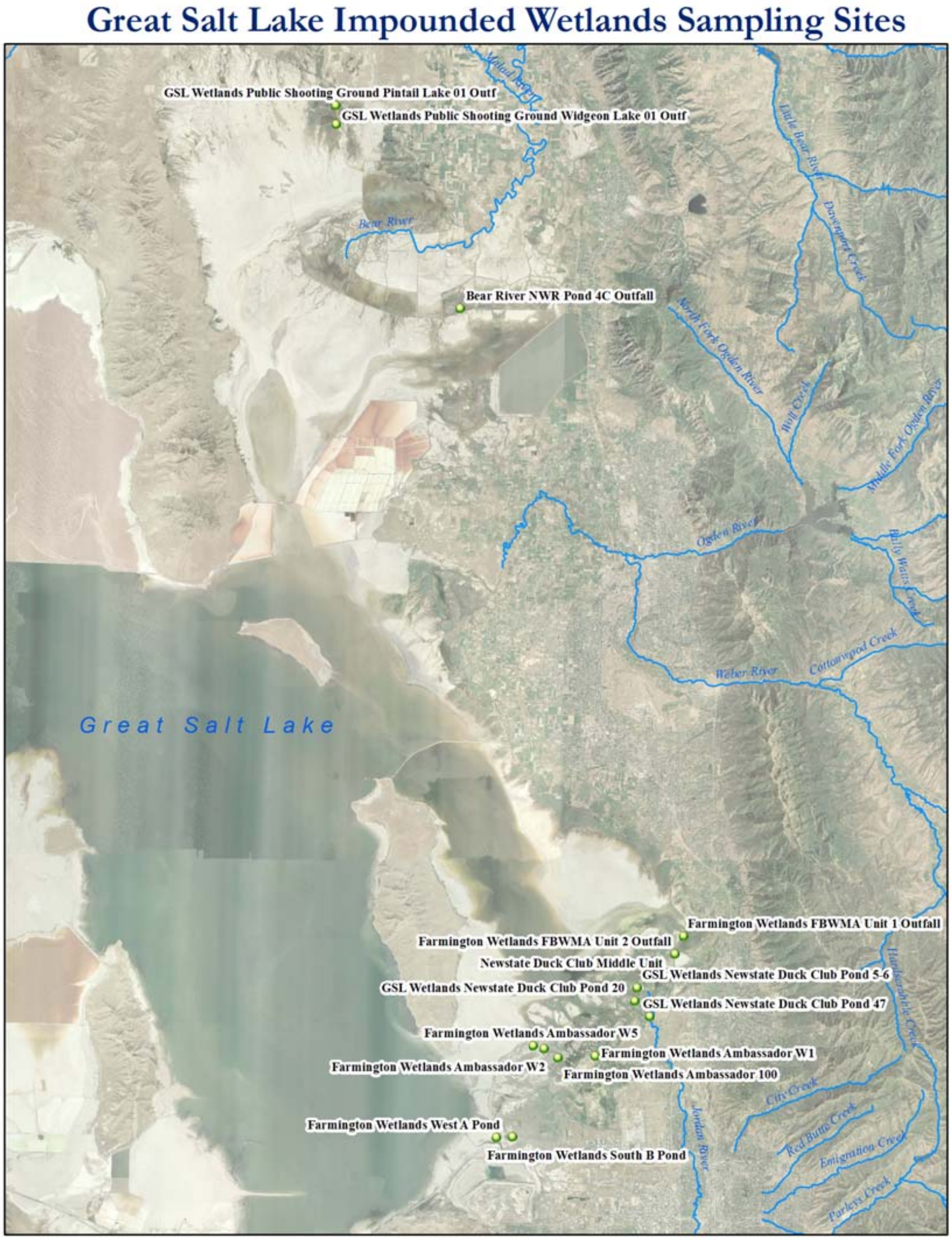
Bear River Migratory Bird Refuge

The BRMBR is part of the USFWS National Wildlife Refuge System and was established in 1928. It is located on the northeastern shore of Bear River Bay of Great Salt Lake. The primary source of water to the refuge is the Bear River. There are significant municipal and industrial discharges to the Bear River, and the water is heavily used and reused for irrigation. One impoundment within the refuge was selected for sampling and is labeled as Bear River NWR Pond 4C Outfall.

Farmington Bay Waterfowl Management Area

The Farmington Bay Waterfowl Management Area (FBWMA) has been owned and managed by the Utah Division of Wildlife Resources since 1935 and encompasses 12,000 acres that include freshwater ponds, marshes, expansive mudflats, and open salt water. It is located on the southeastern shore of Farmington Bay of Great Salt Lake and is managed to provide habitat for waterfowl. The primary source of water is the Jordan River, but it also receives water from other sources including significant flow from the New state duck club, located immediately south of the Turpin Unit. The FBWMA consists of several large connecting ponds. Two ponds were chosen for this study labeled as Farmington Wetlands FBWMA Unit 1 Outfall and Farmington Wetlands FBWMA Unit 2 Outfall.

FIGURE 3-4
Sampling Site Locations



The Rocky Mountain Power Mitigation Pond is adjacent to the FBWMA. The pond fills during spring runoff with freshwater from Farmington Creek but by the summer's end it becomes a hypersaline pond or dries completely. As opposed to the other FBWMA ponds, this pond does not contain carp. The pond selected is labeled as the IMPC Conservation Easement.

New state Duck Club

The New state Duck Club (NDC) is a private duck club located on the southern shore of Farmington Bay on Great Salt Lake. It is heavily managed for waterfowl with significant maintenance projects conducted annually (extensive invasive weed eradication). The NDC has senior water rights and receives water from the Jordan River at the Burnham Dam diversion. The Burnham Dam is located downstream of all municipal and industrial discharges to the Jordan River except the South Davis North Waste Water Treatment Facility. Most of the ponds are inaccessible by land, and specialized boats are used to access them. Four ponds were chosen for sampling and are labeled as GSL Wetlands New State Duck Club Pond 47, GSL Wetlands New State Duck Club Pond 20 GSL Wetlands New State Duck Club Unit 5-6, and New State Duck Club Middle Unit.

Ambassador Duck Club

The Ambassador Duck Club (ADC) is located on the southwest shore of Farmington Bay of Great Salt Lake. It has been in existence since the early 1900s and is heavily managed for waterfowl. It has senior water rights and delivers water to downstream duck clubs. The ponds are accessible by road, and the land surrounding the ponds is used for grazing. It receives Jordan River water through the Surplus Canal. Four ponds were selected for this project and are labeled as Farmington Wetlands Ambassador W1, Farmington Wetlands Ambassador W2, Farmington Wetlands Ambassador W5, and Farmington Wetlands Ambassador 100.

Inland Sea Shorebird Reserve

The Inland Sea Shorebird Reserve (ISSR) is a Kennecott Utah Copper Corporation mitigation project. It is located on the southern shore of Gilbert Bay and encompasses 3,700 acres. The wetlands are managed by a resident biologist, and the reserve provides habitat for both shore birds and water fowl. Two ponds were selected for the project and are labeled as Farmington Wetlands South B Pond and Farmington Wetlands West A Pond.

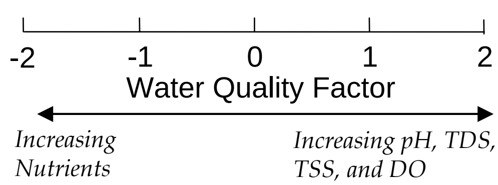
3.3.2 Water Quality

Water quality conditions differed among the wetland sites and ranged from mostly freshwater, nutrient-rich (eutrophic) conditions to more saline, nutrient-poor (oligotrophic) conditions. This range of water quality conditions allowed for an assessment of water quality in the impounded wetlands and how various plant and invertebrate components responded individually to water quality in Farmington Bay wetlands.

One of the hypotheses of the study design was that nutrient levels would attenuate or reduce as water flows through successive impoundments. Data generally did not support this hypothesis. Water column nitrate-nitrite was nearly always below the detection limit (0.05 mg/L) except for the NDC ponds and the first pond of the ADC. There was only a slight reduction of phosphorus found in the water column except at the four study ponds at the ADC. Total phosphorus fell from a mean of greater than 1 mg/L at the first Ambassador Duck Club pond to about 0.1 mg/L in the last (fourth) pond. This attenuation in phosphorus concentrations is hypothesized to be a result of long water retention times found at the ADC versus the other sites. Generally, however, phosphorus appears to remain in the water column and pass from pond to pond in the impounded wetlands. This is thought to be a result of the usually short water retention times as well as the saturation of binding sites in the sediments of the ponds. A readily available supply of phosphorus in the sediments (280 to 585 milligrams per kilogram total phosphorus) may create an equilibrium condition between water and sediment, thus maintaining elevated phosphorus levels in the water column throughout these systems. A series of experiments to study the interaction of water sediment in Farmington Bay seems to verify this hypothesis (Miller and Hoven, 2007).

Recent summaries of past data for Farmington Bay have indicated possible water quality stressor gradients related to nutrients, salinity, pH, DO, and total suspended solids (TSS) and provided insight into how biotic communities related to these water quality parameters (Miller and Hoven, 2007). Table 3-2 is from a recent evaluation of water quality data used to identify potential stressor gradients (CH2M HILL, 2009) and provides a general description of water chemistry conditions across all the wetland ponds. These analyses also revealed a few outliers (e.g., maximum EC, TDS, TSS) that need to be more thoroughly evaluated. A multivariate statistical test such as factor analysis was also used to convert multiple water quality variables (e.g., pH, total dissolved solids [TDS], TSS, DO, total phosphorus, total nitrate-nitrite, and water temperature) into a single water quality factor in CH2M HILL 2005 and 2006(Figure 3-5). The water quality factor, as such, conveniently described the range of water quality variables in a single factor (axis) by scaling these variables across a range of factor scores. Once water quality variables were described by a single water quality factor, biotic variables that describe plants and invertebrate communities were scaled against the water quality factor to assess wetland biotic responses to water quality. See Section 4.0 for discussion of the water quality factor used in the preliminary assessment framework.

FIGURE 3-5
Descriptive Example of the Water Quality Factor Used in Previous Studies on Impounded Wetlands in Farmington Bay



Sources: Miller and Hoven, 2007; CH2M HILL, 2005; CH2M HILL, 2006

TABLE 3-2
Water Quality Characteristics and Potential Stressors
All ponds, all years; shaded values exceed screening criteria.

Parameter	Units	Count	Min	Geo Mean	Percentiles 50th (Median)	75th	90th	Max	Screening value	Notes
Chlorophyll a	µg/L	98	0.9	8.8	8	21	45	104	15	eutrophic
D-Phosphorus	mg/L	85	0.02	0.2	0.2	0.7	1.0	1.4	0.1	eutrophic; (Utah code is 0.05)
T-Phosphorus	mg/L	494	0.02	0.2	0.2	0.6	1.0	6.4	0.1	eutrophic; (Utah code is 0.05)
Nitrogen, ammonia as N	mg/L	447	0.05	0.2	0.2	0.4	0.7	26.6**	1.56	toxicity; (at pH 8.9, Classes 3B, C, D)
Nitrogen, Nitrite+ Nitrate as N	mg/L	146	0.1	1.1	1.6	2.4	4.1	7.8	4	eutrophic
Nitrogen, organic	mg/L	80	0.5	1.6	1.4	2.5	4.7	25.4**	1.9	eutrophic
T-Nitrogen	mg/L	80	0.5	2.0	1.6	3.3	7.8	52.0	1.9	eutrophic
Dissolved oxygen (DO)	mg/L	483	0.04	8.4	9	12	14	23	< 3	toxicity
pH	-	881	6.21	8.9	8.9	9.3	9.7	13.0	<6.5 or >9	toxicity
Salinity*	g/L (ppt)	473	0.2	1.8	1.4	3.0	6.4	59.9**	3.9	toxicity; tolerance limit for F.W. Marsh
Temperature	ºC							35.0	< 27	toxicity
TDS	mg/L	534	254	1,719	1,360	2,790	6,104	20,4000**	(6,100)	toxicity; (90th percentile)
TSS	mg/L	442	4	23.2	22	48	91	4,458**	(91)	toxicity; (90th percentile)
EC*	µmho/cm	853	276	2,909	2,421	4,897	9,256	85,812**	6,000	toxicity; tolerance limit for F.W. Marsh
Sulfate (SO_4)	mg/L	380	21	224	218	315	652	7,930	(650)	toxicity; (90th percentile)

NOTES:
ºC = degrees Celsius
EC = electrical conductance
g/L = gram(s) per liter
µg/L = milligram(s) per liter
µgho/cm = micromhos per centimeter

Max. = maximum Min.=minimum
mg/L = milligram(s) per liter.
*Freshwater marsh salinity and EC tolerance limits from Smith et al., 2009
** Measurements taken at the ISSR South West Pond South, a site not used in the MMI

3.3.3 Plant Community Responses to Water Quality

Miller and Hoven (2007) provide a comprehensive review of the role that SAV plays in supporting both biotic and abiotic wetland processes. This review is briefly summarized in this section of the report to provide background and context of the SAV and metaphyton components of the impounded wetland MMI.

SAV provides many ecological functions in impounded wetlands. Miller and Hoven (2007) summarize some of the abiotic functions that SAV plays in wetland ecosystems, including: protective habitat for macroinvertebrates and other organisms, stabilization of sediments, nutrient cycling and attenuation, and attenuation of other pollutants. SAV also plays a critical role in wetland food webs, in particular, providing forage for migrating waterfowl. In fact, because *Stuckenia sp*., a type of SAV, is the preferred forage taxa by omnivorous waterfowl, many of the impounded wetlands along Great Salt Lake are managed to optimize the growth of these SAV.

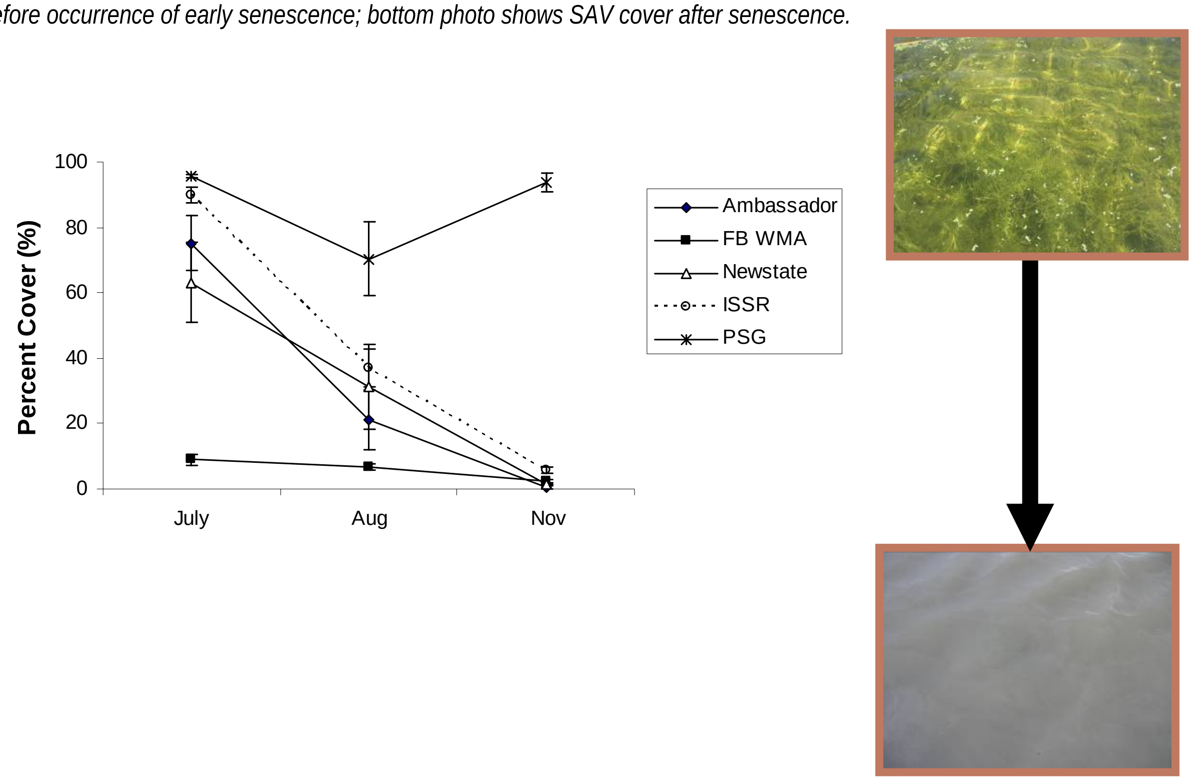
In addition to the ecological functions of SAV, previous studies have also used these organisms to quantify wetland condition. For instance, SAV have been used as indicators of water quality (Kemp et al., 1983; Orthe and Moore, 1983; Stumpf et al., 1999; Tomasko et al., 1996). Other studies have used measures of SAV composition and abundance to quantify the effects of anthropogenic stresses on wetland ecosystems (Brix and Lyngby, 1983; Burrell and Schubel, 1977; Hoven et al., 1999; Ward, 1987; Wolfe et al., 1976). Thus, SAV continues to be an important focus of Great Salt Lake impounded wetland research.

Previous investigations at Great Salt Lake impounded wetlands have found that plant community dynamics in the nutrient-enriched impounded sites differed from those in oligotrophic reference ponds. For instance, at some nutrient-rich ponds, SAV, primarily *Stuckenia sp.,* experienced early senescence in August resulting in a significant reduction in aerial plant cover (Figure 3-6). Of particular importance, these losses occurred prior to the arrival of waterfowl migrants, which diminished the value of SAV as a source of food for these birds. Miller and Hoven (2007) attributed this senescence to degraded water quality and the nutrient enrichment in these ponds, as opposed to naturally occurring seasonal changes in SAV cover (Figure 3-7). Thick layers of biofilms (composed of epiphytic algae, sediment, and possibly bacteria and fungi) were observed on the living leaves of SAV just prior to premature senescence (Figure 3-8). Finally, Miller and Hoven (2007) noted that extensive surface mats of filamentous algae or duckweed often developed more extensively in nutrient rich ponds than in reference ponds.

The mechanisms involved in early SAV senescence are not entirely known, although Miller and Hoven (2007) hypothesized that light limitation, both from leaf biofilms or from surface mats, may play a key role in determining whether or not SAV senescence occurs. Either of these factors can potentially reduce light penetration to below optimal SAV photosynthetic requirements. Further, these shading effects may be exacerbated by shorter photoperiod and lower sun angle late in the growing season. The overall reduction in photosynthesis rates and early SAV senescence result in plants that are incapable of adequate oxygen production to diffuse down to the roots and maintain an oxygen-rich root zone. Another potential factor was physical disturbance by carp that occur in most, if not all, wetland ponds. Additional investigations have explored both of these hypotheses over the last couple of years (Hoven *pers. comm.*).

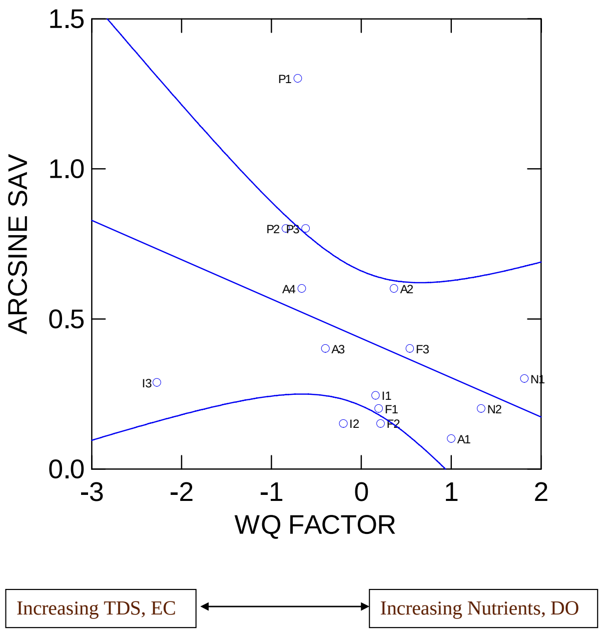
Early senescence of *Stuckenia sp.* has the potential to negatively impact the designated uses of the impounded wetlands in at least three ways. First, there may be negative implication for aquatic life uses because early senescence of *Stukenia sp.* – a preferred food of waterfowl – is a direct alteration of one of the key food chains in these ponds. However, because senescence does not occur at all wetland ponds, it is not clear whether the loss of energy resulting from early senescence is sufficient to negatively impact the populations of waterfowl. Second, the loss of SAV meadows may indirectly degrade conditions for other aquatic dependent forms of wildlife, which are also protected under aquatic life designated uses. For instance, Batzer and Resh (1992) found that experimental removal of 50% of wetland vegetation resulted in a significant decrease of macroinvertebrate richness and abundance. Third, early SAV senescence may impact recreation uses if the loss appreciably decreases waterfowl use during the hunting season, although such ties have not been quantified.

FIGURE 3-6
Mean Percent Arial Cover of SAV
Mean percent area cover (±SE) of SAV during the summer and fall months of 2005 for both nutrient-enriched (Ambassador, FB WMA, New state, and ISSR) and reference (PSG) upper ponds (N= 10, p-value < 0.0001). Top photo shows SAV cover before occurrence of early senescence; bottom photo shows SAV cover after senescence.



Source: Miller and Hoven, 2007

FIGURE 3-7
Arcsine Percent Cover of SAV
Arcsine percent cover of SAV (±95% Confidence Interval) versus the water quality (WQ) factor at nutrient enriched (A = Ambassador Duck Club, F = Farmington Bay WMA, I = Inland Sea Shorebird Reserve, N = New state Duck Club) and reference ponds (P = Public Shooting Grounds). Numerals show the successive ponds at each site.



Source: Miller and Hoven, 2007

FIGURE 3-8
Nutrient-enriched Pond
Nutrient-enriched pond with heavy cover of epiphytic algae and duckweed in the foreground.

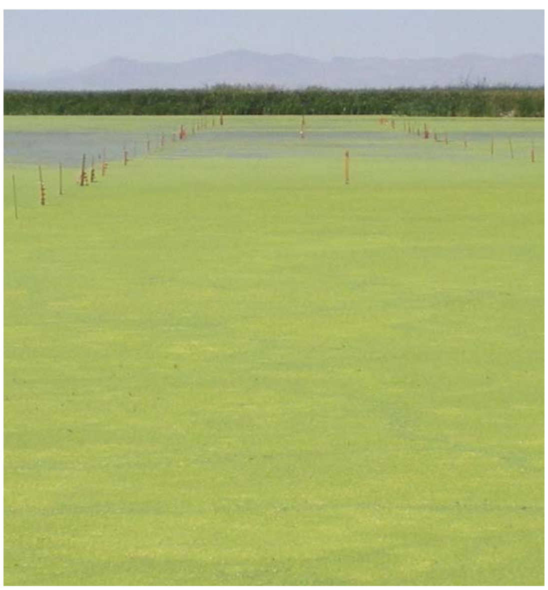


Photo source: Heidi Hoven

3.3.4 Macroinvertebrate Responses to Water Quality

Macroinvertebrates are a key component of wetland food webs and, in terms of the beneficial uses of Farmington Bay wetlands, provide food to birds and other wildlife (e.g., amphibians). Macroinvertebrates have multiple feeding strategies and can also serve as key indicators of functional processes in wetland ecosystems. Different taxonomic groups of macroinvertebrates are sensitive to different pollutants and can act as key indicators of disturbance caused by stressor gradients (e.g., nutrient gradients) in wetland ecosystems. These attributes of macroinvertebrates make them attractive biological indicators in biological assessment programs. To date, macroinvertebrates have been used as key indicators of wetland condition (Gallbrand et al. 2007) and are currently used for wetland assessments or are being considered as primary indicators in the following states: Minnesota, Ohio, North Dakota, Montana, Florida, Massachusetts, Maine, Vermont, Wisconsin, and Michigan (US EPA 2002). Similarly, previous research efforts on Great Salt Lake impounded wetlands have focused on collecting macroinvertebrate data in oligotrophic and nutrient-enriched impoundment wetlands in the Farmington Bay area. Some of the key findings of these previous research efforts are summarized in this section; however, the reader is directed to Gray (2006) and Miller and Hoven (2007) for further details and discussion.

Gray (2005) found that while similar macroinvertebrate taxa were observed across sites, pollution-tolerant macroinvertebrate taxa were more abundant at the freshwater nutrient-rich sites than at the more saline, oligotrophic reference sites (Figure 3-9). In particular, tolerant macroinvertebrates such as flatworms, leeches, gastropods, and chironomids were usually abundant at the nutrient-enriched sites, whereas pollution sensitive species such as ephemeropterans (mayflies) and odonates (damselflies and dragonflies) were in far greater numbers at reference sites.

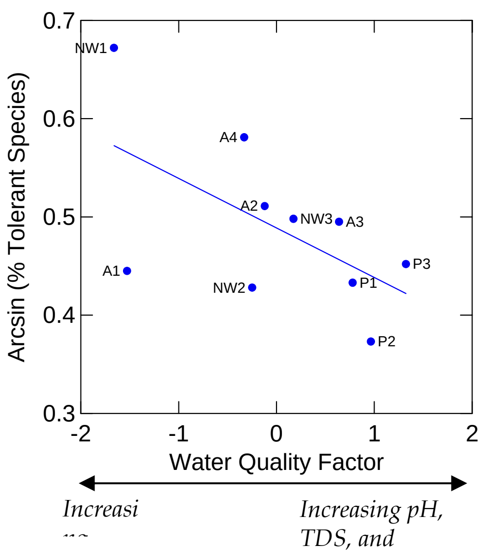
Some of the macroinvertebrate taxa observed at the wetland sites served as extremely sensitive indicators of water quality. A consistently sensitive indicator of water quality was the number of ephemeropterans (mayflies) in the impounded sites. Mayflies were typically far more abundant at the relatively saline, oligotrophic reference sites, than at the freshwater, more nutrient-enriched sites (Figure 3-10). Invertebrate species diversity was also generally higher at the more saline, oligotrophic reference sites than at some of the nutrient enriched sites.

The relative abundance of collector-gatherers (a functional feeding group of macroinvertebrates) was significantly higher in oligotrophic reference sites than in nutrient-enriched sites (Figure 3-11). Collector-gatherers at the reference sites were primarily represented by mayflies and *Hyallela,* both of which are relatively sensitive invertebrate taxa, and some of the more tolerant chironomids.

These previous research efforts also reported some unknowns that may be affecting macroinvertebrate community dynamics at the wetland sites and confounding interpretation of the macroinvertebrate data. Many of these sites are treated for mosquitoes to minimize their effects as disease vectors, including treatment with the biotic agent *Bacillus thurengiensis (Bti)*, as well as other chemical pesticides. Depending on the vector control agent used, these treatments can potentially eliminate or reduce the abundance of certain types of macroinvertebrates (chironomids, mayflies, odonates, hemipterans, and crustaceans) that are sensitive to these vector control agents. It was determined that more information on these vector control schedules, locations and agents used was needed to evaluate how these may be affecting invertebrate community dynamics at those sites. Other potentially confounding factors include the following:

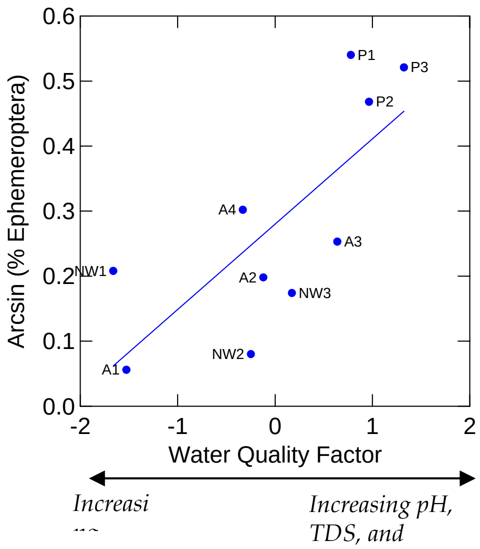
- Salinity, which could affect macroinvertebrate community composition, especially when total salinity exceeds 10 parts per thousand (ppt)
- Variable hydrologic regimes, especially the draining of ponds and time before refilling
- Variable sampling protocol including collection of macroinvertebrate samples that occurred over multiple seasons, at different times, and using multiple sampling methods
- Not all impoundment sites have data within a given season and year

FIGURE 3-9
Percent pollution-tolerant Macroinvertebrates versus Water Quality Factor
Percent pollution-tolerant macroinvertebrates versus water quality factor at nutrient-enriched (A = Ambassador Duck Club, F = Farmington Bay WMA, N = New state Duck Club) and oligotrophic reference ponds (P = Public Shooting Grounds) in 2004. Numerals show the successive ponds at each site.



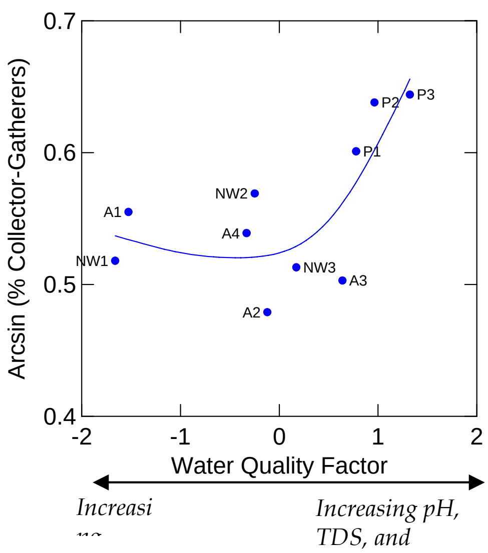
Source: Miller and Hoven, 2007

FIGURE 3-10
Percent Ephemeroptera in the Macroinvertebrate Samples versus Water Quality Factor
Percent ephemeroptera in the macroinvertebrate samples versus water quality factor at nutrient-enriched (A = Ambassador Duck Club, F = Farmington Bay WMA, N = New state Duck Club) and oligotrophic reference ponds (P = Public Shooting Grounds) in 2004. Numerals show the successive ponds at each site.



Source: Miller and Hoven, 2007

FIGURE 3-11
Percent Collector-gatherers in the Macroinvertebrate Samples versus Water Quality Factor
Percent collector-gatherers in the macroinvertebrate samples versus water quality factor at nutrient-enriched (A = Ambassador Duck Club, F = Farmington Bay WMA, N = New state Duck Club) and oligotrophic reference ponds (P = Public Shooting Grounds) in 2004. Numerals show the successive ponds at each site.



Source: Miller and Hoven, 2007

3.3.5 Conclusions

In summarizing the results of research efforts to date, Miller and Hoven (2007) suggest a number of indicators of condition as candidates for inclusion into a Multimetric Index (MMI) of wetlands condition. The measures recommended for inclusion in the preliminary assessment framework are as follows:

1. Macroinvertebrate species composition and density (during nesting season and fall migration season)
2. Percent of ephemeroptera
3. Percent chironomidae
4. Percent odonates or clingers
5. SAV aboveground biomass
6. SAV percent coverage
7. Carbon:Nitrogen:Phosphorus ratios in phytoplankton and macrophytes
8. SAV leaf chlorophyll a/macrophyte fluorescence
9. Turbidity/light penetration
10. Presence/composition of floating vegetation
11. Presence/composition of SAV epiphytes
12. Summer mean diel DO
13. Diel minimum DO

These recommendations and further data evaluations have subsequently been structured into the MMI framework described in this report. This framework separates these indicators into separate biological (e.g., surface mats, SAV, macroinvertebrates) and physical (e.g., water chemistry) components to quantify the relative condition of impounded wetland ponds. Research efforts continue on these wetlands, and this framework allows for the inclusion of additional data as it is available. Again, the intent of this report it to put forth a broad framework that provides a more robust and defensible measure of condition than the currently misapplied pH and DO numeric criteria assigned to some of these wetlands. However, it must be emphasized that while existing data provide measures of relative condition, the MMI requires further evaluation before the MMI can be appropriately used to assess support of the designated uses of impounded wetland ponds.

4.0 Protocol Development

While there are many measures that can and have been used to assess the condition of wetlands, three assemblages were selected for use in the preliminary assessment protocol: (1) water chemistry, (2) vegetation, and (3) macroinvertebrates. This section provides a summary of the background of biological assessments, metrics development methods used, and results from the preliminary assessment protocol for impounded wetlands of Great Salt Lake.

4.1 Background

4.1.1 Basis, Use, and Limitations of Biological Assessments

The development of biological assessment methods in the U.S. largely resulted from the need to interpret and implement provisions in the CWA of 1972. The goal of the CWA is to "protect and maintain the chemical, physical and *biological integrity* of the nation's waters" (emphasis added). While much attention has historically been focused on the chemical and physical characteristics of the nation's waters, it is clear from this goal, and other sections of the CWA (e.g., §303, §304), that states must also protect biological integrity as part of the implementation of water quality standards. Measures are needed to specifically assess and protect the biological integrity of the nation's waters.

The use of the term biological integrity in the CWA required the development of an operational definition of the concept that could be used by the states. The definition of biological integrity currently used is "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." (Frey, 1977; Karr and Dudley, 1981). In short, biological integrity reflects the condition, abundance, and diversity of the resident aquatic biotic community.

Numerous methods have been developed to directly quantify the biological integrity of the nation's waters. Such methods are useful because they integrate the effects of all pollutants, rather than simply measure the quantity of a specific pollutant, and provide an overall measure of the condition of aquatic life designated uses. As described by Karr and Chu (1999), "the most direct and effective measure of the integrity of a water body is the status of its living systems." In the U.S., direct measures of biological condition were first integrated into CWA programs by Ohio in the mid-1980s (Whittier et al., 1987). Since that time nearly every state employs a biological monitoring and assessment program for streams and rivers (http://www.epa.gov/waterscience/biocriteria/States/streams/streams0.html), yet similar programs are far less developed for wetland ecosystems (http://www.epa.gov/waterscience/biocriteria/States/wetlands/wetlands.html).

Specifically for wetlands communities, their range of biological diversity and abundance reflects the range of underlying physical characteristics and hydrology. Because of this inherent variability, wetlands can be evaluated and ranked in terms of their ecological "health" or "integrity." Models that measure wetland integrity assume that quantifiable measures of the ecological community change in response to human-caused stress. The process of bioassessment and the use of biocriteria is well established, and these methods have been developed to measure the health and integrity of biological communities worldwide. Numerous methods for measuring biological integrity have been developed, yet most are similar in the sense that they compare measures of biological composition across gradients of human-caused stress.

In contrast to methods that rely on wetland extent and acreage along with assessments of specific wetland functions using functional assessment methods (Hurby et al., 1998; Smith et al., 1995), wetland assessments that focus on biotic communities provide direct information about the ecological condition of wetlands (Yoder and Rankin, 1998). Measures of the biotic community can be compared along gradients of stressors to identify the expected range in biotic indicators and to define the local unimpaired, "unstressed" condition. The unimpaired, minimally disturbed wetland communities are used to establish the characteristics of the healthy community. The basic concept (not only for wetlands but for ecological communities, in general) is that ecological communities respond to stressors in measurable ways. Various, measurable stressors (e.g., nutrient enrichment, pollutants, physical habitat loss, invasive species) are known to produce measurable responses in the abundance, diversity, or geographic extent of wetland species. As such, biological assessments of wetlands provide the information necessary for determining the degree to which the biological integrity of wetlands is being degraded or restored and for determining if the water quality of wetlands meets goals of aquatic life use protection (Yoder and Rankin, 1998; Gernes and Helgen, 2002).

One common method for measuring the integrity of aquatic ecosystems is the use of multimetric indexes (MMIs), which assemble numerous measures of biological composition into a single measure of relative condition. Typically, MMIs are developed to be used as regional indicators of condition for specific types of water bodies. The value of MMIs is that they reduce complicated abundance and diversity data into numeric indices that are known to respond to stressors. It must be recognized that the MMI values alone do not specify the causal effects of stressors, rather they only quantify the magnitude of departure from un-degraded, or minimally degraded conditions. However, MMIs provide an excellent tool for ranking wetlands and for focusing studies to identify opportunities for remediation or restoration, and also for assessing if water quality goals of aquatic life use protection are being met. Unfortunately, regional MMIs have not been developed for most wetland or other aquatic communities, and, therefore, local studies must be conducted to implement this potentially useful assessment tool.

Karr and Chu (1999) provide a comprehensive discussion of the approaches used in development of indexes of biotic integrity (IBIs)—a term roughly synonymous with MMIs, but strictly specific to biological indicators— and the benefits and limitations to consider when using the IBI approach.

The basic steps in creating a local or regional wetland MMI (Karr and Chu 1999) are as follows:

- Select the appropriate biotic assemblage for quantification. Appropriate examples would be wetland plants or macroinvertebrates.

- For a particular biotic assemblage (e.g., plants or macroinvertebrates), select candidate metrics that are grounded in ecological theory. Each metric should describe aspects of composition (i.e., abundance, richness), condition (fecundity, composition based on pollution tolerance), or functional organization (i.e., functional feeding groups, microhabitat preference) that are known to reflect key properties of the ecosystem.
- Test and evaluate the chosen metrics (measurements of the assemblages that show predictable and measurable responses to stressor gradients). In wetlands, typical stressors would be salinity, DO, nutrients, pollutants (e.g., urban runoff metals, agricultural pesticides) or the presence of carp or other invasive species. Metrics selected for the final MMI should respond predictably to variations along these stressor gradients.
- Ensure that the metrics are not strongly correlated. Evaluate the metric against potential covariates that may alter our interpretation of the data. This will lower the risk potentially overweighting a single line of evidence.
- Combine the metrics into an MMI. Typically, measured attributes of the assemblages are ranked (e.g., 1 through 5, 1 through 10) or continuously rescaled to remove the effects of different units. Once metrics have been transformed to remove the effects of different units or measures that move in different directions (i.e., scores get higher with stress versus scores that decrease with stress) the scores of each metric can be summed to create an overall MMI. For each assemblage that is examined, multiple metrics are typically used to create an overall MMI score.
- Test the MMI. Databases can be split to create a MMI from a subset of wetlands and to test the application on another, local set. Also, MMI scores can be compared to various stressor gradients to see if they behave similarly.

4.1.2 Applicability for Great Salt Lake

Based on over 5 years of previous research efforts, the wetlands of the Great Salt Lake area are particularly well suited to the development and application of assessments methods such as a MMI. Within wetland types (i.e., impoundment wetlands), a range of water quality conditions exist. For instance, impounded wetlands range from being relatively oligotrophic with nutrients at non-detect levels to ponds with extensive nutrient enrichment. Such stressor gradients provide an excellent opportunity for scaling responses of specific metrics that describe the structure or function of biotic communities to gradients of human-caused disturbance. Furthermore, these biotic metrics can ultimately be tied to key beneficial uses such as Utah's three-dimensional aquatic life designation currently used to protect Great Salt Lake wetlands: "use by waterfowl and other aquatic organisms in their food chain."

For example, previous investigation of impounded wetlands around Farmington Bay revealed that more sensitive invertebrate taxa such as ephemeroptera were positively related to indicators of water quality, such as pH, TDS, DO, nutrients, and temperature (CH2M HILL, 2006). Wetland vegetation also provides habitat for wetland macroinvertebrates and amphibians. While many of these studies were conducted to address other questions, data were collected that can be compiled into an assessment framework that quantifies the relative condition of Great Salt Lake impounded wetlands. Studies were also conducted within other wetland classes and similar frameworks will be created for other types of wetlands following future research efforts.

4.1.3 Available Data Sources

UDWQ-compiled data, from both ongoing efforts, are available to develop an MMI for Great Salt Lake impounded wetlands. These include water chemistry, aquatic macrophytes, diatoms, and macroinvertebrates (Miller and Hoven, 2007; Gray, 2009; CH2M HILL, 2009). Some of these research efforts summarized water chemistry data to create a gradient of human-caused stress, across which biotic responses of the plant and macroinvertebrate communities could be evaluated. Table 4-1 provides a summary of research efforts on Great Salt Lake wetlands over the past 5 years that were evaluated for the purposes of creating this MMI. Ultimately, it was not possible to include all potentially useful metrics in this MMI, but the multiple lines of evidence framework lends itself to the inclusion of additional metrics as the assessment framework is refined over the next couple of years (see Section 5.0).

TABLE 4-1
Data Sources and Metrics Analyzed for Developing the MMIs for Impoundment Type Wetlands in the Great Salt Lake Area

Data Group	Metric Group	Metrics Summary	Data Collection Periods
Water Chemistry	Water Quality	pH, DO, TSS, chlorophyll-a, phosphorus (dissolved P, total P and sediment total P), nitrogen (ammonia N, nitrate/nitrite N, dissolved organic N, and sediment total N), salinity	2003–2009
Plants	SAV Algae and Duckweed (Surface Mat Cover)	Maximum SAV, fall SAV, percent change SAV Maximum algal mat cover, Maximum duckweed cover	2008
Macroinvertebrates	Benthic Macroinvertebrates	Ephemeroptera (mayflies) percent of total sample number, Simpson's Diversity Index, Hyalella (Amphipods) percent of total sample number, total taxa, number of coleoptera (beetle) taxa	Mostly based on data from fall of 2007, but also incorporates some data from 2004 and 2005

NOTES:
DO = dissolved oxygen
N = nitrogen
P = phosphorus
SAV = submerged aquatic vegetation
TSS = total suspended solids

4.1.4 Metric Selection: Stakeholder Process

Numerous metrics can potentially be used to create a quantitative index of wetland condition. A number of metrics were first recommended for consideration in Miller and Hoven (2007) per their review of previous research (see Table 4-2). Their objective was to provide candidate parameters that could be developed into an MMI for impounded wetlands of Great Salt Lake.

TABLE 4-2
Metrics Recommended for Consideration in Miller and Hoven, 2007

1. Macroinvertebrate species composition and density (during nesting season and fall migration season)	8. SAV leaf chlorophyll-a/macrophyte fluorescence
2. Percent of ephemeroptera	9. Turbidity/light penetration
3. Percent chironomidae	10. Presence/composition of floating vegetation
4. Percent odonates or clingers	11. Presence/composition of SAV epiphytes
5. SAV above ground biomass	12. Summer mean diel DO
6. SAV percent coverage	13. Diel minimum DO
7. C:N:P ratios in phytoplankton and macrophytes	

NOTES:
C = carbon
DO = dissolved oxygen
N = nitrogen
P = phosphorus
SAV = submerged aquatic vegetation

In 2009, UDWQ conducted a series of meetings with the principal investigators to discuss research conducted since publication of Miller and Hoven (2007) and other wetland scientists not directly involved in UDWQ's previous research efforts. UDWQ's objective in holding these meetings was to understand the subsequent work, how it might be compiled with previous datasets, and how the combined datasets could be developed into a preliminary assessment framework for the impounded wetlands. While extensive work was done regarding diatoms in these wetlands, it was decided that the diatom datasets were not appropriate for an MMI at this time because the sample collection was directed at understanding the role of biofilms in SAV senescence as opposed to obtaining a characterization of wetland diatom composition. The list of metrics that was forwarded for consideration in this preliminary assessment framework is presented in Table 4-3. Metrics were identified for four assemblages: macroinvertebrates, SAV, surface mats, and water chemistry. These metrics were the subject of discussion at a workshop UDWQ facilitated with stakeholders on August 30, 2009.

The UDWQ workshop on August 30, 2009, provided stakeholders with the opportunity to hear presentations from the principal investigators and UDWQ and participate in a general discussion regarding which metrics appeared to hold the most promise for use in the preliminary assessment framework. It was not possible to incorporate all of the comments received during and subsequent to this meeting into the MMI discussed here, nor was it possible for stakeholders to provide all of their comments during this meeting. However, UDWQ made an effort to incorporate as many comments as possible in this preliminary assessment framework. Other recommendations will be incorporated into subsequent versions of the MMI as the data become available. For instance, Utah's Division of Wildlife Resources has collected bird use data that could be a strong metric given the direct tie to aquatic dependent wildlife. In addition, subsequent data collection efforts may explore other taxonomic groups such as emergent vegetation or amphibians. Finally, as the MMI is applied for different regulatory applications it may be useful to weight individual metrics or entire lines of evidence (e.g., chemistry, surface mat, SAV, macroinvertebrates), and incorporate additional lines of evidence (e.g., birds, amphibians). The MMI presented in this report provides a framework to bracket conversations about how future revisions can best meet management needs.

TABLE 4-3
Some assemblages and metrics that stakeholders recommended for consideration as part of the preliminary Impounded Wetland Framework to best capitalize on existing and readily available data.

Macroinvertebrates	Submerged Aquatic Vegetation	Surface Mats	Water Chemistry
Ephemeroptera (mayflies), percent of total sample number	Maximum (pre-collapse) SAV cover	Maximum algae mat cover	Index developed by Dr. Gray
Simpson's Diversity Index	Fall SAV cover	Maximum duckweed mat cover	Nitrogen
Hyalella (amphipods), percent of total sample number	Magnitude of SAV collapse	Maximum surface mat cover	Phosphorus
Total taxa	Percent loss of SAV		Total Suspended Solids
Number of coleoptera (beetle) taxa	SAV light compensation point		Dissolved Oxygen (DO)
	SAV shading matrix		Chemistry MMI

NOTE:
SAV = submerged aquatic vegetation

4.2 Metrics Development Methods

This section summarizes the methods used to derive the metrics for water quality, vegetation, and macroinvertebrates. Detailed descriptions of the field study design and protocols for measurement of the water quality, vegetation, and macroinvertebrate variables are provided in Miller and Hoven (2007). In general, protocols are as follows:

- Sites were selected along a nutrient gradient.
- Data were collected within a 2-week period in July, August, September, and October.
- On each sampling date, five measurements of SAV cover and mats (algae and duckweed information collected separately) were made at randomly selected locations along a transect established at each pond.
- Metrics were calculated as the average of transect values recorded on each collection period.

Sites sampled for water quality, vegetation, and macroinvertebrate data are listed in Table 4-4.

TABLE 4-4
Great Salt Lake Impoundment Wetland Sites Targeted for Sampling of Water Quality, Plant, and Macroinvertebrate Data

Site	Water Quality	Plants	Macro-invertebrates
Farmington Wetlands Ambassador W 1	Y	Y	Y
Farmington Wetlands Ambassador 100	Y	Y	Y
Farmington Wetlands Ambassador W 2	Y	Y	Y
Farmington Wetlands Ambassador W 5	Y	Y	Y
Farmington Wetlands South B Pond	Y	Y	Y*
Farmington Wetlands West A Pond	Y	Y	Y*
Farmington Wetlands FBWMA Turpin Unit Pond	N	N	Y
Farmington Wetlands FBWMA Unit 1 Outfall	Y	Y	Y
Farmington Wetlands FBWMA Unit 2 Outfall	Y	Y	Y
IMPC Conservation Easement	Y	Y	Y*
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall	Y	Y	Y
GSL Wetlands Public Shooting Ground Pintail Lake Outfall	Y	Y	Y
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Inflow	N	N	Y
GSL Wetlands Public Shooting Ground Pintail Lake Inflow	N	N	Y
Bear River NWR Pond 4C Outfall	Y	Y	N
New State Duck Club Middle Unit	Y	Y	Y
GSL Wetlands New State Duck Club Pond 47	Y	Y	Y
GSL Wetlands New State Duck Club Pond 20	Y	Y	Y
GSL Wetlands New State Duck Club Unit 5-6	Y	Y	Y

NOTES:
FBWMA = Farmington Bay Waterfowl Management Area
GSL = Great Salt Lake
N = Site not sampled
Y = Site sampled (asterisk indicates that data were collected but not included in the MMI analyses)

4.2.1 Water Quality Metrics

Summary characteristics were generated for all of the water chemistry data (listed in Table 4-1) that were routinely collected during 2003–2009 at the impoundment wetland sites, including the following:

- Ranges (minimum and maximum values)
- Measures of central tendency (arithmetic mean, geometric mean, median)
- Percentiles of data distribution (10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th})

Once summary statistics were calculated, the next step was to select summary statistics that provide the best measures of wetland condition. This is typically done with measures of central tendency or measures of extreme conditions. Central tendency describes average conditions and is potentially useful in quantifying large differences among ponds, whereas extreme measures (e.g., minimum, maximum, 10^{th} percentile, 90^{th} percentile) often represent measures that are most likely to affect wetland biota. The current standards for DO and pH for Great Salt Lake wetlands are based on such measures of extremes. Each summary statistic derived with these measures is potentially meaningful and was selected in two ways: (1) exploratory empirical models that related chemistry values to measures of biological composition and (2) the examination of the range of values among wetland ponds. The goal was to select chemical summary characteristics that were both correlated to differences in biological composition and variable among wetland ponds.

Chemical summary statistics were first evaluated with Random Forest Models (Breiman, 2001) that predicted (algal mat/duckweed and SAV) metric scores (as factors) from the chemistry data. Random forests models (RFMs) are a type of statistical bootstrapping method and were selected for exploratory analyses because they compensate for many of the limitations in the Great Salt Lake wetlands dataset including relatively few sites and highly skewed distributions for some chemical data. In short, RFMs are generally robust for this dataset because of the following:

- They have little tendency to be overfit.
- They are not susceptible to situations with many predictors and few observations.
- They account for interactions among predictor variables.
- They provide reasonable estimates of the relative importance of chemical summary statistics in predicting biological composition.

RFMs were not created to generate empirical models that could be used to predict biological composition from chemical characteristics; rather, the models were primarily used for data exploration purposes. For example, the variable importance values obtained from these RFMs generally suggested that for nutrient and DO data, measures of low values, high values, and central tendency were important in predicting wetland biota. Similarly, for chlorophyll-a, pH, and TSS, measures of relatively high or low values were generally important predictors of impounded wetland biota among models.

Subsequent to exploratory modeling, the distribution of chemical summary statistics among wetland ponds was evaluated. These data exploration analyses resulted in dropping pH as a parameter. In addition, it was determined that for DO only the minimum values were sufficiently variable to differentiate among ponds, both in concentration and saturation. DO data that summarized maximum conditions (e.g., maximum, 90^{th} percentile) revealed little interpond variation.

The results of all exploratory analyses were confirmed as ecologically reasonable through a review of scientific literature and were used to select parameters for inclusion in a water quality index (WQI) or MMI. Table 4-5 summarizes the water chemistry variables and related statistics that were initially screened to see if they were sufficiently variable among sites to be a potentially useful measure of condition.

TABLE 4-5
Water Chemistry Variable Screening for Inclusion of Variables in the WQI

Water Chemistry Variable	Summary Statistics Screened	Screening Decision	Notes
pH	10th percentile pH 90th percentile pH Maximum pH Minimum pH	Do not include pH in WQI/MMI	Retain parameter in the dataset due to existing standards and stakeholder concerns Variation in the summary statistics was insufficient to distinguish among sites
TSS	Minimum TSS Maximum TSS	Include both minimum TSS and maximum TSS in WQI/MMI	Low TSS values may indicate favorable water quality conditions SAV growth may be inhibited at high TSS values
Chl-a	Minimum Chl-a Maximum Chl-a	Include both minimum Chl-a and maximum Chl-a in WQI/MMI	High values in the water column may indicate high algal production and tendency for algal mat formation Production and respiration activities also relate to DO levels
DO	90th percentile of DO saturation (maximum) Minimum DO Geometric mean of DO	Include only minimum DO in WQI/MMI	Interpretation of grab samples of this variable problematic High values did not differ greatly among sites
P	Minimum P Maximum P Geometric mean P	Include minimum P, maximum P and geometric mean P in WQI/MMI for dissolved P, total P, and sediment total P	RFM models suggested that minimum P was also important. It is however difficult to interpret in the context of measuring relative condition; data suggests that P is good for SAV to a point, after which SAV may decline.
N	Minimum N Maximum N Geometric mean N	Include minimum N, maximum N, and geometric mean N in WQI/MMI for ammonia-N, nitrate/nitrite-N, dissolved organic nitrogen, and sediment total N (single measure for each pond)	RFM models suggested that minimum N was also important. It is however difficult to interpret in the context of measuring relative condition; data suggests that N is good for SAV to a point, after which SAV may decline.

NOTES:
Chl-a = Chlorophyll-a
DO = dissolved oxygen
MMI = multimetric index
N = nitrogen
P = phosphorus
RFM = random forests model
SAV = submerged aquatic vegetation
TSS = total suspended solids
WQI = water quality index

To create a final MMI it is necessary to combine all summary statistics (e.g., maximum, minimum) and parameter constituents to accommodate different units and the relative scale of changes among chemical measures (i.e., an increase of 0.1 mg/l nitrate/nitrite is not equivalent to an increase of 0.1 mg/l ammonia). Also, the rescaling needs to be done in a way that will allow all parameters to be combined into a single chemical MMI. Rescaling and MMI values were calculated using the following steps:

A. Rescale all of the constituent measures within each chemical parameter (see Table 4-5) to generate a dimensionless metric.

1. Calculate the relative concentration across sites by dividing the geometric mean obtained at the site by the geometric mean across all sites.
2. Create a metric for each constituent measure by rescaling the data so that it ranges from 100 (relatively good water quality) to 0 (relatively poor water quality).

   For "decreaser variables"—variables whose values are expected to decrease with stress (e.g., DO)—divide the relative concentration obtained at the site by the maximum relative concentration across all sites, then multiply by 100.

   For "increaser variables" —variables whose values are expected to increase with stress (e.g., TSS, chlorophyll-a, phosphorus, nitrogen)—follow the same process, except subtract the final value from 100 so that lower scores indicate poorer water quality.

B. Combine the constituent metrics used to summarize each parameter into a single MMI for the parameter (e.g., DO, chl-a).

1. Calculate the average of all constituent metrics ($Site_{avg}$).
2. Rescale the average values so that the site with the best water quality receives a score of 100 as follows:

$$MMI_{parameter} = (Site_{avg}/\text{maximum of } Site_{avg} \text{ across sites}) \times 100$$

C. Calculate a final chemical MMI by combining the scores obtained from all parameters.

1. Calculate the average of MMIs obtained for all parameters for each site:

$$\text{Avg } MMI_{site} = (MMI_{chl\text{-}a} + MMI_{DO} + MMI_{TSS} + MMI_{N} + MMI_{P})/5$$

2. Rescale so that the site with the best relative chemistry receives a score of 100:

$$\text{Chemical MMI} = (\text{Avg } MMI_{site}/\text{maximum of Avg } MMI_{site} \text{ across sites}) * 100$$

4.2.2 Plants: SAV and Metaphyton (Surface Mat) Metrics

The overall process for developing the SAV and surface mat (algae and duckweed) metrics follows guidelines and procedures established by Karr and Chu (1999). These indexes were calibrated based on data collected in 2008 and thus represent a preliminary assessment of plant metrics that should provide useful information for guiding the development of more robust metrics that incorporate data over multiple years and other lines of evidence that have been collected to describe the condition of these assemblages. The plant metrics for the impoundment wetlands were established *a priori*, based on previous studies of these ecosystems, with the intent of ultimately relating each metric to the aquatic life designated uses or narrative criteria assigned to these wetlands.

SAV Metrics

As discussed in Section 3.3.3, SAV is a critical component of the food web of impounded wetlands. SAV plays important roles in these wetlands by providing habitat for epiphytic algae and macroinvertebrates, mediating the cycling of nutrients, stabilizing of sediments, and serving as critical forage for migrating waterfowl. Many of the impounded wetlands along Great Salt Lake are managed to optimize the growth of these SAV for use as food by migrating waterfowl. SAV metrics can thus be tied to beneficial use and also serve as important indicators of wetland condition.

The following three metrics were generated to describe SAV condition:

- Maximum SAV (the maximum of transect averages of SAV percent cover from either July or August sampling events)
- Fall SAV (average percent cover from September samples)
- Percent change SAV (the percent change in SAV between the maximum and fall [September] samples).

Surface Mat (Metaphyton) Metrics

Previous research on Great Salt Lake wetlands noted the presence of dense surface mats (metaphyton) of algae (primarily *Cladophora*) or duckweed (*Lemna minor*) on some wetland ponds (Miller and Hoven, 2007). The presence and extent of metaphyton has been used elsewhere as an indicator of wetland condition due to ties with water chemistry and effects on wetland biota (McCormick and O'Dell, 1996; McCormick and Cairns, 1994).

Both direct and indirect effects of metaphyton on water chemistry have been observed in wetland ecosystems. For instance, metaphyton alters wetland nutrient concentrations through uptake and release of nutrients (McDougal et al., 1997; McCormick and O'Dell, 1996). These mats intercept light, which causes decreases in temperature and alters the rates of many biogeochemical processes (Goldsborough and Robinson, 1996). High rates of primary production and decomposition of dead plant material also lead to significant diel DO fluctuations (McCormick et al., 1997). Metaphyton have also been implicated in increases in mercury accumulation (Martin et al.) and even increased *E. coli* concentrations (Pawlit et al., 2003) in wetlands.

Metaphyton also provide habitat for invertebrates (Dodds and Gudder, 1992), yet are resistant to grazing and thus capable of building up biomass quickly. Physical crushing of SAV by heavy buildup of metaphyton has been observed in some Great Salt Lake impounded wetlands, including those in this study (Hoven, personal observations). Shading by metaphyton has also been shown to decrease both primary and secondary production of SAV. Metaphyton metrics can thus serve as important indicators of wetland condition and can also be linked to impacts on beneficial use due to their dynamics with SAV.

The following two metrics were generated to describe metaphyton (surface mat) conditions in the impoundment wetlands:

- Algae Mat = Seasonal Maximum of Algal Mat Cover (maximum of the transect average percent cover of algae, primarily *Cladophora*, observed among sample dates)
- Duckweed Mat = Seasonal Maximum of Duckweed Mat Cover (maximum of the transect average percent cover of duckweed [*Lemna minor*] observed among sample dates)

Exploratory Data Analysis

Exploratory analysis of the plant metrics data was conducted as follows:

- Metrics were plotted against each other to ensure that the metrics are not redundant, that is, that they did not provide measures of similar environmental conditions.
- Each metric was plotted against measures of salinity, a primary covariate that was hypothesized to confound metric interpretation among ponds.
- Plots were made of each metric against various chemical gradients to ensure that the metric changed predictably and was potentially useful as a measure of condition.

SAV and Mat (Metaphyton) Metric Calculations

Each metric was scored using the 5 (best), 3, and 1 scoring scheme (Karr and Chu, 1999) by dividing each metric at break points based on an examination of the data distribution among sites. The final scoring scheme is as follows:

- Maximum SAV and Fall SAV (5 = >80%, 3 = 50–80%, 1 = <50%)
- Percent Change SAV (5 = <10%, 3 = 10–50%, 1 = >50%)
- Algal Mat and Duckweed Mat (5 = <10%, 3 = 10–50%, 1 = >50%)

MMI values for SAV and Metaphyton Indicators were calculated using the following steps:

1. Rescale each constituent metric (e.g., maximum SAV, algal mat) so that a score of 100 represents the best condition observed across ponds:

$$\textit{Constituent Metric} = (\textit{metric value}_{site}/5) * 100$$

2. Average the constituent metrics for both SAV and metaphyton indicators:

$$\textit{Avg SAV Metric} = (\textit{Maximum SAV Metric} + \textit{Fall SAV Metric} + \textit{Percent Change SAV})/3$$

$$\textit{Avg Mat Metric} = (\textit{Algal Mat Metric} + \textit{Duckweed Mat Metric})/2$$

3. Calculate a final MMI for each site for both SAV and metaphyton by dividing the average value by the maximum value observed across sites:

$$\textit{SAV MMI}_{site} = \textit{Avg SAV metric/maximum of Avg SAV metrics across sites}$$

$$\textit{Mat MMI}_{site} = \textit{Avg Mat metric/maximum of Avg Mat metrics across sites}$$

4.2.3 Macroinvertebrate Metrics

As discussed in Section 3.3.4, macroinvertebrates are a key component of wetland food webs and provide food to birds and other wildlife. Because various groups of macroinvertebrates are sensitive to different pollutants, they can act as key indicators of various types of pollution in wetlands. Macroinvertebrates fill multiple ecological niches in wetlands and also serve as key indicators of functional processes in wetland ecosystems. Macroinvertebrate metrics can thus provide useful information for development of an assessment framework because of direct links to beneficial use and ecological condition of wetlands.

Exploratory Data Analysis

Macroinvertebrate data collected in the summer and fall of 2004–2007 were screened for potential metrics, based on results of previous research (Miller and Hoven, 2007; Gray, 2009) and specific metric responses to nutrient gradients. More than 20 macroinvertebrate metrics were evaluated that represented various structural and functional aspects of the macroinvertebrate community (e.g., percent composition by taxon, species composition, species density, diversity indices, feeding groups) (Gray, 2009)

A nutrient stressor gradient was defined as the concentrations of nutrient constituents of nitrogen and phosphorus (total phosphorus, ammonia-N, nitrate-nitrite N), which were combined into a single variable using principal components analysis (PCA). Increasing values along this stressor gradient indicated increasing levels of nutrients in the ponds.

Macroinvertebrate MMI Development

Based on the metrics screening process (Gray, 2009), a total of five macroinvertebrate metrics correlated with the PCA-based nutrient stressor gradient. These metrics (Table 4-6) were incorporated in the development of the macroinvertebrate MMI. The range of values for each of the five metrics was divided into components with each component assigned a score of 5, 3, or 1 (Table 4-6), based on quartiles of either the absolute value range (total taxa, beetle taxa, and Simpson's Diversity Index) or ranked range (percent *Hyalella* and percent Ephemeroptera) (Gray, 2009).

TABLE 4-6
Scoring basis for the macroinvertebrate metrics selected for inclusion in the macroinvertebrate MMI. A scoring system of 1 (poorest condition), 3 (moderate condition) and 5 (best condition) was used following standard methods for MMI development.

	Scoring System		
Metric	**1**	**3**	**5**
Ephemeroptera (mayflies), percent of total sample number	<5%	5%–10%	>10%
Simpson's Diversity Index	<1.9	1.9–3.4	>3.4
Hyalella, (amphipods), percent of total sample number	<5%	5%–10%	>10%
Total taxa	8 or less	9–11	12 or more
Number of Coleoptera (Beetle) taxa	0	1	2 or more

NOTE:
Source: Gray, 2009

For each site, the scores for all five metrics were summed to provide the MMI score for that site. Values of the B-IBI score ranged from a minimum of 5 (each of the five metrics received a score of 1) to a maximum of 25 (each of the five metrics received a score of 5).

4.3 Results

4.3.1 Water Chemistry

The MMIs of each of the key water quality variables and the overall water chemistry MMI are summarized in Table 4-7. The process used to estimate the MMIs quantifies the relative concentration of various water quality parameters across wetland ponds; thus, the MMIs for each parameter are standardized to the same scale ranging from 0 to 100 (Table 4-7). In all cases, scores were adjusted so that a low MMI score indicates water quality conditions that are potentially stressful to wetland biota, whereas high scores indicate better water quality conditions (see Table 4-5). For example, ponds with overall water chemistry MMI scores of 80 or above could be considered to have better water quality conditions (analogous to a B or above grade used in a school setting) than those with MMI scores in the 40s to 60s range (F to D grade) or in the 70s range (average or C grade for water quality). The overall water chemistry MMI incorporates data on all the key water quality variables including nutrients, chlorophyll-a, DO, and TSS (Table 4-5) and thus serves as a single measure or line of evidence of environmental stress in these impounded wetlands.

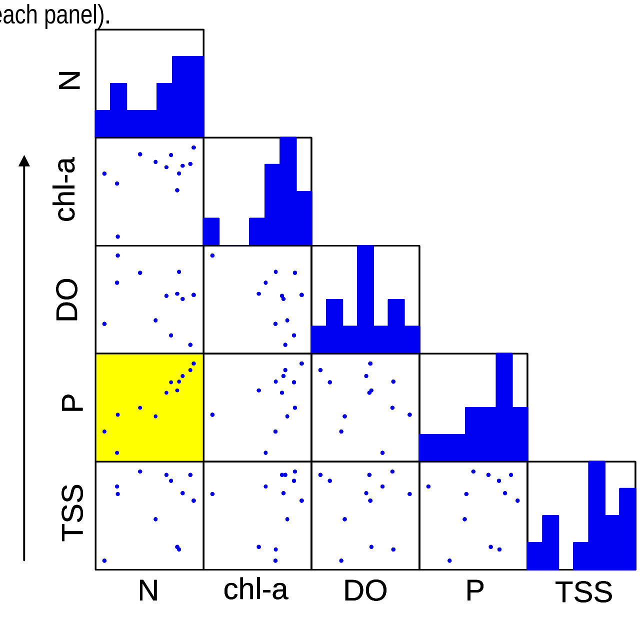
TABLE 4-7
Summary of MMI for Each Water Quality Variable and the Overall Water Chemistry MMI across the Impounded Wetland Sites of Great Salt Lake

Site	N MMI	Chl-a MMI	DO MMI	P MMI	TSS MMI	Water Chemistry MMI
Farmington Wetlands Ambassador W 1	37	65	48	4	91	58
Farmington Wetlands Ambassador 100	78	81	38	67	98	86
Farmington Wetlands Ambassador W 2	91	82	36	85	87	91
Farmington Wetlands Ambassador W 5	97	84	1	91	98	88
Farmington Wetlands South B Pond	99	77	42	82	48	83
Farmington Wetlands West A Pond	86	<1	17	82	72	61
Farmington Wetlands FBWMA Unit 2 Outfall	69	86	19	42	71	68
Farmington Wetlands FBWMA Unit 1 Outfall	87	59	40	70	54	74
IMPC Conservation Easement	70	55	100	91	96	98
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall	81	92	8	78	94	84
GSL Wetlands Public Shooting Ground Pintail Lake Outfall	100	100	39	98	82	100
Bear River NWR Pond 4C Outfall	92	86	55	100	52	92
New State Duck Club Middle Unit	88	75	57	79	53	84
GSL Wetlands New State Duck Club Pond 47	26	75	17	26	46	45
GSL Wetlands New State Duck Club Pond 20	56	93	56	51	100	85
GSL Wetlands New State Duck Club Unit 5-6	37	14	69	44	86	60

NOTES:
Chl-a = chlorophyll-a
DO = dissolved oxygen
FBWMA = Farmington Bay Waterfowl Management Area
GSL = Great Salt Lake
MMI = multimetric index
N = nitrogen
P = phosphorus
TSS = total suspended solids

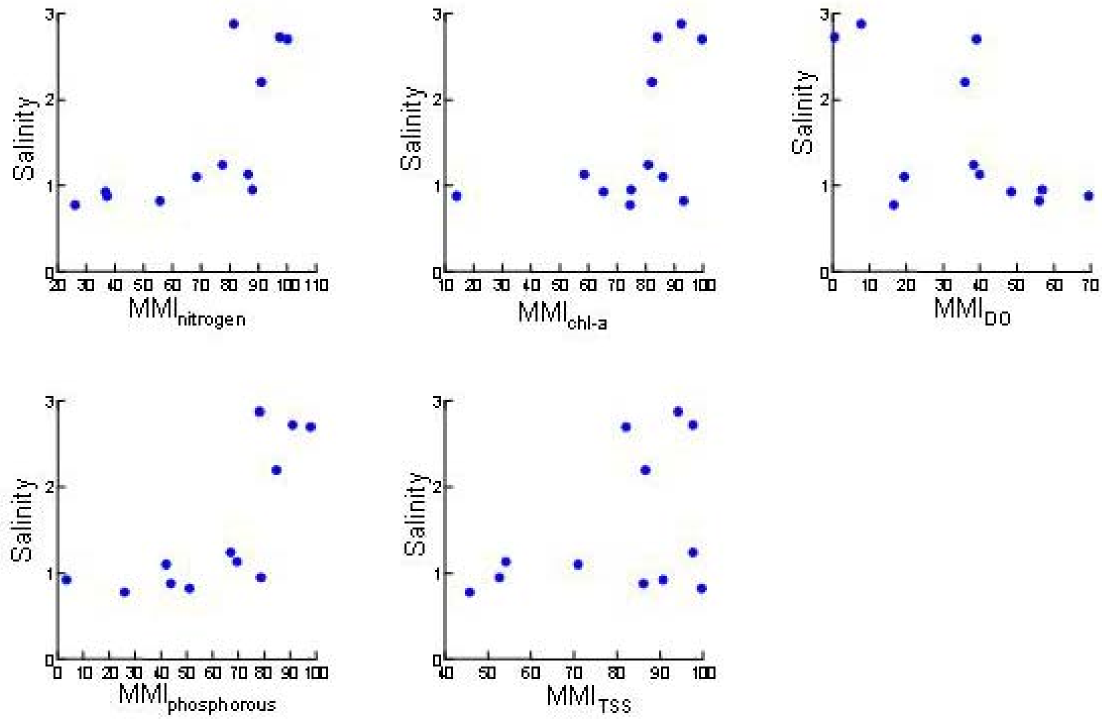
Chemical constituents sometime co-vary with increases in one parameter increasing (or decreasing) in concert with another. In the context of MMI development, strongly correlated variables should generally not be included in the final score to avoid overweighting the effects of a stressor. As a result, scatter plot matrixes of the MMIs for various water quality parameters were evaluated to highlight correlations among water quality parameters (Figure 4-1). None of the chemical MMIs were significantly correlated (ANOVA, $p<0.05$) except the MMIs for nitrogen (N) and phosphorus (P) that were strongly and linearly correlated ($r^2 = 0.84$; $p<0.001$). This was not surprising as previous data suggests that both nitrogen- and phosphorus-nutrient constituents are often present together and contribute to the overall nutrient loads in these impounded wetlands. The general lack of correlations between the majority of the water quality MMIs indicates that these variables are sufficiently independent to warrant their inclusion into the development of an overall water chemistry MMI (Table 4-7). Due to the significant correlation observed between the nitrogen and phosphorus MMIs, subsequent updates to the water chemistry MMI may use a single nutrient MMI in which nitrogen and phosphorus are combined, potentially as nitrogen-to-phosphorus ratios. For the purposes of this report, however, nitrogen and phosphorus MMIs are included along with other water quality MMIs (DO, TSS, and chlorophyll-a) in the development of the overall water chemistry MMI.

FIGURE 4-1
Scatter Plots of water quality MMIs depicting the correlation of the following chemical parameter MMIs: N = Nitrogen, chl-a = Chlorophyll-a, DO = dissolved oxygen, P = phosphorous, and TSS = total suspended solids. None of the chemical parameters evaluated for inclusion in the chemistry MMI were significantly correlated with each other with the exception of Nitrogen (N) and Phosphorous (P) (yellow highlight, $p<0.001$, $r^2 = 0.001$). Bar graphs depict data distribution for the respective MMI parameter (x- or y-axis). The arrow indicates the direction of increase in values for each parameter (e.g., parameter values increase in concentration from the bottom to the top of the panel (y-axis) and from left to right (x-axis) in each panel).



Although sites were selected to minimize the effects of salinity, there was significant variation in salinity concentrations among sites. As a result, salinity remains a potential covariate that that could alter the interpretation of chemical or biological differences observed among ponds. None of the chemical MMIs parameters showed a statistically significant linear relationship with average (expressed as 50^{th} percentile) salinity concentrations (ANOVA, $p > 0.05$). However, a more careful examination of the relationships suggests potential threshold relationships between salinity and the nutrient (nitrogen and phosphorus) MMIs (Figure 4-2). These relationships, however, likely do not depict cause and effect between these parameters but are rather an artifact of the higher degree of variation in salinity in ponds with low nitrogen and phosphorus concentrations (i.e., $MMI_{nitrogen}$ or $MMI_{phosphorous}$ >80), although it is noted that none of the ponds with relatively high nutrient concentrations had relatively high salinity concentrations.

FIGURE 4-2
Scatter plots showing median salinity concentrations (mg/l) as a function of the metrics generated for each of the chemical parameters.



4.3.2 Vegetation

Submerged Aquatic Vegetation

The scores for each of the SAV metrics, the overall SAV MMI, and the overall water chemistry MMI are summarized in Table 4-8. These scores are all standardized to a scale of 0 to 100 to facilitate exploratory comparisons between the SAV metrics, the overall SAV MMIs, and water quality MMIs. Low scores indicate poor SAV conditions as defined by the SAV metrics (maximum SAV, fall SAV, and percent change in SAV), whereas higher scores indicate better SAV conditions. The score of the three SAV metrics for each impounded wetland site were averaged to yield an overall SAV MMI (Table 4-8). Based on the SAV MMI, ponds with overall SAV MMI scores of 80 are rated as having above average SAV conditions (analogous to a B or above grade) than those with MMI scores in the 40s to 60s range (F to D grade) or in the 70s range (average or C grade for SAV condition).

As part of the exploratory data analysis, scatter plots of the SAV metrics were evaluated to highlight any potential correlations between these metrics (Figure 4-3). Only the fall SAV and percent change SAV metrics were significantly correlated ($r^2 = 0.69$; $p<0.001$). Correlations between the maximum SAV and percent change SAV, and maximum SAV and fall SAV, metrics were not significantly correlated ($p>0.05$). This overall lack of correlation among SAV metrics indicates that these variables are sufficiently independent to warrant consideration of their inclusion into the development of the overall SAV MMI (Table 4-8). Both fall SAV and percent change SAV metrics were included in the overall SAV MMI because some sites with low fall SAV appear to be poorly correlated with the percent change SAV metric; that is, these sites still show a large decline in SAV in spite of lower fall SAV values (Figure 4-3). In addition, both of these metric describe different ecological processes, which may prove useful as these metrics are more directly tied to the relative condition of aquatic life designated uses.

TABLE 4-8
SAV MMI Scores and the Overall MMI for SAV and Water Chemistry for Impounded Wetland Sites of Great Salt Lake

Site	Maximum SAV Metric	Fall SAV Metric	Percent Change SAV Metric	Overall SAV MMI	Overall Chemistry MMI
Farmington Wetlands Ambassador W 1	100	20	20	47	58
Farmington Wetlands Ambassador 100	20	60	100	60	86
Farmington Wetlands Ambassador W 2	100	100	60	87	91
Farmington Wetlands Ambassador W 5	100	100	100	100	88
Farmington Wetlands South B Pond	100	100	100	100	83
Farmington Wetlands West A Pond	60	20	20	33	61
Farmington Wetlands FBWMA Unit 2 Outfall	100	100	100	100	68
Farmington Wetlands FBWMA Unit 1 Outfall	60	100	100	87	74
IMPC Conservation Easement	20	20	60	33	98
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall	100	100	100	100	84
GSL Wetlands Public Shooting Ground Pintail Lake Outfall	100	100	100	100	100
Bear River NWR Pond 4C Outfall	100	100	100	100	92
New State Duck Club Middle Unit	100	100	100	100	84
GSL Wetlands New State Duck Club Pond 47	60	20	20	33	45
GSL Wetlands New State Duck Club Pond 20	100	100	100	100	85
GSL Wetlands New State Duck Club Unit 5-6	100	60	100	87	60

NOTES:
FBWMA = Farmington Bay Waterfowl Management Area
GSL = Great Salt Lake
MMI = multimetric index
SAV = submerged aquatic vegetation

Scatter plots of salinity (expressed as 50^{th} percentile of salinity) and SAV metrics were evaluated to explore the effects of salinity as a covariate of SAV metrics (Figure 4-4). None of the SAV metrics were significantly correlated with salinity (Figure 4-4).

FIGURE 4-3
Scatter Plots depicting relationships among SAV metrics used to generate the final SAV MMI. Only the Fall SAV and Percent Change SAV metrics were significantly correlated. Red points are shown as outliers, which indicate the potential importance of including both Fall SAV and Percent Change SAV in the overall SAV MMI.

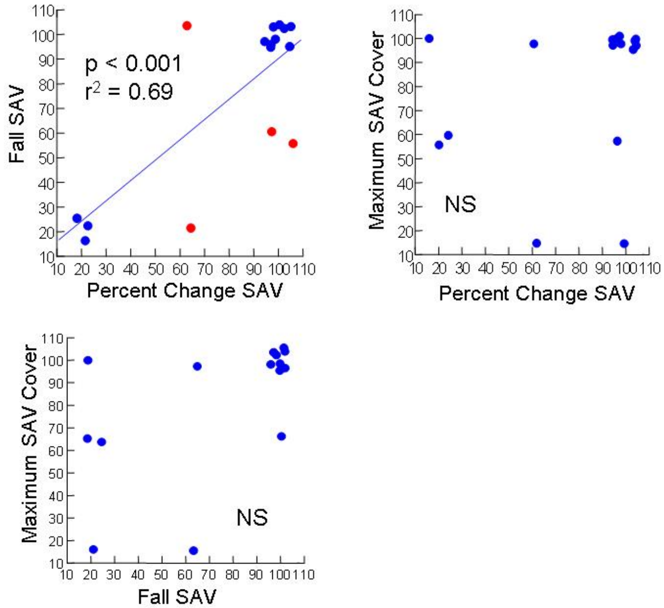
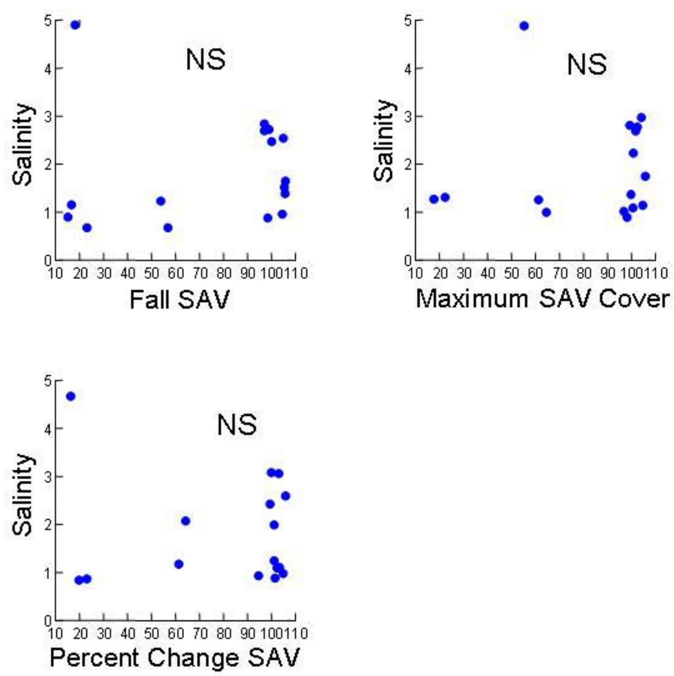
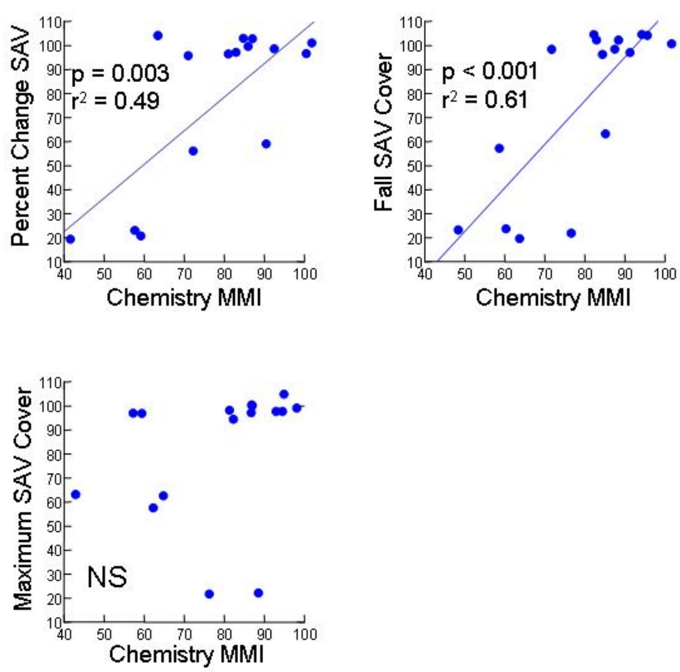


FIGURE 4-4
Scatter Plots of SAV Metrics and Salinity



Scatter plots of the SAV metrics and the overall water chemistry MMI (a measure of the environmental stress for these wetlands) were evaluated (Figure 4-5) to assess whether these metrics respond appropriately to environmental stress in a manner that contributes useful information to the development of the overall SAV MMI. Both fall SAV and percent change SAV metrics responded fairly well to the water chemistry MMI (Figure 4-5); that is, ponds with relatively better water quality (higher chemistry MMI scores) showed less tendency for the SAV to decrease before the arrival of the waterfowl and have greater abundance in the fall (September). However, maximum SAV scores were not linearly related to the water chemistry MMI, but the scatter plot did indicate that the maximum SAV abundance can be low at some sites despite relatively good water quality (Figure 4-5).

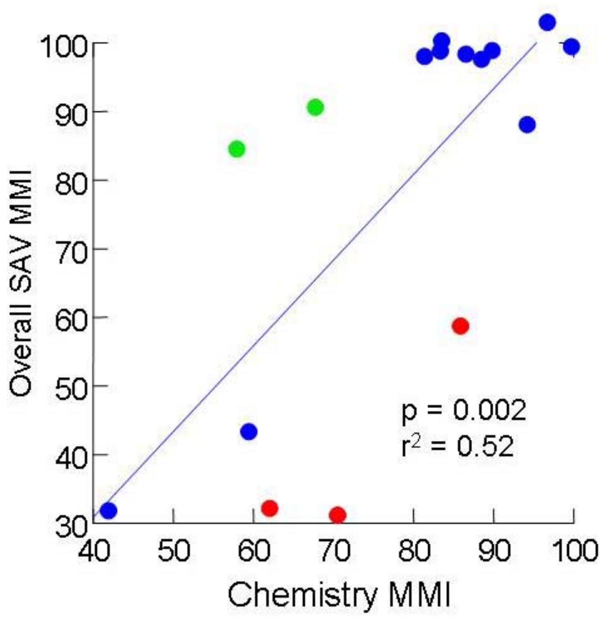
FIGURE 4-5
Scatter Plots of SAV Metrics and the Water Chemistry MMI



Because each of the SAV metrics contributes useful information in relation to the water chemistry MMI, all three SAV metrics were incorporated into the overall SAV MMI (Table 4-8).

The overall SAV MMI is shown as a function of the water chemistry MMI in Figure 4-6. Water chemistry explains approximately 52 percent of the variance in SAV condition. The SAV response indicates that under relatively better water quality (higher water chemistry MMI scores), SAV conditions generally improve in these impounded wetlands. Sources of the remainder of the variance in the SAV MMI (48 percent) could include other factors such as hydrology, inter-pond habitat differences, climate, and sampling error. Major outliers are equally likely to over or under predict SAV conditions from chemical composition, although exploring these outliers may help clarify the relationship that chemistry plays in concert with other wetland characteristics to influence SAV. Subsequent efforts to standardize sampling methods and account for other variables (hydrology management, for example) should help to refine the SAV MMI. These results, however, indicate that SAV metrics and the SAV MMI provide a useful line of evidence in assessing the overall biotic condition of the Great Salt Lake impounded wetlands.

FIGURE 4-6
The combined SAV MMI as a function of the Water chemistry MMI. Green points indicate sites with appreciably better SAV scores than expected from chemistry, whereas red points indicate sites with appreciably lower SAV scores than indicated by chemistry. A plotting feature, random jitter, was used to reveal all the points among sites with both high water chemistry and SAV scores.



Algal and Duckweed Surface Mat Metrics

The scores for the algal mat and duckweed mat metrics, the overall surface mat MMI, and the water chemistry MMI are summarized in Table 4-9. Due to the scoring scheme used to generate these MMIs, each site scored a 20, 60, or 100 for the algae and duckweed mat metrics. All ponds with the most extensive cover of either algae or duckweed ($MMI_{mat\ or\ algae}$ = 20) showed at least some tendency to have both types of mats ($MMI_{mat\ or\ algae} \leq 60$). Similarly, ponds with essentially no tendency to form mats for either algae or duckweed ($MMI_{mat\ or\ algae}$ = 100) never had extensive mat cover ($MMI_{mat\ or\ algae}$ = 20). At least during the year these data were collected, 75% of the ponds indicated little tendency to form surface mats (Mat MMI ≥ 80).

There was no significant linear relationship between the algal mat and duckweed mat metrics (Figure 4-7). This lack of correlation between the metrics indicates that these indicators quantify independent wetland conditions and are sufficiently different to include in the overall surface mat MMI (Table 4-9). However, all of these relationships are somewhat biased by the skewed distribution of mats scores (i.e., most sites did not have mat problems).

TABLE 4-9
Surface Mat MMI Scores for Algae and Duckweed Mats and the Overall MMI for Surface Mats and Water Chemistry for Impounded Wetland Sites of Great Salt Lake

Site	Algal Mat Metric	Duckweed Mat Metric	Overall Surface Mat MMI	Water Chemistry MMI
Farmington Wetlands Ambassador W 1	60	20	40	58
Farmington Wetlands Ambassador 100	100	100	100	86
Farmington Wetlands Ambassador W 2	100	100	100	91
Farmington Wetlands Ambassador W 5	60	100	80	88
Farmington Wetlands South B Pond	100	100	100	83
Farmington Wetlands West A Pond	100	100	100	61
Farmington Wetlands FBWMA Unit 2 Outfall	100	100	100	68
Farmington Wetlands FBWMA Unit 1 Outfall	20	60	40	74
IMPC Conservation Easement	60	100	80	98
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall	60	100	80	84
GSL Wetlands Public Shooting Ground Pintail Lake Outfall	100	100	100	100
Bear River NWR Pond 4C Outfall	100	100	100	92
New State Duck Club Middle Unit	60	100	80	84
GSL Wetlands New State Duck Club Pond 47	60	20	40	45
GSL Wetlands New State Duck Club Pond 20	60	100	80	85
GSL Wetlands New State Duck Club Unit 5-6	60	60	60	60

NOTES:
FBWMA = Farmington Bay Waterfowl Management Area
GSL = Great Salt Lake
MMI = multimetric index

As with other indicators the effect of salinity on mat metrics was evaluated as a potentially confounding relationship. Neither the algae nor the duckweed mat metrics were significantly correlated with salinity (Figure 4-8), which suggests that at least for these ponds, salinity did not affect the tendency of ponds to form surface mats of either algae or duckweed.

FIGURE 4-7
Scatter Plot of Algal Mat and Duckweed Mat Metric Scores
Random jitter function is set so that all data points are visible.

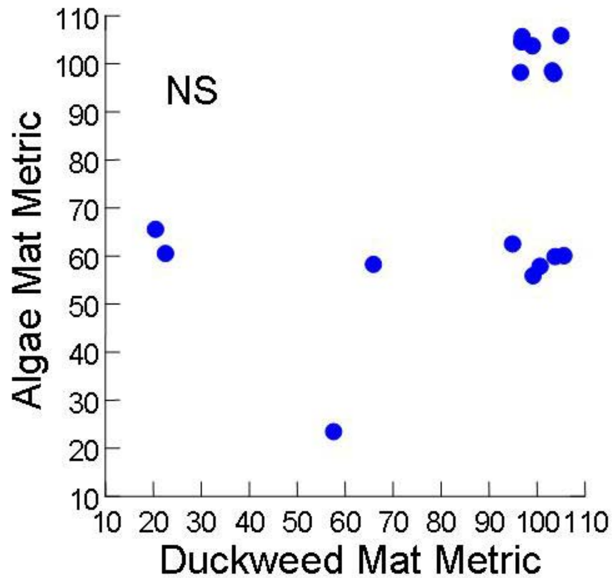
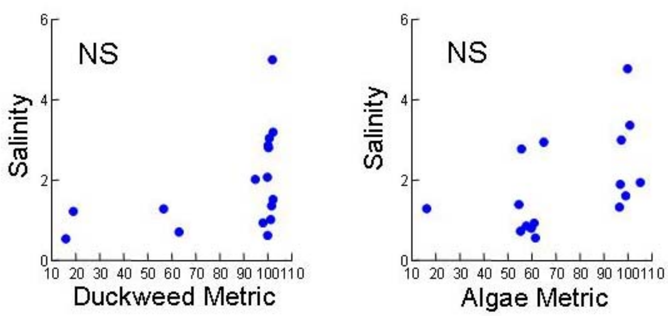


FIGURE 4-8
Scatter Plots showing Non-significant (NS) relationships between Algal Mat or Duckweed Mat Metrics and Salinity.
A plotting function, random jitter, was used so that all data points are visible.



Scatter plots of the surface mat metrics and the overall water chemistry MMI (a measure of the environmental stress for these wetlands) were also evaluated (Figure 4-9) to assess whether these metrics respond appropriately to environmental stress in a manner that contributes useful information to the development of the overall surface mat MMI. Only the duckweed mat metric showed a significant relationship ($r^2 = 0.59$, $p<0.001$) with water chemistry MMI (Figure 4-9); that is, ponds with relatively better water quality (higher chemistry MMI scores) showed less tendency for development of significant duckweed mat cover. Algal mat metric scores were not linearly related to the water chemistry MMI but were also included in the development of the overall surface mat MMI due to the potential effects on SAV and other organisms from shading or physically crushing the SAV following collapse (Hoven *personal comm*.).

The overall surface mat MMI is shown as a function of the water chemistry MMI (Figure 4-10). Water chemistry explains approximately 58 percent of the variance in the surface mat MMI and indicates that under relatively better water quality (higher water chemistry MMI scores), surface mat cover conditions improve (i.e., surface mat cover declines) in these impounded wetlands. Sources of the remainder of the variance in the SAV MMI (42 percent) could likely include hydrological and climatological conditions in addition to habitat and sampling error. Subsequent efforts to standardize sampling methods and account for other variables (hydrology management, for example) should help to refine the surface mat MMI. These results, however, indicate that surface mat metrics and the surface mat MMI provide another useful line of evidence in assessing the overall biotic condition of the Great Salt Lake impounded wetlands.

FIGURE 4-9
Scatter Plots of Duckweed Mat, Algal Mat Metrics, and Overall Water Chemistry MMI

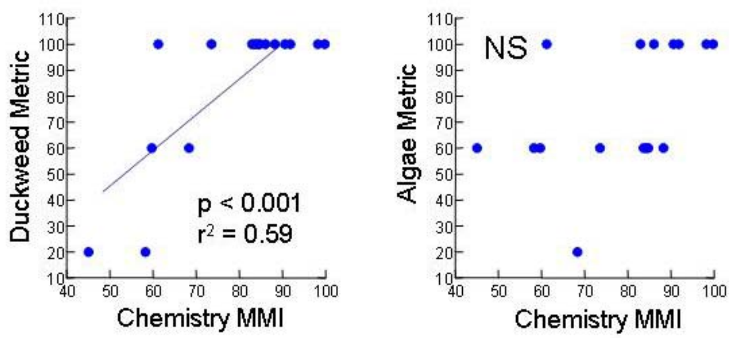
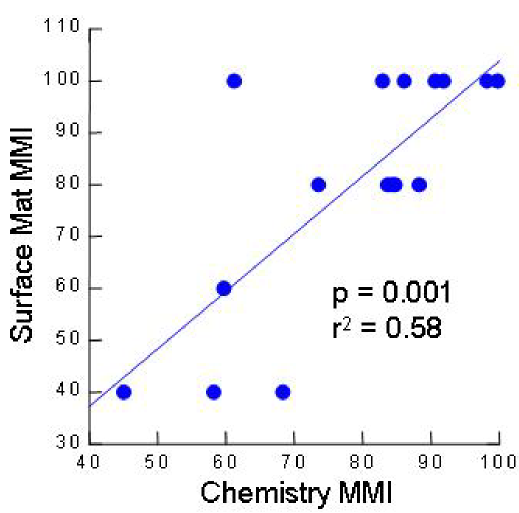


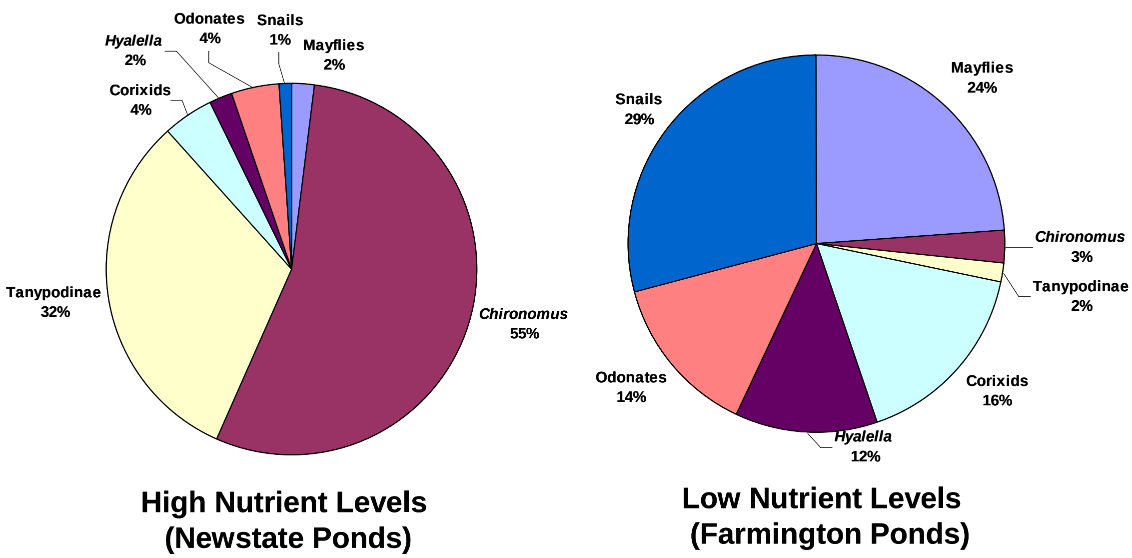
FIGURE 4-10
The overall surface mat MMI, calculated as the average of duckweed and algae scores, as a function of the water chemistry MMI.



4.3.3 Macroinvertebrates

The macroinvertebrate assemblage in ponds with relatively high nutrient levels was dominated largely by pollution-tolerant members of the chironomidae family. *Chironomus* and members of a subfamily of chironomids, tanypodidae, represented 87 percent of the macroinvertebrate community in nutrient-enriched ponds (Figure 4-11). Other invertebrate taxa such as snails, mayflies, odonates, corixids, and amphipods (*Hyalella)* were represented only minimally in the macroinvertebrate community in these ponds. In contrast, low-nutrient ponds had a more structurally and functionally balanced representation of various invertebrate taxa, with a significantly higher proportion of pollution-sensitive (nutrient-sensitive) taxa such as mayflies (Figure 4-11).

FIGURE 4-11
Community Composition of Macroinvertebrates in Representative Ponds with Relatively High and Low Nutrient Levels

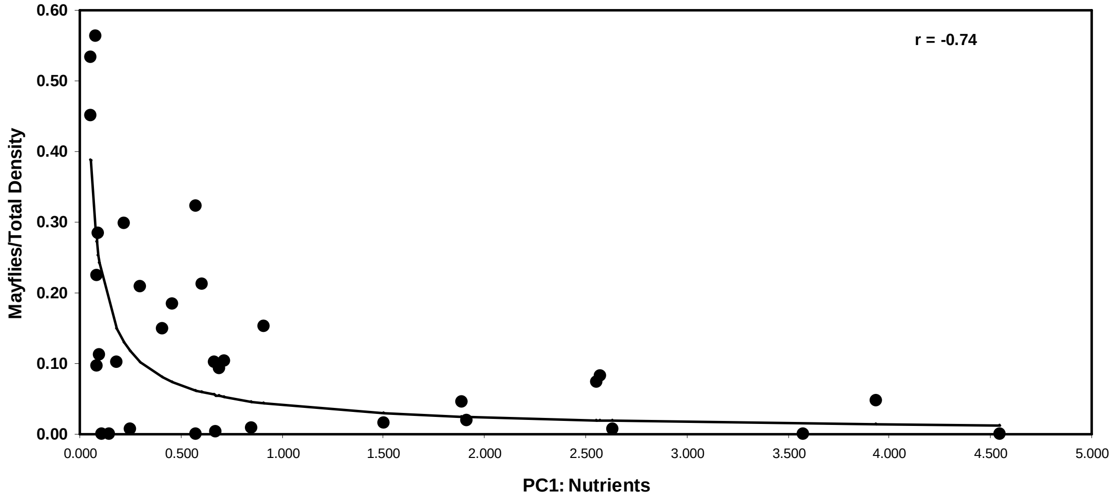


Source: Gray, 2009

Metrics and Nutrients Stressor Gradient

Mayflies, primarily *Callibaetis* and *Caenis,* showed a strong negative correlation along the nutrient stressor gradient (Figure 4-12), especially in relation to nitrogen (Gray, 2009).

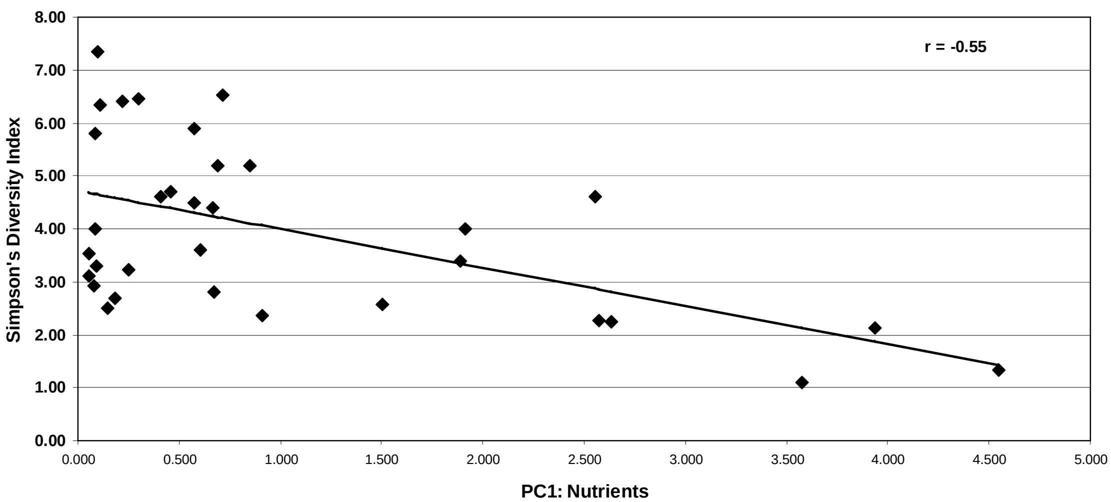
FIGURE 4-12
Mayflies (Ephemeroptera) Metric in Relation to the Nutrient Stressor Gradient



Source: Gray, 2009

Simpson's Diversity Index is a "dominance" index that reflects shifts in community composition (changes in proportions of taxa) and showed a negative correlation along the nutrient stressor gradient (Gray, 2009). As such, benthic macroinvertebrate species diversity generally declines with increasing nutrients (Figure 4-13). However, there is considerable variation in species diversity in ponds with low nutrient levels, suggesting that other factors besides nutrients may also be involved in driving this response.

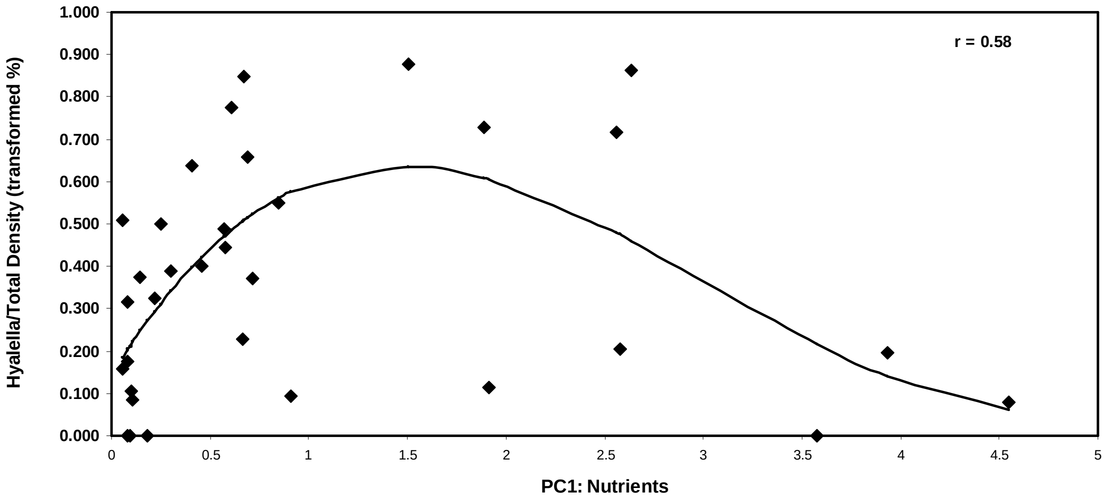
FIGURE 4-13
Simpson's Diversity Index Metric in Relation to the Nutrient Stressor Gradient



Source: Gray, 2009

The amphipod, *Hyalella*, is often abundant in the impounded wetlands of Great Salt Lake (Miller and Hoven, 2007; Gray, 2007; Gray, 2009) and is an important food item for ducks and other waterfowl. The abundance of *Hyalella* in these ponds is thus an important metric tied directly to beneficial uses. *Hyalella* abundance increases with increasing nutrients up to a certain point and then declines (Figure 4-14).

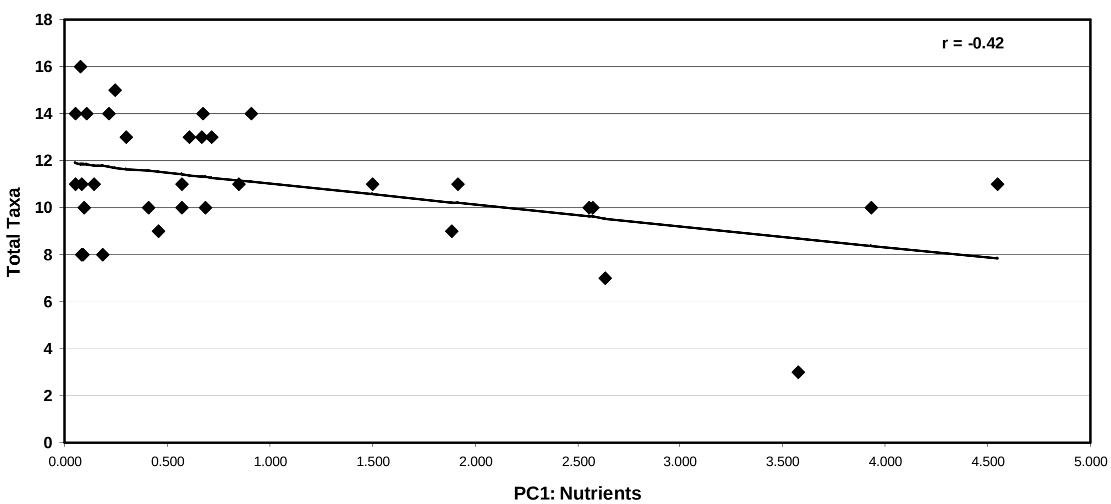
FIGURE 4-14
Hyalella Relative Abundance in Relation to the Nutrient Stressor Gradient



Source: Gray, 2009

The total number of taxa was negatively correlated with nutrients (Figure 4-15). Aquatic beetles accounted for one-fourth of all macroinvertebrate taxa collected, although their densities were proportionally small in relation to those of other macroinvertebrates (Gray, 2009).

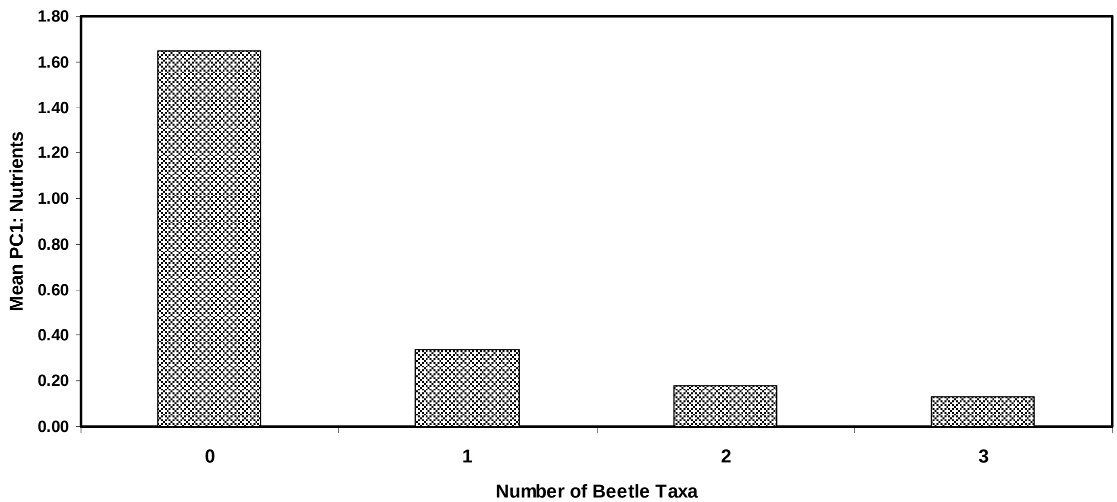
FIGURE 4-15
Total Taxa in Relation to the Nutrient Stressor Gradient



Source: Gray, 2009

Aquatic beetles are an important functional group in wetlands, and as predators, are considered an important metric in bioassessment studies. The diversity of aquatic beetles is high in wetlands of Great Salt Lake (Gray, 2009), and their presence is tied directly to beneficial uses of these wetlands as they are an important component of the shorebird diet (Miller and Hoven, 2007). The occurrence and number of aquatic beetles appear to be related to nutrient levels. Gray (2009) reported that 80 percent of the adult beetles and 96 percent of all beetle larvae were collected in ponds with low nutrients at the current sampling sites (reported in this study) since 2004. More recent data (2007) also supports this conclusion; ponds with low nutrient levels had 1-3 beetle taxa, but aquatic beetles were absent in ponds with high nutrients (Figure 4-16).

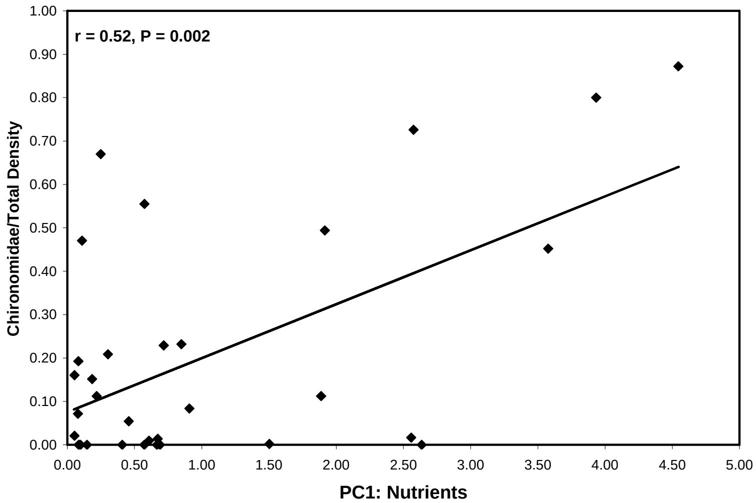
FIGURE 4-16
Number of Aquatic Beetle Taxa in Relation to the Nutrient Stressor Gradient



Source: Gray, 2009

The abundance of midge larvae (chironomidae) is another important metric often considered in bioassessment studies as many members of this family of macroinvertebrates are largely tolerant of pollution, including high nutrient levels. Furthermore, midges are tied to beneficial uses of these wetlands as they are an important component (up to one-third) of the shore-bird diet. Previous studies (Miller and Hoven, 2007; Gray, 2007) on the Great Salt Lake wetlands identified midges as an important metric to consider in bioassessment studies. Consistent with these previous studies, chironomidae densities were positively correlated to nutrients (Figure 4-17).

FIGURE 4-17
Chironomidae Total Density in Relation to the Nutrient Stressor Gradient



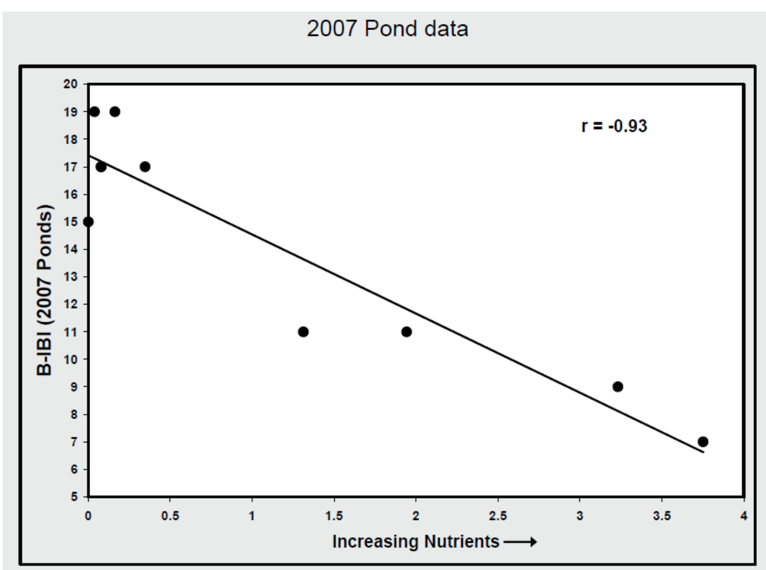
Source: Gray, 2009

This metric, however, was not included in the development of the B-IBI as it was significantly correlated with other metrics such as total taxa, diversity indices, *Hyalella*, and mayflies, and thus would not add any new information to the B-IBI (Gray, 2009).

Macroinvertebrate MMI (Benthic Index of Biotic Integrity B-IBI)

B-IBI scores were regressed against the individual nutrient concentrations and the nutrient stressor gradient (Gray, 2009). The graph of 2007 B-IBI scores against the nutrient gradient is given in Figure 4-18 and indicates a significant relationship. Correlations between the individual nutrients and B-IBI scores also were significant, particularly for nitrogen (for ammonium: $r = -0.71$, $P = 0.02$; for nitrites + nitrates: $r = -0.88$, $P = 0.001$; and for phosphorus: $r = -0.66$, $P = 0.04$; all d.f. = 8).

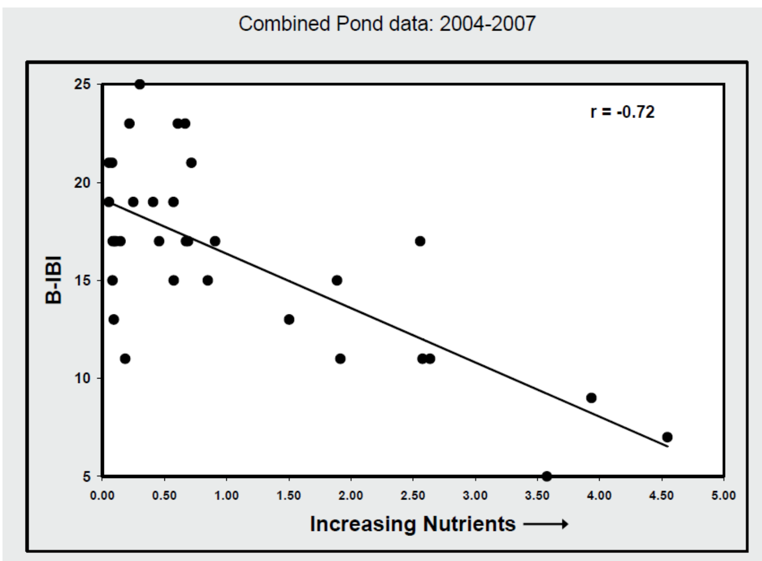
FIGURE 4-18
Benthic Macroinvertebrate MMI (B-IBI) in Relation to the Nutrient Stressor Gradient for 2007. Note that not all sites were sampled in each year, so the plot does not include all sites.



Source: Gray, 2009

A further test of the B-IBI and nutrients relationship was conducted using benthic and nutrient data from ponds sampled in 2006. Sites included 9 of the 10 ponds sampled in 2007; in addition, three Ambassador ponds were included. A nutrient PC1 score was calculated for each site based on nutrient concentrations on or near the time of benthic sampling. In this case, the PC1 variable accounted for 75 percent of variance in the water chemistry data. The graph of 2006 MMI scores against the 2006 nutrient PC1 scores is shown in Figure 4-19. Despite the paucity of high-nutrient sites and the qualitative benthic sampling, the relationship was still significant.

FIGURE 4-19
Benthic Macroinvertebrate MMI (B-IBI) in Relation to the Nutrient Stressor Gradient for 2004–2007. Note that not all sites were sampled in each year, so the plot does not include all sites.



Source: Gray, 200

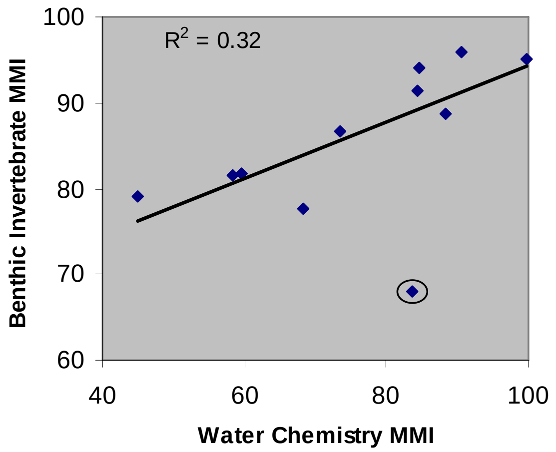
Standardized Benthic Macroinvertebrate MMI

Based on the analyses previously provided, the benthic macroinvertebrate MMI offers another line of evidence that—along with the water chemistry MMI, SAV MMI, and surface mat MMI—can potentially be useful for evaluating the condition of impounded wetlands of Great Salt Lake. However, in order to facilitate the comparison of the benthic macroinvertebrate MMI with the other lines of evidence (chemistry, SAV, and surface mat), the benthic macroinvertebrate MMI scores need to be estimated on similar relative scales (0 to 100) that were used for the chemistry and vegetation MMIs.

The scatter plot in Figure 4-22 shows the rescaled benthic macroinvertebrate MMI in relation to the water chemistry MMI (Figure 4-22) and indicates that under relatively better water quality (higher water chemistry MMI scores), wetland conditions as represented by the macroinvertebrate metrics (Table 4-10) are generally good. One wetland site, the New State

Duck Club Middle Unit, is a significant outlier in this relationship, contributing to disproportional variation in the relationship, possibly due to a relatively low overall abundance observed at this site. Without this outlier, water chemistry explains 71 percent of the variation in the benthic invertebrate MMI.

FIGURE 4-22
Scatter Plot of the Benthic Macroinvertebrate MMI in Relation to the Water Chemistry MMI
The circled data point is an outlier, representing the New State Duck Club Middle Unit Site.



4.4 Summary and Discussion

4.4.1 Multiple Lines of Evidence from MMIs

Together, the MMIs for water chemistry, SAV, surface mat, and benthic macroinvertebrates offer multiple lines of evidence that relate to the physical, chemical (water chemistry), and biological condition of the impounded wetlands of Great Salt Lake. Furthermore, because the metrics that were used to develop these MMIs can be linked to the beneficial uses of these wetlands, these MMIs provide useful overall measures that ultimately will integrate wetland condition with their aquatic life beneficial uses. Once the MMI is refined, the scores of all indicators can be averaged to generate a single overall score card that represents the physical, chemical, and biological condition of these wetland sites (e.g., Table 4-10). Based on the average MMI scores calculated from this preliminary assessment framework, 4 out of a total of 16 impounded wetland sites (25 percent) are in relatively poor condition whereas 2 sites (12.5 percent) are in average condition. The majority of the wetland sites under consideration (10 sites or 62.5 percent) are in relatively good condition as defined by the MMI metrics.

In addition to measures of overall condition, the constituent metrics can be evaluated to diagnose potential reasons that explain differences in wetland condition. For instance, if ponds have consistently poor water chemistry and good biological condition, these sites could be evaluated for differences in management practices that could explain these unanticipated results.

The multiple line of evidence approach with MMIs that quantify condition based on multiple indicators provides a very useful framework on which future bioassessment studies of wetlands of the Great Salt Lake region can be based. This framework allows us to identify the relative condition of wetlands and provides a solid ecological basis for identifying wetlands in good condition and bad, both for individual metrics and for overall wetland condition.

4.4.2 Wetland Condition Assessment based on the MMI Approach and pH/DO Standards

The assessment framework based on the MMI approach presented in this report can be compared with the current wetland assessment method used for Great Salt Lake wetlands that is based on numeric criteria for pH and DO (Table 4-11). Based on the numeric criteria for DO, from 62.5 percent to 100 percent of the impounded wetland sites under consideration would be judged to be in relatively poor condition due to exceedance of these criteria. Based on the numeric criteria for pH, all except one site would be declared to be in poor condition. Yet, the MMI scores indicate that a majority of these wetland sites are in relatively good ecological condition (based on water chemistry, SAV, algal mat, and macroinvertebrate metrics) with only four (25 percent of total sites) in relatively poor condition.

Because of the limitations of DO and pH (discussed in Section 2.0), which vary diurnally and exceed numeric criteria even in wetlands with good water quality (e.g., low levels of nutrients), standards based on DO and pH are difficult to place in context when relating to the ecological condition of impounded wetlands and provide little information with regard to beneficial use support.

An assessment approach that uses MMIs provides a stronger ecological basis for highlighting differences among wetlands and offers insights into potential solutions to improve their condition. Most importantly, despite the sampling inconsistencies and our limited understanding of some causal mechanisms affecting wetland processes, function, and condition, an examination of the data in the context of overall beneficial use support is already providing valuable insights that could lead to the establishment of management practices to protect these beneficial uses.

TABLE 4-10
Summary of Multiple Lines of Evidence Developed as MMI for Water Chemistry, Vegetation (SAV and Surface Mats), and Benthic Macroinvertebrates for the Impounded Wetlands of Great Salt Lake

	Lines of Evidence				
Site	**Water Chemistry MMI**	**SAV MMI**	**Surface Mat MMI**	**Benthic Macro-invert. MMI**	**Average of All MMIs**
Farmington Wetlands Ambassador W 1	58	47	40	82	57
Farmington Wetlands Ambassador 100	86	60	100	100	87
Farmington Wetlands Ambassador W 2	91	87	100	96	93
Farmington Wetlands Ambassador W 5	88	100	80	89	89
Farmington Wetlands South B Pond	83	100	100	.	94
Farmington Wetlands West A Pond	61	33	100	.	65
IMPC Conservation Easement	68	100	100	.	89
Farmington Wetlands FBWMA Unit 2 Outfall	74	87	40	78	69
Farmington Wetlands FBWMA Unit 1 Outfall	98	33	80	87	74
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall	84	100	80	91	89
GSL Wetlands Public Shooting Ground Pintail Lake Outfall	100	100	100	95	99
Bear River NWR Pond 4C Outfall	92	100	100	.	97
New State Duck Club Middle Unit	84	100	80	68	83
GSL Wetlands New State Duck Club Pond 47	45	33	40	79	49
GSL Wetlands New State Duck Club Pond 20	85	100	80	94	90
GSL Wetlands New State Duck Club Unit 5-6	60	87	60	82	72

NOTES:
FBWMA = Farmington Bay Waterfowl Management Area
GSL = Great Salt Lake
MMI = multimetric index
SAV = submerged aquatic vegetation
COLOR CODES (On a scale of 0–100): Blue indicates wetland sites with relatively good MMI scores, indicating good condition (80 and above); yellow indicates wetland sites with average MMI scores, indicating average condition (70–79 and above); red indicated wetlands sites with poor MMI scores, indicating poor condition (<70).

TABLE 4-11
Comparison of Impounded Wetland Conditions Based on Existing DO and pH Standards and as Determined by the Average MMI Scores Derived from Multiple Lines of Evidence (Water Chemistry, SAV, Surface Mat, and Benthic Macroinvertebrate MMIs)

Site	DO 10th Percentile	DO Minimum	DO Saturation 90th Percentile	pH 90th Percentile	Overall Average of MMIs
Farmington Wetlands Ambassador W 1	5.7	3.4	177.4	9.2	57
Farmington Wetlands Ambassador 100	5.7	2.7	149.8	9.7	87
Farmington Wetlands Ambassador W 2	4.7	2.5	184.8	9.9	93
Farmington Wetlands Ambassador W 5	3.7	0.0	151.3	10.0	89
Farmington Wetlands South B Pond	4.6	3.0	206.1	10.2	94
Farmington Wetlands West A Pond	2.4	1.2	147.7	9.5	65
IMPC Conservation Easement	7.2	7.1	185.3	9.8	89
Farmington Wetlands FBWMA Unit 2 Outfall	4.2	1.4	168.0	9.8	69
Farmington Wetlands FBWMA Unit 1 Outfall	3.1	2.8	159.7	9.9	74
GSL Wetlands Public Shooting Ground Widgeon Lake 01 Outfall	4.5	0.6	195.2	9.8	89
GSL Wetlands Public Shooting Ground Pintail Lake Outfall	5.4	2.8	150.7	9.5	99
Bear River NWR Pond 4C Outfall	3.9	3.9	128.7	10.0	97
New State Duck Club Middle Unit	4.3	4.0	184.7	10.1	83
GSL Wetlands New State Duck Club Pond 47	1.5	1.2	128.5	8.7	49
GSL Wetlands New State Duck Club Pond 20	4.8	3.9	214.2	9.9	90
GSL Wetlands New State Duck Club Unit 5-6	6.1	4.9	240.1	9.8	72

NOTES:
DO = dissolved oxygen
FBWMA = Farmington Bay Waterfowl Management Area
GSL = Great Salt Lake
MMI = multimetric index
SAV = submerged aquatic vegetation
COLOR CODES: Blue indicates wetland sites with relatively good condition; Yellow indicates wetland sites in average condition; Red indicated wetlands sites in poor condition.
MMI scores for each line of evidence are in Table 4-10

4.4.3 Data Gaps and Limitations

The assessment framework based on MMIs is flexible and can be built on to accommodate additional information as we move forward with science to improve our understanding of the linkages between the metrics and beneficial uses. For example, we need to improve our understanding of the effects of surface mats on processes affecting SAV and the linkages and dynamics between the presence of duckweed or algae mats and wetland biota. We also need to understand the role that SAV plays in the overall food web in these impounded wetlands, particularly with respect to habitat and food for biota beyond waterfowl. In addition, invertebrate collection methods need to be standardized and seasonal differences in invertebrate metrics (summer, fall) need to be reconciled, especially with respect to the effects of spraying for vector control that can affect some invertebrate metrics.

The MMI-based assessment approach can further be strengthened by the incorporation of additional lines of evidence that reflect various components of the wetland ecosystem. For example, samples to obtain information about diatoms have already been collected and could be included in future assessments as an additional line of evidence. Future assessment efforts might also include emergent vegetation and amphibians or the addition of other non-nutrient related metrics into the chemistry MMI.

Some limitations also exist in the data used to develop the MMIs. For example, water chemistry and macroinvertebrate data for development of the wetland metrics were collected over multiple years, while the SAV and algal/duckweed mat data that were used to develop the MMI assessment framework were gathered in a single year effort (Table 4-1). Early water chemistry data used in the initial research efforts were somewhat inconsistent for this MMI effort, mainly because these data were not explicitly collected for this assessment framework, which is still in the process of being developed and refined. This earlier water quality data has unequal sample sizes, for example, and not all parameters were collected at all locations. These are not meant to be criticisms of the sampling protocol but rather are highlighted as potential artifacts that could be introduced into the dataset as a result of adopting and using existing data for the development of the preliminary MMI-based assessment framework. Currently, water quality data is collected monthly by UDWQ at each pond in an effort to standardize sampling methods specifically for the MMI-based assessment framework.

As is typically the case with the collection of biological data, intra- and inter-annual effects specific to variations in climatic conditions (e.g., dry versus wet years, extremes in temperatures, precipitation) and management practices (e.g., management of hydrology through differential draining and filling of ponds, spraying for vector control) can confound data analysis and interpretation in such multiyear datasets and will need to be considered as the MMIs are further refined. For instance, previously collected SAV and metaphyton data suggest that a single year of data could lead to over- or under-estimation of the condition of wetland ponds. Metrics for the IMPC Conservation Easement seem lower than expected from previously collected data, whereas metrics from the Farmington Wetlands FBWMA Unit 1 Outfall pond seem too high when compared to previous collection efforts. The evaluation of multiple years of data will be useful in identifying sites that are consistently in good or poor condition, while those sites that exhibit year-to-year difference may highlight effects of management practices.

Previous research efforts on the Great Salt Lake wetlands (summarized in Section 3.0, this report) identified some potential confounding factors that should be considered when evaluating the results of these MMIs. These are as follows:

- Herbivorous carp are present in some, if not all, of the impounded wetlands, which could potentially affect both water quality and chemical metrics (Miller and Hoven, 2007). Carp are known to influence the quality of shallow water environments such as these wetland ponds (Kirkagac and Demir, 2004). For instance, carp alter water quality through bioturbation of sediment in ponds, which releases sediment nutrients into the water column (Chumchal et al., 2005). Carp also influence pond SAV directly by feeding on pond vegetation (Kirkagac and Demir, 2004). It was suggested in Miller and Hoven (2007) that carp density should be evaluated as a separate water quality determinant factor. Initial investigations suggest that this influence may not be significant, but further investigations may be warranted.
- Anecdotal observations suggest that periodic draining and hydrological management of wetlands potentially alter the biological integrity of impounded wetlands, which warrants further investigation.

More information on these potentially confounding factors is needed to evaluate how these factors may be affecting the biological integrity of impounded wetland sites.

The Miller and Hoven (2007) report on previous research efforts also identified some unknowns that may be affecting macroinvertebrate community dynamics at the wetland sites and could likely confound our interpretation of the macroinvertebrate data. Many of these wetland sites are treated for vector control which includes treatment with the biotic agent *Bacillus thurengiensis* (*Bti*), as well as chemical pesticides. Depending on the vector control agent used, these treatments can eliminate or reduce the abundance of other sensitive macroinvertebrates (chironomids, mayflies, odonates, hemipterans, and crustaceans). It was determined that more information on these vector control schedules, locations, and agents used was needed to evaluate how these may be affecting invertebrate community dynamics at those sites. Other potential confounding factors that could affect interpretation of macroinvertebrate responses include the following:

- Salinity, which could affect macroinvertebrate community composition, especially when total salinity exceeds 10 ppt
- Variable hydrologic regimes, especially the draining of ponds and time before refilling
- Variable sampling protocol including collection of macroinvertebrate samples that occurred over multiple seasons, using multiple sampling methods
- Missing data; not all impoundment sites have data within a given season and year for all parameters

UDWQ plans to continue working with our partners to fill these data gaps to augment and improve the preliminary MMI developed here. Further evaluations will consider how to weight each line of evidence and constituent metrics. Consideration will need to be given to assigning weights based on specific management questions. For instance, questions of the aquatic life use support may require that weighting be based, in part, on the strength to which the data are tied to the overall ecological integrity of the ponds, whereas the indicators may be weighted differently when evaluating alternative management practices. One strength of using multiple lines of evidence to quantify wetland condition is the ability to accommodate the data requirements of different management objectives.

5.0 Implementation

This section identifies considerations and recommendations for implementation of the preliminary assessment framework for the impounded wetlands of Great Salt Lake.

5.1 Considerations

Implementation of the MMI for the impounded wetlands of Great Salt Lake will need to be based on a number of considerations that are specific to the goals for the UDWQ's wetlands research program. Studies conducted to date have provided a characterization of various ecological assemblages that define the impounded wetlands as expressed in a database. As discussed in Section 4.0, this database and the corresponding analyses provided by the principal investigators serve as the basis for the development of the preliminary assessment framework, an MMI. Inherent to any ecological characterization of this nature, the database includes limitations and uncertainties that must be considered when used (see Section 4.0). Thus, it seems essential that any monitoring completed to expand and/or verify the database should also include sampling that can be used to validate the preliminary MMI. Validation and augmentation of the MMI should be a priority.

Other important considerations include the following:

- Specific data quality objectives should be developed for all future sampling activities and coordinated through a quality assurance program plan.
- All data received from laboratories should be validated prior to use in analyses. Data should be consolidated into one central database for use by researchers.
- Sampling protocol should be standardized and documented in standard operating procedures for future sampling efforts across all assemblages.
- Future sampling efforts should be coordinated so that data across all assemblages can be more directly linked.
- Consistent protocol should be developed and documented for evaluating and handling data.
- Variables such as water level management should be investigated further to define the hydrologic regime and source of water contributing to the conditions in the impounded wetlands being sampled.
- The preliminary MMI was developed to characterize the condition of impounded wetlands relative to nutrient-based water quality metrics. This was done per the objectives outlined in Miller and Hoven (2007) to discern if there is a link between nutrient loads and current wetlands condition. Future efforts to further develop the MMI should further consider the condition of impounded wetlands relative to other factors that may affect water quality, such as salinity level and water level management.

- Validation of the preliminary assessment framework should be completed with a new and independent dataset.

5.2 Next Steps

5.2.1 A New Approach to Managing the Great Salt Lake Watershed

Given some of the current challenges of implementing water quality standards for the protection of the impounded wetlands of Great Salt Lake, the UDWQ plans to use a new watershed approach as a way of increasing the effectiveness of the agency's work to protect wetlands of Great Salt Lake. Use of this approach has two objectives: The first objective is to apply the best available science to refine Utah's existing water quality standards and monitoring strategy to properly reflect the characteristics of wetland ecosystems. The second objective is to create a UDWQ partnership with community stakeholders and federal and state agency staff to protect wetlands through adaptive management. Adaptive management includes the systematic reporting of ecosystem health.

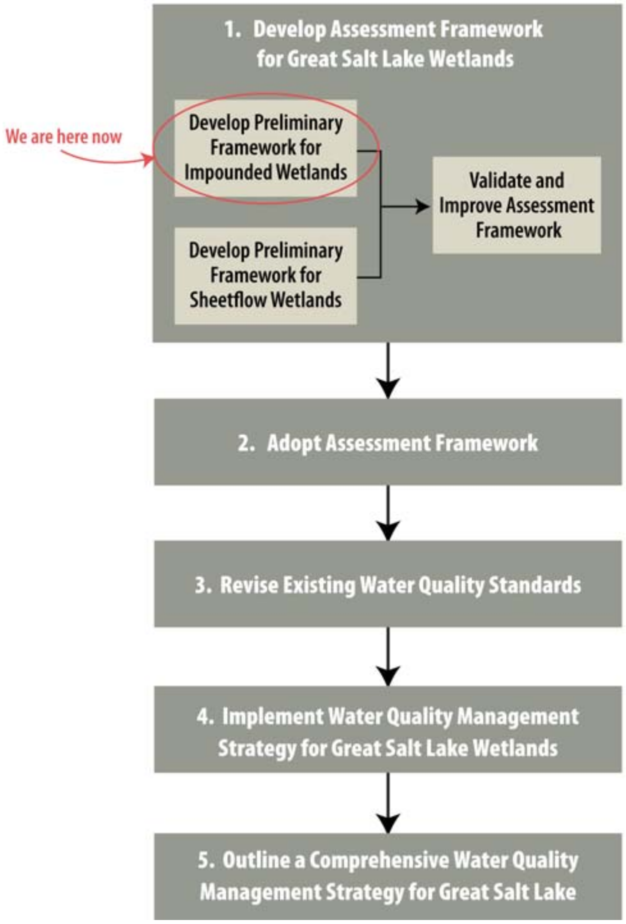
In simplest terms, the watershed approach involves (1) building program partnerships, (2) setting broad-scale ecosystem goals, and (3) using monitoring and assessment information to inform decision-making based on established goals. In contrast with the past approach, the new way signals to stakeholders that sufficient information now exists to move forward with incremental improvements to water quality planning and implementation practices as they relate to wetland protection. The UDWQ and its partners have expended considerable time and resources to build an improved ecological understanding of these wetlands and how they support designated beneficial uses (Miller and Hoven, 2007). A summary of this work is provided herein. The results of future monitoring activity will allow the UDWQ and its partners to evaluate the effectiveness of those planning and implementation practices. Within the framework of adaptive management, refinements will be made as necessary through the process of learning by doing and experimentation to develop solutions.

In addition, new research will be encouraged to help partners better understand the many ecological nuances of Great Salt Lake and its wetlands. Effectiveness monitoring and research will drive the adaptive management process needed to protect wetlands of Great Salt Lake.

5.2.2 Tasks for Implementation of the Proposed Approach

The UDWQ is working with its partners to accomplish five near-term tasks toward implementation of the watershed approach (see Figure 5-1). These tasks will be implemented in a collaborative manner with many opportunities for public input. Stakeholder collaboration will undoubtedly improve the quality of the work and ensure that the concerns of all stakeholders are addressed. Stakeholder collaboration will also allow all parties to see how their protection, conservation, and stewardship work is contribute to meeting a common set of environmental goals in support of the Great Salt Lake ecosystem. Completion of these tasks, in an iterative manner, will provide all stakeholders with assurance that progress is being made to assess and protect Great Salt Lake wetlands in a comprehensive way.

FIGURE 5-1
Proposed Approach for Managing Water Quality of Great Salt Lake Wetlands



The tasks involved in the implementation of the watershed approach for protecting the wetlands of Great Salt Lake include the following:

Develop Monitoring and Assessment Methods for Wetland Ecosystems. Monitoring and assessment methods and a survey design are needed to report the condition of all wetlands of Great Salt Lake and to report the effectiveness of management activity. Work will initially focus on building methods to assess the biological condition of impoundment class wetlands.

Adopt an Assessment (Decision) Framework. The assessment framework will describe how wetland monitoring and assessment data are used with water quality criteria for the categorical reporting of use attainment, including support of waterfowl, shorebird, and other waterbird habitat. The adoption of narrative criteria requires that a robust monitoring and assessment framework be implemented to meet water quality reporting needs. The framework will explicitly describe how assessed wetlands will be categorized in terms of their water quality standard attainment status.

Revise Existing Water Quality Standards. The current numeric criteria will remain in place with the exception of numeric DO and pH criteria for impoundment class wetlands. The numeric criteria for those parameters will be changed to protective narrative criteria for that wetland class. The standards revisions will be supported with documentation. The documentation will explain to stakeholders the technical circumstances of the change and how the narrative criteria will adequately protect designated uses in an accountable manner. Other refinements to water quality standards will be made as new monitoring and assessment data become available.

Implement a Water Quality Management Strategy for Great Salt Lake Wetlands. The water quality management strategy will describe how assessed wetlands will be managed given their reported categorical status. Attention will be directed at solving identified problems as well as examining options to reduce the risk of future wetland degradation. In both cases, the UDWQ will approach problem solving through adaptive management. Adaptive management is based on the synchronized deployment of best management practices and treatments alongside an effectiveness monitoring program. The effectiveness monitoring program is managed with a commitment to revise practices as needed to meet water quality objectives. Those objectives include meeting the goals of the CWA and compliance with applicable administrative rules and requirements. For example, the strategy will explain how new narrative criteria will be taken into account by the UDWQ when evaluating existing point source discharge permits and when issuing new permits.

Outline a Comprehensive Great Salt Lake Water Quality Management Strategy. This strategy will highlight how use of the watershed approach for wetlands and water quality management is coordinated with the UDWQ's other Great Salt Lake assessment initiatives.

5.2.3 Implementation of the Assessment Framework

Work completed to date and summarized herein has focused primarily on the first part of Task 1, the development of a preliminary assessment framework specifically for the Great Salt Lake "impoundment" class of wetlands. This report presents this framework as a "straw man" for the purposes of discussion, validation and improvement through subsequent data collection. The UDWQ's objective is to continue ongoing research to validate and improve this preliminary assessment framework for impounded wetlands but also to develop a similar framework for sheetflow wetlands of Great Salt Lake. Only after each assessment framework has been validated and accepted will the UDWQ adopt the assessment framework as part of Task 2 in the watershed approach.

The UDWQ will be soliciting review comments for the preliminary assessment framework for impounded wetlands through February 2010. The goal is to provide adequate time for the principal investigators, science community, public, and agencies to review and provide feedback to improve the framework before this report is finalized. The UDWQ will then proceed with steps to validate and further improve the assessment framework.

It is anticipated that an assessment framework for the impounded wetlands of Great Salt Lake will not be formally adopted until at least 2012. Ongoing research will focus on improving and validating the preliminary assessment framework with this deadline in mind.

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