FINAL

CORE COMPONENT 2: STRATEGIC MONITORING AND RESEARCH PLAN

A GREAT SALT LAKE WATER QUALITY STRATEGY

Photo courtesy of Charles Uibel—greatsaltlake.photography.com

September 2014

Utah Division of Water Quality

A water quality strategy to ensure Great Salt Lake continues to provide important recreational, ecological, and economic benefits for current and future generations.

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ACRONYMS AND ABBREVIATIONS

BSP	Baseline Sampling Plan
CWA	Clean Water Act
DNR	Department of Natural Resources
DQO	Data Quality Objective
DRC	Dynamic Reaction Cell
dw	Dry Weight
EPA	United States Environmental Protection Agency
HSP	Health and Safety Plan
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
POTW	Publicly Owned Treatment Works
ppm	Part per Million
QAPP	Quality Assurance Project Plan
SOP	Standard Operating Procedure
TMDL	Total Maximum Daily Load
UAC	Utah Administrative Code
UDWQ	Utah Division of Water Quality
UDWR	Utah Division of Wildlife Resources
UPDES	Utah Pollution Discharge Elimination System
UPRR	Union Pacific Railroad
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

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UTAH DIVISION OF WATER QUALITY

EXECUTIVE SUMMARY

Establishing water quality criteria for Great Salt Lake, monitoring the Lake's water quality, assessing its designated use support and implementing pollution control programs are the responsibilities of the Utah Division of Water Quality (UDWQ) (Utah Administrative Code [UAC] R317-2-7). While UDWQ routinely accomplishes these tasks for streams and lakes statewide, Great Salt Lake poses UDWQ and its partners with unique challenges. This component of the Great Salt Lake Water Quality Strategy, the Strategic Monitoring and Research Plan (also referred to as Component 2), provides UDWQ and its partners with a strategy to fulfill its responsibilities under the federal Clean Water Act (CWA) and state law (UAC R317) and to protect this valuable resource. As outlined in this Core Component, the objectives of the Strategic Monitoring and Research plan are to:

1. Implement a Baseline Sampling Plan
2. Improve upon the Baseline Sampling Plan
3. Recommend research to support numeric criteria development, assessments of the aquatic life and recreational designated uses and implement pollution control programs.

Objectives 1 and 2 are curtailed to the open waters of the Great Salt Lake specifically Gunnison Bay, Gilbert Bay, Bear River Bay and Farmington Bay. In addition to open water research, Objective 3 includes recommended research for the Lake's wetlands. A separate wetland monitoring and assessment plan will be developed in Core Component 3 of the Great Salt Lake Water Quality Strategy. In addition, a strategic plan to assess nutrients will be developed in the Strategy's Core Component 4: Nutrient Assessment Plan.

1. INTRODUCTION

1.1 Physical Setting and Study Area

Great Salt Lake (hereafter, "the Lake") is a uniquely dynamic terminal lake located adjacent to a rapidly growing metropolitan area in northern Utah. It 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, the 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 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 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 the 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 the Lake. This results in Lake water that ranges from fresh water to 7 times saltier than sea water and creates a unique habitat for biota that has adapted to and relies on the Lake ecosystem.

1.2 Resources Dependent on Great Salt Lake

Great Salt Lake's unique yet harsh conditions are significant to the ecology and economy of our local region but also the earth's Western Hemisphere. Each of the Lake's resources and users of those resources—including birds, people, the mineral industry, and brine shrimp harvesters—maintain a fragile balance with the ecology of the 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 the Lake as they travel from the near arctic to the high Andes (Colwell and Jehl, 1994). The magnitude of the Wilson's phalarope population was a primary factor in the designation of the Lake as one of six sites within the Western Hemisphere's Shorebird Reserve Network in the United States (Aldrich and Paul, 2002). Over half of the world's population of eared grebes (*Podiceps nigricollis*) use the Lake for up to 4 months during fall migration (Jehl, 1988). In 2007 the population of eared grebes on the Lake exceeded 2.5 million birds (N. Darnall, personal communication, October 15, 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 the 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 refuges, and one federal wildlife refuge. Waterfowl hunting alone was estimated to be almost an $9.5-million industry in 2010-11 (GSLAC 2012a). The total annual economic effect of recreation of the Lake was recently estimated to be almost $136 million (GSLAC 2012a).

As a result of the minerals left behind by evaporation, the Lake is home to a burgeoning mineral industry that has a significant impact on Utah's economy (Isaacson et al., 2002). Several mineral extraction companies currently operating on the Lake generated a total of about 2.8 million tons of sodium chloride, potassium sulfate, magnesium chloride, magnesium metal, chlorine gas, and other products. (Gwynn, 1997). The total annual economic effect of the Lake's mineral industry was recently estimated to be $1.13 billion (GSLAC 2012a).

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 total annual economic effect of the Lake's brine shrimp industry was recently estimated to be almost $56 million (GSLAC 2012a) and is often limited by biological factors rather than market forces (Isaacson et al., 2002).

Combining the annual economic effect of the three industries previously described, the total annual economic output or significance of the Lake to the state of Utah was estimated to be $1.32 billion. This represents an estimated 7,700 full-time and part-time jobs in the region and establishes the Lake as a significant factor in and of significant value to Utah's economy (GSLAC 2012a).

1.3 Need for a Great Salt Lake Monitoring and Research Plan

Stresses to the Lake ecosystem have been increasing in recent decades as a result of development, water diversions, invasive species, and resource extraction. As a result, the complex, dynamic, and resilient nature of the Lake's ecosystem has become evident and the need to understand the system ever more important. Research continues to demonstrate that the Lake is a valuable resource that faces ever increasing pressures. Additional research is necessary for UDWQ and its partners to protect the Lake's water quality, ecological health, and natural resources (Great Salt Lake CMP, 2011; GSLAC 2012a; GSLAC 2012b; UDWQ, 2009; UDWQ, 2011; CH2M HILL, 2008). This Strategic Monitoring and Research Plan was developed to enable UDWQ to proactively manage water quality in the Lake, fulfill its responsibilities under the Clean Water Act and state law, and collaborate with partners to protect this valuable resource.

1.3.1 Technical and Regulatory Challenges

UDWQ is charged with the responsibility to establish water quality criteria for the Lake, monitor its water quality, and assess its designated use support (UAC R317-2-7). Due to the unique geochemistry of the Lake, the direct application of national freshwater or saltwater numeric criteria to the open waters of the Lake may be inappropriate (United States Environmental Protection Agency [EPA] 1987, 2004). Instead, the aquatic life and recreational designated uses of the Lake are protected using the Narrative Standard (UAC R317-2-7). UDWQ has, however, faced repeated challenges in monitoring the Lake and assessing the lake's designated uses.

Questions regarding the ability of the narrative clause to address selenium led to a site-specific numeric standard for selenium for Gilbert Bay of the Lake in 2008 (UDWQ, 2007) and an investigation of mercury in 2009–2011 (UDWQ, 2011). All of these studies have encountered unique challenges in monitoring water quality, and assessing the Lake's designated use support. Some examples of these challenges include the following:

> *UDWQ's efforts to fulfill its responsibilities on Great Salt Lake have consistently encountered significant technical challenges due to the complexities inherent in and uniqueness of Great Salt Lake.*

- Decision making for situations that were not well defined with little or no historical data.

- Typical sampling and laboratory analytical methods were not necessarily applicable for the Lake water, as was established in the selenium standard process (Moellmer et al., 2006; personal communication with USGS, 2011).
- Typical theories as to how selenium and mercury might be processed or cycled by the lake were found to not apply (UDWQ, 2007; 2011).

Using methods and assumptions commonly used for monitoring and assessing fresh or salt water waters could have led to erroneous data and decisions that were too protective or not protective enough and did not address the right source of pollutants (UDWQ, 2011; CH2M HILL, 2008). UDWQ is faced with the reality that an investment is needed to develop Lake specific sampling and analysis methods to manage water quality and assess designated use support.

1.3.2 Development of a Great Salt Lake Health Index

The Great Salt Lake Advisory Council commissioned a study in 2011 to define the ecological health of the four bays of the Lake: Gilbert Bay, Farmington Bay, Bear River Bay, and Gunnison Bay. The study developed a framework for defining the health of the Lake, based on eight ecological targets that capture the biological diversity of the Lake's ecosystem. These targets were system-wide lake and wetlands, open water of bays, unimpounded marsh complex, impounded wetlands, mudflats and playas, isolated island habitat for breeding birds, alkali knolls, and adjoining grasslands and agricultural lands. Based on the findings, most ecological targets surrounding the Lake were considered to be in good health; however, some targets, such as the open water of bays and unimpounded marsh complexes, were found to have a high level of uncertainty due to lack of historical and current data and scientific understanding. Several habitats were also found to be in poor or fair health, including the impounded wetlands around Farmington Bay, and the alkali knoll habitats around Bear River Bay and Farmington Bay (GSLAC 2012b).

The study did not rank the health of the open water areas of Gunnison Bay, Bear River Bay, or Farmington Bay nor was a rank provided for the unimpounded marsh complex habitats surrounding the Lake. This was due to gaps in our understanding of fundamental biogeochemical and ecological processes in the Lake. The study identified eight (8) research needs as high priority reflecting both level of uncertainty and potential future stresses. Four of the 8 highly ranked research needs relate to water quality as follows:

- Level of toxins in water column and sediment that does not impair populations of significant species and current concentrations throughout the lake. These toxins include mercury (including methylmercury), arsenic, cyanotoxins, and avian botulism.

- Maximum level of phytoplankton in winter and in summer that is healthy for Farmington, Bear River, and Gilbert bays.
- Trophic condition supportive of native biota, especially in Farmington and Bear River bays, including thresholds for indicators such as summer chlorophyll a concentrations and invertebrate diversity.
- Indicator of water quality delivered to unimpounded marshes and impounded wetlands. Impacts of various parameters such as toxics, nutrients, and sediments on wetland functions.

The study highlighted the need to better understand the current condition of and stresses (current and projected) to the Lake, not only to better define the health of these ecological targets, but also to protect the Lake's designated uses. This study illustrates the need for research not only for UDWQ to proactively fulfill its responsibilities, but for all local, state, and federal entities to fulfill their responsibilities in protecting this valuable resource.

1.4 Purpose and Objectives

The Strategic Monitoring and Research Plan was developed to enable UDWQ to proactively fulfill its CWA and state responsibilities to monitor and assess water quality for the protection of the Lake's aquatic life and recreational designated uses, support numeric criteria development and the implement pollution control programs. Specifically, the Strategic Monitoring and Research Plan addresses UDWQ's responsibilities to:

- **Monitor the water quality of the Lake.**
    - Identifies a long-term monitoring plan to collect environmental samples to assess the current condition of the open waters of the Lake and track spatial and temporal trends of pollutants of concern that may affect the aquatic life and recreational designated uses.
    - Identifies a Quality Assurance Program Plan (QAPP) that addresses the accuracy, reliability and quality of sampling and analyzing various parameters under highly saline conditions (UDWQ, 2014).
    - Identifies research studies to improve sampling and analytical methods to ensure consistency and defensibility of data and to better leverage available resources.
- **Assess the Lake's aquatic life and recreational designated uses.**

- Identifies monitoring and research to collect essential lake assessment data to determine designated use support.

- **Support the development of numeric water quality criteria and the implementation of pollution control programs.**
  - Identifies monitoring and research needed for the development of numeric water quality criteria for the Lake and determine the effectiveness of pollution control programs

The specific objectives of the Strategic Monitoring and Research Plan are summarized in Figure 1 and are detailed as follows.

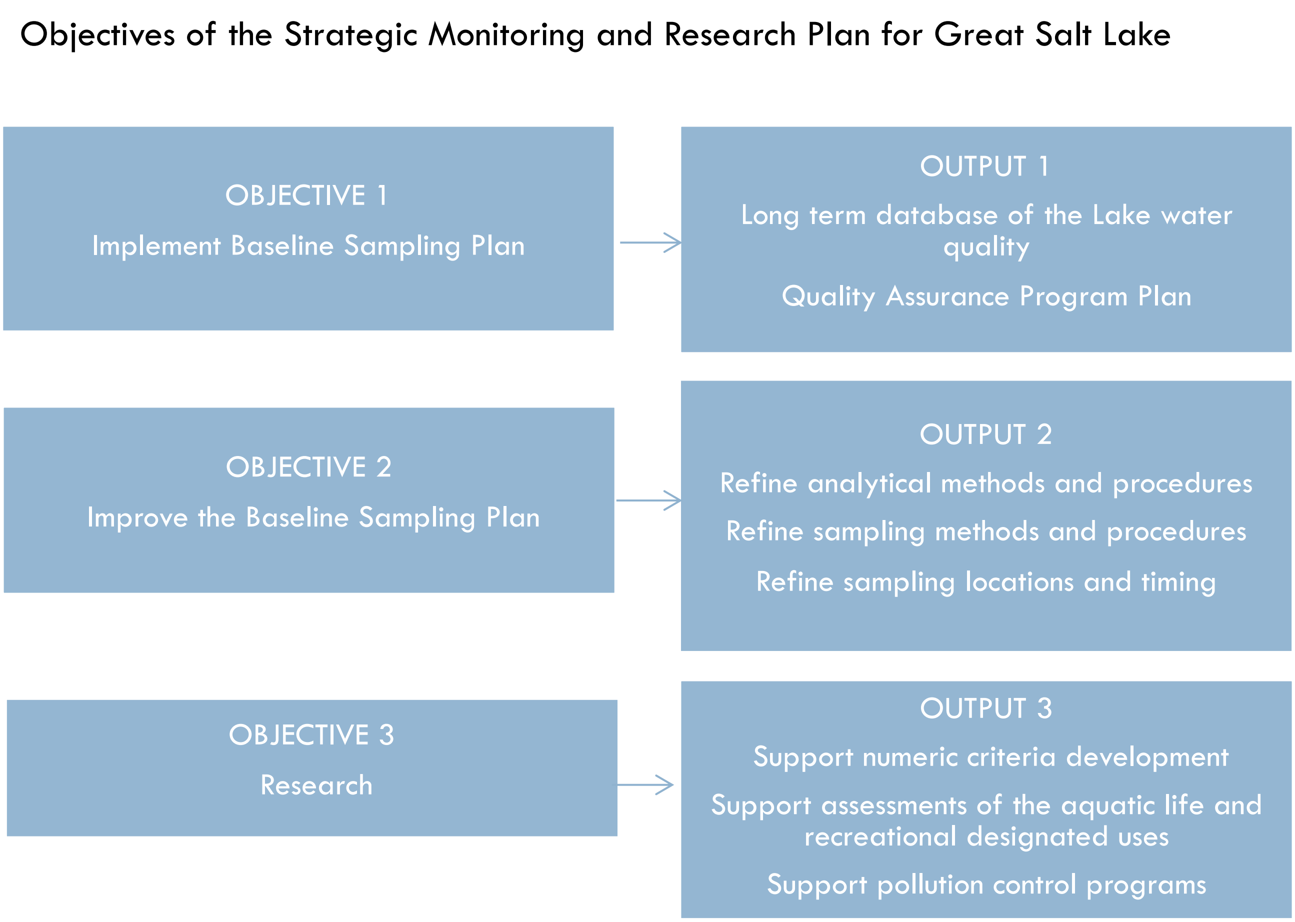

FIGURE 1 OBJECTIVES OF THE STRATEGIC MONITORING AND RESEARCH PLAN

1.4.1 Objective 1—Implement Baseline Sampling Plan

This objective is of highest priority and will be integrated into UDWQ's annual state monitoring program. The intent of the Baseline Sampling Plan (BSP) is to collect environmental samples to assess the current condition of the open waters of the Lake and track spatial and temporal trends of pollutants of concern that may affect the aquatic life and recreational designated uses.

The BSP was designed to collect the data necessary to address the following questions:

- What pollutants are of potential concern for the Lake?
- What are the concentrations of those pollutants in the Lake water or the tissue of brine shrimp and the eggs of nesting birds?
- How do these concentrations vary spatially and temporally?

The BSP includes a Quality Assurance Program Plan (QAPP) that addresses the accuracy, reliability and quality of sampling and analyzing various parameters under highly saline conditions (UDWQ, 2014). These detailed quality assurance procedures are particularly critical for the Lake because standard sampling and analytical methods frequently need to be modified to account for the lake's high salt content. A detailed review of historical data identified the need for further clarification in sampling techniques, laboratory instrumentation, and analytical methods, which will continue to be captured in QAPP revisions. The QAPP also aims to improve collaborative monitoring efforts by helping to ensure data comparability among the entities that collect monitoring data.

Key parameters and pollutants were determined based on results of previous studies conducted by UDWQ and other agencies and include those pollutants that are identified to be of highest risk to the Lake's designated uses. Standardized sampling and analysis facilitates cross-agency use of the data and consistency by all organizations sampling and monitoring the Lake.

UDWQ has monitored and conducted research on the Lake's impounded and fringe wetlands since 2005. Current monitoring of these types of wetlands is guided by Sampling and Analysis Plans (UDWQ 2012, 2013). The assessment framework for these wetlands is still in development and will be described in more detail as Core Component 3 of the Strategy is developed. This section summarizes UDWQ's baseline sampling for the open waters of the Lake as defined by designated use classes 5A through 5D.

1.4.2 Objective 2—Improve Baseline Sampling Plan

This objective is of second highest priority. The identified research studies will work toward refining and improving the BSP and analytical procedures for pollutants of concern in the Lake. These studies will fill data and knowledge gaps and are essential to improving UDWQ's ability to monitor the Lake assess designated use support and proactively develop numeric water quality criteria and implement pollution control programs. Specifically this objective is designed to:

- Identify gaps in accuracy and reliability of existing sampling and analytical procedures for the Lake
- Complete studies to verify and confirm or improve the standard sampling procedures and laboratory analytical methods for accurate representation of the unique water quality of the Lake
- Complete studies to verify and confirm or improve sampling locations, sampling time and frequency, and pollutants that are monitored through the BSP

1.4.3 Objective 3—Research to Support the Development of Numeric Water Quality Criteria, Assessment of the Designated Uses and Implementation of Pollution Control Programs

Numerous questions asked during previous investigations remain unanswered, and answers are essential to developing water quality criteria, improving monitoring activities, and assessing the designated uses of the Lake. Some of these studies have already been initiated or are being completed by UDWQ and other agencies. That does not negate the need for UDWQ to encourage or support their completion to fulfill its responsibilities. These studies will be implemented depending on priority and available funding. Specifically this objective is designed to:

- Complete research to proactively identify potential water quality concerns.
- Complete research required to support the evaluation and development of defensible numeric water quality criteria.
- Complete research required to effectively and defensibly assess designated use support.

2. BASELINE SAMPLING PLAN FOR THE OPEN WATERS OF GREAT SALT LAKE

Monitoring the water quality of the Lake, and thus the development and implementation of a baseline sampling plan, is a critical responsibility of UDWQ and a critical element in UDWQ's strategy to protect the water quality of the Lake. This plan will provide for the long-term routine collection of water quality samples to better characterize pollutants of potential concern in the open waters of the Lake as well as concentrations in brine shrimp and bird eggs to follow movement of these pollutants in the Lake's food web. The primary focus of the BSP is the collection of water samples to evaluate whether the recreational and aquatic wildlife designated uses are supported under the federal CWA and state law.

The BSP will provide the following:

- A public, long-term database of the Lake's water quality
- Appropriate sampling and analytical techniques of various matrices and target pollutants in the lake
- Support for the development of numeric water quality criteria, assessment of the Lake's designated uses and implementation of pollution control programs
- A collaborative approach with partner agencies

UDWQ has monitored and conducted research on the impounded and fringe wetlands since 2005. Current monitoring of these types of wetlands is guided by Sampling and Analysis Plans (UDWQ 2012, 2013). The assessment framework for these wetlands is still in development and will be described in more detail as Core Component 3 of the Strategy is developed. This section summarizes UDWQ's baseline sampling for the open waters of the Lake as defined by designated use classes 5A through 5E (UAC R317-2-6.5).

3.1 Study Area

Figure 2 shows the study area for the BSP. It includes the "open waters of the Lake" defined as Gilbert Bay (Class 5A), Gunnison Bay (Class 5B), Farmington Bay (Class 5D), and Bear River Bay (Class 5C) and is generally bounded by the shoreline as defined by the current lake water level but an area no greater than as represented by the lake's bed elevation of 4,208 feet per UDWQ's segmentation of the waters of Great Salt Lake (UAC R317-2-6). The UPRR Causeway separates Gilbert Bay from Gunnison Bay and Bear River Bay. The Antelope Island Causeway at the northern end of Antelope Island and Island Dike Road at the southern end of Antelope Island separate Gilbert Bay from Farmington Bay. Eight sampling stations are located in Gilbert Bay, 2 in Farmington Bay and 1 in Bear River Bay. More stations will be added to the BSP as resources and access (particularly in Gunnison Bay) becomes available.

3.2 Data Quality Objectives

The EPA's seven-step DQO process (EPA, 2006) was used to guide the requirements and design rationale for the Lake BSP. The DQOs define the type, quantity, and quality of data and establish performance and acceptance criteria to ensure that data collected support the goals of the study.

Table 1 details the DQOs for this sampling plan including the need, goals, data input, study boundaries, decision rules, and performance and acceptance criteria.

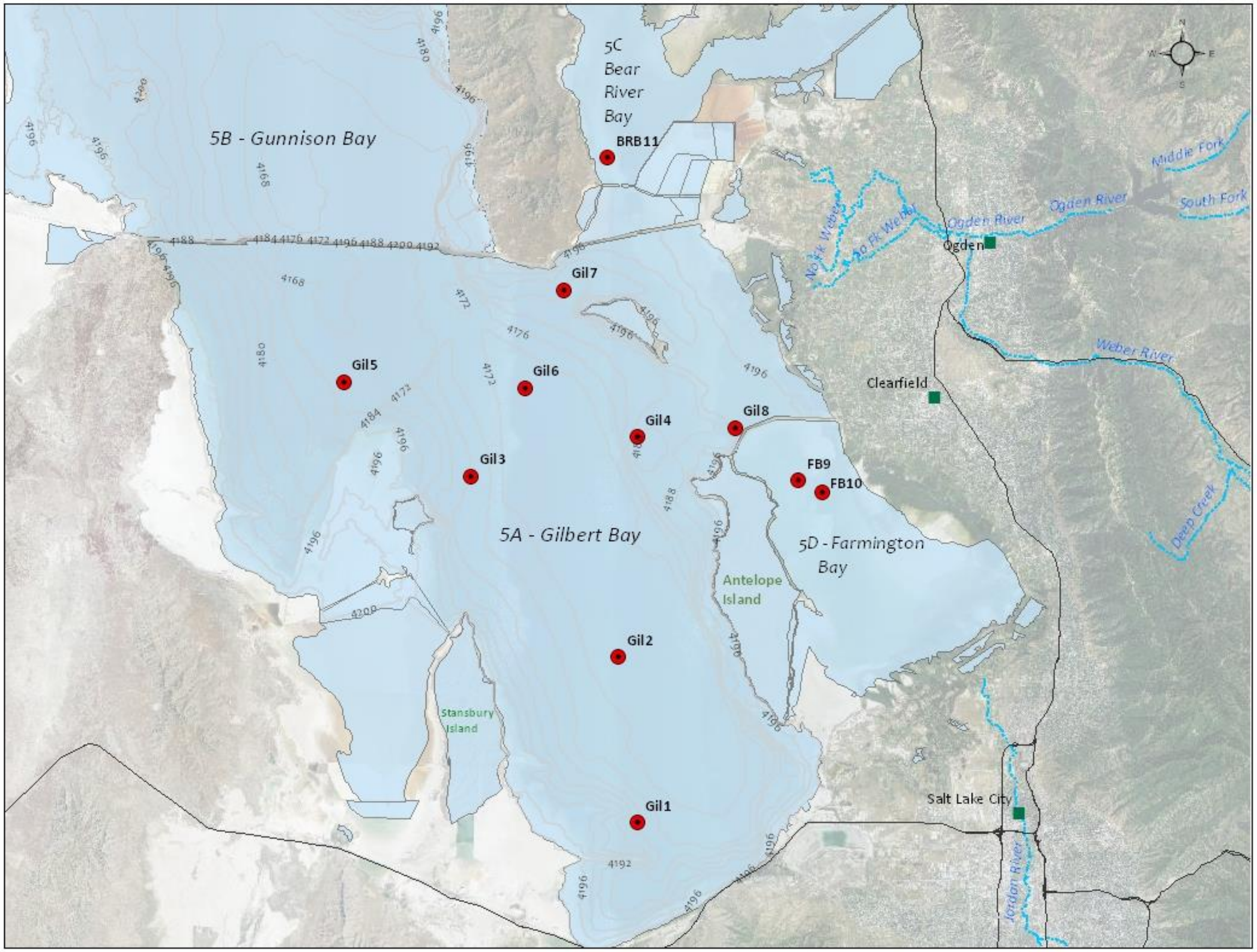

FIGURE 2 GREAT SALT LAKE BASELINE SAMPLING PLAN STUDY AREA AND SAMPLING LOCATIONS

TABLE 1 DATA QUALITY OBJECTIVES FOR THE GREAT SALT LAKE BASELINE SAMPLING PLAN

Step	DQOs for Great Salt Lake Baseline Sampling Plan
Problem Statement and Resources	**Problem** Several pollutants, such as selenium, mercury, and other metals and metalloids, are known to cause adverse effects on the biological health and the designated uses of some water bodies and are known to exist in the waters of the Lake. Little is known about existing concentrations of these pollutants in Great Salt Lake, their temporal and spatial variability, and their fate and transport. Great Salt Lake's unique and complex water chemistry has made assessing these pollutants and tracking their long-term variability difficult and precluded the use of typical numeric water quality criteria to manage the Lake's water quality. This has resulted in a dearth of data that often results in a reactive approach to managing water quality and makes the assessment of the water quality in the Lake extremely difficult. These uncertainties resulted in a large expenditure of resources to develop the criterion for selenium. The Lake is protected by a narrative water quality standard and currently has only one site-specific numeric water quality standard for selenium in Gilbert Bay (UAC R317-2-14). A long-term database of water quality measures (including water and biota tissue chemistry) is needed to assess long-term trends and enable UDWQ to fulfill its responsibilities. A long-term plan to monitor selenium concentrations in bird eggs is needed to assess compliance with the existing numeric criterion. Proven protocols are needed to enable the consistent collection and analysis of environmental samples from Great Salt Lake's hypersaline waters. Research is needed to better understand the idiosyncrasies of Great Salt Lake's ecosystem and how they relate to water quality. These tools are needed to better understand the ecosystem and identify reliable measures that can be used to assess its health. **Project Partners** It is UDWQ's objective to collaborate and coordinate with various state and federal agencies that have management responsibilities, conduct research, and monitor the condition of Great Salt Lake. The following agencies are identified as partners in completing a baseline sampling program and developing protocols for future monitoring of the health of Great Salt Lake: • Davis County Health Department (DCHD) • United States Geological Survey (USGS) • Utah Division of Wildlife Resources/Great Salt Lake Ecosystem Program (UDWR) • Utah Division of Forestry, Fire, and State Lands (FFSL) • Utah Geological Survey (UGS) • United States Fish and Wildlife Service (USFWS) • Environmental Protection Agency (EPA)

Step	DQOs for Great Salt Lake Baseline Sampling Plan
	Available Resources UDWQ will seek to collaborate with partner agencies to provide the resources required for the baseline sampling program. UDWQ will include funds for the proposed baseline sampling program in its annual budget. Monies for supplemental studies will be appropriated on an as-needed basis. **Relevant Deadlines** UDWQ began implementation in Spring 2011 and will continue on an annual basis. A report providing a summary and evaluation of analytical results will be included in the State of Utah's biennial 305(b) *Integrated Report*.
Goal of the Study	**Key Questions** The overall question to be resolved can be stated as, "What is the overall water quality of the open waters of Great Salt Lake?" The following more specific questions will be addressed by the baseline sampling program: • What pollutants are of potential concern for Great Salt Lake? • What are the concentration of those pollutants in Great Salt Lake's water or the tissue of brine shrimp and the eggs of nesting birds? • How do these concentrations vary spatially and temporally? **Possible Outcomes** • Information obtained from the sampling efforts is adequate to accurately quantify concentrations of pollutants in Great Salt Lake. Data are useful for management decisions, designated use support, a better understanding of Great Salt Lake's ecosystem, and guiding future research. • Information obtained from the sampling efforts is not adequate to accurately quantify concentrations of identified pollutants in Great Salt Lake. Steps will be taken to improve and/or develop appropriate sampling and analytical methods for Great Salt Lake and revise the baseline sampling program as needed. • Information obtained is adequate to understand the spatial and temporal variation of identified pollutants in the lake. • Information obtained is not adequate to understand the spatial and temporal variation of pollutants in the lake. Steps are taken to prioritize research needs to understand these variations better and revise baseline sampling program as needed.
Inputs to the Decision	**Informational Inputs** The following information will be collected: • Water and brine shrimp will be sampled twice per year at 11 locations in Great Salt Lake as shown in Figure 2—Once

<table>
<tr><th>Step</th><th>DQOs for Great Salt Lake Baseline Sampling Plan</th></tr>
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during the bird nesting season (in the month of June) and once during the fall brine shrimp cyst harvest (in the month of October). Water samples will be collected 0.5 meters from the bottom of the water column and 0.2 meters from the surface.
A minimum of five (preferably eight) bird eggs each will be collected from American avocets and Black-necked stilts at two locations when present: Bridger Bay on Antelope Island and Saltair. Collocated water, sediment and macronvertebrate samples will be measured concurrently at the site. This will be completed during the bird nesting season (April through June) at a minimum of once every 2 years. An annual assessment will be used to determine if egg sampling will be completed every year and if changes will be made in how many eggs will be collected and from how many locations.
Variables/Characteristics to Be Measured
Total selenium, methyl mercury and total mercury concentrations in the following:
Water
Brine shrimp
Bird eggs
Other metals and metalloids (at a minimum total arsenic, total copper, cadmium, lead, and thallium; others included if part of the same analysis suite or determined to have higher priority) concentrations in the following:
Water
Brine shrimp
Nutrients (total and dissolved nitrogen, total and dissolved phosphorus, and ammonia) and chlorophyll-a concentrations in the following:
Water
In-situ field water measurements include:
Dissolved oxygen, pH, temperature, specific conductivity, secchi depth, total water depth, and the depth of deep brine layer (if present)
Report dry-weight concentrations and moisture percentage of biota samples.
</td></tr>
<tr><td>Study Boundaries</td><td>
Study Area
The study area for this project is shown in Figure 2. This area includes Gilbert Bay (i.e., South Arm), Farmington Bay, Bear River
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<table>
<tr><th>Step</th><th>DQOs for Great Salt Lake Baseline Sampling Plan</th></tr>
<tr><td></td><td>Bay, and Gunnison Bay (i.e., the North Arm) when access becomes available.
Temporal
• Water and brine shrimp samples will be sampled twice per year—once during the bird nesting season (June) and once during the fall brine shrimp cyst harvest (October). An annual assessment will be used to determine if sampling will be completed more frequently.
• Bird eggs and collocated water, sediment and macroinvertebrate samples will be collected during nesting season (April through June) a minimum of once every 2 years. An annual assessment will be used to determine if sampling will be completed more frequently.
Practical Constraints on Data Collection
• Availability of boats and other field equipment, as well as equipment functionality, may limit some activities.
• Staffing and funding availability will need to be confirmed.
• Weather is a major constraint for all sampling and monitoring activities because storms can limit ability to safely conduct sampling and measurement activities at the study area.
• Great Salt Lake levels may be a constraint and affect sampling locations. Currently, there is no readily available access to Gunnison Bay. Gunnison Bay samples will be collected as opportunities arise but no regular sampling location is identified.
• Successfully obtain collection permits from USFWS.
• The presence of bird eggs for sample analysis may be a constraint.
• Not all sampling and analytical methods are fully tested and confirmed.</td></tr>
<tr><td>Decision Rules</td><td>If information is adequate to accurately quantify the concentration of potential pollutants of concern for Great Salt Lake, UDWQ will complete reporting as noted.
If information is not adequate to accurately quantify the concentration of potential pollutants of concern for Great Salt Lake, UDWQ will evaluate results, revise methods, develop appropriate sampling and analytical methods for Great Salt Lake, revise the baseline sampling program as needed, and complete reporting as noted.</td></tr>
<tr><td>Tolerable Limits on Decision Rules</td><td>The measurement quality objectives are specified using the performance criteria in terms of the precision, accuracy, representativeness, completeness, and comparability of the data. These performance criteria provide a measure of how well the established measurement quality objectives were met. In general, the measurement quality objectives for metals and metalloids are about ±20 percent, ±24 percent for total mercury and ±35 percent for methyl mercury. The QAPP will specify all quality</td></tr>
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Step	DQOs for Great Salt Lake Baseline Sampling Plan
	assurance/quality control objectives for sample measurement based on each matrix and may be more restrictive or less restrictive than ±20 percent.
Optimization of the Sampling Design	The baseline sampling program includes the collection and analysis of water, brine shrimp, and bird egg samples to monitor the water quality of Great Salt Lake and assess its condition with respect to water quality criteria. UDWQ's Water Quality Strategy for Great Salt Lake includes supplemental studies that are intended to improve implementation and interpretation of results from the baseline sampling program.

3.3 Pollutants of Concern

Several studies and monitoring programs have identified pollutants that may adversely affect the Lake's ecology and its designated uses. As the public has become more aware of the importance of the Lake, they too have begun to express concerns about the Lake's water quality. Table 2 provides a summary of selected recent literature that describes research relevant to the investigation and identification of pollutants of concern for the Lake.

TABLE 2 POLLUTANTS TO BE MONITORED IN THE GREAT SALT LAKE BASELINE SAMPLING PLAN

Pollutants	Literature
Selenium	Cavitt, 2006; Marden, 2007; Cavitt, 2008a; Cavitt 2008b; UDWQ, 2008; Conover et al., 2008a; Conover et al., 2008b; Conover 2008c; Marden, 2008; Naftz et al, 2009b; Vest et al., 2009; Diaz et al., 2009a; Diaz et al., 2009b
Total and Methyl-Mercury	UDWQ, 2008; Naftz et al., 2008; Naftz et al., 2009a; Vest et al., 2009; UDWQ, 2011
Other Metals and Metalloids	Johnson et al. 2008; Naftz et al., 2009b; USGS, 2004; Vest et al., 2009; Beisner et al., 2009 ; Wurtsbaugh et al., 2014
Nutrients and Cyanotoxins	Naftz et al., 2008; Wurtsbaugh et al., 2009

3.3.1 Selenium

A numeric water quality standard for selenium was established for Gilbert Bay of the Lake in UAC R317-2-14 in November 2008. This standard was developed through an extensive process led by a Selenium Steering Committee composed of prominent stakeholders who were advised by a scientific panel of selenium experts (UDWQ, 2008). The selenium water quality standard of 12.5 milligrams per kilogram is a tissue-based standard applicable to the complete egg/embryo of aquatic-dependent birds that use the waters of Gilbert Bay (Class 5A). UDWQ's objective is to continue to protect the Lake for selenium by monitoring egg tissue from aquatic-dependent birds and to evaluate selenium concentrations that would initiate various monitoring, assessment and management actions. The BSP will result in a long-term database used to assess bird egg concentrations and address the objectives described above.

3.3.2 Mercury

Mercury, a global pollutant that ultimately makes its way into every aquatic ecosystem through the hydrologic cycle, is also a pollutant of concern in the Lake. After a 2003 USGS study found elevated concentrations of total and methyl-mercury in the deep brine layer of Gilbert Bay and evidence of its bioaccumulation in some biota of the Lake (Naftz et al., 2008; Naftz et al., 2009), UDWQ began an endeavor to understand the extent to which mercury poses a risk to the Lake's aquatic birds and organisms in their forage base (UDWQ, 2011). Several other studies as indicated in Table 2 have also concluded that mercury is a significant pollutant of concern in the Lake. While these efforts have greatly improved UDWQ's understanding of mercury in the Lake, significant questions currently remain. For instance, selection of the most appropriate benchmarks to use for quantifying biological responses to mercury has not been finalized. In addition, the link between avian tissue concentrations and exposure to the Lake as opposed to other waters visited by birds remains unknown. These data gaps will be investigated and incorporated into an assessment framework and the development of numeric criteria to help UDWQ determine if the Lake's designated uses are protected or not due to mercury pollution. UDWQ's objective is to continue sampling and monitoring of total and methyl-mercury in the Lake ecosystem.

3.3.3 Other Metals and Metalloids

Though little is known about the input and biogeochemical cycling of metals and metalloids in the lake, concentrations of metals are much higher in recent lake sediments than during the pre-industrial period (Wurtsbaugh et al. 2014). There are concerns about the negative effect of these constituents in the Lake. A study by USGS and others completed from 1998 to 2001 evaluated water quality and completed a biological assessment of the Lake basin (Waddell et al., 2004). This study concluded that most streambed sediments had concentrations of arsenic, cadmium, copper, lead, mercury, silver, and zinc that exceeded aquatic life guidelines. Naftz et al. (2000) also found that deposition of sediment in the Farmington Bay area had elevated concentrations of cadmium, copper, lead, zinc, nitrogen, organic carbon, and phosphorus. Deposition began to increase sometime in the early to mid-1900s and became progressively greater in recently deposited sediment, illustrating the impact of metals on the lake with increased industrial development and urbanization. In addition, in a recent article, Vest et al. (2009) found elevated arsenic levels in wintering waterfowls that use the Lake. UDWQ's objective is to prioritize the tracking of current and changing concentrations of metals and metalloids to proactively protect the lake from these pollutants.

3.3.4 Nutrients

Similar to the metals and metalloids, little is known with regard to the variability, fate, and transport of nutrients in the open waters of the Lake. A few studies by Wurtsbaugh et al. (2006; 2009) have assessed Farmington Bay and identified it to be hypereutrophic with algal blooms occurring most years containing cyanobacteria, including toxic taxa. (Wurtsbaugh et al., 2006; Wurtsbaugh et al., 2009). High nutrient concentrations are partially responsible for these blooms, although, the blooms are also exacerbated by predaceous bugs that consume grazers and leads to increases in algal production (Wurtsbaugh, 2012). These studies have also tried to estimate the impact of excess nutrients in Farmington Bay on the Lake ecosystem via its connectivity with the other bays. In Gilbert Bay, brine shrimp are indiscriminate filter feeders that strongly control algal densities by grazing and the productivity of brine shrimp populations is dependent on the amount of food/nutrients available. Algal abundance in Gilbert Bay is reported as limited by dissolved organic nitrogen in the photic zone (Belovsky, 2011) The UDWR continues to monitor nutrient concentrations in Gilbert Bay to evaluate the impact of nutrients on brine shrimp populations. Tracking nutrient concentrations are thus important to UDWQ to better understand nutrient cycling, interbay transfer and effects on the designated uses. In Core Component 4 of this Strategy, UDWQ will compile all relevant nutrient information to design a plan that monitors and assesses nutrients for the protection of the designated uses.

3.3.5 Summary

The BSP focus is to monitor concentrations of pollutants of concern in the waters, brine shrimp, and aquatic-dependent bird eggs of the Lake as described in Table 3.

TABLE 3 POLLUTANTS TO BE MONITORED IN WATER, BRINE SHRIMP, AND BIRD EGGS OF OPEN WATERS OF THE LAKE

Matrix	Analytes
Water	Total selenium, total and methyl-mercury, total arsenic, total copper, cadmium, lead, thallium, zinc, total phosphorus, total nitrogen, ammonia, nitrate-nitrite, orthophosphate and chlorophyll-a
Brine Shrimp	Total selenium, total mercury, total arsenic, total copper, total cadmium, total lead, total thallium and total zinc
Bird Eggs	Total selenium and total mercury

3.4 Sampling Approach

UDWQ intends that the BSP be adapted to address a variety of factors:

- Newly developed methods
- Availability of new research
- New questions and issues
- New water quality criteria
- New opportunities for collaboration in sample collection and analysis
- Additional funding that may become available

The BSP approach described in the following paragraphs represents sampling and monitoring required to meet UDWQ's current objectives and obligations for management of the open waters of the Lake with available resources. While the approach to sampling on the Lake may change, it is anticipated that the baseline sampling program will be incorporated into UDWQ's long-term monitoring program of waters of the state. Figure 3 summarizes the work plan design for the sampling plan.

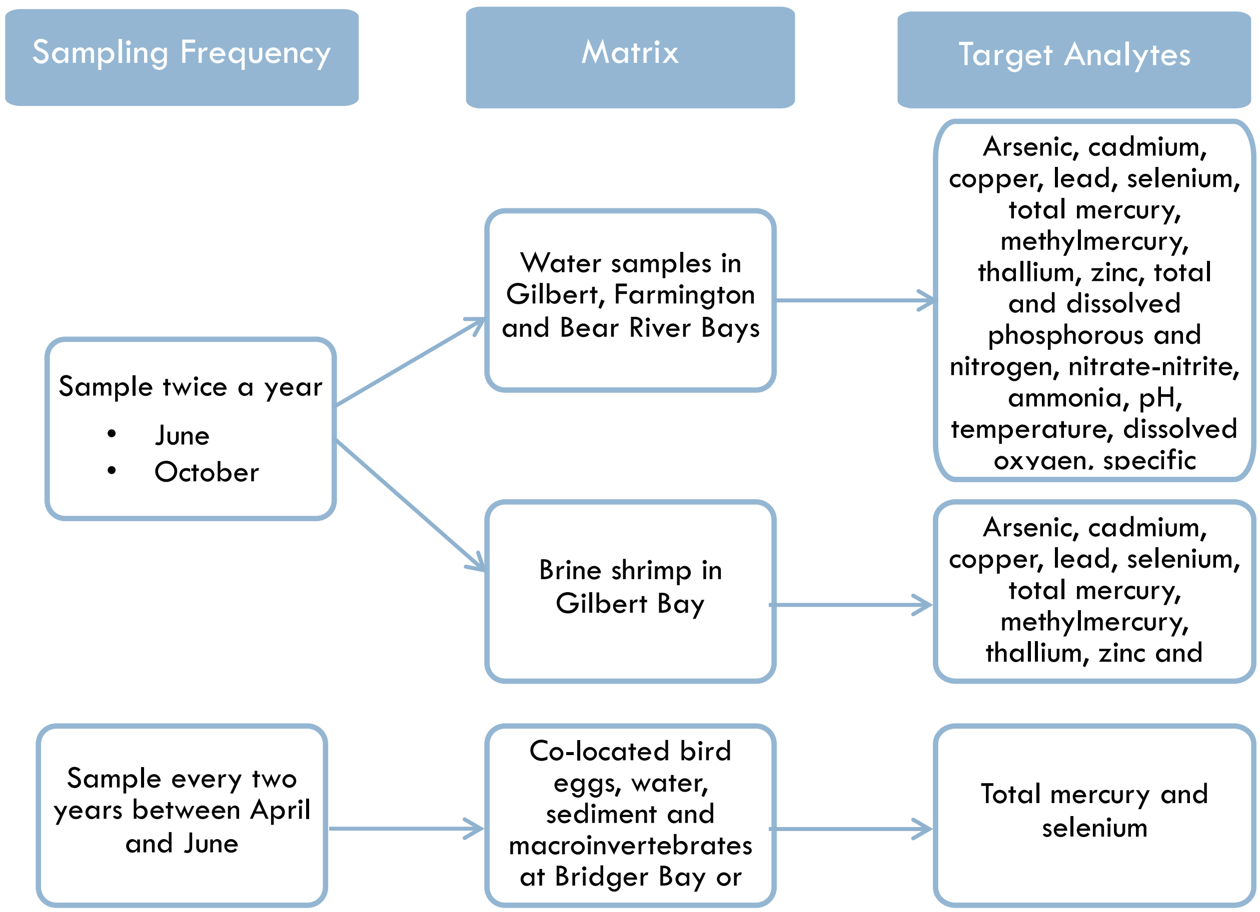

FIGURE 3 GREAT SALT LAKE BASELINE SAMPLING WORK PLAN

3.4.1 Water and Brine Shrimp

Water and brine shrimp will be sampled and analyzed a minimum of twice per year using Standard Operating Procedures and within the Quality Assurance Program Plan requirements (UDWQ, 2014). Samples will be collected once during the bird nesting season (June) and once during the fall brine shrimp cyst harvest (October). Samples will be collected at a minimum of 11 locations; 8 locations in Gilbert Bay, 2 in Farmington Bay and 1 in Bear River Bay as shown in Figure 2 and Table 4. These locations were selected to remain consistent with locations used in routine sample collection and research since 1994, conducted by the Utah Division of Wildlife Resources/Great Salt Lake Ecosystem Program and USGS, Utah Water Science Center (Naftz et al., 2008b). Additional locations, such as in Gunnison Bay, may be added or samples collected more frequently as resources and access become available.

At each location, water samples will be collected 0.5 meters (m) from the bottom of the water column and 0.2 m from the surface. In situ field measurements including temperature, pH, specific conductivity, dissolved oxygen, secchi depth, total water depth, and depth to deep brine layer will be made using a multi-parameter probe at the location where water and/or brine shrimp samples are collected. A composite sample of brine shrimp from three vertical hauls will be collected at Sites 1 through 8 in Gilbert Bay when present.

TABLE 4 SAMPLE POINTS AND COORDINATES

Sample Points	Target Bay	Approximate Coordinates
1	Gilbert Bay	Latitude 40°46'07", Longitude 112°19'38"
2	Gilbert Bay	Latitude 40°53'56", Longitude 112°20'56"
3	Gilbert Bay	Latitude 41°02'23", Longitude 112°30'19"
4	Gilbert Bay	Latitude 41°04'22", Longitude 112°20'00"
5	Gilbert Bay	Latitude 41°06'44", Longitude 112°38'26"
6	Gilbert Bay	Latitude 41°06'37", Longitude 112°27'04"
7	Gilbert Bay	Latitude 41°11'16", Longitude 112°24'44"
8	Gilbert Bay/ Farmington Bay	Latitude 41°04'52", Longitude 112°13'51"
9	Farmington Bay	Latitude 41°02'24.36", Longitude 112°09'51.12"
10	Farmington Bay	Latitude 41°01'53", Longitude 112°08'23"
11	Bear River Bay	Latitude 41°17.34, Longitude 112°22.006
12	Gunnison Bay	To be determined

Water samples and brine shrimp will be analyzed for the minimum analytes shown in Table 3. Additional analytes may be included as part of the same analytical suite, as resources are available, based on future assessment needs or per the objectives of independent research studies.

3.4.2 Bird Eggs

The eggs of shorebirds will be sampled to characterize the birds' exposure to mercury and selenium present in the open waters of the Lake. Bird eggs will be sampled a minimum of once every 2 years to allow UDWQ to assess compliance with the Lake's tissue-based, numeric water quality standard for selenium and document levels of exposure to mercury. Per the recommendations of UDWQ's Selenium Science Panel, American Avocets and Black-necked Stilts foraging along the shoreline of Gilbert Bay will be targeted initially (CH2M HILL, 2008). Bird eggs will be sampled and evaluated and tissues analyzed using SOPs and the QAPP.

A single egg will be collected from a minimum of five avocet nests and five stilt nests (preferably eight nests of each species) after the clutches are completed (total of 10 eggs). Each embryo will be checked for stage of development. Late-stage embryos will be examined for developmental abnormalities, including a determination of the embryo's position in the egg. Egg contents will then be analyzed for total selenium and total mercury and concentrations reported on a dry-weight basis, along with percent moisture of each sample.

Areas considered for bird egg collection will be Bridger Bay on north side of Antelope Island and Saltair. Additional locations may be added or additional eggs collected as allowed by the egg collection permit, as resources are available, or per the objectives of independent research studies. All samples will be collected adjacent to or within the open waters of the Lake to ensure that samples are representative of pollutant exposure from the open waters, rather than other habitats adjacent to the Lake. Implementation of the selenium standard will include egg collection until work is completed to allow water and brine shrimp selenium concentrations to be used as surrogates for designated use support.

3.5 Quality Assurance Project Plan

The QAPP presents the quality assurance and quality control requirements to ensure that the environmental data collected as part of the BSP will be of the appropriate quality to comply with the DQO's (Table1). Specific protocols for sample handling and storage, chain of custody, laboratory analyses, data handling, and data evaluation are defined.

The QAPP includes the following information:

- Project Management including study site description, project organization, data quality objectives, documentation and records
- Data Generation and Acquisition including sample design and methods, sample handling and custody, analytical methods and reporting, quality control requirements, corrective action, data management and data validation and usability

- Standard Operating Procedures (SOPs) for sampling and analyzing key water quality parameters and pollutants

All sampling and analytical activities required by the BSP will follow the requirements described in the QAPP (UDWQ, 2014).

3.6 Reporting

Sampling began in 2011 and will continue on an annual basis. Detailed field and laboratory data, analysis, and summary of results will be presented every other year in the 305(b) *Integrated Report (UDWQ, 2014)*. It is UDWQ's policy to retain analytic data in perpetuity. All project files including electronic copies of analytical data, field notes, data sheets and journals, photographs, analyses, and reports will be retained for a period of at least 10 years after the year of data collection.

3. STUDIES TO IMPROVE BASELINE SAMPLING PLAN FOR THE OPEN WATERS OF GREAT SALT LAKE

The BSP presented in Section 2 represents a starting point that will enable UDWQ to begin the development of a long-term database describing the water quality condition of the Lake. The BSP is intended to be adapted and revised as the knowledge and understanding of the Lake ecosystem processes improves. This section provides a summary of studies UDWQ will complete to inform, build upon, and advance the BSP.

5.1 Introduction

The unique and dynamic nature of the Lake are well documented in the literature, especially as related to the lake's salinity and history of management and modifications. Before the construction of the railroad causeway across the central part of the Lake in 1959, the salinity and chemistry of the water is thought to have been well-mixed throughout the lake (www.wildlife.utah.gov/gsl). After the causeway's completion, the main body of the lake was physically divided into a north arm and a south arm. As a result of the predominance of freshwater inputs in the south, the north arm of the lake became much more saline and the south arm became density stratified, with a deep brine layer variably underlying the mixed, less-saline surface water.

Salinity varies both spatially and temporally within the lake and is affected by lake levels, seasonal fresh water inputs, and dikes and causeways that divide the lake. It ranges from 1 to 6 percent in the Bear River and Farmington Bays to 27 percent in Gunnison Bay (North Arm). The main body of the lake, also known as the Gilbert Bay (South Arm) has salinity ranging from 7 to 15 percent (UDWQ, 2010). In addition, the lake water is alkaline with an average pH of 8.6, and is stratified in some locations with a sharp chemocline occurring at approximately mid-depth. The water column at and below this chemocline (i.e., the deep brine layer) is anaerobic.

This varied water chemistry and complex matrix drives the fate and transport of pollutants in the lake and has an effect on sampling and analytical procedures, possibly making standard methods inappropriate. There is a need to understand these effects to make sampling and analysis of water quality parameters and other variables more reliable. The following section identifies studies UDWQ will complete with the objective of improving the goals, objectives, and sampling and analytical methods described in the BSP. Figure 4 illustrates how the studies will help inform and advance the BSP. Prioritization of these studies is detailed in Section 5.

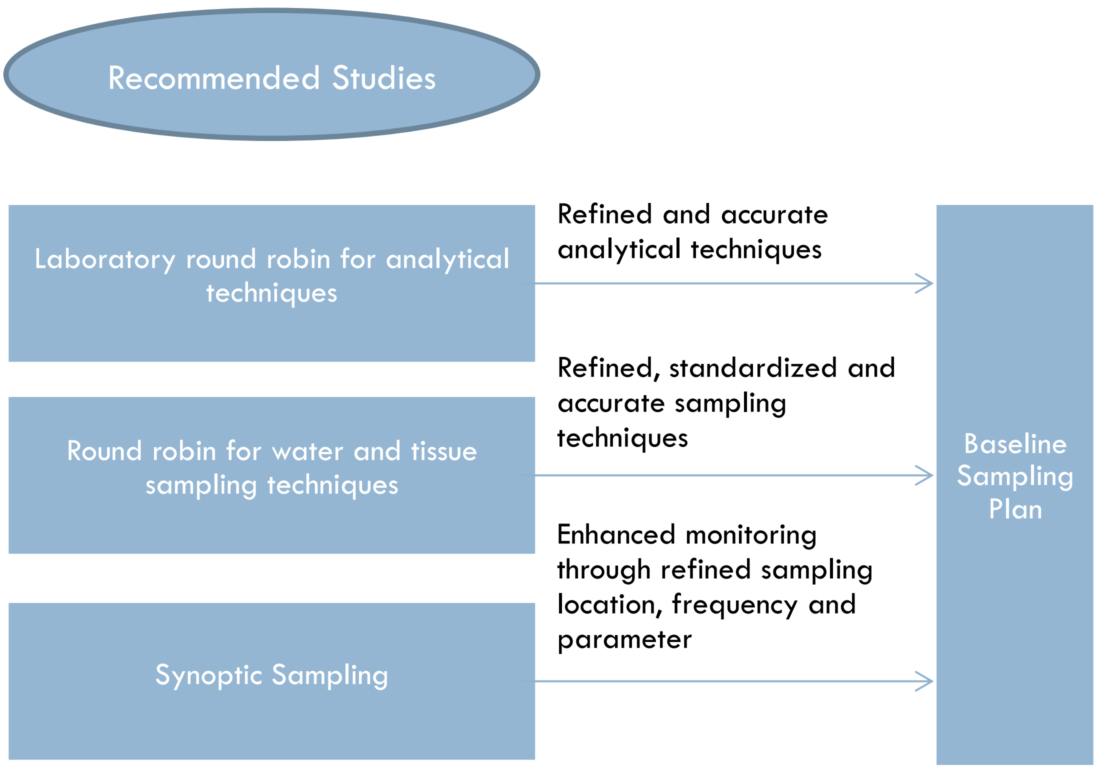

FIGURE 4 RECOMMENDED STUDIES TO IMPROVE UPON THE GREAT SALT LAKE BASELINE SAMPLING PLAN

5.2 Laboratory Round Robin Study for Analytical Techniques

5.2.1 Problem Statement

Due to the complex geochemical properties of the Lake water, sample preservation, storage, and preparation, as well as accurate analysis of target analytes, are challenging. Standard analytical methods may fail to accurately measure certain analytes due to interferences from high concentrations of total dissolved solids and other matrix effects. For example, a round robin study conducted by UDWQ for the assessment of selenium in the Lake found selenium concentrations to vary widely among different analytical techniques used (Moellmer et al., 2006). Similarly, USGS has found that it needed to alter its analytical methods to accurately measure nutrients in the Lake (personal communication, Harold Ardourel, National Water Quality Laboratory, USGS). It is thus prudent to conduct an interlaboratory comparison otherwise known as a laboratory round robin study for key target analytes in the Lake water as part of implementing a long-term monitoring program. This will help identify, develop, and validate reliable analytical methods for the lake.

5.2.2 Study Objectives

This study will focus on identifying, validating, and optimizing laboratory analytical methods and will provide answers to the following questions:

- What analytical methods should be used for analysis of key pollutants of concern in the Lake?
- Which laboratories are best suited for analyzing these samples in terms of accuracy, precision, and cost?
- What quality assurance procedures should be followed for accurate sample handling and analysis?

Recommendations from this study will help standardize analytical methods among different agencies monitoring and studying water quality and the ecosystem of the Lake.

5.2.3 Approach

This study will be conducted during the early phase of the BSP implementation and will focus on key pollutants that are of high priority and pose the greatest risk to the Lake's ecosystem. The Lake's water chemistry varies widely; salinity ranges spatially from 1 to 20 percent in Gilbert, Farmington and Bear River Bays and significant differences can be found between the upper and deep brine layers in Gilbert Bay. The round robin will capture a range of conditions to provide assurances that the methods used for long-term monitoring apply at all conditions. Test water replicating a range of salinities and composition of the Lake water will be shipped to an independent lab for replication and spiking. The independent lab will replicate and/or spike each sample with known concentrations of target analytes before shipping them to participating laboratories for the round robin study.

5.2.4 Variables to be Assessed

The laboratory round robin study will be conducted for the following analytes in water samples:

- Total and methyl-mercury
- Other metals and metalloids—total selenium, total arsenic, total copper, total cadmium, total lead, and total zinc
- Nutrients—total and dissolved nitrogen, total phosphorus, orthophosphate, total Kjeldahl nitrogen, ammonia-N, and nitrate+nitrite-N

The round robin study will include the following analytical methods, though this may be adjusted based on other valid findings of other reliable analytical methods:

- Total mercury—EPA Method 1631, Revision E, using oxidation, purge and trap and cold vapor atomic fluorescence spectrometry or equivalent
- Methyl-mercury—EPA Method 1630 by distillation, aqueous ethylation, purge and trap and cold vapor atomic fluorescence spectrometry and USGS methods by aqueous phase ethylation, followed by gas chromatographic separation with cold vapor atomic fluorescence detection
- Total selenium—Hydride generation – atomic absorption, hydride generation – atomic fluorescence spectrometer, dynamic reaction cell (DRC) inductively coupled plasma – mass spectrometry (ICP-MS), and reductive precipitation with ICP-MS
- Other metals and metalloids—EPA Method 1640, DRC ICP-MS, collision cell ICP-MS, and reductive precipitation with ICP-MS
- Nutrients—Alkaline persulfate digestion methods for simultaneous determination of dissolved and total nitrogen and phosphorus, low-level phosphorus determination by EPA persulfate digestion (Method 365.1), or other USGS-recommended methods

5.2.5 Participating Laboratories

Laboratories to be included in the round robin study will be selected for their ability to comply with the QAPP requirements and have National Environmental Laboratory Accreditation Certification with the State of Utah or equivalent credentials.

5.3 Round Robin Study for Water Sampling Techniques

5.3.1 Problem Statement

Several local, state, and federal agencies are currently sampling water in the Lake for purposes of monitoring trends in water quality and understanding impacts to the ecosystem and to the industries that depend on resources from the Lake. Sampling has historically been done by different investigators with different study objectives. Further, the complex geochemistry of the Lake's water may preclude the use of certain equipment and require unique calibration methods, preservation methods, etc. These differences and issues may potentially bring the accuracy of water quality data into question. Thus, it is important to standardize sampling techniques, sample preservation, and instrument calibrations methods among all agencies. It is the objective of this study to facilitate a discussion among current investigators and other interested parties and complete a round robin study of sampling methods as required to determine the best available method for use by agencies in monitoring the water quality of the Lake. This will facilitate more efficient data comparison in future studies including lake assessments.

5.3.2 Study Objectives

This study will provide answers to the following questions:

- What methods/equipment should be used to collect water and tissue samples from the Lake?
- Do grab samples collected from a certain depth adequately represent lake water quality versus composite samples collected across water depth?
- At what depth(s) should water and tissue samples be collected from portions of Gilbert Bay that have a deep brine layer?
- What method, vertical haul or horizontal tow provides the best representation of exposure of brine shrimp to pollutants?
- What field measurement equipment, calibration methods, and measuring procedures should be followed for dissolved oxygen, salinity, pH, clarity, and temperature measurement in the lake?
- What quality assurance procedures should be followed for accurate sample collection, preservation, storage, and handling?

5.3.3 Approach

UDWQ will facilitate a meeting of current Great Salt Lake investigators, interested agencies and parties to discuss current sampling practices. The discussion will focus on defining current methods and equipment that are used, identifying when and where those methods and equipment are used including the benefits and risks of each, and achieving consensus on standardization of methods and equipment to be used for sampling. The outcome of the meeting(s) will be SOPs for monitoring Lake water quality that are accepted by participating agencies. For any method or equipment that merits further investigation and comparison, UDWQ will facilitate a round robin study, in partnership with other agencies, to determine the preferred and recommended method for monitoring Lake water quality.

Information gathered from this study will inform and improve upon existing water sampling SOPs and standardize them for use among all agencies.

5.3.4 Variables to be Assessed

At a minimum, the following field water quality parameters and sampling methods will be addressed:

- Dissolved oxygen measurement and instrument calibration
- Specific conductivity
- Density
- pH measurement and instrument calibration
- Temperature measurement and instrument calibration
- Clarity measurement and instrument calibration
- Sampling depth (grab samples versus samples composited over depths and standardized sampling depth for upper and deep brine layers)
- Sampling equipment

5.3.5 Spatial Boundaries

In the case of a field round robin, water samples will be collected and field measurements conducted at locations representing typical salinity conditions in Farmington, Bear River, Gunnison and Gilbert Bays.

5.4 Synoptic Sampling of Great Salt Lake

5.4.1 Problem Statement

The lake is both spatially and temporally dynamic in nature. It is essential to characterize and evaluate the Lake's water quality for known pollutants of concern as well as emerging pollutants as listed by the EPA through an intensive short-term synoptic sampling investigation. It is important to verify assumptions regarding sampling locations and seasons. While the BSP will monitor trends for certain pollutants, this study will provide a reference for other possible pollutants and confirm sampling locations/seasons. It will establish an important reference of the Lake's current water quality condition, help in optimizing the long-term BSP, and determine if and how water quality changes over time.

5.4.2 Study Objectives

This study will focus on developing recommendations to improve the BSP by providing answers to the following questions:

- What are the concentrations of potential pollutants not included in the BSP?
- Are pollutants of emerging concern present in the Lake?
- How do concentrations of pollutants vary spatially and temporally?
- What are the optimal sampling times (i.e., seasons) and locations to obtain a good representation of the Lake's water quality condition?
- How do the concentrations of some key pollutants vary with lake flows, lake levels, and lake chemistry (e.g., salinity, pH, temperature, dissolved oxygen, etc.)? How do concentrations of this wider list of potential pollutants change over the long-term?

5.4.3 Approach

This study will be conducted over 1 year with monthly sampling events to accommodate seasonal effects and varying lake levels. Also, the study will be repeated every 5 years to capture potential changes in the lake's water quality and to update or recommend changes to the BSP. Collocated water and brine shrimp samples will be collected. All sampling and analysis will be completed per the most current and accepted SOPs and QAPP (these documents may be updated per the recommended round robin studies discussed previously). It should be noted that a round robin cannot be conducted on all measured variables and characteristics. However, results obtained and lessons learned from existing round robin studies will be referenced as needed.

5.4.4 Variables and Characteristics to be Measured

The following will be sampled dependent on available resources:

- Physicochemical characteristics in water—Flow, depth, pH, temperature, specific conductance, secchi disk depth, turbidity, and total suspended solids
- Chemical characteristics in water—Dissolved oxygen, salinity, total dissolved solids, biochemical oxygen demand, and total organic carbon in water
- Biological characteristics in water—Enterococcoi, chlorophyll a, phytoplankton identification and enumeration, and zooplankton identification and enumeration (including brine shrimp)

- Major ions, metals and metalloids in collocated water, and brine shrimp—Aluminum, antimony, arsenic, asbestos, beryllium, cadmium, calcium, copper, chromium, hexavalent chromium, lead, magnesium, manganese, total mercury, methyl mercury, nickel, potassium, selenium, silver, sodium, thallium, and zinc
- Nutrients in water—Ammonia-N, total and dissolved phosphorus, orthophosphate, total and dissolved nitrogen, nitrate+nitrite-N and total kjeldahl nitrogen
- Future sampling will consider additional pollutants such as emerging pollutants in water, and brine shrimp—Pharmaceutical and personal care products, endocrine disrupters, and persistent organic pollutants.

5.4.5 Spatial Boundaries

The study area will include the entire lake, including Gilbert Bay, Gunnison Bay, Farmington Bay, and Bear River Bay. Sample sites may be adjusted based on accessibility, depth of water, weather constraints, etc. Additional major riverine inflow sites will be considered dependent on available resources.

4. RESEARCH PLAN FOR GREAT SALT LAKE

Great Salt Lake's complex and unique characteristics make establishing water quality criteria, monitoring its water quality, assessing its designated use support and implementing pollution control programs extremely challenging. It is UDWQ's objective to improve on the available dataset and methods for assessing the Lake. This section outlines a systematic and collaborative approach to research that will enable UDWQ to proactively fulfill its responsibilities under the CWA.

The objectives of these studies are to support:

1) *Development of numeric water quality criteria specific to the Lake*
2) *Monitoring of the Lake's water quality*
3) *Assessment of the Lake's designated uses and,*
4) *Implementation of pollution control programs*

6.1 Objectives and Collaboration

The research identified in this section is designed to address UDWQ's regulatory responsibilities in collaboration with its partners. These include supporting the development of numeric water quality criteria, monitoring and assessing designate use support and implementation of pollution control programs. There are numerous questions that have been posed by researchers over the years as they have sought to understand the geochemistry and ecology of the Lake. UDWQ has reviewed a wide array of literature and attended numerous meetings facilitated by Lake researchers and stakeholders to listen to and identify those issues that appear to be of most importance to Lake water quality. A detailed list of research questions, provided in Appendix A, was compiled by CH2M Hill. This list, along with research questions defined as part of other Lake water quality efforts were consolidated into a systematic research framework to leverage synergies between efforts and more efficiently focus available resources. Studies were grouped into the following three research areas (with corresponding section numbers in this document):

- Common Need (Section 4.2)
- Open Water Research (Section 4.3)
- Wetlands Research (Section 4.4)

While work is generally divided to address (1) open water and (2) wetland habitats, these habitats overlap and provide opportunities for collaboration. The research outlined for the Lake's wetlands is ongoing and part of the State Wetland Program Plan (http://www.deq.utah.gov/ProgramsServices/programs/water/wetlands/monitoring.htm). More details on the Wetland Program will be developed as part of Core Component 3 of the Great Salt Lake Water Quality Strategy.

As discussed in previous sections, the Lake provides innumerable opportunities for researchers to investigate the unique and complex interactions and processes that regulate this dynamic resource. The challenge is to review these opportunities and focus efforts and resources on areas most critical for UDWQ to fulfill its responsibilities. Further, there are many resources in the Lake (e.g., minerals, land, wildlife, recreation, water resources, endangered species, water quality, etc.)—all are inextricably linked but are managed by different agencies. Thus, while this section focuses on the identification of research to support UDWQ's efforts to protect and maintain the Lake's water quality, it is important to note that many of these efforts overlap and help address other Lake resources, especially where designated use support relates directly to biological resources and recreation. A collaborative approach to planning, conducting, and reviewing these research needs is critical to efficiently and effectively manage all of the resources of the Lake.

It is UDWQ's intent that the research studies identified in this section are conducted in collaboration and coordination with the other state and federal agencies responsible for the Lake's resources. UDWQ has already engaged with the Great Salt Lake Advisory Council and other entities to become an active partner and participant in their planning and research activities and they, in turn, in UDWQ's investigations (e.g., FFSL's Great Salt Lake Comprehensive Management Plan, the UDWR's Technical Advisory Group, etc.). Ongoing coordination and support among agencies in this research is critical for leveraging resources and focusing efforts to achieve management objectives.

6.2 Common Need

One need, common to all research needs is the formation and maintenance of a data repository for use in UDWQ's Great Salt Lake studies. Development of this data repository will affect how they are conducted, will influence how the results are implemented by UDWQ and its partners, and affect the availability of the data to the public. Another need common to all is a comprehensive model that could be used to dynamically and reliably predict the hydrologic input and response and the hydrodynamics of the Lake. Such a model will improve the understanding of the lake dynamics, the nature and causes of its fluctuations, and consequently assist in predicting lake fluctuations and water quality.

6.2.1 Data Repository

Problem Statement. Effective assessments of water bodies and successful monitoring programs require the integration of all available data from multiple sources. Local, state, federal, and other entities that are studying the Lake need to compile and manage data and analytical reports so that the information gathered is understandable and available to decision makers, stakeholders, and public audiences. This can be achieved by creating an online data repository, where all Lake data that meets UDWQ's or the hosting agency's data quality will be submitted, managed, and accessed.

Study Objective. This project will focus on developing an approach for managing Lake data in a way that enables UDWQ to work with data partners to set priorities, address major water quality issues, and report status and trends more effectively. The database will allow streamlined data entry and retrieval, meet data quality, and provide effective agency and stakeholder use and public access to the data.

Approach. UDWQ uses a database, Ambient Water Quality Management System (AWQMS) for statewide water quality data that will eventually include data from the Lake. UDWQ's intent is to develop independent but compatible databases for each of its special studies (e.g., development of the selenium water quality standard, and assessments of mercury and wetlands). Upon completion of these special studies, these databases will be merged with AQWMS. UDWQ will work with its partners to identify a platform that allows the public access to the Lake project's database but also databases maintained by others for the Lake data.

6.2.2 Great Salt Lake Hydrologic and Hydrodynamic Model

Problem Statement. The fluctuation of the Lake with climate and precipitation has an impact on its water quality, biological communities, and on the industries that depend on its resources. Due to the shallowness of the lake, small changes in lake levels result in large changes in surface area and create a highly variable shoreline. Changes in water quantity also have a measurable impact on lake salinity.

Flow inputs to the Lake from tributaries and discharges have been monitored by USGS flow gauges as part of other studies evaluating sources of selenium, mercury and nutrients (Naftz et al., 2009a; Naftz et al., 2009b). Recently internal salt balance models were adapted to predict salinity changes in Gilbert and Gunnison Bay as a result of an alteration (bridge opening) in the Union Pacific Railroad Causeway (White et al. 2014; UPRR, 2014). The USGS is currently conducting studies to understand how inflows to the Lake mix with the open waters at the Gilbert Bay (USGS, 2013).

Though these studies have and will answer several questions on Lake hydrology and hydrodynamics, to date, no comprehensive model is available that could be used to reliably predict the hydrologic input and response and the hydrodynamics of the Lake for changes in the watershed. Such a model will improve the understanding of the lake dynamics, the nature and causes of its fluctuations, and consequently assist in predicting lake fluctuations and water quality.

This study will be conducted in collaboration with partner agencies and research groups studying watershed hydrology and lake hydrodynamics.

Study Objectives. The first objective of this study is to develop an accurate hydrologic model for the Lake that will be able to predict lake inflows, outputs (e.g., evaporation), and lake levels and will serve as a useful tool in understanding changing lake salinities and pollutant sources and loads. The second objective of this study is to develop a hydrodynamic model of the Lake that will incorporate the hydrologic inputs and outputs but also improve the understanding of circulation and constituent transfer between bays within the Lake. Such a model will be a critical first step in developing a comprehensive fate, transport, and mixing model for nutrients and other pollutants.

Approach. To develop a hydrologic model, past information on flows to the Lake including groundwater inflow, evaporation rates, and lake levels and mixing patterns will need to be compiled and analyzed. The model will also incorporate the influence of water diversions, land use, and other landscape characteristics on water and salt delivery to the Lake. This analysis will be useful to identify data gaps and the need for further data collection. Existing and new information gathered will be used to develop a robust hydrologic model for the Lake.

The effects of surface heat flux and wind forcing on temporal and spatial variations in flow and mixing patterns within the Lake will need to be investigated numerically in a hydrodynamic model. The effect of the various Lake's causeways has been recently modeled for the purpose of altering the railroad causeway (White et al., 2014; UPRR, 2014). As previously described, the USGS has already begun work to understand mixing patterns in the south end of Gilbert Bay (USGS, 2013). A comprehensive hydrodynamic model should incorporate the work produced from these models. Any model will require validation. This study will also validate the model by collecting more data and comparing these with the predicted data by the developed model.

6.3 Open Water Research

Three areas of research were identified to address the needs for the open waters of the Lake (the open water includes all of the Lake's bays but does not include their mudflats or wetlands). The three focus areas are the water, the lower trophic level and the upper trophic level (see Figure 5) and are described as follows:

1. **Water.** One of the highest priorities for establishing criteria and assessing if the water quality is sufficient to support the aquatic wildlife and recreational designated uses is the identification of pollutants present in the Lake and the risk they may pose. As mentioned in earlier sections, some studies have already identified selenium, mercury, several other metals/metalloids, and nutrients to be of potential concern, but many data gaps remain. Information is needed to characterize the effects of Lake hydrology and chemistry on the fate of these pollutants, to track past trends, to identify their sources, and to develop mass balance models to aid in predicting future conditions or quantifying load reductions. Outcomes from these studies will support UDWQ's development of numeric criteria and assessments by identifying (1) what pollutants are of concern, (2) how they are impacted by the lake's unique saline chemistry, and (3) how pollutant loads might be managed and regulated in the future to protect water quality conditions in the Lake and provide dischargers with more certainty in managing their effluent.

2. **Lower Trophic Level.** The lower food chain components of the Lake are represented by planktonic and benthic species, such as algae, bacteria, zooplankton and macroinvertebrates. Maintaining healthy populations of these species is essential for the Lake ecosystem, as they form the critical aquatic food chain for the millions of migratory birds that use the lake water during nesting and wintering. Nutrients and other pollutants in water may pose a risk either because they are toxic to lower organisms; passed up the food chain to higher species such as birds, and humans; or because they negatively affect primary and secondary production in water. Toxic pollutants may bioaccumulate or nutrients can cause eutrophication, resulting in adverse health and reproductive effects, or have negative impacts directly on the ecosystem, such as eutrophication. Whatever the scenario, understanding the fate and transport of these pollutants from water to the components in the Lake food web is important for setting numeric criteria and assessing if pollutants are adversely affecting the ecosystem.

3. **Upper Trophic Level.** The upper food chain of the Lake is represented by several species of birds that visit the lake every year for wintering and nesting. The Lake is extremely important to migratory birds. One of the most important roles the Lake ecosystem has to play is sustaining the migratory birds using the Pacific Flyway and a portion of the Central Flyway. It supports millions of shorebirds, as many as 1.7 million eared grebes, and hundreds of thousands of waterfowl during spring and fall migration every year (http://ut.water.usgs.gov/greatsaltlake/). For some species, the Lake ecosystem is important

for breeding, for others the area is important during migration, and for still others the lake provides important wintering habitat. Some species use the lake for more than one aspect of their natural history. The Lake and its marshes provide a resting and staging area for birds, as well as an abundance of brine shrimp, brine flies, and other invertebrates that serve as their food. Studies have been conducted to identify and enumerate the different avian species in and around the Lake (Manning and Paul, 2003; Cavitt, 2006; Cavitt, 2008a; Cavitt, 2008b) and much work has been done to understand the effects of pollutants on avian population (CH2M HILL, 2008; Vest et al., 2009). The UDWR continues to complete research to understand the use of the Lake by birds and how to better manage this resource. However, scientific uncertainty exists, and there is a need for further research to enable UDWQ to accurately assess the aquatic wildlife designated use.

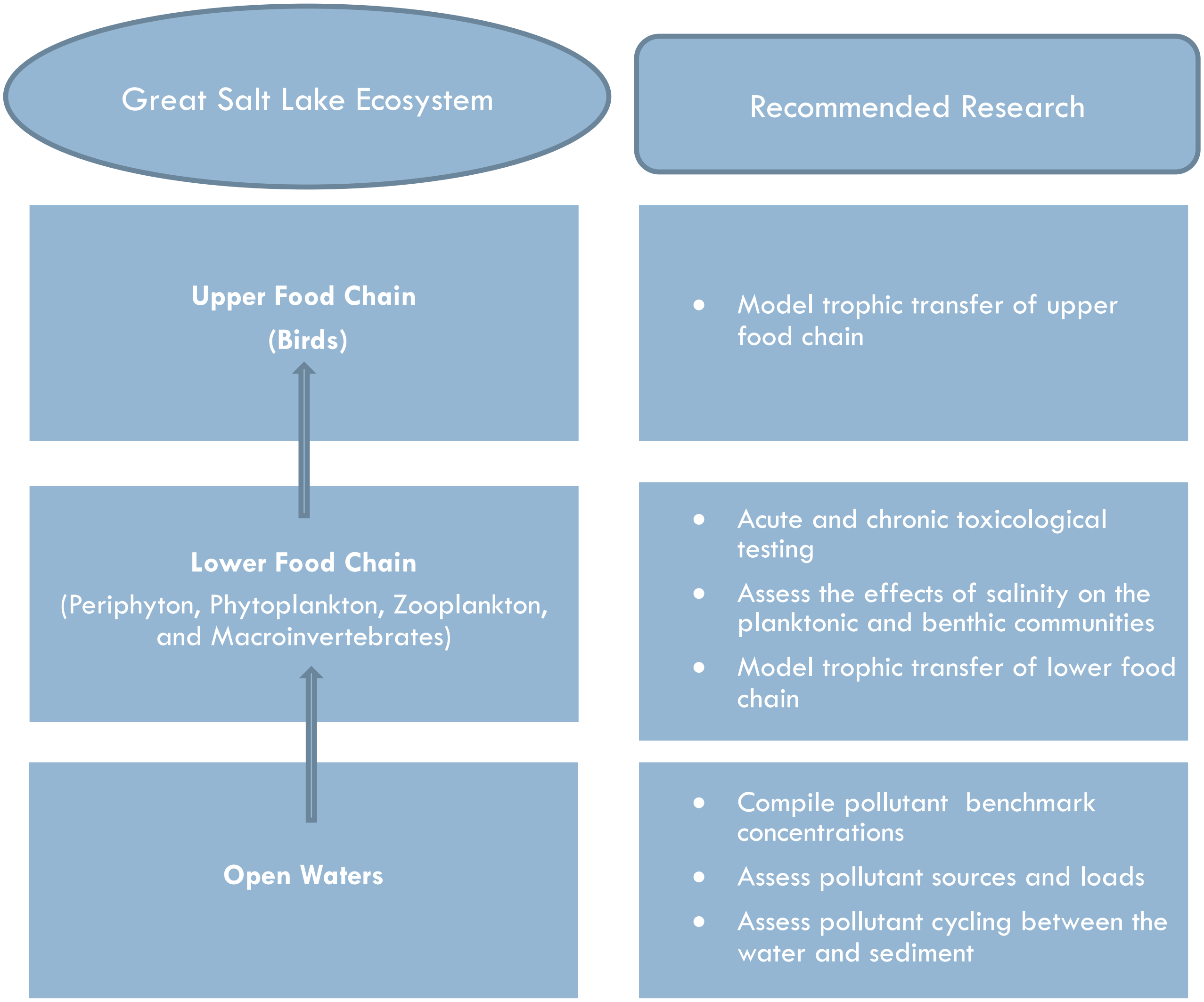

FIGURE 5 RECOMMENDED RESEARCH TO SUPPORT THE DEVELOPMENT OF CRITERIA AND ASSESS THE AQUATIC AND RECREATIONAL DESIGNATED USES

4.3.1 Great Salt Lake Open Water Research

COMPILE WATER QUALITY BENCHMARKS TO PRIORITIZE POLLUTANTS AND DEVELOP CRITERIA

Problem Statement. Pollutant-specific water quality benchmark concentrations can be used to define threshold values against which measured concentrations can be compared, to help assess the potential effects of pollutants on water quality. Benchmarks are pollutant concentrations that are likely to result in adverse effects to aquatic and aquatic-dependent life. Both the USGS and EPA have benchmark concentrations for several pollutants in surface water; however, these are either for freshwater or marine water bodies. Since the Lake is unique with varying levels of salinity, these benchmarks are not applicable for all conditions. A review of the literature is required to identify potential water quality benchmarks for the salinities and species observed in the lake and also to determine if these benchmark concentrations appear to be appropriate for the Lake's foodweb. More discussion of this approach and the research necessary can be found in Component 1: Proposed Approach for Developing Aquatic Life Numeric Criteria for Priority Pollutants.

Study Objectives. The objectives for this study are as follows:

- Conduct a literature review to identify the Lake organisms and potential water quality benchmarks for pollutants that have been identified to pose risks to the aquatic wildlife designated use of the Lake, for waters with various salinities—from fresh to hypersaline.
- Validate the applicability of these benchmark concentrations by looking at how they were derived. Were the benchmarks derived using elements of the food chain that are analogous to the Lake (e.g., a marine benchmark developed to protect fish may not be applicable to the Lake's open waters)?
- Compile benchmarks and supporting documentation in a report that may be reviewed and endorsed by Lake research groups and stakeholders. The intent of the benchmarks is not to serve as numeric water criteria but to provide a tool, similar to those used in risk assessments that can be used to evaluate the Lake's water quality and guide future decisions.

Approach. A literature review will be conducted to define the organisms that live in and rely on the waters of the Lake for sustenance. The literature review will also identify applicable water quality criteria in use today, as well as pollutant concentrations identified by researchers as significant thresholds or benchmarks for the survival of various elements in the food web. Efforts will be focused first on the pollutants targeted by the BSP and then be expanded to include other possible pollutants as identified by the synoptic sampling effort or deemed necessary by UDWQ. Benchmarks will be grouped by their salinity class as defined in Component 1 (i.e., freshwater, marine, and hypersaline waters).

Historical and ongoing water quality and other ecological data, such as collocated concentration of pollutants in water and transfer through the food web, and any observed negative effects on avian reproduction, may be used to determine the degree to which the presence of pollutants in concentrations above the benchmarks demonstrate toxicity. This effort will require collaboration with other studies identified in this section.

All applicable literature will be compiled into a comprehensive review summary, including a list of identified benchmark concentrations, name, location, and percent salinity of the water body and how existing studies determined these benchmark concentrations. Available thresholds or benchmarks will be evaluated in terms of the similarity of methods, organisms, or toxicological characteristics used to derive them with parallel characteristics of the Lake. Benchmarks that were developed using similar elements of the food web will be of particular interest.

Work completed as part of this study will be conducted in coordination with UDWQ's Water Quality Standards Workgroup. Data collected as part of the BSP (section 2 of this component) and the synoptic sampling study (section 3) will be used to compare to relevant water quality benchmarks.

POLLUTANT SOURCES AND LOADS

Understanding the sources and loads of pollutants that are suspected to threaten or concluded to impair the designated uses of the Lake is essential to protecting the water quality. Recent studies to develop water quality criteria and assess the Lake's designated uses for impacts from selenium, mercury, and nutrients each resulted in an evaluation of sources and loads of these pollutants as part of the study (Diaz et al., 2008; Naftz et al., 2008; Peterson and Gustin, 2008; Naftz et al., 2009; UDWQ, 2011). Mass balance models have also been developed for selenium and mercury (Johnson et al., 2006; Diaz et al., 2009; UDWQ 2011). However, these studies and models will need to be revisited to identify gaps and to refine the understanding of where the pollutants come from and what happens to them within the lake.

Sources, Loads, Mass Balance, and Mixing of Nutrients in Great Salt Lake

Problem Statement. Farmington Bay in the Lake was found to be hypereutrophic by a study conducted by Wurtsbaugh et al. (2006). The bay receives discharges from several wastewater treatment plants, the Jordan River, and a sewage canal. It receives nutrients from both point and nonpoint discharges. Also, water samples collected during the summer of 2006 from the bay indicated the presence of cyanobacterium *Nodularia spumigena,* raising concerns about the water quality of the bay. In contrast, the algal population in Gilbert Bay, which is supported by nutrients, is an important diet for brine shrimp and brine flies. Some studies show that Farmington Bay nutrient inputs are critical influences on the lake, especially for Gilbert Bay (Belovsky et al., 2011). In Component 4 of the Great Salt Lake Water Quality Strategy, UDWQ will develop a plan to understand and assess nutrient dynamics in the Lake's bays. An improved understanding of sources, loads, and a mass balance of nutrients within the lake will help in understanding its effects and in managing them. This study will identify the sources of nutrients entering the Lake, estimate total loads, and develop a mass balance and mixing model for nutrients in the Lake.

Study Objectives. This study will begin with identifying the sources and loads of nutrients from tributaries and municipal and industrial discharges to the lake, as well as from flux through sediments, if any, and in developing a mass balance of nutrients in the lake. A nutrient and biological mixing model will then be created for the lake of nutrient fate and transport. This information will then be incorporated into Core Component 4 of the Strategy that will develop a nutrient assessment plan. It will also be used to inform the UDWR's brine shrimp population dynamics model.

Approach. Quantification and modeling of nutrients and water column biota response provides the crucial biological uptake and chemical recycling that is the underpinning for any subsequent waterborne pollutant fate and transport modeling for the lake. The studies and modeling must begin with the development of an accurate hydrodynamic model with added components to describe salinity and nutrient dynamics.

Hydrodynamic model components have been previously described; additional data to support a full nutrient dynamics model include the following:

- Quantification of all influent loads of key nutrient species
- Internal sediment losses and fluxes to the water column
- Atmospheric exchange
- Water column planktonic processing and transformation of nutrients; seasonal measurements of algal biomass, chlorophyll, and nutrient content
- Interbay transfer

Sources, Loads, Mass Balance, and Mixing of Selenium in Great Salt Lake

Problem Statement. Naftz et al. (2008b) conducted a study to identify the sources and loads of selenium entering Gilbert Bay. Both continuous and non-continuous stream gages were used to collect flow data from inflows to Gilbert Bay and the concentration of total selenium, as well as selenium species, were measured to evaluate loads to the Lake. The study concluded that additional unquantified sources may be contributing substantial masses of selenium load to the Lake. These sources may include loads entering from unmeasured surface inflows, groundwater discharge, wind-blown dust that is deposited directly on the lake surface, wet and dry atmospheric deposition falling directly on the lake surface, and lake sediment pore-water diffusion into the overlying water column (internal loading). A separate mass balance was also developed for selenium in Gilbert Bay (Diaz et al., 2009a); however, increases in total selenium concentration during the study also indicated the possibility of unquantified sources entering the lake.

To understand the effects of selenium in the Lake ecosystem and be able to manage its loads in the flows entering the Lake, it is essential to have a strong knowledge of sources of selenium and its mass balance in the Lake. This will also include sources to Bear River Bay and Farmington Bay. An accurate quantification of internal loading and exchange between sediments, the deep brine layer, and the surface layers will be critical to understanding the behavior of selenium and other elements in the Lake. Such an understanding will enable UDWQ to better link the effect of incoming loads of selenium on its concentration in Lake water.

Study Objectives. The objectives of this study are as follow:

- Identify the sources and loads of selenium entering Gilbert Bay, that were not addressed by Naftz et al. (2008b)
- Identify and quantify sources and loads of selenium in Bear River and Farmington Bay
- Refine and validate the selenium mass balance model developed by Diaz et al. (2009a)

Approach. As previously mentioned, the USGS and research teams from the University of Utah have recently completed studies on understanding sources and loads of selenium entering the Lake. The USGS is currently looking at groundwater discharge as a potential mechanism for additional sources of selenium to the Lake (USGS, 2012). For this research work, it is important to collaborate with these teams to build on existing data and fill in gaps in current understanding.

The components of a mass balance model for selenium will include all sources of external and internal loading to the water column as well as a quantification of the loss terms of permanent burial and volatilization. All of these factors need to be tied to a loading and mixing model that accommodates influent loads and hydrodynamic mixing in the Lake. Such a model will be an effective tool to predict lake-wide selenium concentrations that may occur in the future in response to changes in external loading.

There is a lack in the complete understanding of volatilization of selenium from the lake. Thus, improving this understanding through literature review and sample collection and analysis will be an objective. Also, efforts will be made to address the uncertainties in measurement of volatilization.

Sources, Loads, Mass Balance and Mixing of Mercury in Great Salt Lake

Problem Statement. Methyl-mercury concentrations that have resulted in impairments in other waters in the United States have been measured in the Lake. Three species of waterfowl are contaminated with mercury making them unfit for human consumption. These findings prompted considerable research to characterize mercury concentrations in various media, as well as efforts to identify sources of mercury to the Lake (UDWQ, 2011). Recently, UDWQ, in collaboration with the USGS, completed a study that estimated loads of total mercury to the lake through its riverine inputs and as a result of atmospheric deposition (UDWQ, 2011; Naftz et al., 2009). The study concluded that most of the total mercury present in Gilbert Bay is likely contributed by atmospheric deposition of mercury. The load from atmospheric deposition was found to be far more than what was being discharged by the riverine inputs to Gilbert Bay. It will be important to better understand how mercury is being methylated within the Lake so that solutions to this problem may be evaluated. Similar to selenium, a mass balance and mixing model of mercury also needs to be developed. Knowledge of these will help understand and predict how the existing loads might affect the ecosystem in the future and thus inform decision-making.

Study Objectives. The goal of this study is to identify the unquantified sources of mercury to Gilbert Bay, to develop a mass balance and mixing model of mercury for the lake, and to better understand the mechanisms that regulate the methylation of mercury in the Lake.

Approach. Many of the data needs for this study are the same as for selenium mass balance studies, and efforts will be synchronized with the selenium study and the hydrodynamic model previously presented. Additional work is needed to create the analogous quantification of mercury (and methyl-mercury, as needed) in water, sediment, and biota, as was done for selenium. Ongoing research into the methylation of mercury will be supported, particularly to understand the role of bacteria and the deep brine layer.

HYDROLOGY AND CHEMISTRY AFFECTS TO THE POLLUTANTS OF CONCERN

Problem Statement. Lake levels and basic lake chemistry characteristics such as salinity, dissolved oxygen, pH, temperature, density, and clarity play an important role in affecting the fate and transport and in transforming the pollutants that enter the lake. It is essential to understand what happens to these pollutants within the lake waters to gain knowledge on their fate, as well as in regulating them. Such general knowledge is an important component of the loading, fate, transport, and mixing models for various constituents used to develop water quality criteria, assess water quality, and developing UDPES permit discharge limits.

Study Objective. Explore available data to determine relationships between primary pollutants and lake water chemistry and hydrology as may affect pollutant fate and transport.

Approach. This study will use data gathered by the BSP described in Section 2 and the synoptic sampling plan presented in Section 3. While the BSP will monitor trends in the primary pollutants listed previously, the synoptic sampling plan includes extensive monthly sampling across the lake including the pollutants that have been identified to pose risk to the designated uses of the Lake and other water quality parameters that would represent the lake hydrology and chemistry. Further, the synoptic sampling event is to be completed on a 5-year basis. Analysis of these data could be used to study how varying chemistry and hydrology (i.e., inflows, lake level) affect pollutant chemistry.

POLLUTANT INTERACTACTION BETWEEN WATER AND SEDIMENT

Problem Statement. Many pollutants, such as selenium and mercury, are found naturally within the Lake's watershed. However, it is also widely recognized that the inflow of these pollutants has most likely increased since the watershed has developed and urbanized (Naftz et al., 2000). The Lake's natural processes would likely cause many of these pollutants to precipitate from the water column and be deposited in lake sediments. Thus, lake sediments provide an invaluable record of how conditions in the Lake have changed with time.

This study seeks to better understand the sedimentation rates throughout the Lake, long-term precipitation rates of various pollutants, and the permanent burial loss rates of pollutants. The use of brine shrimp cysts found in the sediment column can be used as an additional marker of historic Lake productivity.

Study Objective. The objective of the proposed study is to provide answers to the following questions:

- What are the historic sedimentation rates throughout the Lake (confirm and build on the work completed by Johnson et al. [2008] for the UDWQ selenium study)?
- What are the historical trends in concentrations of pollutants that have been identified to pose risk to the designated uses of the Lake?
- What are their sedimentation/precipitation rates?
- Do pollutants in sediments release to the water column of the Lake as a result of lake chemistry and natural sediment diagenesis and is such sediment flux affected by changing lake chemistry (deep brine layer movements, seasonal anoxia, etc.)?
- What is the permanent burial rate of key pollutants?

Approach. To determine historical trends in concentrations of pollutants, sediment cores are a commonly implemented method. This procedure determines pre-historical conditions and the impact of human activity in a watershed. Some sediment core studies have already been done for the Lake, focusing on reconstructing historical changes in the Lake and also on selenium and mercury (Naftz et al., 2000; Naftz et al., 2008; Naftz et al., 2009a; Naftz et al., 2009b; Oliver, 2008; UDWQ, 2011). Information from these studies will be used to design new data collection as needed.

Sediment core samples were also collected and analyzed to determine sedimentation rates of selenium by Oliver et al. (2009).

Several studies may be required to address the objectives listed previously. While funds may become available to address one objective (i.e., study pollutant levels in sediment for one pollutant), such a study should be coordinated with UDWQ to leverage this effort to also address as many other objectives as possible. This may require cost-sharing to obtain additional samples and/or complete further analyses. Following are a list of suggested studies:

- Review past work to establish sedimentation rates throughout the Lake. Complete additional sediment cores studies as needed to refine the map developed by Oliver (2008). Existing and new cores will be dated using lead-210 and cesium to understand sedimentation rates and how pollutant levels in sediment have changed with time. The objective is to better understand where efforts to understand historic pollutant deposition will be targeted.
- Sediment cores will be analyzed to address, at a minimum, the primary constituents of selenium, mercury, nitrogen, and phosphorus. Combined with sedimentation rates, trends in pollutant levels will be identified both temporally and spatially across the lake. The stratigraphy of intact cores and porewater can be used to estimate diffusive flux rates to and from the overlying water.
- Laboratory studies with intact cores to quantify pollutant flux (e.g., Byron and Ohlendorf, 2007).

Release of pollutants from sediment to water column can be inferred by collecting collocated water column and sediment samples. All water quality parameters, such as pH, dissolved oxygen, temperature, clarity, and salinity, will be measured along with sample collection. Data from these sampling efforts will be used in conjunction with core and flux studies to determine any flux of pollutants into or out of the sediments.

6.3.1 Great Salt Lake Lower Food Chain

The following sections present studies that need to be addressed to improve the current understanding of the Lake's lower food chain (see Figure 5).

EFFECTS OF SALINITY ON PLANKTONIC AND BENTHIC COMMUNITIES

Problem Statement. The salinity of the Lake is spatially and temporally diverse across the open waters. It is saturated in the Gunnison Bay, varies between 6 to 15 percent across the Gilbert Bay, remains low in the Farmington and the Bear River Bays and is almost negligible in the wetlands depending on the lake level and freshwater inflow to the wetlands. It also varies with depth at certain locations in Gilbert Bay where the deep brine layer is present. Such variations create environments for different types of planktonic and benthic species to grow and survive. However, to maintain and manage the Lake ecosystem and its designated uses, it is essential to protect those habitats that provide food sources to brine shrimp, brine flies, and other macroinvertebrates. Thus, it is important to gain an understanding of how salinity might affect the growth and survival of these essential species.

Study Objectives. This study will focus on understanding the effects of salinity on planktonic and benthic species in the Lake and will provide answers to the following questions:

- What species are supported by the varying percent salinity in Gilbert Bay?
- What species are supported in Farmington Bay, Bear River Bay, and their associated wetlands and how are they different from those in Gilbert Bay? How does varying salinity affect these species?
- How are critical invertebrates affected by the saturated conditions of Gunnison Bay?

Approach. The UDWR has been enumerating and studying planktonic and benthic communities of Gilbert Bay as part of the Great Salt Lake Ecosystem Program research. The Great Salt Lake Institute at Westminster College has also been completing groundbreaking work on the role bacteria play in the Lake (Baxter et al., 2013). This study will be completed in collaboration with the UDWR and the Great Salt Lake Institute.

Planktonic and benthic organisms will be sampled at two locations in Farmington Bay and Bear River Bay, respectively; two locations in the Gunnison Bay; and four locations in Gilbert Bay, each representing different percent salinity. During sampling, field measurements of water quality parameters, especially salinity, will be documented. All samples will be identified and enumerated. Appropriate statistical methods will be applied to evaluate correlations between variables.

Results will be compared with previous research completed by the UDWR and Great Salt Lake Institute and evaluated in terms of the salt balance model developed by the USGS and Utah Division of Water Resources. The end product will be a report summarizing the ranges of salinity observed and what drives changes in salinity for each of Lake's bays. A discussion will be provided linking the Lake organisms to these salinities and how they respond to changes.

DEVELOP TROPHIC TRANSFER MODEL FOR LOWER FOOD CHAIN

Problem Statement. Understanding trophic relationships for bioaccumulative pollutants, such as selenium, mercury, and arsenic, is an important part of advancing our knowledge on the dynamics of these pollutants in the Lake, as well is in management and decision making to protect the aquatic wildlife designated use. In 2008, as a part of UDWQ's extensive effort to assess the effects of selenium in Gilbert Bay's ecosystem, Marden (2008) conducted a study to determine trophic relationship of selenium in water, seston, and brine shrimp. However, these relationships were concluded not to be robust by the author, who suggested further investigation into the same. Similarly, UDWQ completed another study in collaboration with USGS, Utah Department of Natural Resources (DNR), USFWS, and EPA in 2011 (UDWQ, 2011) that developed a conceptual model to illustrate the ecological receptors and exposure routes of mercury concentration in the Lake. This study identified data gaps in correlations of concentration of mercury in parts of the Lake's food chain.

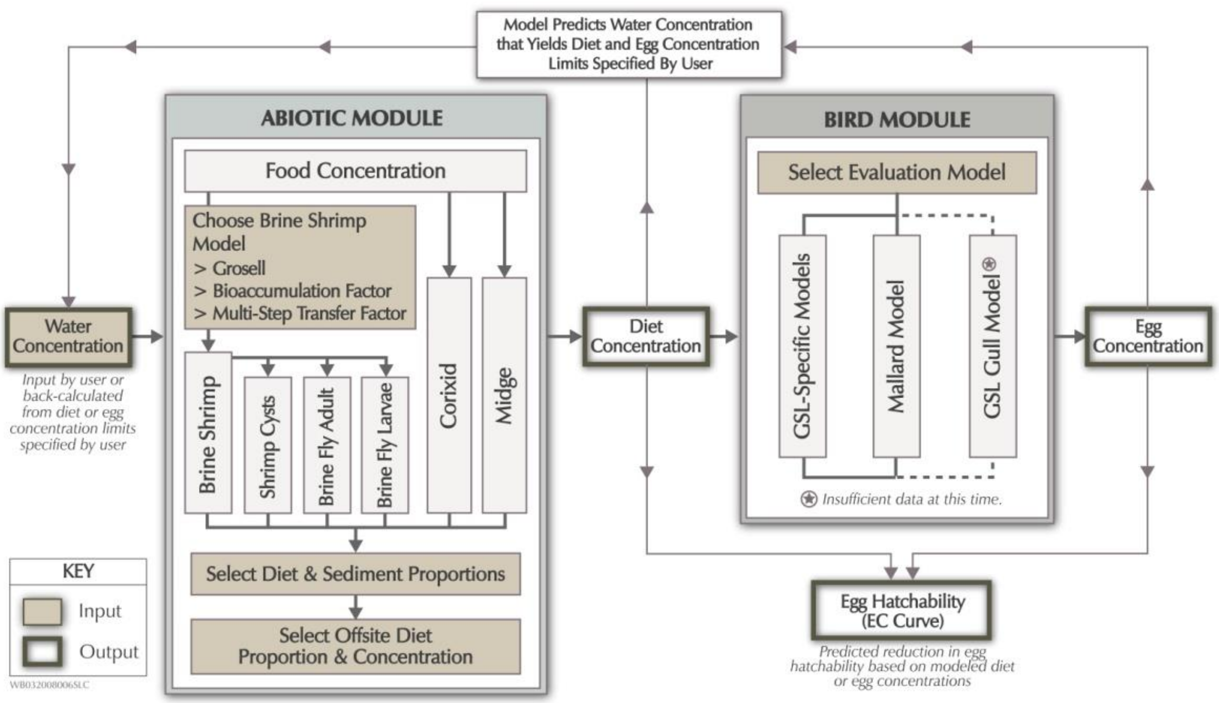

FIGURE 6 GREAT SALT LAKE TROPHIC TRANSFER MODEL FOR SELENIUM

Thus, there is a need to improve the existing trophic transfer and bioaccumulative models and expand them for use across all the bays of the Lake. This study will focus efforts to establish a robust trophic transfer relationship in the Lake only for those pollutants that have been identified to pose a bioaccumulative risk. Though presented as a single study here, this project may be divided into several subcategories, each handling a single pollutant.

Study Objectives. The objective of this study is to establish trophic transfer relationships of bioaccumulative pollutants in the Lake between water, benthic and planktonic species, and different life stages of brine shrimp and brine flies in a way that will be robust and could be used in developing water quality criteria, determining UPDES permit limits, and assessing the support of the Lake's aquatic wildlife designated use.

Approach. Collocated samples of water, brine shrimp and their cysts, and brine fly larvae and pupae will be collected from the lake. Data from the BSP and synoptic sampling studies could be used but may need to be augmented,

Statistical relationships, useful for improving existing biodynamic models and establishing new models, will be developed based on the analysis of seasonal and synoptic data. The data will be developed into trophic dynamic relationships (ratios) describing trophic transfer coefficients between water and invertebrates (or water, seston, and invertebrates). Alternatively, regression relationships will be used to infer causal relationships between water-borne and tissue concentrations for various pollutants. The relationships and resulting models will be used in support of an ecological risk assessment, the development of criteria for the lake.

ACUTE AND CHRONIC TOXICITY TESTING

Problem Statement. Component 1 includes the completion of acute and chronic laboratory toxicity tests as part of the process for the development of water quality criteria for the Lake. As part of this process, UDWQ will complete a review of the literature to identify available toxicity data that are pertinent to the organisms and salinities observed in the Lake ecosystem. If data gaps exist, then UDWQ will complete laboratory toxicity tests to determine the toxicity of various pollutants to organisms that exist in the Lake and in the salinities they experience. This information is critical for the development of numeric criteria that are protective of these organisms and the aquatic wildlife designated use they represent.

UDWQ is evaluating which organisms, salinities, and pollutants are relevant to the development of water quality criteria for the Lake and will be completing a literature review to define appropriate toxicity data and benchmarks for use in the Lake. As such, the actual number and targets for the toxicity tests is ongoing and dependent on available resources.

Study Objective. The objective of these studies is to determine the toxicity of specific pollutants to the organisms that exist in the various salinities of the Lake.

Approach. Per the literature review previously discussed, UDWQ will identify data gaps in available toxicity data for the organisms and salinities observed in the Lake. Critical toxicity endpoints will be identified and prioritized and then laboratory toxicity tests will be designed and implemented. The approach and level of effort for completing a laboratory toxicity test depends on the pollutant and toxicity endpoint being evaluated (e.g., acute systemic, dietary, or reproductive). Care must be given to ensure the studies address the proper pathway of administration, measure of toxicity, time and number of exposures, form of the pollutant used, and the appropriate endpoint.

6.3.2 Great Salt Lake Upper Food Chain

Studies have been conducted to identify and enumerate the different avian species in and around the Lake (Manning and Paul, 2003; Cavitt, 2006; Cavitt, 2008a; Cavitt, 2008b) and much work has been done to understand the effects of pollutants on avian population (CH2M HILL, 2008; Vest et al., 2009). The UDWR continues to complete research to understand the use of the Lake by birds and how to better manage this resource. However, scientific uncertainty exists, and there is a need for further research to enable UDWQ to accurately assess the aquatic wildlife designated use. The following sections present these research needs.

WATERFOWL AT FARMINGTON BAY

AVIAN POPULATION USE OF GREAT SALT LAKE

Problem Statement. The UDWR conducted a 5-year study concluding in 2001 to identify the species of waterbirds and enumerate them through a bird survey (Paul and Manning, 2002; Manning and Paul, 2003). These comprehensive surveys were conducted from 1997 to 2001 and focused on areas where birds were most abundant including the open waters, shoreline, and associated wetlands, including the three major delta regions and nearby wetland complexes that drain into the Lake. This study identified 55 water bird species that use the lake and highlighted the effect of lake elevation on bird use and numbers. The UDWR continues to conduct large-scale bird surveys, and the USFWS is currently monitoring nesting birds in Bear River Migratory Bird Refuge.

There have been some focused efforts to survey Great Salt Lake birds (Cavitt, 2006; Cavitt, 2008a; Cavitt, 2008b). These studies were designed to provide specific information relating to diet and pollutant exposure. Although reproductive success is the most critical endpoint for most pollutant effects, a secondary critical endpoint is adequate body condition, which is required by birds using the Lake to successfully survive the winter and migrate. Migratory non-nesting species, such as eared grebes, phalaropes, and over-wintering ducks, depend on the Lake and may be affected by food-borne pollutants during their time on the Lake or as they continue their migration. These migratory non-nesting species will be monitored if there is reason to believe, based on literature, they are more sensitive to pollutants than nesting species. In addition, little is known about the pollutant levels that these birds are carrying when they arrive at the Lake and whether Lake pollutants affect their survival after they leave the Lake. Periodic surveys are required to track changes in the number and species of birds using the Lake. Tracking avian populations also serves as an important indicator of the environmental conditions of the Lake and other water systems they might use along their migratory paths. Thus, studies will be completed to survey avian species that use the Lake for foraging, wintering, and nesting. As the UDWR is already conducting similar research, UDWQ's work will serve to encourage, coordinate, and collaborate to address specific issues that pertain to the assessment of Lake's aquatic wildlife designated use.

Study Objectives. The objectives of these studies will be to conduct bird surveys to identify avian species that use the Lake for foraging, wintering, and nesting; identify the areas they use for these purposes; and evaluate how these populations change in terms of location, foraging, and nesting.

Approach. Comprehensive surveys by agencies such as the UDWR and USFWS that track population use and trends by species will be encouraged and supported and these data, along with other historic survey data, and will be used as an indicator of Lake-wide bird use as related to environmental conditions. Avian surveys conducted by the UDWR (2001; Manning and Paul, 2003) will be used as the baseline for a long-term avian monitoring program. These surveys will be conducted periodically using the same methods as UDWR studies.

Surveys will be targeted to complete the following:

- Surveys will be conducted of migratory species breeding at the Lake. Species, their numbers, and the locations they use for foraging and nesting will be tracked to identify population trends. Foraging patterns and diet items will be determined for each species so as to determine if and how pollutants may put these birds at risk. In addition, studies will be designed that will monitor pollutant levels in the eggs of birds that use the Lake waters as a food source and breed along its shores (note that selenium and mercury in bird eggs are monitored as part of the BSP).

- Surveys will be conducted of migratory nonbreeding species using methods similar to the surveys being conducted for nesting birds at the lake. Species, their numbers, and the locations they use for foraging will be tracked to identify population trends. Foraging patterns and diet items will be determined for each species so as to determine if and how pollutants may put these birds at risk. In addition, studies will be designed that will monitor pollutant levels in birds arriving at the Lake and their accumulation during their stay. Birds will be tracked to determine survival after they leave the Lake to move on to their breeding grounds.

DEVELOP TROPHIC TRANSFER MODEL FOR UPPER FOOD CHAIN

Problem Statement. Understanding trophic relationships for bioaccumulative pollutants, such as selenium, mercury, and arsenic, is an important part of advancing our knowledge on the dynamics of these pollutants in the Lake, as well as in assessing the aquatic wildlife designated use. As a part of UDWQ's extensive effort to assess the effects of selenium in the Lake ecosystem, Cavitt (2008b) and Conover et al. (2008a) conducted studies to determine trophic relationships of selenium in water, sediments, macroinvertebrates, adult birds, and bird eggs for shorebirds and California Gulls. A conceptual model was developed by CH2M HILL describing the bioaccumulation of selenium from water to brine shrimp (adult and cyst) and diet to bird egg. However, improvements were suggested in these relationships, including improving confidence in relating water concentrations to bird egg condition. Another study by UDWQ in collaboration with the Utah DNR, USGS, USFWS, and EPA on ecological assessment of mercury on the Lake also underlined the need for more information on correlation of pollutants in avian species and their diets. Current EPA

TRAP SET OVER A SHOREBIRD NEST TO CAPTURE MOTHER HEN TO LINK DIET OF MOTHER HEN TO EGGS

guidance for implementing tissue based water quality criteria for methyl-mercury recommend the development of these relationships to support permitting.

SAMPLING SHOREBIRDS TO LINK DIET TO BIRD EGGS

This study will establish a robust trophic transfer relationship between avian species, their eggs, and their diets in the Lake for those pollutants that have been identified to pose a risk to the aquatic wildlife designated use. Though presented as a single study here, this project may be divided into several subcategories, each handling a single pollutant.

Study Objectives. The objective of this study is to establish trophic transfer relationships of bioaccumulative pollutants in the Lake between avian diet, adult avian species, and their eggs in a way that will be robust and can be used in management decisions.

Approach. The results of previous studies on the feeding and nesting habits of birds and the results of the bird egg monitoring study for selenium and mercury will support this study. It can be difficult to establish a relationship between concentrations of pollutants in macroinvertebrates, adult birds, and bird eggs because the proportion of dietary items can be vastly different among individuals. This study will collect samples of macroinvertebrates that the birds feed upon on a weekly basis for about 5 weeks before the nesting season. This will provide a good picture of the variability of pollutants in the diet that the birds are exposed to during the egg production period. The relation to adult birds will be established by either trapping or drawing blood samples from nesting birds or harvest adult birds and collecting blood and liver samples for the analysis of pollutants.

While establishing a work plan for this study, it will be essential to collaborate with agencies, such as the USFWS, that are currently researching contamination in bird eggs and their risks to avian reproduction.

THE EFFECT OF SELENIUM AND MERCURY ON GREAT SALT LAKE AVIAN POPULATIONS

Selenium and mercury have been the focus of research since 2006. While much has been learned, much remains to be understood to assess their impact on the aquatic wildlife designated use, in particular to the avian population of the Lake. The following work addresses key issues that pertain to UDWQ's monitoring of the Lake, evaluation of that data, and assessing aquatic wildlife designated use.

Bird Egg Monitoring for Selenium and Mercury in Great Salt Lake

As part of the BSP (see Section 2) and to support the assessment of the aquatic wildlife designated use and the selenium numeric water quality standard, UDWQ monitors selenium and mercury concentrations in adult avocet and stilt eggs and their associated food web (i.e., water, sediments, and macroinvertebrates).

Studies to Understand the Potential Interaction between Selenium and Mercury and their Effects on Aquatic Birds

Problem Statement. The ecological assessment studies conducted by UDWQ on selenium and mercury in the Lake (UDWQ, 2011; CH2M HILL, 2008) identified the need to understand the interaction of selenium and mercury and their effects on the avian species in the open waters of the Lake. During the selenium assessment study, high selenium concentrations were found in the blood and liver of shorebirds (American avocets and black-necked stilts) compared with those identified in invertebrate food sources. One possible explanation posed for the high concentrations found at the Lake was the potential interaction with elevated mercury concentrations (Santolo and Ohlendorf, 2006). Both mercury and selenium seem to act antagonistically forming a stable complex. This complex may act to increase both the retention and buildup of mercury and selenium in tissues. The interaction of these two pollutants in eggs and the effects to embryos is very complex. Eggs with elevated selenium alone seem to have lower hatchability than eggs with elevated selenium and mercury; however, the deformity rate appears to be higher in the eggs with selenium and mercury.

This study will focus on addressing and understanding this issue.

Study Objectives. The objective of this study is to understand the interaction of selenium and mercury in avian species of the Lake and to understand how this interaction might adversely affect them.

Approach. UDWQ will approach this issue in two phases. The first phase will build on the data obtained from the selenium study completed by UDWQ in 2008 to confirm observations that were made. This will require measuring mercury levels from the sample sites of the selenium study, as well as analyzing concentrations of mercury in bird tissues. This will provide information and reasoning for the higher-than-expected blood selenium concentrations that were found in the selenium study (CH2M HILL, 2008). Concentrations of mercury in the kidneys of birds that were archived during the study will be measured. Some studies on interactions of selenium and mercury in birds have looked at kidneys as well as blood and liver. Analyzing kidneys for mercury will not only determine if there was elevated concentration of mercury at the sample locations but also may determine if the higher selenium concentrations found in blood were due to higher mercury than the other sites.

The second phase of research will focus on laboratory toxicity tests to evaluate the observed interaction and its effect on the aquatic wildlife designated use. This phase of research will require close coordination with the UDWR and the USFWS.

6.4 Wetland Research

Concerns about the potential impact nutrient loads may be having on the Lake's wetlands have prompted UDWQ and others to initiate two wetlands research efforts since 2004. In 2004, a study was initiated to characterize the ecosystem of Farmington Bay, with a goal of understanding the physical, chemical, and ecological processes that are critical to the integrity of Farmington Bay's ecosystem. This program led to the development of a wetland assessment framework to evaluate the relative condition of the Lake's impounded wetlands. In 2011, UDWQ initiated the Willard Spur sampling and research program, with the objective of understanding how to better protect the designated uses of Willard Spur waters. These two research programs are improving understanding of the Lake's wetlands; however, further study is required to enable UDWQ to effectively protect the designated uses of these wetlands. This section summarizes ongoing research but also identifies additional needs. In Core Component 3 of the Great Salt Lake Water Quality Strategy, a plan will be developed to assess and manage wetland water quality that draws on these existing studies.

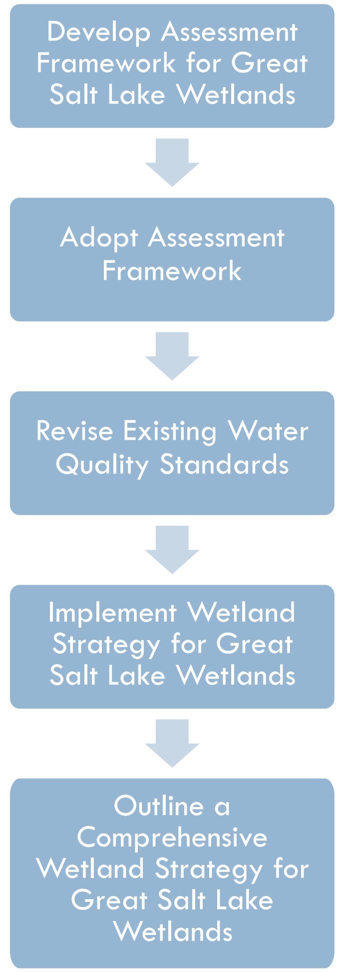

FIGURE 7 WETLAND STRATEGY FOR GREAT SALT LAKE

6.4.1 Wetland Assessment Framework

Problem Statement. Research to characterize 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 functions of the wetlands make determination of suitable numeric criteria for these wetlands difficult. Discussion of using only narrative criteria to protect the wetlands meets with significant concern as narrative criteria alone may not be adequate to protect the designated uses. Regardless of the water quality standards that are implemented in the future, an assessment framework for the wetlands of the Lake is vital to moving forward. This framework, and the science that defines it, will serve as the baseline for documenting whether and how the designated uses of these wetlands are protected. This framework will also serve as the foundation for a new, proposed approach to managing the Lake's wetlands.

Study Objective: The objective of this research is to develop an assessment framework that can be used by UDWQ to assess the relative condition of the Lake's wetlands and identify areas that may not be supporting their designated uses. UDWQ can then conduct focused research on these areas and determine whether appropriate designated uses are being supported.

Approach. UDWQ and others have invested significant resources to better understand the dynamics of the Lake's wetlands (Gray, 2005; Rushforth and Rushforth, 2006a, b, c, d; Miller and Hoven, 2007; Gray, 2009; Rushforth and Rushforth, 2007). A preliminary assessment framework was proposed for the Lake's impounded wetlands in 2009 using data collected beginning in 2004 (UDWQ, 2009). UDWQ is currently working to validate the assessment framework for impounded wetlands and to develop a new preliminary assessment framework for fringe wetlands. The assessment framework for impounded wetlands is focused on developing metrics for three assemblages: macroinvertebrates, submerged aquatic vegetation, and surface mats. Ongoing work to validate this framework will investigate the viability of other indicators such as bird use and important factors such as hydrology. Work to develop a preliminary assessment framework for fringe wetlands will begin using work summarized in Miller and Hoven (2007).

6.4.2 Development of Water Quality Standards for Willard Spur

Problem Statement. Construction of the Perry/Willard Regional Wastewater Treatment Plant (Plant) was completed in 2010. The UDWQ received numerous comments as part of the public notice process for the Plant's UPDES discharge permit to Willard Spur. Many of these comments expressed concern over the potential impact the effluent could have on the water body and petitioned the UDWQ to prohibit all wastewater discharges to Willard Spur or to alternatively reclassify Willard Spur to protect the wetlands and current uses of the water.


A JANUARY MORNING AT WILLARD SPUR

Although the Utah Water Quality Board denied the petition, the Water Quality Board directed UDWQ to develop a study design to establish defensible protections (i.e., site-specific numeric criteria, antidegradation protection clauses, designated use changes, etc.) for the water body. The Water Quality Board also directed UDWQ to pay for phosphorus reductions at the Plant while the study is conducted. This path forward, developed in conjunction with stakeholders, allows the Plant to operate while the studies are underway, with reasonable assurances that the effluent will not harm the ecosystem.

Study Objective. The Willard Spur Science Panel was charged with the responsibility to identify and oversee the studies required to address the question: "What water quality criteria are fully protective of designated uses of Willard Spur waters as they relate to the proposed publicly owned treatment works (POTW) discharge?" This question represents the overall program objective.

Two questions were identified that follow from the program objective (i.e., these questions must be answered for the program objective to be achieved). The questions are as follows:

1. What are the potential impacts of the Perry Willard Regional Wastewater Treatment Plant on Willard Spur?

2. What changes to water quality standards will be required to provide long-term protection of Willard Spur?

Approach. To provide answers to these questions, the Willard Spur Science Panel identified the three following key research areas:

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

A Research Plan (CH2M HILL, 2011) was developed to closely follow the conceptual models defined in a memorandum dated August 2, 2011 ("Draft Conceptual Models"). Figure 8 illustrates how the various research studies fit into this structure as well as accomplish the overall program objective. While this research is focused on Willard Spur, much of the understanding that is gained will apply directly to other Great Salt Lake wetlands. Research across the Lake's wetlands will be closely coordinated and integrated to leverage the knowledge gained and focus efforts on areas of less understanding.

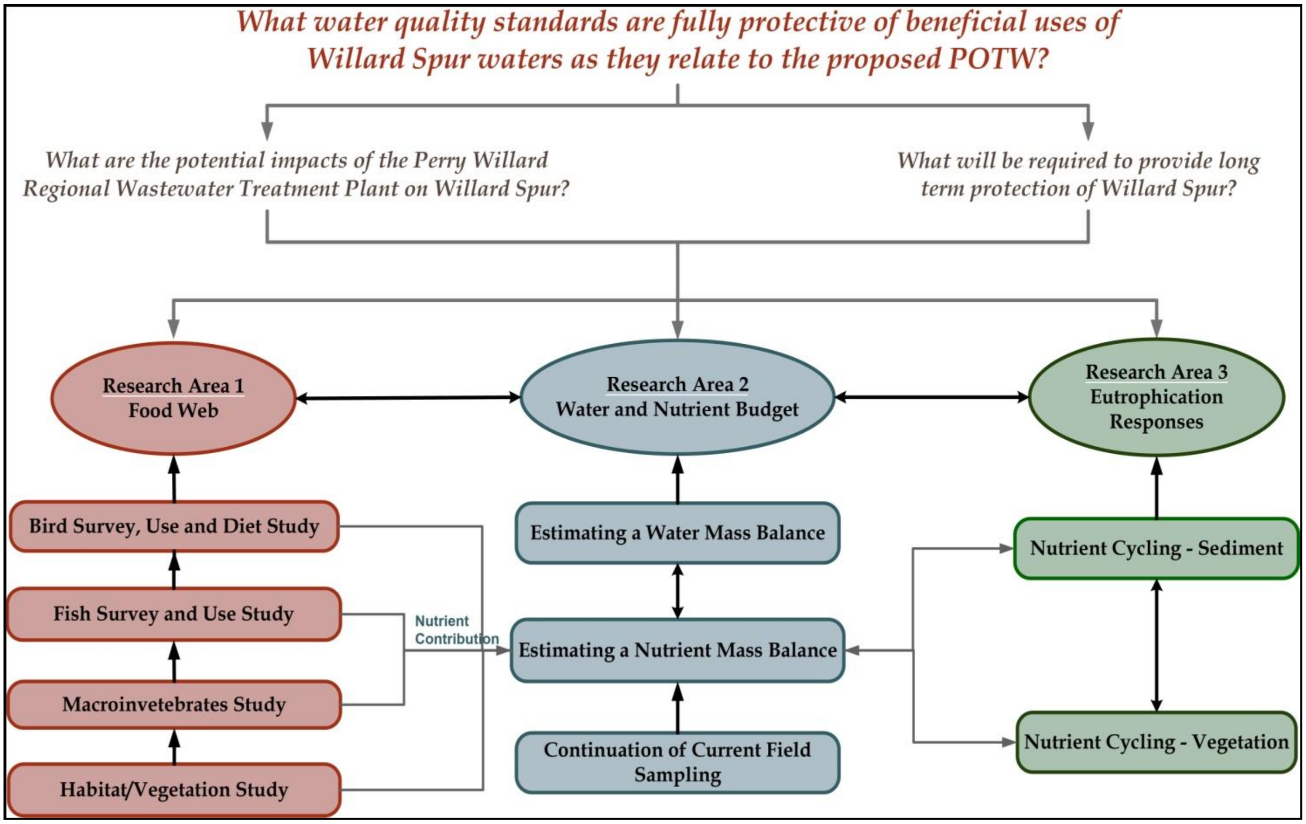

FIGURE 8 OVERALL STRUCTURE OF PROPOSED RESEARCH WORK AT WILLARD SPUR

6.4.3 Additional Wetland Research Needs

DEVELOP WETLAND RESEARCH FRAMEWORK

Problem Statement. While UDWQ's current research programs are working to develop a fundamental understanding of the Lake's wetlands and how to protect them, there are numerous additional areas that require further work. An important realization is that as more is learned about the Lake's wetlands, the more researchers understand how much remains to be known. Core component 3 of the Great Salt Lake Water Quality Strategy will focus on a research framework that is based on clear objectives endorsed by Great Salt Lake wetlands stakeholders. The new research will be focused and prioritized in such a way that it incorporates previous research, addresses specific gaps in knowledge, and addresses management objectives.

Study Objective. To develop a research framework for Core Component 3, UDWQ and its partners will identify WQ program goals, acknowledge previous research, identify and prioritize research to address gaps in understanding, coordinate efforts, and document progress.

Approach. UDWQ will work with its partners to develop the framework for Core Component 3. The framework will identify key objectives for research, key stressors that are of concern, responses to those stressors, factors that can influence the response, and how those stressors may affect designated uses. The framework will consolidate much of the above into a conceptual model for the major wetland types associated with the Lake. UDWQ has already developed two preliminary conceptual models that were used to guide research for Willard Spur. These conceptual models will be reviewed and new conceptual models be developed to frame our current understanding. UDWQ will then work with its partners to identify which components have already been addressed through previous research and which areas require additional research and then, together with stakeholders, prioritize efforts in such a way that management objectives can be met. The framework will be revisited with stakeholders to communicate progress and coordinate efforts.

5. TIMELINE

UDWQ has undertaken a significant effort over the last several years to engage its partners and the stakeholders of the Lake to better understand their objectives, plans, and issues and incorporate them into the Strategic Monitoring and Research Plan. Component 2 is the result of integrating this input with UDWQ's current understanding of the Lake and its responsibilities under the CWA and state law.

As previously described, implementing the BSP and then completing studies to improve on it are among UDWQ's highest priorities. This work is critical to shifting UDWQ from reacting to possible water quality problems toward proactively monitoring, developing criteria, and assessing the Lake's designated uses. Table 5 provides a list of the studies for Objectives 1, 2 and 3 with a timeline for completion. The timeline will be updated every 3 years when the Strategy documents are reviewed.

It is important to note that some of these studies are already being implemented by UDWQ and/or others in response to critical needs. Those projects that are currently being led by others are noted. They require UDWQ's support but not necessarily significant involvement. Some of the studies would only be necessary to implement if the Lake is listed on the 303(d) list as impaired for its designated use and a Total Maximum Daily Load Analysis is required to quantify sources and loading to the lake. Some of the studies provide information as a prerequisite to others. All studies are subject to discussion and coordination within UDWQ and its partners and available funding. It is recognized that extenuating circumstances may cause UDWQ to alter the timeline or implement research that hasn't been identified in this component.

TABLE 5 TIMELINE OF STUDIES FOR OBJECTIVES 1, 2 AND 3

Study Description	In order of location in Document (Section No.)	Timeline (will be updated every 3 years)
Objective 1. Implement the Baseline Sampling Plan		
Implement Baseline Sampling Plan	2	Began in 2011, ongoing
Objective 2. Improve the Baseline Sampling Plan		
Round Robin Study for Evaluating Laboratory Analytical Techniques	3.2	2014
Round Robin Study for Evaluating Water Sampling Techniques	3.3	2016
Synoptic Sampling of Great Salt Lake	3.4	2016
Objective 3. Recommended Research		
Great Salt Lake Data Repository	4.2.1	Dependent on resources
Great Salt Lake Hydrologic and Hydrodynamic Model	4.2.2	Other agency's efforts, 2014-2016
Determine Potential Water Quality Benchmarks	4.3.1.1	Ongoing
Sources, Loads, Mass Balance, and Mixing of Nutrients in Great Salt Lake	4.3.1.2	To be developed in Core Component 4
Sources, Loads, Mass Balance, and Mixing of Selenium in Great Salt Lake	4.3.1.3	Commence if the Lake is declared impaired for Selenium
Sources, Loads, Mass Balance, and Mixing of Mercury in Great Salt Lake	4.3.1.4	Commence if the Lake is declared impaired for Mercury
Effects of Lake Hydrology and Chemistry on Pollutants of Concern	4.3.1.5	Ongoing
Interaction of Pollutants between Water and Sediment in Great Salt Lake	4.3.1.6	Other's efforts
Effects of Salinity on Planktonic and Benthic Communities in Great Salt Lake	4.3.3.1	2015
Trophic Transfer Model for Lower Food Chain	4.3.3.2	Commence if needed
Acute and Chronic Toxicity Tests	4.3.3.3	2013-2016
Avian Population Use of Great Salt Lake	4.3.4.1	Other agency's efforts, ongoing
Trophic Transfer Model for Upper Food Chain	4.3.4.2	Commence if needed

Study Description	In order of location in Document (Section No.)	Timeline (will be updated every 3 years)
Bird Egg Monitoring for Selenium and Mercury in Great Salt Lake	4.3.4.3	Began in 2010, ongoing
Studies to Understand the Interaction of Selenium and Mercury and Their Effects on Avian Population in Great Salt Lake	4.3.4.4	Other Agency's efforts, ongoing
Great Salt Lake Wetland Assessment Framework	4.4.1	Monitoring began in 2005 and Assessment began in 2009, ongoing Will be outlined in Core Component 3
Development of Water Quality Criteria for Willard Spur	4.4.2	2011–2015
Develop Wetland Research Framework	4.4.3.1	To be developed in Core Component 3

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APPENDIX A: QUESTIONS OF INTEREST

The following questions represent results from an initial "brainstorming" session completed by CH2M HILL to identify potential questions that the Great Salt Lake Sampling and Research Program may address. Research questions developed to understand water quality criteria required for the protection of designated use in Willard Spur, from the Utah Division of Water Quality's (UDWQ's) ongoing Willard Spur program were also integrated into the list to address water quality issues in Great Salt Lake wetlands. This is not intended to be a comprehensive list but is intended to stimulate discussion, prioritization, and identification of questions to be addressed by a sampling program undertaken by UDWQ.

1. **What are current concentrations of various pollutants in water, sediments, and tissues from Great Salt Lake (e.g., selenium, mercury, arsenic, copper, zinc, nutrients, cyanotoxins, etc.) and how do they vary?**

   a) Which pollutants pose the greatest risk to the designated uses of Great Salt Lake?

   b) What methods should be used to sample, handle, and analyze water, sediments, and tissues from Great Salt Lake?

      i) What Standard Operating Procedures (SOPs) should be used for sampling and handling samples?

      ii) What quality assurance procedures should be used for sampling, handling, and analyzing samples (Quality Assurance Project Plan [QAPP])?

      iii) What laboratory should be used for analyzing samples of different types (recognizing different laboratories may be needed for different media)? Required certifications?

   c) How do concentrations of these pollutants vary in water?

      i) How do they vary by salinity, clarity, temperature, pH, dissolved oxygen, and density of Great Salt Lake water?

      ii) How do they vary by depth and location? Is the lake well-mixed? Can we sample the lake in only one or two locations and correctly assume they are representative of the lake?

      iii) How do they vary by month and year? Are they linked to lake level? Can we collect samples in different seasons?

d) How do concentrations of these pollutants vary in sediment?

   i) What are the sediment characteristics and how have deposition rates/patterns changed spatially and temporally?

   ii) How do they vary by location? By depth of sediment? Can or should sediments be dated?

   iii) What is the sediment oxygen demand (SOD) in Great Salt Lake? How does it change spatially and temporally? What processes control or drive SOD in Great Salt Lake?

e) Do these pollutants cycle between sediments and water column and how?

   i) What controls sediment and pore water chemistry in the lake? Does it change spatially and temporally?

   ii) How much of the pollutants load is stored in sediments? How much of the sediment stores are available for reintroduction into the system?

   iii) What is the current sediment/water exchange rate for various pollutants of concern in Great Salt Lake? How does it change spatially and temporally? What processes control or drive this flux?

   iv) How does it affect macroinvertebrate and submerged aquatic vegetation (SAV) populations, especially in the wetlands? Do sulfide and metal concentrations play a major role?

f) How do concentrations of these pollutants vary in lower food chain items (e.g., seston, brine shrimp, brine flies and other macroinvertebrates)?

   i) How do concentrations in water vs. seston correlate?

      (1) What is the composition of seston? What species of algae are present, when, where?

   ii) How do concentrations in water vs. seston vs. brine shrimp correlate?

   iii) How do concentrations in water/sediment vs. brine fly larvae vs. brine fly adults correlate?

   iv) How do concentrations in water vs. brine shrimp cysts correlate?

   v) How do concentrations in water vs. other macroinvertebrates correlate?

   vi) Collect adult brine shrimp and cysts from a variety of locations and archive them.

g) How do concentrations of these pollutants vary in avian populations?

i) How do concentrations in water vs. food chain vs. bird tissue (i.e., blood, liver, egg) vary? By location? Time of year?

1. What species of birds currently use Great Salt Lake? What are their populations? How do the numbers vary throughout the year?
2. Where do the birds nest and feed? What are they eating, when, where?
3. How has bird use (species and population) changed over time in Great Salt Lake? Are the birds opportunistic or specific in what they are looking for?
4. How does bird use (species or population) vary with changes in habitat, water level, and water quality?
5. How does concentration of pollutants in lower food chain vs. avian population correlate?

h) How are concentrations of these pollutants influenced by salinity?

2. Do current mercury levels present a risk to the designated uses of Great Salt Lake?

a) What are mercury concentrations in collocated water, sediment, algae, macroinvertebrates, zooplankton, and bird tissues and eggs?

i) What form of mercury is observed and in what quantity in these various media?

ii) What methods should be used for sample collection, handling, and analysis?

(1) Do we report data on wet-weight or dry-weight basis (regardless of which is used, moisture percentage also should be reported to facilitate conversion from one to the other)?

iii) Are differences in analytical methods/results between laboratories significant?

b) Do existing mercury concentrations represent an impairment of Great Salt Lake designated uses?

i) What thresholds or benchmarks (i.e., indirect indicators) are appropriate for mercury in the Great Salt Lake environment (i.e., food chain and bird tissues)?

(1) How sensitive are the various species to mercury? What species is most sensitive?

(2) Are common thresholds in the literature for freshwater applicable to Great Salt Lake?

(3) Does presence of selenium mitigate toxic effects of mercury in birds?

(4) Does the salinity of Great Salt Lake influence toxic effects?

ii) What is our level of certainty regarding pathway of mercury into bird tissues?

(1) Are we confident what (and where) the birds we are sampling are eating at Great Salt Lake? Can we link bird tissue concentrations to the food they were eating?

(2) Can we link bird egg concentrations to the adults that laid eggs and food they ate?

(3) How much time do particular species of birds spend on the lake? How much of the mercury observed in bird tissues is from Great Salt Lake? How much of it is from nearby freshwater habitats? How much of it is "imported" by migrants?

(4) Does the time and location birds are sampled affect observed concentrations? How does the residence time of birds correlate with time the bird was sampled?

iii) Do mercury concentrations represent an impairment of Great Salt Lake designated uses?

(1) Do concentrations adversely affect the survival, growth, or reproduction of algae, brine shrimp, brine flies, waterfowl, or shorebirds?

c) What are the sources of mercury?

i) What is the mercury balance for Great Salt Lake? What holes are there in understanding?

ii) What is the atmospheric contribution of mercury to Great Salt Lake?

iii) What is the contribution of mercury from Great Salt Lake tributaries?

iv) What is the rate of mercury deposition to and release from Great Salt Lake sediments? Can permanent sediment burial be estimated?

v) What is the mercury load in the water column? Shallow brine layer vs. deep brine layer?

vi) What is source of mercury for the deep brine layer?

vii) What controls the formation of methyl mercury in Great Salt Lake?

3. Do current nutrient concentrations present a risk to the designated uses of Great Salt Lake?

a) What are the current concentrations or values for the following: nutrients, chlorophyll a, dissolved oxygen, cyanotoxin, algal species composition, and secchi depth? What are the composition, frequency, extent and duration of algal blooms?

i) How do they vary spatially?

ii) How do they vary temporally?

iii) How do they vary by nutrient concentration in water?

iv) What methods should be used for sample collection, handling, and analysis?

v) Are differences in analytical methods/results between laboratories significant?

b) Do existing nutrient concentrations cause impairment of Great Salt Lake designated uses?

i) Which of the following indicators provide the best information regarding risk to the designated uses of Great Salt Lake? Are there others?

(1) Algal biomass (chlorophyll a)

(2) Trophic State Index values

(3) Dominance of blue-green algae

(4) Number, extent and duration of algal blooms

(5) Nutrient concentrations and ratios

(6) Dissolved oxygen concentrations

(7) Cyanotoxin concentrations

ii) What thresholds or benchmarks (i.e., indirect indicators) are appropriate for indicators of nutrient enrichment in the Great Salt Lake environment?

(1) How does salinity affect these thresholds?

(2) How do they affect algal, brine shrimp, and brine fly populations?

(3) Do any of the indicators directly affect avian populations (i.e., habitat, feeding)?

(4) Do any of the indicators directly affect the recreational use of Great Salt Lake?

c. Does presence of nutrients affect the availability of food and preferred habitats of the avian population using Great Salt Lake?

4. Can our understanding of selenium bioaccumulation and cycling in Great Salt Lake be improved?

a) Improve the current model describing bioaccumulation of selenium from water to brine shrimp (adult and cyst) and diet to bird egg. Would like to improve confidence in relating water concentrations to bird egg condition.

i) What are the concentrations of selenium in collocated shorebird eggs and food items?

ii) What are the concentrations of selenium in collocated water, seston, and brine shrimp?

iii) What are the concentrations of selenium in collocated water, sediment, brine fly larvae, and brine fly adults?

iv) How similar are concentrations of selenium in brine shrimp and brine fly larvae when sampled in the same vicinity?

b) Is the mallard model of diet to bird egg still the best model? Does the mallard still represent the most sensitive species?

c) How does the current Great Salt Lake numeric water quality standard for selenium compare to anticipated new national criteria incorporating tissue concentrations?

d) How can we better understand correlation between selenium and mercury in bird blood, livers, and eggs?

e) How do selenium loads to Great Salt Lake affect selenium concentrations and biotic exposure in Great Salt Lake?

i) What is the annual hydrograph of incoming flows to Great Salt Lake from tributary streams?

ii) What is the selenium load from each tributary?

iii) What is the atmospheric input of selenium to Great Salt Lake?

iv) What is the concentration of selenium in Great Salt Lake water and how does it vary temporally and spatially? And in relation to loading to the lake?

(1) What form of selenium is observed and in what quantity in these various media?

v) Can we better estimate volatilization drivers and rates?

vi) Can we better estimate sedimentation rates and sediment mineralization back to the water column?

vii) Can we better estimate selenium losses through permanent burial in the sediments?

viii) How has selenium loading varied historically? Can we estimate historical selenium loads from limited inflow data and selenium concentrations? Can we correlate this information with sediment cores to get estimates of longer term loading changes?

5. How does salinity vary in and across Great Salt Lake and how does that impact designated uses?

a) What are physical dynamics of salinity in Great Salt Lake?

i) What is the annual hydrograph of incoming flows to Great Salt Lake from tributary streams?

ii) What is the annual cycle of lake levels on Great Salt Lake? How does it correspond to incoming flows?

iii) How do evaporation rates vary with salinity?

(1) Do we have a means to collect continuous climate data?

(2) How to evaporation pan rates vary across the area of the lake?

iv) How does salinity vary across the different areas of Great Salt Lake (e.g., North Arm, South Arm, Bear River Bay, Farmington Bay, Ogden Bay, etc.)?

v) What is the depth of deep brine layer? What drives its size and location?

vi) Validate UGS water and salt balance model.

(1) How might future development affect hydrology of Great Salt Lake?

(2) What are flow patterns in Great Salt Lake? What drives flow patterns?

(3) How does temperature vary by depth/location? What drives temperature variations?

(4) What is the bathymetry across all regions of Great Salt Lake?

vii) How much of the salinity variation can be explained by volume vs. north/south arm flow interaction and precipitated salt in north arm?

viii) What impact do the causeways have upon salinity and flow patterns?

ix) What is the relationship between inflows and lake level and salinity?

x) What methods should be used for sample collection, handling, and analysis?

xi) Are differences in analytical methods/results between laboratories significant?

b) How does salinity define the characteristics of the ecosystem across Great Salt Lake?

i) How are algal populations affected by salinity?

ii) How are brine shrimp populations affected by salinity?

iii) How are brine fly populations affected by salinity?

iv) How are avian populations affected by salinity?

c) What levels of salinity represent important thresholds that limit or impair designated uses?

6. **Do current *E. coli* bacteria concentrations present a risk to the designated uses of Great Salt Lake?**

   a) What are concentrations of *E. coli* in waters of Great Salt Lake?

      i) How do they vary temporally and spatially?

      ii) What methods should be used for sample collection, handling, and analysis?

      iii) Are analytical methods/results between laboratories significant?

   b) Do existing *E. coli* concentrations represent an impairment of Great Salt Lake designated uses?

      i) What thresholds or benchmarks (i.e., indirect indicators) are appropriate for *E. coli* in the Great Salt Lake environment?

      ii) How representative are *E. coli* as an indicator organism for bacteria and viruses, particularly pathogens, in the Great Salt Lake water column?

7. **Any other factors that might present a risk to the designated uses of Great Salt Lake?**

   a) Do other potential pollutants present a risk to the designated uses of Great Salt Lake?

      i) What metals/metalloids are present and in what form, e.g., arsenic, zinc, aluminum, etc.?

      ii) What cyanotoxins are present, where, and in what concentrations?

      iii) What other pollutants, as listed by the United States Environmental Protection Agency (EPA) as "Pollutants of Emerging Concern" (CECs) are detectable in Great Salt Lake water and/or at levels of toxicological concern? Such classes of chemicals include:

         (1) Persistent organic pollutants such as polybrominated diphenyl ethers (PDBEs) and other organics

         (2) Pharmaceuticals and personal care products including human-prescribed drugs, over the counter medicines, and bactericides.

         (3) Veterinary medicines (various antibiotics and hormones)

         (4) Endocrine-disrupter chemicals including organochlorine pesticides

         (5) Nanomaterials (little known of environmental fate and effects)

   b) What thresholds or benchmarks (i.e., indirect indicators) are appropriate for these pollutants in the Great Salt Lake environment (i.e., food chain and bird tissues)?

8. How do habitat/vegetation vary in Great Salt Lake wetlands are what drives the variations?

a) What is the existing distribution and biomass of vegetation, including emergent vegetation, submerged aquatic vegetation, invasive species, phytoplankton, and algae, within Great Salt Lake wetlands?

b) How does this distribution affect habitat and change spatially and temporally with changing water levels, season, and water quality?

c) What does the literature reveal about a link between invasive species and nutrients and changes in habitat and use by wildlife?

d) What role does vegetation play in the cycling of pollutants in Great Salt Lake wetlands?

e) What controls the response of emergent vegetation, SAV, phytoplankton, and algae and how do they interact? How do pollutants affect these elements and their response?

f) How do emergent vegetation, SAV, phytoplankton, and algae contribute to the pollutant loads?