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CORE COMPONENT 2: STRATEGIC MONITORING AND RESEARCH PLAN

A GREAT SALT LAKE WATER QUALITY STRATEGY

April 2012

Utah Division of Water Quality

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

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ACRONYMS AND ABBREVIATIONS

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

CORE COMPONENT 2: STRATEGIC MONITORING AND RESEARCH PLAN

UTAH DIVISION OF WATER QUALITY

EXECUTIVE SUMMARY

Establishing water quality standards for Great Salt Lake, monitoring its water quality, and assessing its beneficial use support are the primary 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:

- ☐ Support the development of water quality standards for Great Salt Lake
- ☐ Monitor the waters of Great Salt Lake
- ☐ Complete research to assist in assessing Great Salt Lake's health and beneficial uses

Implementation of this strategy is critical toward UDWQ fulfilling its responsibilities under the Clean Water Act (CWA) and moving toward a proactive approach of protecting this valuable resource.

I. INTRODUCTION

1.1 Physical Setting and Study Area

Great Salt Lake is a uniquely dynamic terminal lake located adjacent to a rapidly growing metropolitan area in northern Utah (see Figure 1-1). 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, Great Salt Lake has no outlet; water that flows in can only evaporate or percolate into the substrate.

Great Salt Lake is the sixth-largest lake in the United States 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 Great Salt Lake each year. The vast majority of lake inflow typically comes from three drainages—the Jordan River (9 percent), Weber River (13 percent), and Bear River (39 percent). Additional inflow comes from groundwater (3 percent), direct precipitation (31 percent), and other minor east-side streams (5 percent) (Arnow and Stephens, 1987). Because the lake's only substantial water loss mechanism is evaporation, minerals, salts, and sediments from the watershed accumulate in Great Salt Lake. This results in lake water that is typically 3 to 7 times saltier than sea water and creates a unique habitat for biota that has adapted to and relies on the Great Salt Lake ecosystem.

Figure 1-1 illustrates the location of various features of Great Salt Lake. It shows Gilbert Bay (also known as the South Arm), Gunnison Bay (also known as the North Arm), Stansbury Bay, Carrington Bay, Farmington Bay, Bear River Bay, and Willard Bay. Great Salt Lake wetland areas are generally located along the eastern shore of Great Salt Lake including areas along Ogden Bay, Farmington Bay, Bear River Bay, and Willard Spur. The Union Pacific Railroad (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. A series of evaporation pond dikes separate Gilbert Bay from what was historically known as Stansbury Bay.

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 Great Salt Lake, often dependent on the annual conditions of the lake for its scale, diversity, and economic value.

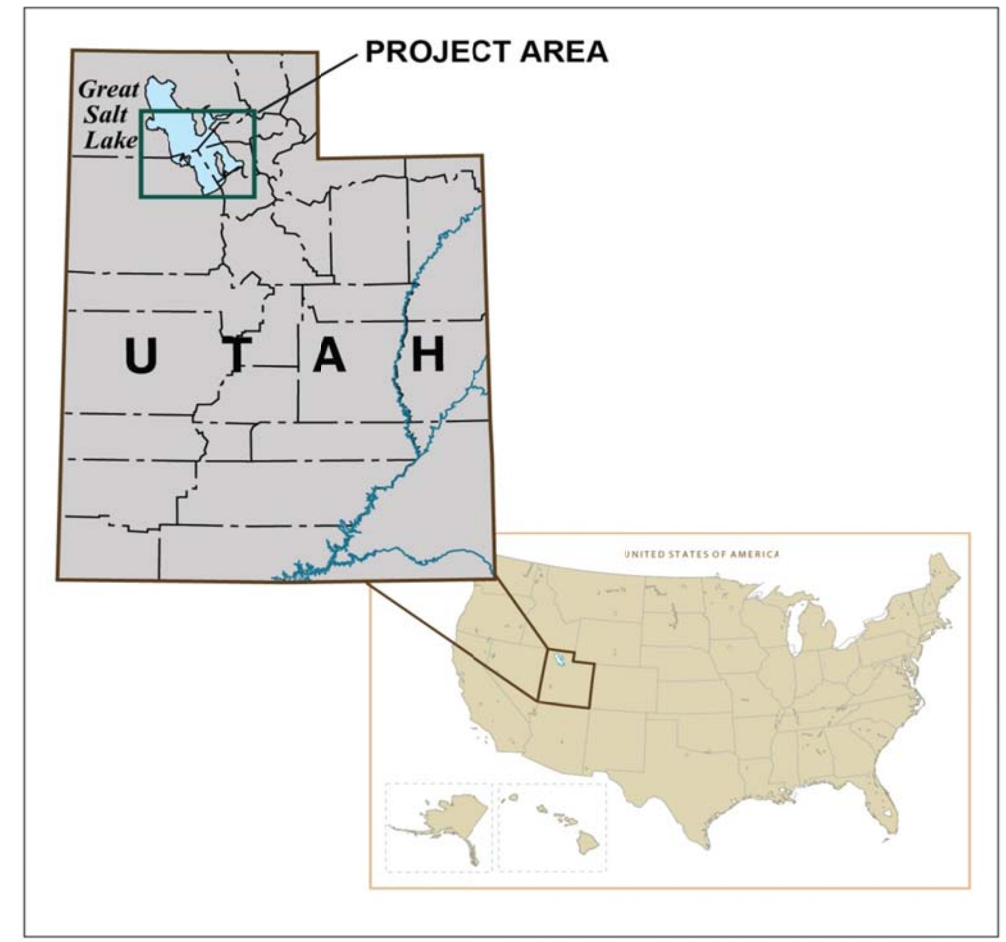
Millions of birds use the lake as they migrate from breeding grounds as far away as the arctic to wintering areas as far away as Argentina. For example, up to 1 million Wilson's phalaropes (*Phalaropus tricolor*)—or more than two-thirds of the world's population—annually migrate through Great Salt Lake as they travel from the near arctic to the high Andes (Colwell and Jehl, 1994). The magnitude of the Wilson's phalarope population was a primary factor in the designation of Great Salt Lake as one of six sites within the Western Hemisphere's Shorebird Reserve Network in the United States (Aldrich and Paul, 2002). Over half of the world's population of eared grebes (*Podiceps nigricollis*) use Great Salt Lake for up to 4 months during fall migration (Jehl, 1988). In 2007 the population of eared grebes on Great Salt 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 Great Salt Lake. Thousands of people visit the lake annually to enjoy sailing, hiking, hunting, and watching the diverse bird life. Along the lake are two state parks, numerous state wildlife refuges, and one federal wildlife refuge. Waterfowl hunting alone was estimated to be almost an $8-million industry in 1998 (Isaacson et al., 2002). The total annual economic effect of recreation of Great Salt Lake was recently estimated to be almost $136 million (Bioeconomics, Inc., 2012).

As a result of the minerals left behind by evaporation, Great Salt 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 Great Salt Lake generated a total of about 2.8 million tons of sodium chloride, potassium sulfate, magnesium chloride, magnesium metal, chlorine gas, and other products—all estimated to be worth about $300 million in 1995 (Gwynn, 1997). This represents about 16 percent of the annual value of all minerals produced in 1995 in Utah (United States Geological Survey [USGS], 1995). The total annual economic effect of Great Salt Lake's mineral industry was recently estimated to be $1.13 billion (Bioeconomics, Inc., 2012).

Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1980, 1984

0 10 20 MILES
0 10 20 KILOMETERS



LEGEND

- Great Salt Lake, altitude 4,200 feet
- Intermittent water body
- Utah State Park or National Monument

FIGURE 1-1
Study Area
Great Salt Lake Water Sampling Plan

Great Salt Lake produces a significant portion of the world's supply of brine shrimp cysts. Commercial harvest on the lake began in 1952, and the lake has become an internationally renowned source of cysts for their quality as feed for the aquaculture and ornamental fish industry. The market value was estimated to average $8 million to $11 million annually with an estimated peak value of $58 million in 1995. The annual harvest from Great Salt Lake is often limited by biological factors rather than market forces (Isaacson et al., 2002). The total annual economic effect of Great Salt Lake's brine shrimp industry was recently estimated to be almost $56 million (Bioeconomics, Inc., 2012).

Combining the annual economic effect of the three industries previously described, the total annual economic output or significance of Great Salt 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 Great Salt Lake region and establishes Great Salt Lake as a significant factor in and of significant value to Utah's economy (Bioeconomics, Inc., 2012).

1.3 Need for a Great Salt Lake Monitoring and Research Plan

Increasing development within Great Salt Lake's watershed and use of its natural resources has not only increased pressure on the lake but they have also increased awareness of just how complex, dynamic, and flexible the Great Salt Lake ecosystem is. Research continues to show the pressures Great Salt Lake faces, the value it represents, and that it poses UDWQ and its partners with a unique challenge to protect (Great Salt Lake CMP, 2011; Bioeconomics, Inc., 2012; SWCA, 2012; UDWQ, 2009; UDWQ, 2011; CH2M HILL, 2008). This Strategic Monitoring and Research Plan was developed to enable UDWQ to proactively address this challenge, fulfill its responsibilities in a proactive manner, and collaborate with its partners to protect this valuable resource.

1.3.1 Technical and Regulatory Challenges

UDWQ is charged with the responsibility to establish water quality standards for Great Salt Lake, monitor its water quality, and assess its beneficial use support (UAC R317-2-7). Due to the unique geochemistry of Great Salt Lake, the direct application of national freshwater quality criteria to the open waters of Great Salt Lake is inappropriate (United States Environmental Protection Agency [EPA] 1987, 2004). Thus, UDWQ has historically used a narrative clause in the state water quality standards to protect

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

the beneficial uses of Great Salt Lake. UDWQ has, however, faced repeated challenges in monitoring the lake and implementing existing water quality standards to assess the lake's beneficial uses.

Questions regarding the applicability of existing freshwater numeric criteria and the ability of the narrative clause to assess the wetlands of Great Salt Lake led UDWQ to begin development of an assessment framework for Great Salt Lake impounded wetlands in 2004 (Miller and Hoven, 2007; UDWQ, 2009; Miller et al., 2011) and evaluate water quality standards for Willard Spur in 2010 (http://www.willardspur.utah.gov/). Questions regarding the ability of the narrative clause to address selenium led to the development of site-specific numeric criteria for selenium for Great Salt Lake in 2006–2008 (CH2M HILL, 2008) and an investigation of mercury in 2009–2011 (UDWQ, 2011). All of these studies have encountered unique challenges in implementing existing and establishing new water quality standards, monitoring water quality, and assessing Great Salt Lake's beneficial use support. Some examples of these challenges include the following:

- 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 Great Salt 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.
- Existing freshwater numeric criteria for dissolved oxygen and pH were found not to apply to the impounded wetlands of Great Salt Lake.
- Assessment of beneficial use support in Great Salt Lake wetlands continues to present many challenges.

Using methods and assumptions commonly used for fresh or ocean 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 contaminants (UDWQ, 2011; CH2M HILL, 2008). UDWQ is faced with the reality that an investment is needed to develop the methods, the data, and a better understanding of Great Salt Lake to be able to proactively fulfill its responsibilities.

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 Great Salt Lake: Gilbert Bay, Farmington Bay, Bear River Bay, and Gunnison Bay. The study developed a framework for defining the health of Great Salt Lake, based on eight ecological targets that capture the biological diversity of the lake's ecosystem. These targets were systemwide 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 Great Salt 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 open water of Gunnison Bay (SWCA, 2011).

The study established the need to better understand the current condition and stresses (current and projected) on Great Salt Lake, not only to better define the health of these ecological targets, but also to protect Great Salt Lake's beneficial 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 Objectives

The objective of the Strategic Monitoring and Research Plan is to enable UDWQ to proactively fulfill its responsibility to protect Great Salt Lake's water quality and beneficial uses. Specifically, the Strategic Monitoring and Research Plan provide a strategy to address UDWQ's responsibilities for Great Salt Lake:

1. **Support the development of water quality standards for Great Salt Lake.** Identifies monitoring and research required to support the evaluation of existing water quality standards and identify the need for and develop new water quality standards for Great Salt Lake as discussed in Component 1.

2. **Monitor the waters of Great Salt Lake.** Identifies a plan to provide essential lake assessment data to determine long-term water quality trends, quantify water quality problems, establish water quality goals, assess beneficial use support, and determine the effectiveness of pollution control programs. Identifies research studies to improve upon monitoring methods to improve consistency and defensibility and better leverage available resources.

3. **Complete research to support assessing Great Salt Lake's beneficial uses.** Identifies research required to support the above goals and the assessment of Great Salt Lake's beneficial uses. These studies will provide an essential understanding of Great Salt Lake's complex biogeochemistry, hydrology, and ecosystem; its beneficial uses; and how the lake's water quality

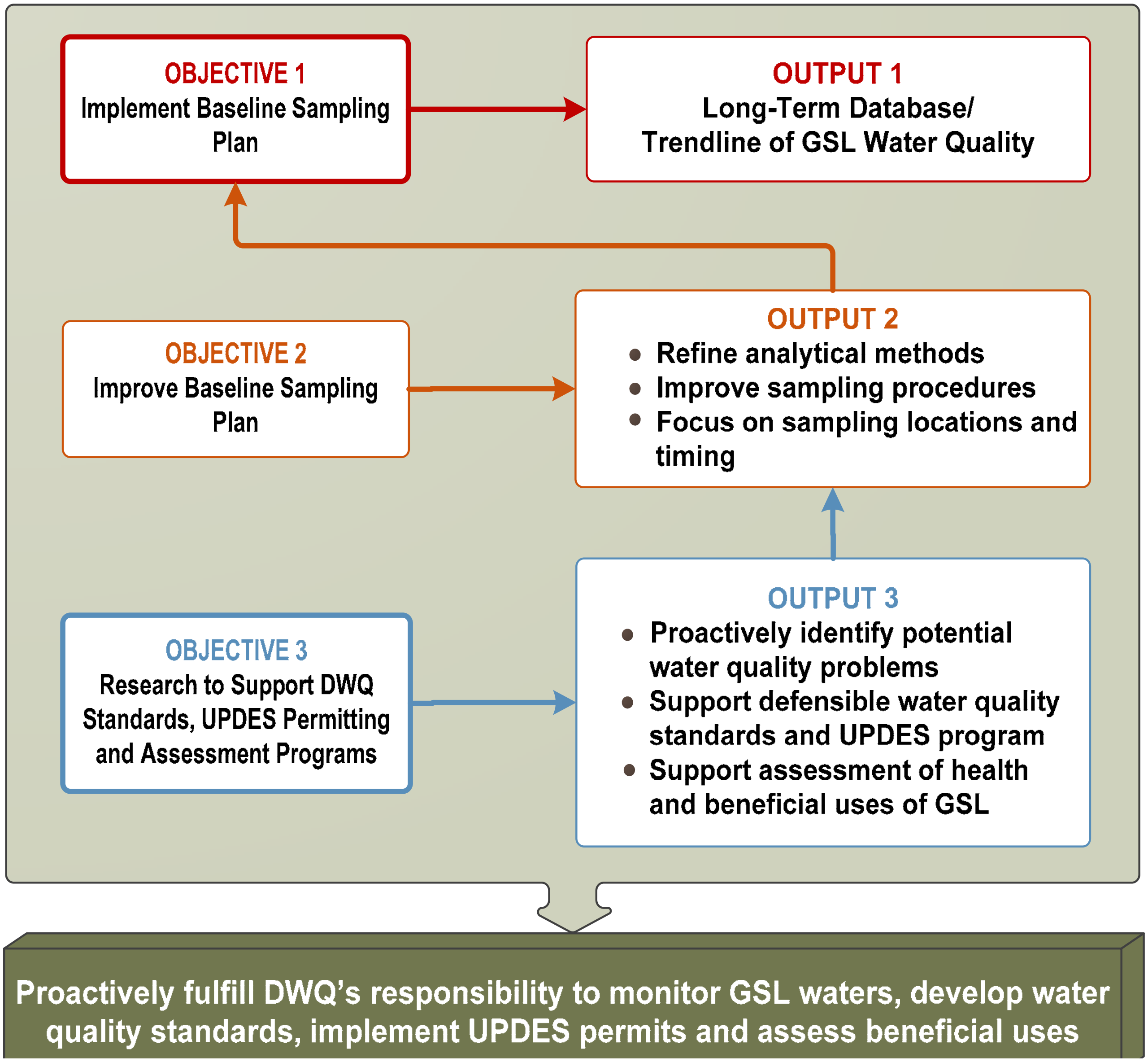
may affect them. They provide significant opportunities for collaboration with other local, state, and federal agencies.

While the Strategic Monitoring and Research Plan supports the development of water quality standards for Great Salt Lake as described in Component 1, it focuses on UDWQ's monitoring and assessment responsibilities for Great Salt Lake. It works to answer the following key questions:

- ☐ What is the current water quality condition of Great Salt Lake and how does it change seasonally and spatially?
- ☐ How can the accuracy, reliability, and quality of sampling and analyzing various parameters in the complex and dynamic ecosystem of the Great Salt Lake be improved?
- ☐ What areas of research are required to help evaluate and develop water quality standards, better focus monitoring efforts, and assess the lake's health and beneficial uses?

The specific objectives of the Strategic Monitoring and Research Plan are summarized in Figure 1-2 and are detailed as follows.

FIGURE 1-2. GREAT SALT LAKE SAMPLING PLAN TASK SUMMARY



1.4.1 Objective 1—Implement Baseline Sampling Plan

This objective is of highest priority and will be integrated into UDWQ's annual monitoring program. The objective is to sample a set of key water quality parameters in Great Salt Lake and its wetlands to determine long-term water quality trends, quantify water quality problems, establish water quality goals, assess beneficial use support, and determine the effectiveness of pollution control programs. Implementation of this plan is the foundation to proactively fulfilling UDWQ's responsibilities for Great Salt Lake.

Key parameters and contaminants were determined based on results of previous studies conducted by UDWQ and other agencies and include those that are currently identified to be at highest risk to the lake's beneficial uses. Standard operating procedures (SOPs) were identified that can be implemented consistently by all organizations sampling and monitoring Great Salt Lake to ensure consistent quality and facilitate cross-agency use of the data. The baseline sampling plan includes the following:

- Data quality objectives (DQOs) that define and establish the basis for the baseline sampling program
- A work plan to meet the DQOs
- Details on sampling locations and frequency
- SOPs for sampling and analyzing key water quality parameters and contaminants
- A Quality Assurance Project Plan (QAPP)

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 baseline sampling plan and analytical procedures for key contaminants in the lake. These studies fill numerous gaps and are essential to improving UDWQ's ability to monitor Great Salt Lake and proactively develop water quality standards, Utah Pollution Discharge Elimination System (UPDES) permits, and assess Great Salt Lake's beneficial uses. Specific objectives are as follows:

- Identify gaps in accuracy and reliability of existing sampling and analytical procedures for the Great Salt 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 Great Salt Lake
- Complete studies to verify and confirm or improve sampling locations, sampling time and frequency, and contaminants that are monitored through the baseline sampling plan

1.4.3 Objective 3—Research to Support UDWQ Standards, UPDES Permitting, and Assessment Programs

Numerous questions asked during previous investigations remain unanswered, and answers are essential to developing water quality standards, improving monitoring activities, and assessing the health and beneficial uses of Great Salt 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 for it to fulfill its responsibilities. These studies will be implemented depending on priority and available funding. The specific objectives of this task include the following:

- ☐ Complete research to proactively identify potential water quality problems.
- ☐ Complete research required to support the evaluation and development of defensible water quality standards. The standards directly support the UPDES program by establishing discharge limits for pollutants to the lake.
- ☐ Complete research required to effectively and defensibly assess the health and beneficial uses of Great Salt Lake.

1.5 Prioritization of Monitoring and Research Needs

UDWQ has undertaken a significant effort over the last several years to engage its partners and the stakeholders of Great Salt Lake to better understand their objectives, plans, needs, issues, and concerns 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 Great Salt Lake and its responsibilities under the CWA.

As previously described, UDWQ's highest priority is to implement the baseline sampling plan and then complete studies to improve on it. This work is critical to shifting UDWQ from reacting to possible water quality problems toward proactively monitoring, developing standards, and assessing Great Salt Lake's beneficial uses. Table 1-2 provides a summary of how studies for Objectives 1 and 2 are prioritized with a suggested timeline for completion.

Additional research studies were identified to address Objective 3. Each of these studies is important and helps achieve the stated objectives. However, in an environment where funds are not always available, it is necessary to prioritize efforts. Table 1-3 provides a summary of how studies for Objective 3 are prioritized with a timeline for completion. It is important to note that some of these studies are already being implemented by UDWQ and/or others in response to critical needs, thus their high priority is implied by this action. 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 will be necessary to implement if the lake is listed on the 303(d) list as impaired for its beneficial use and a Total Maximum Daily Load Analysis is required to quantify sources and loading to the lake. The remaining studies are prioritized based on existing issues that UDWQ must address and its need to proactively develop water quality standards and assess Great Salt Lake's beneficial uses.

The recommended timeline for completion is identified only as a guideline as some studies provide information that are a prerequisite for 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 reprioritize efforts to address needs as they arise.

TABLE 1-2. PRIORITIZATION OF STUDIES FOR OBJECTIVES 1 AND 2

Priority	Study Description	Location in Document (Section No.)	Recommended Timeline
Objective 1 – Implement Baseline Sampling Plan			
1	Implement Baseline Sampling Plan	2.0	Began in 2011, continuing
Objective 2 – Improve Baseline Sampling Plan			
1	Round Robin Study for Evaluating Laboratory Analytical Techniques	3.2	Begin in 2012
2	Round Robin Study for Evaluating Water Sampling Techniques	3.3	2013–2014
3	Brine Shrimp Sampling Method Optimization	3.4	2014–2015
4	Synoptic Sampling of Great Salt Lake	3.5	2013–2014, repeat every 5 years

TABLE 1-3. PRIORITIZATION OF STUDIES FOR OBJECTIVE 3

Priority	**Study Description**	**Location in Document (Section No.)**	**Recommended Timeline**
Objective 3 – Complete Research to Better Understand Great Salt Lake Ecosystem and Protect its Beneficial Uses			
1	Great Salt Lake Wetland Assessment Framework	4.4.1	2009–2015
2	Development of Water Quality Standards for Willard Spur	4.4.2	2011–2015
3	Determine Potential Water Quality Benchmarks	4.3.1.1	2012–2013
4	Bird Egg Monitoring for Selenium and Mercury in Great Salt Lake	4.3.3.3	Began in 2010, continuing
5	Develop Wetland Research Framework	4.4.3.1	Begin in 2013
6	Avian Population Use of Great Salt Lake	4.3.3.1	Other agency's efforts, continuing
7	Trophic Transfer Model for Upper Food Chain	4.3.3.2	Continuing
8	Laboratory Toxicity Tests	4.3.2.3	
9	Effects of Salinity on Planktonic and Benthic	4.3.2.1	

TABLE 1-3. PRIORITIZATION OF STUDIES FOR OBJECTIVE 3

Priority	Study Description	Location in Document (Section No.)	Recommended Timeline
Objective 3 – Complete Research to Better Understand Great Salt Lake Ecosystem and Protect its Beneficial Uses			
	Communities in Great Salt Lake		
10	Great Salt Lake Data Repository	4.2.1	
11	Trophic Transfer Model for Lower Food Chain	4.3.2.2	
12	Great Salt Lake Hydrologic and Hydrodynamic Model	4.3.1.2	
13	Sources, Loads, Mass Balance, and Mixing of Nutrients in Great Salt Lake	4.3.1.2	
14	Sources, Loads, Mass Balance, and Mixing of Selenium in Great Salt Lake	4.3.1.2	
15	Sources, Loads, Mass Balance, and Mixing of Mercury in Great Salt Lake	4.3.1.2	
16	Effects of Lake Hydrology and Chemistry on Contaminants of Concern	4.3.1.3	
17	Interaction of Contaminants between Water and Sediment in Great Salt Lake	4.3.1.4	
18	Studies to Understand the Interaction of Selenium and Mercury and Their Effects on Avian Population in Great Salt Lake	4.3.3.3	
19	Miscellaneous Topics	4.4.3.2	

1.6 Document Organization

The remainder of this document is organized into the following sections:

- **Section II** provides the Great Salt Lake baseline sampling plan (Objective 1).
- **Section III** provides recommendations to refine and improve the baseline sampling plan (Objective 2).
- **Section IV** identifies key research needs for Great Salt Lake as they pertain to UDWQ's responsibilities (Objective 3).
- **Section V** provides a list of the references cited in this document.

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

Monitoring the water quality of Great Salt 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 Great Salt Lake. This plan will provide for the routine collection of environmental samples and reporting of concentrations of key contaminants of concern in the water, macroinvertebrates, and bird eggs that are indicative of the water quality of the open waters of Great Salt Lake. The activities described in this section will enable UDWQ to determine long-term water quality trends, quantify water quality problems, establish water quality goals, assess beneficial use support, and determine the effectiveness of pollution control programs.

While UDWQ is currently also sampling Great Salt Lake wetlands, the assessment framework for these wetlands is still in development and will be described elsewhere. This section summarizes UDWQ's baseline sampling for the open waters of Great Salt Lake.

2.1 Introduction

2.1.1 Background

The importance of the complex yet unique characteristics of Great Salt Lake to migratory birds, local recreation, brine shrimp, and mineral industries and its significance to the ecology and economy of the region is well documented (Colwell and Jehl, 1994; USGS, 1995; Jehl, 1988; Aldrich and Paul, 2002; Isaacson et al., 2002). Millions of birds use the lake water and its surrounding wetlands every year as they migrate from breeding grounds as far away as the Arctic to wintering areas as far away as Argentina. Recreational opportunities abound on and around the lake, which attracts thousands of visitors annually to enjoy sailing, hiking, hunting, and watching the diverse bird life. Great Salt Lake is also home to the mineral and brine shrimp industries, which also make significant contributions to Utah's economy (Bioeconomics, Inc., 2012).

These same complex and unique characteristics also make it challenging for UDWQ to develop water quality standards, monitor the lake's water quality, and assess the lake's beneficial uses. Existing freshwater standards are generally not applicable. Only one numeric criterion (selenium) has been adopted for the lake at the writing of this plan, leaving UDWQ with a narrative clause for use in its assessments. A lack of long-term data and scientific uncertainty about the fate and transport of contaminants in the lake and its associated food web further complicate UDWQ's assessments.

What was first considered a relatively simple ecosystem composed of algae, brine shrimp, brine flies, and bird life is now understood to be quite complex and dynamic. UDWQ needs a baseline sampling program for Great Salt Lake that will provide the following:

- ☐ Establish a public, long-term database of the lake's water quality that will enable UDWQ to determine long-term water quality trends, quantify water quality problems, establish water quality goals, assess beneficial use support, and determine the effectiveness of pollution control programs
- ☐ Confirm appropriate sampling and analytical techniques of various matrices and target contaminants in the lake
- ☐ Support the development of water quality standards and the assessment of Great Salt Lake's health and beneficial uses
- ☐ Facilitate a collaborative approach with partner agencies

2.1.2 Baseline Sampling Program Objectives

The objective of the baseline sampling program is to enable UDWQ to collect environmental samples to determine long-term water quality trends, quantify water quality problems, establish water quality goals, assess beneficial use support, and determine the effectiveness of pollution control programs.

This sampling plan defines the DQOs, sampling procedures, analytical procedures, safety considerations, and documentation and reporting requirements to be implemented by UDWQ as part of this program.

2.1.3 Study Area

Figure 2-1 shows the study area for the baseline sampling program. It includes the "open waters of Great Salt 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. A series of evaporation pond dikes separate Gilbert Bay from what was historically known as Stansbury Bay.

2.2 Data Quality Objectives

The EPA's seven-step DQO process (EPA, 2006) was used to guide the requirements and design rationale for the Great Salt Lake baseline sampling program. 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 2-1 details the DQOs for this sampling plan.

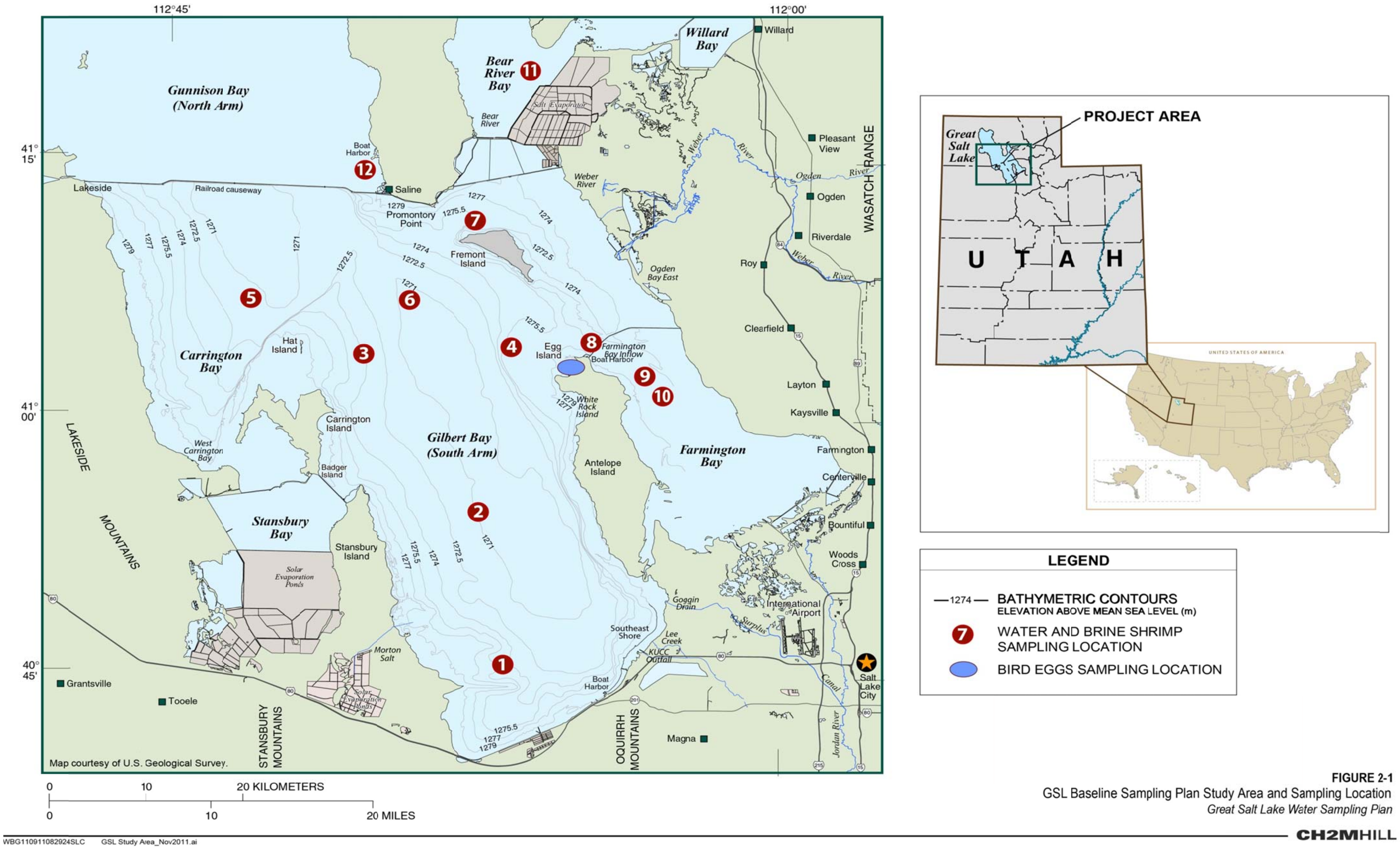


FIGURE 2-1
GSL Baseline Sampling Plan Study Area and Sampling Location
Great Salt Lake Water Sampling Plan

TABLE 2-1. DQOs FOR GREAT SALT LAKE BASELINE SAMPLING PROGRAM

Step	DQOs for Great Salt Lake Baseline Sampling Program
1. Problem Statement	**Problem** Several contaminants of concern, such as nutrients, selenium, mercury, and other trace metals, are known to cause adverse effects on the biological health and the beneficial uses of some water bodies and are known to exist in the waters of Great Salt Lake. Little is known about existing concentrations of these contaminants 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 contaminants and tracking their long-term variability difficult and precluded the use of typical numeric water quality standards to manage Great Salt Lake's water quality. This has resulted in a dearth of data that often results in a reactive approach to managing its water quality and makes the assessment of the water quality in Great Salt Lake extremely difficult. These uncertainties resulted in a large expenditure of resources to develop the criterion for selenium. Great Salt 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 strategy to monitor selenium concentrations in bird eggs is needed to comply with the existing numeric criterion. Proven protocols are needed to enable the consistent collection and analysis of environmental samples from Great Salt Lake. 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 Team** 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 potential partners in completing a baseline sampling program and developing protocols for future monitoring of the health of Great Salt Lake: • Utah Division of Wildlife Resources (UDWR) • Utah Division of Forestry, Fire, and State Lands • Utah Geological Survey • Davis County Health Department • USGS • United States Fish and Wildlife Service (USFWS) **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.

TABLE 2-1. DQOs FOR GREAT SALT LAKE BASELINE SAMPLING PROGRAM

Step	DQOs for Great Salt Lake Baseline Sampling Program
	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 provided to UDWQ to provide adequate time for inclusion in the preparation of the State of Utah's biennial 305(b) report.
2. Goal of the Study/Decision Statements	**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 are the concentrations of potential contaminants of concern (i.e., nutrients, selenium, mercury, etc.) in Great Salt Lake's water or the brine shrimp and the eggs of nesting birds? • How do these concentrations vary spatially, seasonally, and annually? **Possible Outcomes** • Information obtained from the sampling efforts is adequate to accurately quantify concentrations of contaminants in Great Salt Lake. Data are useful for management decisions, 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 contaminants 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 contaminants 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.
3. Inputs to the Decision	**Informational Inputs** The following information will be collected: • Water and brine shrimp samples will be sampled biannually at 12 locations in Great Salt Lake as shown in Figure 2-1—Once during the bird nesting season (in the month of June) and once during the fall brine shrimp cyst harvest (in the month of October). An assessment framework (see Figure 2-3) will be used to determine if water and brine shrimp sampling will be completed at more locations and on a more frequent basis. • A minimum of five (preferably eight) bird eggs each will be collected from American avocets and black-necked stilts at two locations: Bridger Bay on Antelope Island and Saltair as shown in Figure 2-1. This will be completed during bird nesting season (April through June) at a minimum of once every 2 years. An assessment framework (see Figure 2-3) will be used to determine

TABLE 2-1. DQOs FOR GREAT SALT LAKE BASELINE SAMPLING PROGRAM

Step	DQOs for Great Salt Lake Baseline Sampling Program
	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 and mercury concentrations in the following: • Water • Brine shrimp • Bird eggs Methyl-mercury concentration in the following: • Water Trace metals (at a minimum total arsenic, total copper, cadmium, lead, and thallium; others included if part of the same analysis suite) concentration in the following: • Water • Brine shrimp Nutrient (total nitrogen, total phosphorus, and ammonia) and chlorophyll-a concentrations in the following: • Water Dissolved oxygen, pH, temperature, conductivity, secchi depth, total water depth, and the depth of deep brine layer (if present) will be measured in water as well. Report dry-weight concentrations and moisture percentage of biota samples.
4. Study Boundaries	The study area for this project is shown in Figure 2-1. This area includes the Gilbert Bay or the South Arm, Farmington Bay, Bear River Bay, and Gunnison Bay (i.e., the North Arm). **Temporal** • Water and brine shrimp samples will be sampled semiannually—once during the bird nesting season (June) and once during the fall brine shrimp cyst harvest (October). An assessment framework (see Figure 2-3) will be used to determine if sampling will be completed more frequently. • Bird eggs will be collected during nesting season (April through June) a minimum of once every 2 years. An assessment framework (see Figure 2-3) 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.

TABLE 2-1. DQOs FOR GREAT SALT LAKE BASELINE SAMPLING PROGRAM

Step	DQOs for Great Salt Lake Baseline Sampling Program
	• 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 and sufficient mass of macroinvertebrates needed for sample analysis may be a constraint. • Not all sampling and analytical methods are fully tested and confirmed.
5. Decision Rules	• If information is adequate to accurately quantify the concentration of contaminants of concern for Great Salt Lake, UDWQ will complete reporting as noted. • If information is not adequate to accurately quantify the concentration of contaminants 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.
6. Tolerable Limits on Decision Rules	Data quality may also be specified under measurement quality objectives. This quality assessment typically involves specifying 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. For this investigation, measurement quality objectives for chemical measurements will be specified in the QAPP; in general, the measurement quality objectives for selenium and trace metals are about ±20 percent, for total mercury are about ±24 percent, and for methyl mercury are about ±35 percent. The QAPP will specify all quality assurance/quality control objectives for sample measurement based on each matrix and may be more restrictive or less restrictive than ±20 percent.
7. 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 standards. An assessment framework is included that allows UDWQ to adapt the baseline sampling program to specific concentrations of selenium observed in Great Salt Lake. UDWQ's strategy for Great Salt Lake includes supplemental studies that are intended to improve implementation and interpretation of results from the baseline sampling program.

2.3 Contaminants of Concern

Several studies and monitoring programs have identified contaminants that may adversely affect Great Salt Lake's ecology and its beneficial uses. As the public has become more aware of the importance of Great Salt Lake, they too have begun to express concerns about the lake's water quality condition. Table 2-2 provides a summary of selected recent literature that has investigated and identified contaminants of concern that could potentially adversely affect the Great Salt Lake ecosystem.

TABLE 2-2. CONTAMINANTS TO BE MONITORED IN THE GREAT SALT LAKE BASELINE SAMPLING PLAN

Contaminants	Literature
Selenium	Cavitt, 2006; Marden, 2007; Cavitt, 2008a; Cavitt 2008b; CH2M HILL, 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	CH2M HILL, 2008; Naftz et al., 2008; Naftz et al., 2009a; Vest et al., 2009; UDWQ, 2011
Trace Metals	Johnson et al. 2008; Naftz et al., 2009b; USGS, 2004; Vest et al., 2009; Beisner et al., 2009
Nutrients	Naftz et al., 2008; Wurtsbaugh et al., 2009

2.3.1 Selenium

A numeric water quality criterion for selenium was established for Great Salt 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 (CH2M HILL, 2008). The selenium water quality criterion of 12.5 milligrams per kilogram is a tissue-based standard based on 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 Great Salt Lake for selenium by monitoring egg tissue from aquatic-dependent birds, refining the trophic transfer model through ecosystem monitoring, evaluating trigger selenium concentrations that initiate various monitoring, assessment and management actions, and identifying management actions to mitigate further increases in selenium concentrations. The baseline sampling program will work toward developing a long-term database to assess bird egg concentrations and address these objectives.

2.3.2 Mercury

Mercury, a global pollutant that ultimately makes its way into every aquatic ecosystem through the hydrologic cycle, is also a contaminant of concern in Great Salt Lake. After a 2003 USGS study found elevated concentrations of total and methyl-mercury in the waters and evidence of its bioaccumulation in the biota of Great Salt 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 Great Salt Lake aquatic birds and organisms in their forage base (UDWQ, 2011). Several other studies as indicated in Table 2-2 have also concluded that mercury is a significant contaminant of concern in Great Salt Lake. Questions still remain on whether avian species are exposed to mercury at Great Salt Lake or elsewhere. More research needs to be done on avian species that feed primarily on brine shrimp and brine flies, as well as on the relationship between selenium and mercury. UDWQ's objective is to continue sampling and monitoring of total and methyl-mercury in the Great Salt Lake ecosystem.

2.3.3 Trace Metals

Though little is known about the input and biogeochemical cycling of trace elements in the lake, there are concerns about the negative effect of these constituents in Great Salt Lake. A study by USGS and others completed from 1998 to 2001 evaluated water quality and completed a biological assessment of the Great Salt 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 contaminated sediment in the Farmington Bay area with 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 trace metals on the lake with increased urbanization. In addition, in a recent article, Vest et al. (2009) found elevated arsenic levels in wintering waterfowls of Great Salt Lake. UDWQ's objective is to prioritize the tracking of current and changing concentrations of arsenic and copper to proactively protect the lake from these potential contaminants. Other trace metals are of concern but will be tracked as resources are available.

2.3.4 Nutrients

Similar to the trace metals, little is known with regard to the variability, fate, and transport of nutrients in the open waters of Great Salt Lake. A few studies by Wurtsbaugh et al. have assessed Farmington Bay of Great Salt Lake and identified it to be hypereutrophic with blooms of toxic cyanobacteria and measurable concentrations of cyanotoxins (Wurtsbaugh et al., 2006; Wurtsbaugh et al., 2009). These studies have also estimated the impact of excess nutrients in Farmington Bay on the Great Salt Lake ecosystem via its connectivity with the other bays. The UDWR continues work to evaluate the impact of nutrients on the brine shrimp industry. Tracking nutrient concentrations are thus important to UDWQ to better understand nutrient cycling and effects in the lake.

2.3.5 Summary

The baseline sampling program's focus will be to monitor concentrations of potential contaminants in the waters, brine shrimp, and aquatic-dependent bird eggs of Great Salt Lake as described in Table 2-3.

TABLE 2-3. CONTAMINANTS TO BE MONITORED IN WATER, BRINE SHRIMP, AND BIRD EGGS OF OPEN WATERS OF GREAT SALT LAKE

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

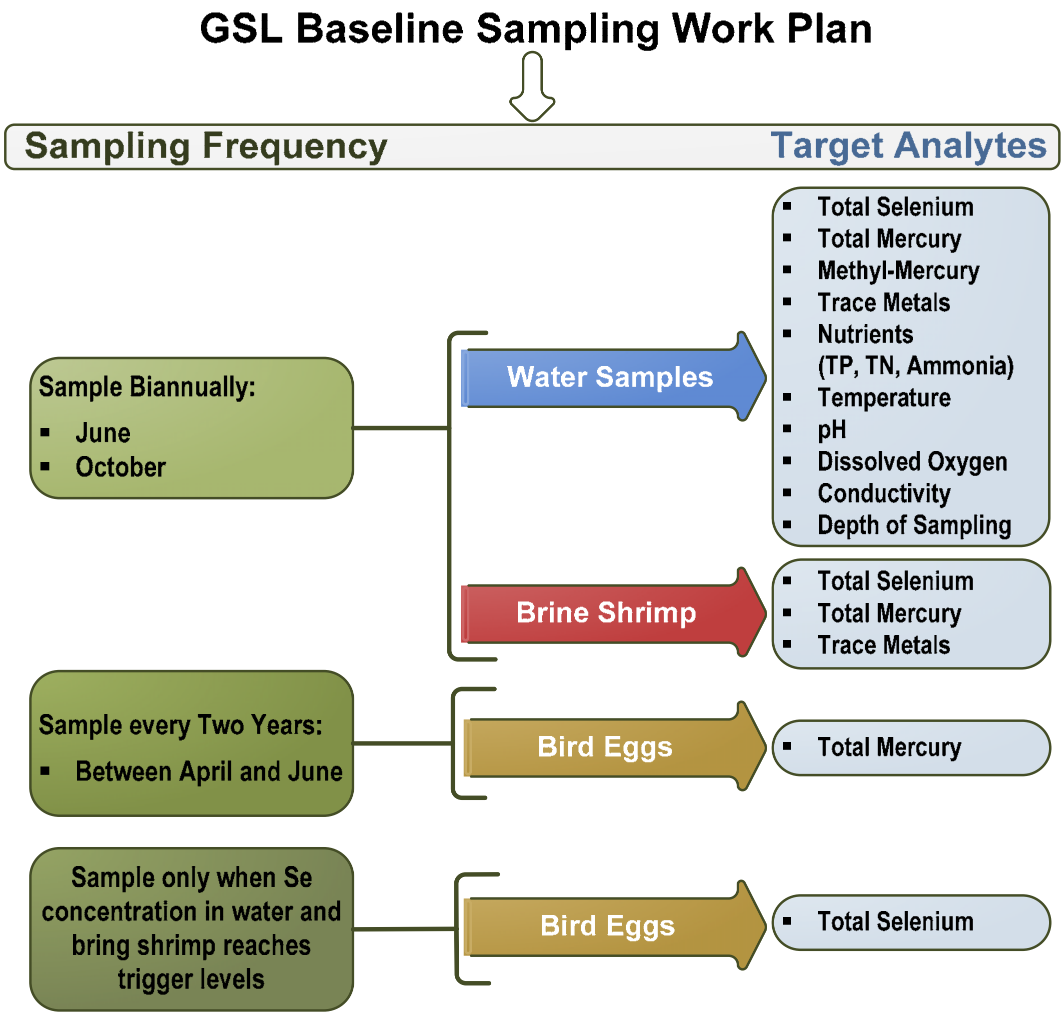
2.4 Sampling Approach

UDWQ intends that the baseline sampling program be adapted to address a variety of factors:

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

The baseline sampling approach described in the following paragraphs is the minimum sampling and monitoring required to meet UDWQ's current objectives and obligations for management of the open waters of Great Salt Lake. While the approach to sampling on Great Salt 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 2-2 summarizes the work plan design for the sampling plan.

FIGURE 2-2. GREAT SALT LAKE BASELINE SAMPLING WORK PLAN



2.4.1 Water and Brine Shrimp

Water and brine shrimp will be sampled and analyzed a minimum of twice per year using SOPs and the QAPP. Samples will be collected once during the bird nesting season (April through June) and once during the fall brine shrimp cyst harvest (September through November). Samples will be collected at a minimum of 11 locations as shown in Figure 2-1 and Table 2-4. These locations were selected to remain consistent with locations used in routine sample collection and research completed by the UDWR and USGS (Naftz et al., 2008b). Additional locations may be added or samples collected more frequently as resources are available, per the objectives of independent research studies or as dictated by the selenium assessment framework described in Section 1.5. All samples will be collected adjacent to or within the open waters of Great Salt Lake, Farmington Bay, and Bear River Bay so samples are representative of contaminant exposure from the open waters of Great Salt Lake and

Farmington Bay. All results for tissue samples will be reported on a dry-weight basis, along with the percent moisture for each sample, insofar as adequate biomass can be collected.

The deep brine layer will be sampled for total and methyl-mercury, total selenium, total arsenic, total copper, cadmium, lead, and thallium, when it is present.

TABLE 2-4. 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°03'59", Longitude 112°13'47"
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°19'38", Longitude 112°19'29
12	Gunnison Bay	Latitude 41°15'19", Longitude 112°29'46"

Note:
*(http://wdr.water.usgs.gov/nwisgmap/?state=ut)

Water samples and brine shrimp will be analyzed for the minimum analytes shown in Table 2-3. Additional analytes may be included if included as part of the same analytical suite, as resources are available or per the objectives of independent research studies.

At a minimum, measurements documenting the temperature, pH, conductivity, dissolved oxygen, secchi depth, total water depth, and depth to deep brine layer will be made at the location where water and brine shrimp samples are collected.

2.4.2 Bird Eggs

The eggs of shorebirds will be sampled to characterize the birds' exposure to metals present in the open waters of Great Salt Lake. Bird eggs will be sampled a minimum of once every 2 years to allow UDWQ to assess compliance with Great Salt 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 in the open waters of Great Salt Lake 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.

The area considered for bird egg collection will be, at a minimum, Bridger Bay on north side of Antelope Island as shown in Figure 2-1. Additional locations may be added or additional eggs collected as allowed by the egg collection permit, as resources are available, per the objectives of independent research studies, or as dictated by the selenium assessment framework described in Section 2.5. All samples will be collected adjacent to or within the open waters of Great Salt Lake so samples are representative of contaminant exposure from the open waters of Great Salt Lake. All results for tissue samples will be reported on a dry-weight basis, along with the percent moisture for each sample, insofar as adequate biomass can be collected.

2.5 Selenium Assessment Framework

UDWQ's Selenium Science Panel discussed various alternatives for implementing a water quality standard for selenium in the open waters of Great Salt Lake. Given the uncertainties of the current understanding of selenium cycling in Great Salt Lake, the bioaccumulative nature of selenium, the need to incorporate both water-borne and tissue-based selenium concentrations, and the desire to proactively protect and manage the water quality of Great Salt Lake, the Science Panel developed a concept for a tiered approach to implementing the selenium water quality standard. The approach relies on the Bioaccumulation Model developed as part of the selenium research program to relate water, brine shrimp and bird egg concentrations (CH2M HILL, 2008).

Selenium monitoring completed as part of the Great Salt Lake baseline sampling program will follow this tiered approach. Figure 2-3 illustrates the framework of the tiered approach as adapted to incorporate the final selenium water quality standard. The intent of the tiered approach is for analytical results to be summarized by statistical measures, using a geometric mean, of lake-wide results for each medium that is sampled (e.g., geometric mean of analytical results for annual brine shrimp samples and from one nesting season for bird egg samples). UDWQ will use the defined criteria in the selenium assessment framework and analytical results from the previous calendar year to determine the actions to be implemented for the following calendar year.

The tiered approach was developed to address the following objectives:

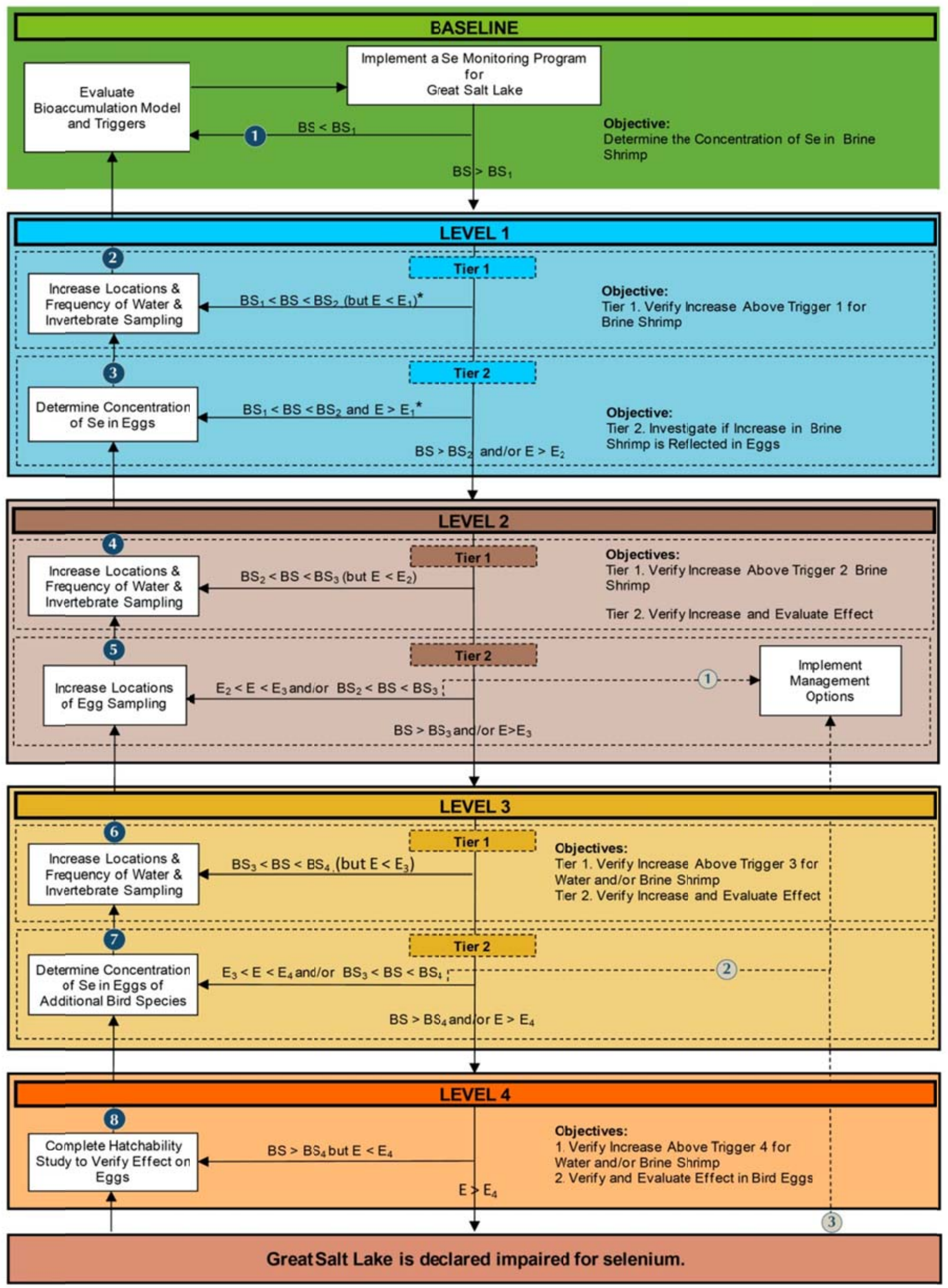
- ☐ Monitor Great Salt Lake to assess trends in selenium concentrations and determine whether they are approaching or exceeding the water quality standard in eggs, using brine shrimp as indicators of whether the standard is likely to be exceeded in bird eggs
- ☐ Address current uncertainty in modeled bioaccumulation relationships by validating expected bioaccumulation with new data for water and brine shrimp concentrations and, if appropriate, egg selenium and hatchability
- ☐ Evaluate trigger selenium concentrations that initiate various monitoring, assessment, and management actions identified in the assessment framework
- ☐ Evaluate the lake with respect to the numeric water quality standard for selenium
- ☐ Initiate management actions based on applicable selenium triggers

The approach implements various trigger concentrations for brine shrimp and egg selenium that increase monitoring levels and management options if and when actual selenium concentrations increase.

Use of this approach will allow UDWQ to continually assess and improve on the relationships included in the Bioaccumulation Model and the trigger levels included in the approach (see Table 2-5). The increasing levels of monitoring and implementation of management options, when necessary, are intended to provide a more robust and defensible dataset to confirm an apparent upward trend in selenium concentrations, as well as provide a means to assess efforts to mitigate the upward trend, if one occurs.

Table 2-5 summarizes the trigger bird egg concentrations included in the final tissue-based, numeric water quality standard (UAC R317-2A-14) and the associated brine shrimp concentrations estimated by the Bioaccumulation Model (Version 5.0). Tables 2-6 and 2- 7 summarize recommended changes to the baseline sampling program and management actions corresponding to observed changes in selenium concentrations in brine shrimp and bird eggs. Tables 2-5, 2-6, and 2-7 will be used in conjunction with Figure 2-3.

FIGURE 2-3. ASSESSMENT FRAMEWORK FOR SELENIUM IN GREAT SALT LAKE



NOTE: If GSL bird eggs were not sampled in previous calendar year, utilize the geomean of egg Se concentrations from prior 2 years.

TABLE 2-5. TRIGGER LEVELS CORRESPONDING TO SELENIUM ASSESSMENT FRAMEWORK FOR OPEN WATERS OF GREAT SALT LAKE

Matrix	Units	Trigger 1 Concentration	Trigger 2 Concentration	Trigger 3 Concentration	Trigger 4 Concentration
Brine Shrimp (BS)	ppm (dw)	5.3	7.0	10.8	13.7
Egg (E)	ppm (dw)	5.0	6.4	9.8	12.5

Notes:
dw = Dry Weight
ppm = Part per Million
Egg values obtained from UAC R317-2-14, values for water and brine shrimp back calculated using Bioaccumulation Model version 5.0 (CH2M HILL, 2008). See Figure 2-3 for the Selenium Assessment Framework.

TABLE 2-6. DESCRIPTION OF SAMPLING ACTIVITIES REQUIRED BY SELENIUM ASSESSMENT FRAMEWORK FOR OPEN WATERS OF GREAT SALT LAKE

No.	Description of Sampling Activities
1	Sample water and brine shrimp at 11 locations semiannually
2	Increase sampling of water and brine shrimp to 11 locations on quarterly basis
3	Add sampling of bird eggs at one location for two shorebird species on annual basis, sample water and brine shrimp at 11 locations on quarterly basis
4	Increase sampling of water and brine shrimp to 16 locations on quarterly basis, sample bird eggs at one location for two shorebird species on annual basis
5	Increase sampling of eggs to two locations for two shorebird species on annual basis, sample water and brine shrimp at 16 locations on quarterly basis
6	Increase sampling of water and brine shrimp to 16 locations on monthly basis, sample bird eggs at two locations for two shorebird species on annual basis
7	Increase sampling of eggs to include two shorebird species and gulls, each at two locations on annual basis; sample water and brine shrimp at 16 locations on monthly basis
8	Complete a hatchability study on two shorebird species and gulls, sampling of eggs to include two shorebird species and gulls, each at two locations on annual basis; sample water and brine shrimp at 16 locations on monthly basis

TABLE 2-7. DESCRIPTION OF MANAGEMENT ACTIONS REQUIRED BY SELENIUM ASSESSMENT FRAMEWORK FOR OPEN WATERS OF GREAT SALT LAKE

No.	Description of Management Action
1	Initiation of a Level II Antidegradation review by the State for all discharge permit renewals or new discharge permits for Great Salt Lake; the Level II Antidegradation review may include an analysis of loading reductions
2	Initiation of preliminary TMDL studies to evaluate selenium loading sources
3	Declare impairment. Formalize and implement TMDL

Notes:
TMDL= Total Maximum Daily Load
Management actions obtained from UAC R317-2-14.

2.6 Sampling Procedures/Methodology

All sampling activities required by the baseline sampling program will follow the methods described in SOPs defined by UDWQ. Before going out for field sampling, a checklist of all routine material and equipment needed during sampling will be prepared. A separate list will be created for specialized sampling equipment, if required. Specialized sampling may include materials and equipment for clean sampling methods. In addition, safety gear, such as life jackets and safety vests, as well as appropriate clothing and shoes, will be worn as required during sampling.

2.6.1 Health and Safety

A site hazard analysis and Health and Safety Plan (HSP) will be prepared before completing sampling activities as required by UDWQ. While possible hazards include accessing the lake and nesting sites, the use of motorized vehicles, possible extreme weather (exposure to rough water, cold water, lightning, sun, temperatures, etc.), and working in and around moving water, the field sampling team will assess all hazards and address them in the HSP before going to the field. All staff involved with field sampling activities will follow the HSP.

2.7 Quality Assurance Project Plan

All sampling and analytical activities required by the baseline sampling program will follow the requirements described in the QAPP defined by UDWQ.

2.8 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 in an annual report. This report is due by March 1 following the end of the calendar year when samples were collected.

UDWQ will keep project files including electronic copies of analytical data, field notes, data sheets and journals, photographs, analyses, and reports for a period of at least 5 years after the year of data collection.

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

The baseline sampling plan presented in Section II does not represent the final word in what Great Salt Lake research needs and target contaminants are—or even the sampling methods that should be used. It is a starting point that will enable UDWQ to begin the development of a long-term database describing the condition of Great Salt Lake. The baseline sampling plan is intended to be adapted and revised as the knowledge and understanding of Great Salt Lake ecosystem processes improves. This section provides a summary of studies UDWQ will complete to inform, build on, and advance the baseline sampling plan.

3.1 Introduction

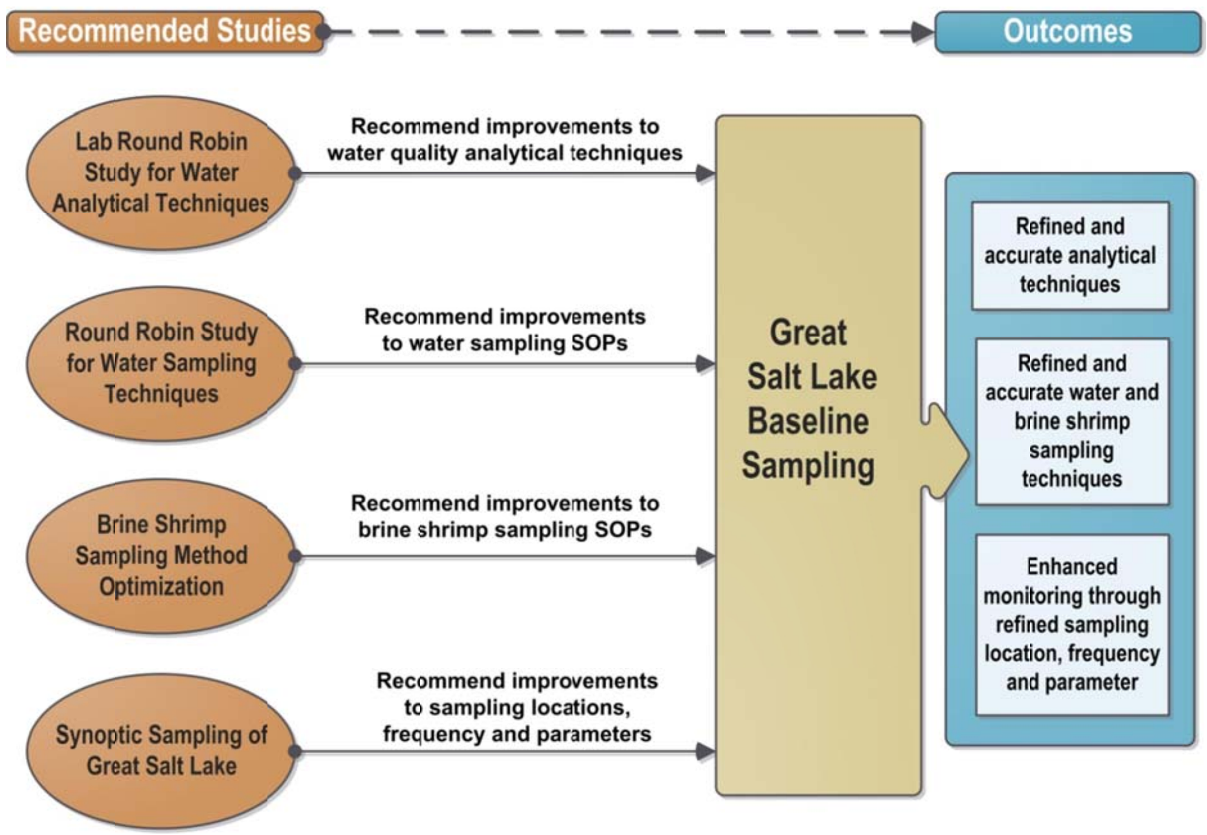
The unique and dynamic nature of Great Salt Lake is well documented in the literature, especially as related to the lake's salinity and history of management and modifications. Before the construction of the railroad causeway across the central part of Great Salt Lake in 1959, the salinity and chemistry 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.

The objective of these studies is to improve the goals, objectives, and sampling and analytical methods described in the baseline sampling plan.

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 0.5 to 6 percent in the Farmington Bay to 25 percent or higher in Gunnison Bay (North Arm). The main body of the lake, also known as the Gilbert Bay (South Arm) has salinity ranging from 6 to 15 percent (USGS, 2009). 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 middepth. 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 contaminants 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 baseline sampling plan. Figure 3-1 illustrates how the studies will help inform and advance the baseline sampling plan. Prioritization of these studies is detailed in Section 1.5.

FIGURE 3-1. SCHEMATIC REPRESENTATION OF HOW THE STUDIES WILL INFORM AND ADVANCE THE GREAT SALT LAKE BASELINE SAMPLING PLAN



3.2 A Laboratory Round Robin Study for Great Salt Lake Water Quality Analytical Techniques

3.2.1 Problem Statement

Due to the complex geochemical properties of Great Salt Lake water, sample preservation, storage, and preparation, as well as accurate analysis of target analytes, can be 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 Great Salt 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 assess nutrients in Great Salt Lake (personal communication, Harold Ardourel, National Water Quality Laboratory, USGS). It is thus prudent to conduct a laboratory round robin study for key target analytes in Great Salt Lake water as part of implementing a long-term monitoring program. This will help identify, develop, and validate reliable analytical methods for the lake.

3.2.2 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 contaminants of concern in Great Salt Lake?
- ☐ Which laboratories are best suited for analyzing these samples?
- ☐ 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 Great Salt Lake.

3.2.3 Management Objectives

This study will address UDWQ's responsibility to monitor Great Salt Lake. It will help ensure that data collected is relevant, defensible, and useful for determining long-term water quality trends, quantifying water quality problems, establishing water quality goals, assessing beneficial use support, and determining the effectiveness of pollution control programs.

3.2.4 Approach

This study will be conducted during the early phase of the Great Salt Lake baseline monitoring program and will focus on key contaminants that are of high priority and pose the greatest risk to the lake's ecosystem. Great Salt Lake's water chemistry varies widely; salinity ranges spatially from 3 to 20 percent and significant differences can be found between the upper and deep brine layers. Ideally, the round robin will capture a range of conditions to provide assurances that the methods used for long-term monitoring apply at all conditions. However, such an effort is likely cost prohibitive. Alternatively, samples could be collected from a location representing a typical salinity condition of Great Salt Lake. UDWQ could begin with samples from one location to determine the best methods and laboratory and then complete a second round robin to determine the applicability across the range of Great Salt Lake water quality conditions, as well as water depths. Water samples will be collected per UDWQ's SOP and 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. UDWQ will determine at a later stage whether or not the independent lab can participate in the round robin study.

During water sample collection, essential water quality parameters, such as dissolved oxygen concentration, pH, turbidity, density, temperature, depth, and salinity, will be measured and recorded.

3.2.5 Variables to be Assessed

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

- ☐ Total and methyl-mercury
- ☐ Trace metals/metalloids—total selenium, total arsenic, total copper, total cadmium, total lead, and total thallium
- ☐ Nutrients—total nitrogen, total phosphorus, ammonia-N, and nitrate+nitrite-N

While collecting water samples, field measurements of salinity, dissolved oxygen, pH, temperature, and turbidity will be conducted using a calibrated field multimeter.

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
- ☐ Trace metals—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

3.2.6 Participating Laboratories

Laboratories to be included in the round robin study will be selected for their ability to comply with the QAPP and have National Environmental Laboratory Accreditation Certification with the State of Utah. Those that comply with QAPP protocol without state certification will be asked to apply for certification before work is initiated.

3.2.7 Spatial Boundaries

One sample will be collected from Great Salt Lake in the Gilbert Bay, representing a typical salinity condition of the lake.

3.3 Round Robin Study for Water Sampling Techniques in the Great Salt Lake

3.3.1 Problem Statement

Several local, state, and federal agencies are currently sampling water in Great Salt 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 Great Salt Lake. Sampling has historically been done by different investigators with different study objectives. Further, the complex geochemistry of Great Salt Lake 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 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 Great Salt Lake. This will facilitate more efficient data comparison and use to understand and predict the lake water quality better.

3.3.2 Study Objectives

This study will provide answers to the following questions:

- ☐ What methods/equipment should be used to collect water samples from the upper and deep brine layer of Great Salt Lake?
- ☐ Do grab samples collected from a certain depth adequately represent lake water quality versus composite samples collected across water depth?
- ☐ At what depth should water samples be collected from the upper and deep brine layer?

- ☐ 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?

3.3.3 Management Objectives

This study will address UDWQ's responsibility to monitor Great Salt Lake. It will help ensure that data collected is relevant, defensible, and useful for determining long-term water quality trends, quantifying water quality problems, establishing water quality goals, assessing beneficial use support, and determining the effectiveness of pollution control programs.

3.3.4 Approach

UDWQ will facilitate a meeting of current Great Salt Lake investigators and interested agencies 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 most beneficial and the benefits and risks of each, and achieving consensus on standardization of methods and equipment to be used for sampling Great Salt Lake water. The outcome of the meeting(s) will be SOPs for monitoring Great Salt 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 Great Salt 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.

3.3.5 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
- ☐ 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

3.3.6 Spatial Boundaries

In the case of a field round robin, water samples will be collected and field measurements conducted at locations representing a typical salinity condition of Great Salt Lake in the Gilbert Bay.

3.4 Brine Shrimp Sampling Method Optimization

3.4.1 Problem Statement

Brine shrimp are a critical element in the Great Salt Lake ecosystem. They serve as food to the millions of birds that nest at and migrate through the lake every year and contribute significantly to Utah's economy through their hard-walled eggs (cysts) that are commercially harvested and used worldwide in the aquaculture and ornamental fish industries. The lake is an internationally renowned source for high-quality cysts. The total annual economic effect of Great Salt Lake's brine shrimp industry was recently estimated to be almost $56 million (Bioeconomics, Inc., 2012). Thus, accurate and consistent methods for monitoring of brine shrimp are needed to assess whether Great Salt Lake is supporting its beneficial uses, to understand the potential impact of trace metals/metalloids (especially selenium and mercury) on brine shrimp, and to help evaluate the transfer of these contaminants through trophic compartments of the Great Salt Lake food web.

Between 2006 and 2008, UDWQ coordinated studies to assess the impacts of selenium on the Great Salt Lake ecosystem. As a part of that study, selenium concentrations were measured in brine shrimp to assess temporal and spatial variations (Marden, 2008). The study resulted in very useful data but highlighted some uncertainties that could be introduced depending on the brine shrimp sampling procedure that is used. For example, it was not clear if a better representation of brine shrimp exposure to contaminants in the lake was obtained when brine shrimp were collected via a vertical haul using a plankton net or via a horizontal tow using a net of proper mesh size behind a boat. The UDWR has consistently used the vertical haul method for its brine shrimp population studies; therefore, using this method could present opportunities for collaboration if it is deemed to be the most appropriate for evaluating potential contaminants. Another example pertains to how the brine shrimp are handled after collection. Selenium concentrations in brine shrimp samples were found to be lower when rinsed with distilled water and sorted out by age class from other zooplanktons compared with unrinsed and unsorted samples (personal communication, Brad Marden). This study aims to isolate the variables to determine the most appropriate method for sampling brine shrimp from Great Salt Lake.

3.4.2 Study Objective

This study will focus on providing recommendations to finalizing an SOP for sampling brine shrimp. The study will work to answer the following questions:

- ☐ Which method, vertical haul, or horizontal tow provides the best representation of exposure of brine shrimp to contaminants in Great Salt Lake?
- ☐ Do concentrations of key contaminants in brine shrimp vary with depth and at what depth should brine shrimp be sampled?
- ☐ How should brine shrimp samples be processed before shipping for analysis (i.e., sorting, rinsing, preservation, etc.)?
- ☐ The UDWR collects brine shrimp samples to assess population dynamics. Can a sample that has been processed for population estimation be analyzed for contaminants and still be representative of Great Salt Lake water quality conditions?

FIGURE 3-2. BRAD MARDEN SAMPLING BRINE SHRIMP FROM GREAT SALT LAKE

3.4.3 Management Objectives

This study will address UDWQ's responsibility to monitor and assess the beneficial uses of Great Salt Lake. It will help ensure that data collected is relevant, defensible, and useful for determining long term water quality trends, quantifying water quality problems, establishing water quality goals, assessing beneficial use support, and determining the effectiveness of pollution control programs.

3.4.4 Approach

This section provides a general approach. This may be adjusted to accommodate other reliable sampling and sample handling methods being implemented by agencies that are currently studying brine shrimp in Great Salt Lake.

Simultaneous sampling will be conducted at the same locations and time using different vertical and horizontal brine shrimp collection methods. Additional methods, such as an oblique tow, could also be investigated (i.e., start at a bottom depth with boat moving forward; steadily tow net at angle to the surface). Vertical tows will encompass the entire water column, with or without the deep brine layer, to within a net's length of the bottom (to not stir up bottom sediment into the net). The samples will then be homogenously replicated into various batches and will be subjected to the following:

- ☐ Rinse sample using distilled water, sort and analyze for contaminants
- ☐ Rinse sample using filtered lake water, sort and analyze for contamination
- ☐ Rinse sample using distilled water and analyze for contamination without sorting
- ☐ Rinse sample using lake water and analyze for contamination without sorting
- ☐ Analyze for contaminants without rinsing or sorting samples

Sorting will consist of hand removal of all debris and non–brine shrimp organisms from the samples.

3.4.5 Variables to be Assessed

All brine shrimp samples will be analyzed for total selenium and total mercury.

3.4.6 Spatial Boundaries

Any three locations may be selected from Figure 2-1 in Section II within the Gilbert Bay of Great Salt Lake.

3.4.7 Temporal Boundaries

Temporal boundaries are not applicable to this study.

3.5 Synoptic Sampling of Great Salt Lake

3.5.1 Introduction

The lake is both spatially and temporally dynamic in nature. Its unique biogeochemistry and hydrology create an environment that is complex, difficult to develop water quality standards for, difficult to assess, and may change both spatially and temporally. For UDWQ to fulfill its responsibilities, it is essential to characterize and evaluate the lake's water quality for known contaminants of concern as well as emerging contaminants 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 baseline sampling plan will monitor trends for certain contaminants, this study will provide a benchmark for many other possible contaminants and confirm sampling locations/seasons. It will establish an important benchmark of the lake's current water quality condition, help in optimizing the long-term baseline sampling plan, and determine if and how water quality changes over time.

3.5.2 Study Objectives

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

- ☐ What are the concentrations of potential contaminants not included in the baseline sampling plan in the water and sediment of Great Salt Lake?
- ☐ Are contaminants of emerging concern present in Great Salt Lake?
- ☐ How do concentrations of potential contaminants vary spatially and temporally?
- ☐ What are the optimum 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 contaminants 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 concentrations change over the long term?

3.5.3 Management Objectives

This study will address UDWQ's responsibility to monitor and assess the beneficial uses of Great Salt Lake. It will also inform and help UDWQ to prioritize the development of water quality standards for Great Salt Lake. It will help ensure that data collected is relevant, defensible, and useful for determining long-term water quality trends, quantifying water quality problems, establishing water quality goals, assessing beneficial use support, and determining the effectiveness of pollution control programs.

3.5.4 Approach

This study will be conducted over 1 year with monthly or bimonthly sampling events to accommodate seasonal effects and varying lake levels. Also, the study will be repeated every 5 years to capture potential changes in lake's water quality and to update or recommend changes in the baseline monitoring program. Collocated water, sediment, 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.

3.5.5 Variables and Characteristics to be Measured

- ☐ 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—Fecal coliform, chlorophyll a, phytoplankton identification and enumeration, and zooplankton identification and enumeration (including brine shrimp)
- ☐ Trace elements in collocated water, sediment and brine shrimp—Aluminum, antimony, arsenic, barium, boron, cadmium, calcium, cobalt, copper, chromium, hexavalent chromium, gold, iron, lead, lithium, magnesium, manganese, total mercury, methyl mercury, molybdenum, nickel, palladium, potassium, platinum, selenium, silicon, silver, sodium, tin, titanium, thallium, vanadium, and zinc
- ☐ Nutrients in water and sediments—Ammonia-N, total and dissolved phosphorus, total nitrogen, and nitrate+nitrite-N
- ☐ Emerging contaminants in water, sediments, and brine shrimp—Pharmaceutical and personal care products, endocrine disrupters, and persistent organic pollutants. UDWQ will facilitate a committee to discuss options and target those contaminants of most concern for Great Salt Lake.

3.5.6 Spatial Boundaries

The study area will include the entire lake, including Gilbert Bay (South Arm), Carrington Bay, Gunnison Bay (North Arm), Ogden Bay, Farmington Bay, Bear River Bay, and Willard Spur. The UDWR's standard lake-wide sampling locations be used for this study. These may be adjusted based on accessibility, depth of water, weather constraints, etc.

3.5.7 Temporal Boundaries

Sample collection will be conducted every month during 1 year and will be repeated every 5 years.

IV. RESEARCH PLAN FOR GREAT SALT LAKE

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

4.1 Introduction

4.1.1 Objective

The research identified in this section will be completed as part of UDWQ's strategy to protect the beneficial uses of Great Salt Lake and proactively fulfill its responsibilities under the Clean Water Act. Each study is designed to address UDWQ's specific management objectives and responsibilities in collaboration with its partners. These include supporting the development of water quality standards, monitoring, UPDES permitting, and assessment programs.

4.1.2 Opportunity for Collaboration

As discussed in previous sections, Great Salt 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 (i.e., questions that could be and need to be answered) and focus efforts and resources on areas most critical for UDWQ to fulfill its responsibilities. Further, there are many resources in Great Salt 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 management of Great Salt Lake's water quality, it is important to note that many of these efforts overlap and help address other Great Salt Lake resources as well. A collaborative approach to planning, conducting, and reviewing these research needs is critical to efficiently and effectively managing all of the resources of Great Salt 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 Great Salt Lake's resources. UDWQ has already engaged with the Great Salt Lake Advisory Council and other agencies to become an active partner and participant in their planning and research activities and they, in turn, in UDWQ's investigations (e.g., Great Salt Lake Comprehensive Management Plan, the UDWR's Technical Advisory Group, UDWQ's Willard Spur Steering Committee and Science Panel, Great Salt Lake Water Monitoring Council, etc.). Ongoing coordination and support among agencies in this research is critical for leveraging resources and focusing efforts to achieve management objectives.

4.1.3 Section Organization

There are numerous questions that have been posed by researchers over the years as they have sought to understand the geochemistry and ecology of Great Salt Lake. UDWQ has reviewed a wide array of literature and attended numerous meetings facilitated by Great Salt Lake researchers and stakeholders (from 2004 to present) to listen to and identify those issues that appear to be of most importance to Great Salt Lake water quality. A detailed list of research questions, provided in Appendix A, was compiled to summarize many of the issues identified for Great Salt Lake. This list, along with research questions defined as part of UDWQ's efforts in Willard Spur and the development of a Great Salt Lake wetland assessment framework, were consolidated into a systematic research framework to leverage synergies between efforts and more efficiently focus available resources. While work is generally divided to address (1) open water and (2) wetland habitats, these habitats overlap and provide opportunities for collaboration.

> ***The objective of these studies is to support:***
>
> 1) *The development of water quality standards*
> 2) *Monitoring of Great Salt Lake waters*
> 3) *The assessment of Great Salt Lake's beneficial uses and enable UDWQ to proactively fulfill its responsibilities under the CWA*

Figure 4-1 provides a schematic summary of the questions deemed most critical toward enabling UDWQ to proactively fulfill its responsibilities. Studies were grouped into the following three research areas (with corresponding section numbers in this document):

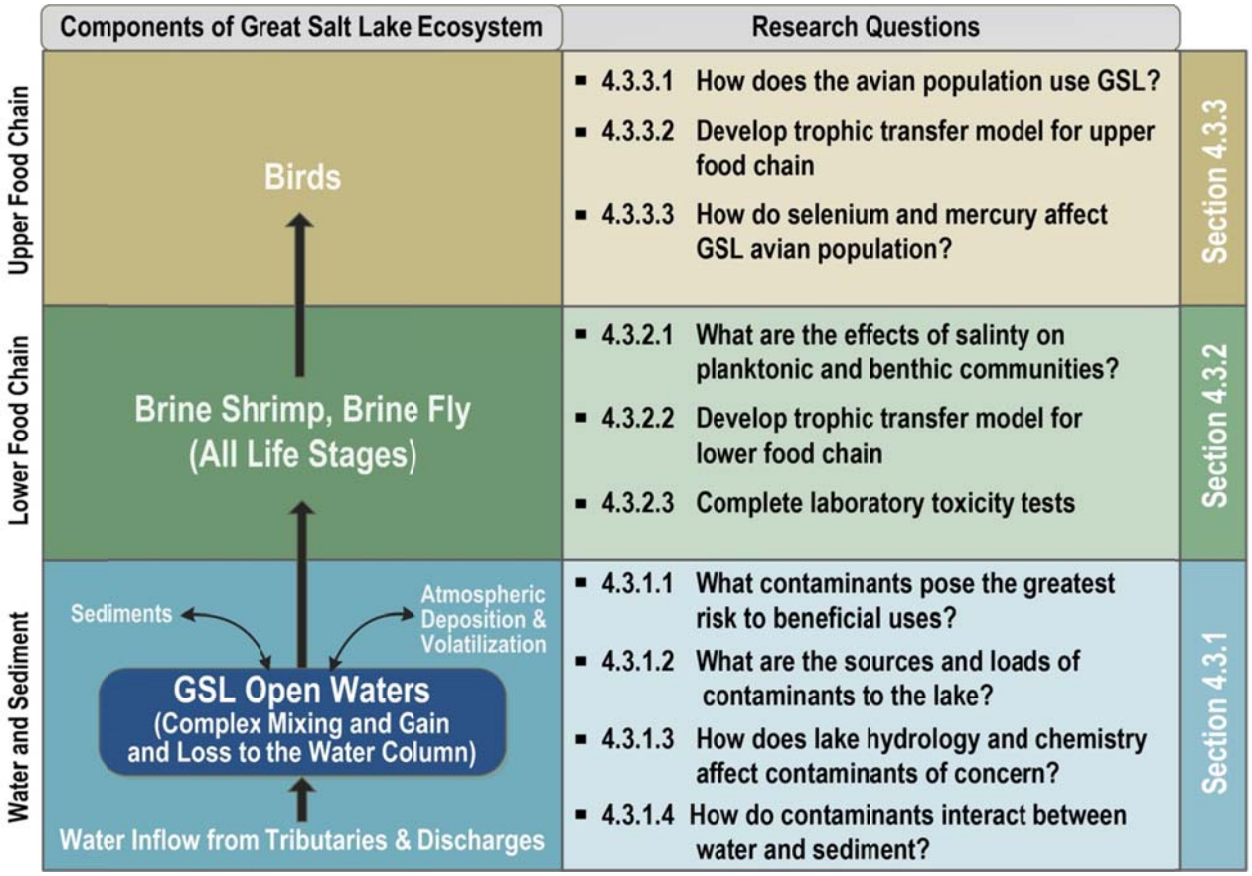
4.2 Common Need
- 4.2.1 Data Repository

4.3 Open Water Research
- 4.3.1 Great Salt Lake Water and Sediment
- 4.3.2 Great Salt Lake Lower Food Chain
- 4.3.3 Great Salt Lake Upper Food Chain

4.4 Wetlands Research
- 4.4.1 Wetland Assessment Framework
- 4.4.2 Willard Spur
- 4.4.3 Additional Wetlands Research Needs

Refer to Section I for a prioritization of these studies. A detailed discussion of research needs follows.

FIGURE 4-1. RESEARCH QUESTIONS TO SUPPORT THE DEVELOPMENT OF STANDARDS FOR AND ASSESSMENT OF GREAT SALT LAKE



4.2 Common Need

One need is common to all research needs, will affect how they are conducted, and eventually will influence how the results are implemented by UDWQ and its partners and the availability of the data to the public: the formation and maintenance of a data repository for use in UDWQ's Great Salt Lake studies. This section summarizes this need.

4.2.1 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 Great Salt 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 standards will be submitted, managed, and accessed.

Study Objective. This project will focus on developing an approach for managing Great Salt 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 standards, and provide effective agency and stakeholder use and public access to the data.

Management Objective. This study will facilitate the storage and retrieval of quality data for use in developing water quality standards, monitoring the waters of Great Salt Lake, UPDES permitting, and assessing the lake's support of beneficial uses.

Approach. UDWQ is developing a database for statewide water quality data that will eventually include data from Great Salt Lake. UDWQ's intent is to develop independent but compatible databases for each of its special studies (e.g., development of water quality standards for selenium and Willard Spur). Upon completion of these special studies these databases will be merged with UDWQ's statewide water quality database. UDWQ will work with its partners to identify a platform that allows the public access to this database but also databases maintained by others for Great Salt Lake data.

4.3 Open Water Research

Three areas of research were identified to address needs for the open water of Great Salt Lake (the open water includes all of Great Salt Lake's bays but does not include their mudflats or wetlands). The three areas begin with understanding the water and sediment that serve as the foundation to the ecosystem and support of its beneficial uses. The discussion then moves to the lower and then upper trophic levels of the ecosystem. The following sections identify studies that need to be addressed to proactively fulfill UDWQ's responsibilities to protect Great Salt Lake (see Figure 4-1).

4.3.1 Great Salt Lake Water and Sediment

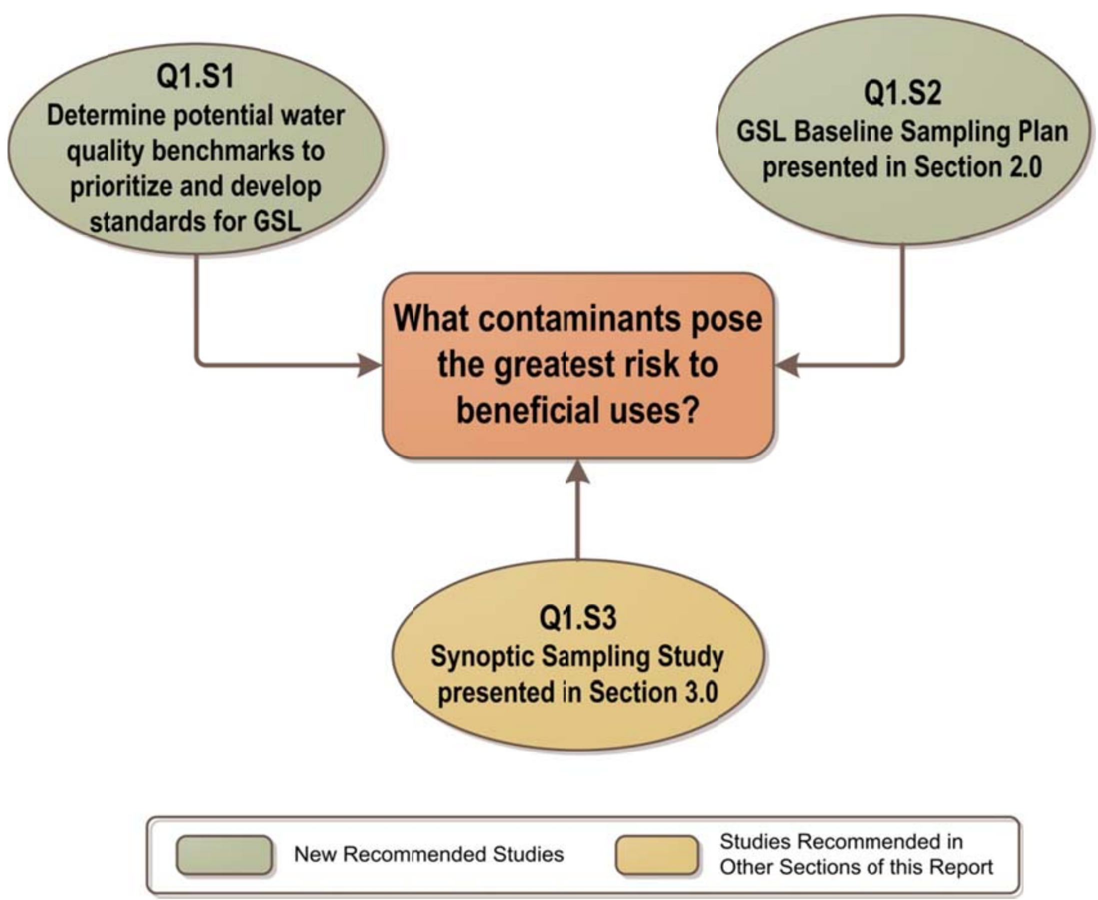
One of the highest priorities for establishing standards and assessing if the water quality is sufficient to meet beneficial uses is the identification of contaminants present in the lake that currently could pose risk to the ecosystem and, therefore, impair the lake's beneficial uses. As mentioned in earlier sections, some studies have already identified selenium, mercury, and some trace metals and nutrients to be of concern, but many data gaps remain. Information is needed to characterize the effects of lake hydrology and chemistry on the fate of these contaminants, to track past trends, to identify their sources, and to develop mass balance models to aid in predicting future conditions. Outcomes from these studies will support UDWQ's development of standards and assessments by identifying (1) what contaminants are of concern, (2) how they are impacted by the lake's unique saline chemistry, and (3) how contaminant loads might be managed and regulated in the future to protect water quality conditions in the Great Salt Lake and provide dischargers with more certainty in managing their effluent.

The following subsections address each of these questions. It should be noted that some of these questions may be addressed by the studies identified in Sections II and III or by the ongoing efforts of partners. The objective is to better define what is known and fill in known data gaps to enable UDWQ to proactively fulfill its responsibilities.

WHAT CONTAMINANTS POSE THE GREATEST RISK TO BENEFICIAL USES?

Figure 4-2 presents an approach of how this question will be addressed. Study number Q1.S1 is a new study, while Studies Q1.S2 and Q1.S3 are presented in previous sections.

FIGURE 4-2. APPROACH TO QUESTION 1



Determine Potential Water Quality Benchmarks to Prioritize and Develop Standards for Great Salt Lake

Problem Statement. Contaminant-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 contaminants on water quality. Benchmarks are pollutant concentrations that are unlikely to result in adverse effects to aquatic and aquatic-dependent life. Both the USGS and EPA have benchmark concentrations for several contaminants in surface water; however, these are either for freshwater or marine water bodies. Since Great Salt 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 observed in the lake and also to determine if these benchmark concentrations appear to be appropriate for the Great Salt Lake ecosystem. More discussion of this approach and the research necessary can be found in Component 1: Proposed Approach for Developing Numeric Criteria for Great Salt Lake.

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

- ☐ Conduct a literature review to identify Great Salt Lake organisms and potential water quality benchmarks for contaminants that have been identified to pose risks to the beneficial uses of Great Salt 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 Great Salt Lake (e.g., a marine benchmark developed to protect fish may not be applicable to Great Salt Lake open waters)?
- ☐ Compile benchmarks and supporting documentation in a report that may be reviewed and endorsed by Great Salt 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 Great Salt Lake's water quality and guide future decisions.

Management Objectives. The work will inform the prioritization of pollutants and applicability for development of water quality standards for Great Salt Lake and assist in the assessment of Great Salt Lake's support of beneficial uses.

Approach. A literature review will be conducted to define the organisms that live in and rely on the waters of Great Salt Lake for sustenance. The literature review will also identify applicable water quality standards in use today, as well as contaminant 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 contaminants targeted by the baseline sampling plan and then be expanded to include other possible contaminants as identified by the synoptic sampling effort or deemed necessary by UDWQ. Benchmarks will be grouped by their applicable salinity (i.e., freshwater, marine, and hypersaline waters).

Historical and ongoing water quality and other ecological data, such as collocated concentration of contaminants in water, sediment 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 contaminants 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 Great Salt Lake. Benchmarks that were developed using similar elements of the food web will be of particular interest. For example, benchmarks developed for fish are not necessarily applicable to Great Salt Lake as fish do not tolerate the salinities of Great Salt Lake.

Work completed as part of this study will be conducted in coordination with UDWQ's Water Quality Standards Workgroup.

Q1 S2—Great Salt Lake Baseline Sampling Plan

Details on the Great Salt Lake baseline sampling plan are presented in Section II.

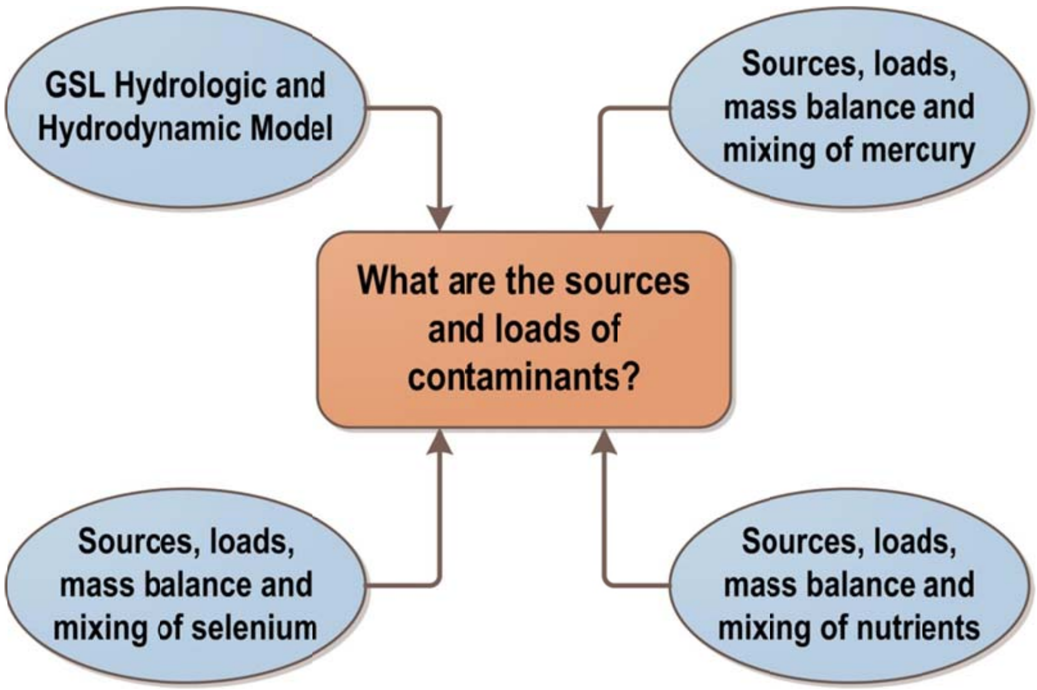
Q1 S3—Great Salt Lake Synoptic Sampling Study

Details on the synoptic sampling study are presented in Section III.

WHAT ARE THE SOURCES AND LOADS OF CONTAMINANTS?

Understanding the sources and loads of contaminants that are suspected to threaten or concluded to impair the beneficial uses of Great Salt Lake is essential protecting the water quality. Recent studies to develop water quality standards and assess Great Salt Lake's beneficial uses for impacts from selenium, mercury, and nutrients each resulted in an evaluation of sources and loads of these contaminants 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 may need to be revisited to identify gaps and to refine the understanding of where the contaminants come from and what happens to them within the lake. Figure 4-3 presents an approach of how this question will be addressed. A similar approach will be followed if additional contaminants of concern are identified. Further details on these studies are presented as follows.

FIGURE 4-3. APPROACH TO QUESTION 2



Great Salt Lake Hydrologic and Hydrodynamic Model

Problem Statement. The fluctuation of Great Salt 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 Great Salt 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 a study was also completed by Dr. David Tarboton at the Utah State University on Great Salt Lake's water budget. The USGS is currently conducting studies to understand how inflows to Great Salt Lake mix with the open waters at the Gilbert Bay.

Though these studies have and will answer several questions on Great Salt Lake hydrology and hydrodynamics, to date, no comprehensive model is available that could be used to dynamically and reliably predict the hydrologic input and response and the hydrodynamics of Great Salt 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.

This study will be conducted in collaboration with other past and existing research groups studying Great Salt Lake hydrology and hydrodynamics.

Study Objectives. The first objective of this study is to develop an accurate hydrologic model for Great Salt 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 contaminant sources and loads. The second objective of this study is to develop a hydrodynamic model of Great Salt Lake that will incorporate the hydrologic inputs and outputs but also improve the understanding of how such flows mix within Great Salt Lake. Such a model will be a critical first step in developing a comprehensive fate, transport, and mixing model for nutrients and other contaminants.

Management Objectives. The development of a hydrologic model will provide UDWQ with a mechanism to better identify how lake salinities may change and contaminant sources and loads. Understanding how salinity will vary will help guide the development and implementation of water quality standards per Component 1. The development of a hydrodynamic model will provide UDWQ with a mechanism to better understand the fate and transport of contaminants and how they may impact Great Salt Lake's water quality. This will assist UDWQ in developing water quality standards, improve monitoring the waters of Great Salt Lake, assist with UPDES permitting, and assess Great Salt Lake's support of beneficial uses.

Approach. To develop a hydrologic model, past information on flows to Great Salt Lake, evaporation rates, and lake levels and mixing patterns will need to be compiled and analyzed. This analysis will be useful to identify data gaps and the need for further data collection. The gaps will be addressed and additional flow gauges will be installed if required. Existing and new information gathered will be used to develop a robust hydrologic model for the lake.

A significant element of this study will be to establish and maintain long-term flow gauges for Great Salt Lake tributaries. These gauges will be operated in conjunction with the collection of water samples to evaluate contaminant sources and loads entering Great Salt Lake (see studies that follow). Thus the flow gauges will address the need to refine the hydrologic model but also to enable estimates of contaminant loads from each tributary.

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 Great Salt Lake causeways is also an area that has been the subject of research but for which much remains to be understood. As previously described, the USGS has already begun work to understand these mixing patterns; however, much remains to be understood to enable a useful hydrodynamic model. 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.

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

Problem Statement. Farmington Bay in Great Salt 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 Great Salt Lake, 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). 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 Great Salt Lake, estimate total loads, and develop a mass balance and mixing model for nutrients in Great Salt 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 used to inform the UDWR's brine shrimp population dynamics model.

Management Objectives. Understanding the sources, fate, and transport of nutrients into and within Great Salt Lake will inform the UDWR's brine shrimp population dynamics model to better assess the lake's support of its beneficial uses. It will also support the monitoring of Great Salt Lake's waters and the prioritization and development of water quality standards, if needed.

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 contaminant 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 mixing model include the following:

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

This model will inform the UDWR's efforts and assist both agencies in assessing Great Salt Lake's beneficial uses.

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 the South Arm of Great Salt Lake. Both continuous and noncontinuous stream gages were used to collect flow data from inflows to the South Arm 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 Great Salt 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 the South Arm (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 Great Salt 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 incoming loads of selenium have on its concentration in lake water.

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

- ☐ Identify the sources and loads of selenium entering the South Arm of Great Salt Lake 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)

Management Objectives. This study will develop a mass balance model that can be used by UDWQ to verify existing water quality standards, verify that current methods for setting limits on acceptable selenium discharges to Great Salt Lake are appropriately protective, and assist UDWQ to meet its obligations if selenium in Footnote 14 is exceeded.

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 Great Salt Lake. The USGS is currently looking at groundwater discharge as a potential mechanism for additional sources of selenium to Great Salt Lake. 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 lakewide 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 Great Salt Lake. Some Great Salt Lake 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 Great Salt Lake. 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 the South Arm 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. Though no further needs were specifically identified in the study, it is important to better understand how mercury is being methylated within Great Salt

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 Great Salt Lake 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 Great Salt Lake.

Management Objectives. Methyl-mercury has been identified to be a potential problem in Great Salt Lake and could impair its beneficial uses. Understanding the sources of mercury, its mass balance, and how the lake regulates the methylation of mercury in Great Salt Lake will enable UDWQ to quantify water quality problems, establish water quality goals, assess beneficial use support, and determine the effectiveness of pollution control programs.

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.

HOW DOES LAKE HYDROLOGY AND CHEMISTRY AFFECT CONTAMINANTS 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 contaminants that enter the lake. It is essential to understand what happens to these contaminants 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 standards, assess water quality, and developing UDPES permit discharge limits.

Study Objective. Explore available data to determine relationships between primary contaminants and Great Salt Lake water chemistry and hydrology as may affect contaminant fate and transport.

Management Objectives. This work will inform the prioritization and development of water quality standards, how UPDES permits are structured and implemented, and improve the monitoring of Great Salt Lake waters and assessment of its beneficial uses.

Approach. This question can be addressed using data gathered by the baseline sampling plan described in Section II and the synoptic sampling plan presented in Section III. While the baseline sampling plan will monitor biannual trends in the primary contaminants listed previously, the synoptic sampling plan includes extensive monthly or bimonthly sampling across the lake including the contaminants that have been identified to pose risk to the beneficial uses of Great Salt 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 contaminant chemistry.

HOW DO CONTAMINANTS INTERACT BETWEEN WATER AND SEDIMENT

Problem Statement. Many contaminants, such as selenium and mercury, are found naturally within Great Salt Lake's watershed. However, it is also widely recognized that the inflow of these contaminants 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 contaminants to precipitate from the water column and be deposited in lake sediments. Thus, Great Salt Lake's sediment provides an invaluable record of how conditions in Great Salt Lake have changed with time.

This study seeks to better understand the sedimentation rates throughout Great Salt Lake, long-term precipitation rates of various contaminants, and the permanent burial loss rates of contaminants. The use of brine shrimp cysts found in the sediment column can be used as an additional marker of historic Great Salt 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 Great Salt 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 contaminants that have been identified to pose risk to the beneficial uses of Great Salt Lake?
- ☐ What are their sedimentation/precipitation rates?
- ☐ Do contaminants in sediments release to the water column of the Great Salt 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 contaminants?

Management Objectives. Understanding the effect of legacy sediments upon the water quality of Great Salt Lake and the fate of contaminants that are discharged to Great Salt Lake is essential to the development of water quality standards, focusing monitoring efforts, developing appropriate UPDES permits, and assessing the support of Great Salt Lake's beneficial uses.

Approach. To determine historical trends in concentrations of contaminants, sediment cores are a commonly implemented method. This procedure determines prehistorical conditions and the impact of human activity in a watershed. Some sediment core studies have already been done for the Great Salt Lake, focusing on reconstructing historical changes in Great Salt 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). It should be noted that a new study of Great Salt Lake sediment cores is currently underway; however, information pertaining to project objectives was not available at the time of this writing. A similar approach will be adapted to determine the sedimentation rates of other contaminants in Great Salt Lake.

Several studies may be required to address the objectives listed previously. While funds may become available to address one objective (i.e., study contaminant levels in sediment for one contaminant), 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 Great Salt 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 contaminant levels in sediment have changed with time. The objective is to better understand where efforts to understand historic contaminant deposition will be targeted.
- ☐ Sediment cores collected as part of Item 1 will be analyzed to address, at a minimum, the primary constituents of selenium, mercury, nitrogen, and phosphorus. Combined with sedimentation rates, trends in contaminant 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 contaminant flux (e.g., Byron and Ohlendorf, 2007).

Release of contaminants 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 contaminants into or out of the sediments.

4.3.2 Great Salt Lake Lower Food Chain

The lower food chain components of Great Salt Lake are represented by planktonic and benthic species, such as algae, bacteria, and macroinvertebrates. Maintaining healthy populations of these species is essential for the Great Salt 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.

Contaminants and nutrients 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, fishes, and humans; or because they negatively affect primary and secondary production in water. Contaminants may bioaccumulate or nutrients can cause eutrophication, resulting in adverse health and reproductive effects, or have negative impact directly on the ecosystem, such as eutrophication caused by the presence of excess nutrients. Whatever the scenario, understanding the fate and transport of these contaminants and nutrients from water and sediment to the components in Great Salt Lake food web is important for setting standards and assessing if bioaccumulative contaminants or nutrients are adversely affecting the ecosystem.

FIGURE 4-4. SAMPLING BRINE SHRIMP ON GILBERT BAY

The following sections present studies that need to be addressed to improve the current understanding of the Great Salt Lake lower food chain (see Figure 4-1).

WHAT ARE THE EFFECTS OF SALINITY ON PLANKTONIC AND BENTHIC COMMUNITIES?

Problem Statement. The salinity of Great Salt Lake is spatially and temporally diverse across the open waters and the wetlands. 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 Bay (http://ut.water.usgs.gov/greatsaltlake/salinity/index.html), 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 Great Salt Lake ecosystem and its beneficial 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 Great Salt Lake and will provide answers to the following questions:

- ☐ What species are supported by the varying percent salinity in the 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 Great Salt Lake invertebrates affected by the saturated conditions of Gunnison Bay?

Management Objectives. Understanding how and what causes salinity to vary in Great Salt Lake and how changing salinity may affect the planktonic and benthic communities is important to developing water quality standards that are appropriate for (see Component 1) and accurately assessing the beneficial uses that can be supported by a given salinity.

Approach. The UDWR has been enumerating and studying planktonic and benthic communities of Great Salt Lake 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 Great Salt Lake. This study will be completed in collaboration with the UDWR and the Great Salt Lake Institute.

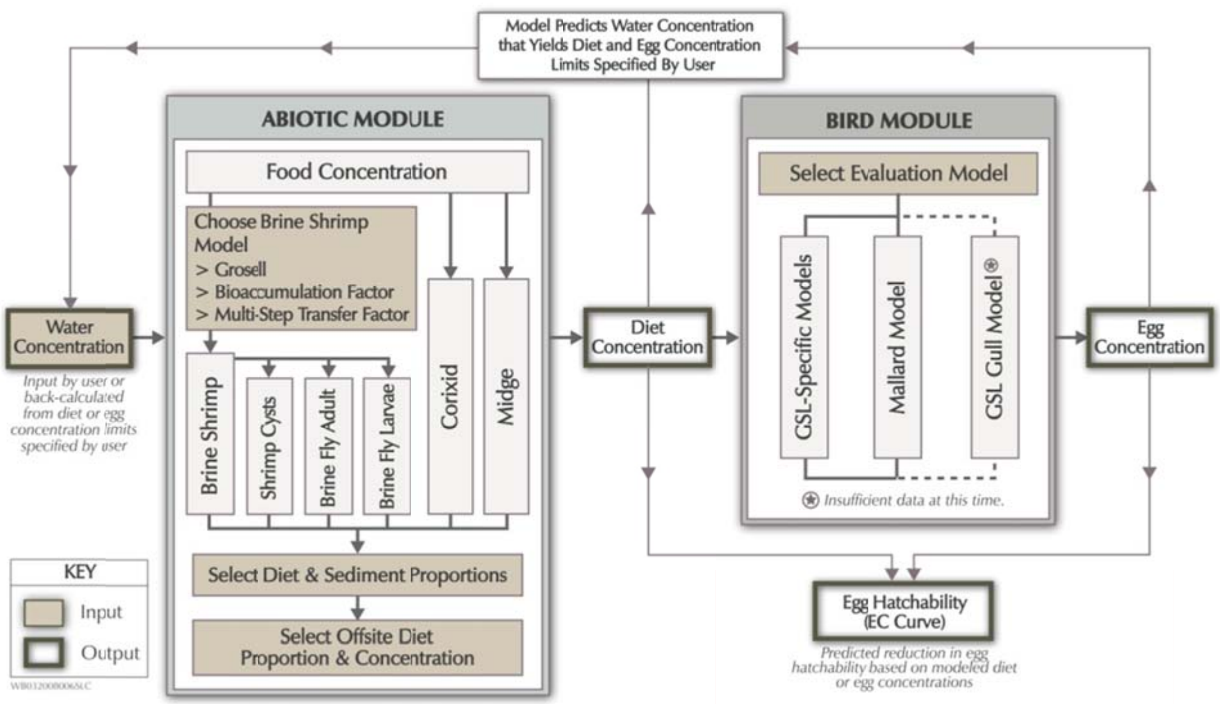
Planktonic and benthic organisms will be sampled at two locations in Farmington Bay and Bear River Bay, respectively; two locations in the North Arm; and four locations in the South Arm, each representing different percent salinity. Organisms can be collected from the deep brine layer, if observed. During 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 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 Great Salt Lake's water bodies. A discussion will be provided linking Great Salt 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 contaminants, such as selenium, mercury, and arsenic, is an important part of advancing our knowledge on the dynamics of these contaminants in Great Salt Lake, as well is in management and decision making to protect the beneficial uses of Great Salt Lake. 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 Great Salt Lake. This study identified data gaps in correlations of concentration of mercury in parts of the Great Salt Lake food chain.

FIGURE 4-5. 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 Great Salt Lake water bodies. This study will focus efforts to establish a robust trophic transfer relationship in Great Salt Lake only of those contaminants 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 contaminant.

Study Objectives. The objective of this study is to establish trophic transfer relationships of bioaccumulative contaminants in Great Salt 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 standards, determining UPDES permit limits, and assessing the support of Great Salt Lake's beneficial uses.

Management Objectives. Bioaccumulative contaminants are of concern for the aquatic food chain but also for the health of Great Salt Lake birds and the humans who consume them. Understanding how these contaminants enter and bioaccumulate in the food chain is essential to applying eventual water quality standards to UPDES permits and assessing if Great Salt Lake is supporting its beneficial uses.

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 baseline sampling plan and synoptic sampling studies could be used but may need to be augmented to capture

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

COMPLETE LABORATORY TOXICITY TESTS

Problem Statement. Component 1 includes the possibility of completing laboratory toxicity tests as part of the process for the development of water quality standards for Great Salt Lake. UDWQ will first complete a review of the literature to identify available toxicity data that are pertinent to the organisms and salinities observed in Great Salt Lake. If data gaps exist, then UDWQ will need to complete laboratory toxicity tests to determine the toxicity of various contaminants to organisms that exist in Great Salt 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 beneficial uses they represent.

UDWQ is currently evaluating which organisms, salinities, and contaminants are relevant to the development of water quality standards for Great Salt Lake and will be completing a literature review to define appropriate toxicity data and benchmarks for use in Great Salt Lake. As such, the actual number and targets for the toxicity tests are unknown at this time.

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

Management Objective. Laboratory toxicity tests are an essential element in developing water quality standards that can be used to assess the beneficial uses of Great Salt Lake (see Component 1).

Approach. Per the literature review previously discussed, UDWQ will identify data gaps in available toxicity data for the organisms and salinities observed in Great Salt 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 contaminant 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 contaminant used, and the appropriate endpoint.

4.3.3 Great Salt Lake Upper Food Chain

The upper food chain of Great Salt Lake is represented by several species of birds that visit the lake every year for wintering and nesting. The Great Salt Lake is extremely important to migratory birds. One of the most important roles the Great Salt 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 Great Salt 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. As previously described, these birds are not only important to the Great Salt Lake ecosystem but also to the recreation industry and the health of those who hunt and eat waterfowl. It is thus evident that understanding and sustaining the avian population in the Great Salt Lake ecosystem is of utmost importance.

Studies have been conducted to identify and enumerate the different avian species in and around Great Salt Lake (Manning and Paul, 2003; Cavitt, 2006; Cavitt, 2008a; Cavitt, 2008b) and much work has been done to understand the effects of contaminants on avian population (CH2M HILL, 2008; Vest et al., 2009). The UDWR continues to complete research to understand the use of Great Salt 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 this beneficial use.

The following sections present these research needs.

HOW DOES THE AVIAN POPULATION USE 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 Great Salt Lake surface, shoreline, and associated wetlands, including the three major delta regions and nearby wetland complexes that drain into Great Salt 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.

FIGURE 4-6. WATERFOWL AT FARMINGTON BAY

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 contaminant exposure. Although reproductive success is the most critical endpoint for most contaminant 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 contaminants during their time on Great Salt Lake or as they continue their migration. These migratory non-nesting species will be monitored if there is reason to believe they are more sensitive to contaminants than nesting species. In addition, little is known about the contaminant levels in that these birds are carrying when they arrive at the lake and whether lake contaminants 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 Great Salt Lake and other water systems they might use along their migratory paths. Thus, studies will be completed to survey avian species that use Great Salt 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 Great Salt Lake's beneficial uses.

Study Objectives. The objectives of these studies will be to conduct bird surveys to identify avian species that use Great Salt 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.

Management Objectives. Understanding which avian species use the lake, how they use it, and where they use it are important for the development of water quality standards, monitoring the Great Salt Lake's waters, and UPDES permitting. Most importantly, this work will inform UDWQ's assessment of Great Salt Lake's beneficial uses.

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 the UDWR study used and is currently using.

Surveys will be targeted to complete the following:

- ☐ Surveys will be conducted of migratory species breeding at Great Salt 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 contaminants may put these birds at risk. In addition, studies will be designed that will monitor contaminant levels in the eggs of birds that use Great Salt Lake waters as a food source and breed along its shores (note that selenium and mercury in bird eggs is monitored as part of the baseline sampling plan).
- ☐ 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 contaminants may put these birds at risk. In addition, studies will be designed that will monitor contaminant levels in birds arriving at Great Salt Lake and their accumulation during their stay. Birds will be tracked to determine survival after they leave Great Salt Lake to move on to their breeding grounds.

DEVELOP TROPHIC TRANSFER MODEL FOR UPPER FOOD CHAIN

Problem Statement. Understanding trophic relationships for bioaccumulative contaminants, such as selenium, mercury, and arsenic, is an important part of advancing our knowledge on the dynamics of these contaminants in Great Salt Lake, as well as in assessing the beneficial uses of Great Salt Lake. As a part of UDWQ's extensive effort to assess the effects of selenium in the Great Salt 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 Great Salt Lake also underlined the need for more information on correlation of contaminants in avian species and their diets. Current EPA guidance for implementing tissue based water quality standards for methyl-mercury recommend the development of these relationships to support permitting.

FIGURE 4-7. TRAP SET OVER A SHOREBIRD NEST TO CAPTURE MOTHER HEN TO LINK DIET OF MOTHER HEN TO EGGS

Sampling Shorebirds to Link Diet to Bird Egg

This study will establish a robust trophic transfer relationship between avian species, their eggs, and their diets in Great Salt Lake of those contaminants that have been identified to pose a risk to the beneficial uses of Great Salt Lake.

Though presented as a single study here, this project may be divided into several subcategories, each handling a single contaminant.

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

Management Objectives. Bioaccumulative contaminants are of concern for the aquatic food chain but also for the health of Great Salt Lake birds and the humans who consume them. Understanding how these contaminants enter and bioaccumulate in the food chain is essential to applying eventual water quality standards to UPDES permits and assessing if Great Salt Lake is supporting its beneficial uses.

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 on Great Salt Lake presented will support this study.

It can be difficult to establish a relationship between concentrations of contaminants 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 on on a weekly basis for about 5 weeks before the nesting season. This will provide a good picture of the variability of contaminants 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 contaminants.

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.

HOW DO SELENIUM AND MERCURY AFFECT 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 beneficial uses, in particular to the avian population of Great Salt Lake. The following work addresses key issues that pertain to UDWQ's monitoring of Great Salt Lake, evaluation of that data, and assessing Great Salt Lake's beneficial uses.

Bird Egg Monitoring for Selenium and Mercury in Great Salt Lake

As part of the baseline sampling plan (see Section II) and to support the assessment of Great Salt Lake beneficial uses, 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 Great Salt 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 Great Salt 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 Great Salt 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 contaminants 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 Great Salt Lake and to understand how this interaction might adversely affect them.

Management Objectives. Understanding whether there is a significant interaction between selenium and mercury in the avian species of Great Salt Lake is critical for accurately interpreting results from UDWQ's monitoring program, developing water quality standards, evaluating UPDES permits, and assessing Great Salt Lake's beneficial uses.

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 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 beneficial use. This phase of research will require close coordination with the UDWR and the USFWS.

4.4 Wetland Research

Concerns about the potential impact nutrient loads may be having on Great Salt Lake wetlands have prompted UDWQ and others to initiate two wetlands research programs 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 were critical to the integrity of Farmington Bay's ecosystem. This program evolved into the development of a wetland assessment framework to be used to evaluate the relative condition of Great Salt Lake impounded wetlands. In 2011, UDWQ initiated the Willard Spur sampling and research program, with the objective of understanding how to better protect the beneficial uses of Willard Spur waters. These two research programs have and are making progress in improving the understanding of Great Salt Lake wetlands; however, further study is required to enable UDWQ to effectively protect the beneficial uses of these wetlands. This section summarizes ongoing research but also identifies additional needs.

FIGURE 4-8. UDWQ'S PROPOSED APPROACH FOR GREAT SALT LAKE WETLANDS WATER QUALITY STRATEGY

4.4.1 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 function of the wetlands makes determination of suitable numeric criteria for these wetlands difficult and time consuming. Discussion of using only narrative criteria to protect the wetlands meets with significant concern as narrative criteria alone may not be adequate to protect the beneficial uses. Regardless of the water quality standards that are implemented in the future, an assessment framework for the wetlands of Great Salt Lake is vital to moving forward. This framework, and the science that defines it, will serve as the baseline for documenting if and how the beneficial uses of these wetlands are protected. This framework will also serve as the foundation for a new, proposed approach to managing the wetlands of Great Salt Lake.

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 Great Salt Lake wetlands and identify areas that may not be supporting their beneficial uses. UDWQ can then complete focused research on these areas to be able to determine if they are supporting their beneficial uses.

Management Objectives. This research will support the development of appropriate water quality standards for Great Salt Lake wetlands, monitoring of these waters, and assessing their support of beneficial uses.

Approach. UDWQ and others have invested significant resources to better understand the dynamics of Great Salt Lake wetlands (Miller and Hoven, 2007; Gray, 2005; Gray, 2009; Rushforth and Rushforth, 2006a, b, c, d; Rushforth and Rushforth, 2007). A preliminary assessment framework was proposed for Great Salt Lake impounded wetlands in 2009 using data collected beginning in 2004 (CH2M HILL, 2009). UDWQ is currently working to validate the assessment framework for impounded wetlands and develop a new preliminary assessment framework for fringe wetlands. The preliminary assessment framework for impounded wetlands focused on developing metrics for four assemblages: macroinvertebrates, submerged aquatic vegetation, surface mats, and water chemistry. Ongoing work to validate this framework will investigate the viability of other indicators such as diatoms and 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).

4.4.2 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.

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, beneficial 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.

FIGURE 4-9. A JANUARY MORNING AT WILLARD SPUR

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 standards are fully protective of beneficial 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 as they relate to the proposed POTW discharge?

Management Objective. The objective of this work is to develop appropriate water quality standards and methods for monitoring and assessing the support of Willard Spur's beneficial uses.

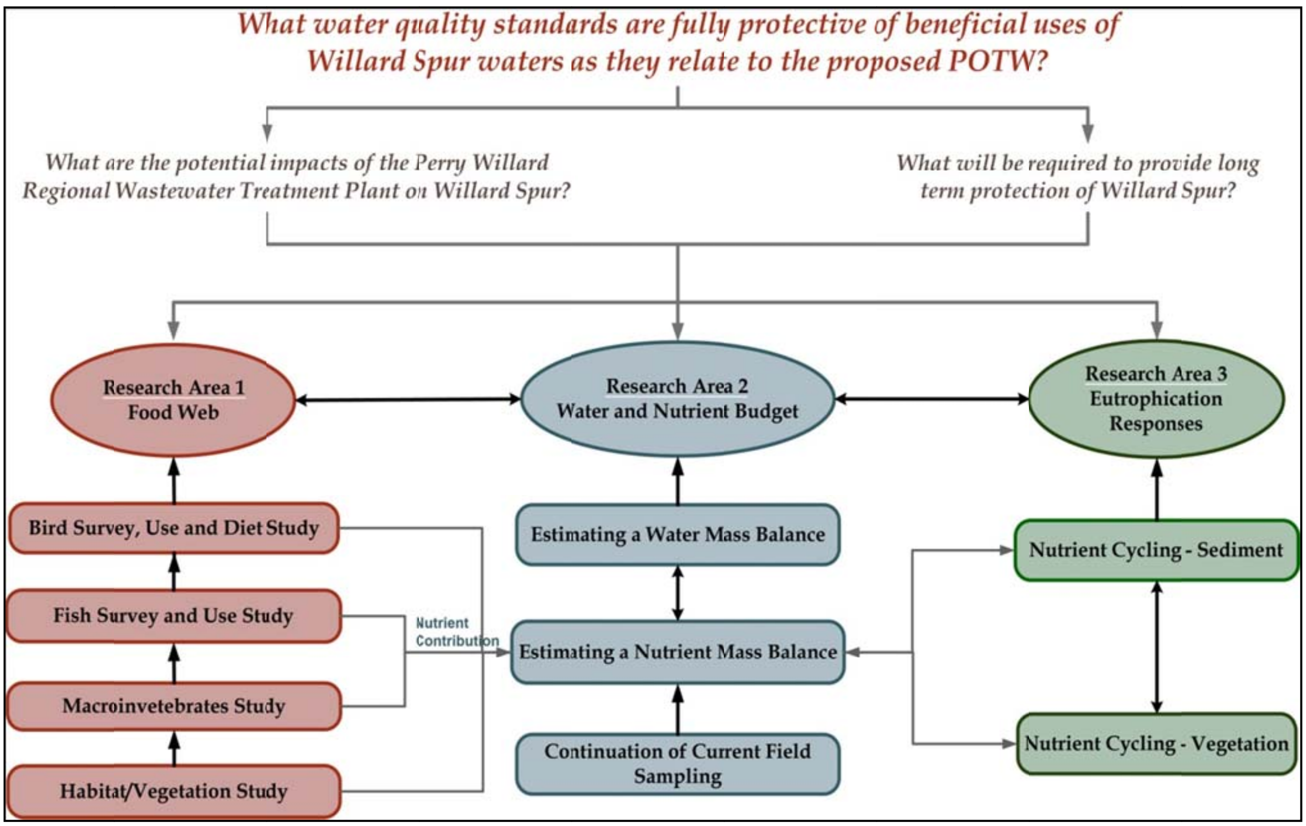
Approach. To provide answers to these questions, the Willard Spur Science Panel identified the three following key research areas:

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 4-10 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 Great Salt Lake wetlands will be closely coordinated and integrated to leverage the knowledge gained and focus efforts on areas of less understanding.

FIGURE 4-10. OVERALL STRUCTURE OF PROPOSED RESEARCH WORK AT WILLARD SPUR



4.4.3 Additional Wetland Research Needs

DEVELOP WETLAND RESEARCH FRAMEWORK

Problem Statement. While UDWQ's current research programs are working to develop a fundamental understanding of Great Salt Lake wetlands and how to protect them, there are numerous additional areas that require research. An important realization is that as more is learned about

FIGURE 4-11. WETLANDS NEAR OGDEN BAY

Great Salt Lake wetlands, the more researchers understand that they do not know. Much research can be done without addressing management objectives. Thus it is essential that a research framework be developed that is based on clear objectives endorsed by Great Salt Lake wetlands stakeholders. It is important that new research 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 that UDWQ and its partners can use to understand each others' objectives, acknowledge previous research, identify and prioritize research to address gaps in understanding, coordinate efforts, and document progress.

Management Objective. The objective of this work is to develop a framework that facilitates effective collaboration to develop water quality standards, monitor, and assess the beneficial uses of Great Salt Lake wetlands.

Approach. UDWQ will work with its partners to develop this research framework. 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 beneficial uses. The framework will consolidate much of the above into a conceptual model, ideally developed for each unique stressor. 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.

ADDITIONAL RESEARCH NEEDS

Following are questions and issues that have been raised as part of other research studies. Research will be completed in these areas to ensure that UDWQ's strategy to protect wetlands is well informed, defensible, and focuses on the right indicators and factors. More areas will likely be identified as part of the development of the research framework previously described. The areas of research are as follows:

1. What is the influence of legacy nutrients and metals in wetland sediments upon the water quality and beneficial uses of these wetlands?
2. What factor do metals in sediments play in observed responses that have generally been attributed to nutrients (Miller et al., 2011)?
3. Why do submerged aquatic vegetation appear to senesce earlier in "impacted" impounded wetlands vs. "reference" sites? Does this indicate that beneficial uses are not being supported?
4. Does the presence of surface algal mats indicate that beneficial uses are not being supported?
5. What role does water quality play in the propagation of invasive species such as phragmites? How do these invasive species influence other indicators that UDWQ is considering for use in assessing Great Salt Lake wetlands?
6. Many Great Salt Lake impounded wetlands are managed systems. What factor does the altered hydrology play in the observed responses? Can hydrologic manipulations be improved to improve water quality? (See also CH2M HILL, 2012.)
7. How does the apparent early senescence of submerged aquatic vegetation and presence of surface algal mats affect the avian beneficial use of Great Salt Lake impounded wetlands?
8. Further develop mapping and database infrastructure for Great Salt Lake wetlands to integrate scientific knowledge, work efforts, and resources among researchers.
9. Complete a landscape-level HGM-based reclassification of Great Salt Lake wetlands for use as a sampling frame in future wetland assessments.

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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 standards required for the protection of beneficial 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 contaminants 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 contaminants pose the greatest risk to the beneficial 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 contaminants 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 contaminants 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 contaminants 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 contaminants 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 contaminants 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 contaminants 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 contaminants 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 contaminants in lower food chain vs. avian population correlate?

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

2. Do current mercury levels present a risk to the beneficial 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 beneficial 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 beneficial 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 beneficial 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 beneficial uses?

i) Which of the following indicators provide the best information regarding risk to the beneficial 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 beneficial 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 beneficial uses?

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

a) Do other potential contaminants present a risk to the beneficial 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 contaminants, as listed by the United States Environmental Protection Agency (EPA) as "Contaminants 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 contaminants 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 contaminants in Great Salt Lake wetlands?

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

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