Resource Evaluations

Union Pacific Railroad Great Salt Lake Causeway Culvert Closure and Bridge Construction Project

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1 Introduction

1.1 Purpose of This Report

The Union Pacific Railroad (UPRR) is seeking a Department of the Army permit in the form of a federal Clean Water Act (CWA) Section 404 Individual Permit for the permanent closure of a culvert, known as the east culvert, in a rock-fill railroad causeway that crosses the Great Salt Lake. The Great Salt Lake is a water of the U.S. subject to regulation under the CWA. Pursuant to CWA Section 401, the Section 404 permit is also subject to issuance of a Section 401 Certification by the Utah Division of Water Quality (UDWQ).

What is the UPRR Project (proposed action)?

The UPRR Project, also called the proposed action, is defined as the permanent closure of the east culvert of the Great Salt Lake railroad causeway and construction of a 150-foot-long bridge as compensatory mitigation for closing both the east and west culverts.

This report provides background information about the project alternatives and discusses the potential effects of UPRR's proposed project on the lake's ecological resources. This document also reviews the potential effects of a no-action alternative, which represents what would happen if the U.S. Army Corps of Engineers (USACE), the permitting agency, does not issue the CWA Section 404 permit as proposed. In addition, this report reviews the public interest factors that USACE will consider as part of the CWA Section 404 permitting process.

As described in the December 13, 2013, USACE public notice for the project, the project includes permanently closing the east culvert and implementing a previously authorized compensatory mitigation action to offset the effects of closing the east and west culverts of the causeway. USACE assigned the compensatory mitigation as part of a Nationwide Permit (NWP) authorization, which it issued in November 2012 (USACE 2012), for permanently closing a structure called the west culvert. The current CWA Section 404 permit application does not include permanently closing the west culvert, since that activity was previously authorized and carried out (USACE 2012).

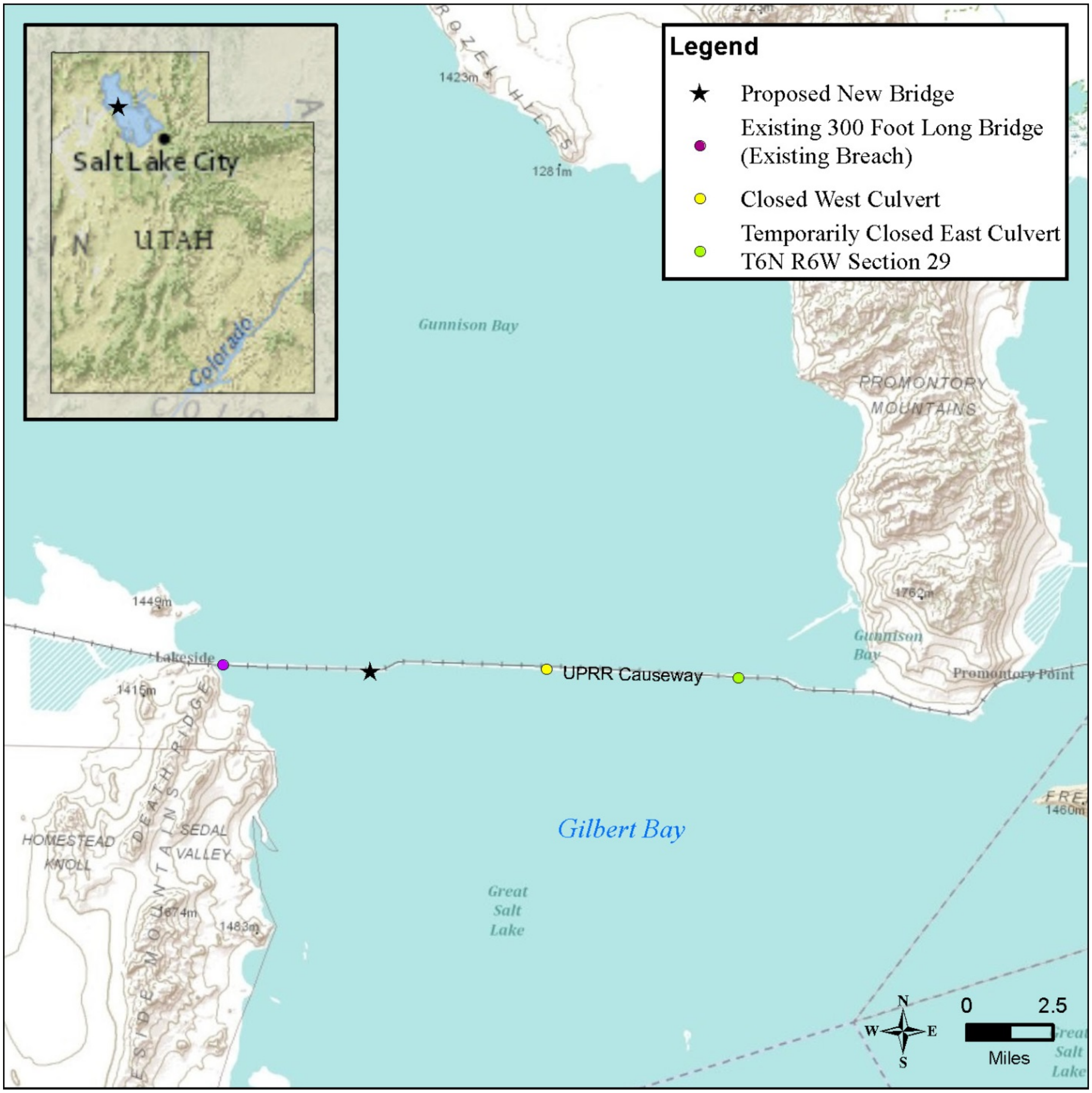
At the time USACE issued the NWP authorization for permanently closing the west culvert, UPRR and USACE knew that the east culvert would also eventually need to be closed. UPRR is required to submit a compensatory mitigation plan as a condition of the November 2012 NWP authorization, and the mitigation proposal will also compensate for the effects of closing the east culvert. UPRR's original compensatory mitigation proposal was to construct a 180-foot-long bridge to replace the aquatic functions provided by the east and west culverts before they were closed. At that time, USACE authorized construction of the bridge, but that authorization did not issue final approval of a mitigation and monitoring plan.

1.2 Project Background

The proposed project would be located in the Great Salt Lake, which is in northwestern Utah. The lake is about 75 miles long and 28 miles wide and covers about 1,700 square miles. It is the largest U.S. lake west of the Mississippi River and the fourth-largest terminal lake in the world. Due to the lack of an outlet, the lake is typically 3 to 5 times saltier than the ocean (USGS 2013c).

UPRR operates trains on a rock-fill causeway built by UPRR's predecessor in 1959. This rock-fill causeway separates the lake into areas that are called the North Arm and the South Arm. Water and salt are conveyed back and forth between the lake's North and South Arms through the permeable rock-fill causeway and an existing 300-foot-long bridge (which the Utah Division of Water Resources constructed in 1984). Until recently, water and salt were also conveyed by two culverts in the causeway (the east and west culverts). The east culvert is about 6 miles west of Promontory Point, and the west culvert is about 11 miles west of Promontory Point (Figure 1-1). Both culverts are about 15 feet wide by about 20 feet deep. Over time, the culverts have settled and become submerged.

Figure 1-1. UPRR Project Area



The North and South Arms normally have different water surface elevations (WSE) and salinities. These differences, along with the physical characteristics of the causeway, affect the transfer of water and salt between the two arms. Depending on the lake WSE, the less dense (less saline) South Arm brine generally flows north to the North Arm, and the more dense (more saline) North Arm brine flows south into the South Arm.

As a result of these varying water conditions and salinities, UDWQ has given the North Arm a different beneficial-use classification than the South Arm. Within the South Arm, three interconnected bays (Gilbert Bay, Bear River Bay, and Farmington Bay) have been assigned unique beneficial-use classifications. The beneficial-use classifications recognize that the lake has unique recreational and wildlife resources.

What are beneficial uses?

Lakes, rivers, and other water bodies have uses to humans and other life. These uses are called beneficial uses. For more information, see Section 1.6, Thresholds of Significance Used for Impact Analyses.

When inspections revealed that the culverts were settling and breaking with the risk of collapsing, UPRR applied in May 2011 for the necessary approvals to close the two culverts. At that time, UPRR also proposed to construct a 180-foot-long bridge to compensate for the loss of water and salt transfer between the North and South Arms that the culverts had historically contributed to the overall water and salt transfer, with the intent of avoiding salinity changes that could impair the lake's beneficial uses.

During the process of reviewing UPRR's original proposal, federal and state agencies raised a number of concerns about the potential impacts of the project. Virtually every agency commenting on UPRR's proposal insisted that UPRR update, calibrate, and use the U.S. Geological Survey's (USGS) Water and Salt Balance Model of the Great Salt Lake, Utah (referred to in this report as the 1998 USGS Model) as a means of evaluating the effects of carrying out UPRR's proposal on the water and salt balance between the two arms of the lake. Agencies also raised issues relating to the effects of the proposed project on the lake's resources. UPRR undertook a re-revaluation of its proposal and the project's potential impacts.

As this re-evaluation continued, the condition of the culverts continued to deteriorate. USACE authorized the permanent closure of the west culvert in November 2012 (USACE 2012). As part of the November 2012 authorization for closing the west culvert, USACE authorized UPRR's compensatory mitigation proposal concept—construction of a 180-foot-long bridge—that would provide the arm-to-arm water and salt transfer function that was previously provided by the free-flowing west and east culverts.

In December 2013, it became necessary for UPRR to close the east culvert under an emergency authorization from USACE when additional inspections revealed an imminent risk of the east culvert failing. The 2013 emergency closure of the east culvert also required the approval of UDWQ. USACE authorized temporary closure of the east culvert (USACE 2013), and UPRR received a Utah Water Quality 401 Certification from UDWQ for the temporary closure (UDWQ 2013a). USACE's temporary culvert closure authorization included direction to UPRR to submit an individual permit application to provide a permanent solution.

What is the objective of UPRR's compensatory mitigation?

The objective of the mitigation is to duplicate, as closely as possible, the transfer of water and salt that was occurring through the causeway with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

As reflected in USACE's direction to UPRR, the objective of UPRR's compensatory mitigation is to duplicate, as closely as possible, the transfer of water and salt that was occurring through the causeway with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

As part of the individual permit process, UPRR has implemented its impacts re-evaluation plan, which was submitted to USACE and UDWQ on September 25, 2013 (UPRR 2013a). The September 25 plan consisted of two elements: (1) conducting water and salt balance modeling and (2) evaluating the potential effects of the project on environmental resources associated with the Great Salt Lake. The impacts re-evaluation plan was described in the September 25, 2013, letter from UPRR to USACE. This resource report is intended to address the second item of the re-evaluation plan: the potential effects of the proposed project on the lake's environmental resources.

1.3 Studies Completed by UPRR in Support of the Project

1.3.1 Summary of the Water and Salt Balance Modeling

UPRR conducted the three-step water and salt balance modeling plan as part of re-evaluating the effects of closing the east and west culverts and constructing the originally proposed 180-foot-long bridge on the water and salt balance between the North and South Arms of the Great Salt Lake. The plan was described in the September 25, 2013, letter from UPRR to USACE (UPRR 2013a). The three steps of the modeling plan are as follows:

- **Modeling step 1:** development of the 1998 UPPR/USGS Model to run under historic hydrologic conditions for the period 1987–1998, plus simulations
- **Modeling step 2:** development of the 2012 UPRR/USGS Model to run under historic hydrologic conditions for the period 1987–2012, plus calibration and simulations
- **Modeling step 3:** development of the 2012 UPRR/USGS Varying Hydrology Model to run under constant wet, mild, and dry conditions for 25 years, plus simulations

The 2012 UPRR/USGS Model simulations (modeling step 2) are based on 26 years of data, and the 2012 UPRR/USGS Varying Hydrology Model (modeling step 3) simulated 25 years of operation. For each step of the modeling plan, the UPRR/USGS model simulated the WSE, salinity, and salt loads of the North and South Arms of the Great Salt Lake for the following two simulations:

- **Culvert Simulation – Simulated conditions for the east and west culverts before closure of the west culvert in 2012:** The east and west culverts were represented as they existed in November 2012: open and free flowing, and the elevations of the culvert inverts were those from 2012. With these simulations, there are three mechanisms for transferring water and salt through the causeway: the existing 300-foot-long bridge, the two culverts, and the causeway fill.
- **Proposed Bridge Simulation – Simulated conditions associated with the bridge proposed as compensatory mitigation for the culvert closures:** The originally proposed 180-foot-long bridge was included as a defined opening in the causeway, and the two culverts were removed (assumed to be filled). With these simulations, there are three mechanisms for transferring water and salt through the causeway: the existing 300-foot-long bridge, the originally proposed 180-foot-long bridge, and the causeway fill.

UPRR compared the results of the culvert and proposed bridge simulations for each modeling step (UPRR 2014a). The lake conditions that were compared were WSE; flows through the causeway fill, the existing 300-foot-long bridge, the originally proposed 180-foot-long bridge, and the culverts; North and South Arm salt loads; and North and South Arm salinity. For each modeling step, the simulation of the bridge at 180 feet long resulted in a more dense (more saline) South Arm than with the culvert simulation. Likewise, the North Arm was less dense (less saline) in the simulation of the 180-foot-long bridge than in the culvert simulation. This is primarily attributable to greater north-to-south flows relative to south-to-north flows for the simulation with the 180-foot-long bridge than for the simulation with the free-flowing culverts. Thus, there would be more net salt transfer from the North Arm to the South Arm with a 180-foot-long bridge in place than with the free-flowing culverts in place.

Based on the results of this three-step modeling effort, UPRR evaluated adjustments to the geometry for the originally proposed 180-foot-long bridge that would result in the function of the bridge and its effects on the water and salt balance that more closely resembled and replaced the function of the free-flowing east and west culverts as they existed as of 2012.

1.3.2 Summary of the *Bridge Evaluation Report*

The results of the water and salt balance modeling for the 180-foot-long bridge prompted UPRR to complete a bridge evaluation that studied the effects of various bridge geometries on the water and salt balance between the North and South Arms. UPRR compared the results for each bridge geometry studied to the culvert simulation results. The results are presented in the *Bridge Evaluation Report* (UPRR 2014b) that was submitted to USACE on June 2, 2014.

This evaluation was conducted to determine the appropriate size of bridge to meet the compensatory mitigation objective, which is to duplicate, as closely as possible, the transfer of water and salt that was occurring through the causeway with the culverts functioning as documented in November 2012 when it was necessary to close the first culver (the west culvert). The bridge evaluation used the UPRR/USGS models that had been created for modeling steps 2 and 3. Four alternate bridge sizes were incorporated into the model codes for comparison to the culvert simulation.

Based on the analysis described in *Bridge Evaluation Report*, UPRR determined that the results of the water and salt balance model simulations indicate that a 150-foot-long bridge with an invert elevation of 4,183 feet would most closely match the results of the culvert simulation most of the time. Bridge alternatives are discussed in more detail in Chapter 2, Project Description and Additional Project Alternatives.

What is an invert?

An invert is the bottom of a bridge opening.

Therefore, UPRR proposes to change the bridge geometry of the originally proposed compensatory mitigation to a different bridge geometry: a 150-foot-long bridge with an invert elevation of 4,183 feet. The results of the water and balance model indicate that lake conditions in the North and South Arms are most similar for this bridge geometry compared to the culvert simulations for the parameters of total causeway flow ratios, salinity ratios, and salt loads. This analysis shows that there would be a slight change in the lake salinity and salt loads and that the new bridge geometry would best replace the aquatic function of the culverts and would provide water and salt transfer through the causeway similar to that provided by the culverts. For the purpose of the impact analyses described in this report, UPRR’s proposed project includes a 150-foot-long bridge at an invert elevation of 4,183 feet.

Other bridge alternatives considered are described in Chapter 2, Project Description and Additional Project Alternatives. The alternatives analysis focuses on how these options would change the long-term water and salt transfer compared to the historic water and salt transfer provided by the causeway with free-flowing culverts. For example, a transfer that allows more North Arm water, which is more saline than South Arm water, to move into the South Arm than the culverts allowed would increase the salinity of the South Arm in relation to what would have occurred with the culverts in place; such a change in the water and salt balance could result in different or additional impacts to the resources evaluated in this report. Therefore, such an alternative would not meet the mitigation objective to facilitate replacement of the aquatic function provided by the free-flowing culverts stated by USACE in its direction to UPRR. This document evaluates potential effects on the lake’s ecological resources in relation to the impacts of the project on water and salt balance as designed to meet the compensatory mitigation objective.

1.4 Purpose of and Need for Action

The UPRR Project (the proposed action) is needed to complete the permitting necessary to make the east culvert closure permanent. The east culvert was closed originally to prevent it from failing, which would have caused a shutdown of the causeway to train traffic due to potential safety issues related to culvert failure. The proposed action is also needed to authorize the compensatory mitigation required to offset the effects of the permanent closure of the east culvert and the effects of closing the west culvert, which was carried out under a previous authorization.

What is the purpose of the UPRR Project (proposed action)?

The purpose of the UPRR Project is to maintain a safe rail corridor across the Great Salt Lake by making the previous east culvert closure permanent and to mitigate the effects of closing the two culverts by constructing a bridge to duplicate the functions of the now-closed culverts.

The purpose of the project is to maintain safe rail operations across the Great Salt Lake causeway by making the previous east culvert closure permanent and to mitigate the effects of closing the two culverts by constructing a bridge to duplicate the functions of the now-closed culverts.

1.4.1 Culvert Condition and Necessity of Closure

In a July 2011 NWP 14 Preconstruction Notification (PCN) sent to USACE, UPRR described the conditions of the west and east culverts as in the process of failing—cracking and in disrepair. Failure of one or both of the culverts could lead to closure of the causeway to train traffic and/or significant delays in freight movement, which could adversely affect local and regional economies.

Prior to submitting the PCN, UPRR analyzed repair alternatives and determined that the best long-term choice was to close the culverts. To replace the function of the culverts, UPRR proposed to construct a bridge that would span a new breach in the causeway. At the time the PCN was submitted, UPRR planned to permanently fill both culverts after construction of the bridge.

USACE initially denied UPRR's application. However, during a July 2011 inspection, a team of divers and geotechnical engineers observed significant deterioration of the west culvert. After an August 2012 meeting with USACE, UPRR sent a letter requesting reconsideration of its application and declaring that immediate action would be needed to close the west culvert to avoid a potential derailment. At the time of the inspection, UPRR documented that the condition of the east culvert was not as critical and that the culvert could remain in place to allow circulation between the North and South Arms of the lake until a new bridge could be constructed.

On August 29, 2012, USACE authorized closure of the west culvert using NWP 14 (USACE 2012). This authorization also permitted construction of a bridge as compensatory mitigation to replace the functions of the culverts. USACE's authorization acknowledged that there would be a delay in constructing the bridge because it was necessary for UPRR to develop a compensatory mitigation and monitoring plan for USACE's approval. The west culvert was fully closed in November 2012. The 2012 NWP 14 authorization did not include closure of the east culvert. The east culvert was intended to remain open until appropriate mitigation could be approved and constructed.

After the permanent closure of the west culvert, UPRR developed and submitted an initial compensatory mitigation plan. However, USACE, UDWQ, and other agencies raised a number of concerns about the adequacy of the analysis to support the plan. Therefore, UPRR agreed to conduct an extensive re-evaluation of potential impacts, culminating in the submission of its September 25, 2013, plan referenced above.

As UPRR continued implementing its September 25, 2013, impacts re-evaluation plan, UPRR determined via an inspection on October 11, 2013, that the east culvert was in danger of failing. On October 21, 2013, UPRR notified USACE of the imminent threat of failure of the east culvert and requested authorization to close it. On December 6, 2013, USACE issued authorization to temporarily close the east culvert using NWP 14, and UDWQ issued a Utah Water Quality 401 Certification on December 16, 2013. In the NWP verification (USACE 2013), USACE stated that the east culvert closure authorization was temporary and did

> … not address the permanent solution for maintaining train operations across the UPRR Causeway. Activities in waters of the United States proposed for permanent solution, including whether to leave the east culvert fill material in-place, will be evaluated under our standard permit procedures.

USACE issued a public notice on December 13, 2013, to authorize the permanent fill and closure of the east culvert and the construction of new bridge to offset the impacts of the fill activity associated with the permanent closure of the east and west culverts. The public notice also identified the requirement for a Utah Water Quality 401 Certification from UDWQ.

1.4.2 Importance of Continued Rail Operations across the Union Pacific Railroad Causeway

UPRR has been part of Utah's history since the completion of the transcontinental railroad in the 1860s. Utah is a hub for UPRR today. UPRR has more than 1,400 employees in the state and has made private investments of more than $290 million in Utah's transportation infrastructure from 2007 to 2012.

In response to USACE's requests during the review process for authorizing emergency closure of the east culvert, UPRR submitted on November 8, 2013, additional analysis describing the social and economic hardships that would result from the potential closing of the causeway across the Great Salt Lake to train traffic (UPRR 2013b). The corresponding economic and social benefits that would be realized through implementing the UPRR Project (avoiding a shutdown of the causeway to train traffic) are summarized below. Safe and efficient train traffic through Utah, and avoidance of severe economic and social impacts that would result from shutting down the Great Salt Lake causeway to train traffic, would be realized by implementing the proposed project (closure of the east culvert in the causeway across the Great Salt Lake).

Just as a causeway shutdown clearly would have adversely affected interstate commerce, closing the culvert, which was necessary to allow continued safe and efficient train traffic, would benefit interstate commerce because it would allow the causeway to stay open and operating. UPRR's customers rely heavily on interstate shipments over UPRR's Lakeside Subdivision main line, which crosses the Great Salt Lake on the causeway. Maintaining a safe and reliable transportation corridor would avoid effects on interstate shipments that normally cross the lake and would avoid the ripple effect of a causeway shutdown that would extend throughout the rail network.

The Great Salt Lake causeway structure is an integral part of the Lakeside Subdivision, which is the main east-west line linking West Coast, Midwestern, and eastern customers and markets. Closing the east culvert would make it possible for the causeway to remain open and operable, which in turn would allow this portion of the east-west interstate rail line to remain operable. In contrast, the collapse of the culvert would cause an immediate loss of productive use of UPRR's property (not only the causeway itself but an additional 178 route-miles between Ogden, Utah, and Wells, Nevada), a loss that would continue until the causeway's structural integrity was restored.

Authorizing temporary closure of the east culvert, which in turn allowed the continued safe operation of the causeway and the interstate rail route that relies on it, made it possible to avoid the significant economic impacts of a shutdown described in UPRR's November 8, 21, and 27, 2013, submittals to USACE. Authorization of the east culvert closure as permanent under an individual permit and construction of a bridge as compensatory mitigation would enable UPRR to continue using the Great Salt Lake causeway and UPRR's Lakeside Subdivision.

1.5 No-Action Alternative and Baseline Conditions

No-Action Alternative. As part of its environmental review process, USACE must consider the effects of not issuing an individual permit for permanently closing the east culvert and not providing the compensatory mitigation required to offset the effects of closing the east and west culverts. This situation is referred to as the *no-action alternative*, since USACE would not take the action of issuing the individual permit.

With the no-action alternative, no permit would be issued, the east culvert would remain temporarily closed, and UPRR would continue to coordinate with USACE to identify acceptable compensatory mitigation for the culvert closure to be included in the mitigation and monitoring plan, as contemplated in the USACE 2013 NWP 14 authorization (USACE 2013). Until a final mitigation and monitoring plan is approved and any necessary permits are issued, no compensatory mitigation (a bridge) would be constructed to replace the aquatic function lost due to closing the west culvert, and the permanent solution for maintaining safe rail operations across the causeway (including permanent closure of the east culvert) would remain outstanding.

What are the conditions with the no-action alternative?

With the no-action alternative, no permit would be issued, the east culvert would remain temporarily closed, and UPRR would continue to coordinate with USACE to identify acceptable compensatory mitigation for approval.

Baseline Conditions. The term *baseline conditions* refers to the ecological and physical state of the project area before the project is implemented. UPRR worked with USACE to define baseline conditions for this project. The west culvert closure was permitted and completed in 2012, so it would normally be considered part of the environmental baseline. However, because developing and implementing mitigation for the effects of closing the west culvert are part of the current individual permit proposal, this impacts analysis treats the environmental baseline as the conditions before closing the west culvert. In addition, the effects of closing the west culvert on aquatic resources are analyzed as part of the project effects that must be less than minimal with implementation of the compensatory mitigation plan. Therefore, the baseline conditions are different than the conditions with the no-action alternative.

What are the baseline conditions?

The baseline conditions assume that both culverts are open and free flowing, the existing 300-foot-long bridge west of the west culvert is present and functioning within the causeway, and the proposed new bridge is not in place.

Under these circumstances, both culverts are assumed to be open and free flowing, and the water and salt balance varies from year to year based on a number of factors including lake levels, surface water inflows, density gradients, and causeway characteristics. The culverts are located in the causeway in their positions and elevations as of November 2012, before the west culvert was closed. The causeway openings include the existing 300-foot-long bridge west of the west culvert and the free-flowing east and west culverts. Water also flows through the permeable rock-fill causeway.

This report uses these baseline conditions to evaluate the effects of the proposed project on various resources because these conditions were present during recent studies focused on the lake and were used for developing the culvert simulations that were evaluated as part of the evaluation of impacts using the water and salt balance model (UPRR 2014a). Baseline conditions here are not a “snapshot” (that is, tied to a specific date) in this case, because the lake and resource conditions have not been constant over time. The baseline scenario represents the natural variability in lake conditions such as lake level, salinity, and salt load over time that existed or would have existed with the culverts at their 2012 location and elevation so that the resource analyses described in this report can focus on how the proposed project and/or bridge alternatives might affect those resources over time.

1.6 Thresholds of Significance Used for Impact Analyses

As discussed in Section 1.1, Purpose of This Report, this report evaluates how changes to the water and salt balance resulting from the proposed project and project alternatives could affect the lake’s ecological resources. The bridge elevation and geometry have been selected in order to meet the mitigation objective for this project, which is to duplicate as closely as possible the aquatic function of the culverts at the time they were open and free flowing in November 2012. UPRR has set the proposed bridge geometry to duplicate the contribution of the water and salt transfer as closely as possible in light of its modeling work.

To complete the impacts analysis as described in UPRR’s September 25, 2013, impacts re-evaluation plan, this report considers whether the slight changes in water and salt balance that would occur with this project would have a significant adverse effect on the lake resources described in this report. In order to determine whether the proposed project’s potential adverse effects on these resources would be significant, the analyses in this report consider how and whether the project’s impacts to these resources might impair the beneficial uses of the Great Salt Lake designated by UDWQ. Impairment of the designated beneficial would be considered a significant adverse effect of the project. The lake’s beneficial uses are:

- **Gilbert Bay (part of the South Arm):** Protected for frequent primary and secondary contact recreation, waterfowl, shore birds, and other water-oriented wildlife including their necessary food chain.
- **Gunnison Bay (the North Arm):** Protected for infrequent primary and secondary contact recreation, waterfowl, shore birds, and other water-oriented wildlife including their necessary food chain.

What are narrative standards?

Narrative standards are general statements that describe unacceptable water quality conditions such as visible pollution or undesirable aquatic life. Discharges of waste that would result in these conditions are prohibited.

The lake’s water and salt balance and associated resource conditions have varied greatly over time. Published data do not show that the lake’s beneficial uses have been adversely affected and therefore impaired as the lake’s physical conditions have varied over time. If the project were to cause a change in these resources that significantly varies outside the historic range and impairs the lake’s beneficial uses, such an effect would be considered a significant adverse effect.

The State of Utah has not established numeric water quality standards for the lake (with the exception of the tissue-based selenium standard for Gilbert Bay) to protect the beneficial uses of Gilbert and Gunnison Bays. Therefore, the State's narrative water quality standards apply for protecting the beneficial uses of the lake. The narrative standards are (Utah Administrative Code [UAC] R317-2-7.2):

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

In general, the impacts analyses described in this report evaluate whether the proposed project would impair the Great Salt Lake's designated beneficial uses. Such an effect would be considered a violation of the state's narrative water quality standards. The project would be considered to have a significant adverse effect if it would directly impair the designated beneficial uses and violate the narrative water quality standards. In addition, the project would have a significant adverse impact if it were to change the ecological factors analyzed in this report in such a way that these factors in turn impair the lake's beneficial uses. Each resource chapter in this report includes specific parameters for determining whether the proposed project would result in changes to the factors that can affect a specific resource or resources, outside the historic variability, in a way that would impair the lake's beneficial uses.

UPRR expects that, after the bridge is constructed and water begins to flow through the new bridge opening, there could be less-than-minimal post-construction short-term effects on the North and South Arms' salt loads and salinities. UPRR also expects that, at some point after the bridge is completed, lake conditions would equalize (that is, such initial differences in WSE and density gradients between the two arms would be smaller) and the post-construction short-term effects would no longer exist. Once the immediate varying conditions resulting from the bridge opening stabilize, the lake would continue to react to other "normal" factors (such as inflows and evaporation) that influence lake conditions, and the lake conditions, including water and salt balance, would continue to vary within their historic ranges. These potential post-construction short-term effects are based on data and observations made before and after the existing 300-foot-long bridge was opened in 1984.

1.7 Contents of This Report

The following chapters of this report describe the proposed project and the project alternatives that UPRR considered (Chapter 2) and discuss the effects of the project on specific ecological resources of the lake (Chapters 3 through 8). A summary of the effects of the proposed project and project alternatives is presented in Section 9.1, Summary of Project Effects.

In addition, UPRR discusses the project effects and how the project might affect or be affected by public interest factors in Section 9.2, Public Interest Review. These public interest factors are specifically identified by USACE, and regulations require that USACE consider these factors as part of the CWA Section 404 permitting process.

During public and agency review of UPRR's original proposal to close the existing culverts and as a result of the recent permanent closure of the west culvert and temporary closure of the east culvert, resource agencies and commenters on UPRR's proposals have expressed concerns about potential impacts to Great Salt Lake ecological resources that could result from closing the culverts and constructing the compensatory mitigation (bridge). UPRR is addressing those concerns in part by evaluating potential impacts to those resources in this report. As a result, the resources studied for this report are:

- Water chemistry (Chapter 3)
- Water quality (Chapter 4)
- Deep brine layer (Chapter 5)
- Mercury and methyl mercury (Chapter 6)
- Biological resources (Chapter 7)
- Lake circulation (Chapter 8)

Each resource section is organized into the following subsections:

- **Affected Environment:** a description of the current environment (existing conditions) and the current scientific understanding of the resource
- **Environmental Consequences:** an analysis of the proposed project's effects on the resource with various alternative bridges and with the no-action alternative, and any short-term post-construction effects

2 Project Description and Additional Project Alternatives Considered

This chapter provides a detailed description of the proposed project, identifies the project alternatives that were considered by UPRR, and explains how UPRR screened the alternatives. This chapter also addresses mitigation alternatives, which are discussed as part of the proposed project.

2.1 Regulatory Requirements

National Environmental Policy Act Requirements. USACE has stated that its permit action requires completion of an Environmental Assessment (EA) pursuant to the National Environmental Policy Act (NEPA).The Council on Environmental Quality (CEQ) regulations that implement NEPA state that an EA must briefly discuss the proposed action (or *proposed project*) and alternatives to the proposed action [40 Code of Federal Regulations (CFR) 1508.9(b)].

Furthermore, 33 CFR 325, Processing of Department of the Army Permits, Appendix B, NEPA Implementation Procedures for the Regulatory Program, states:

> When the EA confirms that the impact of the applicant's proposal is not significant and there are no "unresolved conflicts concerning alternative uses of available resources * * *" [*asterisks in original*] (section 102(2)(E) of NEPA), and the proposed activity is a "water dependent" activity as defined in 40 CFR 230.10(a)(3), the EA need not include a discussion on alternatives. In all other cases where the district engineer determines that there are unresolved conflicts concerning alternative uses of available resources, the EA shall include a discussion of the reasonable alternatives which are to be considered by the ultimate decision-maker.

As stated in the USACE public notice for the project, UPRR submitted information during the emergency permitting process for the east culvert closure regarding culvert repair alternatives considered (USACE 2014). Those alternatives were summarized in submissions UPRR made on November 8, 21, and 27, 2013. Also as stated in the notice, additional alternatives have been developed during the project review. USACE has requested that UPRR include a discussion of these alternatives in this analysis. Therefore, this chapter provides information about the alternatives that UPRR considered as well as a detailed description of the project.

Mitigation Requirement. When USACE issued the permit for permanent closure of the west culvert in August 2012, it prescribed mitigation intended to compensate for the effects of closing both the east and west culverts on aquatic resources. Federal regulation 33 CFR 332 establishes standards and criteria for the use of all types of compensatory mitigation associated with actions requiring a Department of the Army permit. Federal regulation 33 CFR 332.3(a)(1) states:

> The fundamental objective of compensatory mitigation is to offset environmental losses resulting from unavoidable impacts to waters of the United States authorized by DA [Department of the Army] permits. The district engineer must determine the compensatory mitigation to be required in a DA permit, based on what is practicable and capable of compensating for the aquatic resource functions that will be lost as a result of the permitted activity.

Consistent with this regulation, the compensatory mitigation objective for this project is duplicating as closely as possible the aquatic functions of the culverts in relation to the water and salt balance between the two arms of the Great Salt Lake. USACE approved construction of a bridge as compensatory mitigation in concept in connection with the 2012 NWP 14 verification for the west culvert closure

(USACE 2012). However, that approval was conditioned on submitting a satisfactory compensatory mitigation and monitoring plan. In order to buttress the analysis of impacts needed to develop an acceptable mitigation and monitoring plan, UPRR developed and implemented its September 25, 2013, impacts evaluation plan in close coordination with USACE, UDWQ, and coordinating agencies.

First, UPRR conducted water and salt balance modeling to evaluate how effective the 180-foot-long bridge would be in duplicating the aquatic functions (transfer of water and salt) provided by the two free-flowing culverts before they were closed (UPRR 2014a). Next, after completing the three-step modeling effort called for in its September 25, 2013, plan, UPRR evaluated three bridge alternatives and their effects on the water and salt balance. This analysis found that a 150-foot-long bridge would provide the most similar match to the baseline conditions, which assumes that both culverts are free-flowing and in their 2012 position (UPRR 2014b). (For a description of the baseline conditions, see Section 1.5, No-Action Alternative and Baseline Conditions.) This chapter provides information about the bridge alternatives that UPRR studied.

Clean Water Act Section 404 (b)(1) Requirements. The regulations at 40 CFR 230 include the CWA Section 404(b)(1) guidelines for specification of disposal sites for dredged or fill material. Because the proposed project requires a standard (individual) permit under Section 404, USACE and UPRR must consider practicable alternatives to the proposed discharge, such as not discharging at all or discharging into an alternative aquatic site with potentially less-damaging consequences [40 CFR 230.5(c)]. An alternative is considered *practicable* if it is available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes [40 CFR 230.10(a)(2)].

What is a practicable alternative?

A practicable alternative is available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes.

This chapter examines whether the bridge and project alternatives identified by UPRR are practicable.

2.2 Project Description

2.2.1 Project Details

The elements of the project and compensatory mitigation proposed by UPRR that are subject to authorization under the CWA consist of the following:

- Authorizing permanent closure of the east culvert (this would be an administrative action because the east culvert is already closed; the temporary closure has already been authorized and completed)
- Constructing a 150-foot-long bridge as compensatory mitigation for the effects of closing the east and west culverts on waters of the U.S.
- Constructing a temporary shoofly to accommodate rail traffic while the compensatory mitigation (bridge) is installed

What is the proposed shoofly?

The proposed shoofly is a temporary embankment with railroad tracks. A shoofly is established to reroute train traffic so that construction can occur on the main track.

The proposed bridge and compensatory mitigation plan (which must be approved by USACE and UDWQ) would also be used to compensate for effects on waters of the U.S. associated with the previously approved project to permanently close the west culvert. The waters of the U.S. that would be affected by the proposed project are the open waters of the Great Salt Lake, specifically the lake's Gilbert and Gunnison Bays. The authorization to make permanent the prior close of the east culvert would allow the prior fill of 0.17 acre of saline open water to remain in place, and constructing the bridge would fill an additional 0.003 acre of saline open water. Constructing the shoofly (temporary) rail parallel to the part of the causeway where the bridge would be constructed would temporarily fill 1.28 acres of saline open water. UPRR would remove the temporarily placed fill after the bridge is built.

What are waters of the U.S.?

Under the Clean Water Act, waters of the U.S. are defined as waters that are navigable waters, those that are interstate waters, and/or those used for interstate commerce, their tributaries, and their associated wetlands. Waters of the U.S. are under the jurisdiction of USACE.

UPRR considered a number of alternatives to closing the east culvert as part of the emergency closure authorization process in 2013. That process resulted in the authorization to place the fill necessary to close the east culvert and to maintain that fill on a temporary basis—until a "permanent solution for maintaining train operations across the UPRR Causeway" is authorized under an individual permit. The fill that UPRR placed into the east culvert under the temporary authorization was limited to the area within the east culvert itself and the footprint of the causeway. The proposed project would minimize impacts to the causeway area by leaving in place the fill material that was placed as part of the emergency closure of the east culvert and limiting the footprint of the bridge to the area that supports the minimum size needed to provide conditions that best duplicate the baseline conditions over time. This plan would negate the need for additional disturbance of the lakebed in adjacent areas relating to this element of the project.

As stated in the USACE public notice for the project, the permanent solution proposed as part of this project includes all the permitting needed to make the east culvert closure permanent, to construct a compensatory mitigation bridge, and to place the temporary shoofly during bridge construction (USACE 2014). As requested by USACE, this analysis summarizes and evaluates alternatives to the compensatory mitigation bridge design that were developed during UPRR's modeling and impacts evaluation process. The analysis also considers the no-action alternative, which is described in Section 1.5, No-Action Alternative and Baseline Conditions.

2.2.2 Compensatory Mitigation Proposal

UPRR first submitted a compensatory mitigation proposal for constructing a 180-foot-long bridge to USACE in 2011 (UPRR 2011) as part of its original application for authorization to close the east and west culverts. Based on the results of its extensive modeling effort, and as reported previously to USACE and UDWQ, UPRR has studied different bridge geometries with the intent of identifying a bridge and associated opening that would provide the most similar match to the baseline conditions (UPRR 2014a, 2014b).

As a result of this further study, UPRR has adjusted its proposal to include constructing a 150-foot-long bridge instead of a 180-foot-long bridge. The 150-foot-long bridge would have an invert elevation of 4,183 feet; the 180-foot-long bridge that was previously proposed would have had an invert elevation of 4,178 feet. UPRR documented the bridge evaluation process in the *Bridge Evaluation Report* (UPRR 2014b) that was submitted to USACE on June 2, 2014. The remainder of this section summarizes the bridge alternative screening process and results.

Background

In September 2013, UPRR developed a work plan to re-evaluate the effects of the project as requested by USACE and other permitting agencies to support authorizing the culvert closures. This work plan allowed for adjusting UPRR's compensatory mitigation proposal (the 180-foot-long bridge) (UPRR 2013a).

The work plan recognized that a more-detailed evaluation of the effects on the water and salt balance of the lake and other resources from the proposed 180-foot-long bridge was needed to ensure that the causeway with a bridge provides the most similar functions in terms of water and salt balance as did the causeway with free-flowing culverts. UPRR conducted a three-step water and salt balance modeling effort to compare the effects of the 180-foot-long bridge to the effects of the culverts. This modeling indicated that the causeway with the 180-foot-long bridge would result in higher South Arm salinities and salt loads than did the causeway with the free-flowing culverts (UPRR 2014a).

Specifically, as reflected in USACE's direction to UPRR, in order to meet the mitigation objective described by USACE, UPRR must demonstrate that the project would have less-than-minimal effects on Great Salt Lake resources. That mitigation objective is to duplicate, as closely as possible, the transfer of water and salt that was occurring through the causeway with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

Development of Bridge Alternatives

Building a new structure that results in a different water and salt balance in the lake than the culverts might have secondary effects on lake resources. UPRR's mitigation objective is to design and construct a bridge that would function in a manner that results in the long-term water and salt balance conditions that are the most similar to the historic water and salt balance conditions that were present before both culverts were closed. UPRR's primary criterion for screening the compensatory mitigation bridge alternatives is *to minimize long-term changes in the water and salt transfer between the North and South Arms of the Great Salt Lake from what was occurring with the culverts in place and free flowing.*

What was UPRR's primary screening criterion?

UPRR's primary criterion for screening the compensatory mitigation bridge alternatives is to minimize long-term changes in the water and salt transfer between the North and South Arms of the Great Salt Lake from what was occurring with the culverts in place and free flowing.

In order to identify bridge alternatives that could be considered in light of this mitigation objective, UPRR first simulated conditions for the east and west culverts before the west culvert was closed in 2012 (the west culvert was the first culvert closed). The results of this simulation were used as the baseline against which each bridge alternative was compared.

Compensatory Mitigation Bridge Alternatives Considered

Table 2-1 below summarizes the bridge alternatives that UPRR considered in the various model simulations. For all alternatives, the model assumed that water continues to flow through the causeway via an existing 300-foot-long bridge to the west and through the permeable causeway. Detailed information about each alternative, the modeling process, and modeling results is included in the *Bridge Evaluation Report* (UPRR 2014b).

Table 2-1. Bridge Alternatives Considered as Compensatory Mitigation

in feet NAVD 29

Alternative	Length	Bottom Width	Invert Elevation
A (original proposal)	180	61	4,178
B	150	31	4,178
C (current proposal)	150	49	4,183
D	150	66	4,188

Source: UPRR 2014b
NAVD 29 = North American Vertical Datum of 1929

UPRR compared the effects of five simulations (free-flowing culverts and four bridge alternatives) under two models (the 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model) on many parameters including North and South Arm salinities and salt loads; total causeway flows between the two arms; the ratio of south-to-north and north-to-south flows; and the ratio of the average TDS concentration in the North Arm to that in the South Arm. The modeling showed how the four bridge alternatives would affect the salinity and salt loads in the North and South Arms under conditions of historic variability (2012 UPRR/USGS Model) and during wet, mild, and dry hydrologic cycles (2012 UPRR/USGS Varying Hydrology Model).

UPRR assigned points ranging from 1 to 4 to each alternative and for each scenario studied to determine a final ranking. Within each scenario, the alternative that best matched the culvert simulation received 1 point, and the alternative with the fourth-best match received 4 points. Overall, the fewer points an alternative received, the better it matched the culvert simulation. Table 2-2 below summarizes the results of the modeling effort.

Table 2-2. Rankings of Bridge Alternatives Evaluated by the UPRR/USGS Models

Model	180-Foot-Long Bridge, 4,178 Feet (Alt. A)	150-Foot-Long Bridge, 4,178 Feet (Alt. B)	150-Foot-Long Bridge, 4,183 Feet (Alt. C)	150-Foot-Long Bridge, 4,188 Feet (Alt. D)
2012 UPRR/USGS Model (historic variability for the period 1987–2012)	4th-best match *4 points*	3rd-best match *3 points*	2nd-best match *2 points*	Best match *1 point*
2012 UPRR/USGS Varying Hydrology Model, wet cycle (4.1 MAF/year of inflow, resulting in a WSE of 4,209 feet)	4th-best match *4 points*	3rd-best match *3 points*	2nd-best match *2 points*	Best match *1 point*
2012 UPRR/USGS Varying Hydrology Model, mild cycle (2.6 MAF/year of inflow, resulting in a WSE of 4,200 feet)	4th-best match *4 points*	3rd-best match *3 points*	Best match *1 point*	2nd-best match *2 points*
2012 UPRR/USGS Varying Hydrology Model, dry cycle (1.7 MAF/year of inflow, resulting in a WSE of 4,195 feet)	3rd-best match *3 points*	Best match *1 point*	2nd-best match *2 points*	4th-best match *4 points*
Total points (lowest points represent best match)	**15**	**10**	**7**	**8**
Overall rank	**4**	**3**	**1**	**2**

MAF = million acre-feet
WSE = water surface elevation of the South Arm

Based on the analysis described in the *Bridge Evaluation Report* and summarized above in Table 2-2, UPRR has determined that the results of the simulation of the 150-foot-long bridge with an invert at 4,183 feet (Alternative C) most closely match the results of the culvert simulation most of the time. A summary comparison of the modeling results for all alternatives for specific parameters is presented in Appendix A of the *Bridge Evaluation Report* (UPRR 2014b). Therefore, UPRR adjusted its compensatory mitigation bridge proposal to be consistent with Alternative C.

Screening of Bridge Alternatives

USACE also considers several issues when evaluating project alternatives.

- Is an alternative site available?
- Does the alternative meet the USACE overall project purpose?
- Is the alternative practicable in terms of cost? Costs may be higher for alternatives, but not so much higher as to be unreasonable. Costs are qualitatively compared to norms for similar types of projects.
- Is the alternative practicable in terms of logistics?
- Is the alternative practicable in terms of existing technology?
- Does the alternative involve impacts to waters of the U.S. that are substantially greater than those of the applicant's proposed project?
- Does the alternative involve impacts to special aquatic sites?

The analysis in this report considers USACE's overall project purpose to be fulfilling its responsibilities to respond to UPRR's permit application and ensuring that the project meets all applicable requirements, including meeting all of the permit approval criteria discussed in the public notice for the project to ensure that the project meets the established mitigation objective described in Section 1.2, Project Background, and results in less-than-minimal effects. USACE has not stated additional project purposes beyond fulfilling these responsibilities.

Because the compensatory mitigation bridge is a critical element of the overall project, UPRR considered the criteria listed above when screening the four bridge alternatives. Table 2-3 below summarizes the results of screening the bridge alternatives.

Table 2-3. Screening Results for the Four Bridge Alternatives

Criterion	Screening Result
Project purpose: maintain a safe rail transportation corridor across the causeway	All alternatives meet this criterion.
Is an alternative site available?	No. The bridge location is sited to meet the following conditions: provide water and salt transfer between the North and South Arms, be located in a deeper part of the lake, and be in a location that is geotechnically stable.
Is the alternative practicable in terms of logistics?	Yes. All alternatives would require construction of a temporary shoofly, which would prevent the need to address logistical challenges associated with redirecting rail traffic during construction.
Is the alternative practicable in terms of existing technology?	Yes.
Would the alternative involve impacts to waters of the U.S. that are substantially greater than those of the project as proposed (which is Alternative C)?	Potentially yes. Potential impacts to waters of the U.S. would be similar for all alternatives in terms of the effects of placing the fill material itself. However, it is not clear that the alternatives would have similar effects in terms of aquatic functions. Alternative C most closely meets the mitigation objective of duplicating the aquatic functions of the culverts and resulting in less-than-minimal effects on aquatic resources. The risk of impacts to such aquatic resources is greater for each of the other bridge alternatives. UPRR has chosen Alternative C to minimize the risk that greater impacts could result.
Would the alternative involve impacts to special aquatic sites?	Yes. All alternatives would be located in the Great Salt Lake, which is considered a special aquatic site.
Are there other environmental or social considerations?	• **Alternative A:** Overall, would be the poorest match to the historic pre-project water and salt transfer conditions. • **Alternative B:** Best match for dry-cycle conditions but poor match for other conditions (historic variability, wet cycle, and mild cycle). • **Alternative C:** Overall, would best match the historic pre-project water and salt transfer conditions. • **Alternative D:** Would match the historic pre-project water and salt transfer conditions, but not as well as Alternative C would (poorest dry-cycle match).

The screening results show that any of the bridge alternatives could meet UPRR's purpose and need, would be logistically and technologically feasible, and would have similar impacts on waters of the U.S. and special aquatic sites, although the risk of failing to meet the compensatory mitigation is higher for each of the other alternatives. The resource impacts analyses described in this report consider all four bridge alternatives.

2.3 Summary of Additional Bridge Alternatives

Based on the information presented in this chapter and in the *Bridge Evaluation Report* (UPRR 2014b), the remainder of this report evaluates the following bridge alternatives:

- **Proposed action:** USACE authorizes permanently closing the east culvert, and UPRR constructs a temporary shoofly and builds a 150-foot-long bridge (Bridge Alternative C) at invert elevation 4,183 feet as compensatory mitigation
- **Alternative A:** USACE authorizes permanently closing the east culvert, and UPRR constructs a temporary shoofly and builds a 180-foot-long bridge at invert elevation 4,178 feet as compensatory mitigation
- **Alternative B:** USACE authorizes permanently closing the east culvert, and UPRR constructs a temporary shoofly and builds a 150-foot-long bridge at invert elevation 4,183 feet as compensatory mitigation
- **Alternative D:** USACE authorizes permanently closing the east culvert, and UPRR constructs a temporary shoofly and builds a 150-foot-long bridge at invert elevation 4,188 feet as compensatory mitigation
- **No action:** USACE does not issue a Department of the Army permit, the east culvert remains closed, and UPRR constructs a temporary shoofly and builds a bridge (size to be determined) as compensatory mitigation

3 Water Chemistry

This chapter describes the existing conditions of the water chemistry of the Great Salt Lake and the potential effects of the proposed project. Other lake water characteristics are water quality, which is discussed in Chapter 4, Water Quality; the deep brine layer, which is discussed in Chapter 5, Deep Brine Layer; and mercury and methyl mercury, which are discussed in Chapter 6, Mercury and Methyl Mercury.

For this evaluation, discussions about water chemistry cover the lake's salinity and minerals. Specifically, the water chemistry parameters addressed in this category are salinity (the saltiness of water or the quantity of dissolved solids in water) and the major ions (sodium, chloride, magnesium, sulfate, potassium, and calcium). The sum of these major ions makes up most of the total dissolved solids (TDS) concentration when the Great Salt Lake's water is dried and weighed. Lake waters analyzed for TDS concentrations can also be represented and reported as percent salinity. Water density also provides insight into the water chemistry of a hypersaline lake.

3.1 Affected Environment

This section reviews the methods used to describe the affected environment (also known as existing conditions), provides a general description of the Great Salt Lake's water chemistry, summarizes the water chemistry conditions of the Great Salt Lake as measured by the Utah Geological Survey (UGS) and other published water chemistry data about the lake, and describes USGS's historical water and salt balance model.

3.1.1 Methodology

UPRR evaluated the existing conditions of the lake's TDS concentration, water density, and salinity in three steps.

1. UPRR reviewed existing information that describes the lake's water chemistry.
2. UPRR reviewed recent lake water chemistry monitoring and analysis for both the North and South Arms by conducting vertical water column and spatial analyses. The analysis of the South Arm is focused on Gilbert Bay, since the project lies between Gilbert Bay in the South Arm and Gunnison Bay (the North Arm).
3. UPRR reviewed the baseline case of the water and salt balance model developed by USGS and modified by UPRR, as described in Section 1.3.1, Summary of the Water and Salt Balance Modeling.

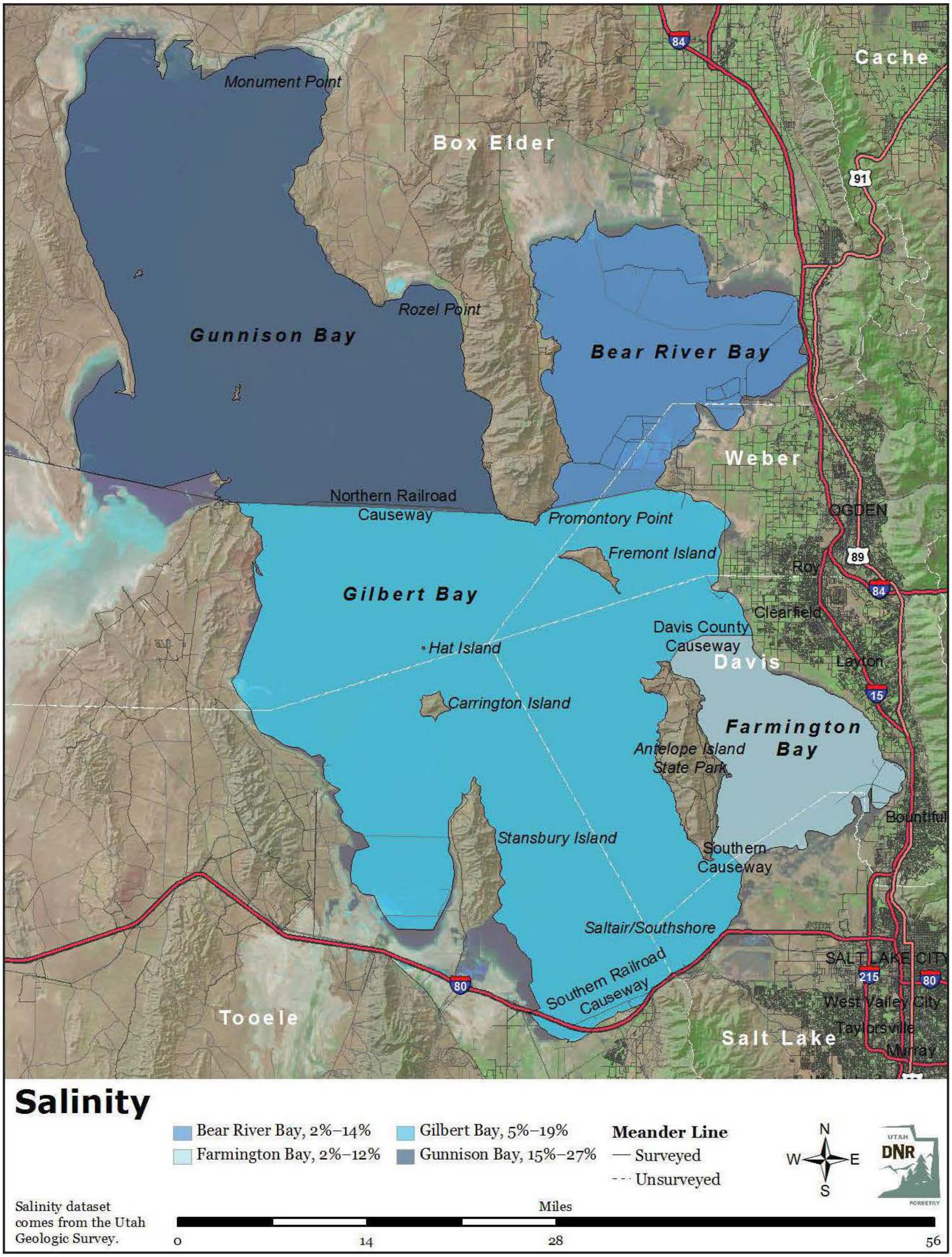
3.1.2 General Description of the Great Salt Lake's Water Chemistry

The Great Salt Lake is a saline terminal lake that is characterized by natural fluctuations in WSE and resulting varying salinity ranges (UDFFSL 2013). The 2012 Great Salt Lake Comprehensive Management Plan has characterized the salinity ranges in the various parts of the lake as shown in Figure 3-1 below. Changes in the lake's salinity depend on decadal, annual, and seasonal variations of inflows (from surface water, precipitation, and groundwater) and outflows (from evaporation). Thus, as the lake receives more inflow and the lake's volume increases, salinity decreases.

What is a terminal lake?

A terminal lake is a lake that has no outflow to other external bodies of water such as rivers or oceans.

Figure 3-1. Salinity Ranges for Great Salt Lake Bays, 1982–2010



Source: UDFFSL 2013

The WSEs and salinities of Gunnison and Gilbert Bays are also influenced by flows through the causeway in addition to inflows and outflows to and from each bay. The rock-fill UPRR causeway crosses the lake and forms two partially connected bodies of water: the North Arm (Gunnison Bay) and the South Arm (Bear River, Farmington and Gilbert Bays). Water in the South Arm is less saline than water in the North Arm because all three of the lake's major tributaries (the Bear, Weber, and Jordan Rivers) flow into the South Arm (specifically into Bear River Bay, Gilbert Bay, and Farmington Bay, respectively). The three bays of the South Arm are separated by causeways and natural topographic features and have differing salinity ranges (Figure 3-1 above).

Water and salt transfer through the causeway between the North and South Arm as follows: the denser (more saline) North Arm water flows south through the causeway along the lake bed, while the less dense (less saline) South Arm water flows north through the causeway near the surface. This stratification of lake water flow through the causeway is called bidirectional flow, since the exchange of water through the causeway can occur in both directions based on chemical and hydrodynamic principles.

The salinities of the two arms of the lake are influenced primarily by factors such as the hydraulic conductivity of the causeway fill, the size and depth of openings in the causeway, the relative WSEs of the two arms of the lake, and time (UGS 2002). These factors can be generally combined into two primary elements: WSE (which is also dependent on the inflows to the lake) and the flow between the two arms.

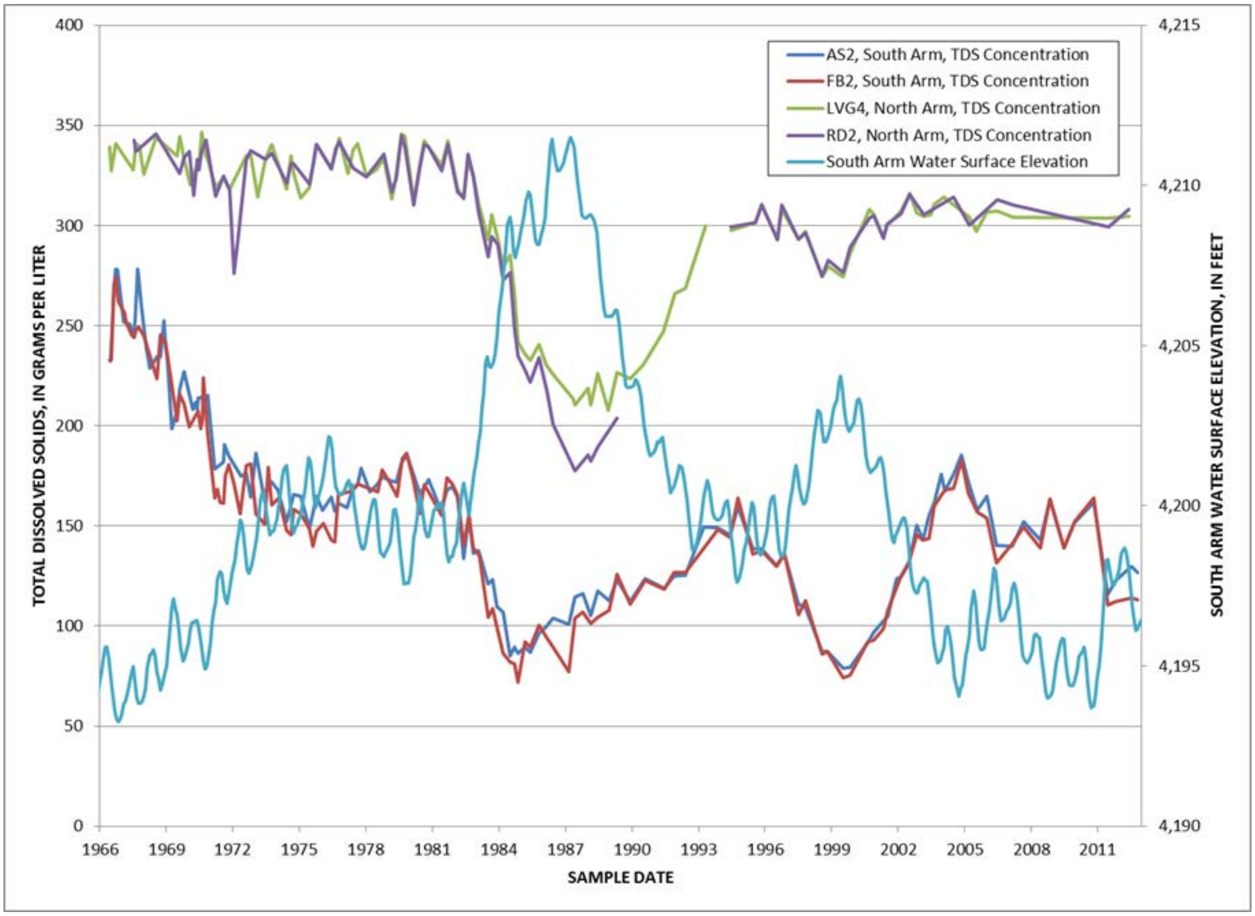
What is hydraulic conductivity?

Hydraulic conductivity is the measure of a material's capacity to transmit water. In this chapter, it refers to how much water can flow through the causeway rock fill between Gunnison and Gilbert Bays.

As WSE decreases due to evaporation and less lake inflow, the concentration of ions in the water increases. Figure 3-2 below shows the correlation between WSE, as measured by USGS at the Saltair water level gage (which is about 40 miles southeast of the causeway in the South Arm) and measured TDS concentrations at four UGS sampling locations (South Arm locations AS2 and FB2 and North Arm locations LVG4 and RD2 in Figure 3-3 on page 26). UGS has been sampling lake ion and TDS concentrations at these locations since 1966.

Figure 3-2 clearly shows that, as WSE increases, TDS concentrations decrease at all four sample locations. Figure 3-2 also shows the variability in WSE and TDS concentrations for the past 26 years. Over this period, human and natural modifications were made to the causeway, including the construction of and subsequent modifications to a 300-foot-long bridge (breach), the raising of the causeway during the 1980s, and the subsidence of the east and west culverts over time.

Figure 3-2. TDS Concentrations and WSEs in the North and South Arms



> **What are QS and QN?**
>
> QS describes the total south-to-north flow through the causeway.
> QN describes the total north-to-south flow through the causeway.

Based on the causeway's characteristics, water is transferred in both directions, with South Arm water flowing north and North Arm water flowing south. This bidirectional flow through the causeway, and ultimately the ratio of south-to-north causeway flow (QS) to north-to-south causeway flow (QN), drives the salt transfer between the North and South Arms and influences the arms' salinities.

USGS has documented the relationship between the ratio of QS/QN to the ratio of the TDS concentration in the North Arm to that in the South Arm (USGS 2000). A decrease in the ratio of QS to QN favors net movement of salts to the South Arm, and an increase in the ratio favors net movement of salt to the North Arm (USGS 2000). Greater water density differences and WSE differences between the two arms also force an increase in flow through the causeway fill and openings for a given WSE.

As the ratio of QS to QN increases, more salt is transferred from the South Arm to the North Arm. Conversely, as the ratio of QS to QN decreases, more salt is transferred from the North Arm to the South Arm. The ratios are influenced by WSE, salinity gradients, and the geometries of the causeway openings. USGS and the Utah Division of Water Resources have used these relationships to design and subsequently modify the geometry of the existing 300-foot-long bridge in the causeway.

3.1.3 UGS Lake Sampling Data

UPRR found two sources of water chemistry data: UGS and UDWQ. UGS has historically collected and continues to collect water chemistry samples in both the South and North Arms, and analyses of these samples are reported in the *Great Salt Lake Brine Chemistry Database, 1966–2011* (UGS 2012). UGS measures temperature and WSE, measures the salinity and density of the water, and analyzes chemicals at different depths in the water column.

UDWQ began measuring chemical constituents in the South Arm at different locations than UGS in 2011; however, UDWQ reports concentrations for metals and nutrients (UDWQ 2013b). As part of UDWQ's baseline sampling program, field instruments are used to report conductivity, from which TDS concentrations are calculated. Due to the different measurement techniques and sampling locations and the short period of data collection (2 years), the UDWQ data were not used for the water chemistry analysis.

The following parameters have been analyzed and reported by UGS: water density, sodium, magnesium, potassium, calcium, chlorine, sulfate (SO_4), bromine, lithium, boron, and TDS concentration. A weight percentage of TDS concentration is also calculated and reported as salinity.

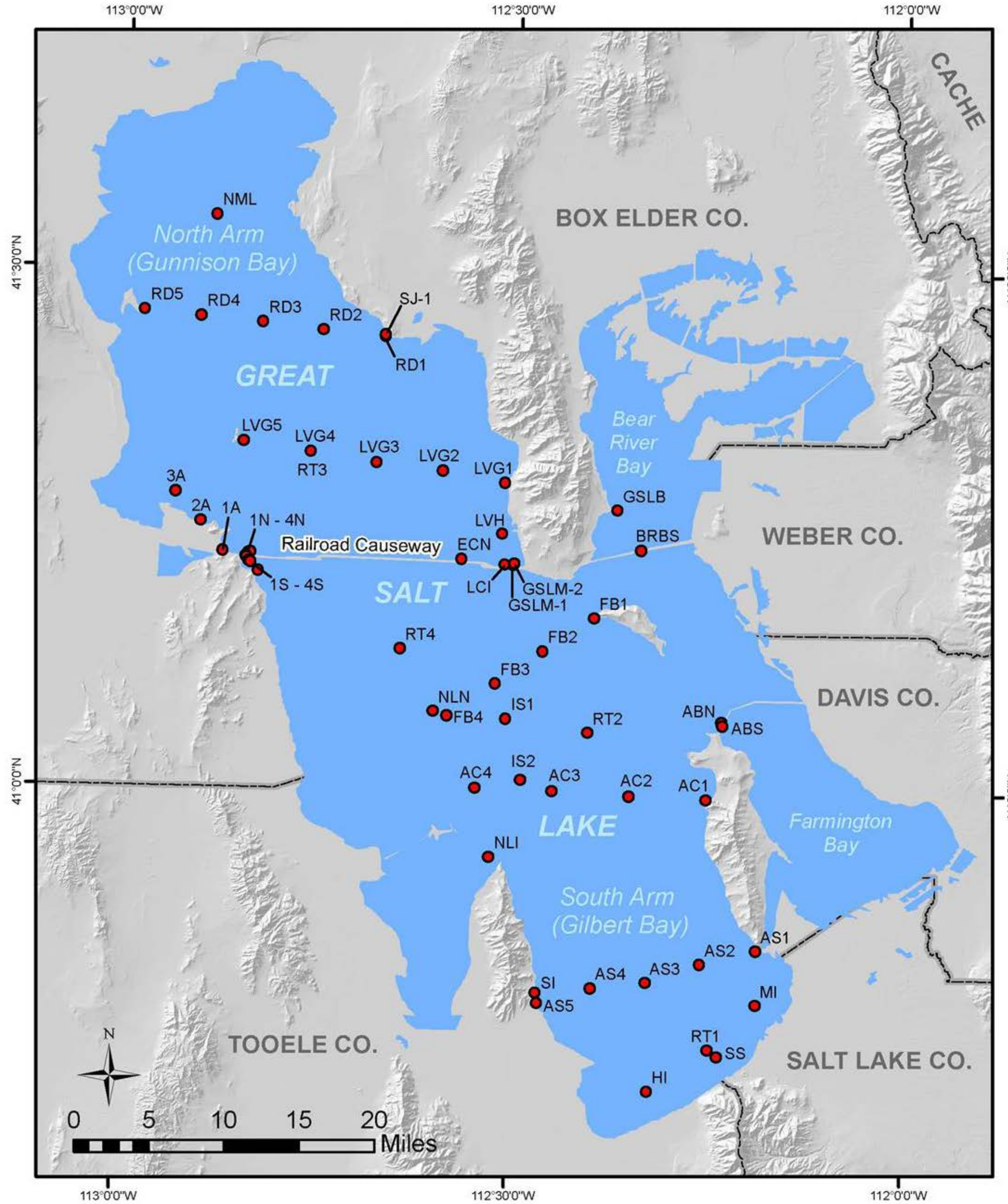
Figure 3-3 below shows all the locations on the Great Salt Lake at which UGS has sampled. Not all of the analyses are performed for all sampling locations. According to UGS, numerous locations were sampled early in the sampling program, but data indicated that fewer sampling locations were sufficient to characterize the lake (UGS 2012). Currently, only a few of the following four locations are sampled during each sampling event: LVG4 and RD2 in the North Arm and AS2 and FB2 in the South Arm (Figure 3-3 below). Nevertheless, a fairly continuous record of chemical analyses for these four locations is available from 1966 through 2011 (UGS 2012).

UGS conducts sampling events as funding allows, but typically biannually. All four sampling locations referenced above—AS2, FB2, LVG4, and RD2—report water densities, TDS concentrations, and salinity typically at every 5 feet throughout the water column. Table 3-1 shows the name, area, lake bed elevation, and period of record for each of these sampling locations. Figure 3-4 following Figure 3-3 below provides a magnified perspective of the four sampling locations used for this analysis.

Table 3-1. UGS Sampling Locations for Data Evaluation

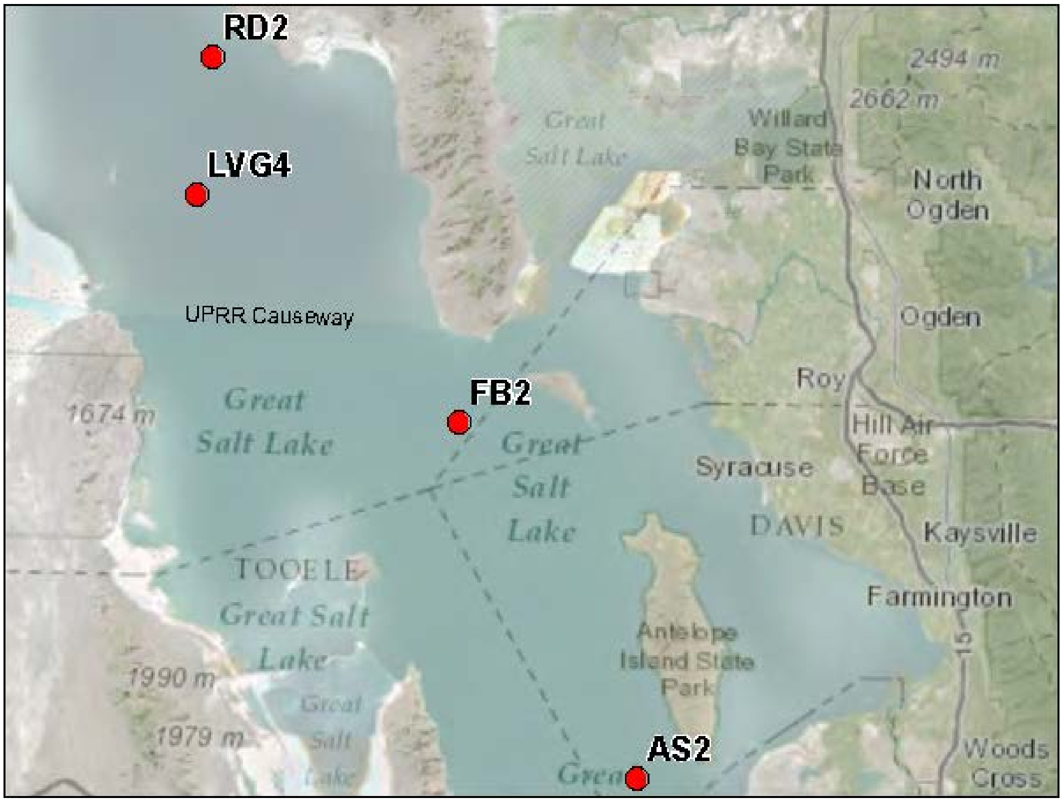
Name	Area	Lake Bed Elevation (feet)	Period of Record
AS2	South Arm	4,169	1966–2012
FB2	South Arm	4,171	1966–2012
LVG4	North Arm	4,173	1966–2007, 2011–2012
RD2	North Arm	4,176	1967–2007, 2011–2012

Figure 3-3. Historic and Current UGS Water Chemistry Sampling Locations



Source: UGS 2012

Figure 3-4. UGS Sampling Locations Used for Water Chemistry Evaluations



Source: UGS 2012

Vertical Water Column Evaluation

For this analysis, UPRR used the UGS data from 2000–2012. These data are the most current and reflective of recent conditions of both the North and South Arms. In addition, when these data were obtained, (1) the WSEs were similar to what they were in November 2012 before the west culvert was closed and (2) both culverts were free flowing from 2004 to 2012. Also, the last modification to the existing 300-foot-long bridge was made in 2000, so the effects on the lake's water chemistry from the flow through the 300-foot-long bridge are similar through this period.

North Arm

Water chemistry data for the North Arm have been collected since 1966 (Table 3-1 above; UGS 2012). With respect to 2000–2012, the data set is fairly complete. North Arm sampling locations LVG4 and RD2 lack data from 2008 to 2010 due to restricted access to these locations. However, the amount of information available provides a sufficient sample to review the water chemistry in this arm. Water column samples for the North Arm were collected and analyzed at 5-foot vertical increments throughout the water column (from the lake bed to the water surface). UPRR plotted TDS concentrations for each location against the sample's elevation in the water column to create a TDS concentration profile graph that shows the vertical variability of TDS concentrations within the water column.

During the period 2000–2012, the North Arm WSE ranged from about 4,203 feet to just under 4,195 feet, with the TDS concentration ranging from about 290 grams per liter (g/L) to just under 320 g/L for both North Arm sampling locations. Figure 3-5 and Figure 3-6 below show the TDS concentration profile graphs for North Arm sampling locations LVG4 and RD2. Most profiles show very little variation from the surface to the bottom of the water column, although the top of the water column is slightly less dense.

However, there was considerable variation in the concentration profile as shown in the July 2011 and June 2012 profiles. This variation is probably a result of the unusually high inflows to the lake during spring runoff in 2011. These two sampling events show that the profiles varied from about 290g/L at the surface to about 317 to 325 g/L at the bottom. When the TDS concentration of the water approaches 355 g/L it is considered at saturation, depending on water temperature (USGS 1973). At saturation, salt will precipitate out and collect on the bottom of the lake.

Figure 3-5. North Arm TDS Concentration Profile for UGS Sampling Location LVG4

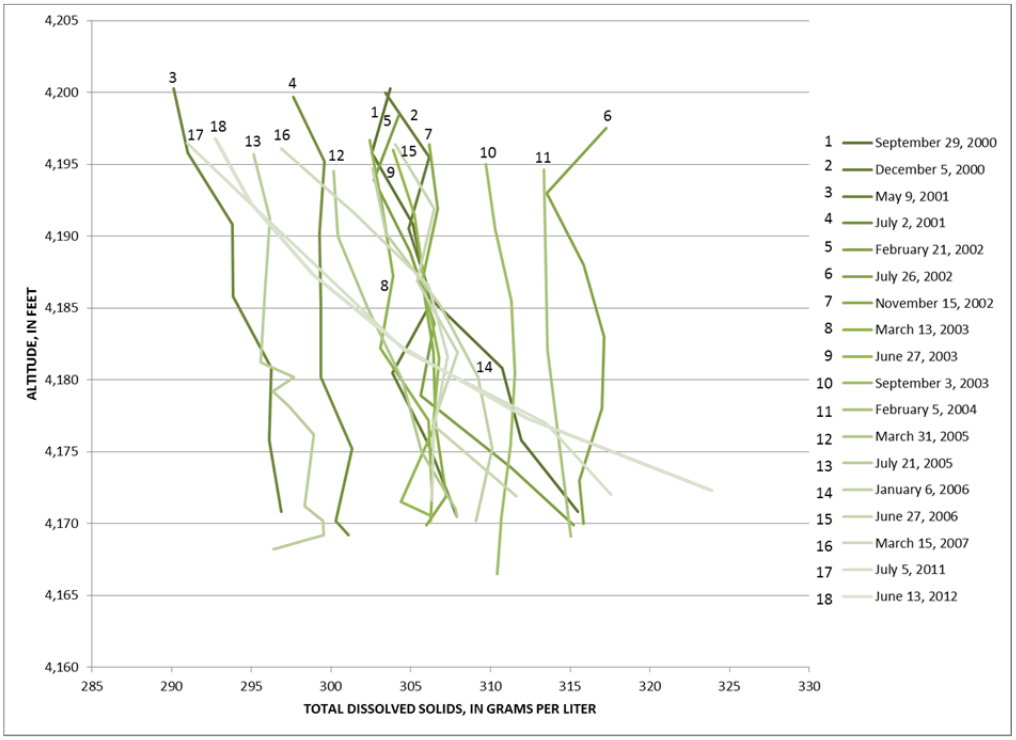
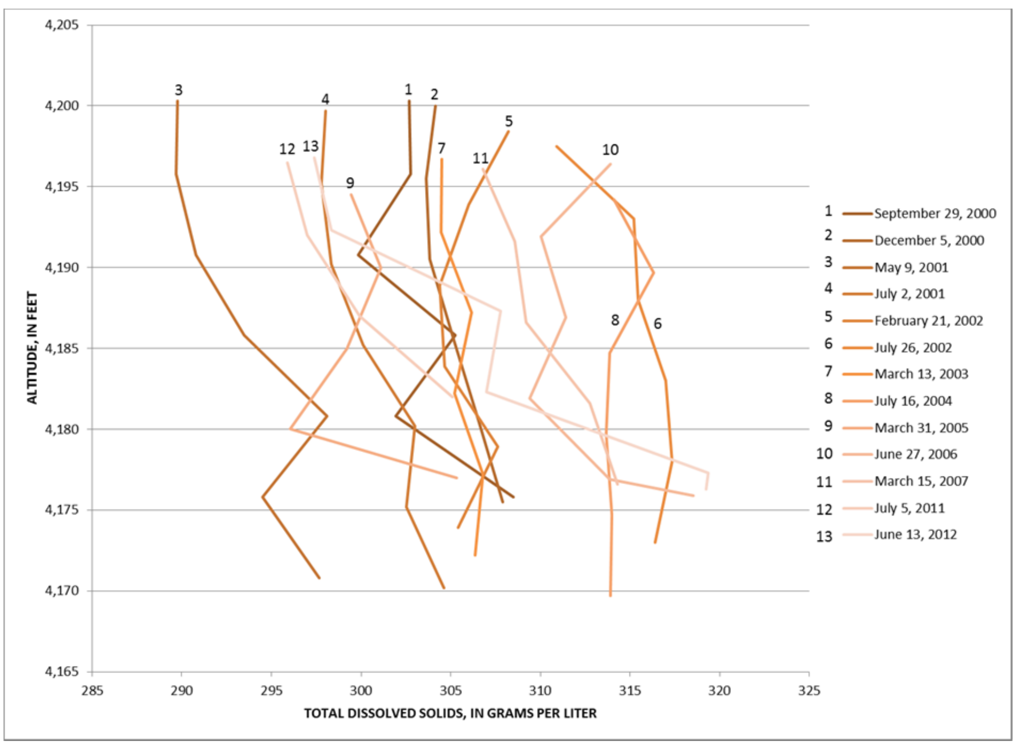


Figure 3-6. North Arm TDS Concentration Profile for UGS Sampling Location RD2



South Arm

Water chemistry data for the South Arm have been collected since 1966 (Table 3-1 above; UGS 2012). With respect to 2000–2012, the data set is complete. UPRR created TDS concentration profile graphs for two sampling locations in the South Arm (specifically, Gilbert Bay). UPRR's evaluation of the TDS concentration profile shows the variable presence of a halocline. TDS concentrations are uniform for most of the upper part of the water column, but, for some sampling events, TDS concentrations in the lower part of the water column increased dramatically.

> **What is a halocline?**
>
> A halocline is a relatively sharp discontinuity in salinity at a particular depth. Water that is more saline sinks below water that is less saline; therefore, the water salinity below the halocline is much higher than the water salinity above the halocline.

During the period 2000–2012, the South Arm WSE ranged from about 4,204 feet to just under 4,195 feet, and the TDS concentration in the upper brine layer ranged from 90 g/L to almost 190 g/L for both South Arm sampling locations.

Figure 3-7 and Figure 3-8 below show the TDS concentration profile graphs for UGS South Arm sampling locations AS2 and FB2. As the figures show, as the WSE dropped, salinity in the lake increased during the sample period. The UGS data also show that the halocline (presence of the deep brine layer) at location FB2, which is closer to the causeway than is location AS2, was not continuously present for the period 2000–2010.

Figure 3-7. South Arm TDS Concentration Profile for UGS Sampling Location AS2

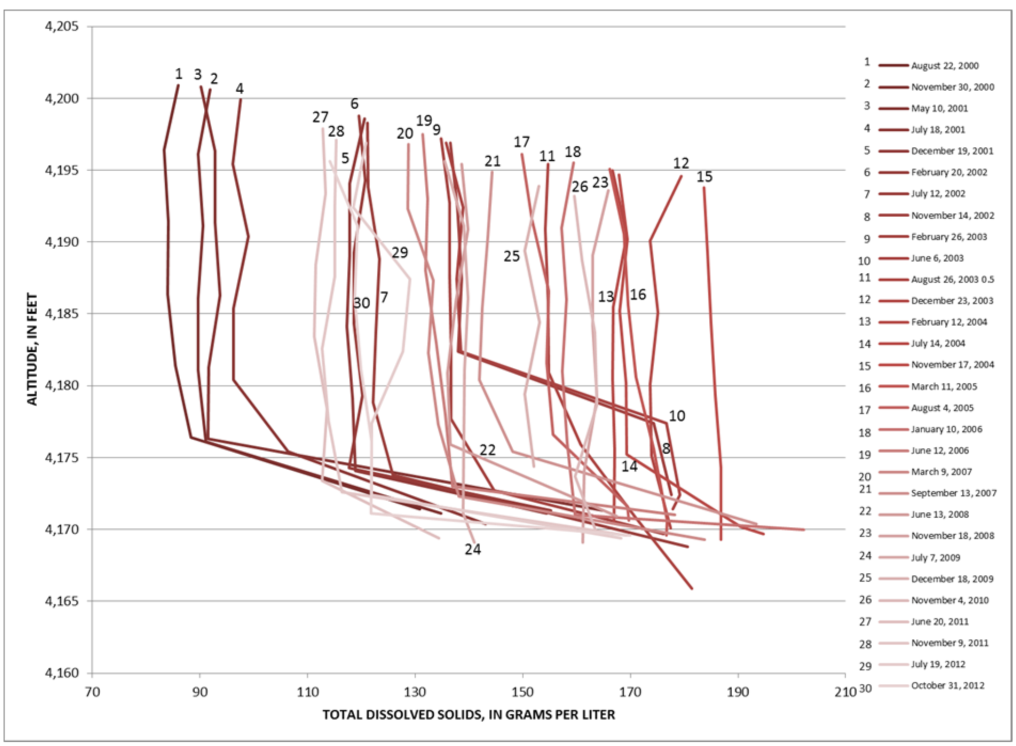
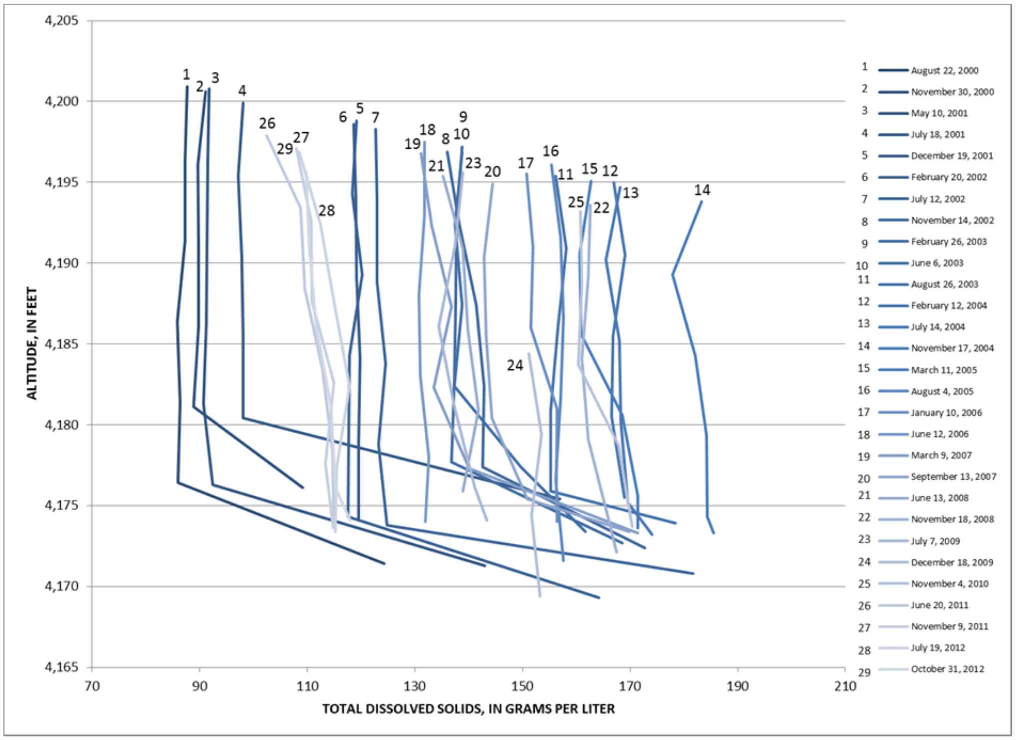


Figure 3-8. South Arm TDS Concentration Profile for UGS Sampling Location FB2



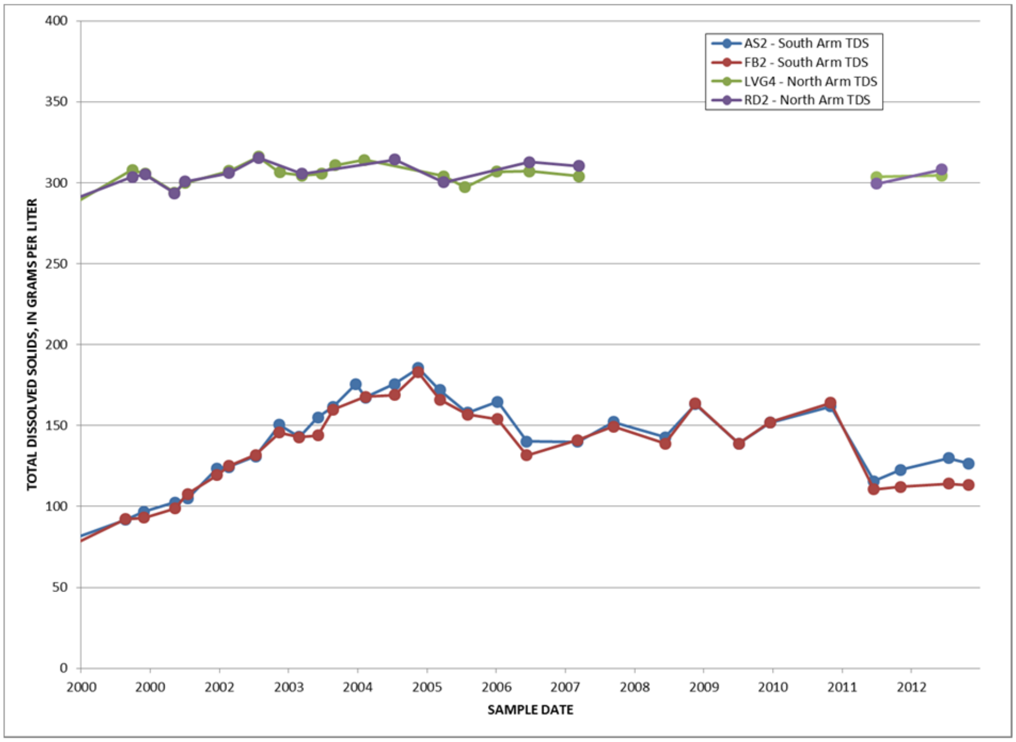
The factors that affect the presence of the halocline include the amount of north-to-south flow through the causeway and the mixing of the deep brine layer with the upper brine layer. From 2000–2010, the amount of more-saline north-to-south flow through the causeway might have been reduced due to the low WSE, the invert (bottom) elevation of the causeway openings relative to the WSE, the culvert inverts (bottoms of the culverts), and limited culvert flow capacity prior to 2004.

Although these factors appear to affect the flow of the denser water to the South Arm, once the deep brine layer is present, it mixes with the upper brine layer, and neither the rate of diffusion (mixing rate) nor the factors that affect the rate of diffusion are understood. Nevertheless, the deep brine layer is considered to be a source of TDS to the upper water column. A more detailed discussion of the deep brine layer is presented in Chapter 5, Deep Brine Layer.

Spatial Water Chemistry Evaluation

To determine whether the water chemistry in the lake varies spatially, UPRR compared average TDS concentrations at sampling locations LVG4 and RD2 for the North Arm and AS2 and FB2 for the South Arm. Figure 3-9 below compares the laboratory density from 2000 through 2012 for these locations. Water samples at these locations were taken at 5-foot intervals within the water column from the lake surface to the lake bed.

Figure 3-9. TDS Concentrations for UGS Sampling Locations AS2, FB2, LVG4, and RD2



The water chemistry samples from both locations in Gilbert Bay (South Arm) appear to vary over the years but have similar average TDS concentration, with less than 15.6 g/L of difference between the two locations. UPRR also performed a regression analysis of the 29 overlapping sample dates between 2000 and 2012, and the results show a high correlation with a regression coefficient between the two South Arm locations of 0.98. These results also show that the TDS concentration varied little between the sampling locations over the sample period, which indicates that TDS concentrations in areas of Gilbert Bay vary over time based on inflow, but at any specific point in time they are spatially well mixed.

Water chemistry samples from the North Arm for both locations also appear to have about the same average TDS concentration, varying less than 6.24 g/L between locations. UPRR also performed a regression analysis of the 12 overlapping sample dates between 2000 and 2012, and the results show a high correlation with a regression coefficient between the two locations of 0.81. These results also show that the TDS concentration varied little between the sampling locations over the sample period, which indicates that TDS concentrations in areas of the North Arm vary over time based on inflow, but at any specific point in time they are spatially well mixed.

Summary

During the period 2000–2012, the North Arm WSE ranged from 4,200 feet to just under 4,195 feet, and TDS concentrations ranged from about 290 g/L to almost 320 g/L for both locations (Figure 3-5, Figure 3-6, and Figure 3-9 above). The TDS data show that, for the past 10 years, the North Arm has been generally vertically mixed and was not stratified. The TDS concentrations in areas of the North Arm varied over time based on inflow, but, at any specific time, they were spatially well mixed. This is consistent with previous studies of the North Arm during different periods (UGS 2002; Wurtsbaugh and Jones 2012).

Similarly, during the period 2000–2012, the South Arm WSE ranged from 4,200 feet to just under 4,195 feet, the TDS concentration in the deep brine layer ranged from 90 g/L to almost 190 g/L, and the TDS concentration in the upper brine layer, when present, ranged from 90 g/L to almost 140 g/L. Higher TDS concentrations are observed at lower WSEs and, as in the North Arm, concentrations in the deep brine layer and the upper brine layer were consistent within each other. The TDS concentrations in areas of Gilbert Bay varied over time based on inflow, but, at any specific time, they were spatially well mixed.

3.1.4 Water and Salt Balance Model Results

UPRR conducted water and salt balance modeling to evaluate the effects of replacing the culverts with a bridge. As part of the modeling effort, simulations were prepared to determine the baseline conditions in the North and South Arms when the east and west culverts were free flowing (unobstructed) and as they existed in November 2102 before the west culvert was closed.

The results of the culvert simulations (baseline) as compared to the results for the bridge alternatives are presented in detail in the *Bridge Evaluation Report* (UPRR 2014b) and the *Final Water and Salt Balance Modeling Report* (UPRR 2014a) and are summarized below.

In the *Bridge Evaluation Report*, UPRR presented the North and South Arm salinity results from the culvert simulations compared to the bridge alternatives described in Chapter 2, Project Description and Additional Project Alternatives, for the following models:

- Calibrated 2012 UPRR/USGS Model run under historic hydrologic conditions for the period 1987–2012
- 2012 UPRR/USGS Varying Hydrology Model run under constant wet, mild, and dry conditions for 25 years

A more detailed discussion of the modeled lake effects from the 150-foot-long bridge at 4,183 feet and other alternatives is included in Section 1.3.2, Summary of the *Bridge Evaluation Report*. For the culvert simulations, water and salt transfer through the causeway was simulated based on the following causeway characteristics as they existed in November 2012 before the culverts were closed:

- East and west culvert invert elevations are set at their 2012 elevation of 4,173 feet.
- Culvert flows are calculated using Holley's equations and are represented as free flowing.
- Existing 300-foot-long bridge is in place at the previous breach, which is west of the culverts.

Causeway fill conductivity parameters remained consistent with the USGS Water and Salt Balance Model (USGS 2000).

Lake Salinity Conditions

Table 3-2 compares the South and North Arm salinities for the four bridge alternative simulations. For the 2012 UPRR/USGS model simulations, the WSE varies over the 26-year period used for the model as a result of causeway characteristics and varying inflow, with the South Arm gaining and losing salt over time. Figure 3-10 following the table illustrates the South Arm salinity over the 1987–2012 period for the 2012 UPRR/USGS Model simulations for each bridge alternative simulation compared to the culvert simulation.

What is salinity?

Salinity is the saltiness of water or the quantity of dissolved solids in water, which can be expressed as a percentage.

Table 3-2. 2012 UPRR/USGS Model – Salinity Comparison

Parameter	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C) a	150-foot-long bridge, 4,188 feet (Alt. D)
South Arm					
Average South Arm salinity, %	14.3	17.0	16.2	15.6	14.5
Ending South Arm salinity, % (2012)	12.3	18.1	16.2	14.4	11.9
Average South Arm TDS concentration, g/L	158	191	181	173	160
Ending South Arm TDS concentration, g/L (2012)	133	205	181	159	129
North Arm					
Average North Arm salinity, %	25.6	24.1	24.6	24.9	25.4
Ending North Arm salinity, % (2012)	28.4	28.1	28.1	28.1	28.2
Average North Arm TDS concentration, g/L	307	286	292	297	304
Ending North Arm TDS concentration, g/L (2012)	346	341	341	341	343

TDS = total dissolved solids, g/L = grams per liter

[a] Bridge Alternative C is part of the proposed action.

Figure 3-10. 2012 UPRR/USGS Model – South Arm Salinity Comparison

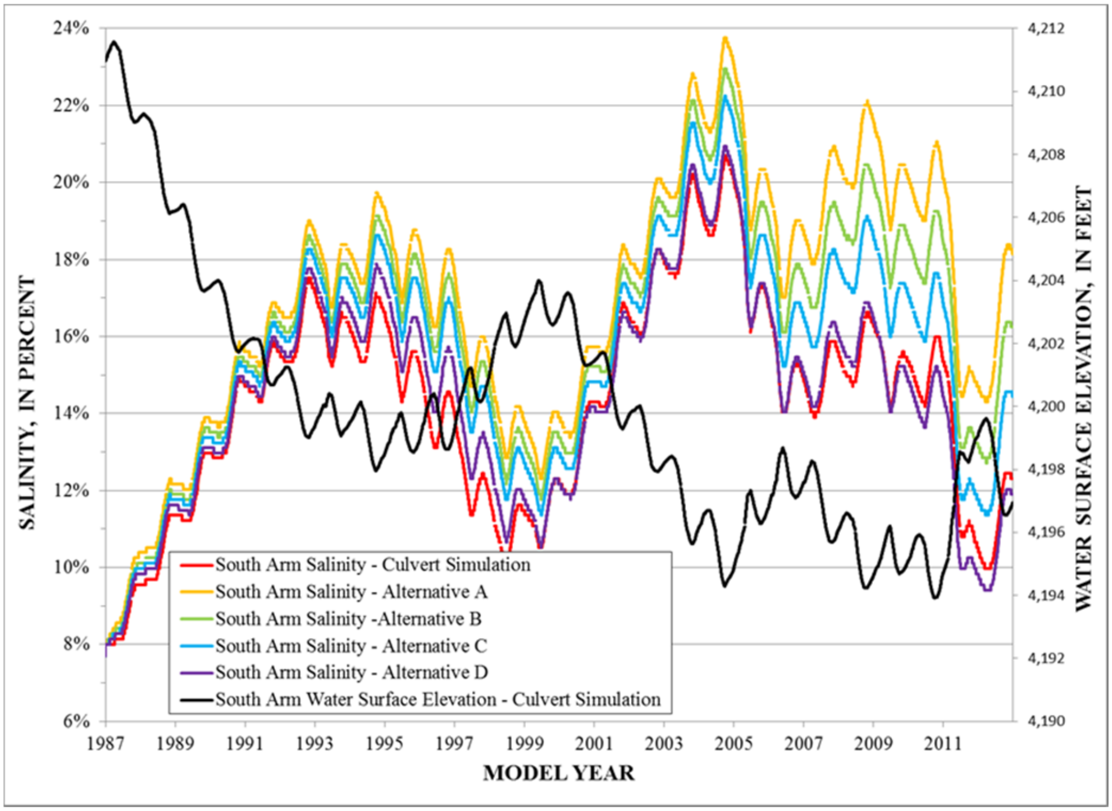
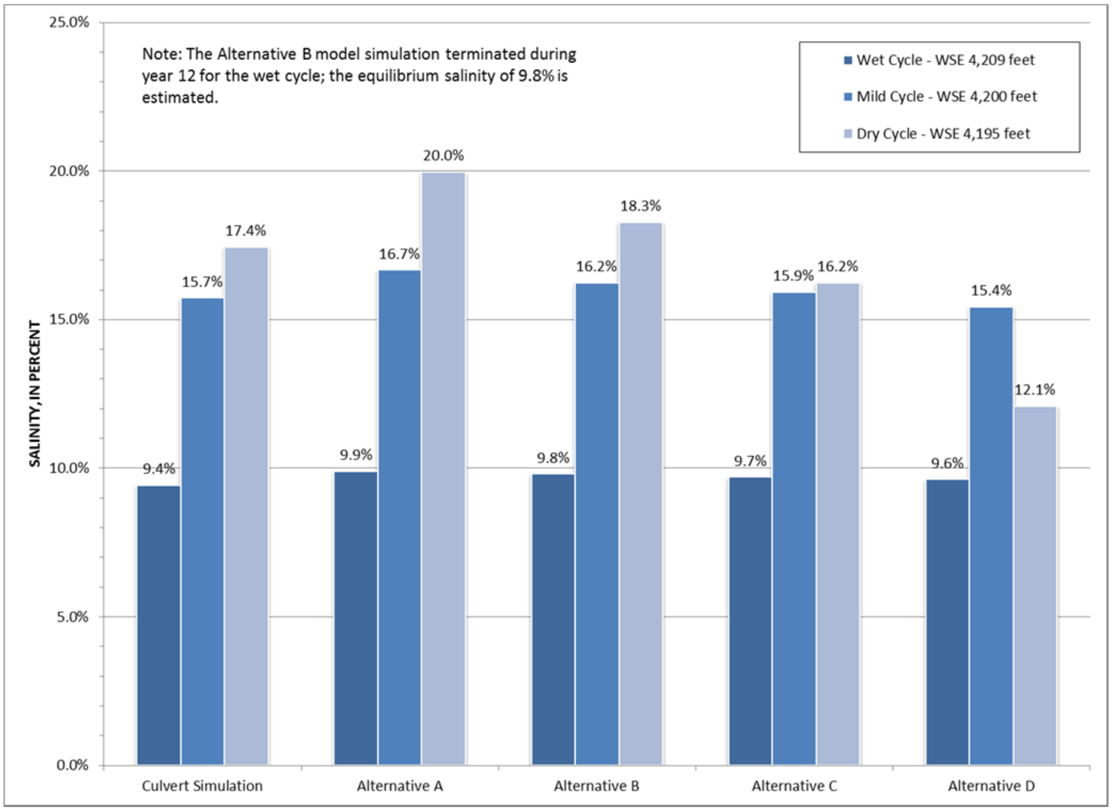


Figure 3-11 below shows summary South Arm salinity data (at equilibrium) for the wet, mild, and dry hydrologic cycles as projected with the 2012 UPRR/USGS Varying Hydrology Model. *Equilibrium* is defined as the point where minimal changes in lake elevation and salinity are occurring from year to year during the model simulation. Comparisons of other parameters (such as North Arm salinity) are provided in the *Bridge Evaluation Report* (UPRR 2014b).

Figure 3-11. 2012 UPRR/USGS Varying Hydrology Model – Average Annual South Arm Salinity Comparison at Equilibrium



Lake Salt Load Conditions

UPRR compared the North and South Arm salt loads for each model with the culvert and alternative bridge geometry simulations. Table 3-3 below shows summary comparison data for the 2012 UPRR/ USGS Model. For this model, the WSE varies over the 26-year period, with the South Arm gaining and losing salt. Figure 3-12 following the table illustrates the South Arm salt load over time for the 2012 UPRR/USGS Model simulations.

Table 3-4 following Figure 3-12 shows salt load summary data for the wet, mild, and dry hydrologic cycles run with the 2012 UPRR/USGS Varying Hydrology Model for the culvert simulation (baseline) and the alternative bridge geometries. These average salt loads are averaged over the last year of the 25-year model period. The WSEs at equilibrium are about 4,209 feet, 4,200 feet, and 4,195 feet for the wet, mild, and dry hydrologic cycles, respectively.

Table 3-3. 2012 UPRR/USGS Model – Salt Load Comparison

in billion tons

Parameter	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B)	150-foot-long bridge, 4,183 feet (Alt. C) [a]	150-foot-long bridge, 4,188 feet (Alt. D)
Average South Arm dissolved salt load	2.04	2.39	2.28	2.19	2.03
Ending South Arm dissolved salt load (2012)	1.40	2.15	1.88	1.65	1.31
Average North Arm dissolved and precipitated salt load	2.53	2.18	2.29	2.38	2.54
Ending North Arm dissolved and precipitated salt load (2012)	3.15	2.40	2.67	2.91	3.25

[a] Bridge Alternative C is part of the proposed action.

Figure 3-12. 2012 UPRR/USGS Model – South Arm Salt Load Comparison

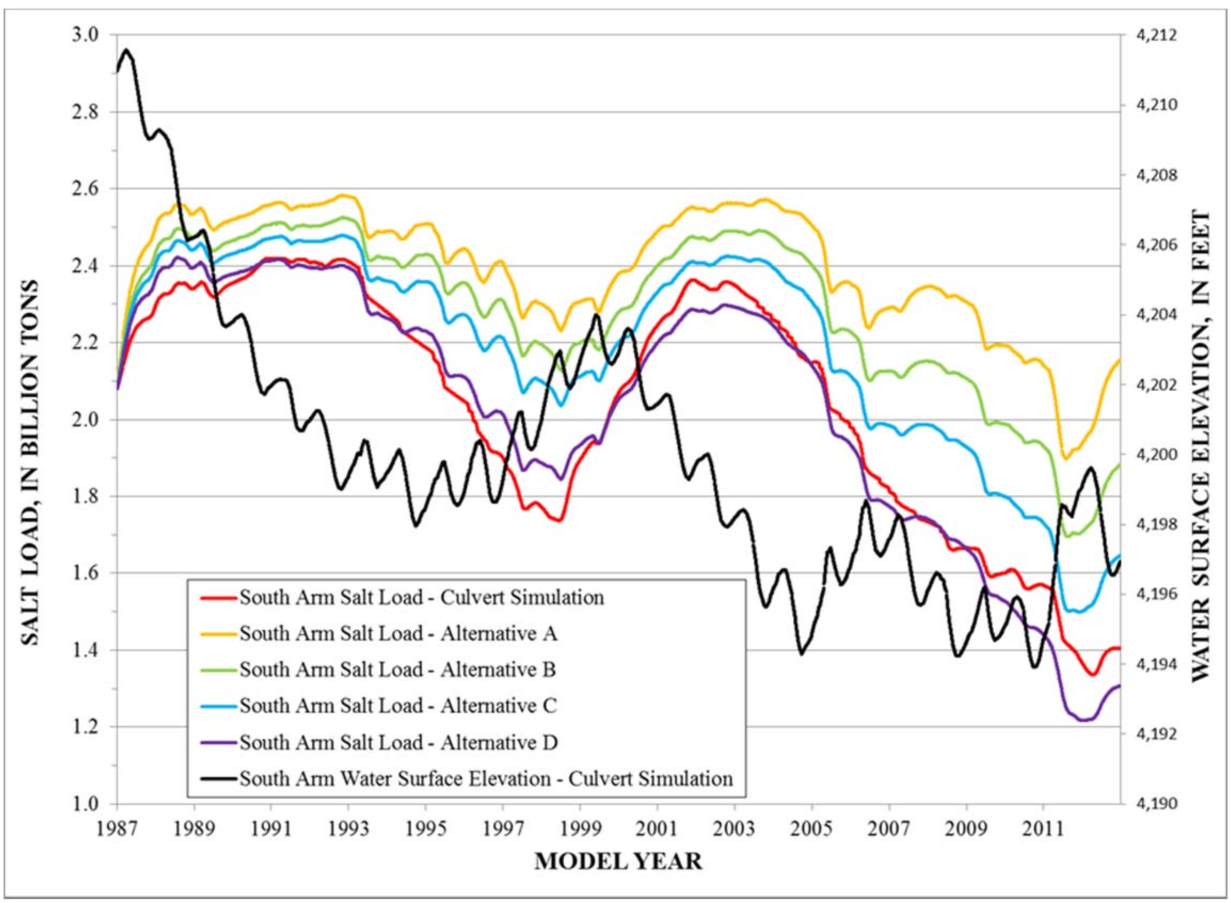


Table 3-4. 2012 UPRR/USGS Varying Hydrology Model – Salt Load Comparison at Equilibrium

in billion tons

Parameter [a]	Culverts	180-foot-long bridge, 4,178 feet (Alt. A)	150-foot-long bridge, 4,178 feet (Alt. B) [b]	150-foot-long bridge, 4,183 feet (Alt. C) [c]	150-foot-long bridge, 4,188 feet (Alt. D)
Wet Cycle, WSE elevation 4,209 feet					
Average South Arm dissolved salt load	2.33	2.45	2.43	2.40	2.38
Average North Arm dissolved and precipitated salt load	2.22	2.10	2.13	2.15	2.17
Mild Cycle, WSE elevation 4,200 feet					
Average South Arm dissolved salt load	2.32	2.47	2.40	2.35	2.26
Average North Arm dissolved and precipitated salt load	2.23	2.09	2.16	2.21	2.29
Dry Cycle, WSE elevation 4,195 feet					
Average South Arm dissolved salt load	1.85	2.18	1.94	1.68	1.18
Average North Arm dissolved and precipitated salt load	2.71	2.38	2.61	2.87	3.37

[a] Salt load is averaged over the last year of the simulation, when the model is at equilibrium.
[b] The Alternative B model was terminated during year 12 for the wet cycle. Salt loads for Alternative B are estimated.
[c] Bridge Alternative C is part of the proposed action.

3.2 Environmental Consequences

This section describes the potential effects of the project on the water chemistry in the North and South Arms.

3.2.1 Methodology

To evaluate the potential effects of the project on water chemistry in the North and South Arms, UPRR conducted water and salt balance modeling for the project with the proposed 150-foot-long bridge and the bridge alternatives (see Section 1.3.1, Summary of the Water and Salt Balance Modeling, and Section 1.3.2, Summary of the *Bridge Evaluation Report*). UPRR also reviewed existing qualitative and quantitative published studies discussing water chemistry to identify the key factors that affect water chemistry. For this analysis, *water chemistry effects* are defined as changes caused by the project in the water chemistry (represented by salinity and salt loads) of the North and South Arms of the Great Salt Lake that are outside the historic variability for these two parameters.

What are water chemistry effects?

Water chemistry effects are defined as changes caused by the project in the water chemistry (represented by salinity and salt loads) of the North and South Arms of the Great Salt Lake that are outside the historic variability for these two parameters.

The lake's beneficial uses have not been determined to be impaired by the historic variability of salinity and salt loads (UDWQ 2010, 2014c). Nevertheless, the project would have an adverse effect if it were to change the salinity and salt loads such that these parameters are not within their historic variability and those changes outside the historic variability were to impair the lake's beneficial uses.

3.2.2 Factors That Affect Water Chemistry in the Great Salt Lake

To determine which factors to consider for the impact analysis, UPRR reviewed studies that have commented or provided analytical data on the nature of water chemistry in the lake (Table 3-5). These studies, which include *Water and Salt Balance of Great Salt Lake, Utah, and Simulation of Water and Salt Movement through the Causeway, 1987–98* (USGS 2000), *Great Salt Lake: an Overview of Change* (UGS 2002), *Great Salt Lake Brine Chemistry Database, 1966–2011* (UGS 2012), and *The Great Salt Lake's Deep Brine Layer and Its Importance for Mercury Bioaccumulation in Brine Shrimp* (Artemia franciscana) (Wurtsbaugh and Jones 2012), present analytical data or discuss the vertical and spatial variability of the lake's water chemistry. Most of the studies concluded with the identification of factors that cause salinity and salt loads in the lake to vary.

Table 3-5. Factors That Affect Lake Water Chemistry

Source	Type of Study	Factors That Cause Variability in Water Chemistry/ Data Provided
USGS 2000	Qualitative and quantitative	Quantity of fresh water inflow or WSE, causeway conveyance properties, and mineral extraction
UGS 2002	Qualitative	Hydraulic conductivity, size and elevation of causeway openings
Wurtsbaugh and Jones 2012	Qualitative	Flows between arms

In summary, the most widely documented factors that affect water chemistry are surface inflows, WSEs and causeway properties, relative flow between arms, density gradient, head difference (South Arm WSE minus North Arm WSE), and mineral extraction. The impact analysis discussed in Section 3.2 focuses on causeway conveyance properties, the size and elevation of causeway openings, and the flows between arms because these are the only factors that could be affected by the proposed action and alternatives.

What is head difference?

The South Arm WSE is always higher than the North Arm WSE. Head difference, or hydraulic gradient, is the South Arm WSE minus the North Arm WSE.

The project would not affect how the lake rises and falls, which is due mostly to surface water inflow and evaporation. The lake's beneficial uses have not been determined to be impaired by the historic variability of salinity and salt loads.

3.2.3 Water and Salt Balance Model Simulations Process

UPRR conducted water and salt balance modeling using the model documented in Water-Resources Investigations Report 00-4221 (WRI 4221), *Water and Salt Balance of Great Salt Lake, Utah, and Simulation of Water and Salt Movement through the Causeway, 1987–98* (USGS 2000). As described in Section 1.3.1, Summary of the Water and Salt Balance Modeling, and Section 1.3.2, Summary of the *Bridge Evaluation Report*, model simulations were prepared and used to compare the water and salt balance between the North and South Arms associated with a causeway with functioning culverts to a condition in which the causeway has closed culverts and a specified bridge is in place. The process originally started with two simulations: the pre-project culvert simulation and a bridge simulation with a 180-foot-long bridge. The results of simulations are documented in the *Great Salt Lake Causeway Final Water and Salt Balance Modeling Report* (UPRR 2014a).

The results of the original bridge simulation with a 180-foot-long bridge indicated that this bridge size would affect bidirectional flow through the causeway such that the South Arm would be denser (more saline) than what would occur with the free-flowing culverts (baseline conditions) for each of the models prepared (UPRR 2014a). The results of this initial analysis prompted UPRR to re-evaluate the bridge size to meet the objective of UPRR's compensatory mitigation proposal. This mitigation objective is to duplicate, as closely as possible, the transfer of water and salt that was occurring with the culverts functioning as documented in November 2012 when it was necessary to close the first culvert (the west culvert).

UPRR conducted additional modeling with the 2012 UPRR/USGS Model and the 2012 UPRR/USGS Varying Hydrology Model to evaluate various bridge sizes to better match the transfer of water and salt that occurred with the free-flowing culverts. The finding of this subsequent modeling, which is documented in the *Bridge Evaluation Report* (UPRR 2014b), is that a bridge with a smaller opening would better match the water and salt transfer than would the originally proposed 180-foot-long bridge. The difference in the alternative bridge simulations compared to the culvert simulation is that the culvert openings are removed to replicate closed culverts and the new bridge opening is added to replace the culverts. The differences among the alternative bridge simulations consist of the following different bridge lengths, invert elevations, and bottom widths:

- **Proposed Action (Alternative C):** 150-foot-long span with a bottom width of 49 feet and an invert elevation of 4,183 feet
- **Alternative A:** 180-foot-long span with a bottom width of 61 feet and an invert elevation of 4,178 feet (original size of the mitigation bridge)
- **Alternative B:** 150-foot-long span with a bottom width of 31 feet and an invert elevation of 4,178 feet
- **Alternative D:** 150-foot-long span with a bottom width of 66 feet and an invert elevation of 4,188 feet

As shown in Section 3.1.4, Water and Salt Balance Model Results, UPRR modeled each simulation and compared how each bridge size would affect WSEs, salinity, and salt loads resulting from various inflows and outflow conditions.

UPRR's revised mitigation proposal to replace the aquatic function for the culvert closures is to construct a 150-foot-long bridge with an invert elevation of 4,183 feet (UPRR 2014b). This bridge size would best replace the aquatic function of the culverts and would provide water and salt transfer through the causeway similar to that historically provided by the free-flowing culverts over time.

3.2.4 Effects of the Proposed Action and Alternatives

Section 3.1.4, Water and Salt Balance Model Results, presents the results of the bridge simulation using a 150-foot-long bridge compared to the free-flowing culvert simulation and bridge alternative simulations. These model results comparing salinity and salt loads are summarized below.

Proposed Action

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salinities from 8% to about 20.7%, and the bridge simulation resulted in increased South Arm salinity of about 1.3% (average) and 2.1% (ending) compared to the culvert simulation salinities. Salinity data from the 2012 UPRR/USGS Model are included in Table 3-2, 2012 UPRR/USGS Model – Salinity Comparison.

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salt loads from 1.3 billion tons to 2.4 billion tons, and the bridge simulation resulted in an increased South Arm salt load of about 0.2 billion tons (average) and 0.3 billion tons (ending) compared to the culvert simulation salt loads. Salt load data from the 2012 UPRR/USGS Model are included in Table 3-3, 2012 UPRR/USGS Model – Salt Load Comparison.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salinity of 0.3% and 0.2%, compared to the culvert simulation, for the wet and mild cycles, respectively. The bridge simulation resulted in decreased South Arm salinity of 1.2%, compared to the culvert simulation, for the dry cycle. Salinity data from the 2012 UPRR/USGS Varying Hydrology Model are included in Figure 3-11, 2012 UPRR/USGS Varying Hydrology Model – Average Annual South Arm Salinity Comparison at Equilibrium.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salt loads of 0.07 billion tons and 0.03 billion tons, compared to the culvert simulation, for the wet and mild cycles, respectively. The bridge simulation resulted in decreased South Arm salt load of 0.17 billion tons, compared to the culvert simulation, for the dry cycle. Salt load data from the 2012 UPRR/USGS Varying Hydrology Model are included in Table 3-4, 2012 UPRR/USGS Varying Hydrology Model – Salt Load Comparison at Equilibrium.

Alternative A

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salinities from 8% to about 20.7%, and the bridge simulation resulted in increased South Arm salinity of about 2.7% (average) and 5.8% (ending) compared to the culvert simulation salinities. Salinity data from the 2012 UPRR/USGS Model are included in Table 3-2, 2012 UPRR/USGS Model – Salinity Comparison.

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salt loads from 1.3 billion tons to 2.4 billion tons, and the bridge simulation resulted in an increased South Arm salt load of about 0.35 billion tons (average) and 0.75 billion tons (ending) compared to the culvert simulation salt loads. Salt load data from the 2012 UPRR/USGS Model are included in Table 3-3, 2012 UPRR/USGS Model – Salt Load Comparison.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salinity of 0.5%, 1.0%, and 2.6%, compared to the culvert simulation, for the wet, mild, and dry cycles, respectively. Salinity data from the 2012 UPRR/USGS Varying Hydrology model are included in Figure 3-11, 2012 UPRR/USGS Varying Hydrology Model – Average Annual South Arm Salinity Comparison at Equilibrium.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salt loads of 0.12 billion tons, 0.15 billion tons, and 0.33 billion tons, compared to the culvert simulation, for the wet, mild, and dry cycles, respectively. Salt load data from the 2012 UPRR/USGS Varying Hydrology Model are included in Table 3-4, 2012 UPRR/USGS Varying Hydrology Model – Salt Load Comparison at Equilibrium.

Alternative B

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salinities from 8% to about 20.7%, and the bridge simulation resulted in increased South Arm salinity of about 1.9% (average) and 3.9% (ending) compared to the culvert simulation salinities. Salinity data from the 2012 UPRR/USGS Model are included in Table 3-2, 2012 UPRR/USGS Model – Salinity Comparison.

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salt loads from 1.3 billion tons to 2.4 billion tons, and the bridge simulation resulted in an increased South Arm salt load of about 0.24 billion tons (average) and 0.48 billion tons (ending) compared to the culvert simulation salt loads. Salt load data from the 2012 UPRR/USGS Model are included in Table 3-3, 2012 UPRR/USGS Model – Salt Load Comparison.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salinity of 0.4%, 0.5%, and 0.9%, compared to the culvert simulation, for the wet, mild, and dry cycles, respectively. Salinity data from the 2012 UPRR/USGS Varying Hydrology model are included in Figure 3-11, 2012 UPRR/USGS Varying Hydrology Model – Average Annual South Arm Salinity Comparison at Equilibrium.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salt loads of 0.10 billion tons, 0.08 billion tons, and 0.09 billion tons, compared to the culvert simulation, for the wet, mild, and dry cycles, respectively. Salt load data from the 2012 UPRR/USGS Varying Hydrology Model are included in Table 3-4, 2012 UPRR/USGS Varying Hydrology Model – Salt Load Comparison at Equilibrium.

Alternative D

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salinities from 8% to about 20.7%, and the bridge simulation resulted in increased South Arm salinity of about 0.2% (average) and decreased South Arm salinity of about 0.4% (ending) compared to the culvert simulation salinities. Salinity data from the 2012 UPRR/USGS Model are included in Table 3-2, 2012 UPRR/USGS Model – Salinity Comparison.

For the 2012 UPRR/USGS Model, the culvert simulation resulted in a range of South Arm salt loads from 1.3 billion tons to 2.4 billion tons, and the bridge simulation resulted in a decreased South Arm salt load of about 0.01 billion tons (average) and 0.09 billion tons (ending) compared to the culvert simulation salt loads. Salt load data from the 2012 UPRR/USGS Model are included in Table 3-3, 2012 UPRR/USGS Model – Salt Load Comparison.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salinity of 0.2%, compared to the culvert simulation, for the wet cycle, and decreased South Arm salinity of 0.3% and 5.3%, compared to the culvert simulation, for the mild and dry cycles, respectively. Salinity data from the 2012 UPRR/USGS Varying Hydrology Model are included in Figure 3-11, 2012 UPRR/USGS Varying Hydrology Model – Average Annual South Arm Salinity Comparison at Equilibrium.

For the 2012 UPRR/USGS Varying Hydrology Model, the bridge simulation resulted in increased South Arm salt loads of 0.05 billion tons, compared to the culvert simulation, for the wet cycle and decreased South Arm salt loads of 0.06 billion tons and 0.67 billion tons, compared to the culvert simulation, for the mild and dry cycles, respectively. Salt load data from the 2012 UPRR/USGS Varying Hydrology Model are included in Table 3-4, 2012 UPRR/USGS Varying Hydrology Model – Salt Load Comparison at Equilibrium.

Summary of Effects of the Proposed Action and Alternatives

UPRR conducted water and salt balance model simulations for the culvert simulation and for the four bridge alternatives. The results of the water and salt balance modeling show that the water and salt transfer through the causeway with the proposed action would best match the causeway characteristics of the baseline conditions. With the proposed action, the results show that the transfer of water and salt through the causeway would increase, which, in turn, would slightly increase South Arm salinity and salt loads compared to the pre-project culvert simulation results for three of the four model simulations. The fourth model simulation (2012 UPRR/USGS Varying Hydrology Model, dry cycle) indicated a slight decrease in South Arm salinity and salt load for the proposed action simulation compared to the pre-project culvert simulation.

The salinity and salt loads resulting from the proposed action would best match the salinity and salt loads resulting from the culvert simulation. These slight changes in water and salt transfer through the causeway under the modeling conditions compared to the water and salt transfer provided by the causeway with free-flowing culverts would not be outside the historic variability of South and North Arm salinity and salt loads in such a way that these changes would impair the lake's beneficial uses and cause a significant adverse effect.

3.2.5 Effects of the No-Action Alternative

With the no-action alternative, the east culvert would remain temporarily closed pending the identification and approval of a permanent closure solution. UPRR would necessarily continue to seek USACE and UDWQ approval to make the east culvert closure permanent. In addition, the compensatory mitigation element of the proposed action would not be implemented, with the result that the aquatic functions of the culverts would not be replaced until the necessary approvals are granted.

Any resulting adverse change to water chemistry (outside of historic variability) caused by an incremental reduction of water and salt transfer through the causeway that impairs the lake's beneficial uses and continues unmitigated with the no-action alternative would likely continue until a permanent closure solution and mitigation plan is approved and implemented. UPRR also would necessarily continue to pursue USACE and UDWQ approval of an acceptable compensatory mitigation plan in support of making the east culvert closure permanent. It would be speculative to predict how long a new or revised individual permit action and corresponding mitigation proposal would take to be approved.

3.2.6 Construction-Related Effects

During project construction, none of the alternatives would affect water chemistry due to placing temporary fill for the shoofly or removing the fill once the new bridge is complete. Because these construction-related water quality effects would be short term and limited to minor releases of sediment, they would not impair the lake's beneficial uses and cause a significant adverse effect on local or lakewide water chemistry resources.

3.2.7 Post-construction Short-Term Effects

For the proposed action and alternatives, once the bridge is in place, the shoofly is removed, and the bridge opening conveys bidirectional flows, there would be a short-term transition period in which the differences in the North and South Arm WSEs and salinity gradients would change rapidly, and then the rate of change would decrease. UPRR evaluated this short-term transition period by reviewing the historic data surrounding the period when the existing 300-foot-long bridge was opened in 1984.

The existing bridge was constructed during 1984, and, on August 1, 1984, the bridge opening began conveying bidirectional flow. At the time, the lake WSE was about 4,209 feet and the 300-foot-long bridge had a bottom elevation of 4,200 feet, which allowed a flow depth about 9 feet. At that time, prior to the bridge opening, the difference in WSEs between the North and South Arms was about 3.2 feet, and the difference in densities between the North and South Arms was 16%.

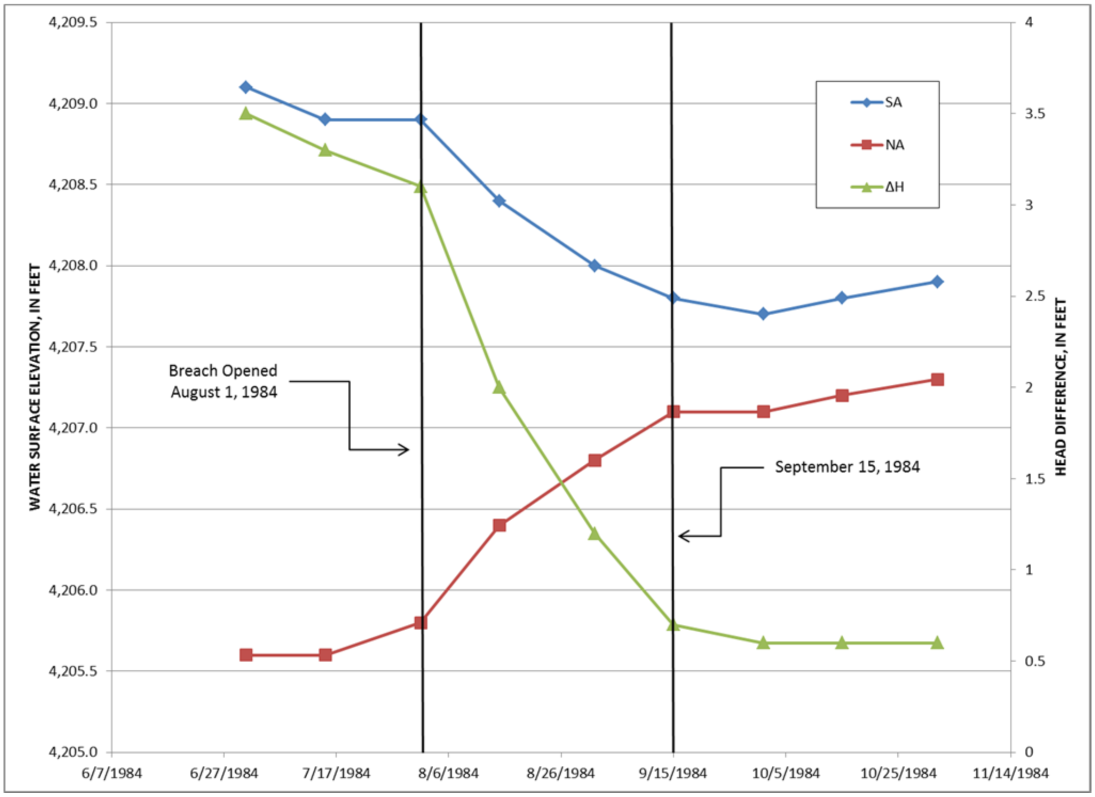
UPRR evaluated the WSE and density data before and after the bridge was opened to assess the short-term effects of the opening and the duration those effects.

Water Surface Evaluation

UPRR analyzed the South and North Arm WSE data reported for the USGS Great Salt Lake gages at the Saltair Boat Harbor (USGS 10010000) and near Saline, Utah (USGS 10010100), respectively (USGS 2014a), for the periods before and after the 300-foot-long bridge was opened in August 1984. During this period, USGS reported the WSEs on the 1st and the 15th of each month. UPRR also analyzed the head difference, which is the difference between the South and North Arm WSEs. Because the South Arm WSE is higher than the North Arm WSE, the head difference is always represented as the South Arm WSE minus the North Arm WSE.

Figure 3-13 below shows the South and North Arm WSEs and the head difference between the two arms for the period June through October 1984. The data indicate that the head difference dropped dramatically within the reporting dates of August 1 and September 15, a period of about 6 weeks, and that afterward the rate of change decreased. The factors that affect the head difference and the change in head difference between the two arms consist of (1) lake WSE, (2) the relationship between the lake WSE and the breach bottom (flow depth through the breach), and (3) annual inflow variation. Each year, the head difference is greatest in May or June (generally following the peak inflows to the lake) and lowest in September (associated with high evaporation and low inflows).

Figure 3-13. Lake WSE Comparison, June–October 1984



As of June 2014, the South Arm WSE is about 4,195 feet, and the head difference between the two arms is about 1 foot. The bottom of the 300-foot-long bridge is currently at 4,192 feet after being lowered in 2000, which could affect head difference in that the head difference might increase as flow through the bridge is restricted due to low lake levels. With the proposed 150-foot-long bridge with an invert at 4,178 feet, a flow depth through the new opening of about 17 feet is expected if the WSE is at about 4,195 feet.

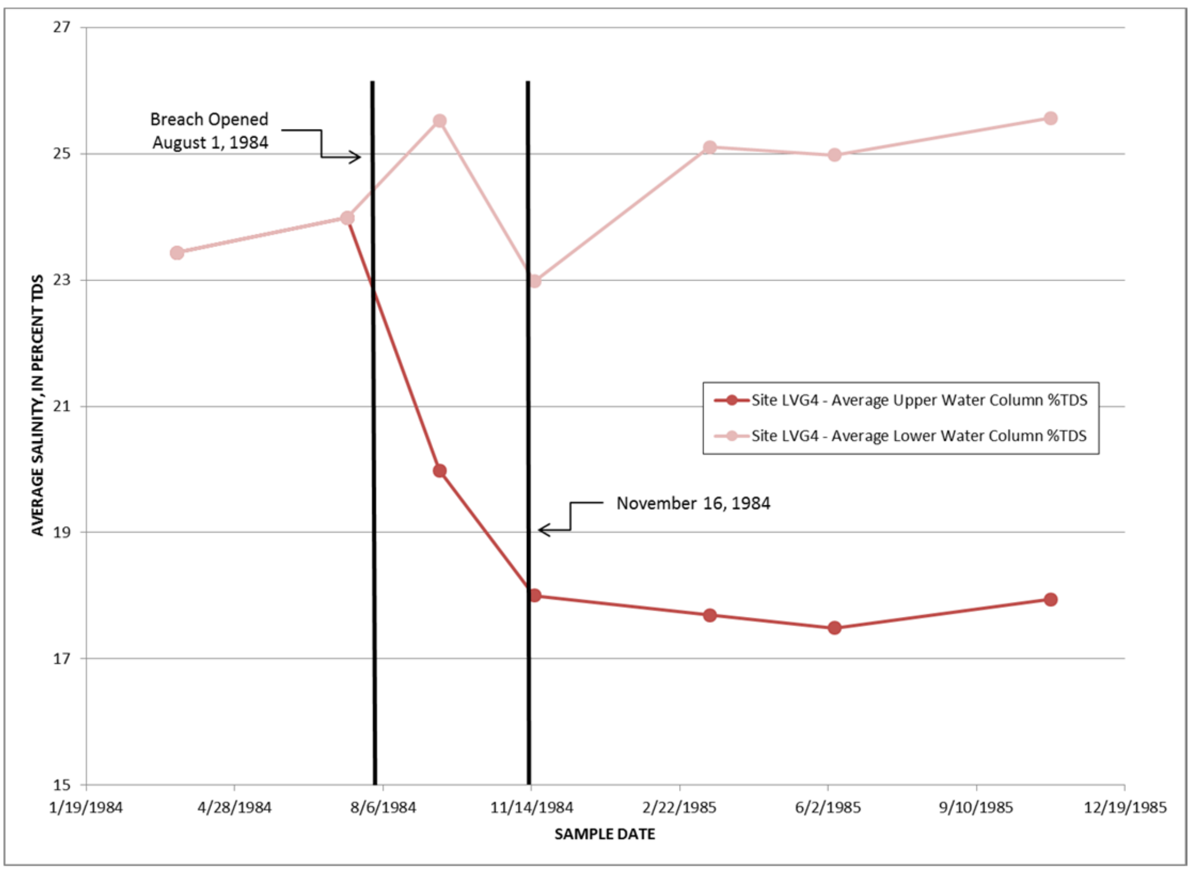
Based on this analysis, comparing the lake conditions in 1984 to those in 2014, UPRR expects the transition period for changes in head difference between the South and North Arms to occur similarly depending on lake level, head difference, and the relationship of the lake level to the existing 300-foot-long bridge before the new bridge was opened.

Gunnison Bay Salinity Evaluation

UPRR analyzed the North Arm salinity data reported by UGS at sampling location LVG4 (Figure 3-3, Historic and Current UGS Water Chemistry Sampling Locations, and Figure 3-4, UGS Sampling Locations Used for Water Chemistry Evaluations; UGS 2012) for the periods before and after the 300-foot-long bridge was opened. During this period, UGS collected and analyzed North Arm water samples at 5-foot intervals and reported salinity levels for each sample.

Figure 3-14 below shows the North Arm salinity data for the upper and lower water column samples for the period 1984–1985. The data indicate that the North Arm salinity was vertically mixed before the bridge opened and became stratified afterward, meaning that the less dense (less saline) South Arm water remained unmixed with the denser (more saline) North Arm water. The rapid change in density appears to have occurred between the sampling dates of July 13, 1984, and November 16, 1984, a period of about 4 months. Afterward, the rate of change decreased. The factors that could affect the change in North Arm salinity include head difference and the relationship between lake level and the breach bottom (flow depth through the breach). When the existing 300-foot-long bridge was opened, the flow depth through the breach was about 9 feet deep, since the WSE elevation was about 4,209 feet.

Figure 3-14. North Arm Salinity Comparison, 1984–1985



As of June 2014, the South Arm WSE is about 4,195 feet, and the bottom of the 300-foot-long bridge is currently at 4,192 feet, allowing about 3 feet of flow through the bridge. With the proposed 150-foot-long bridge with an invert at 4,178 feet, the new opening would convey a flow depth of about 17 feet at the same WSE.

Based on this analysis, comparing the lake conditions in 1984 to those in 2014, UPRR expects the transition period for changes in North Arm salinity to occur similarly depending on lake level, head difference, and the relationship of the lake level to the existing 300-foot-long bridge before the new bridge was opened, in that some stratification of the North Arm water could occur.

Gilbert Bay Salinity Evaluation

UPRR analyzed the South Arm salinity data reported by UGS at sampling locations AS2 and FB2 (Figure 3-3, Historic and Current UGS Water Chemistry Sampling Locations, and Figure 3-4, UGS Sampling Locations Used for Water Chemistry Evaluations; UGS 2012) for the periods before and after the 300-foot-long bridge was opened. During this period, UGS collected and analyzed South Arm water samples at 5-foot intervals and reported salinity levels for each sample.

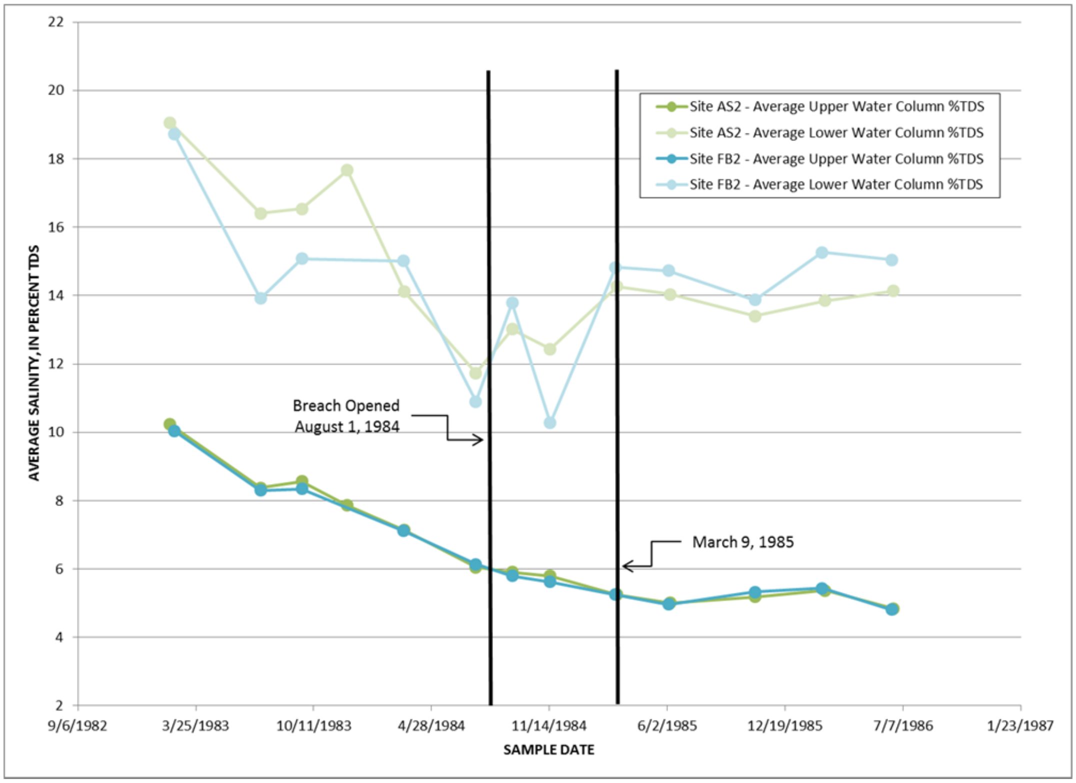
Figure 3-15 below shows the South Arm salinity data for the upper and lower water column samples for the period 1984–1985. The data indicate that the South Arm salinity was stratified, meaning that a less dense upper brine layer is unmixed with the denser deep brine layer and that opening the 300-foot-long bridge allowed more North Arm water to flow to the South Arm. The resulting change in the density of the deep brine layer appears to have occurred between the sampling dates of July 12, 1984, and March 6, 1985, a period of about 20 months. Afterward, the rate of change decreased. While the effects of opening the bridge on South Arm salinity were not as obvious as the effects on WSE and North Arm salinity, the data indicate that the deep brine layer remained denser as the upper water column became less dense due to the rising lake levels. The upper water column salinity appeared to become less dense as a result of the rising lake levels.

The factors that could affect the change in the salinity of the deep brine layer include lake level and the relationship between lake level and the breach bottom (flow depth through the breach). When the existing 300-foot-long bridge was opened, the flow depth through the breach was about 9 feet, since the WSE elevation was about 4,209 feet.

As of June 2014, the South Arm WSE is about 4,195 feet, and the bottom of the 300-foot-long bridge is currently at 4,192 feet, allowing about 3 feet of flow through the bridge. With the proposed 150-foot-long bridge with an invert at 4,178 feet, the new opening would convey a flow depth of about 17 feet at the same WSE.

Based on this analysis, comparing the lake conditions in 1984 to those in 2014, UPRR expects the transition period for changes in the salinity of the South Arm deep brine layer to occur similarly depending on lake level and the relationship of the lake level to the existing 300-foot-long bridge prior to opening the new bridge.

Figure 3-15. South Arm Salinity Comparison, 1983–1986



Summary of Post-construction Short-Term Effects

For the proposed action and alternatives, once the bridge is in place and the shoofly is removed, the bridge would be opened to convey water between the North and South Arms. When the bridge is opened, there would be a period of less-than-minimal post-construction short-term effects during which the differences in WSE and salinity between the two arms would rapidly change. Over time, the differences would move toward equilibrium, and the post-construction effects would no longer exist.

UPRR analyzed the short-term post-construction transition period that was observed when the existing 300-foot-long bridge was opened in 1984. Short-term post-construction effects on lake WSE and salinity were evaluated. Data suggest that, when the 300-foot-long bridge was opened in 1984, the head difference declined sharply for about 6 weeks, less dense (less saline) water appeared in the North Arm, and the deep brine layer in the South Arm became denser (more saline).

During the 1984 transition period, no short-term effects on North and South Arm salinities were documented as causing a significant adverse effect and impairing the lake's beneficial uses, and no new or additional data would support a different outcome with the proposed action or one of the alternatives.

4 Water Quality

This chapter describes the existing water quality of the Great Salt Lake and the potential effects of the proposed project. For the purpose of this evaluation, discussions about water quality are intended to cover the lake's water quality parameters including metals, nutrients, and other parameters such as dissolved oxygen.

Other lake water characteristics are water chemistry, which is discussed in Chapter 3, Water Chemistry; the deep brine layer, which is discussed in Chapter 5, Deep Brine Layer; and mercury and methyl mercury, which are discussed in Chapter 6, Mercury and Methyl Mercury.

4.1 Affected Environment

This section reviews the methods used to describe the affected environment (also known as existing conditions), describes the water quality regulations for the Great Salt Lake, describes the water quality of the Great Salt Lake as measured by UDWQ and USGS, lists the existing permitted discharge sites in the study area, and reviews other published water quality data about the lake.

4.1.1 Methodology

Section 4.1 focuses on typical water quality parameters, which are broadly classified as physical parameters, metals, nutrients, inorganics, radiological parameters, organics, bacteriological parameters, and pollution indicators. UPRR evaluated the lake's existing water quality using the following methods:

- Reviewed other recent water quality reports and focused the review and analysis on recent reports and analysis for Gilbert and Gunnison Bays, since these data are the most current data about conditions near the project. That is, the lake levels when these data were collected are similar to the lake levels in November 2012 prior to the closing of the first culvert.
- Reviewed the results of the water and salt balance modeling, which identifies lake salinity and salt load conditions for the baseline conditions (that is, two free-flowing culverts as they were functioning before they were closed in 2012). As stated in the May 9, 2014, UDWQ letter regarding anti-degradation analysis, changes in lake salinity can be used by UPRR as a surrogate for changes in specific water quality parameters (UDWQ 2014a).
- Identified permitted facilities that discharge effluent to the lake, including permitted municipalities that discharge stormwater.

4.1.2 Water Quality Regulations for the Great Salt Lake

This section describes the regulatory standards that apply to the Great Salt Lake, including those related to beneficial uses, water quality, impaired waters, and antidegradation. Due to the unique physical, chemical, and biological makeup of the Great Salt Lake, freshwater and marine water quality standards that normally regulate surface waters cannot be applied directly. The Great Salt Lake Comprehensive Management Plan (CMP) states that typical freshwater and marine water numeric water quality standards might not apply to the Great Salt Lake due to its unique biogeochemical processes, which are due to the lake's hypersaline water and which can change the fate and transport of pollutants. The CMP also states that the Great Salt Lake does not support the aquatic species from which typical standards based on toxicity are developed (UDFFSL 2013).

Beneficial Uses. UDWQ has classified the Great Salt Lake into five beneficial-use classes associated with and named for the major geographic areas of the lake: Gilbert Bay, Gunnison Bay, Bear River Bay, Farmington Bay, and transitional waters along the shoreline of the Great Salt Lake (Utah Administrative Code [UAC] R317-2-6). The project study area is immediately bounded by Gilbert Bay to the south and Gunnison Bay to the north, but, since these areas are part of the larger system, this section considers all five classes.

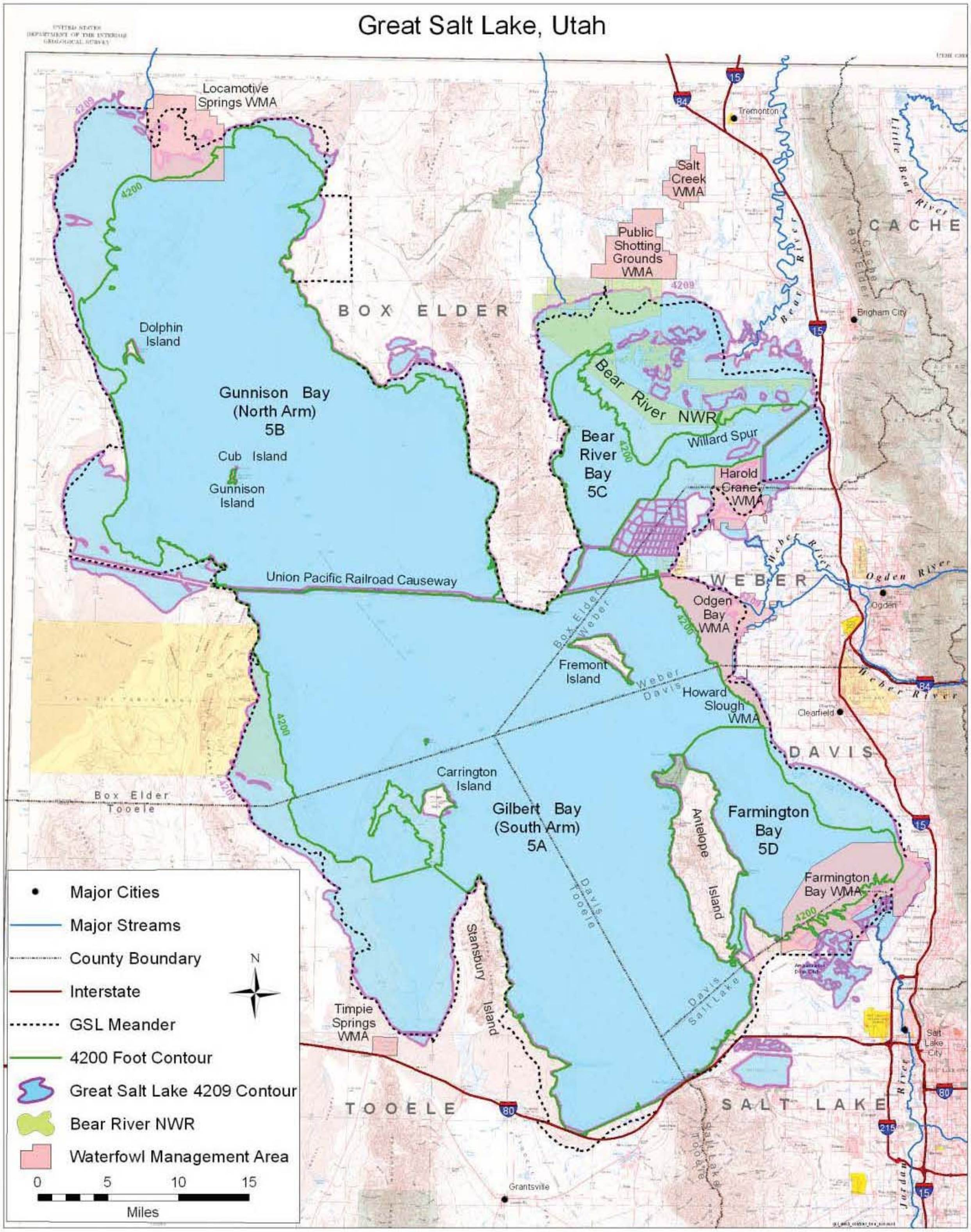
Table 4-1 lists the five classes associated with the Great Salt Lake with the geographical boundaries and beneficial uses of each class. Figure 4-1 following the table illustrates the Great Salt Lake and the areas associated with the designated classes. These areas have varying salinity levels that affect the use of the water by people and other biological communities.

Table 4-1. Beneficial-Use Classes for the Great Salt Lake

Class	Location	Geographical Boundary	Beneficial Uses
5A	Gilbert Bay (South Arm)	All open waters at or below approximately 4,208 feet in elevation south of the UPRR causeway, excluding all of Farmington Bay south of the Antelope Island causeway and salt evaporation ponds.	Protected for frequent primary and secondary contact recreation, waterfowl, shore birds. and other water-oriented wildlife, including their necessary food chain
5B	Gunnison Bay (North Arm)	All open waters at or below approximately 4,208 feet in elevation north of the UPRR causeway and west of the Promontory Mountains, excluding salt evaporation ponds.	Protected for infrequent primary and secondary contact recreation, waterfowl, shore birds. and other water-oriented wildlife. including their necessary food chain
5C	Bear River Bay (South Arm)	All open waters at or below approximately 4,208 feet in elevation north of the UPRR causeway and east of the Promontory Mountains, excluding salt evaporation ponds.	Protected for infrequent primary and secondary contact recreation, waterfowl, shore birds. and other water-oriented wildlife. including their necessary food chain
5D	Farmington Bay (South Arm)	All open waters at or below approximately 4,208 feet in elevation east of Antelope Island and south of the Antelope Island causeway, excluding salt evaporation ponds.	Protected for infrequent primary and secondary contact recreation, waterfowl, shore birds. and other water-oriented wildlife. including their necessary food chain
5E	Transitional waters along the shoreline of the Great Salt Lake	All waters below approximately 4,208 feet in elevation to the current lake elevation of the open water of the Great Salt Lake receiving their source water from naturally occurring springs and streams, impounded wetlands, or facilities requiring a Utah Pollutant Discharge Elimination System (UPDES) permit. The geographical areas of these transitional waters change corresponding to the fluctuation of open-water elevation.	Protected for infrequent primary and secondary contact recreation, waterfowl, shore birds. and other water-oriented wildlife. including their necessary food chain

Source: UAC R317-2-6

Figure 4-1. Designated Water Bodies and Beneficial Uses of the Great Salt Lake



Source: UDWQ 2012a

Water Quality Standards. UDWQ applies numeric and narrative standards to waters of the state to protect designated beneficial uses. Numeric standards refer to specific water quality criteria that are applied to each class of water to protect its beneficial uses. Gilbert Bay (Class 5A) has an established tissue-based standard for selenium (UAC R317-14), but no other numeric standards apply to the Great Salt Lake in terms of water quality. The selenium criterion is 12.5 milligrams per kilogram (mg/kg) dry weight in bird egg tissue.

Narrative standards are applied to all waters within the state's boundaries, including the Great Salt Lake. Narrative standards are general statements that prohibit the discharge of waste or other substances that result in unacceptable water quality conditions such as visible pollution or undesirable aquatic life. If a water body does not meet numeric or narrative water quality standards and the beneficial uses of that water body are adversely affected, the water body could be designated as impaired under the federal CWA and targeted for activities to improve its water quality.

UDWQ is conducting water quality sampling in the Great Salt Lake to assess existing water quality and develop numeric water quality criteria for the lake (UDWQ 2012b). UDWQ's strategy recognizes that the numeric criteria, once developed, might vary based on salinity levels that in turn affect biological and human uses of the lake.

Impaired Waters. Neither the Great Salt Lake nor any part of the lake is proposed for or on the state list of impaired waters (UDWQ 2010, 2014c). The list of impaired waters is referred to as the 303(d) list since the listing process follows the regulatory requirements of Section 303(d) of the CWA. Impaired waters are defined as those water bodies not meeting their beneficial uses. Typically, these waters exceed the specific numeric water quality standards associated with a specific class or beneficial use.

Antidegradation Policy. Along with protection of Great Salt Lake for beneficial uses, the State of Utah has a statewide antidegradation policy that protects water bodies from activities that could lower or degrade water quality. Activities that lower or degrade water quality can be allowed if UDWQ determines that these activities are necessary for important economic or social development. To facilitate this policy, all waters in Utah are designated as Category 1, 2, or 3 waters. The Great Salt Lake is considered a Category 3 water subject to antidegradation reviews (UAC R317-2-12). Category 3 waters are considered all other waters not designated Category 1 or 2.

4.1.3 General Description of the Great Salt Lake's Water Quality

As discussed in Section 4.1.2, Water Quality Regulations for the Great Salt Lake, the hypersaline nature of the lake waters creates challenges for applying water quality regulations. These conditions also create challenges in the sampling and analyses of water quality parameters because the high chloride concentrations interfere with traditional laboratory analyses. As noted in the 2012 UDWQ publication *A Great Salt Lake Water Quality Strategy*, water quality monitoring has been conducted in the past. However, the data have been collected intermittently. Furthermore, UDWQ states that the laboratory analyses that were previously conducted did not use adequate quality procedures to produce accurate and reliable data (UDWQ 2012a).

The Great Salt Lake CMP identifies selenium, mercury, nutrients, and algae as specific water quality concerns in the Great Salt Lake and summarizes the results of recent studies and assessments focused on these parameters (UDFFSL 2013). The CMP also states that the relationship between the varying lake WSEs and water quality constituents is not well understood.

UDWQ has initiated an approach to gather water quality data in an effort to eventually establish appropriate numeric water quality standards to ensure protection for the lake's beneficial uses (UDWQ 2012a). As part of this approach, the State has established specific implementation activities to gather water quality data about the lake. UDWQ currently collects water quality samples twice per year from 11 locations in Bear River Bay, Farmington Bay, and Gilbert Bay, shown in Figure 4-2 below. These locations are all in the South Arm; there are no current sampling locations in the North Arm (Gunnison Bay), though UDWQ plans to add two sites when access challenges are overcome (UDWQ 2014c).

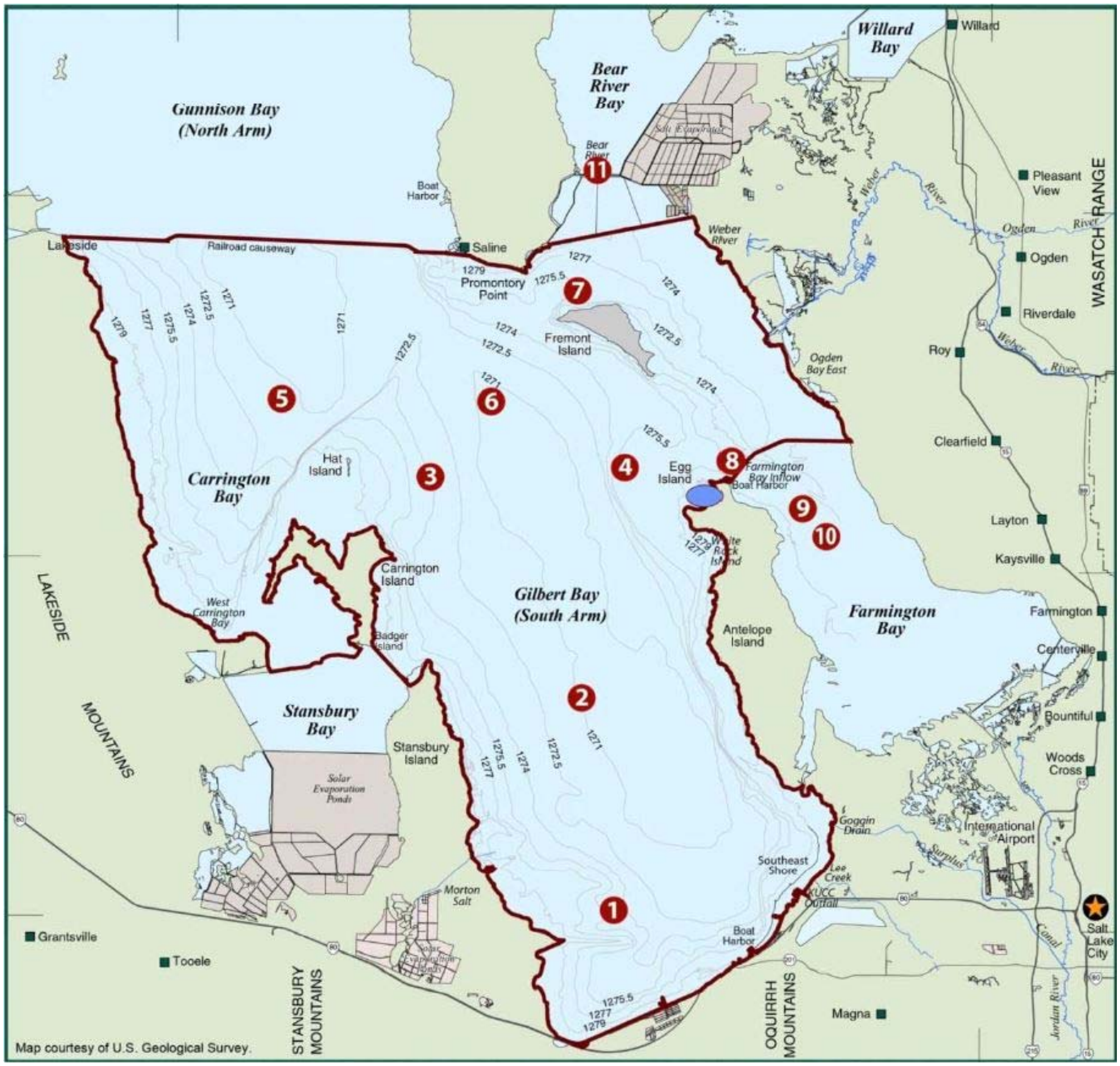
This water-quality sampling will help UDWQ describe existing water quality conditions, since it has determined that reliable historic data are lacking. Currently, the baseline open-water water quality sampling events are conducted twice a year. These events, which began in 2011, collect and analyze water samples in order to assess current conditions and to track spatial and temporal trends of contaminants of concern (Table 4-2) that could affect the lake's beneficial uses (UDWQ 2012b).

Table 4-2. Pollutants Analyzed in UDWQ's Baseline Water Quality Sampling Plan

Type of Pollutant	Target Analytes
Metals	Total selenium, total mercury, methyl mercury, total arsenic, total copper, total cadmium, total lead, total thallium
Nutrients	Total phosphorus, total nitrogen, ammonia
Other parameters	Chlorophyll-a, temperature, pH, dissolved oxygen

Source: UDWQ 2012b

Figure 4-2. Baseline Water Quality Sampling Locations in the Great Salt Lake



Source: UDWQ 2012b

To evaluate the existing water quality of the Great Salt Lake, UPRR obtained and evaluated the unpublished laboratory results summarized by UDWQ for the South Arm sampling events in 2011 and 2012 (UDWQ 2013b). At each site, replicate samples were collected from two depths in two seasons. Although these are the most recent water quality sampling events, UPRR recognizes that, with only four measurements per sampling location and only two years of sampling, no long-term or short-term trends can be identified and analyzed. However, data comparisons can be made.

UPRR evaluated the Gilbert Bay data points (1 through 7) to identify averages of specific pollutants (metals) for the upper and lower water columns (Table 4-3 below). Upper water column samples were collected at 0.2 meter (about 8 inches) down from the water surface, and lower water column samples were collected at 0.5 meter (about 20 inches) up from the lake bottom. Note that most of the sampling sites have relatively high lake bottom elevations, such that they are not deep enough to exhibit a deep brine layer. In 2011 and 2012, sites 2, 5, and 6 exhibited a deep brine layer (UDWQ 2014c).

Table 4-3. Water Quality Averages in Gilbert Bay from UDWQ's Water Quality Sampling

in micrograms per liter (µg/L)

UDWQ Site	Water Column	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Selenium	Total Thallium
1	Upper	65.5	0.0192	2.145	1.22	0.358	0.033
	Lower	72.9	0.0162	2.120	1.16	0.327	0.035
2 [a]	Upper	74.9	0.0154	1.710	1.15	0.365	0.034
	Lower	121.5	0.1691	5.332	7.73	0.606	0.059
3	Upper	79.4	0.0199	1.565	0.99	0.341	0.033
	Lower	73.7	0.0235	1.703	1.03	0.343	0.037
4	Upper	65.9	0.0187	1.775	1.24	0.376	0.037
	Lower	73.4	0.0197	1.888	1.18	0.344	0.036
5 [a]	Upper	71.3	0.0229	1.760	1.07	0.327	0.037
	Lower	113.8	0.1434	5.971	5.36	0.432	0.052
6 [a]	Upper	80.6	0.0244	1.893	1.07	0.413	0.036
	Lower	104.9	0.1530	5.560	6.34	0.427	0.056
7	Upper	68.7	0.0224	1.745	1.17	0.314	0.035
	Lower	70.9	0.0216	1.823	1.13	0.370	0.036

Source: UDWQ 2013b

[a] A deep brine layer was present at this location during the sampling period.

UPRR examined reported data for sampling point 5 (closest to the project area) and sampling points 1 and 6 to review the spatial variation across Gilbert Bay during the two sampling years. Vertical variability is examined at the same sampling locations (1, 5, and 6), since samples are collected at 0.5 meter (about 20 inches) up from the lake bottom and 0.2 meter (about 8 inches) down from the surface of the water. Salinity in Gilbert Bay ranged between 11.8% and 13.2% over the study period based on field measurements (UDWQ 2014c).

Vertical and Spatial Examination of Metal Concentrations

To show how lake water quality varied spatially and between the upper and lower brine layers across Gilbert Bay during the 2011 and 2012 sampling events. While these sampling events support the existing water quality sampling program, the program is not near completion and this data is shown only to represent conditions in 2011 and 2012.

UPRR examined average metal pollutant concentrations at UDWQ sites 1, 5, and 6. UDWQ is currently sampling for six metals. UPRR examined the spatial and vertical variability of the data for total arsenic, total lead, and total selenium as representative of the other water quality pollutants. Mercury is discussed in Chapter 6, Mercury and Methyl Mercury.

Figure 4-3 shows average values for total arsenic, which vary spatially as well as vertically for the four sampling events in 2011 and 2012. However, the results for total lead concentrations in Figure 4-4 below suggest that sites 5 and 6 were more similar to each other during the two years' sample periods for both the upper and lower brine layers than either site is to site 1. Figure 4-5 below shows the total selenium data for the three sites, with no obvious similarities.

Figure 4-3. Average Total Arsenic in the South Arm at UDWQ Sites 1, 5, and 6

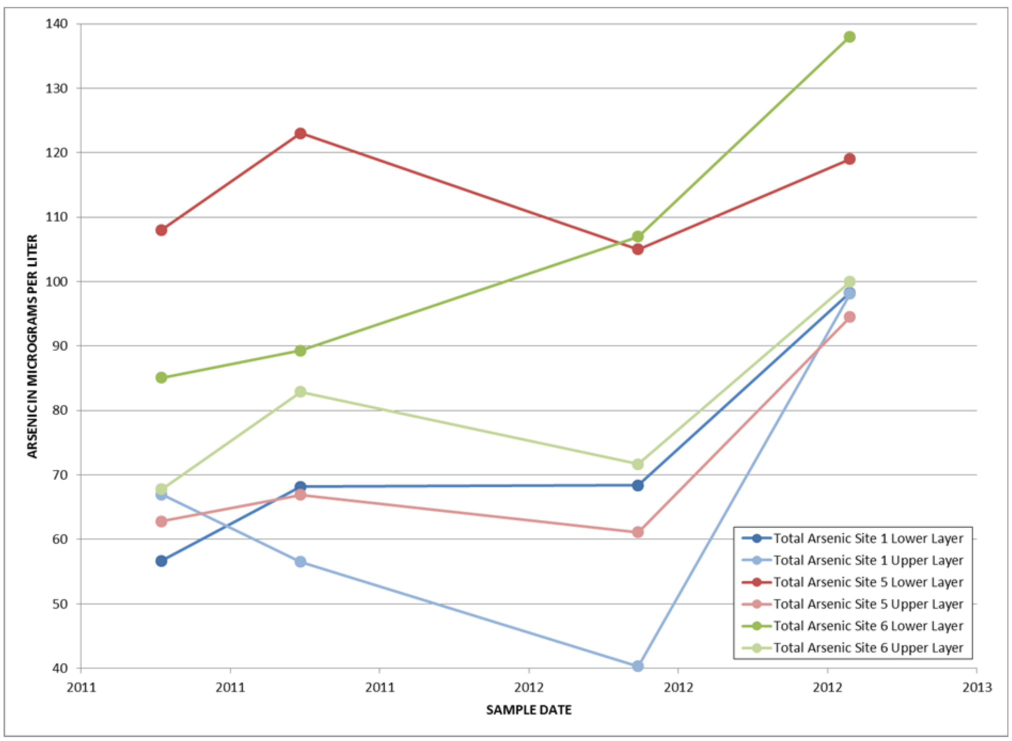


Figure 4-4. Average Total Lead in the South Arm at UDWQ Sites 1, 5, and 6

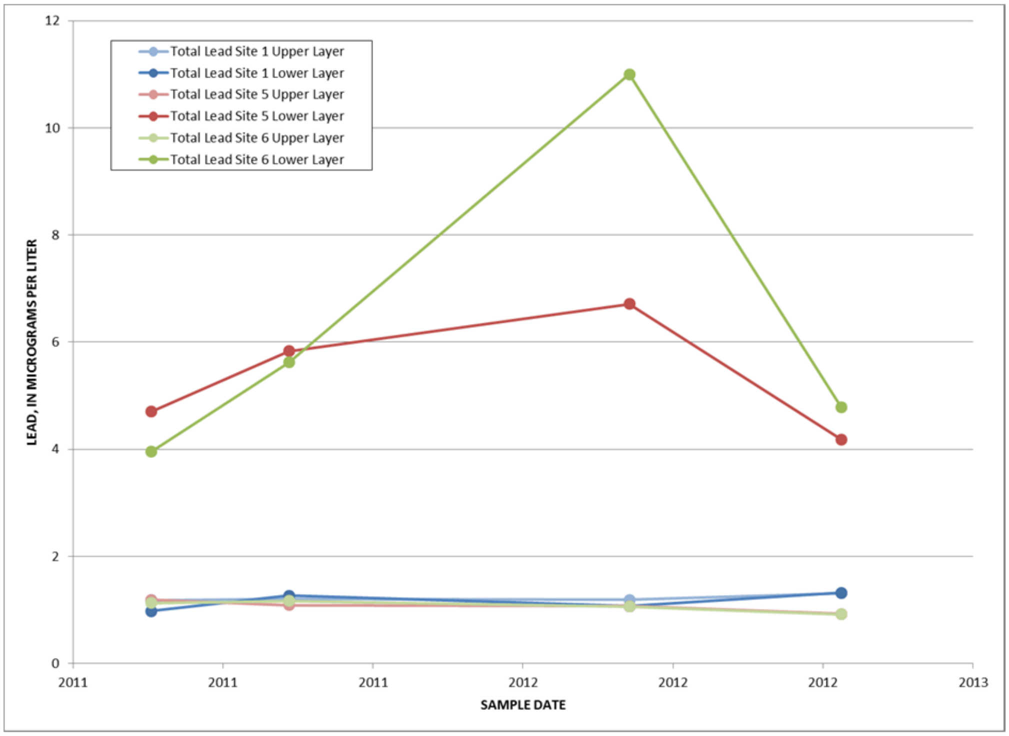
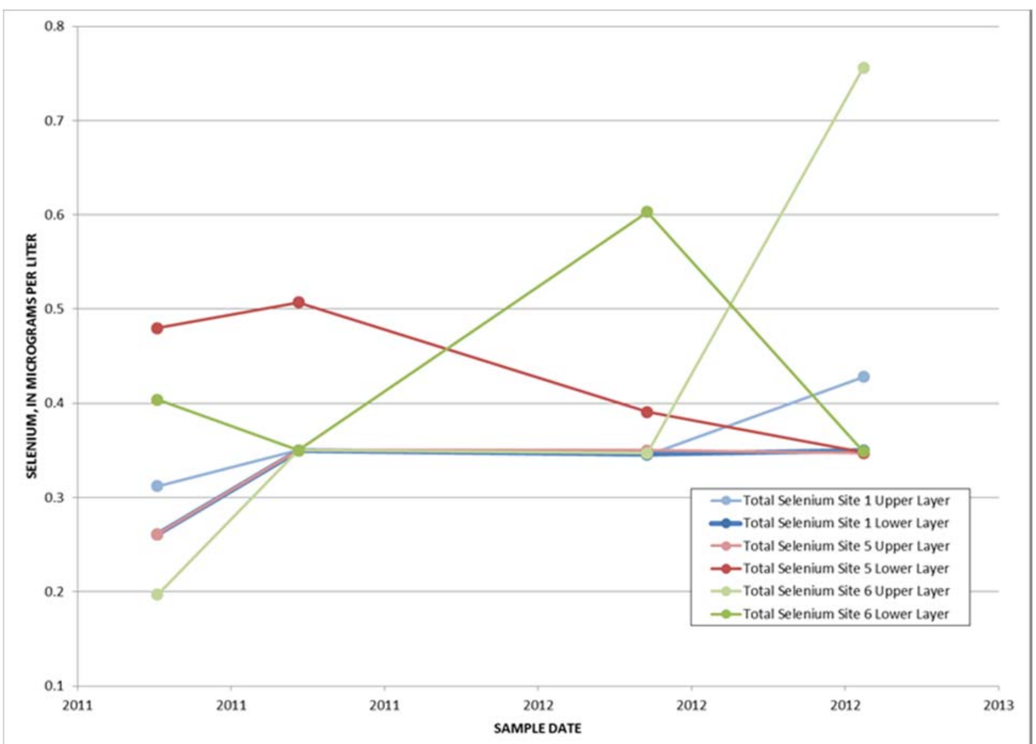


Figure 4-5. Average Total Selenium in the South Arm at UDWQ Sites 1, 5, and 6

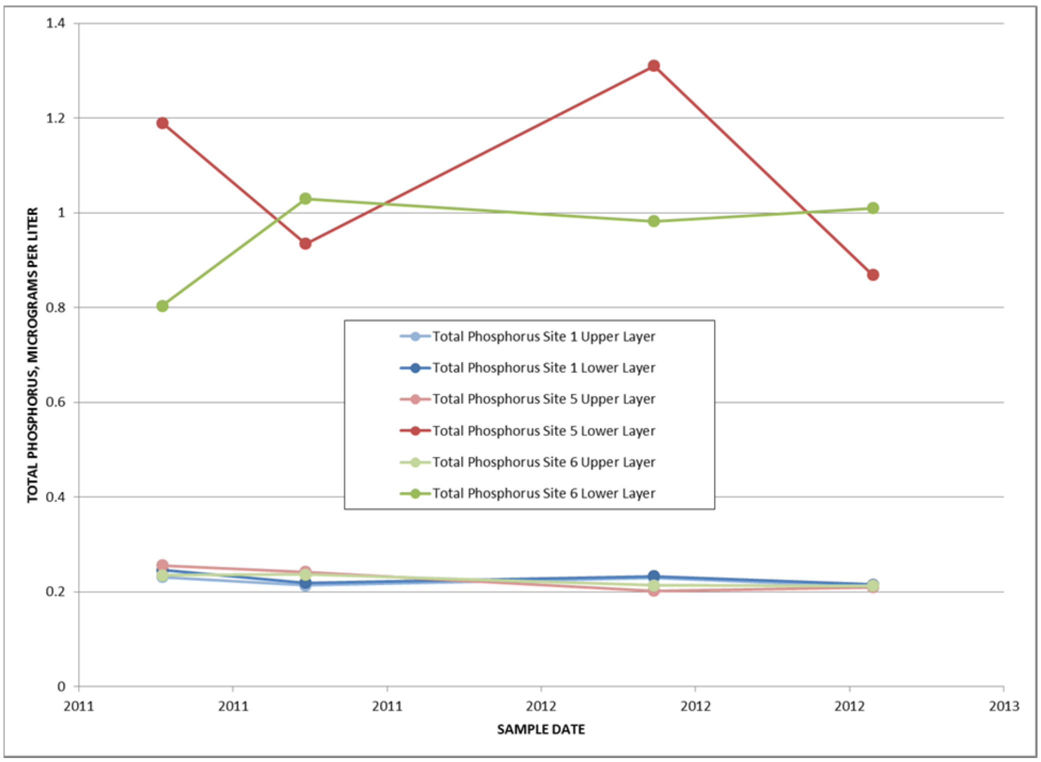


Vertical and Spatial Examination of Nutrient Concentrations

USGS collected water quality samples for total phosphorus for the UDWQ sampling events in 2011 and 2012. The comparison results for sites 1, 5, and 6 are shown in Figure 4-6. Within-event averages of the four results are computed for the upper and lower brine layers. The baseline sample data suggest that the deep brine layer averages for sites 5 and 6, while variable, were more comparable with each other than with site 1's lower layer during the 2011 and 2012 sampling periods, while the upper brine layer averages for all three sites were comparable.

Site 1 appeared to be completely mixed vertically during the 2011 and 2012 sampling periods. Since site 1 is located in a portion of the lake with a relatively high lake bottom (estimated at 4,191 feet, as shown above in Figure 4-2), the data make sense, that is, there was no discernible difference between the upper and lower phosphorous concentrations, and the concentration difference within the lower-layer samples indicates that there was no deep brine layer at that location.

Figure 4-6. Average Total Phosphorus in the South Arm at UDWQ Sites 1, 5, and 6



Vertical and Spatial Examination of Dissolved Oxygen

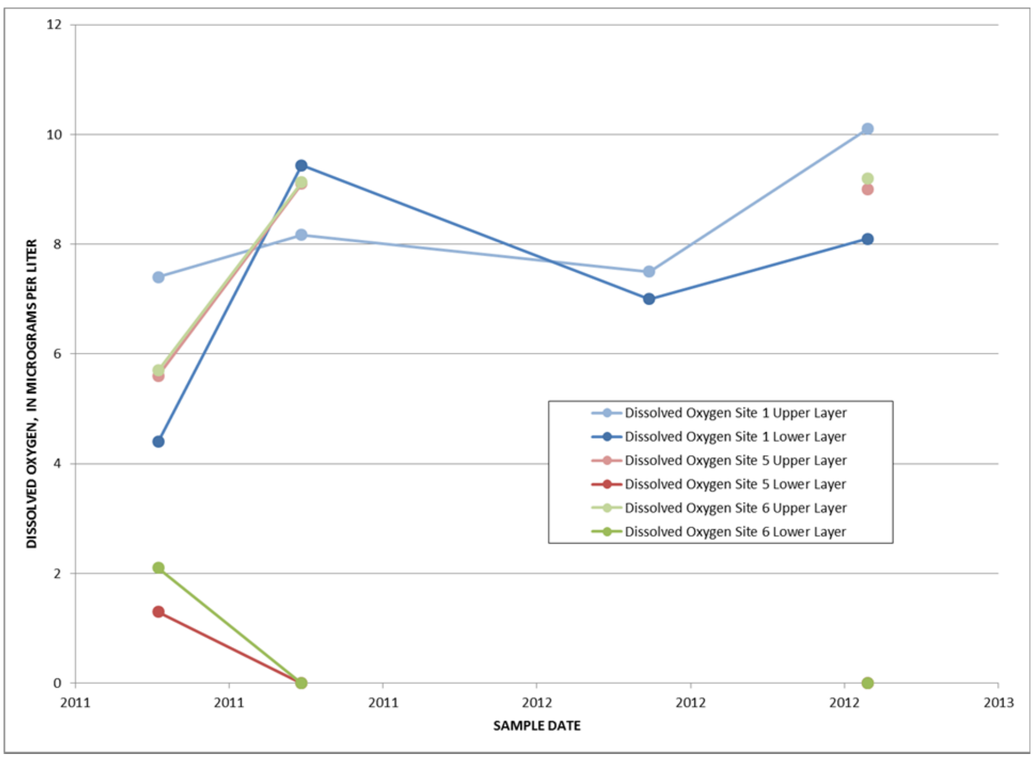
USGS collected and analyzed water quality samples for dissolved oxygen for the UDWQ sampling events in 2011 and 2012. The comparison results for sites 1, 5, and 6 are shown in Figure 4-7. Averages of the four event results are computed for the upper and lower brine layers. Note that, for the June 2012 sampling event, no dissolved oxygen data were reported for sites 5 and 6.

An examination of the dissolved oxygen data suggests that the lower brine layer averages for sites 5and 6 were more comparable with each other during the sampling period than with site 1, based on three samples. This is an indication that, at sites 5 and 6, a deep brine layer is present and anoxic. The upper brine layer averages for the three sites were comparable. Site 1 appeared to be mixed vertically (completely oxygenated) in 2011 and 2012, and this is because the site is located in a portion of the lake with a higher lake bottom than sites 5 and 6 and will not have a deep brine layer present.

What are anoxic waters?

Anoxic waters are areas of water that are depleted of dissolved oxygen.

Figure 4-7. Average Dissolved Oxygen in the South Arm at UDWQ Sites 1, 5, and 6



Draft 2014 Integrated Report

On May 30, 2014, UDWQ released for comments the draft 2014 Integrated Report (UDWQ 2014c), which is the State's evaluation of the water quality conditions of Utah's streams, rivers, and lakes, including the Great Salt Lake. Chapter 7 of the report is devoted to the water quality conditions of the Great Salt Lake and interprets the water quality data from 2011 and 2012 that UDWQ provided to UPRR before the report was published, as well as other data and information. UDWQ divided its assessment into four parts: (1) salinity, chemical stratification, and its effects on metal and metalloid concentrations; (2) temperature, pH, and dissolved oxygen; (3) metals; and (4) nutrients. Recall that no samples were collected from Gunnison Bay. Below, UPRR has reproduced UDWQ's observations about Gilbert Bay's water quality and summarized them below.

Salinity, Chemical Stratification, and Its Effects on Metal and Metalloid Concentrations

Over both years (2011 and 2012), the average salinity at all sites and depths in Gilbert Bay was 12.5% compared to Farmington Bay at 4.1% and Bear River Bay at 1% to 5% (UDWQ 2014c). During this period, the average salinity in Gilbert Bay varied between 11.8% and 13.2%. A large inflow of surface water (due to fast snowmelt) in 2011 likely accounts for the lower salinity observed in 2011 compared to 2012.

In the deeper parts of Gilbert Bay, UDWQ observed an interface between a upper, oxygenated brine layer and a deep, denser anoxic deep brine layer. The Gilbert Bay sites where a deep brine layer was observed are sites 2, 5, 6, and 8. UDWQ states (UDWQ 2014c, 8):

> The deep brine layer develops when saltier, more dense water from Gunnison Bay (27% saline) is transported to Gilbert Bay and sinks to the bottom of the water column. From October 2011 to 2012, a deep brine layer was present at sites Gil2, Gil5, and Gil6. Overall, the average salinity in the shallow layer at these sites was 11.8% as compared to 18.2% in the deep brine [layer]. The deep brine layer has little to no oxygen (hypoxic and anoxic, respectively), which can lead to a lower redox potential than oxic waters which increases the solubility of some metals. As a result, the concentrations of arsenic, lead, copper, total mercury, and methyl mercury were notably higher in the deep brine layer in both 2011 and 2012. The higher salinity and hypoxic conditions in the deep brine layer also create[] conditions that are inhospitable to brine shrimp and brine flies, which reduces their direct exposure to the higher pollutant concentrations. However, exposure is not entirely eliminated because some mixing of the deep brine layer with the overlying oxic layer occurs.

UDWQ also observed density stratification at sites 8 and 9 between Gilbert and Farmington Bays due to denser Gilbert Bay water overlain by fresher Farmington Bay water.

Temperature, pH, and Dissolved Oxygen

Over the 2011–2012 monitoring period, the average temperature, pH, and dissolved oxygen over all sites and depths in Gilbert Bay were 17.7 degrees Celsius, 8.2, and 6.2 mg/L, respectively. The deep brine layer sites in Gilbert Bay (sites 2, 5, and 6) were consistent with each other, each with a pH of 7.7. The deep brine layer sites were also hypoxic with an average dissolved oxygen concentration of 0.5 mg/L.

Metal and Metalloid (Metals) Concentrations

The effects of metals in water on aquatic organisms can range from necessary and beneficial to toxic, depending on the metal and the concentration. In addition, the salinity of the water can affect how metals behave (that is, transport, cycling, and storage). As stated in the section titled Salinity, Chemical Stratification, and Its Effects on Metal and Metalloid Concentrations on page 60, some metals are more soluble in anoxic water, and the concentrations of these metals were markedly increased in the anoxic deep brine layer compared to the upper, more oxygenated brine layer of Gilbert Bay where aquatic organisms reside.

Recognizing that they are not directly applicable, but seeking to benchmark water quality results, UDWQ compared lake metals concentration data to Utah numeric freshwater water quality chronic criteria for the protection of freshwater aquatic life and U.S. Environmental Protection Agency (EPA) chronic criteria for the protection of ocean aquatic life.

In 2011 and 2012, UDWQ analyzed Gilbert Bay upper and lower brine layer samples for arsenic, copper, cadmium, lead, total mercury, methyl mercury, selenium, and thallium (see Table 4-3, Water Quality Averages in Gilbert Bay from UDWQ's Water Quality Sampling, on page 55). The report discusses the average concentrations of metals in Gilbert Bay and states that, generally, metals concentrations increased from the upper brine layer to the deep brine layer at sites where a deep brine layer was present.

- The average of arsenic concentrations in Gilbert Bay over all sites and depths over the monitoring period ranged from 27.9 to 157 micrograms per liter (µg/L). Arsenic concentrations doubled at sites where there was a deep brine layer, where the average arsenic concentration in the shallow layer was 67.1 ± 20.8 µg/L (range of 27.9 to 100 µg/L) increasing to 113.4 ± 19.6 µg/L (range of 85.1 to 157 µg/L) in the deep brine layer. UDWQ compared arsenic concentrations to both the EPA recommended ocean chronic criterion of 36 µg/L and the freshwater criterion of 150 µg/L, which is higher. Arsenic concentrations exceeded the ocean criterion in 97% of samples in Gilbert Bay. However, only one arsenic measurement exceeded the freshwater aquatic criterion: site 2 for the deep brine layer.
- The average of copper concentrations in Gilbert Bay over all sites and depths over the monitoring period ranged from 0.175 to 15.0 µg/L. Copper concentrations increased with depth from 1.8 ± 0.6 µg/L (range of 0.88 to 3.75 µg/L) in the shallow layer to 5.6 ± 5.4 µg/L (range of 0.175 to 15 µg/L) in the deep brine layer. Copper concentrations exceeded the ocean criterion of 3.1 µg/L in 17% of the total samples, mostly in the deep brine layer. No samples of copper exceeded the freshwater criterion.
- The average of lead concentrations in Gilbert Bay over all sites and depths over the monitoring period ranged from 0.439 to 13.4 µg/L. Four percent of lead samples exceeded the ocean criterion of 8.1 µg/L, all of which were located at sites where the deep brine layer was present (sites 2 and 6). No samples of lead exceeded the freshwater criterion.
- The average of mercury concentrations in Gilbert Bay's upper layer over the monitoring period ranged from 1.23 to 10.30 nanograms per liter (ng/L), and methyl mercury concentrations ranged from 0.15 to 2.88 ng/L. In contrast, mercury and methyl mercury in the deep brine layer ranged from 26.4 to 47.3 ng/L and 8.7 to 29.3 ng/L, respectively. Of all samples, 19% of the measurements exceeded the human-health-based criterion of 12 ng/L; all exceedences were in the deep brine layer. Similarly, 10.5% of measurements exceeded the methyl mercury freshwater aquatic benchmark of 2.8 ng/L. However, none of the measurements, even those from the deep brine layer, exceeded the EPA total mercury ocean aquatic criterion of 940 ng/L.
- Measurements of cadmium, selenium, and thallium in the water column were below the method detection limit or below the reporting limit in the majority of samples, and concentrations were estimated. None of the sample results for these analytes exceeded the freshwater or ocean criteria or benchmarks.

Metals Concentrations in Gilbert Bay Brine Shrimp. UDWQ states (UDWQ 2014c, 11):

> Aquatic organisms take up metals from the water and food which can result in concentrations that exceed the concentrations in the surrounding water. Exposure to these pollutants can be transferred up the food chain from lower to higher trophic levels. In Gilbert Bay, brine shrimp and brine flies occupy a middle trophic level, and their entire life cycle occurs within the lake. Brine shrimp and brine flies can absorb metals directly from the water or take up metals from the algae they feed upon. Predators such as birds can be exposed when they eat the shrimp or flies.

In 2011 and 2012, UDWQ collected 32 brine shrimp samples from Gilbert Bay and analyzed them for arsenic, cadmium, copper, lead, total mercury, selenium, and thallium. UDWQ did not collect or analyze brine flies. Metals were detected. However, since UDWQ does not have benchmarks for metals in brine shrimp, no comparisons were made.

What is a trophic level?

A trophic level is organisms at the same position in the food chain.

Nutrient Concentrations

UDWQ states (UDWQ 2014c, 16):

> Nutrients (phosphorous and nitrogen) are natural parts of aquatic ecosystems and support the growth of algae and aquatic plants that provide food for aquatic organisms. However, excess nutrients can lead to an overabundance of algae that degrades water quality, threatens aquatic organisms, and impairs recreational uses. For several reasons discussed below, nutrient and algal dynamics in [the Great Salt Lake] are very different than in most waterbodies. Among other complications, the potential effects of nutrient enrichment on the aquatic life uses are different among the lake's bays. The hydrologic modifications of dikes and causeways restrict circulation from Farmington to Gilbert Bay, potentially resulting in higher concentrations of nutrients in Farmington Bay and lower concentrations in Gilbert Bay. [At the same time, Farmington Bay might also be the main source of nutrients to Gilbert Bay.] In Gilbert Bay, brine shrimp are indiscriminate filter feeders that strongly control algal densities by grazing, and the productivity of brine shrimp is dependent on the amount of food/nutrients available. Algal abundance can rapidly increase when brine shrimp abundance is low and then rapidly decrease as brine shrimp abundance increases. This boom-and-bust cycle typically occurs 2 to 3 times per year from April to October. Peak algal abundance in Gilbert Bay typically occurs between November and April when brine shrimp grazing is absent. Algal growth is limited by nitrogen during this time.

In 2011 and 2012, UDWQ analyzed upper and lower brine layer samples from Gilbert Bay for dissolved phosphorus, nitrogen, and chlorophyll-a.

- Dissolved phosphorus concentrations in Gilbert Bay over all sites and depths over the monitoring period ranged from 0.05 to 1.61 mg/L. The average concentrations of dissolved phosphorus in the upper and deep brine layers were 0.18 ± 0.04 mg/L and 0.72 ± 0.12 mg/L, respectively. On average, bay-wide, over all depths, 70% of total phosphorous is in the dissolved form.
- Dissolved nitrogen concentration in Gilbert Bay over all sites and depths over the monitoring period ranged from 2.53 to 9.07 mg/L. Concentrations of dissolved nitrogen in the upper and deep brine layers were an average 2.9 ± 0.18 mg/L and 6.8 ± 1.28 mg/L, respectively. On average, bay-wide, over all depths, 91% of total nitrogen is dissolved.
- Chlorophyll-a concentrations in Gilbert Bay over all sites and depths over the monitoring period ranged from 0.004 to 128 µg/L. Concentrations of chlorophyll-a in the upper and deep brine

layers were an average 11.7 ± 27.9 µg/L and 43.3 ± 36.2 µg/L, respectively. The greatest concentrations of chlorophyll-a, ranging from 1.02 to 128 µg/L, occurred at site 8 located in the culvert between Farmington and Bear River Bays.

In Gilbert Bay, there is a large difference in nutrient concentrations between the upper and deep brine layer, which suggests two pools of nutrients. The total-nitrogen-to-total-phosphorous ratio of 9 supports the conclusion that Gilbert Bay is nitrogen limited, as reported by Belovsky and others (2011) (UDWQ 2014c, 17). Chlorophyll-a concentrations are a surrogate measure of algal productivity and represent the amount of photosynthesizing algae in the water column. The boom-and-bust cycle for algae in Gilbert Bay is reflected in the highly variable chlorophyll-a concentrations.

4.1.4 Water and Salt Balance Model Results

As discussed in Section 3.1.4, Water and Salt Balance Model Results, UPRR conducted water and salt balance modeling to evaluate the effects of the proposed project on the North and South Arms. The modeling effort determined lake salinities and salt loads resulting from the baseline condition, when the east and west culverts were operating as free flowing (unobstructed) and as they existed in November 2012 before they were closed.

Under the culvert simulations, culverts free-flowing and at the November 2012 position prior to closure, the salinities and salt loads of the North and South Arms varied, based on lake inflows, lake levels, causeway characteristics and density gradients.

4.1.5 Existing Permitted Discharge Sites

UPRR reviewed existing permitted discharges to the North and South Arms of the Great Salt Lake to understand what other types of activities and permitted discharges might affect the water quality in the project area. UDWQ permits discharges to waters of the state under the Utah Water Quality Act (UAC R317-8) through the Utah Pollutant Discharge Elimination System (UPDES) rules. Under this program, industries and municipalities that discharge wastewaters or other pollutants into water bodies must obtain a UPDES permit. UPDES permits are implemented consistent with water quality protection measures prescribed as part of each permit. UPRR accessed the state database to identify UPDES permitted facilities that discharge directly to the Great Salt Lake (AGRC 2014).

Figure 4-8 below shows the existing permitted discharges to the Great Salt Lake in relation to the project area. Approximately 100 permitted facilities that discharge directly to the lake are shown; however, over 600 permitted facilities exist and discharge to the lake’s tributaries upstream of the boundaries of the lake (AGRC 2014). Figure 4-9 below shows the municipalities with permitted stormwater discharges to the Great Salt Lake in relation to the project area. Fifty-five municipalities, including Box Elder, Weber, Davis, and Salt Lake Counties, and UDOT have regulated stormwater discharges to the lake and nearby tributaries (UDWQ 2014b).

Figure 4-8. Existing UPDES Permitted Facilities

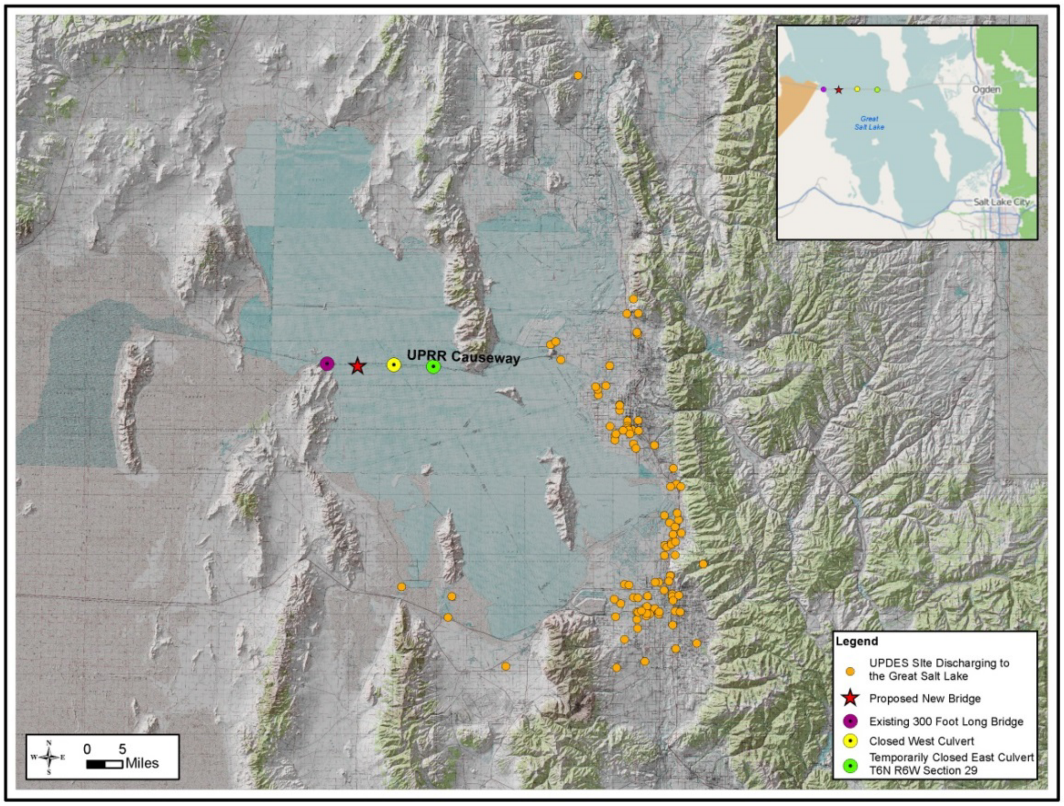
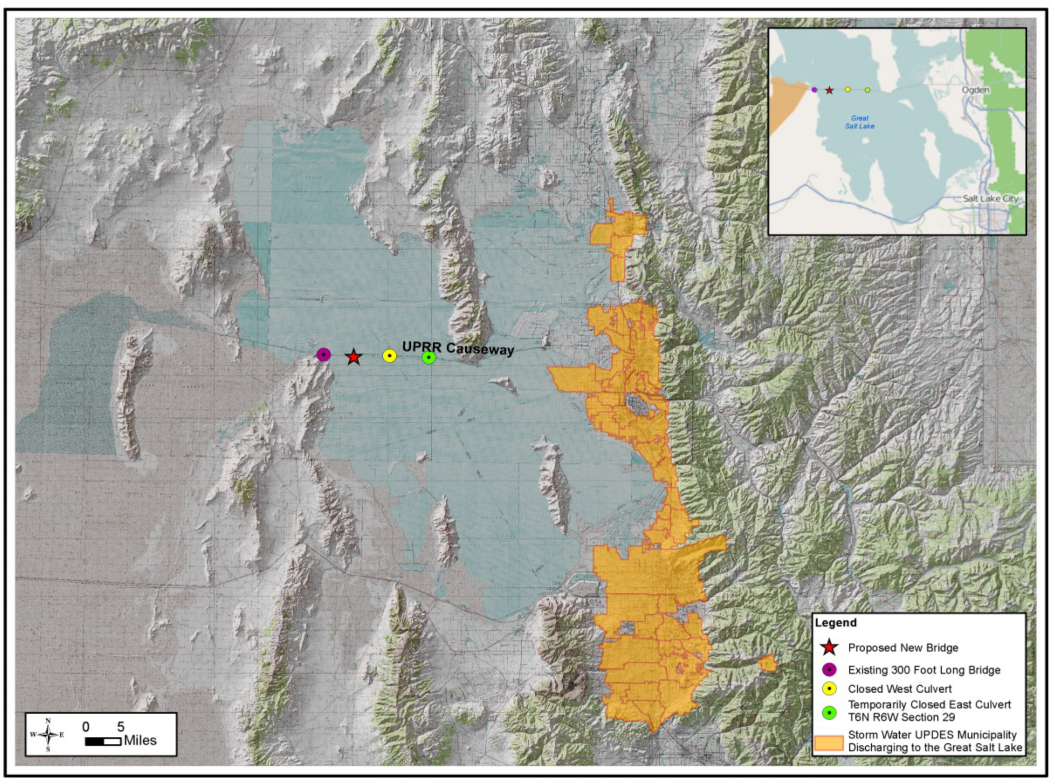


Figure 4-9. Existing UPDES Stormwater Discharge Permitted Municipalities



4.1.6 Other Published Water Quality Data

UPRR reviewed other published water quality studies in Gunnison and Gilbert Bays of the lake, some of which are qualitative. As stated in Section 4.1.3, General Description of the Great Salt Lake's Water Quality, past quantitative water quality analyses are suspect due to analytical procedures and accuracies, and UDWQ does not consider them to be representative of baseline conditions. Although a complete literature review of all water quality is not appropriate due to data reliability, applicability to the project or project area and changing lake conditions, some of the more recent publications and studies are summarized below.

- UGS (1980) discussed and reviewed metals analyses data in the context of commercial extraction. This report identifies average concentrations of copper, zinc, cadmium, mercury, lead, arsenic, manganese, molybdenum, selenium, and silver for the upper and lower brine layers in the South Arm and through the North Arm. The report describes the challenges of consistent analytical procedures due to interferences of the high salt concentrations; however, it concludes that the metals concentrations are low throughout the lake, with the highest concentrations occurring in the deep brine layer. The authors compared the total and dissolved concentrations to interim EPA mining effluent limits and concluded that the metals are present at a lower concentration than the limits. The authors also compared the in-lake concentrations to surface water inflows and in-lake sediment concentrations. The authors conclude that soluble metal concentrations are low and that the total metals, along with suspended clays, organic materials, and carbonates, are dropping out to form the sediment layer of the lake, which is confined by the anaerobic conditions of the deep brine layer.
- Many water quality studies, coordinated by the Great Salt Lake Science Panel in the mid-2000s, were conducted to support the UDWQ efforts to establish the selenium tissue-based water quality standard. These studies focused on how selenium, a trace metal, is transported through the lake to biological receptors (brine shrimp and brine flies) and on the resulting toxicity of selenium in birds. These studies led to the current egg-tissue-based water quality criteria for selenium in Gilbert Bay.
- Mercury and methyl mercury studies are discussed in Chapter 6, Mercury and Methyl Mercury.
- A qualitative discussion published by UDFFSL (2013) indicates that, due to the lake's high salinity, some pollutants are sequestered (not bioavailable), but that these pollutants might become available to aquatic organisms if the lake becomes less saline. This report identified the primary pollutants of concern as selenium, mercury and nutrients and identified that more monitoring is required to determine whether beneficial uses are affected by poor water quality.

UPRR determined that water quality studies focusing on the Bear River Bay (Willard Spur) and Farmington Bay (nutrient studies) are not directly related to the project or project impacts and do not need be addressed in this report.

4.2 Environmental Consequences

This section describes the potential effects of the proposed project on the lake's water quality.

4.2.1 Methodology

To evaluate the potential effects of the project on water quality in the North and South Arms, UPRR reviewed available quantitative and qualitative lake water quality data and reports that describe water quality and key factors that affect water quality and conducted water and salt balance modeling for the project with the 150-foot-long bridge.

What are water quality effects?

Water quality effects are defined as changes caused by the project that are outside the historic range of variability for salinity and salt load based on the water and salt balance model results. A *water quality effect* is also defined as the release of a pollutant that would degrade the lake's existing water quality.

For this analysis, *water quality effects* are defined as changes caused by the project that are outside the historic variability for salinity and salt load based on the water and salt balance model results. Salinity and salt load changes are used as a surrogate for specific water quality parameters (UDWQ 2014a). That is, if there were no significant change in salinity, then the factors that affect the fate and transport of specific water quality parameters would not be changed, so there would not be a significant effect on water quality. A *water quality effect* is also defined as the release of a pollutant that would degrade the lake's existing water quality.

The lake's beneficial uses have not been determined to be impaired by the historic variability of salinity and salt loads (UDWQ 2010, 2014c). Nevertheless, the project would have an adverse effect if it were to change the salinity and salt loads such that these parameters are not within their historic variability and those changes outside the historic variability were to impair the lake's beneficial uses.

4.2.2 Factors That Affect Water Quality in the Great Salt Lake

Table 4-4 summarizes the factors that, according to qualitative and quantitative studies, cause variability in the lake's water quality. The impact analysis considers how the proposed action and alternatives might affect these factors and, therefore, variability in water quality.

Table 4-4. Factors That Affect Water Quality

Source	Type of Study	Factors that Cause Variability in Water Quality
USGS 2000	Qualitative and quantitative	Quantity of fresh water inflow, WSE, causeway conveyance properties, and mineral extraction
UGS 2002	Qualitative	Causeway fill properties (hydraulic conductivity) size and elevation of causeway openings relative to lake levels
Wurtsbaugh and Jones 2012	Qualitative	Flows transferred through the causeway between the North and South Arms

4.2.3 Effects of the Proposed Action and Alternatives

As discussed in Section 3.1.4, Water and Salt Balance Model Results, UPRR prepared model simulations for the proposed action and alternatives and compared the results to the baseline simulations with the free-flowing culverts in place. These model simulations generally resulted in a slight change in South Arm salinity and salt loads. For the proposed action, three of the four models resulted in an increase of the South Arm salinity and salt load compared to the baseline conditions, and, for one of the models (2012 UPRR/USGS Varying Hydrology Model, dry cycle), the South Arm salinity and salt load decreased compared to the baseline conditions. For all model runs, the South and North Arm salinities and salt loads varied in response to lake inflows, lake levels, head differences between the North and South Arms, causeway characteristics, and the relative relationship between lake levels and causeway openings.

Table 4-5 summarizes the water and salt balance effects associated with each alternative simulation compared to the baseline simulation. Table 2-2, Rankings of Bridge Alternatives Evaluated by the UPRR/USGS Models, on page 17 summarizes the overall ranking of the proposed action and alternatives in terms of water and salt balance model results.

Table 4-5. Model Results Comparison of South Arm Salinity and Salt Loads (Compared to Baseline [a])

Model	Proposed Action: 150-foot-long Bridge, 4,183 Feet [b]	Alternative A: 180-foot-long Bridge, 4,178 Feet	Alternative B: 150-foot-long Bridge, 4,178 Feet	Alternative D: 150-foot-long Bridge, 4,188 Feet
Salinity				
2012 UPRR/USGS Model – Average change in South Arm salinity over the 26-year model period	+1.3%	+2.7%	+1.9%	+0.2%
2012 UPRR/USGS Varying Hydrology Model – Average change in South Arm salinity at equilibrium when the lake reaches the target WSE				
Wet cycle, WSE 4,209 feet	+0.3%	+0.5%	+0.4%	+0.2%
Mild cycle, WSE 4,200 feet	+0.2%	+1.0%	+0.5%	–0.3%
Dry cycle, WSE 4,195 feet	–1.2%	+2.6%	+0.9%	–5.3%
Salt Load				
2012 UPRR/USGS Model – Average change in South Arm salt load over the 26-year model period	+0.2 BT average	+0.35 BT average	+0.24 BT average	–0.01 BT average
2012 UPRR/USGS Varying Hydrology Model – Average change in South Arm salt load at equilibrium when the lake reaches the target WSE				
Wet cycle, WSE 4,209 feet	+0.07 BT	+0.12 BT	+0.10 BT	+0.05 BT
Mild cycle, WSE 4,200 feet	+0.03 BT	+0.15 BT	+0.08 BT	–0.06 BT
Dry cycle, WSE 4,195 feet	–0.17 BT	+0.33 BT	+0.09 BT	–0.67 BT

BT = billion tons; WSE = water surface elevation

[a] Baseline is the condition in which the east and west culverts are free flowing and the compensatory mitigation is not in place.

[b] The proposed action includes Bridge Alternative C.

UPRR conducted water and salt balance modeling of the alternatives and compared the effects of the proposed action and alternatives on South Arm salinity and salt loads to the baseline simulation. The proposed action would best match the baseline conditions for water and salt loads. Alternative A would be least similar to the baseline conditions for water and salt loads for most of the models, and, therefore, would have the most potential to result in long-term salinity and salt load changes that differ from historic variability or to change future variability. The water quality effects of Alternatives B and C would be somewhere in between those described for the proposed action and Alternative A.

Using salinity as a surrogate for specific water quality parameters, the proposed action would best match the South Arm salinity effects compared to the baseline simulations, such that the variability in salinity would remain within the historic variability and would not impair the lake's beneficial uses.

What is salinity?

Salinity is the saltiness of water or the quantity of dissolved solids in water, which can be expressed as a percentage.

Existing water quality data for the upper and deep brine layers in Gilbert Bay are variable and limited, and, due to the lack of data, no conclusions can be made regarding water quality trends for any of the alternatives or for the water quality parameters analyzed. UPRR examined the water quality data (for arsenic, lead, selenium, total phosphorus, and dissolved oxygen) for three sites across Gilbert Bay. The data show some similarities of pollutant concentrations among the three sampling sites, both spatially and vertically, but the analyses are based on 2 years of data and are representative of sample sites only (only one of which is near the project site). Because the proposed action would not change the salinity and salt load outside the historic variability for which more data are available, it is also unlikely to adversely affect water quality trends.

No water quality data are currently collected to characterize Gunnison Bay. The extent to which the proposed action and Alternatives A, B, and D might affect water quality in Gilbert Bay and Gunnison Bay also cannot be determined due to a lack on long-term information about the pollutants that are being monitored.

The proposed action would not affect the salinity and salt load variability of the lake, since the bridge that is part of the proposed action would be sized to match as closely as possible the ratio of north-to-south and south-to-north flows provided by the free-flowing culverts. Therefore, the proposed action would not affect the long-term transfer conditions (and associated water quality conditions) between the North and South Arms.

All of the alternatives would require a permit to place fill into waters of the state, and no discharge of any pollutants would occur with the project. Further, any permit would contain conditions prohibiting the release or discharge of pollutants (metals and nutrients) that would potentially degrade water quality. Because all of the alternatives would comply with permit conditions, none of them would cause long-term water quality effects that could impair the lake's beneficial uses.

Finally, sources of pollutants (metals and nutrients) to both arms of the lake have been documented as surface water inflows and permitted discharges (UGS 1980). The proposed action and alternatives would not affect surface water inflows or existing or future permitted discharges. The proposed action and alternatives would not have a permitted effluent discharge to the lake, so none of the alternatives would increase the concentrations of pollutants in the lake.

In summary, the proposed action and alternatives would not affect the long-term variability in water quality (metal and nutrient concentrations) in a way that would impair the lake's beneficial uses and cause a significant adverse effect.

4.2.4 Effects of the No-Action Alternative

With the no-action alternative, the east culvert would remain temporarily closed pending the identification and approval of a permanent closure solution. UPRR would necessarily continue to seek USACE and UDWQ approval to make the east culvert closure permanent. In addition, the compensatory mitigation element of the proposed action would not be implemented, with the result that the aquatic functions of the culverts would not be replaced until the necessary approvals are granted.

Any resulting adverse change of water quality (outside of historic variability) caused by an incremental reduction in water and salt transfer through the causeway that impairs the lake's beneficial uses and continues unmitigated with the no-action alternative would likely continue until a permanent closure solution and mitigation plan is approved and implemented. UPRR also would necessarily continue to pursue USACE and UDWQ approval of an acceptable compensatory mitigation plan in support of making the east culvert closure permanent. It would be speculative to predict how long a new or revised individual permit action and corresponding mitigation proposal would take to be approved.

4.2.5 Construction-Related Effects

During project construction, all of the alternatives could reduce local water quality for a short period of time due to placing temporary fill for the shoofly and removing the fill once the new bridge is complete. Permit conditions will require UPRR to minimize these short-term water quality effects to the extent practical. Because these construction-related water quality effects would be short term and would be reduced by using best management practices, they would not impair the lake's beneficial uses and cause a significant adverse effect.

4.2.6 Post-construction Short-Term Effects

For the proposed action and alternatives, once the bridge is in place and the shoofly is removed, the bridge would be opened to convey water between the North and South Arms. When the bridge is opened, there would be a period of less-than-minimal post-construction short-term effects during which the differences in WSE and salinity between the two arms would rapidly change. Over time, the differences would move toward equilibrium, and the post-construction effects would no longer exist. For more information about these post-construction short-term effects, see Section 3.2.7, Post-construction Short-Term Effects, in Chapter 3, Water Chemistry.

UPRR analyzed the short-term post-construction transition period that was observed when the existing 300-foot-long bridge was opened in 1984. Short-term post-construction effects on lake WSE and salinity were evaluated. Data suggest that, when the 300-foot-long bridge was opened in 1984, the head difference declined sharply for about 6 weeks, less dense (less saline) water appeared in the North Arm, and the deep brine layer in the South Arm became denser (more saline).

During the 1984 transition period, no short-term effects on North and South Arm salinities were documented as causing a significant adverse effect and impairing the lake's beneficial uses, and no new or additional data would support a different outcome with the proposed action or one of the alternatives.

5 Deep Brine Layer

This chapter describes the existing conditions of the deep brine layer of Gilbert Bay and the potential effects on the deep brine layer from the proposed project. Other lake water characteristics are water chemistry, which is discussed in Chapter 3, Water Chemistry; water quality, which is discussed in Chapter 4, Water Quality; and mercury and methyl mercury, which are discussed in Chapter 6, Mercury and Methyl Mercury.

What is a deep brine layer?

A deep brine layer is a lower, denser (more saline), fetid layer of water in a saline lake. A deep brine layer requires stratified waters that do not completely circulate, meaning that the lower layers of the lake do not mix with water that is above.

5.1 Affected Environment

This section reviews the methods used to describe the affected environment (also known as existing conditions), describes the presences and sources of the deep brine layer of Gilbert Bay as measured by UGS, and reviews other published data.

5.1.1 Methodology

To describe the existing characteristics of the deep brine layer in the Great Salt Lake, UPRR reviewed existing literature about the deep brine layer and analyzed available water chemistry data.

5.1.2 General Description of the Great Salt Lake's Deep Brine Layer

A deep brine layer is a lower, denser (more saline), fetid layer of a lake with stratified waters that do not completely circulate, meaning that the deep brine layer does not completely mix with water that is above. In the Great Salt Lake, the deep brine layer has most recently been documented to occur only in parts of the South Arm. This report focuses on the deep brine layer in Gilbert Bay, which is part of the South Arm.

What is a halocline?

A halocline is a relatively sharp discontinuity in salinity at a particular depth. Water with a higher concentration of salinity sinks below water that is less saline; therefore, saltier haloclines lie below less salty ones.

Gunnison Bay (the North Arm) has most recently been documented to be completely mixed throughout the water column. That is, the difference in density between the upper water layers and the lower water layers is not as great in Gunnison Bay as it is in Gilbert Bay. Gunnison Bay has historically had periods with a deep brine layer; however, UGS data indicate that, since the 1990s, the water in Gunnison Bay has been well mixed (see Section 5.1.4, Brine Conditions of the North Arm).

In the Great Salt Lake, the North Arm receives little freshwater inflow and is always more saline than the South Arm, which receives much more freshwater inflow. When the North Arm WSE is below about 4,200 feet, the North Arm can remain at saturated salinities (UDFFSL 2013). This higher-saline water is denser, and it underflows via a density gradient through the causeway to the South Arm of the lake (Wurtsbaugh and Jones 2012), resulting in a deep brine layer in the South Arm. This deep brine layer is a halocline where the lower water layer is significantly more saline than the upper water layer.

The top of the deep brine layer in the South Arm was documented to occur at about 4,180 feet in elevation from 1965 through 1984 (UGS 2002). From 1984 through 1998, the transition zone between the top of the deep brine layer and the water above the deep brine layer, an area called the interface, elevated to a depth of 4,189 feet in elevation, after which it began a subside as the lake levels lowered. By 1992, there was no interface in the South Arm. From 1998 to 2004 and from 2005 to 2010, an interface appeared again, reaching a maximum elevation of about 4,178 feet each time.

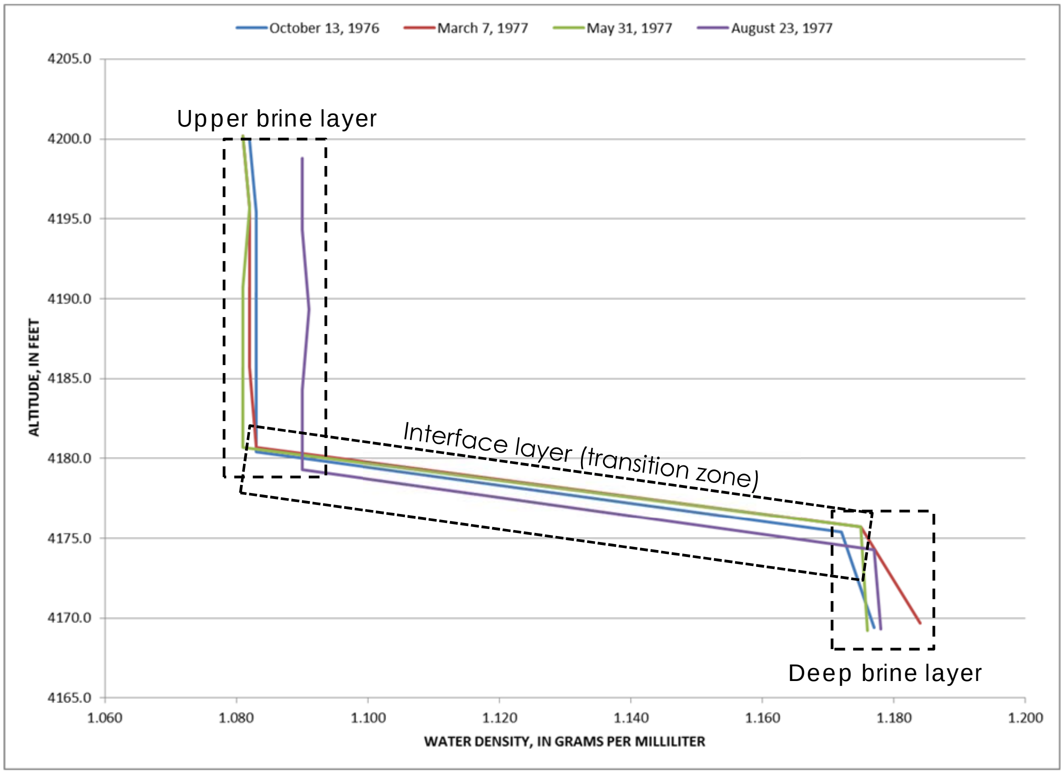
The presence of a halocline suggests that there is a source, or multiple sources, of brine more saline than the South Arm feeding the deep brine layer. The deep brine layer can, at times, be extensive, covering about 44% of the area of Gilbert Bay (Wurtsbaugh and Jones 2012). At other times, due to reduced fresh water inflows and associated lake levels, reduction of north-to-south flows, and vertical mixing of the upper and deep brine layers, the deep brine layer can disappear (UGS 2002).

Since the causeway was built, the deep brine layer in the South Arm has been observed and described by various agencies and researchers, particularly UGS. However, none of the agencies or others who have studied the deep brine layer has been able to quantify the parameters that control the rates of diffusion and mixing of the deep brine layer with the upper brine layer. Therefore, data describing the occurrence and variation of this deep brine layer are lacking. Currently, neither the state nor federal government has regulations concerning this deep brine layer.

The Great Salt Lake Comprehensive Management Plan (CMP) provides a description of the deep brine layer. The CMP explains that "brine flowing to a bay of less salinity tends to resist mixing with the fresher water and remains in a fairly coherent 'tongue'" (UDFFSL 2013). This tongue is a result of the deep brine sinking and pooling in the deepest pockets of the lake. The CMP also describes the deep brine layer as hypersaline, turbid, and generally anoxic. The anoxic conditions occur when the halocline is present for several years at a time. Because of the stable condition and limited interaction with surface winds, the deep brine layer has limited exposure to oxygen, thus becoming anoxic.

Another distinct feature of the deep brine layer is the interface, which is gradational-density zone between the deep brine layer and the upper brine layer (Gwynn 2014). This interface, or transition, zone is visible on a density profile graph. Figure 5-1 below shows a water density profile of the South Arm at UGS sampling location AS2 between 1976 and 1977. Water density was analyzed in a laboratory at 20 degrees Celsius and was reported in the *Great Salt Lake Brine Chemistry Database, 1966–2011* (UGS 2012).

Figure 5-1. Halocline in the South Arm at UGS Sampling Location AS2



Source: Data analyzed from UGS 2012

Each dated sample shown in Figure 5-1 above shows three distinct sections. The top layer of the column stays at nearly the same density, or concentration. This is the top, less-dense upper brine layer that covers the South Arm. The middle layer has an abrupt increase in salinity representing the transition zone or interface. The bottom layer steadies and remains at a nearly constant concentration to the bottom. This bottom layer, shown at about 1.180 grams per milliliter (g/mL) in Figure 5-1, is the deep brine layer. For the data shown, the deep brine layer of Gilbert Bay is about 9% more saline than the upper brine layer.

Although the flow from the North Arm of heavier brine is nearly continuous (Loving and others 2002), the deep brine layer in the South Arm does not generally increase in depth. This indicates that the deep brine layer is continually eroding and mixing with the upper brine layer (Wurtsbaugh and Jones 2012). UGS has also stated that, when the elevation of the top of the deep brine layer is at about 4,180 feet, it is stable (becoming neither larger nor smaller in volume) as a result of equal rates of north-to-south flows and mixing between the deep brine layer and the upper brine layer (UGS 2002).

5.1.3 Available Published Data

UDWQ released for comments the draft 2014 Integrated Report (UDWQ 2014c). Chapter 7 of the report is devoted to the Great Salt Lake and interprets the water quality data from 2011 and 2012 that UDWQ provided to UPRR before the report was published, as well as other data and information. UDWQ divided its assessment into four parts: (1) salinity, chemical stratification, and its effects on metal and metalloid concentrations; (2) temperature, pH, and dissolved oxygen; (3) metals; and (4) nutrients. Recall that no samples were collected from Gunnison Bay. UPRR has reproduced UDWQ's observations about Gilbert Bay's water quality and summarized them in the section titled Draft 2014 Integrated Report in Section 4.1.3, General Description of the Great Salt Lake's Water Quality.

UGS has historically collected and continues to collect water chemistry samples in both the North and South Arms, and analyses of these samples are reported in the *Great Salt Lake Brine Chemistry Database, 1966–2011* (UGS 2012). In the early years of the UGS lake-monitoring program, a field density and brine temperature were taken. For some reason, these two parameters were discontinued in about 1986, and the only density that has been reported since then is the laboratory density. The field density was often not very accurate due to the bouncing boat platform from which the samples were taken.

The chemical analyses associated with the monitoring program measure Na, Mg, K, Ca, Cl, SO_4, and TDS. In the early years of the program, Li, B, and Br were analyzed. Analysis of these parameters was discontinued 1986, since UGS had acquired enough data to characterize the nature of the elements in the lake. A weight percentage of TDS is also calculated and reported as salinity.

Chemical Concentrations

Na^+	Sodium, in grams per liter (g/L)
Mg^{+2}	Magnesium, in g/L
K^+	Potassium, in g/L
Ca^{+2}	Calcium, in g/L
Cl^-	Chloride, in g/L
SO_4^{-2}	Sulfate, in g/L
Br	Bromine, in parts per million (ppm)
Li	Lithium, in ppm
B	Boron, in ppm
TDS	Total dissolved solids, in g/mL
WT%-TDS	Weight percentage of total dissolved solids

Not all of the analyses are performed for all sampling locations. According to UGS, early in the sampling program, numerous locations were sampled, but data indicated that fewer sampling locations were sufficient to characterize the lake (UGS 2012). Currently, only two to three locations are sampled during each sampling event. At a few locations in the North and South Arms—LVG4 and RD2 in the North Arm and AS2, FB2, RT2, and RT4 in the South Arm—a fairly continuous record of chemical analyses is available from 1966 through 2011 (UGS 2012).

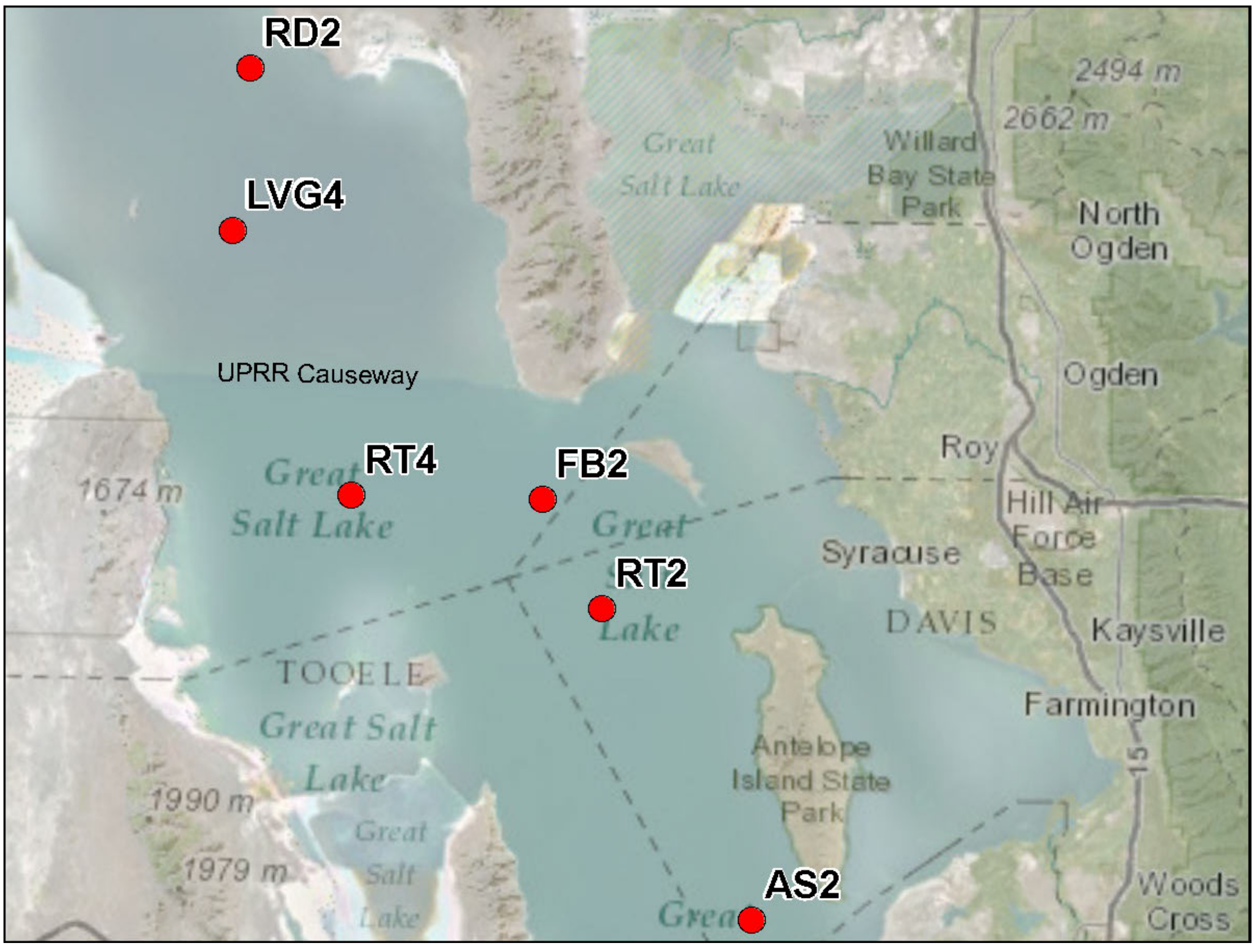
UGS conducts sampling events as funding permits, but typically biannually. Recently, UDFFSL has funded the sampling program to about $15,000 per year, and the main reason samples were not taken oftener was that, due to a shortfall in funding, UGS has to coordinate boat transportation with either the Utah Division of Water Quality or the Utah Division of Parks and Recreation (which manages part of the lake). The research tower locations (RT2 and RT4) report density at depths of every 5 feet down to about the interface and then every foot to the bottom of the lake throughout the water column. All other sampling locations report densities typically at every 5 feet throughout the water column.

To describe and evaluate the deep brine layer for this report, UPRR obtained and evaluated the reported laboratory density measurements from six of the UGS sampling locations across the Great Salt Lake. Due to a lack of longevity in most sampling locations, only two sampling locations were used for the North Arm evaluations and four for the South Arm evaluations. Table 5-1 below shows the name, area, lake bed elevation, and period of record for each sampling location. Figure 5-2 following the table shows the locations of the six sampling locations used for this report.

Table 5-1. UGS Sampling Locations for Deep Brine Layer Evaluation

Name	Area	Lake Bed Elevation (feet)	Density Period of Record
AS2	South Arm	4,169	1966–2012
FB2	South Arm	4,171	1966–2012
LVG4	North Arm	4,173	1966–2007, 2011–2012
RD2	North Arm	4,176	1967–2007, 2011–2012
RT2	South Arm	4,169	1978–2009
RT4	South Arm	4,169	1984–2004, 2007–2010

Figure 5-2. UGS Sampling Locations Used for the Deep Brine Layer Evaluation



5.1.4 Brine Conditions of the North Arm

Historic UGS data indicated the presence or non-presence of a deep brine layer in the North Arm over time. When a deep brine layer is present, a typical water column includes a well-mixed upper brine layer, a relatively small interface layer where mixing occurs, and a deep brine layer that increases in density with depth. If a deep brine layer is not present, a typical water column will be completely mixed with little variability between the upper and lower layers.

UPRR used density data starting from the top of the interface layer downward to represent and characterize the deep brine layer in the North Arm. By inspecting the water column density profiles and the data, UPRR observed that the top of the interface layer was identifiable by a typical density change of 0.5% or greater with depth in the water column. The interface layer was calculated at each selected sampling location over time for a vertical and spatial analysis. See Figure 5-1 above for a sample density profile.

Vertical Density Evaluation

UPRR evaluated data from two UGS sampling locations, LVG4 and RD2, in the North Arm to analyze the water column and to determine the presence and behavior of a deep brine layer during a 12-year sample period (2000–2012). These locations provide the most longevity of data in the North Arm, since they lack data from only late 2007 to early 2011. This data gap was due to site access restrictions.

The laboratory densities for each location were plotted against the sample elevation for a density profile graph to show the variability of the deep brine layer, if one was present. Figure 5-3 and Figure 5-4 below show the density profile graphs for LVG4 and RD2.

Both locations show relatively similar densities with depth at each sample date. An evaluation of the profiles shows that the North Arm, for most of the sampling events, was completely mixed vertically in the water column during 2000–2012, containing no halocline or deep brine layer. Two of the density profiles (2011 and 2012) indicate the presence of halocline. These finding are generally consistent with previous studies of the North Arm brine during different periods (UGS 2002; Wurtsbaugh and Jones 2012).

Figure 5-3. North Arm Density Profile for UGS Sampling Location LVG4

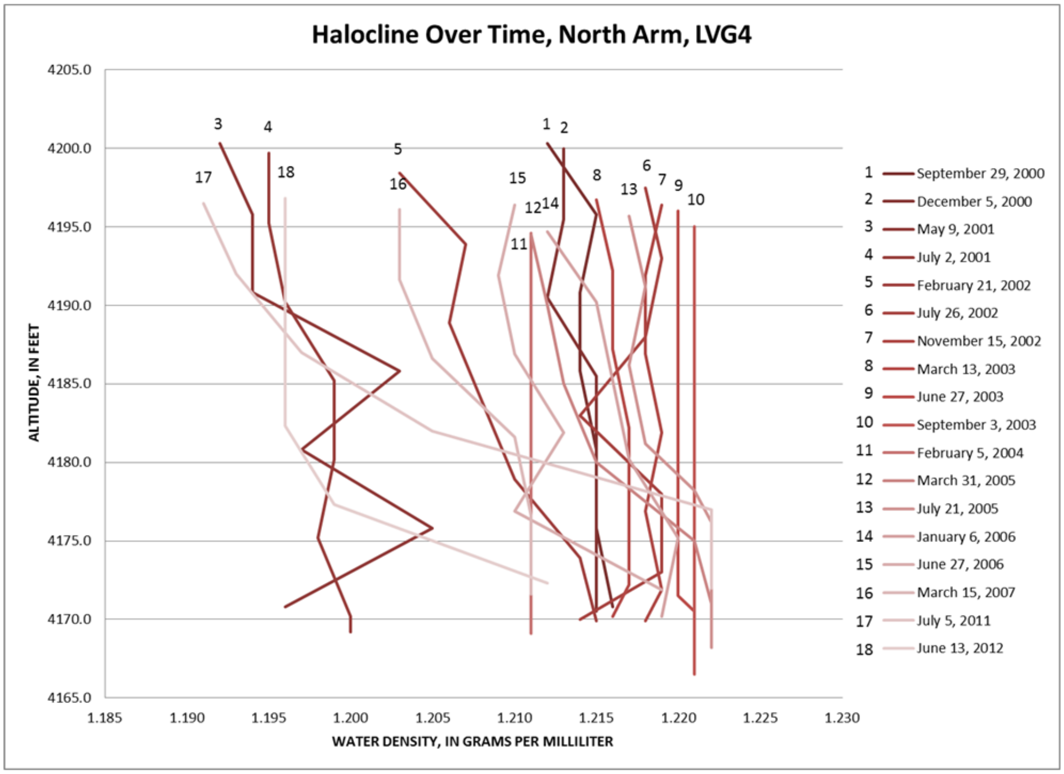


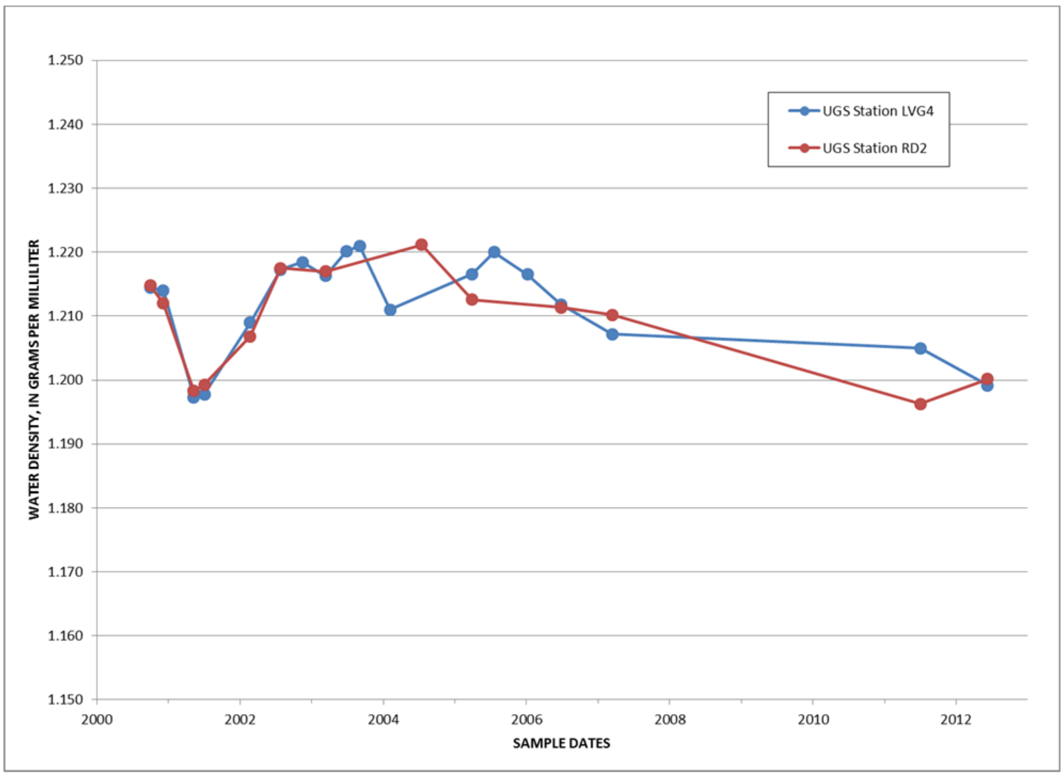
Figure 5-4. North Arm Density Profile for UGS Sampling Location RD2

Spatial Density Evaluation

To show how the lake water density in the North Arm varies spatially, UPRR compared densities at sampling locations LVG4 and RD2. Figure 5-5 shows the laboratory density over time for both locations. Sample dates containing data for both locations appear to have about the same densities, varying less than 0.009 g/mL between locations. UPRR also completed a regression analysis of the 18 overlapping sample dates between 2000 and 2012, and the results show a high correlation with a regression coefficient between the two locations of 0.91.

These results show that the North Arm was completely mixed spatially as well as vertically for most of the period 2000–2012. Therefore, based on this analysis, there is no evidence that a deep brine layer was continually present in the North Arm during 2000–2012, nor was there a spatial difference between the evaluated sampling locations.

Figure 5-5. North Arm Density for UGS Sampling Locations LVG4 and RD2



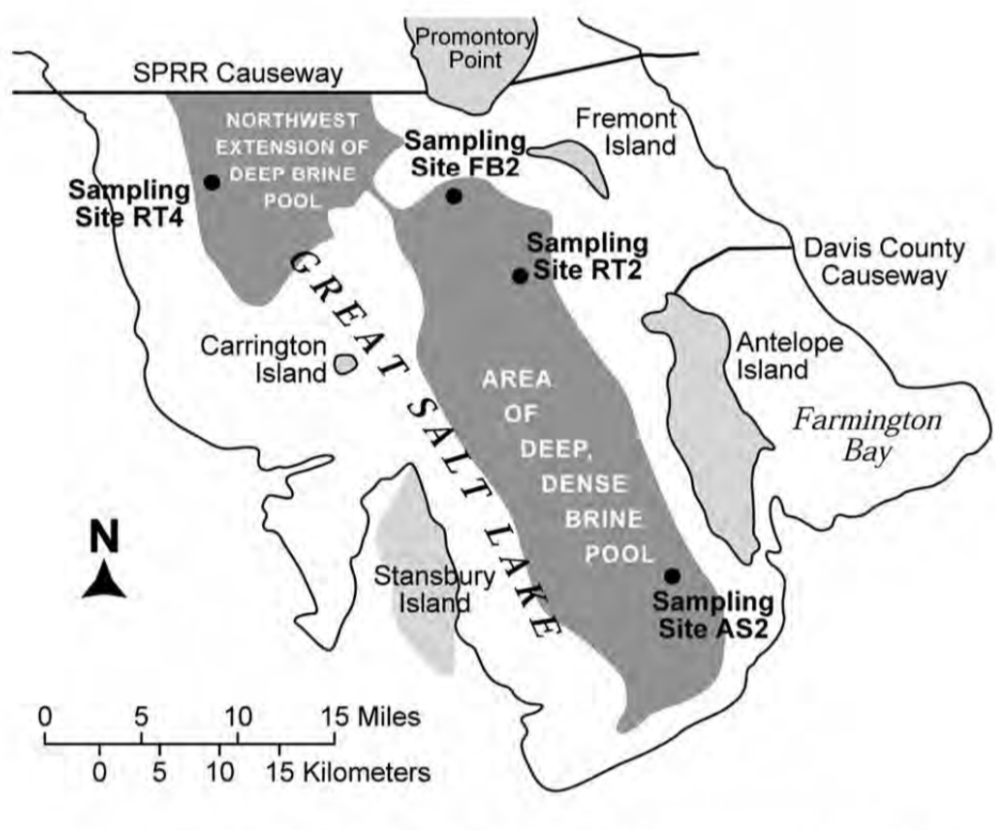
5.1.5 Brine Conditions in Gilbert Bay

For the spatial and vertical analysis of Gilbert Bay, UPRR evaluated data from four UGS sampling locations: AS2, FB2, RT2, and RT4. In Gilbert Bay, a topographical saddle-like ridge, or threshold, extends from Carrington Island to Promontory Point, as shown in Figure 5-6.This threshold separates the deep brine layer in the South Arm into two distinct pools. Figure 5-6 shows the passage of dense brine between the two pools over the threshold as well as the general location of the deep brine layer in the South Arm, when the top of the deep brine layer is at about 4,180 feet in elevation (UGS 2002). Figure 5-6 also illustrates that the deep brine layer is located in only the deepest parts of Gilbert Bay, or in areas where the lake bottom is the deepest.

Sampling location RT4 is located in the northwestern part of the South Arm and has a lake bed elevation of 4,169 feet. It is the only UGS sampling location on the west side of the threshold. UGS sampling locations AS2, FB2, and RT2 are all in the main part of Gilbert Bay. FB2 has a lake bed elevation of 4,171 feet, and AS2 and RT2 are located at a lake bed elevation of 4,196 feet, which is the lowest topographic elevation in Gilbert Bay.

Figure 5-6. Extents of the Deep Brine Layer

at elevation 4,180 feet



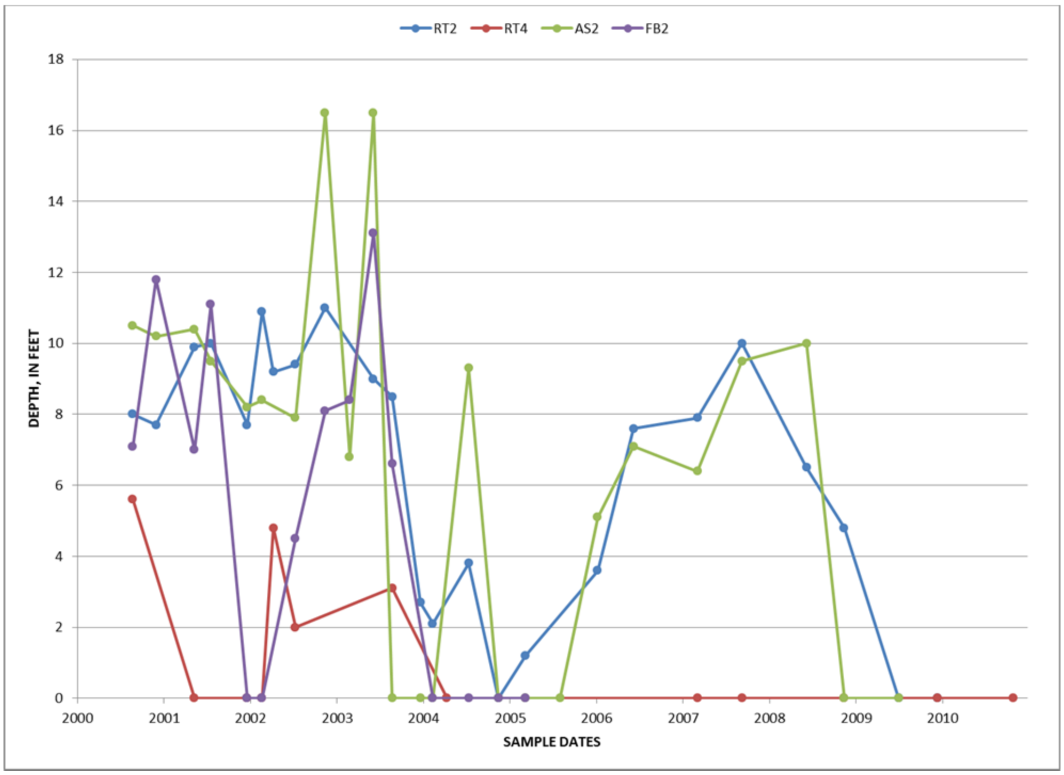
Source: UGS 2002

Vertical Density Evaluation

The density profile evaluation shows the variable presence of a halocline throughout the study period. To characterize the deep brine layer over time, the top of the transition zone of the deep brine layer was graphed over time at each location in Gilbert Bay. The deep brine layer starts at the top of the transition zone and continues down to the lake bed. UPRR used density data starting from the top of the interface layer downward to represent and characterize the deep brine layer. UPRR created density profile graphs for the four sampling locations for data collected during 2000–2012.

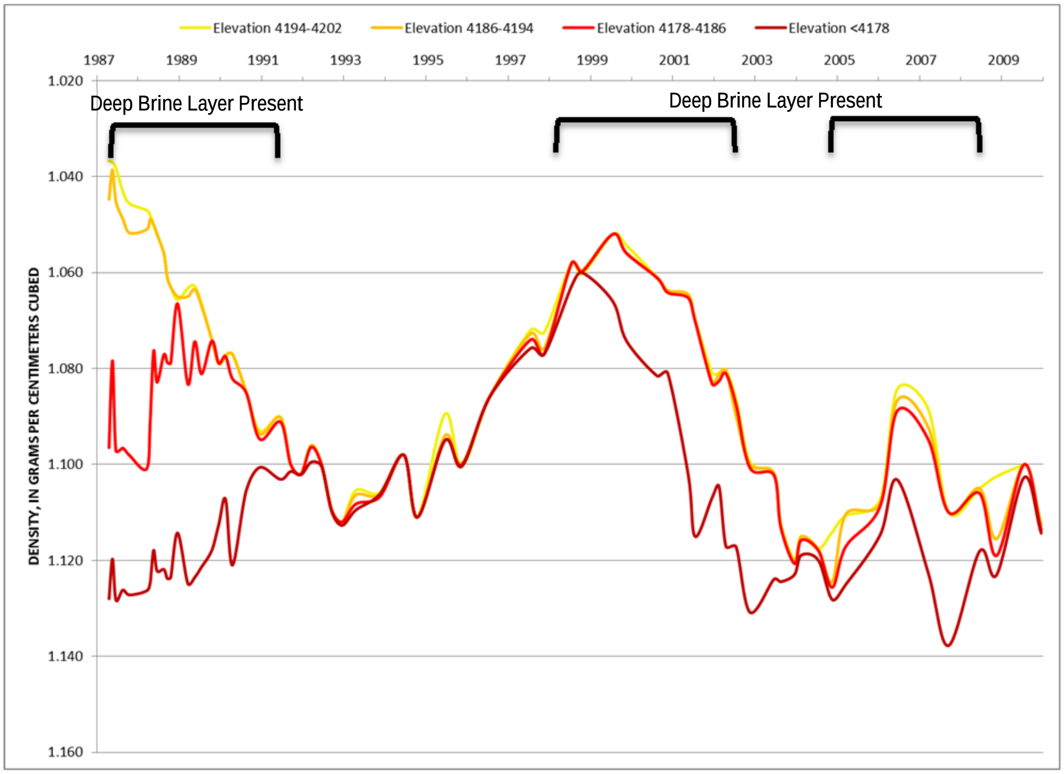
Figure 5-7 shows the depth of the deep brine layer for each of the four sampling locations throughout the study period. This graph can be interpreted to show that, in the northwestern pool (sampling location RT4), the deep brine layer has not existed since 2004 and was less frequent during the study period, occurring in 2000, 2002, and 2003 only. The graph also shows that the deep brine layer (at the AS2, FB2, and RT2 sampling locations) occurred more frequently and disappeared and reappeared at different locations at different times throughout the period 2000–2012.

Figure 5-7. Depth of the Deep Brine Layer in Gilbert Bay



However, when density is plotted against time for each of the sampling locations, the results show that, during the periods when there is no defined deep brine layer, there is complete mixing between the upper and deep brine layers. Figure 5-8 below shows the water densities at sample elevations in the water column over time for sampling location RT2. A deep brine layer is observed from 1987 to 1991 when the water column is clearly stratified. The deep brine layer occurs again from 1998 to about 2003 and from 2005 to 2009 when the upper densities become less saline. The deep brine layer is not observed from 1991 to 1998 when the water column is mixed. This pattern is consistent for all four sampling locations for the same period.

Figure 5-8. Deep Brine Layer in Gilbert Bay at UGS Sampling Location RT2



The UGS data show that the deep brine layer at these sampling locations is not continuously present for the period 2000–2010 because at times the upper and deep brine layers are completely mixed.

Great Salt Lake: A Scientific, Historical and Economic Overview (UGS 1980) states that the stratification of the brine in the South Arm into two layers was observed in 1965 after the construction of the rock-filled causeway. The periodic formation of the deep brine layer and the mixing of the deep brine layer with the upper brine layer, due to increased upper layer brine density, are also referenced in the Great Salt Lake Comprehensive Management Plan (UDFFSL 2013).

UGS (2002) suggests that multiple factors might contribute to the presence or non-presence of the deep brine layer in the South Arm. These factors include a reduction of north-to-south flow through the causeway; increased salinity of the upper brine layer, which can then more readily mix with the deep brine layer due to reduced lake inflows; and low lake levels, which drop the interface layer of the bidirectional flow below the causeway openings.

Spatial Density Evaluation

To show how the lake water density varies spatially, UPRR compared densities at the four UGS sampling locations. Water densities at sample elevations representing the deep brine layer and the upper brine layer were plotted over time for all four sampling locations and are shown in Figure 5-9 and Figure 5-10 below, respectively. The average water density that represents the deep brine layer across the sampling locations is 1.108 g/mL, with a range of 0.007 g/mL or 0.7%. The average water density that represents the upper brine layer across the sampling locations is 1.082 g/mL, with a range of 0.003 g/mL or 0.2%. These results show that the upper and deep brine layers are spatially mixed across the four UGS sampling locations for 2000–2012.

Figure 5-9. Densities in the Deep Brine Layer in Gilbert Bay

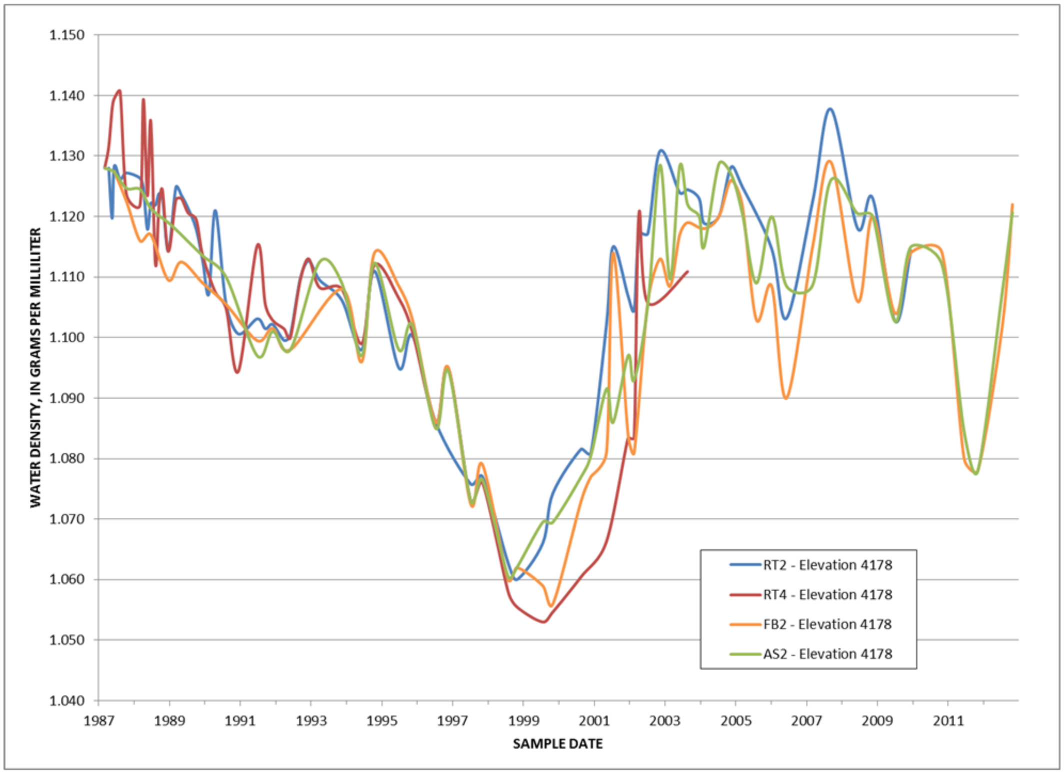
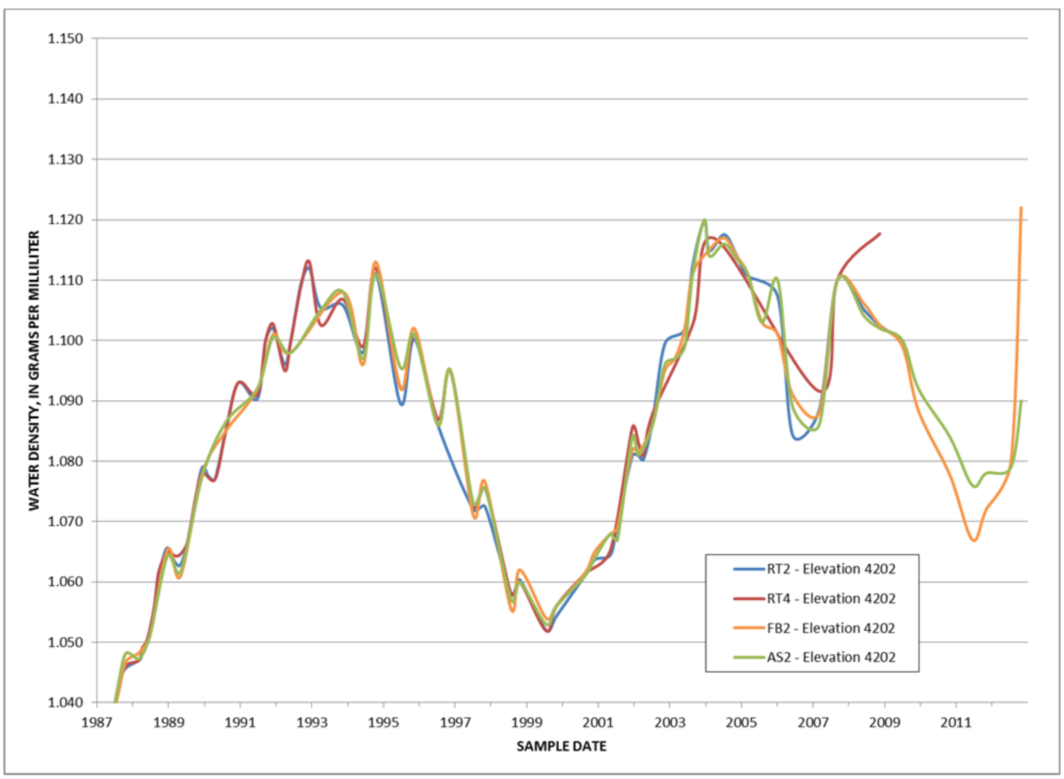


Figure 5-10. Densities in the Upper Brine Layer in Gilbert Bay



5.1.6 Sources of the Deep Brine Layer

UPRR reviewed published data and reports pertaining to the deep brine layer in Gilbert Bay. Although there are many references to the periodic stratification of brine, it appears that no study or research identifies the primary factors controlling the rates of mixing and diffusion (that is, the processes that lead to a deep brine layer).

USGS is currently conducting a study of deep brine flow across the threshold. USGS's preliminary findings show deep brine flowing in both directions, from the northwestern pool of the South Arm to the main part of the South Arm and from the main part of the South Arm to the northwestern pool. USGS has not published its findings and continues to research and study the flow of deep brine at the threshold (USGS 2014b).

UPRR conducted a regression analysis on water density data collected during 1987–2012 that examined the relationship between the presence of a deep brine layer and South Arm WSE and between the presence of a deep brine layer and total flow from the North Arm to the South Arm through the causeway fill and openings. Total north-to-south flow through the causeway was computed by the water and salt balance model originally developed by USGS (2000) and updated and modified by UPRR to simulate lake conditions for the period 1987–2012 (UPRR 2014a).

Table 5-2 shows the results of the analysis for each UGS sampling location. The higher the regression coefficient, the stronger the relationship between the variables. In other words, a higher WSE regression coefficient indicates that the presence of the deep brine layer is more correlated to WSE. However, these variables are not independent of each other. As the WSE increases, depth of flow through the causeway increases, which affects the head difference and density gradients that in turn affect the bidirectional flow through the causeway. The WSE coefficient is slightly higher, for some sites evaluated, than the north-to south flow coefficient, indicating a better relationship of WSE with the presence of a deep brine layer than with north-to-south flows through the causeway.

Table 5-2. Regression Coefficients for the Presence of a Deep Brine Layer in the South Arm

UGS Sampling Location	Regression Coefficient WSE	Regression Coefficient North-to-South Flows through Causeway	Overlapping Months
AS2	0.72	0.64	56
FB2	0.56	0.52	56
RT2	0.55	0.47	54
RT4	0.60	0.60	66

These results suggest that the deep brine layer might be more affected by the WSE, and thus inflows to the lake, than it is influenced by north-to-south flow through the causeway. However, because north-to-south flow is also partially dependent on WSE as well as on the causeway conveyance properties, it is probable that both contribute to the presence of the deep brine layer.

UPRR's conclusion after reviewing existing and ongoing studies about the known and suspected characteristics of the deep brine layer is that many factors might influence the presence or non-presence of the deep brine layer. The source of the South Arm's deep brine layer is likely the north-to-south flow through the causeway. What are not researched or determined are the controlling parameters that quantitatively affect the rate of diffusion and mixing between the upper and deep brine layers.

5.2 Environmental Consequences

This section describes the potential effects of the proposed project on the South Arm's deep brine layer. Because the North Arm is and has been well mixed, UPRR focuses the discussion on the presence of the deep brine layer in Gilbert Bay.

5.2.1 Methodology

UPRR reviewed existing qualitative and quantitative published studies discussing the deep brine layer to identify the key factors that affect the deep brine layer and then considered whether and how the proposed project might affect the factors in a way that would influence the deep brine layer and potentially impair the beneficial uses of Gilbert and Gunnison Bays. The deep brine layer is defined for this analysis as the presence of a halocline in parts of Gilbert Bay. For this analysis, *deep brine layer effects* are defined as changes caused by the project that are outside the historic variability of the deep brine layer, based on the review of data and the water and salt balance model results.

What are deep brine layer effects?

Deep brine layer effects are defined as changes caused by the project that are outside the historic variability of the deep brine layer, based on the review of data and the water and salt balance model results.

The lake's beneficial uses have not been determined to be impaired by the historic variability of the deep brine layer (UDWQ 2010, 2014c). Nevertheless, the proposed project would have an adverse effect if it were to change the deep brine layer, or the factors that affect the deep brine layer, such that these parameters are not within their historic variability and those changes outside the historic variability were to impair the lake's beneficial uses.

5.2.2 Factors That Affect the Deep Brine Layer in the Great Salt Lake

Though no studies have fully assessed the deep brine layer, three studies have hypothesized about the nature of the deep brine layer in the Great Salt Lake (Table 5-3). These studies discussed the vertical and spatial variability of the deep brine layer. Most of the studies concluded with the identification of factors that appear to cause the variability. UGS has documented the presence or non-presence of the deep brine layer since 1966; however, UGS publishes only the data results and does not provide any interpretation.

Table 5-3. Factors That Affect the Deep Brine Layer

Source	Type of Study	Factors
UGS 2002	Qualitative	Lake level, north-to-south flows, vertical mixing
Wurtsbaugh and Jones 2012	Qualitative and quantitative	North-to-south flows, vertical mixing, density gradient, storm events
UDFFSL 2013	Qualitative	Lake level, north-to-south flows, vertical mixing, upper brine layer density, density gradient

5.2.3 Effects of the Proposed Action and Alternatives

UPRR analyzed historic, measured laboratory densities (UGS 2012) to evaluate the variability of the deep brine layer and conducted water and salt balance modeling to evaluate the effects of the proposed action and alternatives on the deep brine layer.

As discussed in Section 3.1.4, Water and Salt Balance Model Results, UPRR prepared model simulations for the proposed action and alternatives and compared the results to the baseline simulations with the free-flowing culverts in place. These model simulations generally resulted in a slight change in South Arm salinity and salt loads. Table 5-4 below summarizes the water and salt balance effects associated with each alternative simulation compared to the baseline simulation. Table 2-2, Rankings of Bridge Alternatives Evaluated by the UPRR/USGS Models, on page 17 summarizes the overall ranking of the proposed action and alternatives in terms of water and salt balance model results.

What is laboratory density?

Laboratory density is water density as analyzed in a laboratory setting. This report uses water density as analyzed in a laboratory at 20 degrees Celsius and reported in the *Great Salt Lake Brine Chemistry Database, 1966–2011* (UGS 2012).

The parameters of the water and salt balance model that matter most when evaluating the deep brine layer are north-to-south flows and the ratio of south-to-north flows to north-to-south flows. The proposed action and alternatives would change north-to-south flows, some alternatives more than others, but the changes need to be considered along with the predicted south-to-north flows. Table 5-4 below shows the ratios of the average total north-to-south flows and south-to-north to north-to-south flows associated with each alternative for all of the model runs.

Table 5-4. Model Results Comparison of Ratio of Flows

Parameter	Culverts (Baseline Condition)	Proposed Action	Alternative A	Alternative B	Alternative D
2012 UPRR/USGS Model					
Average total flow north to south, cfs	917	1,398 (+481)	2,162 (+1,245)	1,687 (+770)	1,039 (+122)
Ratio of the average total south-to-north flow to north-to-south flow	2.16	1.83	1.55	1.70	2.11
2012 UPRR/USGS Varying Hydrology Model					
Wet Cycle					
Average total flow north to south, cfs	3,548	4,224 (+676)	4,817 (+1,269)	4,497 (+949)	3,999 (+451)
Ratio of the average total south-to-north flow to north-to-south flow	1.64	1.54	1.48	1.51	1.57
Mild Cycle					
Average total flow north to south, cfs	1,969	2,131 (+162)	2,907 (+938)	2,414 (+445)	1,779 (–190)
Ratio of the average total south-to-north flow to north-to-south flow	1.73	1.68	1.50	1.60	1.80
Dry Cycle					
Average total flow north to south, cfs	1,181	987 (–194)	1,822 (–641)	1,365 (–184)	500 (–681)
Ratio of the average total south-to-north flow to north-to-south flow	1.79	1.96	1.54	1.70	2.82

For all scenarios, Alternative A is the poorest match to the baseline conditions when comparing flow ratios. The proposed action flow ratio would most closely match the mild cycle for the 2012 UPRR/USGS Varying Hydrology Model. The Alternative B flow ratio would most closely match the dry cycle for the 2012 UPRR/USGS Varying Hydrology Model, and the Alternative D flow ratio would most closely match the baseline ratio for the 2012 UPRR/USGS Model and the wet cycle for the 2012 UPRR/USGS Varying Hydrology Model.

All of the modeled scenarios would increase north-to-south flow through the causeway with the exception of Alternative D under the mild cycle and all options tested under the dry cycle. The exceptions show a decrease in flow through the causeway and therefore a smaller amount of more-saline water moving from the North Arm to the South Arm. In all of the other cases, there would be a slight increase in north-to-south flow, a condition that could slightly increase the volume of the deep brine layer, depending on the mixing rate of the deep brine layer with the upper brine layer. UPRR analyzed the ratio of the bidirectional flows to minimize the overall effects on salinity. The magnitude of increase would depend on the alternative.

North-to-south flow is only one factor that is believed to influence the deep brine layer, and the proposed 150-foot-long bridge has been sized to best match the ratio of south-to-north to north-to-south flows in order to balance the lake salinity and salt loads. For Gilbert Bay, the other most widely documented factors that influence the deep brine layer are lake level, vertical mixing, diffusion, and the density gradient. The proposed action and alternatives would not affect the lake level, vertical mixing, diffusion, or the overall density gradient. UPRR does not expect the minor changes associated with any of the alternatives studied to significantly change the variable presence of the deep brine layer in Gilbert Bay, because research does not suggest that changing one of the controlling parameters influencing the deep brine layer (north-to-south flows) would change the presence or behavior of the deep brine layer.

Accordingly, the proposed action and alternatives would not adversely affect the variable presence or nature of the deep brine layer in parts of Gilbert Bay and, therefore, would not affect the long-term behavior of the deep brine layer in a way that would impair Gilbert Bay's beneficial uses.

5.2.4 Effects of the No-Action Alternative

With the no-action alternative, the east culvert would remain temporarily closed pending the identification and approval of a permanent closure solution. UPRR would necessarily continue to seek USACE and UDWQ approval to make the east culvert closure permanent. In addition, the compensatory mitigation element of the proposed action would not be implemented, with the result that the aquatic functions of the culverts would not be replaced until the necessarily approvals are granted.

Any resulting adverse change in the deep brine layer (outside of historic variability) caused by an incremental reduction in water and salt transfer through the causeway that impairs the lake's beneficial uses and continues unmitigated with the no-action alternative would likely continue until a permanent closure solution and mitigation plan is approved and implemented. UPRR also would necessarily continue to pursue USACE and UDWQ approval of an acceptable compensatory mitigation plan in support of making the east culvert closure permanent. It would be speculative to predict how long a new or revised individual permit action and corresponding mitigation proposal would take to be approved.

5.2.5 Construction-Related Effects

Construction of the proposed action and alternatives would not cause significant effects on any of the factors believed to influence the deep brine layer. Furthermore, the deep brine layer is documented to be variable, and a few months of construction activity at the bridge site are not likely to affect the overall variability. Because the construction-related effects would occur for a short period of time due to placing temporary fill for the shoofly and removing the fill once the new bridge is complete and would be reduced by using best management practices, they would not impair the lake's beneficial uses and cause a significant adverse effect.

5.2.6 Post-construction Short-Term Effects

For the proposed action and alternatives, once the bridge is in place and the shoofly is removed, the bridge would be opened to convey water between the North and South Arms. When the bridge is opened, there would be period of less-than-minimal post-construction short-term effects during which the differences in WSE and salinity between the two arms would rapidly change. Over time, the differences would move toward equilibrium, and the post-construction effects would no longer exist. For more information about these post-construction short-term effects, see Section 3.2.7, Post-construction Short-Term Effects, in Chapter 3, Water Chemistry.

UPRR analyzed the short-term post-construction transition period that was observed when the existing 300-foot-long bridge was opened in 1984. Short-term post-construction effects on lake WSE and salinity were evaluated. Data suggest that, when the 300-foot-long bridge was opened in 1984, the head difference declined sharply for about 6 weeks, less dense (less saline) water appeared in the North Arm, and the deep brine layer in the South Arm became denser (more saline).

During the 1984 transition period, the short-term effects on North and South Arm WSEs and salinities were not documented as impairing the lake’s beneficial uses, and no new or additional data would support a different outcome with the proposed action or one of the alternatives.

6 Mercury and Methyl Mercury

This chapter describes the existing mercury (Hg) and methyl mercury (MeHg) conditions of the Great Salt Lake. Water chemistry (salinity) is discussed in Chapter 3, Water Chemistry, and other water quality parameters are discussed in Chapter 4, Water Quality.

What is methyl mercury?

Methyl mercury (MeHg) is the bioavailable form of mercury (Hg). MeHg is converted from Hg by bacteria that live in anaerobic aquatic lakebed and wetland sediments and surface water. MeHg is a potent neurotoxin that bioaccumulates and biomagnifies in the food chain.

6.1 Affected Environment

This section reviews the methods that UPRR used to describe the affected environment (also known as existing conditions) and reviews published data about Hg and MeHg conditions in the lake. Section 6.1.2 describes the regulatory context. Section 6.1.3 reports what is known about Hg and MeHg in the lake and presents the results of recent studies that explored the fate and transport of Hg and MeHg. Section 6.2 describes the potential effects of the proposed project on Hg and MeHg.

6.1.1 Methodology

To describe the Hg and MeHg conditions in the lake, UPRR reviewed published qualitative and quantitative lake Hg and MeHg studies to identify the key factors that affect the sources, transport, and fate of Hg and MeHg and the Hg methylation process. UPRR also used the results of the water and salt balance modeling prepared for the proposed action and alternatives.

6.1.2 Regulatory Context

The water quality regulations that apply to the Great Salt Lake were described in Section 4.1.2, Water Quality Regulations for the Great Salt Lake. This section describes Hg-specific regulations and policies.

Water Quality Standard for Mercury. Water quality standards consist of designated beneficial uses and water quality criteria. As discussed in Section 4.1.2, Water Quality Regulations for the Great Salt Lake, the designated beneficial-use classes of water in the project vicinity reflect the different salinity and hydrologic regimes associated with different areas of the lake: Gilbert Bay (Class 5A), Gunnison Bay (Class 5B), Bear River Bay (Class 5C), and Farmington Bay (Class 5D) and their surrounding wetlands (Class 5E). Each of these waterbodies is protected through its associated beneficial-use class for infrequent primary and secondary contact recreation, waterfowl, shore birds, and other water-oriented wildlife including their necessary food chain. Gilbert Bay (Class 5A) is also protected for frequent primary and secondary contact recreation.

The attachments to the *2010 Utah Integrated Report Water Quality Assessment 305(b) Report* show that numeric Hg water quality criteria for the Great Salt Lake are under development but are not yet available (UDWQ 2010). Consequently, the water quality criteria that apply to Hg for the lake's beneficial uses are the narrative standards (UAC R317-2-7.2), which state:

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

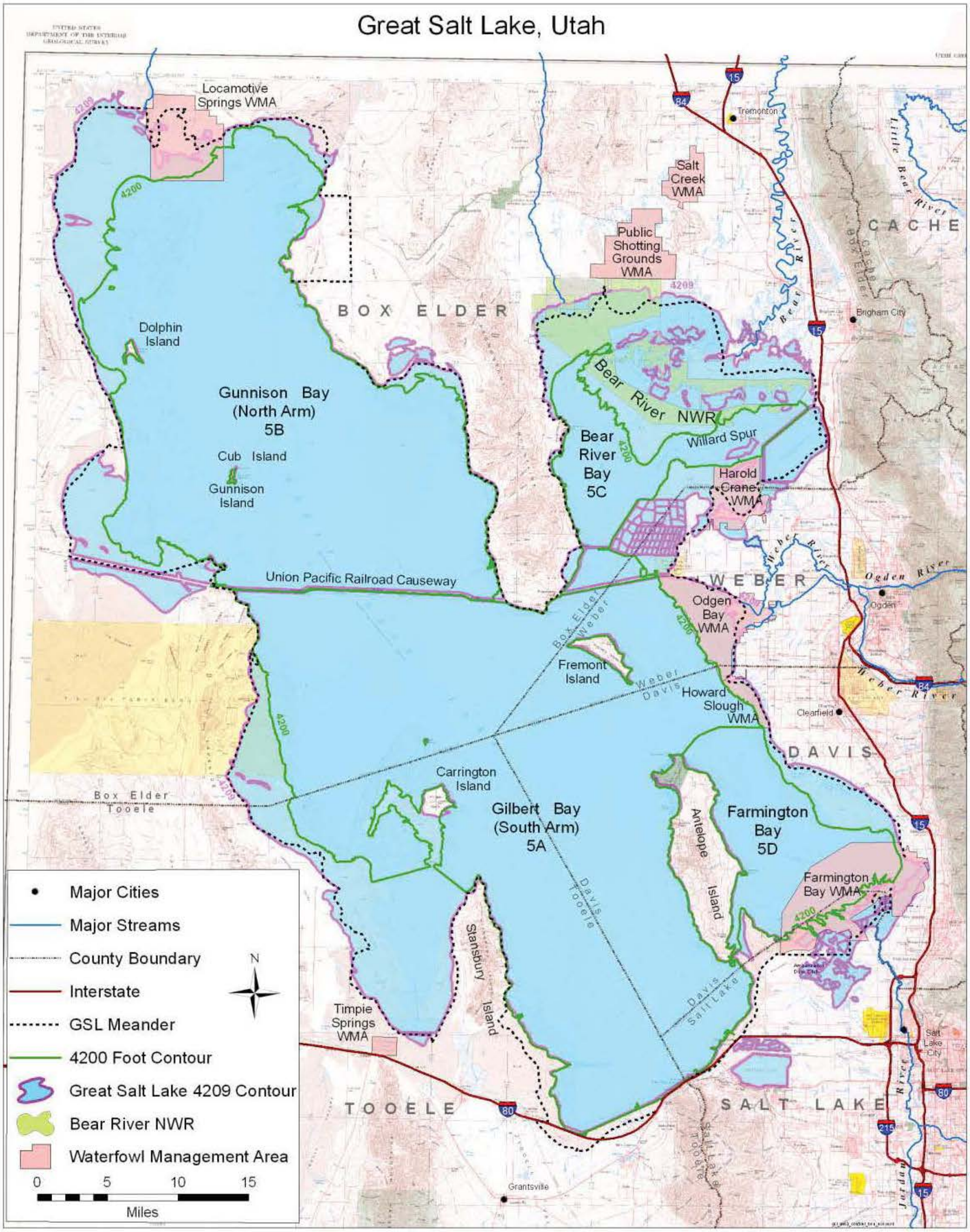
In other words, at this time, the Hg water quality standard in the project vicinity (Figure 6-1 below) consists of the designated beneficial uses for open water in Gilbert Bay (Class 5A) and Gunnison Bay (Class 5B) as well as the narrative standards.

Impaired Waters. Section 303(d) of the CWA requires that, every 2 years, each State submit to EPA a list of rivers, lakes, and reservoirs in the state that do not meet their water quality standards. Such waterbodies are designated as impaired. Based on a review of this list and its associated Total Maximum Daily Load Priority Schedule, the four Great Salt Lake bays are not listed as either impaired or unimpaired. The *2010 Utah Integrated Report Water Quality Assessment 305(b) Report* identifies the Great Salt Lake as Category 3B, which consists of waters whose data and information are insufficient to determine an assessment status (UDWQ 2010). The Great Salt Lake's status is expected to be updated in the 2012–2014 Integrated Report cycle. This report has been published in draft form in order to receive public comments.

Fish and Waterfowl Ingestion Advisories. In Utah, the Utah Department of Health's Environmental Epidemiology Program is responsible for developing fish and waterfowl ingestion advisories. Fifteen of Utah's waterbodies have fish ingestion advisories for Hg (UDWQ 2010, 2014c); however, none of these waterbodies is the Great Salt Lake. The lake does have Hg-based consumption limits for three duck species that forage in marshes on the eastern edges of Bear River and Farmington Bays (Utah Department of Health and Utah Division of Wildlife Resources 2014).

Antidegradation Policy. Along with protection of the Great Salt Lake for beneficial uses, the Utah Department of Environmental Quality (UDEQ) has an antidegradation policy that protects water bodies from activities that could lower or degrade water quality. Activities that lower or degrade water quality may be allowed if UDEQ determines that these activities are necessary for important economic or social development. To facilitate this policy, all waters in Utah are designated as Category 1, 2, or 3 waters. The Great Salt Lake is considered a Category 3 water and is subject to antidegradation reviews (UAC R317-2-12).

Figure 6-1. Designated Water Bodies and Beneficial Uses of the Great Salt Lake



Source: UDWQ 2012a

6.1.3 Mercury in the Environment

Hg is a global pollutant that ultimately makes its way into every aquatic ecosystem through the hydrologic cycle (Scudder and others 2009). USGS estimates that human-related sources account for 50% to 75% of the annual input of Hg to the global atmosphere and, on average, 67% of the total Hg that is deposited via the atmosphere in the United States. Elevated Hg concentrations that are attributed to atmospheric deposition have been documented in aquatic ecosystems worldwide, even ecosystems that are far from industrial sources of Hg.

What is methylation?

Methylation is the conversion of inorganic Hg to its organic form, MeHg.

Methylation is the single most important step in the environmental Hg cycle because it greatly increases Hg's toxicity and its potential for bioaccumulation (Scudder and others 2009). Laboratory studies estimate that the bioaccumulation potential for MeHg is a thousand-fold greater than that of inorganic Hg.

In aquatic ecosystems, MeHg is found in elevated concentrations throughout the food chain. Though lower-trophic organisms can be highly tolerant of MeHg burdens, physiological effects have been demonstrated in top predators at low concentrations (Scudder and others 2009). The process by which Hg is accumulated into the lower trophic levels of aquatic food webs is not well understood. Although diet has been demonstrated to be the dominant mechanism of MeHg uptake in fish, factors such as size, age, community structure, feeding habits, and food-chain length are also important in determining the ultimate concentration of MeHg in fish tissues.

Accumulation of MeHg in fish tissue is considered a significant threat to the health of both wildlife and people (Scudder and others 2009). About 95% or more of the Hg found in most fish fillets is MeHg. Women of child-bearing age and infants are particularly vulnerable to the effects of consuming Hg-contaminated fish.[1] As of 2006, 48 States, the District of Columbia, one territory (American Samoa), and two Native American tribes had issued fish-consumption advisories for Hg (Scudder and others 2009). These advisories represent 14,177,175 lake acres and 882,963 river-miles, or 35% of the United States' total lake acreage and about 25% of its river-miles (Scudder and others 2009).

6.1.4 General Description of Mercury in the Great Salt Lake

Hg is a contaminant of worldwide concern that is produced by mining and other industries. As in the rest of the United States, Hg is found in aquatic habitats throughout Utah (Gardberg 2011). Since 2000, 35 fish species from 200 river or stream sites and 122 lakes or reservoirs in Utah have been tested for Hg.[2] Based on those data and others, 15 of those sites have fish ingestion advisories for Hg, and all 15 have been placed on the state's Section 303(d) list as impaired due to its Hg concentration (UDWQ 2014c). Waterbodies in Utah that have fish tissue advisories are listed at www.fishadvisories.utah.gov.

Hg is found in three oxidation states: 0 (elemental), 1+ (or I; mercurous), and 2+ (or II; mercuric). These forms of Hg are called "species," and the transformation of these species into MeHg is a complicated multistep, multifactor process that defies simplification (CALFED Bay-Delta Program 2005). In general, in its oxidated form, Hg(II), which is the form most common in aquatic environments, can more easily react with chemical compounds (such as sulfur, carbon, and chloride) dissolved in water and create other gaseous, aqueous, and solid species of Hg. The conversion of Hg(II) to MeHg is important because MeHg is much more toxic than Hg(II).

[1] Hg is known to cause brain damage as well as kidney and lung problems in people and wildlife.

[2] Of the total amount of Hg found in fish muscle tissue, MeHg is more than 95% (Bloom 1992; ATSDR 1999).

Hg and MeHg are present in the sediment, surface water, brine shrimp (*Artemia franciscana*), and waterfowl of the Great Salt Lake. The conditions in Gilbert Bay's deep brine layer favor the conversion of elemental Hg to MeHg when elemental Hg is present. The fate and transport of MeHg within the Great Salt Lake and its food webs are not completely understood.

The sources of Hg that enters the Great Salt Lake are local rivers and the global atmosphere. Rivers enter the lake predominantly on its east side, more than 20 miles from the location of the proposed project. In 2007, USGS undertook a modeling study to differentiate between riverine and atmospheric sources of Hg that enters the Great Salt Lake (Naftz and others 2009). Based on that study, USGS estimates that about 80% of the Hg in the Great Salt Lake is of atmospheric origin and 20% is of riverine origin.

Although Hg has been measured in the sediment, water, and biota of the Great Salt Lake, the lake is not listed as impaired for Hg. The lake does have Hg-based consumption limits for three duck species that forage in marshes on the eastern edges of Bear River and Farmington Bays (Utah Department of Health and Utah Division of Wildlife Resources 2014).

UDWQ released for comments the draft 2014 Integrated Report (UDWQ 2014c). Chapter 7 of the report is devoted to the water quality conditions of the Great Salt Lake and interprets the water quality data from 2011 and 2012 that UDWQ provided to UPRR before the report was published, as well as other data and information. UDWQ divided its assessment into four parts: (1) salinity, chemical stratification, and its effects on metal and metalloid concentrations; (2) temperature, pH, and dissolved oxygen; (3) metals; and (4) nutrients. Recall that no samples were collected from Gunnison Bay. UPRR has reproduced UDWQ's observations about Gilbert Bay's water quality and summarized them in the section titled Draft 2014 Integrated Report in Section 4.1.3, General Description of the Great Salt Lake's Water Quality.

Gilbert Bay

The project site is bounded to the south by the open-water habitat of Gilbert Bay, which is part of the South Arm. Under various water level and hydrological conditions, Gilbert Bay stratifies into both a deep brine layer and an upper brine layer above, with average salinities of 16.5% to 22.9% in the deep brine layer and 12.6% to 14.7% in the upper brine layer. The deep brine layer is anoxic, and biota are found only in the oxygenated upper brine layer above it.

What is an anoxic environment?

An anoxic environment is an environment without oxygen.

Hg and/or MeHg have been measured in sediment, water, algae, brine shrimp, and eared grebes (*Podiceps nigricollis*) collected from Gilbert Bay (Table 6-1 below). Brine shrimp samples collected in 2006 and 2007 from the middle of the lake showed a statistically significant increase in Hg concentration from summer to fall. Brine shrimp cysts collected in the fall had Hg concentrations of 171 micrograms per kilogram (μg/kg) dry weight (Peterson and Gustin 2008).

Black and Swanson (2013) found that, along with dissolved organic carbon and sulfate, the MeHg concentrations in the deep brine layer were spatially invariable, while MeHg concentrations in the upper brine layer were variable, with the highest average concentrations measured in the southern part of the lake's South Arm. The authors also observed that the concentration of MeHg in the upper brine layer decreased over the summer.

Table 6-1. Range of Mercury Concentrations in the Sediment, Water, and Biota of Gilbert Bay

Location	Date(s)	Number of Samples	Concentration Range		Source
			Mercury	Methyl Mercury	
Grebe Livers (dry weight)					
Gilbert Bay	Nov. 1997	66	11.6 mg/kg (gMean), 12.6 mg/kg (max)	—	USFWS 2009
	Sept. 1998	12	6.69 mg/kg (gMean), 9.51 mg/kg (max)	—	
	Dec. 1998	4	13.5 mg/kg (gMean), 19.3 mg/kg (max)	—	
	Apr. 2000	3	4.39 mg/kg (gMean), 8.75 mg/kg (max)	—	
	May 2000	21	1.96 mg/kg (gMean), 20.5 mg/kg (max)	—	
Brine Shrimp (dry weight)					
Gilbert Bay	2011–2012	32	0.001–0.086 mg/kg	—	UDWQ 2014c
West of Antelope Island State Park	2006–2007	Multiple	0.28–0.45 mg/kg	—	Peterson and Gustin 2008
Gilbert Bay	1996, 1999	40	0.32 mg/kg (gMean), 0.38 mg/kg (max)	—	USFWS 2009
Gilbert Bay USGS Sites (1996)	1996	17	0.362 ppm (min), 0.601 ppm (max)	—	
Gilbert Bay USGS Sites (1999)	1999	27	0.284 ppm (min), 0.382 ppm (max)	—	
Gilbert Bay	2000	28	<0.2 ppm	—	

Table 6-1. Range of Mercury Concentrations in the Sediment, Water, and Biota of Gilbert Bay

Location	Date(s)	Number of Samples	Concentration Range		Source
			Mercury	Methyl Mercury	
Brine Shrimp Cysts (dry weight)					
Gilbert Bay USGS Sites, 1996	1996–1997	4	<0.2 ppm (mean)	—	USFWS 2009
Gilbert Bay USGS Sites, 1999	1999	4	<0.2 ppm (mean)	—	
Gilbert Bay	2000	28	<0.2 ppm (mean)	—	
Brine Flies (dry weight)					
Gilbert Bay	2008	—	Periphyton 152 ng/g (mean), larvae 189 ng/g (mean), pupae 379 ng/g (mean), adults 659 ng/g (mean)	—	Wurtsbaugh and others 2011
Upper Brine Layer					
Gil 1 through Gil 8, all depths	2011–2012	64	1.2–47.3 ng/L	0.2–29.3 ng/L	UDWQ 2014c
Gil 1 through Gil 8, 0.2 m from surface	2011–2012	31	1.2–10.3 ng/L	0.15–2.9 ng/L	
Gil 2 bottom Gil 5 bottom Gil 6 bottom	2011–2012	9	26.4–47.3 ng/L	8.7–29.3 ng/L	
West of Antelope Island State Park, near shore	2006–2007	Multiple	2.9 ± 0.7 ng/L to 6.7 ± 1.4 ng/L (filtered)	520 ± 240 pg/L to 2,500 ± 950 pg/L (filtered)	Peterson and Gustin 2008
West of Antelope Island State Park, middle of the lake	2006–2007	Multiple	2.3 ± 0.3 ng/L to 3.6 ± 1.9 ng/L (filtered)	800 ± 90 pg/L to 2,000 ± 500 pg/L (filtered)	Peterson and Gustin 2008
41.206ºN 112.672ºW [a]	2009–2011	3	13.9 ng/L	5.25 ng/L	Wurtsbaugh and Jones 2012
Site 2 (at 3 m)	2011		2.9 ng/L	1.5 ng/L	

Table 6-1. Range of Mercury Concentrations in the Sediment, Water, and Biota of Gilbert Bay

Location	Date(s)	Number of Samples	Concentration Range: Mercury	Concentration Range: Methyl Mercury	Source
Howard Slough [b] (at 10 cm)	2008	22	—	0.7–0.3 ng/L	Cline and others 2008
Gilbert Bay	1950–2010	Multiple	0.1–0.9 µg/g	—	Wurtsbaugh and Jones 2012
Deep Brine Layer					
Deep brine layer	2003–2007	15	—	24 ng/L (mean)	USGS data cited by Naftz and others 2009
Various	2009–2012	Multiple	—	Approx. 15–30 ng/L	Black and Swanson 2013
41.206ºN 112.672ºW [a] (at 7.8 m)	2009–2011	3	46.0 ng/L	26.3	Wurtsbaugh and Jones 2012
Not specified	—	—	7 ng/L (min), 100 ng/L (max)	31%–60% of total	Naftz and others 2008 cited by Barandiaran 2013
Site 2 (at 7.8 m)	Aug. 2001	2	89.1 ng/L (mean)	42.5 ng/L	Cline and others 2008
Sediment (dry weight)					
Site 3510 (at 0–2 cm)	2004–2006	2	0.126 mg/kg (mean)	—	Naftz and others 2009
Gilbert Bay	1996, 1999	38	0.220 mg/kg (gMean), 0.414 mg/kg (max)	—	USFWS 2009
Gilbert Bay USGS Sites, 1996	1996–1997	10	<0.2–0.373 mg/kg	—	
Gilbert Bay USGS Sites, 1999	1999	28	<0.2–0.414 mg/kg	—	

Of the total amount of Hg found in fish muscle tissue, MeHg is more than 95% (Bloom 1992; ATSDR 1999).

[a] Deepest part of Gilbert Bay; approximately 1 kilometer south of the UPRR causeway (Wurtsbaugh and Jones 2012)

[b] Howard Slough State Waterfowl Management Area

ppm = parts per million
mg/kg = milligrams per kilogram
µg/g = micrograms per gram
ng/g = nanograms per gram
ng/L = nanograms per liter
pg/L = picograms per liter

min = minimum
max = maximum
gMean = geometric mean
m = meters
cm = centimeters

Gunnison Bay

The project area is bounded to the north by Gunnison Bay, which is the lake's North Arm. An open-water habitat with little freshwater input, Gunnison Bay is often saturated with salt, and salinity has averaged ≥25% for the last 10 years. Gunnison Bay generally is not stratified, and the entire water column is oxygenated (Chapter 5, Deep Brine Layer). At this salinity, the biological resources of Gunnison Bay are limited to bacteria and algae (Chapter 7, Biological Resources). In 2012, Hg was measured in the surface water of Gunnison Bay at 17 nanograms per liter (ng/L) (Wurtsbaugh and Jones 2012).

Mercury Methylation

Hg methylation is a product of both biotic and abiotic processes. Sulfate-reducing blue-green bacteria and other microbes that thrive in conditions of low or no dissolved oxygen—conditions such as the sediment-water interface or the hypolimnion of a stratified lake—take Hg(II) and convert it to MeHg. MeHg can also be formed by abiotic (chemical) processes. Environmental factors such as temperature, dissolved organic carbon, salinity, acidity (pH), oxidation-reduction conditions, and the form and concentration of sulfur in water and sediments influence the rates of Hg methylation and the reverse reaction known as demethylation (Alpers and Hunerlach 2000). Iron also can play a role.

What are biotic and abiotic processes?

Biotic processes are associated with living organisms such as bacteria that interact with the ecosystem. Abiotic processes are associated with sunlight, temperature, chemical, and other non-living influences on the ecosystem.

Demethylation, which is the process by which MeHg is decomposed, can take place abiotically (chemically) or by the action of several demethylating microbes. Photolytic decomposition, which is chemical decomposition caused by light or any other form of electromagnetic radiation, is the only abiotic demethylation mechanism that is significant in surface waters exposed to sunlight (Naftz and Krabbenhoft 2008). The process of photolytic decomposition is documented as occurring near the shoreline between Bear River and Farmington Bays (Naftz and Krabbenhoft 2008).

What is a hypolimnion?

In a stratified lake, the hypolimnion is the bottom layer.

However, the overall effect of demethylation on the aquatic Hg cycle is still unclear, and the end products of the MeHg degradation have not been clearly identified. Regarding biotic demethylation, molecular biology researchers have shown that MeHg degradation performed by microorganisms generally proceeds through two distinct pathways: oxidative and reductive. Reductive demethylation is mainly linked to Hg resistance in the involved microorganisms. Both biotic pathways for MeHg degradation are encountered in aquatic environments (Barandiaran 2013).

The water chemistry of the Great Salt Lake is described in Chapter 3, Water Chemistry, and water quality is described in Chapter 4, Water Quality. A physical description of the Great Salt Lake's deep brine layer is provided in Chapter 5, Deep Brine Layer. Biological resources are described in Chapter 7, Biological Resources. When taken together, conditions that favor the conversion of Hg(II) to MeHg exist in Gilbert Bay's deep brine layer, when it is present. The deep brine layer:

- Is anoxic.
- Contains high concentrations of dissolved organic carbon and particulate organic carbon. Black and Swanson (2013) cite dissolved organic carbon concentrations from about 60 to 90 mg/L. In August 2010, particulate organic carbon was 0.10 mg/L in the upper brine layer and 11.2 mg/L in the deep brine layer (Wurtsbaugh and Jones 2012). In 2006 and 2007, dissolved organic carbon ranged from 35 to 53 mg/L in the deep brine layer (Peterson and Gustin 2008).
- Contains sulfate. Dissolved sulfides in the lake range from <0.1 to 1.4 mg/L (Barandiaran 2013).
- Is populated by cyanobacteria (blue-green algae), which are sulfate-reducing bacteria.

6.1.5 Fate and Transport of Methyl Mercury in the Great Salt Lake

Hg is present and is bioaccumulating in the Great Salt Lake. However, the fate and transport of MeHg, the bioavailable form of Hg, in the lake and its food webs are not completely understood. In the lake, brine shrimp feed on microbes containing MeHg. The brine shrimp are consumed by waterfowl, which can be consumed by people and higher-trophic species. In its methylated form, Hg accumulates through each of these steps.

Are the conditions in the deep brine layer favorable for mercury methylation?

Conditions in the deep brine layer are favorable for mercury methylation because the deep brine layer is:

- Anoxic
- High in dissolved sulfide
- High in organic carbon

In 2005, the Utah Department of Health and the Utah Division of Wildlife Resources issued consumption advisories for common goldeneye (*Bucephala clangula*), cinnamon teal (*Anas cyanoptera*), and northern shoveler (*Anas clypeata*) ducks because of high Hg levels in these species. The advisory specifies consumption limits for meat from these species of ducks that are harvested from marshes on the eastern edges of Bear River and Farmington Bays (Utah Department of Health and Utah Division of Wildlife Resources 2014).

The authors of a 2008 report that describes the biogeochemical cycling of Hg in the Great Salt Lake found that Hg and MeHg concentrations in the lake were among the highest reported in the United States (Naftz and others 2008). This finding came as a surprise because, prior to this study, other research had shown that salinity inhibits Hg methylation (Barandiaran 2013). The 2008 report prompted further research regarding Hg methylation and the presence of MeHg in the lake, including studies initiated at Utah State University, at the University of Utah, and by USGS (Naftz and others 2011; Wurtsbaugh and Jones 2012; Barandiaran 2013; Black and Swanson 2013; Hartman and others 2013).

UPRR reviewed four papers that describe MeHg fate and transport processes in the open-water conditions of the Great Salt Lake in the vicinity of the project site (that is, Gilbert and Gunnison Bays). A 2013 master's thesis (Barandiaran 2013) describes and reviews current knowledge (as of 2013), and a 2012 report discusses the relationship between the deep brine layer and Hg bioaccumulation in brine shrimp (Wurtsbaugh and Jones 2012). Another recent report describes MeHg hotspots in the lake (Black and Swanson 2013). A fourth paper documents the maternal transfer of MeHg between female brine shrimp and their cysts (Saxton and others 2013). The remainder of this section reviews the findings of these four papers.

Current Knowledge about Methyl Mercury in the Great Salt Lake

Danielle Barandiaran's 2013 master's thesis "Methylmercury Fate in the Hypersaline Environment of the Great Salt Lake: A Critical Review of Current Knowledge" (Barandiaran 2013) summarizes what is known about Hg methylation in the Great Salt Lake and assesses whether there is enough evidence to determine whether the methylation of Hg is due primarily to biotic or abiotic reactions in the lake. To meet this objective, Barandiaran (1) provides a thorough review of the state of knowledge about Hg and MeHg fate and transport, highlighting the apparent contradictions in the literature, contradictions that she attributed primarily to different environments, and (2) experimentally explores what happens to MeHg production when sulfate reduction is stopped in samples collected from the Great Salt Lake.

Based on the literature review and the experiment, Barandiaran observes that (1) biotic and abiotic processes other than sulfide reduction are occurring in the Great Salt Lake's water, (2) little Hg methylation is taking place in the upper brine layer, and (3) a greater amount of Hg methylation is taking place in the deep brine layer. Barandiaran summarizes her findings as follows:

> The biogeochemistry of Hg in saline aqueous environments is highly dynamic and complex. Its behavior in the GSL [Great Salt Lake] is further complicated by the unusual conditions of high elevation, high solar radiation, and extremely high salinity. Although there is much that could be improved with the microcosm study [a study she conducted], both the experimental results and the literature review suggest that both biotic and abiotic processes contribute to Hg methylation in the lake. Although the presence of MeSn [methyltin] and MeI [methyliodide] in the Great Salt Lake has not been investigated, based on the environmental history of the region, they probably occur in the lake and could contribute to Hg methylation. At the very least it would be good to determine background levels of MeI before proposed biofuel production involving high levels algae that produce MeI as a by-product are introduced into the lake.[3] I also recommend testing for microbes other than sulfate-reducing bacteria that are able to methylate Hg, such as iron-reducing bacteria and other microbes containing the hgcAB cluster genomes.

Barandiaran found that both biotic and abiotic processes contribute to Hg methylation in the lake but did not describe how MeHg might move from the deep brine layer to the upper brine layer.

[3] Increasing the lake's algae production was proposed as a means to decrease the concentration of Hg in algae consumed by brine shrimp and, hence, the concentration in brine shrimp. This process is called *biodilution*.

Deep Brine Layer and Mercury Bioaccumulation

Wurtsbaugh and Jones (2012) designed a laboratory study to assess the possible transport and transfer of MeHg from the Great Salt Lake's deep brine layer to brine shrimp. At the start, they hypothesized two mechanisms of transfer:

> **What is a chemocline?**
>
> A chemocline is the vertical density change within a water column.

- Turbulent mixing events during storms might entrain (transfer) some of the Hg-rich water from the deep brine layer into the mixed water above it, which is where the shrimp reside.
- Shrimp might pass through the interface layer that separates the deep brine layer and upper brine layer and feed there; if this area has higher levels of MeHg, then the shrimp could encounter higher MeHg levels.

Based on the results of the study, the authors rejected both hypotheses. No mixing was observed between the deep brine layer and the upper brine layer. Further, the authors found that the brine shrimp did not enter into or feed in the anoxic deep brine layer, as they initially hypothesized, but did feed on the abundant algae that accumulated on the deep brine layer's surface, in the interface layer. They observed:

> The mercury bioaccumulation in the shrimp is, however, moderated by the fact that the mercury in the deep brine layer is "diluted" by high concentrations of particulate organic matter there, and by the algae that grow when the deep water mixes with surface water. More work is needed to understand the cause of high total and methyl mercury concentrations in the deep brine layer and the hydrodynamics behind the mixing of deep brine water into the upper strata that contains the invertebrates which sustain bird populations and the cyst-harvesting industry in the Great Salt Lake.

Nevertheless, though not observed in their study, they concluded that MeHg must transfer out of the deep brine layer into the upper brine layer and that further studies would be needed to characterize that transport.

> [T]he transport of mercury and especially methyl mercury from the deep brine layer into the mixed [upper brine] layer via entrainment [transfer] is likely the dominant source of the mercury incorporated into brine shrimp and other invertebrates.

Methyl Mercury Hotspots in the Great Salt Lake

The goal of this study (Black and Swanson 2013) was to inform ongoing strategizing of ways to reduce or mitigate MeHg production in the Great Salt Lake. The objective of this study was to determine whether specific regions, media, or habitats of the lake are contributing more MeHg than others to the ecosystem.

> **What are sheetflow wetlands?**
>
> Sheetflow wetlands are areas that have a shallow layer of fresh water flowing over the land.

To address their objective, from 2009 to 2011, the authors collected water column, sediment, and pore water samples from multiple locations in the Great Salt Lake to examine the spatial and temporal distributions of Hg and MeHg. Included in the study were sediment and surface water within the freshwater-influenced bays, freshwater impounded wetlands, and sheetflow wetlands adjacent to freshwater bays. Then, for each habitat and zone, the MeHg production potential (MPP) was determined. The MPP is the rate that Hg(II) is converted to MeHg in the studied media. It accounts for both Hg methylation and demethylation processes and is experimentally determined by spiking the sediment or water sample with Hg(II) and measuring Hg(II) and MeHg after a period of time (such as an hour).

The authors found:

- Spatially, the highest average MeHg concentrations were measured in the surface water and pore water samples associated with the deep brine layer and sheetflow wetlands.
- Over the course of the summer, MPP remained fairly constant in the water column habitats but decreased in sediments.
- Despite favorable conditions and consistently high MeHg concentrations in the deep brine layer, measured MPPs were not as high as expected, based on studies performed at other locations. This study found that:
    - Hg concentrations in the deep brine layer were spatially invariable, while concentrations in the sediment slurry below the deep brine layer were spatially variable.
    - Within the deep brine layer, organic carbon, trace elements, sulfate, and sulfide showed little or no spatial variation.
    - Demethylation processes were most pronounced in the deep brine layer.
    - Based on literature reviews and study results, the deep brine layer appears to have a low fraction of bioavailable MeHg.
    - The sediment slurry provides a consistent source of MeHg to the deep brine layer.
    - There was no correlation between organic matter and methylation rates in the deep brine layer or the sediment slurry.
- The sheetflow wetlands also exhibited favorable conditions for MeHg production.
    - Sheetflow wetlands provide an ideal habitat for macroinvertebrate populations that represent food sources for nesting and migratory shorebirds.
    - A positive correlation was found between methylation rates and organic matter.

The study concludes:

> High and spatially content MeHg concentrations (approx. 15–30 ng/L) in the DBL [deep brine layer] of the Great Salt Lake could potentially provide for the transfer of MeHg to the Great Salt Lake ecosystem. However, entry of MeHg into the ecosystem may not be related to the DBL, but rather may occur within the freshwater wetlands on the eastern boundary of the Great Salt Lake. The highest concentrations of MeHg in water and sediment [that biota could contact] were found in the South Arm of the Great Salt Lake and the sheetflow wetlands, representing possible “hot spots” for MeHg introduction into the food web.

Therefore, as the authors expected, spatial variability in MeHg concentrations and production were observed between the various locations.

Maternal Brine Shrimp Transfer of Inorganic Mercury and Methyl Mercury to Brine Shrimp

The transfer of Hg from females to their offspring can play an important role in Hg accumulation and toxicity during early development. Saxton and others (2013) quantified the transfer of inorganic Hg and MeHg from female brine shrimp to their eggs from the Great Salt Lake. They reported that

> … essentially all of the mercury in both the female brine shrimp and their eggs was MeHg (94 ± 17% and 90 ± 21%, respectively). The brine shrimp eggs had MeHg concentrations that were 84 ± 2% lower than in the females, reflecting the fact that females transferred 45 ± 4% of their total body mass but only 11 ± 3% of their MeHg burden to their eggs. As a result of this sequestration, the concentration of MeHg in the female brine shrimp increased by 62 ± 8% during egg formation.

6.2 Environmental Consequences

6.2.1 Methodology

UPRR reviewed existing qualitative and quantitative published studies discussing Hg and MeHg to identify the key factors that affect the nature of Hg and MeHg and then considered whether and how the proposed project might affect these factors in a way that would influence the presence of Hg and MeHg in the lake and potentially impair the lake's beneficial uses. For this analysis, *mercury and methyl mercury effects* are defined as changes caused by the project that are outside the historic variability of Hg and MeHg in the lake, based on the review of data and water and salt balance model results.

> **What are mercury and methyl mercury effects?**
>
> *Mercury and methyl mercury effects* are defined as changes caused by the project that are outside the historic variability of Hg and MeHg in the lake, based on the review of data and water and salt balance model results.

The lake's beneficial uses have not been determined to be impaired by Hg or MeHg (UDWQ 2010, 2014c), and the proposed project would not be a new source of Hg or MeHg to the lake. Nevertheless, the project would have an adverse effect if it were to change the Hg and MeHg concentrations and the lake's physical processes in such a way that MeHg concentrations in the lake's wildlife or food chain were to increase, such that these parameters are not within their historic variability and those changes outside the historic variability were to impair the lake's beneficial uses.

To evaluate the effects of the proposed project on Hg and MeHg in the lake, UPRR:

> **What is bio-uptake?**
>
> Bio-uptake is the process of taking a chemical into a system, most commonly as water or food into a body.

- Reviewed existing qualitative and quantitative published studies to identify the key factors that affect the Hg methylation, bio-uptake, and trophic transfer processes in the lake, as well as where in the lake they are occurring.
- Reviewed information about physical processes in the lake, such as circulation (Chapter 8, Lake Circulation) and deep brine layer characteristics (Chapter 5, Deep Brine Layer), to identify physical constraints on bio-uptake and trophic transfer of MeHg.
- Reviewed the water and salt balance modeling for the project with the proposed action and alternatives (described in Chapter 2, Project Description and Additional Project Alternatives

Considered). The water and salt balance modeling can be used as a surrogate for changes in water quality parameters (UDWQ 2014c).

Based on this information, UPRR assessed whether there are locations in the project vicinity where MeHg bio-uptake and trophic transfer to wildlife could increase over baseline conditions due to the proposed project.

6.2.2 Factors That Affect Mercury Methylation in the Great Salt Lake

To determine which factors to consider for the impact analysis, UPRR reviewed studies that have commented on or provided analytical data on the sources, nature, and extent of Hg and MeHg in the lake (Table 6-2). These studies also present data regarding He and MeHg in specific areas of the lake.

Table 6-2. Factors That Affect Mercury Methylation, Bio-uptake, and Trophic Transfer in the Great Salt Lake

Source	Type of Study	Factors
Peterson and Gustin 2008; Scudder and others 2009; USFWS 2009; UDWQ 2014c	Qualitative and quantitative	Ongoing Hg sources to the lake are atmospheric and riverine. Once in the lake, Hg persists as both Hg and MeHg.
Barandiaran 2013	Qualitative and quantitative	Hg methylation occurs via both biotic and abiotic processes. Anoxic, high-organic-carbon, and high-sulfide conditions promote Hg methylation. Some organisms are more tolerant than others of higher exposures and/or doses of Hg. Brine shrimp are tolerant of Hg burdens.
Black and Swanson 2013	Qualitative and quantitative	Wildlife exposure to MeHg is predominantly due to foraging in wetlands and near-shore environments. The slight contribution of MeHg from the deep brine layer to wildlife in open water is not discernible.
Wurtsbaugh and Jones 2012	Qualitative and quantitative	Hydrodynamics (the transfer of MeHg from the deep brine layer to the upper brine layer) is occurring but is not quantified. Algae accumulate in the interface layer between the deep brine layer and the upper brine layer, where brine shrimp feed; biodilution is observed.
Naftz and others 2008	Qualitative and quantitative	Conditions exist for Hg methylation in the deep brine layer.
Chapter 8, Lake Circulation	Qualitative and quantitative	In Gilbert Bay, mechanical mixing between the upper brine layer and the deep brine layer is not observed.
Chapter 5, Deep Brine Layer	Qualitative and quantitative	The deep brine layer is located in Gilbert Bay. The thickness and surface area of the deep brine layer change periodically but not necessarily seasonally or annually.

> **What are margin sediments?**
>
> Margin sediments are sediments located along a lake shoreline.

Methylation. Factors that affect methylation include the presence of Hg, anoxic conditions, high concentrations of dissolved organic carbon and particulate organic carbon, high concentrations of dissolved sulfide, and populations of sulfide-reducing bacteria (CALFED Bay-Delta Program 2005). These conditions exist within the sediments and deep brine layer of the Great Salt Lake. In the project vicinity, these conditions exist in Gilbert Bay's deep brine layer. Gunnison Bay is not stratified and is oxygenated. Wetland and margin sediments are more than 20 miles from the project site, so they would not affect or be affected by the proposed project.

Methyl Mercury Bio-uptake and Tropic Transfer. Although MeHg is produced in the deep brine layer, it does not appear to be escaping from the deep brine layer into the upper brine layer at a discernible rate (Wurtsbaugh and Jones 2012). Circulation patterns and weather patterns do not appear to increase mixing between the deep brine layer and the upper brine layer, which would increase the rate of MeHg transfer into the upper brine layer. Brine shrimp do not feed within the deep brine layer and therefore are not exposed to the MeHg in the deep brine layer. Algae can rest on top of the deep brine layer, a preferred foraging site for brine shrimp; however, bio-dilution is exhibited by brine shrimp feeding at this location. Brine cysts harvested in the late summer and fall have lower concentrations of MeHg than do their parents.

6.2.3 Water and Salt Balance Effects

As discussed in Section 3.1.4, Water and Salt Balance Model Results, UPRR prepared model simulations for the proposed action and alternatives and compared the results to the baseline condition simulation, which assumes that the free-flowing culverts are in place. Alternative A would be least similar to the baseline conditions for water and salt loads for most of the models and, therefore, would have the most potential to result in long-term salinity and salt load changes that differ from historic variability or to change future variability. Alternative B would provide the best match for one of the four model simulations and the third-best match (out of four) for the other three model simulations. Alternative D would provide a better match to baseline conditions for two of the four model simulations.

For the proposed action, three of the four model results showed a slight increase of the South Arm salinity and salt load compared to the baseline conditions. The results for the fourth model (2012 UPRR/USGS Varying Hydrology Model, dry cycle) showed a decrease in South Arm salinity and salt load compared to the baseline conditions. For all models, the South and North Arm salinities and salt loads varied in response to lake inflows, lake levels, head differences between the North and South Arms, causeway characteristics, and the relative relationship between lake levels and causeway openings.

6.2.4 Effects of the Proposed Action and Alternatives

UPRR reviewed studies to evaluate the variability of the presence of Hg and MeHg and conducted water and salt balance modeling to evaluate the proposed action and alternatives on the presence of Hg and MeHg in the lake. The project would not discharge any effluent or wastewater that contains Hg or MeHg.

As discussed in Section 3.1.4, Water and Salt Balance Model Results, UPRR prepared model simulations for the proposed action and alternatives and compared the results to the baseline simulations with the free-flowing culverts in place. These model simulations generally resulted in a slight change in South Arm salinity and salt loads. Section 3.1.4 summarizes the water and salt balance effects associated with each alternative simulation compared to the baseline simulation. Table 2-2, Rankings of Bridge Alternatives

Evaluated by the UPRR/USGS Models, on page 17 summarizes the overall ranking of the proposed action and alternatives in terms of water and salt balance model results.

Based on the results of water and salt balance modeling, UPRR expects that future rates of chemical exchange between the deep brine layer and the upper brine layer will remain within historic variation. Hg contamination is common in Utah's aquatic food webs and affects both the waterfowl and wildlife. As in the rest of the state, Hg and/or MeHg are found throughout the Great Salt Lake in its sediment, water, and wildlife. The highest concentrations of Hg are found in shoreline wetland sediments and in the sediments below Gilbert Bay's deep brine layer (Black and Swanson 2013). Gunnison Bay is well mixed and does not stratify.

Gilbert Bay's deep brine layer exhibits four characteristics that have been found to be conducive for Hg methylation: it is anoxic, contains high concentrations of dissolved organic carbon and particulate organic carbon, contains high concentrations of dissolved sulfide, and is populated by cyanobacteria (blue-green algae). MeHg has been found in the deep brine layer at concentrations as high as 30 ng/L.

UPRR reviewed studies that identified factors that could increase MeHg concentrations in wildlife or their food chain and did not find evidence that the proposed action and alternatives would increase MeHg concentrations in Great Salt Lake biota. This conclusion is based on the following factors:

- Under current conditions, the thickness and surface area of the deep brine layer change periodically but not necessarily seasonally or annually. The proposed action would not affect the factors that lead to these seasonal or annual changes. With the proposed action and alternatives, the thickness and surface area of the deep brine layer would continue to increase and decrease within the historically observed variability.
- Though high MeHg concentrations are measured in the deep brine layer, a mechanism for MeHg to leave the deep brine layer and enter the upper brine layer has not been observed (Wurtsbaugh and Jones 2012). There is no evidence that the rate of MeHg transport out of the deep brine layer would increase due to the proposed action or alternatives. Wind, temperature, and circulation would not be affected by the project.
- Entry of MeHg to the Great Salt Lake food web is most efficient and direct from the shoreline wetlands (Black and Swanson 2013). In relative terms, the contribution of MeHg from the Great Salt Lake's shoreline wetlands to the base of the Great Salt Lake food chain is vastly greater than the contribution from the upper brine layer (Black and Swanson 2013).The proposed action and alternatives would not be near, nor would they disturb, shoreline wetlands.
- Despite the slight changes in salinity, the water and salt balance model shows that, under all scenarios, South Arm salinity, and therefore the nature of the deep brine layer, would continue to increase and decrease within the historically observed variability, suggesting that any MeHg transport process from the deep brine layer would remain within historic bounds.
- Sources of Hg and MeHg to both arms of the lake have been documented as surface water inflows and permitted discharges (Naftz and others 2009). The proposed action and alternatives would not affect atmospheric discharges, surface water inflows, or existing or future permitted discharges. The proposed action and alternatives would not have a permitted effluent discharge to the lake, so none of the alternatives would degrade ambient lake Hg concentrations.

Finally, the proposed action and alternatives would not increase the amount of Hg in the lake or the availability of MeHg and would not change or affect the current levels of Hg and MeHg in the lake's biota. Accordingly, the proposed action and alternatives would not impair the lake's beneficial uses and cause a significant adverse effect.

6.2.5 Effects of the No-Action Alternative

With the no-action alternative, the east culvert would remain temporarily closed pending the identification and approval of a permanent closure solution. UPRR would necessarily continue to seek USACE and UDWQ approval to make the east culvert closure permanent. In addition, the compensatory mitigation element of the proposed action would not be implemented, with the result that the aquatic functions of the culverts would not be replaced until the necessarily approvals are granted.

Any resulting adverse change in Hg and MeHg (outside of historic variability) caused by an incremental reduction in water and salt transfer through the causeway that impairs the lake's beneficial uses and continues unmitigated with the no-action alternative would likely continue until a permanent closure solution and mitigation plan is approved and implemented. UPRR also would necessarily continue to pursue USACE and UDWQ approval of an acceptable compensatory mitigation plan in support of making the east culvert closure permanent. It would be speculative to predict how long a new or revised individual permit action and corresponding mitigation proposal would take to be approved.

6.2.6 Construction-Related Effects

Construction of the proposed action and alternatives would not cause significant, long-term effects on any of the factors believed to influence the in-lake Hg methylation processes, nor would they introduce Hg or MeHg into the lake. Because the construction-related effects would occur for a short period of time due to placing temporary fill for the shoofly and removing the fill once the new bridge is complete and would be reduced by using best management practices, they would not impair the lake's beneficial uses and cause a significant adverse effect.

6.2.7 Post-construction Short-Term Effects

For the proposed action and alternatives, once the bridge is in place and the shoofly is removed, the bridge would be opened to convey flow between the North and South Arms. When the bridge is opened, there would be a period of less-than-minimal short-term effects during which the differences in WSE and salinity between the two arms would rapidly change. Over time, the differences would move toward equilibrium, and the post-construction effects would no longer exist. For more information about these post-construction short-term effects, see Section 3.2.7, Post-construction Short-Term Effects, in Chapter 3, Water Chemistry.

UPRR analyzed the short-term post-construction transition period that was observed when the existing 300-foot-long bridge was opened in 1984. Short-term post-construction effects on lake WSE and salinity were evaluated. Data suggest that, when the 300-foot-long bridge was opened in 1984, the head difference declined sharply for about 6 weeks, less dense (less saline) water appeared in the North Arm, and the deep brine layer in the South Arm became denser (more saline).

During the 1984 transition period, no short-term effects on North and South Arm WSEs and salinities were documented as causing a significant adverse effect and impairing the lake's beneficial uses due to changes in Hg or MeHg concentrations, and no new or additional data would support a different outcome with the proposed action or one of the alternatives.

7 Biological Resources

This chapter describes the biological resources of the Great Salt Lake. Salinity and salt loads, which can affect brine shrimp and brine flies, are discussed in detail in Chapter 3, Water Chemistry.

7.1 Affected Environment

This section presents information about the existing biological resource conditions of the project area (specifically Gilbert and Gunnison Bays) and the Great Salt Lake ecosystem. For this evaluation, UPRR focused the discussion about biological resources on brine shrimp and brine flies. Brine shrimp and brine flies are part of the food chain of the lake, and the lake's beneficial uses include protections for shore birds and other water-oriented wildlife including their necessary food chain.

7.1.1 Methodology

The information presented in Section 7.1 is taken from published literature about the lake and online databases about species that use the area. UPRR researched biological resources, focusing on phytoplankton brine shrimp and brine flies within Gunnison and Gilbert Bays. UPRR's research focused on recent data (gathered in the years after the causeway was constructed).

7.1.2 General Description of the Great Salt Lake Ecosystem

The driving forces for the Great Salt Lake ecosystem are lake level (which is a direct result of water inflows and outflow) and salinity (UDFFSL 2013). The Great Salt Lake ecosystem includes a diversity of dynamic habitats including freshwater marshes, mudflats, rivers and streams with adjacent riparian areas, estuaries, saline to hypersaline waters, and upland areas.

What are the main forces that affect the Great Salt Lake ecosystem?

The driving forces for the Great Salt Lake ecosystem are lake level (which is a direct result of water inflows and outflow) and salinity.

The lake ecosystem includes about 400,000 acres of wetlands that are located mainly along the eastern shorelands. About 260,000 acres of these wetlands are protected areas, most of which are managed to provide productive waterfowl or shorebird habitat. Uplands, which provide important foraging and breeding/nesting habitats for wildlife, include islands, shrublands, grasslands, dunes and sandbars, dikes and levees, and agricultural land. Rivers, streams, and estuaries provide support for fish, aquatic invertebrates, birds, and other wildlife (UDFFSL 2013).

The lake is designated a part of the Western Hemisphere Shorebird Reserve Network because of its importance to migratory birds (USGS 2013a). The Great Salt Lake is also within the Pacific Flyway, which is a major north-south route for migratory birds that includes the area that extends from the arctic region in the north to the southern tip of South America in the south. The flyway is bounded by the Rocky Mountains on the east, so the lake is on the eastern side of the "band" that makes up the flyway (BirdLife International, no date).

With its large size, diverse habitats with abundant food supplies, and location within the otherwise generally arid Great Basin, the Great Salt Lake ecosystem functions as an oasis for millions of migratory birds. About 250 species of birds, 64 species and subspecies of mammals, 23 species and subspecies of fish, 19 species of reptiles, and eight species of amphibians are known to use the ecosystem (UDFFSL 2013). The lake is internationally significant for its role as a major North American migratory bird flyway, as vital shorebird breeding habitat, and due to its enormous size and influence on the climate and ecology of the area.

Groups of birds that use the lake area include waterbirds, shorebirds, waterfowl, diurnal raptors, owls, and marsh- and upland-associated songbirds. The lake and its marshes provide a resting and staging area for the birds as well as an abundance of brine shrimp and brine flies that serve as food (USGS 2013b). Several million birds use the lake area during the spring, summer, and fall migration, and many of these birds migrate thousands of miles (GSLEP 2002). The Great Salt Lake provides the largest staging population in the world for Wilson's phalaropes (*Phalaropus tricolor*) (500,000)—over 50% of the global population. The lake also hosts the largest populations of American avocets (*Recurvirostra americana*) (250,000) and black-necked stilts (*Himantopus mexicanus*) (65,000) in the Pacific Flyway and over 10% of all red-necked phalaropes (*Phalaropus lobatus*) (240,000).

The lake also hosts the world's largest assemblage of snowy plovers (*Charadrius alexandrinus*) (3,700) and the only staging area for marbled godwits (*Limosa fedoa*) (58,000) in the interior of the United States (Aldrich and Paul 2002 as cited in UDFFSL 2013; Luft and Niell 2011 in UDFFSL 2013). Millions of migratory waterfowl use the Great Salt Lake ecosystem, and the number of breeding waterfowl is estimated to exceed 750,000 birds (UDWR 2005). The lake hosts over 75% of the western population of tundra swans (*Cygnus columbianus*) (60,000) and about 25% of the continental population of northern pintails (*Anas acuta*) (1,000,000) (Aldrich and Paul 2002 as cited in UDFFSL 2013).

Salinity ranges for the lake and for specific bays of the lake have been documented and referenced over time, and often these documents and references vary widely. UGS has sampled, analyzed, and reported salinity levels for various locations on the lake since 1966 (UGS 2012). Since about 1960, salinity in the North Arm has ranged from 16% to 29%, but salinity in the South Arm has ranged from 6% to 28% because most fresh water that enters the lake enters this arm (Stephens 1990; Stephens 1998 as cited in Larson and Belovsky 2013). The aquatic habitats in the main bays and arms vary with changes in salinity and nutrient inputs, changes that are affected by hydrology, geology, and human-made structures and human management.

The South Arm, which is made up of three distinct bays—Gilbert, Bear River, and Farmington Bays—provides different habitats, mostly due to the different levels of salinity in each bay. The factors that affect the salinity levels in each bay include the location of the major river tributaries to the lake and the hydraulic connectivity between the bays.

Table 7-1 summarizes the salinity levels in Gunnison Bay, which is the lake's North Arm, and the three bays that make up the South Arm for the period 1982 through 2010.

Table 7-1. Salinity Ranges in the Bays of the Great Salt Lake, 1982–2010

Bay	Arm	Salinity Range (%)
Gunnison	North	15–27
Gilbert	South	5–19
Farmington	South	2–12
Bear River	South	2–14

Source: UDFFSL 2013

Farmington and Bear River Bays are less saline than Gilbert Bay. Many different algae and bacteria in Farmington and Bear River Bays use the available nutrients, and the algae and bacteria support a variety of invertebrates and macroinvertebrates. Fish are present in these two bays near sources of freshwater inflow: the Jordan River for Farmington Bay and the Bear River for Bear River Bay (UDFFSL 2013). Because Farmington and Bear River Bays are not near the project site, this report does not address them.

Because the project is adjacent to Gunnison Bay (the North Arm) and Gilbert Bay (part of the South Arm), the following sections describe the ecology of those specific areas of the lake.

7.1.3 Gunnison Bay (the North Arm)

Salinity in Gunnison Bay (the North Arm of the Great Salt Lake) is documented to range from about 15% to 27% (UDFFSL 2013), which is substantially higher than in other areas of the lake as a result of lake level, limited inflows from other surface waters, water and salt transfer from the South Arm to the North Arm through the causeway, evaporation, and limited precipitation. During the high-salinity conditions that have occurred at low lake levels, the North Arm has been limited to six phytoplankton species and is dominated by one unicellular green algal species, *Dunaliella salina*. This species releases beta-carotene and haloarchaea (bacteria-like microorganisms) that give the water its pink to purple color. Haloarchaea also convert nontoxic mercury into toxic methyl mercury (UDFFSL 2013).

Brine shrimp (*Artemia franciscana*) and their cysts are generally abundant in the South Arm and generally do not thrive in the North Arm due to the North Arm's higher salinity levels. In the North Arm, brine shrimp can survive where there are favorable low-saline conditions. At relatively high lake levels (4,208 feet to 4,212 feet) that result in reduced salinity, brine shrimp could successfully reproduce in the North Arm, but otherwise brine shrimp generally do not generally persist in the North Arm. Brine cysts can occur in the North Arm only when brine shrimp are present. Brine fly (*Ephydra* spp.) larvae are tolerant of high salinity and are relatively abundant in the North Arm near the shorelines but are somewhat limited by fewer sources of food compared to the South Arm (UDFFSL 2013).

7.1.4 Gilbert Bay (in the South Arm)

Biological diversity and productivity in the South Arm are considerably higher than in the North Arm, mainly due to lower salinities and much greater freshwater inflows. These inflows provide abundant nutrient inputs to sustain a diversity of phytoplankton and benthic algae, which are the primary producers for two weakly linked food webs. The identified zooplankton (the animal constituent of plankton; usually weak swimmers that drift with the current) in Gilbert Bay include several species of rotifers, nematodes, and ciliates, but brine shrimp and brine flies are by far the most abundant animals by several orders of magnitude (Belovsky and others 2011).

What are benthic algae?

Benthic algae are algae that grow on bottom sediments. Most benthic algae are filamentous (long and thin in a chain-like series) or colonial, but some are microscopic single-celled organisms.

Brine shrimp are a keystone species of the lake ecosystem due to their abundance and their role as primary consumers in the phytoplankton food web. Brine shrimp seasonally limit phytoplankton abundance (a top-down influence) and exert bottom-up influence on aquatic insects and waterbirds. The benthic algae food web has not been studied as intensively as has the phytoplankton food web but is conceptually simple. The benthic habitat is dominated by blue-green algae that accumulate as algal mats on the bottom of the lake. Brine fly larvae graze on benthic algae and detritus (organic matter produced by the decomposition of organisms). Brine fly larvae and flies are consumed by aquatic insects and waterbirds. There is little interaction between brine fly larvae and brine shrimp through competition or predation (Belovsky and others 2011). Brine shrimp cysts that are harvested commercially in Gilbert Bay are processed and sold as fish food.

7.1.5 Phytoplankton

The abundance of phytoplankton in the Great Salt Lake varies by species in response to fluctuating environmental conditions and grazing by brine shrimp. As a result, the species composition varies dramatically by month and by year. The primary environmental factors that affect phytoplankton variability are salinity, temperature, and nutrient availability. Researchers have identified more than 60 species of phytoplankton (Belovsky and others 2011).

Salinity in Gilbert Bay has ranged from about 5% to 19% between 1982 and 2010 (UDFFSL 2013). According to Belovsky (2005), when salinity ranges from 3% to 15%, the overall biomass of phytoplankton increases with increasing salinity. Above this range, higher salinity becomes limiting to phytoplankton productivity (Belovsky and others 2011). The proportion of chlorophytes (green algae) increases with increasing salinity, while that of cyanobacteria (blue-green algae) decreases. The species of diatoms that predominate in the Great Salt Lake are single-celled algae characterized by a cell wall made of silica. Diatoms appear to be more abundant when salinity levels are lower, and they give the lake water a gold hue (Stephens 1998 as cited in Belovsky and others 2011).

As temperature increases, the overall biomass of phytoplankton decreases (analyzed from 10 to 30 degrees Celsius). The proportion of chlorophytes decreases with increasing temperature, while that of diatoms and cyanobacteria increases (Belovsky 2005).

The overall biomass of phytoplankton increases with higher levels of nutrients. The proportion of chlorophytes increases with increasing nutrients, while the proportions of diatoms and cyanobacteria decrease. Generally, nitrogen concentrations are the limiting factor for phytoplankton growth in the South Arm (Stephens and Gillespie 1976; Belovsky and others 2011). Nutrients in the water column of the lake fluctuate with lake level, water depth, and season and are controlled primarily by releases of in-lake pools of nitrogen stored in deep waters released into the shallower levels of the lake water when the lake water mixes vertically (Belovsky and others 2011).

In summary, in the absence of brine shrimp, annual phytoplankton abundance is determined primarily by nutrient availability (Belovsky and others 2011).

7.1.6 Brine Shrimp

Brine shrimp in the Great Salt Lake typically reproduce in two ways: by releasing live young into the lake in spring and summer and by releasing eggs in the form of dormant cysts that overwinter in the lake and then hatch in spring. As food availability, water temperature, and day length decline and salinity increases later in the season, female brine shrimp start producing cysts (UDFFSL 2013). Brine shrimp start to die when water temperatures drop below 42 degrees Fahrenheit (°F), and no adult brine shrimp survive the winter, but the population is restored each spring from hatching cysts that overwintered (Belovsky and others 2011).

What is a brine shrimp cyst?

A brine shrimp cyst is an overwintering egg that contains a dormant brine shrimp embryo protected by a hard-walled outer layer.

As water temperatures increase during late January and early February, the cysts begin hatching; peak hatching occurs in March or early April. The brine shrimp young, called *nauplii*, molt through several juvenile stages before maturing into reproductive adult brine shrimp. Up to four generations of shrimp can be produced in the Great Salt Lake during a single growing season. Additionally, brine shrimp can reproduce by nondormant cysts during periods when they are extremely stressed by food limitations or other environmental conditions.

Salinity and temperature are important factors in brine shrimp fecundity (reproductive capacity) and survival. Brine shrimp abundance is typically limited by phytoplankton densities, which are greatly reduced by brine shrimp grazing. Both low and high salinity reduce food availability. At lower salinities, diatoms are more abundant, and green algae concentrations are relatively low (Belovsky 1998). Diatoms are too large for brine shrimp nauplii to consume (Stephens 1998), so brine shrimp populations are reduced under these conditions. As salinity decreases to around 6%, brine shrimp cysts sink to the lake bottom, where they cannot hatch in the spring, and, at 3% salinity, adult shrimp fail to reproduce (Stephens 1990).

In the 1980s, reduced salinity from increasingly high lake levels greatly diminished brine shrimp abundance in the South Arm. During this same period, brine shrimp re-established in the North Arm (Stephens 1990). High salinity becomes limiting to phytoplankton productivity, and brine shrimp do not typically persist in the North Arm at low to moderate lake levels (Belovsky and others 2011).

As stated in Section 7.1.5, Phytoplankton, salinity in the South Arm has ranged from 6% to 28% since the 1960s, but it has not exceeded 18% since 1970. Information provided by the Great Salt Lake Ecosystem Program (GSLEP 2014) states that the maximum salt tolerance for adult brine shrimp is around 30% salinity. (Water with about 28% salinity in the Great Salt Lake is at saturation, depending on temperature.) Optimal levels for brine shrimp cyst production are 14% to 17%. Low salinity levels tend to cause cysts to crack prematurely. According to the Great Salt Lake Ecosystem Program, brine shrimp cysts require 10% or lower salinity to initiate hatching, and spring runoff and precipitation generally lower Great Salt Lake surface salinities to these levels (GSLEP 2014).

What are the suitable salinity levels for brine shrimp life stages?

Numerous studies have indicated differing ranges of "optimal" salinity for the different stages of the brine shrimp's life cycle. This report references ranges identified by the State of Utah, which suggest that suitable salinity levels for brine shrimp reproduction are 14% to 17% for cyst production and less than 10% for hatching (GSLEP 2014).

Cysts in higher-salinity water will float in order to take advantage of surface precipitation. Within the Great Salt Lake, cysts found in water of 16% to 28% salinity had a lower density (and thus weight) than those found in the 10% to 14% range, causing them to float to the surface where less-salty water would be found. Cysts sink in water that is less than 8% saline, which may be advantageous, because salinity increases with depth (GSLEP 2014).

Low lake salinities also allow other competitors to invade areas that were once unsuitable and can alter phytoplankton composition and interrupt food chains. Higher lake salinities result in adults who reach maturity quicker but are shorter in length and result in offspring that develop quickly but are smaller and have a relatively longer abdomen (GSLEP 2014).

In 1999, the Utah Division of Wildlife Resources conducted a limited experiment to test short-term brine shrimp survival and hatching in the Great Salt Lake and found that brine shrimp have poor survival above 15% salinity and can hatch in 8% to 9% maximum salinity. The test, which had low sample sizes and left out long-term effects, suggested that the Great Salt Lake was “borderline” for brine shrimp production based on the tested conditions (GSLEP 2010). Other studies have indicated different salinity levels for the shrimp’s lifecycle stages. Considering these study results and the results of other brine shrimp studies in the Great Salt Lake and other areas that support similar species of brine shrimp, the data (Stephens and Birdsey 1999; GSLEP 2010; UDFFSL 2013) show that:

- For the period of 1982 through 2010, salinity in Gilbert Bay (part of the South Arm) ranged from 5% to 19%.
- Survival, reproductive output, and body size of brine shrimp decrease in high lake salinities.
- The North Arm is currently too saline to support brine shrimp.
- The optimum salinity for growth and reproduction is not known because it is a function of an interaction of salinity and temperature, food supply, and competitors. However, the suitable salinity range *appears* to be 14% to 17% for cyst production and less than 10% for hatching.

Temperature fluctuations that occur at lower lake levels also affect brine shrimp viability. Non-dormant shrimp cannot tolerate temperatures above 85 °F and below 40 °F, and the populations of females with cysts in September are correlated with temperature (UDFFSL 2013).

The principal consumers of brine shrimp are corixids (see page 112), migratory birds, and humans (through commercial harvesting), but these interactions do not appear to limit brine shrimp abundance (Belovsky and others 2011).

Brine Shrimp Industry

Brine shrimp cysts are commercially harvested from the Great Salt Lake for the aquaculture industry. They are collected in the dormant stage (that is, as cysts). The cysts can be hatched to provide a highly nutritious food for larval fish and other crustaceans (such as shrimp) that are commercially cultured for human consumption (Belovsky and others 2011). Commercial harvesting of lake brine shrimp began in 1952 when the Sanders Brine Shrimp Company began harvesting brine shrimp for tropical fish food. Several years later, companies began harvesting brine shrimp cysts because cysts can be dried, packaged, and stored for long periods and hatched as needed.

During the 1950s, brine shrimp and their eggs were commercially harvested in the North Arm, but, in 1962, salinity in the North Arm reached 28%. From 1962 to 1982, harvesting brine shrimp was considered to be economically feasible in the South Arm only, but it resumed in the North Arm during the 1980s when higher lake levels resulted in lower salinity and the South Arm was below the suitable salinity range (Stephens 1990). Since then, the lake level has dropped, and harvesting occurs primarily in the South Arm.

The Utah Division of Wildlife Resources regulates the commercial brine shrimp industry by restricting harvesting based on cyst population numbers. Management strategies are focused on maintaining cyst populations at a level so that brine shrimp production for the next season is assured (Belovsky and others 2011). Even with harvesting removing an average of 61% (and in some years more than 90%) of cysts each year, harvesting does not appear to lower brine shrimp numbers from year to year (Belovsky and others 2011).

According to the Utah Division of Forestry, Fire and State Lands, optimal salinity levels for harvesting brine shrimp in Gilbert Bay are at lake levels ranging from 4,193 feet to 4,201 feet, which generally correlate to salinities of about 16% to 23% (UDFFSL 2013). Harvesting can take place outside this range, and this has occurred many times because the salinities of the lake and the various bays vary from year to year.

Other Organisms That Affect Brine Shrimp

Corixids

Corixids are small, predatory, flying aquatic insects that live in and around the edges of the Great Salt Lake where water salinity is less than 6% (UDFFSL 1999). At lower salinity levels, corixids could reduce brine shrimp populations; however, corixid populations have been limited by the salinity levels in the lake during recent years (Belovsky and others 2011). Their diet includes brine shrimp and brine flies, but corixid predation has a negligible effect on brine shrimp in the South Arm (Belovsky and others 2011).

Migratory Birds

Brine shrimp and brine fly production is an essential element of the food chain for sustaining many migratory birds. The large numbers of migrating waterbirds that annually stop over at the Great Salt Lake rely on brine shrimp and brine fly larvae to provide energy for breeding and/or migration to or from other breeding grounds. The lake annually hosts up to 2.5 million eared grebes (*Podiceps nigricollis*), which is up to 50% of the North American population. Eared grebes feed on brine shrimp almost exclusively during their 8-to-10-month stay. Grebe populations need to consume 26,500 to 29,600 adult brine shrimp per day during their migratory staging (Conover and Caudell 2009), which occurs primarily in Bear River and Farmington Bays (GSLEP 2002).

Up to 500,000 Wilson's phalaropes (one-third of the global population) gather annually on the Great Salt Lake in August to feed on brine shrimp before migrating to South America. Red-necked phalaropes and gulls also feed on brine shrimp in the open waters of Bear River and Farmington Bays (GSLEP 2002).

7.1.7 Brine Flies

There are two well-documented species of brine flies in the Great Salt Lake. The more abundant is *Ephydra gracilis*, which is smaller; the less abundant is *Ephydra hians*, which is larger. The lifecycle of a brine fly consists of four stages: egg, larva, pupa, and adult. Each female lays about 75 eggs on the surface of the water or on floating debris such as brine fly pupal casings, dead brine shrimp, or cysts. The eggs sink to the bottom of the lake before they hatch into larvae. They typically pupate on benthic algal mats, but, during warm weather, the larval stage also can pupate on the surface of the lake on floating masses of algae.

The flies overwinter in immature stages. Flies emerging from the bottom of the lake float to the surface in a bubble of air. The lifecycle can be completed in 21 to 30 days and can extend longer during periods of cooler temperatures. Adult brine flies live only 3 to 4 days, and one or two generations of flies reach maturity each year (UDFFSL 2013).

Brine fly populations begin to increase rapidly around the first week of June, peak during July and August, and then decrease as temperatures begin to drop (Vorhies 1917). Brine fly abundance is variable from year to year and depends on changes in water chemistry and other environmental conditions (particularly temperature), but it has been estimated to total over 110 billion flies plus 10 billion pupae per year along about 300 miles of shoreline around the South and North Arms (Oldroyd 1964 as cited in UDFFSL 2013).

Brine flies are a vital element to sustaining the Great Salt Lake ecosystem. Brine fly larvae consume benthic algae and, by doing so, remove over 120,000 tons of organic matter each year from the lake. Adult brine flies are important prey for corixids and other invertebrates, small mammals, reptiles, and birds living near the shores of the lake. Adult and larval brine flies are also consumed by waterbirds and provide an important food source for many migratory birds (UDFFSL 2013).

Lake levels exert a strong influence on brine fly abundance from year to year due to the effects of water chemistry and other environmental conditions associated with differing water levels. Brine flies are fairly tolerant of high salinity, high temperatures, and low concentrations of dissolved oxygen (Stephens 1990).

During years with a high lake level, the increase in freshwater inputs and inundated shoreline habitats where brine flies pupate could decrease the brine fly population. Fluctuations in lake levels could result in strong bottom-up effects on corixids and other primary and secondary predators that directly or indirectly depend on brine flies (UDFFSL 2013).

7.2 Environmental Consequences

This section describes the potential effects of the proposed project on biological resources.

7.2.1 Methodology

To evaluate the potential effects of the project on biological resources, UPRR considered published literature and data about biological resources described in Section 7.1.3, Gunnison Bay (the North Arm), and Section 7.1.4, Gilbert Bay (in the South Arm), and the results of water and salt balance modeling. For this analysis, *biological resource effects* are defined as changes caused by the project that are outside the historic variability of the biological resources in the lake, based on the review of data and water and salt balance model results.

> **What are biological resource effects?**
>
> *Biological resource effects* are defined as changes caused by the project that are outside the historic variability of the biological resources in the lake, based on the review of data and water and salt balance model results.

The lake's beneficial uses have not been determined to be impaired by the historic variability of the biological resources in the lake (UDWQ 2010, 2014c). Nevertheless, the project would have an adverse effect if it were to cause changes to brine shrimp and brine flies such that these resources are not within their historic variability and those changes outside the historic variability were to impair the lake's beneficial uses.

Brine shrimp and brine flies are middle steps in the Great Salt Lake food chain; they rely on phytoplankton for food and are a food source for birds. Accordingly, the project would have an adverse effect if it were to change the long-term range of salinity in the South Arm such that the change adversely affects brine shrimp and/or brine fly fecundity and survival and therefore impairs a beneficial use. Because Gunnison Bay has historically not provided optimal habitat for brine shrimp or cysts, the analysis focuses on Gilbert Bay in the South Arm.

7.2.2 Effects of the Proposed Action and Alternatives

Effects on Brine Shrimp

In order to quantitatively assess the effects of the project on salinity and hence brine shrimp populations, UPRR used the water and salt balance modeling results described in Chapter 3, Water Chemistry, to compare the potential effects of the proposed action and alternatives on salinity to known brine shrimp salinity tolerances in Gilbert Bay of the South Arm.

As discussed in Section 3.1.4, Water and Salt Balance Model Results, UPRR prepared model simulations for the proposed action and alternatives and compared the results to the baseline simulations with the free-flowing culverts in place. These model simulations generally resulted in a slight change in South Arm salinity and salt loads. Table 7-2 summarizes the water and salt balance effects associated with each alternative simulation compared to the baseline simulation. Table 2-2, Rankings of Bridge Alternatives Evaluated by the UPRR/USGS Models, on page 17 summarizes the overall ranking of the proposed action and alternatives in terms of water and salt balance model results.

Table 7-2 summarizes the modeled salinity results for the proposed action and alternatives and compares them to the information published by the State of Utah about suitable brine shrimp salinity ranges for the baseline and with-project salinity conditions predicted using the models. These ranges, which are assumed to be 14% to 17% for cyst production and less than 10% for hatching, represent the best conditions rather than all conditions. In some years, hatching occurs in salinities higher than 10% (GSLEP 2014).

Table 7-2. 2012 UPRR/USGS Model – Salinity Comparison

Alternative	Baseline Conditions		With-Project Conditions	
	Range of South Arm Salinity (%)	Within Suitable Ranges?	Range of South Arm Salinity (%)	Within Suitable Range?
Proposed Action	8.0–20.7	Production and hatching within range	8.0–22.2	Production and hatching within range
Alternative A	8.0–20.7	Production and hatching within range	8.0–23.8	Production and hatching within range
Alternative B	8.0–20.7	Production and hatching within range	8.0–23.0	Production and hatching within range
Alternative D	8.0–20.7	Production and hatching within range	8.0–20.8	Production and hatching within range

The model results indicate that, under the baseline conditions, salinity was not always within the suitable ranges for cyst production and/or hatching. The water and salt balance model represents the North and South Arms, including all the bays, as each having an average salinity, when in reality the South Arm is a more complex system that has a range of salinities depending on the specific location within the South Arm and any of the three bays. Comparing the baseline conditions to the with-project conditions shows that the conditions with the proposed action and alternatives would not be substantially different than any of the baseline conditions. This conclusion applies regardless of the salinity suitability ranges that might be used. The key point is that the proposed action and alternatives would not adversely change the long-term salinity ranges compared to these variable baseline conditions.

The water and salt balance model results do not indicate that the proposed action and alternatives would result in salinity ranges that would be different from what was modeled as occurring under the baseline conditions. The project would not change the conditions for brine shrimp cyst production or hatching compared to baseline salinities and would not impair the lake's beneficial uses and cause a significant adverse effect.

Effects on Brine Flies

Neither the proposed action nor alternatives would affect inflows to the lake, which are the primary factor affecting lake levels. Since the project would not affect lake levels, it would not substantially affect the area of surface water available for brine fly egg deposition, nor would it affect a substantial amount of lake bottom or shoreline. A small area of the North Arm lake bottom would be temporarily affected during construction, but, once the bridge construction (under either the proposed action or any of the bridge alternatives) is completed, the lake bottom would again be available for use by brine fly larvae. Neither the proposed action nor alternatives would affect the presence or abundance of floating debris that might be used by pupating larvae during warm weather (when larvae might use floating masses of algae as well as benthic algal mats).

As shown above in Table 7-2, neither the proposed action nor alternatives would significantly change South Arm salinity levels compared to baseline conditions. Brine flies have persisted under the baseline conditions and would continue to do so with the project, since salinity conditions with the project would not change. The project would not affect the lake level, which is a strong influence on brine fly populations, and therefore the project would not impair the lake's beneficial uses and cause a significant adverse effect.

7.2.3 Effects of the No-Action Alternative

With the no-action alternative, the east culvert would remain temporarily closed pending the identification and approval of a permanent closure solution. UPRR would necessarily continue to seek USACE and UDWQ approval to make the east culvert closure permanent. In addition, the compensatory mitigation element of the proposed action would not be implemented, with the result that the aquatic functions of the culverts would not be replaced until the necessarily approvals are granted.

Any resulting adverse change to conditions for brine shrimp and brine flies (outside of historic variability) caused by an incremental reduction in water and salt transfer through the causeway that impairs the lake's beneficial uses and continues unmitigated with the no-action alternative would likely continue until a permanent closure solution and mitigation plan is approved and implemented. UPRR also would necessarily continue to pursue USACE and UDWQ approval of an acceptable compensatory mitigation plan in support of making the east culvert closure permanent. It would be speculative to predict how long a new or revised individual permit action and corresponding mitigation proposal would take to be approved.

7.2.4 Construction-Related Effects

Construction for the proposed action and alternatives would not cause significant effects on any of the factors believed to influence the presence of brine shrimp and brine flies and would not affect the lifecycle stages of brine shrimp or brine flies in the lake. Local, short-term releases of sediment due to constructing and removing the temporary shoofly might cause a temporary change in brine shrimp distribution due to impacts on food sources and habitat, but such effects would be limited to the work area and would not affect the long-term population trends of brine shrimp in the lake. Because the construction-related effects would be short term and would be reduced by using best management practices, they would not impair the lake's beneficial uses and cause a significant adverse effect.

7.2.5 Post-construction Short-Term Effects

For the proposed action and alternatives, once the bridge is in place and the shoofly is removed, the bridge would be opened to convey flow between the North and South Arms. At the time the bridge is opened, there would be a period of less-than-minimal post-construction short-term transition effects during which the differences in WSE and salinity between the two arms would change rapidly. Over time, the differences would move toward equilibrium, and the post-construction effects would no longer exist. For more information about these post-construction short-term effects, see Section 3.2.7, Post-construction Short-Term Effects, in Chapter 3, Water Chemistry.

UPRR analyzed the short-term post-construction transition period that was observed when the existing 300-foot-long bridge was opened in 1984. Short-term post-construction effects on lake WSE and salinity were evaluated. Data suggest that, when the 300-foot-long bridge was opened in 1984, the head difference declined sharply for about 6 weeks, less dense (less saline) water appeared in the North Arm, and the deep brine layer in the South Arm became denser (more saline).

During the 1984 transition period, no short-term effects on North and South Arm salinities were documented as causing a significant adverse effect and impairing the lake's beneficial uses, and no new or additional data would support a different outcome with the proposed action or one of the alternatives.

8 Lake Circulation

This chapter discusses the potential effects of the proposed project on lake circulation. Lake circulation refers to the currents and patterns of waters within and between the North and South Arms of the Great Salt Lake.

8.1 Affected Environment

This section reviews the methods used to describe the affected environment (also known as existing conditions), describes the UPRR water and salt balance modeling effort, and reviews published studies of lake circulation patterns.

8.1.1 Methodology

This section addresses water currents and circulation of waters within and between the North and South Arms. The UPRR railroad causeway from Promontory Point westerly to Lakeside, Utah, also referred to as the northern railroad causeway (Figure 8-1 below), forms the boundary between Gunnison Bay (the North Arm) and Gilbert Bay (part of the South Arm). The Antelope Island causeway, which separates Gilbert Bay and Farmington Bay, and the southern railroad causeway are not part of the project and are not evaluated.

UPRR reviewed published studies and research projects that qualitatively or quantitatively evaluate, assess, and document circulation patterns in the Great Salt Lake. Although a detailed discussion of limnology (the study of inland waters) is beyond the scope of this analysis, this report addresses lake circulation as the movement of brine (spatial and direction patterns) in Gilbert and Gunnison Bays.

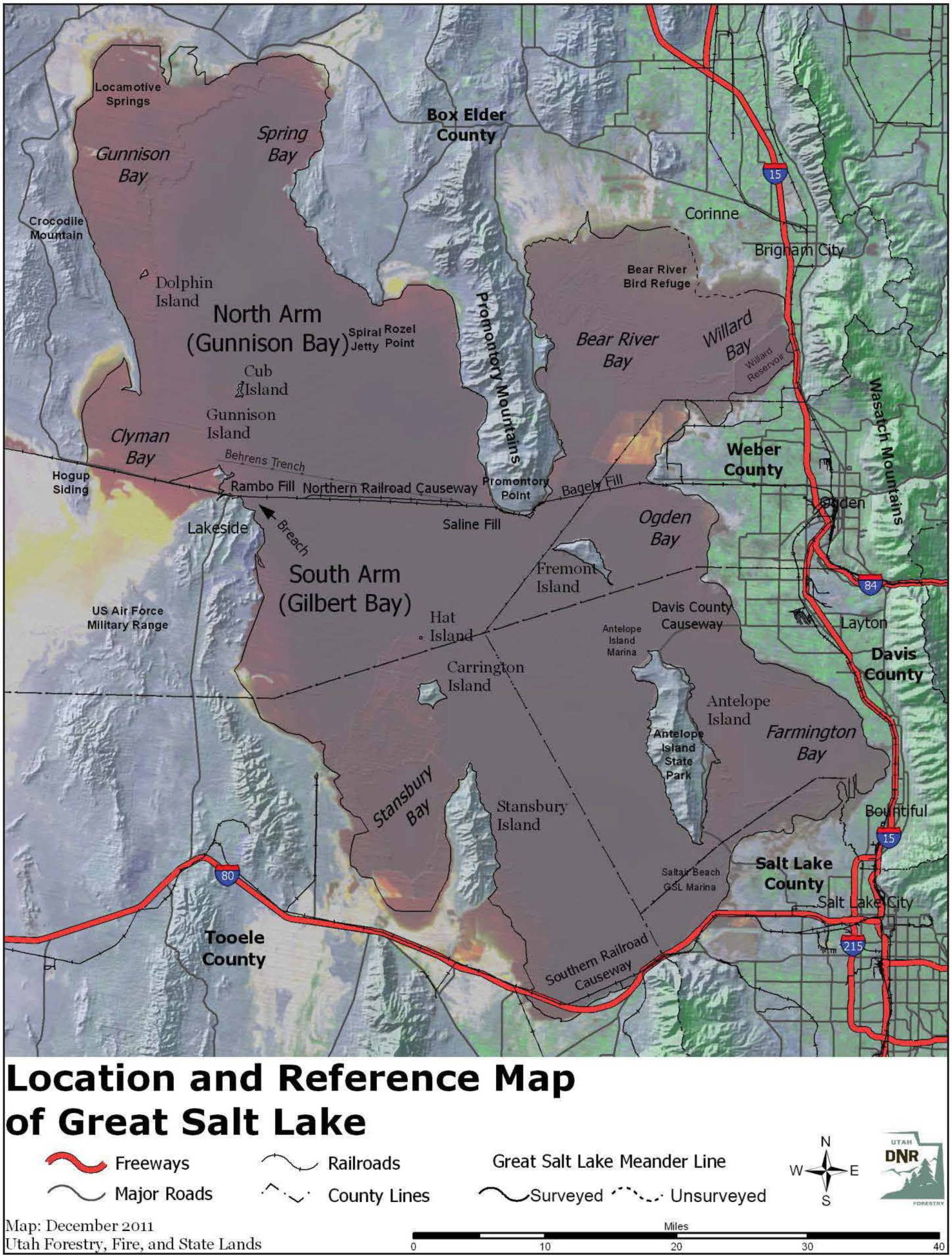
8.1.2 General Description of Circulation in the Great Salt Lake

The circulation of waters within and between the lake's bays is affected by environmental and human influences (UDFFSL 2013). Human-related physical influences include railroad and roadway causeways, flood-control facilities (dikes and levees), industrial facilities, and surface water diversions. These influences can change the way water moves into and within the lake. The Antelope Island and UPRR causeways are two examples of long, permeable barriers that affect how water moves within the lake. Management actions such as surface water diversions and flood-control actions can affect the lake level, which can also affect the way the lake water circulates.

Figure 8-1 below shows the lake's bays and some of the elements that affect circulation, such as the UPRR causeway (shown as the Northern Railroad Causeway and Bagley Fill), the Davis County (roadway) Causeway, and the Southern Railroad Causeway.

The project location would be on the Northern Railroad Causeway between Gunnison and Gilbert Bays. This resource evaluation focuses on the circulation of waters within Gunnison and Gilbert Bays in relation to the location of the proposed bridge.

Figure 8-1. Great Salt Lake Bays and Causeway Locations



Source: UDFFSL 2013

8.1.3 Published Data on Lake Circulation

Water circulation within the different bays has been documented in various scientific reports, which are summarized below.

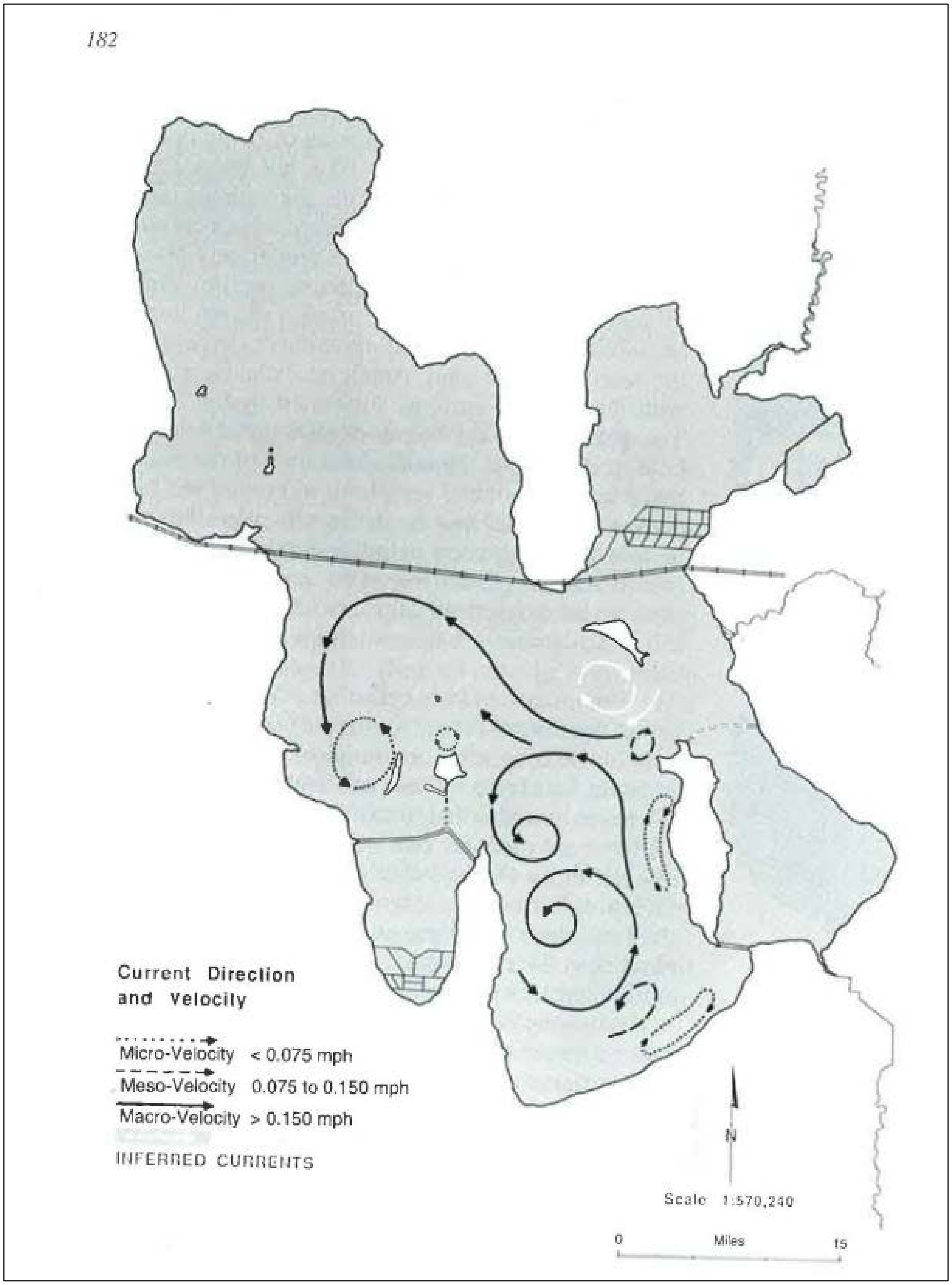
Dr. Paul Jewell reported recently on the creation of a hydrodynamic model of Gilbert Bay using the Princeton Ocean Model (POM). This study was partially funded by USGS. The results were presented at a conference, but the research has not yet been published. Surface water currents and deep brine layer currents were evaluated. The factors that Jewell identified as affecting the currents were river inflow, wind, and solar radiation (Jewell 2014).

Rich (2002) conducted research in 1991 to determine lake circulation patterns and the reason for the counterclockwise motion of the waters in Gilbert Bay, which is part of the South Arm. Satellite-tracked drifter buoys were used to gather direction, velocity, and water temperature data for Gilbert Bay. These data were analyzed in conjunction with weather information collected from a weather station on Antelope Island. Data were collected for 48 days in the spring and early summer of 1991 while the lake was rising as a result of snowmelt and was at a WSE of about 4,202 feet.

Rich made the following observations:

- A counterclockwise circulation pattern was documented for Gilbert Bay. The cause of the pattern is supported by water temperature, wind velocity, and direction data. These data indicate that, as the wind moves across the lake from south to north, warmer water in the east side of Gilbert Bay moves downwind (to the north). Cooler water along the bay’s western shore flows toward the east, filling in the areas where the eastern waters were, thereby creating a counterclockwise rotation (Figure 8-2 below).
- One specific drift buoy followed a westward current to within 5 miles of the existing 300-foot-long bridge, but the buoy then turned south and moved southerly away from the railroad causeway. Rich concluded that the size of the bridge is “too small to affect or alter the course of the broader circulation pattern found in the South Arm.”

Figure 8-2. Gilbert Bay Circulation Patterns in Rich (2002)

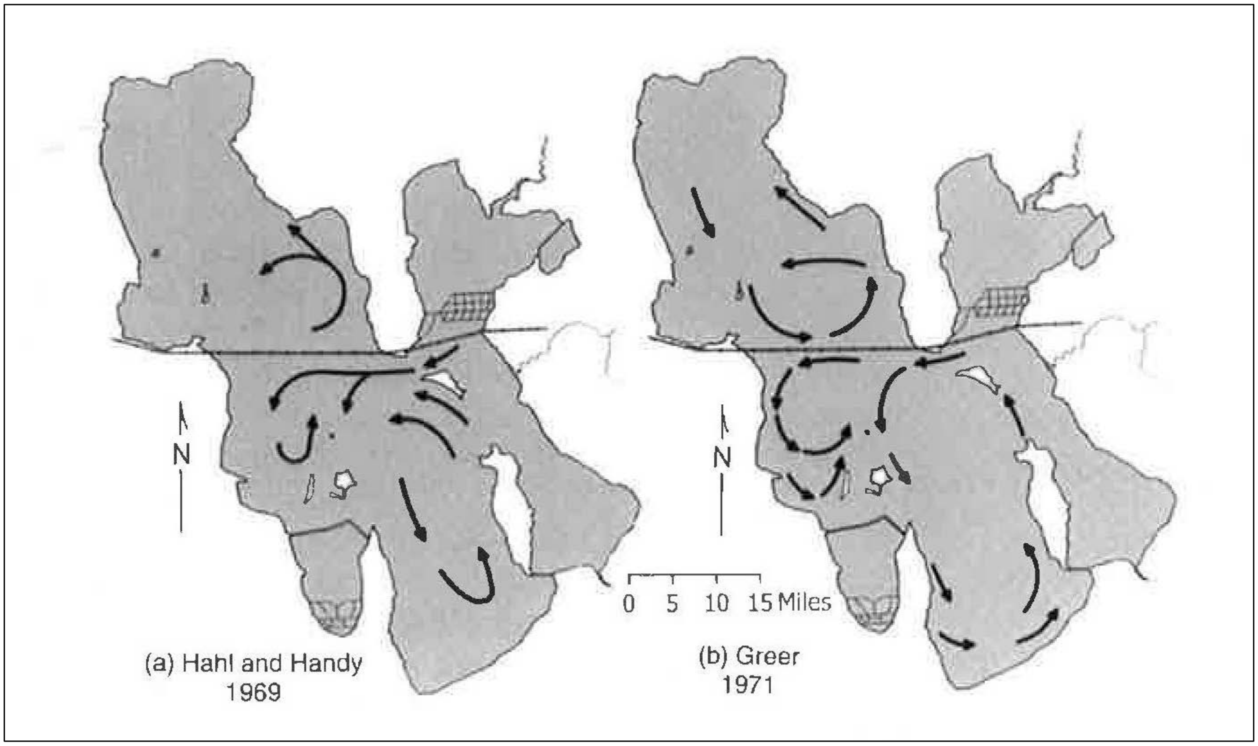


Source: Rich 2002, Figure 12

Other qualitative and/or quantitative lake current studies have been conducted previously. These studies indicate that there are surface currents and deep brine layer currents within various bays of the lake.

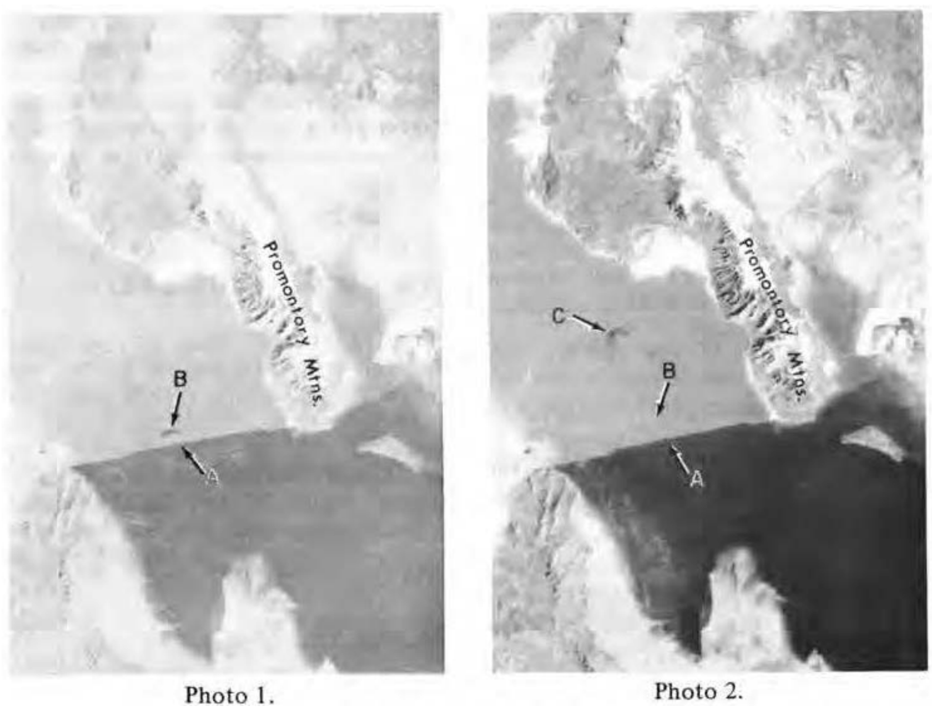
- In the mid-1960s, Hahl and Handy (1969) observed patterns of westerly flow along the railroad causeway. Using qualitative methods, they inferred a counterclockwise flow pattern based on shoreline deposits of sand and debris and aerial images of river inflows (Figure 8-3 below).
- In 1971, Greer (1971) found counterclockwise current patterns in both Gunnison and Gilbert Bays (Figure 8-3 below).
- In the 1970s, Lin (1974) conducted a quantitative study using equipment to track the surface and deep currents over several hours. He concluded that the current patterns were a result of wind direction. His results showed clockwise and counterclockwise currents in both the upper and deep brine layers of Gilbert Bay and in Gunnison Bay (Figure 8-5 below).
- In 1975, Katzenberger and Whelan (1975) studied lake circulation using qualitative observations while collecting water samples, qualitative observations while conducting search-and-rescue operations and scuba diving, and quantitative data from recording current speed and direction measurements. The authors found several counterclockwise patterns in Gilbert Bay. The report states that the chief factor affecting lake currents in Gilbert Bay is inflows (from Bear River Bay and Farmington Bay) that control two major patterns. These patterns are a result of surface water flow velocities entering the lake, with the highest velocities in the spring during snowmelt runoff. The authors also found that the Gunnison Bay patterns are influenced by the south-to-north flow through the east and west culverts. As the water flows through the culverts, it continues in a northwest-flowing pattern through Gunnison Bay, with little to no rotational pattern developed (Figure 8-5 below). Other factors identified that influence currents in Gilbert Bay were evaporation, lake bottom topography, subsurface inflow, and the deep brine layer of Gilbert Bay. This study discounted that periodic winds had long-term effects on lake current patterns.
- In 1978, Dr. Wally Gwynn with the Utah Geological and Mineral Survey conducted a dye study (Gwynn 1978). This study tracked biodegradable dye that was placed in the North Arm at the west culvert and tracked over several days of relatively calm winds (Photo 1 and Photo 2 in Figure 8-4 below). Using satellite images, the dye was observed to extend northerly about 1.4 miles after 2 hours and about 8 miles after 26 hours, with no indication of a circular pattern. UGS concluded that the movement of the dye was due to surface currents and not wind.
- In 1979, the Utah State Water Research Laboratory created a mathematical, hydrodynamic circulation model for Gilbert Bay that developed relationships between water depth, inflows and outflow, barometric pressure, and fluid density and other friction factors. The model found clockwise and counterclockwise patterns; however, the instability of the model and the lack of field verification data led the researchers to determine that the modeling required additional data collection to be conclusive (Figure 8-5 below) (UGS 2002, 173).

Figure 8-3. Great Salt Lake Circulation Patterns in Hahl and Handy (1969) and Greer (1971)



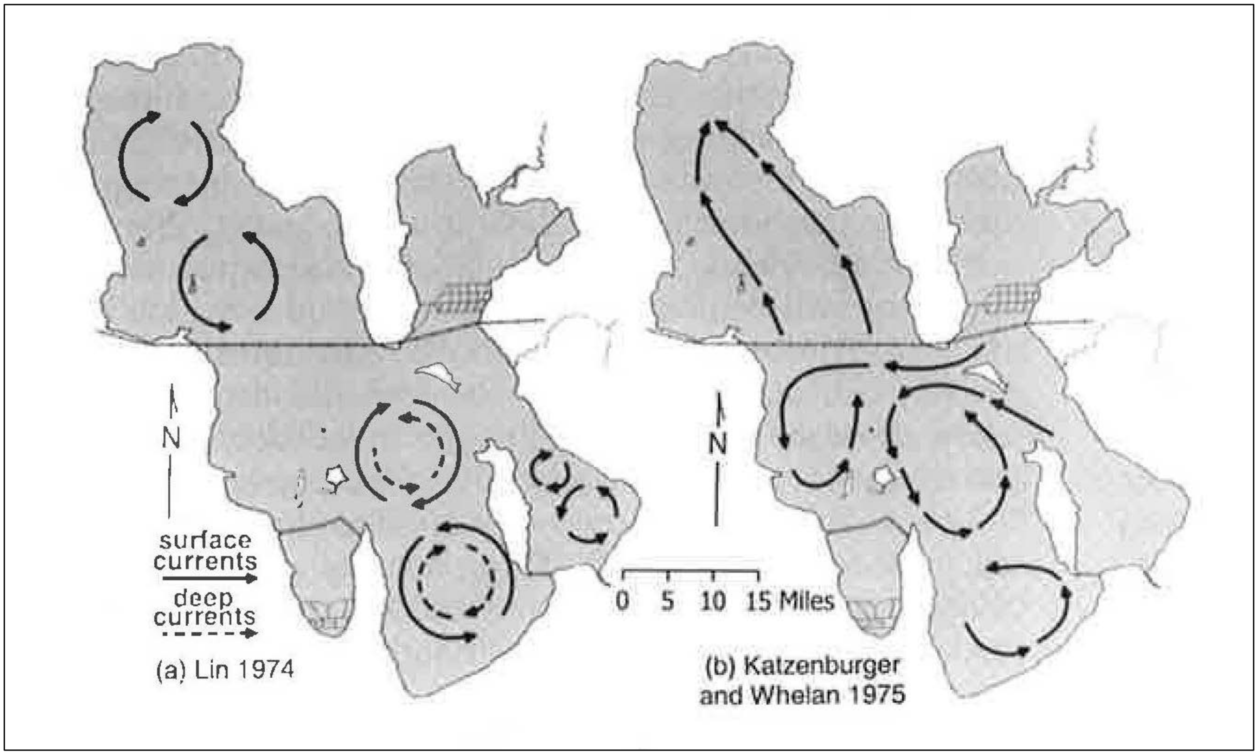
Source: Rich 2002, Figure 2

Figure 8-4. Gunnison Bay Circulation Patterns in Gwynn (1978)



Source: Gwynn 1978

Figure 8-5. Great Salt Lake Circulation Patterns in Lin (1974) and Katzenberger and Whelan (1975)



Source: Rich 2002, Figure 3

8.2 Environmental Consequences

This section describes the potential effects of the proposed project on the lake circulation patterns in Gilbert and Gunnison Bays.

8.2.1 Methodology

To evaluate the potential effects of the proposed project on lake circulation patterns in Gilbert and Gunnison Bays, UPRR reviewed published qualitative and quantitative lake current and circulation studies to identify the key factors that affect circulation and conducted water and salt balance modeling for the proposed action and alternatives. For this analysis, *circulation effects* are defined as effects of the project on the flow of the upper and deep brine layers, velocity, and current patterns that occur in Gunnison Bay (the North Arm) and Gilbert Bay (part of the South Arm).

What are circulation effects?

Circulation effects are defined as effects of the project on the flow of the upper and deep brine layers, velocity, and current patterns that occur in Gunnison Bay (the North Arm) and Gilbert Bay (part of the South Arm).

The project would have an adverse effect on circulation if it were to change any of the contributing factors described in this section in a way that would impair the lake's beneficial uses.

8.2.2 Factors That Affect Great Salt Lake Circulation

UPRR reviewed seven studies to assess circulation and how it affects water and salt transfer, or brine movement, in the lake (Table 8-1). All of these studies have been conducted to determine the overall circulation patterns of the lake with the causeway in place. While some have focused on the current, velocities, and direction of the upper brine layer, others have evaluated the current, velocities, and direction of the deep brine layer. Most of the studies have concluded by identifying circulation patterns and the factors that cause those patterns.

Table 8-1. Factors That Affect Lake Circulation Patterns

Source	Type of Study	Location of Study	Focus of Study	Factors
Hahl and Handy 1969	Qualitative	Gunnison and Gilbert Bays	Surface currents	Coriolis effect, inflow, wind, evaporation, density currents
Lin 1974	Quantitative	Gunnison, Gilbert, and Farmington Bays	Surface and deep brine currents	Wind
Katzenberger and Whelan 1975	Qualitative and quantitative	Gunnison and Gilbert Bays	Surface currents	Inflow, evaporation, lake bottom topography, subsurface inflow, deep brine layer
Gwynn 1978	Quantitative	Gunnison Bay	Surface currents	Flows through the east and west culverts
Rich 2002	Quantitative	Gilbert Bay	Surface currents	Water temperature, wind velocity and direction
Jewell 2014	Numeric model	Gilbert Bay	Surface currents	River inflow, density gradient, wind and solar radiation

8.2.3 Effects of the Proposed Action and Alternatives

The proposed action and alternatives would not change any of the factors that affect lake circulation patterns in Gilbert and Gunnison Bays. Because the east and west culvert are currently closed, the proposed action and alternatives would not change the flows through the east and west culverts, which is the only factor listed in Table 8-1 above that is related to causeway characteristics (Gwynn 1978). With either the proposed action or any of the alternatives, flow between the North and South Arms would be reintroduced. The water and salt balance modeling results show that the proposed action best matches the pre-culvert closure conditions for water and salt transfer. As described in Chapter 3, Water Chemistry, the modeling results for the bridge alternatives would have varying effects on water and salt transfer.

The proposed action and alternatives would not affect the primary factors that influence lake circulation in Gilbert Bay (wind, river inflows, and Coriolis effect). The circulation patterns in the North Arm have been documented to be northerly, with the flows through the culverts moving south to north and then dissipating (Gwynn 1978). The new bridge would also convey water northerly through Gunnison Bay in a similar pattern. Because of this, the proposed action and alternatives would not impair the lake's beneficial uses and cause a significant adverse effect due to effects on circulation patterns.

8.2.4 Effects of the No-Action Alternative

With the no-action alternative, the east culvert would remain temporarily closed pending the identification and approval of a permanent closure solution. UPRR would necessarily continue to seek USACE and UDWQ approval to make the east culvert closure permanent. In addition, the compensatory mitigation element of the proposed action would not be implemented, with the result that the aquatic functions of the culverts would not be replaced until the necessarily approvals are granted.

Any resulting adverse change in lake circulation (outside of historic variability) caused by an incremental reduction in water and salt transfer through the causeway that impairs the lake's beneficial uses and continues unmitigated with the no-action alternative would likely continue until a permanent closure solution and mitigation plan is approved and implemented. UPRR also would necessarily continue to pursue USACE and UDWQ approval of an acceptable compensatory mitigation plan in support of making the east culvert closure permanent. It would be speculative to predict how long a new or revised individual permit action and corresponding mitigation proposal would take to be approved.

8.2.5 Construction-Related Effects

Construction of the proposed action and alternatives would require using a temporary shoofly for rail traffic as the bridge is being built. However, construction activities, including placing and removing the temporary shoofly, would not affect any of the primary factors that influence water circulation patterns in Gunnison and Gilbert Bays. Therefore, these short-term construction-related effects would not impair the lake's beneficial uses and cause a significant adverse effect due to effects on circulation patterns.

8.2.6 Post-construction Short-Term Effects

For the proposed action and alternatives, once the bridge is in place and the shoofly is removed, the bridge would be opened to convey water between the North and South Arms. When the bridge is opened, there would be a period of less-than-minimal post-construction short-term effects during which the differences in WSE and salinity between the two arms would rapidly change. Over time, the differences would move toward equilibrium, and the post-construction effects would no longer exist. For more information about these post-construction short-term effects, see Section 3.2.7, Post-construction Short-Term Effects, in Chapter 3, Water Chemistry.

UPRR analyzed the short-term post-construction transition period that was observed when the existing 300-foot-long bridge was opened in 1984. Short-term post-construction effects on lake WSE and salinity were evaluated. Data suggest that, when the 300-foot-long bridge was opened in 1984, the head difference declined sharply for about 6 weeks, less dense (less saline) water appeared in the North Arm, and the deep brine layer in the South Arm became denser (more saline).

During the 1984 transition period, no short-term effects on Gunnison and Gilbert Bay circulation patterns were documented as causing a significant adverse effect and impairing the lake's beneficial uses, and no new or additional data would support a different outcome with the proposed action or one of the alternatives.

9 Summary and Public Interest Factors

This chapter summarizes the effects of the proposed action and alternatives on the ecological resources of the lake that were evaluated in this report. In addition, in this chapter UPRR reviews the project's effects and how the project might affect or be affected by public interest factors. These public interest factors are specifically identified by USACE, and regulations require that USACE consider these factors as part of the CWA Section 404 permitting process.

9.1 Summary of Project Effects

In summary, the proposed project and alternatives would not affect the deep brine layer, mercury and methyl mercury, biological resources, or lake circulation. For these resources, the proposed project and alternatives would not significantly change the baseline conditions and would be within the historic variability in influencing factors, such as salinity, arm-to-arm flow, WSEs, atmospheric conditions, and inflows.

Water chemistry, which serves as a surrogate for water quality, would vary among the alternatives, and the magnitude of variation depends on which model results are compared. Because the model results varied, UPRR conducted a combined screening of the alternatives (Table 2-2, Rankings of Bridge Alternatives Evaluated by the UPRR/USGS Models, on page 17). Based on the ranking, UPRR determined that a 150-foot-long bridge with an invert of 4,183 feet (originally identified as Alternative C and presented as the proposed project in this report) would provide the best overall match to the baseline conditions (the conditions that would have occurred with the culverts intact).

The proposed project and alternatives would not significantly affect the factors that affect the lake's resources in a way that would cause a significant adverse effect by impairing the lake's beneficial uses, which are primary and secondary contact recreation, waterfowl, shore birds, and other water-oriented wildlife including their necessary food chain. The construction-related effects associated with the proposed project and alternatives would also not impair primary and secondary contact recreation, waterfowl, shore birds, and other water-oriented wildlife including their necessary food chain.

Regardless of the bridge geometry that is ultimately selected, any of the options studied could cause short-term changes in salinity and local density gradients as the project area moves toward equilibrium. These post-construction short-term effects are not expected to cause or contribute to long-term changes in lakewide salinity or the cyclical nature of the South Arm's deep brine layer.

With the no-action alternative, the east culvert would remain temporarily closed pending the identification and approval of a permanent closure solution. UPRR would necessarily continue to seek USACE and UDWQ approval to make the east culvert closure permanent. In addition, the compensatory mitigation element of the proposed action would not be implemented, with the result that the aquatic functions of the culverts would not be replaced until the necessarily approvals are granted.

Any resulting adverse change in the factors considered in this report (outside of historic variability) caused by an incremental reduction in water and salt transfer through the causeway that impairs the lake's beneficial uses and continues unmitigated with the no-action alternative would likely continue until a permanent closure solution and mitigation plan is approved and implemented. UPRR would necessarily continue to pursue USACE and UDWQ approval of an acceptable compensatory mitigation plan in support of making the east culvert closure permanent. It would be speculative to predict how long a new or revised individual permit action and corresponding mitigation proposal would take to be approved.

Accordingly, the no-action alternative differs from the proposed project and alternatives in that no compensatory mitigation bridge would be approved because no action would be taken. Further, the compensatory bridge that is ultimately approved by USACE and UDWQ might have a different geometry.

Table 9-1. Summary of Project Effects

No-Action Alternative	Proposed Project	Alternatives
Water Chemistry		
Effects on South Arm Salinity (Compared to Baseline Conditions)		
Long-term effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	• 2012 UPRR/USGS Model: 1.3% average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.3% increase for wet cycle, 0.2% increase for mild cycle, and 1.2% decrease for dry cycle	*Alternative A* • 2012 UPRR/USGS Model: 2.7% average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.5% increase for wet cycle, 1.0% increase for mild cycle, and 2.6% increase for dry cycle *Alternative B* • 2012 UPRR/USGS Model: 1.9% average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.4% increase for wet cycle, 0.5% increase for mild cycle, and 0.9% increase for dry cycle *Alternative D* • 2012 UPRR/USGS Model: 0.2% average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.2% increase for wet cycle, 0.3% decrease for mild cycle, and 5.3% decrease for dry cycle
Effects on South Arm Salt Load (Compared to Baseline Conditions)		
Long-term effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	• 2012 UPRR/USGS Model: 0.2-billion-ton (BT) average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.07-BT increase for wet cycle, 0.03-BT increase for mild cycle, and 0.17-BT decrease for dry cycle	*Alternative A* • 2012 UPRR/USGS Model: 0.35-BT average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.12-BT increase for wet cycle, 0.15-BT increase for mild cycle, and 0.33-BT increase for dry cycle *Alternative B* • 2012 UPRR/USGS Model: 0.24-BT average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.10-BT increase for wet cycle, 0.08-BT increase for mild cycle, and 0.09-BT increase for dry cycle *Alternative D* • 2012 UPRR/USGS Model: 0.01-BT average increase • 2012 UPRR/USGS Varying Hydrology Model: 0.05-BT increase for wet cycle, 0.06-BT decrease for mild cycle, and 0.67-BT decrease for dry cycle

Table 9-1. Summary of Project Effects

No-Action Alternative	Proposed Project	Alternatives
Water Chemistry (*continued*)		
Construction Effects		
Construction effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	Possible short-term water quality effects, due to constructing and removing the temporary shoofly, that are not expected to affect local or lakewide water chemistry	(All alternatives except no action) Possible short-term water quality effects due to constructing and removing the temporary shoofly
Post-construction Short-Term Effects		
Post-construction short-term effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	Possible rapid salinity and WSE changes in the project area during the transition period	(All alternatives except no action) Possible rapid salinity and WSE changes in the project area during the transition period
Water Quality		
Long-term, construction, and post-construction short-term effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	***Long-term Effects*** Analysis uses salinity as a surrogate for specific water quality parameters; see *Water chemistry* above ***Construction Effects*** Possible short-term water quality effects, due to constructing and removing the temporary shoofly, that are not expected to affect local or lakewide water quality parameters ***Post-construction Short-Term Effects*** Possible rapid salinity and WSE changes in the project area during the transition period that are not expected to affect water quality parameters	***Long-term Effects*** See *Water chemistry* above

Table 9-1. Summary of Project Effects

No-Action Alternative	Proposed Project	Alternatives
Deep Brine Layer		
Effects on Ratio of South-to-North Flow to North-to-South Flow (Compared to Baseline Conditions)		
Long-term effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	• 2012 UPRR/USGS Model: decrease of 0.33 • 2012 UPRR/USGS Varying Hydrology Model: decrease of 0.10 for wet cycle, decrease of 0.05 for mild cycle, and increase of 0.17 for dry cycle • Mild-cycle ratio would most closely match the baseline conditions under the 2012 UPRR/USGS Varying Hydrology Model	*Alternative A* • 2012 UPRR/USGS Model: decrease of 0.61 • 2012 UPRR/USGS Varying Hydrology Model: decrease of 0.16 for wet cycle, 0.23 for mild cycle, and 0.25 for dry cycle • Poorest match to the baseline conditions *Alternative B* • 2012 UPRR/USGS Model: decrease of 0.46 • 2012 UPRR/USGS Varying Hydrology Model: decrease of 0.13 for wet cycle, 0.13 for mild cycle, and 0.09 for dry cycle • Dry-cycle ratio would most closely match the baseline conditions under the 2012 UPRR/USGS Varying Hydrology Model *Alternative D* • 2012 UPRR/USGS Model: decrease of 0.05 • 2012 UPRR/USGS Varying Hydrology Model: decrease of 0.07 for wet cycle, increase of 0.07 for mild cycle, and increase of 1.03 for dry cycle • Would most closely match the baseline conditions under the 2012 UPRR/USGS Model and the wet-cycle ratio under the 2012 UPRR/USGS Varying Hydrology Model
Construction Effects		
Construction effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	No effect	No effect

Table 9-1. Summary of Project Effects

No-Action Alternative	Proposed Project	Alternatives
Deep Brine Layer (*continued*)		
Post-construction Short-Term Effects		
Post-construction short-term effects similar to either proposed project or one of the alternatives, depending on the approved compensatory mitigation.	Could increase the Gilbert and Gunnison Bay density gradients for a short time when the bridge is opened; otherwise not expected to affect long-term variability in the density gradient	Same as proposed project for all alternatives
Mercury (Hg) and Methyl Mercury (MeHg)		
Same as proposed project	***Long-term Effects*** • Not a source of Hg and not near known sources of Hg • No effects on the factors (source, lake inflows, lake hydrodynamics, and biotic and abiotic processes) thought to contribute to MeHg behavior in the Great Salt Lake ***Construction Effects*** No effect ***Post-construction Short-Term Effects*** Could increase Gilbert Bay density gradient for a short time when the bridge is opened; otherwise not expected to affect factors that affect MeHg availability as a result	***Long-term Effects*** Same as proposed project for all alternatives

Table 9-1. Summary of Project Effects

No-Action Alternative	Proposed Project	Alternatives
Biological Resources		
Same as proposed project	***Long-term Effects*** • No effects on salinity variability, so no effects on any brine shrimp life stages • No effects on lake levels, so no effects on any brine fly life stages ***Construction Effects*** Potential short-term water quality effects could cause short-term local effects on brine shrimp and brine fly habitats ***Post-construction Short-Term Effects*** Possible rapid changes in salinity and WSE could temporarily cause local, direct effects on brine shrimp and brine flies but would not adversely affect lakewide conditions that support these elements of the lake's beneficial uses (necessary food chain)	***Long-term Effects*** Same as proposed project for all alternatives
Lake Circulation		
Same as proposed project	***Long-term Effects*** No effects on factors that influence lake circulation patterns in Gilbert or Gunnison Bays ***Construction Effects*** No effects on factors that influence lake circulation patterns ***Post-construction Short-Term Effects*** No effects on factors that influence lake circulation patterns	***Long-term Effects*** Same as proposed project for all alternatives

9.2 Public Interest Review

USACE's decision whether to issue a Section 404 permit is based on an evaluation of the probable impacts of the proposed activity and on the effects of the project's intended use on the public interest [33 CFR 320.4(a)]. This report discusses the potential effects of the proposed project in Chapters 3 through 8. This section focuses on the factors included in the USACE public interest review.

The regulations at 33 CFR 320.4(a) list the public interest factors that USACE should consider during its permit review. The factors listed include conservation, economics, aesthetics, general environmental concerns, wetlands, historic properties, fish and wildlife values, flood hazards, floodplain values, land use, navigation, shore erosion and accretion, recreation, water supply and conservation, water quality, energy needs, safety, food and fiber production, mineral needs, considerations of property ownership and, in general, the needs and welfare of the people.

USACE provided UPRR with a template that lists factors that USACE normally considers as it prepares its permit decision documents. These templates include the public interest review factors listed in 33 CFR 340.4 as well as factors normally considered as part of a CWA Section 404 (b)(1) analysis.

Table 9-2 below combines the public interest factors included in 33 CFR 340.4 and the factors normally considered as part of a CWA Section 404 (b)(1) analysis and summarizes the applicability of each factor to the proposed project.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Physical/Chemical Characteristics		
Aquifer recharge	The project would not change or otherwise affect water available for aquifer recharge or conditions that contribute to aquifer recharge.	Not addressed.
Baseflow	The project would not affect lake inflows (surface water, precipitation, or groundwater). The project would result in minor changes in flow between the North and South Arms of the lake.	Flow changes are discussed in the *Bridge Evaluation Report*, which was previously submitted to USACE under separate cover. The changes are summarized in several places in this report, including Chapter 3, Water Chemistry, Chapter 4, Water Quality, Chapter 5, Deep Brine Layer, and Chapter 8, Lake Circulation.
Current patterns and water circulation	The project would create a new opening in an existing causeway to compensate for closing two culverts. This change would not affect overall, lakewide circulation.	Water circulation and current patterns are addressed in Chapter 8, Lake Circulation.
Erosion and accretion patterns	The project area is normally inundated, and armoring protects the railroad causeway from erosion. The area is not near any sources of eroded material that would influence accretion of the causeway or shoreline. The project would not change the erosion and accretion patterns of adjacent areas. UPRR will regularly inspect and, if necessary, will remove material deposited in the bridge opening if the accumulated material adversely affects the function of the opening. This activity would not affect lakewide erosion or accretion.	Not addressed in this report. Maintaining the opening at its design size will be addressed in the project's mitigation and monitoring plan.
Flood hazards and floodplain values	The project would be situated in the Great Salt Lake, which normally holds water (that is, is flooded under normal conditions). The project would not change the elevation of the causeway nor would it increase flood hazards to the causeway or adjacent property. Lake levels are a function of natural and human-influenced processes, including inflow from runoff and permitted discharges, short-term and long-term weather patterns, and water-management practices. The project would not affect the location of the floodplain of the Great Salt Lake and would not affect the functions that contribute to overall lake levels.	Not addressed.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Physical/Chemical Characteristics (*continued*)		
Mixing zone in light of the depth of water at the disposal site; current velocity, direction, and variability at the disposal site; degree of turbulence; water column stratification discharge vessel speed and direction; rate of discharges per unit of time; and any other relevant factors affecting rates and patterns of mixing	The project would not affect lake long-term mixing and related salinity gradients. The project would not affect the depth of water or degree of turbulence in the lake. The project could have short-term effects on the potential rapid change in salinity and WSE when the new bridge is constructed when water flows through the new bridge opening during the transition period.	Effects on salinity gradients and mixing are addressed in Chapter 3, Water Chemistry, and Chapter 5, Deep Brine Layer.
Normal water level fluctuations	The project would not affect lake inflows or evaporation.	Not addressed.
Salinity gradients (water quality)	The project would not cause a significant adverse effect on the lake's long-term salinity gradient conditions, which naturally fluctuate as a result of many factors. The project could result in some short-term changes in water transfer from the North Arm to the South Arm in the area where the new bridge is constructed when water flows through the new opening until conditions equalize.	Salinity and potential short-term effects are addressed in Chapter 3, Water Chemistry, and Chapter 5, Deep Brine Layer.
Storm, wave, and erosion buffers	The existing causeway is currently armored with large riprap. A short section of the causeway and its armoring would be removed in the area where the bridge would be built. The bridge would be designed to protect against scour that might be caused by rough water that occurs as a result of extreme storms, including waves. UPRR armored the east culvert area when the culvert was temporarily closed. UPRR would not do anything more at the east culvert location. The project would not affect any other areas with armoring.	Not addressed.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Physical/Chemical Characteristics (*continued*)		
Substrate	The project would involve creating an opening in an existing causeway and spanning that opening with a bridge. Soil maps for the project area show that the area is identified as *water, saline*. Substrate in the area is lake clays, which are the most common substrate in the lakebed. The physical characteristics of the clays (color, particle size) vary throughout the lake, depending on the color and type of the original source rocks. Plasticity and structure vary as well (Gwynn and Murphy 1980). The east culvert is already closed. UPRR would not do any further work in the area of the east culvert, and therefore the project would not affect the substrate at that location.	The bridge would be designed to ensure geotechnical stability, thus ensuring safe, long-term rail operations. It is in UPRR's interest to build a safe, stable structure that is appropriate for soils in the area. Substrate and soils are thus not addressed further in this report.
Suspended particulates/turbidity	The project would not cause any long-term water quality effects as a result of suspended particulates or turbidity. UPRR will implement best management practices during construction to reduce potential short-term effects on water quality due to sediment. The bridge would be protected from erosion after it is constructed.	Water quality effects due to construction activities are addressed in Chapter 4, Water Quality.
Water quality	UPRR must qualify for and receive a CWA Section 401 water quality certification for the project.	Water quality is addressed in Chapter 4, Water Quality.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Biological Characteristics		
Biological availability of possible contaminants in dredged or fill material, considering hydrography in relation to known or anticipated sources of contaminants; results of previous testing of material from the vicinity of the project; known significant sources of persistent pesticides from land runoff or percolation; spill records for petroleum products or designated (Section 311 of the CWA) hazardous substances; other public records of significant introduction of contaminants from industries, municipalities, or other sources	The project involves removing causeway material as needed to provide the approved invert. The Utah Department of Environmental Quality does not list any hazardous spill sites or other hazardous sites in the project area (or anywhere along the causeway). The project would not introduce pesticides or other contaminants. Mercury has recently become a concern in the Great Salt Lake, and commenters have expressed concern that the project could affect lake conditions such that it increases the bioavailability of methyl mercury. This report found that the project is not expected to affect lake conditions in a way that could change the bioavailability of methyl mercury outside its historic variability.	Mercury and methyl mercury are addressed in Chapter 6, Mercury and Methyl Mercury.
Fish, crustaceans, mollusks, and other aquatic organisms in the food web	The Great Salt Lake supports brine shrimp, which are an important part of the lake's food web.	Brine shrimp are discussed in Chapter 7, Biological Resources.
Wildlife values	The part of the Great Salt Lake in and near the project site supports brine shrimp and brine flies and/or provides suitable habitat for portions of these species' life cycles. Migratory birds that use the lake forage for brine shrimp and brine flies.	Biological resources are discussed in Chapter 7, Biological Resources. That chapter focuses on how the project might affect brine shrimp and brine flies, which are important factors in the lakewide food web.
Special aquatic sites	The Great Salt Lake is a special aquatic site. The proposed project and alternatives would affect the Great Salt Lake equally.	UPRR proposes to install a bridge as compensatory mitigation for project impacts and submit for approval a mitigation and monitoring plan. USACE has agreed to the mitigation concept but must still approve a mitigation plan. Mitigation is not otherwise addressed in this report.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Biological Characteristics (*continued*)		
Threatened and endangered species	USACE has determined that the project would not affect any federally listed threatened or endangered species or critical habitat for such species. USACE has also determined that the project would not adversely affect essential fish habitat (EFH) as defined in the Magnuson-Stevens Fishery Conservation and Management Act.	Not addressed.
Human Use Characteristics		
Aesthetics	The proposed mitigation (bridge construction) would permanently change the appearance of a short section of the causeway, but this section is not normally viewed by large numbers of people and is not visible from public-access areas around the lake. The change would not cause significant adverse effects on the visual environment.	Not addressed.
Air quality	The project would not change the long-term ambient air quality conditions nor would it introduce new sources of air pollution.	Not addressed.
Conservation and general environmental concerns	The Great Salt Lake is a regionally important resource that is the subject of a comprehensive management plan. The lake is important to residents for its ecological and economic values. As described throughout this report, the project would not affect any of these values. It also would not affect any ongoing conservation efforts associated with the Great Salt Lake or with wildlife that use the lake.	Not addressed.
Economics	A loss of railway function across the causeway and the lake could have adverse economic impacts to UPRR. Commenters have expressed concern that the project could affect the conditions of resources (such as salt and brine shrimp) in the lake and cause economic effects on commercial businesses that extract or harvest these resources.	UPRR has previously provided information to USACE regarding the cost of losing the ability to use the causeway for rail operations. That information is not repeated in this report. As described in Chapter 3, Water Chemistry, the proposed project would not cause a significant adverse effect on the water and salt balance in the Great Salt Lake or impair its beneficial uses, including biological uses. Accordingly, the proposed project would not adversely affect the distribution of minerals or biological resources that are of economic value and are currently extracted or harvested from areas associated with the lake.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Human Use Characteristics (*continued*)		
Energy needs	The project would not require an increase in the amount or type of energy needed to operate.	Not addressed.
Food and fiber production	The project would not be located in or near areas that are used for food and fiber production. Brine shrimp cysts that are commercially harvested from the lake are discussed under *Wildlife values* above.	Not addressed.
Historic properties	USACE has determined that the causeway, which was built in 1959 and would be affected by the project, is not eligible for listing on the National Register of Historic Places and has found that the project would have no effect on historic properties. The Utah State Historic Preservation Officer (SHPO) has concurred with USACE's finding of effect.	Not addressed.
Land use	The project would not change current or planned land uses in the project area. The project would be located in the Great Salt Lake, which is managed consistent with direction prescribed in the Great Salt Lake Comprehensive Management Plan (UDFFSL 2013). The Utah Division of Forestry, Fire and State Lands has responsibility for managing sovereign lands in the Great Salt Lake. UPRR has worked and will continue to work with the Division as needed to ensure that operation of the causeway is consistent with existing authorizations issued by the Division.	Not addressed.
Mineral needs	Commercial extractors are permitted to extract minerals from the Great Salt Lake. Mineral-extraction businesses and interested parties have expressed concern that the project could affect the lake's balance of minerals and therefore cause adverse effects on the-mineral extraction industry.	As described in Chapter 3, Water Chemistry, the proposed project would not cause a significant adverse effect on the water and salt balance in the Great Salt Lake. Accordingly, the proposed project would not affect the distribution of minerals that are of economic value and are currently extracted from areas associated with the lake.
Navigation	Historically, the west and east culverts provided navigation through the causeway at certain lake levels. Over time, this function was lost as the culverts became submerged due to settlement and as the lake level changed. The mitigation proposed as part of the project includes building a bridge to replace the closed culverts. By installing this bridge, UPRR would restore the ability of small boats to move between the North and South Arms of the lake at average lake levels.	The proposed mitigation would enable navigation between the North and South Arms of the lake at average lake levels. Navigation is not otherwise addressed in this report.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Human Use Characteristics (*continued*)		
Needs and welfare of the people	The project would be located in a remote area in which no one lives. The project would not affect the general welfare of people in the immediate vicinity. If UPRR were to lose the ability to use the causeway for rail traffic, there would be significant economic impacts because, among other things, traffic would have to be rerouted through the state's largest urban area, which includes Salt Lake City. Continued operation of the causeway as a railway is important to maintain UPRR's contributions to the local, regional, and national economy, a contribution that affects the welfare of people who work in and rely on industries and services supported by the railroad. The project is designed in a manner to ensure that the local, regional, and national contribution of this section of railway is maintained at current levels.	Addressed as part of the project purpose and need in Chapter 1, Introduction. UPRR has previously provided USACE with information about the adverse effects of closing the causeway and thereby forcing UPRR to reroute rail traffic through the Ogden and Salt Lake City urban areas. These effects are summarized in Chapter 2, Project Description and Additional Project Alternatives.
Noise	The project would not cause any long-term effects on the ambient noise environment. Construction activities could temporarily increase noise levels at the construction site. There are no sensitive noise receivers in the project area, since it is in the middle of the Great Salt Lake. Furthermore, such noise impacts would be short term and would probably not be louder than the regular train traffic that travels through the area.	Not addressed.
Parks, national and historical monuments, national seashores, wilderness areas, research sites, and similar areas	The project would not be located in a park, national or historical monument area, national seashore, or wilderness area. The Great Salt Lake is managed according to a comprehensive management plan administered by the State of Utah. UPRR operates the causeway consistent with the land use and easements identified in that plan. The project area is not a designated research area, but the State and others (for example, graduate students) regularly collect lake data. The project would not affect any areas regularly used for data collection.	Not addressed.
Prime and unique farmland	The project area does not support prime and/or unique farmland.	Not addressed.
Property ownership	The project would not change current or future property ownership in the project area.	Not addressed.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Human Use Characteristics (*continued*)		
Recreation	See *Navigation* above. Building the bridge would allow recreational navigation by small boats between the North and South Arms of the lake at average lake levels. The project would not otherwise affect recreational uses of the Great Salt Lake.	The proposed mitigation bridge would allow recreational navigation of small boats between the North and South Arms of the lake at average lake levels. Recreation is not otherwise addressed in this report.
Recreational and commercial fisheries	Gilbert and Gunnison Bays are too saline to support recreational and commercial fisheries. Gilbert and Gunnison Bays are not protected to support cold- or warm-water fish. The lake supports commercial harvesting of brine shrimp cysts. The project would not affect the abundance or distribution of brine shrimp and the production of cysts, so UPRR does not expect the project to affect the brine shrimp industry.	Brine shrimp are addressed in 7, Biological Resources.
Safety	The project is needed to ensure safe operation of UPRR trains that travel over the causeway. Continued safe operation is a project need, and the project is designed to address this need.	Addressed as part of the project purpose and need in Chapter 1, Introduction.
Traffic/transportation patterns	The project involves rail traffic and is necessary to ensure the continued safe operation of rail traffic across the Great Salt Lake. The project would not otherwise affect traffic or transportation patterns. If the causeway becomes unsafe or unusable for rail traffic, UPRR would have to route trains through the largest urban area in the state. Adding trains to this route could adversely affect vehicle transportation associated with congestion near the at-grade rail crossings by adding delay (more trains cause more vehicles to stop at rail crossings).	The project purpose and need addresses the importance of continued safe rail operation across the causeway (Chapter 1, Introduction). UPRR has previously provided USACE with information about the adverse effects of closing the causeway and thereby forcing UPRR to reroute rail traffic through the Ogden and Salt Lake City urban areas. These effects are summarized in 2, Project Description and Additional Project Alternatives.

Table 9-2. Summary of the Project's Relationship to the USACE Public Interest Review Factors

Public Interest Review Factor	Applicability to the Project	Where Addressed in This Report
Human Use Characteristics (*continued*)		
Water supply and conservation	The project would not affect water supplies. The project would not use water.	Not addressed.
Wetlands	The project would affect non-wetland waters of the U.S. The project would not affect wetlands. The project would not cause indirect effects on wetlands along the shore of the Great Salt Lake because it would not affect lake inflow locations or amounts.	Not addressed.

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