CHAPTER 7 GREAT SALT LAKE

Photograph courtesy of Charles Uibel at http://www.greatsaltlake.photography/

2014 Integrated Report

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Chapter 7 Great Salt Lake

2014 INTEGRATED REPORT

INTRODUCTION

The importance of the complex and unique terminal Great Salt Lake (GSL) to migratory birds, recreation, brine shrimp, and mineral industries, and its significance to the ecology and economy of the region are well documented (Adler, 1999; Gwynn, 2002; Aldrich and Paul, 2002; Bioeconomics, 2012; Great Salt Lake Advisory Council, 2012; Utah Division of Forestry, Fire and State Lands 2013). Millions of birds use the lake every year as they migrate from breeding grounds as far north as the Arctic to wintering areas as far south as Argentina. Recreational opportunities abound on and around the lake, which attracts thousands of visitors annually to enjoy sailing, hiking, hunting, and watching the diverse bird life. GSL is also home to the mineral and brine shrimp industries, which annually contribute 700 million dollars to Utah's economy (Bioeconomics, 2012).

The lake has been impacted by increased urbanization and industrial, agricultural, and municipal discharges over the years. Assessing the impacts of these stressors on the lake is hampered by the lack of applicable numeric water quality criteria. Numeric criteria that are broadly applied to other water bodies are generally not applicable to the lake because of its unique saline ecology, biogeochemistry, and hydrology. To date, there is one numeric water quality standard for GSL, and it is 12.5 milligrams of selenium per kilogram (mg/kg) of bird tissue based on the complete egg or embryo of aquatic-dependent birds that use the waters of Gilbert Bay (Utah Administrative Code [UAC] R317-2-14). In addition, the lack of published, high quality data and scientific uncertainty about the fate and transport of potential pollutants in the lake and subsequent effects on its associated food web further complicate the assessment efforts.

Utah's freshwater lake assessment methods rely primarily on comparisons to numeric criteria to determine if the designated uses are being supported. Ancillary information such as fish kills and trophic state further inform the assessments. Utah's freshwater lakes and reservoirs are relatively stable environments compared to GSL, and they can be assessed using methods developed for temperate lakes outside of Utah. No other lake in the world is comparable to GSL, however, and therefore assessment methods must be created.

To develop the appropriate assessment methods to begin addressing data gaps, the Utah Division of Water Quality (DWQ) launched *A Great Salt Lake Water Quality Strategy* (hereafter referred to as the Strategy) in 2012. The Strategy defines a comprehensive water quality approach for protecting GSL's recreation and aquatic wildlife designated uses (DWQ 2012). The Strategy defines a process to fill critical knowledge gaps, improve the precision and clarity of DWQ's water quality management decisions, reduce regulatory uncertainty for regulated entities, and improve all partners' capacity to be stewards of GSL water quality.

The Strategy contains five core components:

1. Proposed Approach for Developing Numeric Criteria for Great Salt Lake
2. Strategic Monitoring and Research Plan
3. A Wetland Program
4. Public Outreach Plan
5. Resource Plan

This report presents progress made on the following Strategy activities:

- Results from the 2011 and 2012 Great Salt Lake Baseline Sampling Plan (BSP) (Core Component 2: Strategic Monitoring and Research Plan)
- Development of a species list, prioritization of pollutants, and development of a work plan for toxicological testing (Core Component 1: Developing Numeric Criteria)
- Results of the Great Salt Lake Wetlands Research Program that were discussed in detail in Chapter 4 Wetlands (Core Component 3: A Wetland Program)

The assessment of GSL water quality relies on the data generated by these activities, especially the BSP. Routine targeted monitoring for the BSP began in 2011 following the development of a Quality Assurance Program Plan for sampling and analysis in 2010. An assessment of GSL water quality depends on multiple years of data and relevant numeric water quality criteria or suitable peer-reviewed benchmarks with which to evaluate the data. Because there are only 2 years of quality-assured data and because the development of numeric criteria and/or the review of benchmarks is ongoing, this chapter of the 2012-2014 *Integrated Report* (IR) will focus on progress made to characterize and prioritize the potential pollutants of concern in GSL's water, brine shrimp, and bird eggs. This chapter concludes with a bay-by-bay assessment of GSL water quality for the protection of the designated uses and includes the data needed before a designated use support determination can be made. Data considered from previous IRs and research carried out for DWQ is incorporated by reference.

For the 2010 IR, GSL was placed in Assessment Category 3C, with the data being insufficient to determine designated use support. The key data gaps identified were:

- a systematic characterization of pollutant concentrations,
- a method to translate the narrative criteria for assessment including identification of benchmarks for priority pollutants,
- numeric criteria for comparison, and
- methods to evaluate use support in the absence of comparable reference sites

As documented here, substantial progress has been made during this reporting cycle to address these data gaps. However, significant data gaps remain for the 2012 and 2014 IR, and Class 5 GSL remains in Category 3C.

APPLICABLE DESIGNATED USES AND NARRATIVE WATER QUALITY CRITERIA

Under the authority of both state law (UAC R317) and the federal Clean Water Act, DWQ is entrusted with the responsibility of restoring and maintaining the chemical, physical, and biological integrity of Utah's lakes, rivers, and wetlands. The State of Utah's Rule 317-2 for Standards of Quality for Waters of the State lists GSL in its own designated use protection class (Class 5). In 2008, the State of Utah further refined the Class 5 designated use into five subclasses (Classes 5A, 5B, 5C, 5D, and 5E) to more accurately reflect the unique ecosystems supported by the different salinity and hydrologic regimes of each of GSL's four major bays and the immediately adjacent wetlands (UAC R317-2-6). The designated uses assigned to all five classes (UAC R317-2-6.5) are primary and secondary contact recreation (e.g., water quality sufficient to swim at Antelope Island and/or wade while duck hunting at one of the wildlife management areas) and wildlife protection (e.g., a quality sufficient for waterfowl, shorebirds, and other water-oriented wildlife, including their necessary food chain). These are the designated uses that must be protected under federal and state law.

As previously mentioned, GSL mostly lacks numeric water quality criteria to ensure protection of its designated uses. However, in the absence of numeric criteria, the lake remains protected by the Narrative Standards (UAC R317-2-7.2) described here:

> *Narrative Standards*
>
> *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.*

Assessing the water quality with the Narrative Standards is complicated for several reasons. One of the most significant challenges is an absence of suitable reference sites that have not been affected by anthropogenic stressors. If reference sites were available, observed GSL water quality and biological conditions could be assessed. This and other challenges led DWQ to employ a comprehensive approach to protecting GSL water quality. As outlined in the Strategy, DWQ has begun to develop site-specific numeric water quality criteria along with strategic monitoring to assess water quality. Until numeric criteria or other suitable comparison criteria are developed, DWQ will continue to monitor and report pollutant concentrations in GSL's water, brine shrimp, and aquatic-dependent birds' eggs.

GREAT SALT LAKE BASELINE SAMPLING PLAN

Background and Purpose

To meet the objectives outlined in the Strategy's second core component, *Strategic Monitoring and Research Plan*, DWQ began routine, targeted monitoring in 2011, following the direction of the Great Salt Lake BSP. The BSP describes procedures for the long-term, routine collection of water quality samples to better characterize pollutants of potential concern in the open waters of GSL, as well as concentrations in brine shrimp and bird eggs to follow movement of these pollutants in the lake's food web. The primary focus of the

BSP is the collection of water samples to evaluate whether the recreational and aquatic wildlife designated uses are supported under the Clean Water Act. Avian egg tissue samples are collected to specifically assess use support against Gilbert Bay's selenium criterion. Brine shrimp tissue samples are collected to evaluate dietary exposure to birds. Sediments were not sampled because of the lack of availability of sediment criteria.

The BSP includes a Quality Assurance Project Plan (QAPP) that defines the quality assurance and quality control requirements to ensure that the collected environmental data are precise, accurate, representative, complete, and comparable for saline water (DWQ, 2014b). Among other things, the QAPP requires reporting of quality assurance statistics to quantify the variation in analytical results attributable to different sampling or analysis procedures. These detailed quality assurance procedures are particularly critical for GSL because standard sampling and analytical methods frequently need to be modified to account for the lake's high salt content. A detailed review of data from the last several years has identified the need for further clarification in sampling techniques, laboratory instrumentation, and analytical methods, which will continue to be captured in QAPP revisions. The QAPP also aims to improve collaborative monitoring efforts by helping to ensure data comparability among the entities that collect monitoring data.

As outlined in the Strategy, monitoring of GSL water quality is a critical input for informed decision making. Intended uses of the data by DWQ include the following:

- Screening and refining the list of potential pollutants of concern in GSL and prioritizing pollutants for toxicological testing of key aquatic organisms, which is a critical step in the development of numeric water quality criteria.
- Determining ambient conditions to support Utah Pollution Discharge Elimination System permitting.
- Assessing the current water quality condition and reporting the condition every 2 years in the IR.
- Guiding future monitoring efforts.
- Determining long-term water quality trends, quantifying water quality problems, and establishing water quality goals.

Sampling Design

The BSP is designed for the collection of GSL water, brine shrimp, and aquatic-dependent bird egg data to assess whether the recreational and aquatic wildlife designated uses are supported. Table 7-1 summarizes the media sampled, target analytes, and rationale for selection of the media as it relates to designated use support. The specific metals were selected by DWQ from the U.S. Environmental Protection Agency's (EPA') list of 126 "priority pollutants" (40 Code of Federal Regulations [CFR] 423, Appendix A) based on the perceived threat to GSL's designated uses and based on available funding for laboratory analyses allotted for the BSP. Table 7-2 lists the month and year, targeted bay, and the medium sampled (water, brine shrimp, or bird egg) during the 2011–2012 monitoring period.

TABLE 7-1. METALS AND NUTRIENTS MEASURED IN WATER, BRINE SHRIMP, AND AQUATIC-DEPENDENT BIRD EGGS; RATIONALE FOR SELECTION; AND COMPARISON CRITERIA.

Matrix	Analytes	Rationale for Selection	Comparison Criteria
Water	Metals: Total selenium, total mercury and methylmercury, total arsenic, total copper, cadmium, lead, thallium Nutrients: Total phosphorus, total nitrogen, ammonia, and chlorophyll-a Field measurements: Temperature, pH, DO, specific conductivity, and depth	Direct measurement of media covered by the Clean Water Act for recreational and aquatic wildlife beneficial use support.	Metals: EPA-recommended numeric water quality chronic criteria for the protection of salt water aquatic wildlife and Utah fresh water numeric water quality standards.
Brine shrimp	Total selenium, total mercury and methylmercury, total arsenic, total copper, cadmium, lead, and thallium	Indicator of attainment of aquatic wildlife beneficial use as the food chain of avian species.	Evers's et al. dietary risk ranges for total mercury. Dietary risk ranges for the rest of the metals will be compiled in the future.
Bird eggs	Total selenium and total mercury	Indicator of attainment of aquatic wildlife beneficial use that includes shorebirds and reflects the potential for biomagnification and/or bioaccumulation due to time spent foraging at GSL.	Gilbert Bay selenium numeric water quality standard Evers et al. (2004) egg tissue risk ranges for total mercury.

TABLE 7-2. 2011–2012 MEASUREMENTS OF WATER, BRINE SHRIMP, AND SHOREBIRD EGGS.

Date	Bay	Medium Sampled	Metals	Nutrients	Field Measurements
June 2010	Gilbert Bay (Saltair)	Shorebird eggs	X (Hg and Se only)	NA	NA
June 2011	Gilbert Bay (Bridger Bay, Antelope Island)	Shorebird eggs	X (Hg and Se only)	NA	NA
	Farmington Bay (Farmington Bay Waterfowl Management Area	Shorebird eggs	X (Hg and Se only)	NA	NA
July 2011	Gilbert Bay	Water	X	X	X
	Gilbert Bay	Brine shrimp	X	NA	NA
	Farmington Bay	Water	X	Not sampled[2]	Not sampled[2]
	Bear River[1] Bay	Water	Not sampled	Not sampled	Not sampled
October 2011	Gilbert Bay	Brine shrimp	X	X	X
	Farmington Bay	Water	X	X	X
	Bear River Bay	Water	X	Not sampled	
June 2012	Gilbert Bay (Antelope Island Causeway and Ogden Bay Waterfowl Management Area)	Shorebird eggs	X (Hg and Se only)	NA	NA
June 2012	Gilbert Bay	Water	X	X	X
	Gilbert Bay	Brine shrimp	X	NA	NA
	Farmington Bay	Water	X	X	X
	Bear River[3] Bay	Water	Not sampled	Not sampled	Not sampled
October 2012	Gilbert Bay	Water	X	X	X

Date	Bay	Medium Sampled	Metals	Nutrients	Field Measurements
	Gilbert Bay	Brine shrimp	X		
	Farmington Bay	Water	X	FB10 Not sampled[4]	FB09 Not sampled[5]
	Bear River Bay	Water	X		

Notes:
NA: Not applicable
1. Not sampled due to high velocities under the Great Salt Lake Minerals Bridge. Moved location farther north.
2. Salinity and DO not sampled due to probe calibration issues. Only pH and temperature recorded.
3. Dry, no water
4. Nutrients not sampled at site FB10
5. Probe malfunction at site FB9

In 2011 and 2012, water quality samples were collected in June and October at 11 sites in the open waters of GSL, as follows: eight in Gilbert Bay, two in Farmington Bay, and one in Bear River Bay (Figure 7-1 and Table 7-3). Gunnison Bay was not included due to access constraints and insufficient funding. Once these issues are resolved, DWQ plans to incorporate routine monitoring of at least two sites in Gunnison Bay.

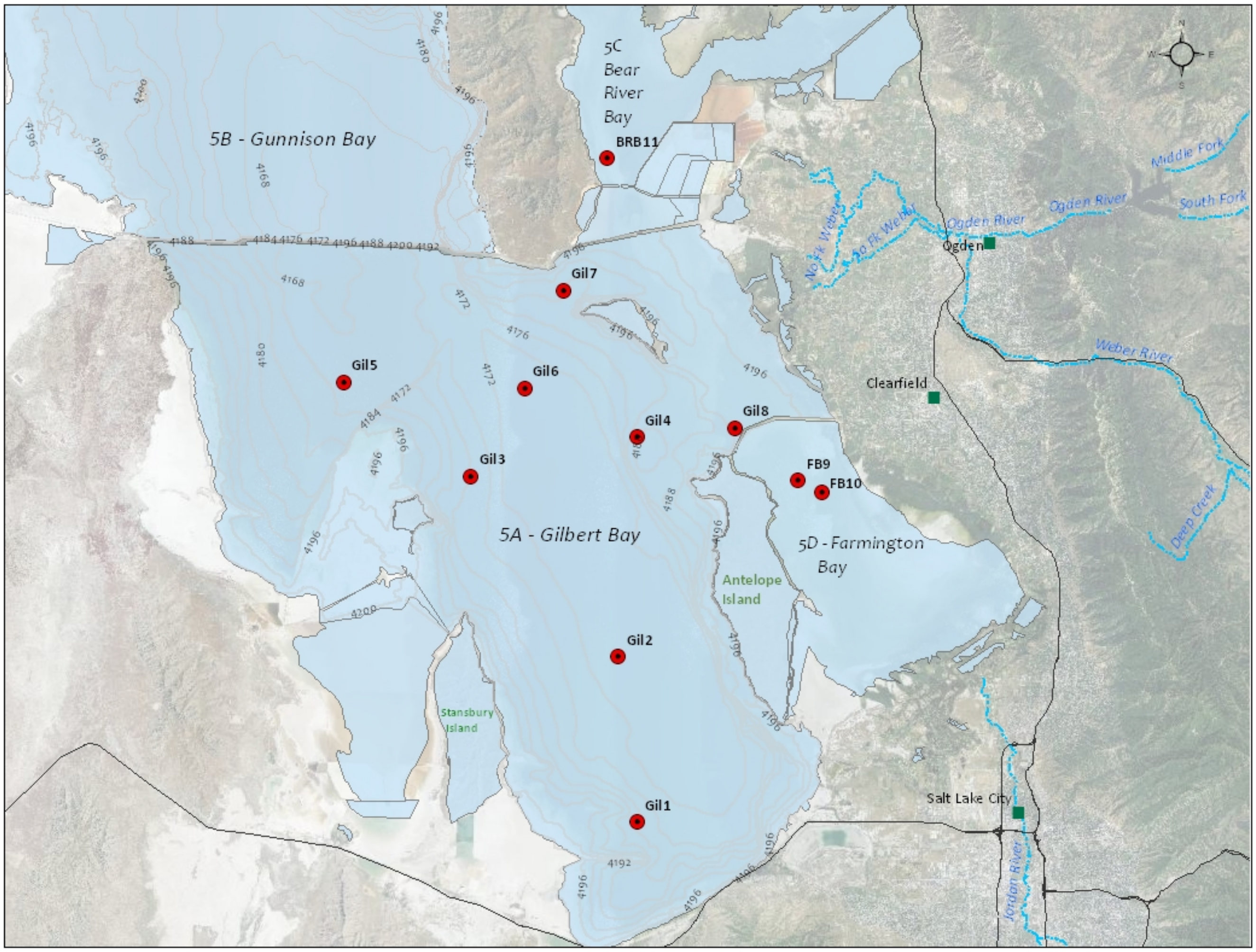

FIGURE 7-1. SAMPLING SITES IN THE BSP. THE STUDY AREA ALSO INCLUDES THE OPEN WATERS OF GREAT SALT LAKE, INCLUDING GILBERT BAY, GUNNISON BAY, FARMINGTON BAY, AND BEAR RIVER BAY AT CURRENT LAKE WATER LEVEL. THE UNION PACIFIC RAILROAD CAUSEWAY SEPARATES GILBERT BAY FROM GUNNISON BAY AND BEAR RIVER BAY. THE ANTELOPE ISLAND CAUSEWAY AT THE NORTHERN END OF ANTELOPE ISLAND AND THE ISLAND DIKE ROAD AT THE SOUTHERN END OF ANTELOPE ISLAND SEPARATE GILBERT BAY FROM FARMINGTON BAY.

TABLE 7-3. BASELINE SAMPLING PLAN SITES INCLUDING TARGET BAY, DWQ SITE NAME, CORRESPONDING USGS SITE NAME, AND TARGETED MEDIA.

DWQ Sample Points	Target Bay and DWQ Site Name	Coordinates	USGS NWIS Site Name and Description	Matrix, Depth of Sample
1	Gilbert Bay Gil1	Latitude 40°46'07", Longitude 112°19'38"	USGS 404607112193801 GSL 4069, 8 miles west of Saltair Marina	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
2	Gilbert Bay Gil2	Latitude 40°53'56", Longitude 112°20'56"	USGS 405356112205601 GSL 3510, 6 miles west of Antelope Island	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
3	Gilbert Bay Gil3	Latitude 41°02'23", Longitude 112°30'19"	USGS 410323112301901 GSL 2820, 2 miles east of Carrington Island	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
4	Gilbert Bay Gil4	Latitude 41°04'22", Longitude 112°20'00"	USGS 410422112200001 GSL 2767, 4 miles west of north tip of Antelope Island	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
5	Gilbert Bay Gil5	Latitude 41°06'44", Longitude 112°38'26"	USGS 410644112382601 GSL 2565, northwest of Hat Island	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
6	Gilbert Bay Gil6	Latitude 41°06'37", Longitude 112°27'04"	USGS 410637112270401 N1018 6 miles southwest of Fremont Island	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
7	Gilbert Bay Gil7	Latitude 41°11'16", Longitude 112°24'44"	USGS 411116112244401 GSL 2267, 1 mile northwest of Fremont Island	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
8	Gilbert Bay/ Farmington Bay Gil8	Latitude 41°04'52", Longitude 112°13'51"	USGS 410401112134801 GSL Farmington Bay outflow at Causeway Bridge	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom Brine shrimp
9	Farmington Bay FB9	Latitude 41°02'24.36", Longitude 112°09'51.12"	USGS 410224112095101 Farmington Bay, 1.4 miles east, 3.5 miles south of Farmington Bay Marina	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom
10	Farmington Bay FB10	Latitude 41°01'53", Longitude 112°08'23"	USGS 410153112082301 GSL 2963, Farmington Bay 4 miles southeast of Antelope Island Marina	Water sample, 0.2 m from surface Water sample, 0.5 m from bottom
11	Bear River Bay BRB11	Latitude 41 17.340, Longitude 112 22.006	USGS 10010060 North of Great Salt Lake Minerals Bridge	Water sample, 0.2 m from surface

Sample collection in June and October was designed to coincide with the bird nesting season and the brine shrimp cyst harvest, respectively. At each site, water samples were collected 0.5 meter (m) from the bottom of the water column and 0.2 m from the surface. When the depth of the water column was less than 1m, one sample at the surface was taken. Field measurements documenting the temperature, pH, specific conductivity, dissolved oxygen (DO), Secchi disk depth, total water depth, and depth to deep brine layer (if present) were made at 0.5 m-depth intervals. Brine shrimp samples were collected at each location in Gilbert Bay after water sample collection.

U.S. Geological Survey (USGS) Utah Water Science Center personnel collected the Gilbert Bay samples; Davis County Health Department personnel collected the Farmington Bay samples; and DWQ monitoring personnel collected the Bear River Bay samples. Sampling at Bear River Bay was problematic. In 2011, field measurements could not be made at the site established under the Great Salt Lake Minerals Bridge because currents were too strong to allow for accurate readings. In 2012, the site was moved north, but water levels were too low to allow for sampling in June. As a result, only two water column samples are available over both years.

The eggs of American Avocets and/or Black-necked Stilts, which forage along the shoreline of Gilbert Bay, were sampled once per year in 2010, 2011, and 2012, per the Standard Operating Procedures included in the QAPP (DWQ, 2014b). Each embryo was checked for stage of development as determined by egg flotation. Late-stage embryos were examined for developmental abnormalities, including a determination of the embryo's position in the egg.

Metal concentrations in all sampled media were analyzed by a commercial laboratory, Brooks Rand Labs in Seattle, Washington. Nutrients were analyzed by the USGS National Water Quality Laboratory in Lakewood, Colorado. Stage of development, malformation, and malposition of avian embryos were examined by Dr. John Cavitt at the Avian Ecology Laboratory at Weber State University in Ogden, Utah. All sampling and analytical activities were performed in accordance with the QAPP requirements.

The metals data were compiled, verified, and validated for their quality and usage against the acceptance and performance criteria set forth in the QAPP (DWQ, 2014a). For the 2011 and 2012 BSP data, 14 out of 864 samples analyzed were rejected for a percent complete of 98.4%. The rejection of all 14 samples was due to a methylmercury concentration greater than the total mercury concentration even though all quality-controlled laboratory samples passed the acceptance criteria. All field and nutrient data are stored in the USGS Nation Water Information System (NWIS) and can be accessed through the NWIS mapper.[1] All the metals data reside with DWQ in the Great Salt Lake Water Quality database and are available upon request.

[1] http://maps.waterdata.usgs.gov/mapper/

Results and Discussion

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

Each bay of GSL has a distinct difference in salinity, as exhibited in 2011 and 2012. Over both years, the average salinity at all sites and depths in Gilbert Bay was 12.5% as compared to Farmington Bay, which was much fresher at 4.1% saline (Figure 7-2 and Table 7-4). Bear River Bay is the least saline of the bays, averaging 1.0–5.0% (DWQ, 2010). The sole measurement of salinity in Bear River Bay for this reporting cycle was derived from a measurement of specific conductivity of 714 micro-Siemens/centimeter (µS/cm) in October 2012, which equates to approximately 0.05% saline, which is fresh water. (Sea water is generally 3.5% saline.) A change in salinity from 2011 to 2012 occurred in both Gilbert and Farmington Bays. Average salinity in Gilbert Bay went from 11.8% to 13.2% and in Farmington Bay from 1.9% to 5.6%. In the spring of 2011, unseasonably warm weather resulted in rapid, significant snowmelt in the Wasatch Mountains. As a result, the elevation of Gilbert Bay rose 4 feet (from an elevation of 4,195 feet to an elevation of 4,198 feet) from February to July. In comparison, the mean monthly rise in elevation between February and July from 1989 to 2013 was 0.25 feet (USGS, 2014). This unusually large freshwater input likely accounts for the lower salinity observed in 2011 when compared to 2012.

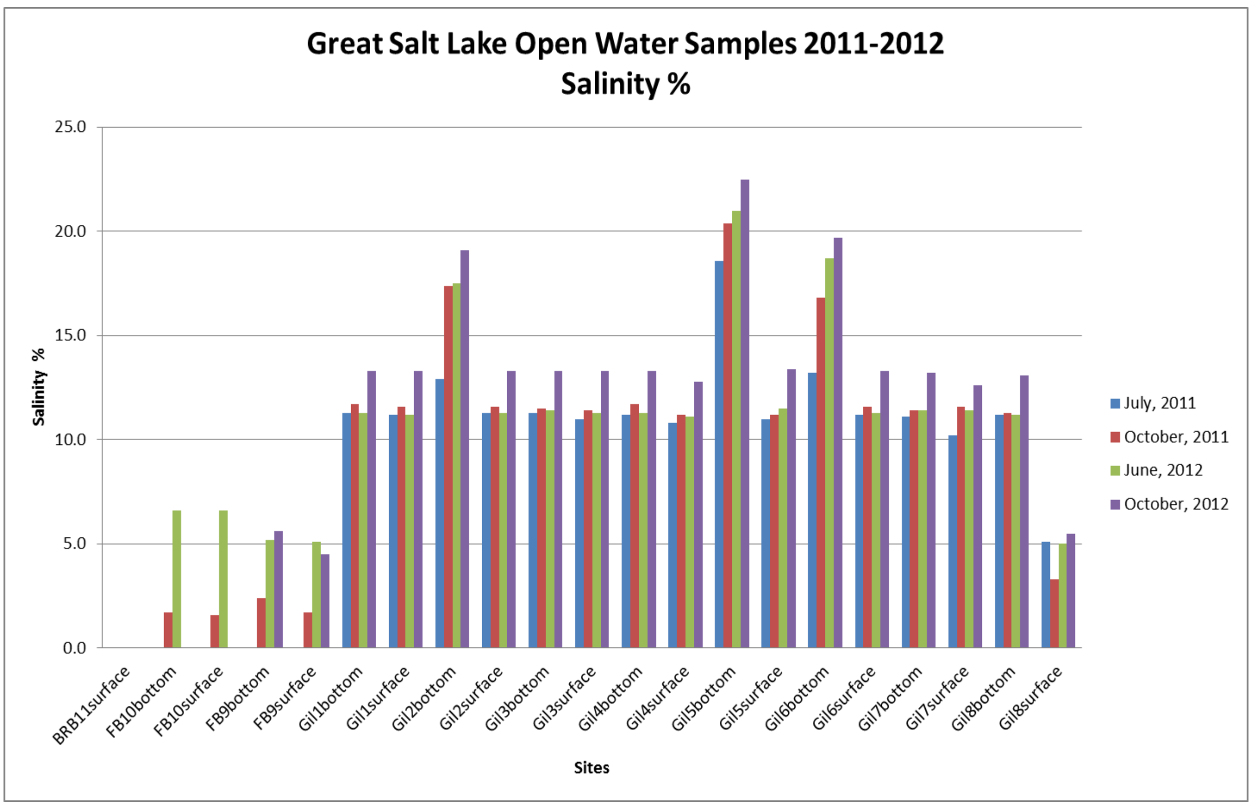

FIGURE 7-2. PERCENT SALINITY AT THE SURFACE AND BOTTOM OF THE WATER COLUMN AT EACH SITE IN GILBERT, FARMINGTON, AND BEAR RIVER BAYS.

TABLE 7-4. PERCENT SALINITY OF OPEN WATER SITES, PER SITE PER DATE.

	Percent Salinity			
Great Salt Lake Open Water Sites	**July 2011**	**October 2011**	**June 2012**	**October 2012**
BRB11surface	NA	NA	NA	NA
FB10bottom	NA	1.7	6.6	NA
FB10surface	NA	1.6	6.6	NA
FB9bottom	NA	2.4	5.2	5.6
FB9surface	NA	1.7	5.1	4.5
Gil1bottom	11.3	11.7	11.3	13.3
Gil1surface	11.2	11.6	11.2	13.3
Gil2bottom	12.9	17.4	17.5	19.1
Gil2surface	11.3	11.6	11.3	13.3
Gil3bottom	11.3	11.5	11.4	13.3
Gil3surface	11.0	11.4	11.3	13.3
Gil4bottom	11.2	11.7	11.3	13.3
Gil4surface	10.8	11.2	11.1	12.8
Gil5bottom	18.6	20.4	21.0	22.5
Gil5surface	11.0	11.2	11.5	13.4
Gil6bottom	13.2	16.8	18.7	19.7
Gil6surface	11.2	11.6	11.3	13.3
Gil7bottom	11.1	11.4	11.4	13.2
Gil7surface	10.2	11.6	11.4	12.6
Gil8bottom	11.2	11.3	11.2	13.1
Gil8surface	5.1	3.3	5.0	5.5
Average Farmington Bay salinity	**NA**	**1.9**	**5.9**	**5.1**
Average Gilbert Bay salinity	**11.4**	**12.2**	**12.4**	**14.1**
Average Gilbert Bay surface salinity	**10.2**	**10.4**	**10.5**	**12.2**
Average Gilbert Bay bottom salinity	**12.6**	**14.0**	**14.2**	**15.9**
Note: NA – Not available or applicable				

In the deeper portions of Gilbert Bay, a chemocline is present at the interface between a shallow oxygenated surface layer and a deep, denser anoxic brine layer commonly referred to as the deep brine layer. The deep brine layer develops when saltier, denser water from Gunnison Bay (27% saline) is transported to Gilbert Bay and sinks to the bottom of the water column. From October 2011 to October 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 or no oxygen (hypoxic and anoxic, respectively); this can lead to a lower redox potential than can occur in oxic water, which increases the solubility of some metals. As a result, the concentrations of arsenic, lead, copper, total mercury, and methylmercury 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, reducing 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 (Belovsky et al., 2011).

Density stratification was present at site Gil8, located at the culvert between Gilbert and Farmington Bays, which showed an average 7.0% difference in salinity, and also at site FB9 in Farmington Bay, which showed an average 6.3% difference in salinity. The stratification at these sites is due to denser oxic Gilbert Bay water overlain by fresher Farmington Bay water. There was no density stratification at site FB10.

Temperature, pH, and Dissolved Oxygen

Over the 2011–2012 monitoring period and over all sites and depths in Gilbert Bay, the average temperature was 17.7° Celsius (C); pH was 8.2; and DO was 6.2 milligrams per liter (mg/L). Overall, Farmington Bay was cooler (15.6°C) and more basic (pH 9.1), and was lower in DO (5.2 mg/L) than Gilbert Bay. On October 5, 2012, the average temperature in Bear River Bay was 13.6°C, and the pH was 8.8. The deep brine layer sites in Gilbert Bay (sites Gil2bottom, Gil5bottom, and Gil6bottom) had a pH of 7.7 and were hypoxic, with an average DO concentration of 0.5 mg/L. In Farmington Bay at site FB9, density stratification was present in October 2011 and June 2012; however, average DO levels did not decrease from the surface to the bottom of the water column, as seen in Gilbert Bay. See Figures 7-3, 7-4, and 7-5, and Tables 7-5, 7-6, and 7-7 for temperature, pH, and DO in all bays.

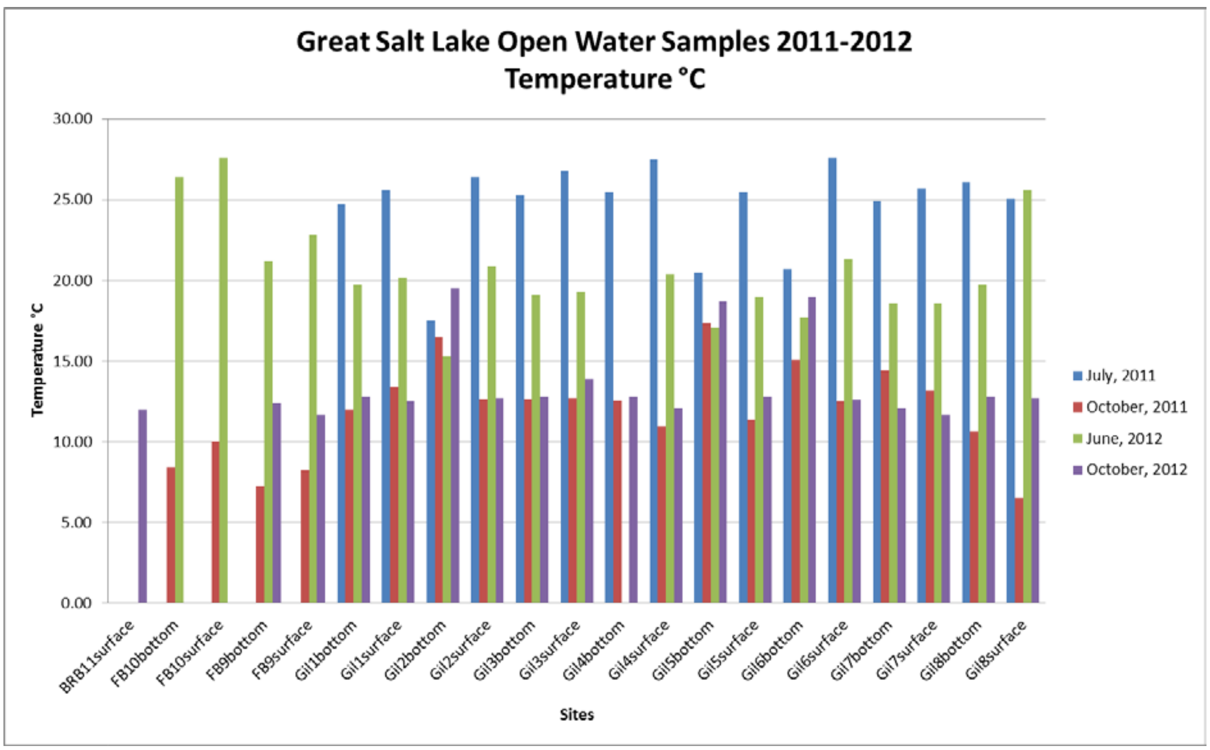

FIGURE 7-3. TEMPERATURE AT THE SURFACE AND BOTTOM OF THE WATER COLUMN AT EACH SITE IN GILBERT, FARMINGTON, AND BEAR RIVER BAYS.

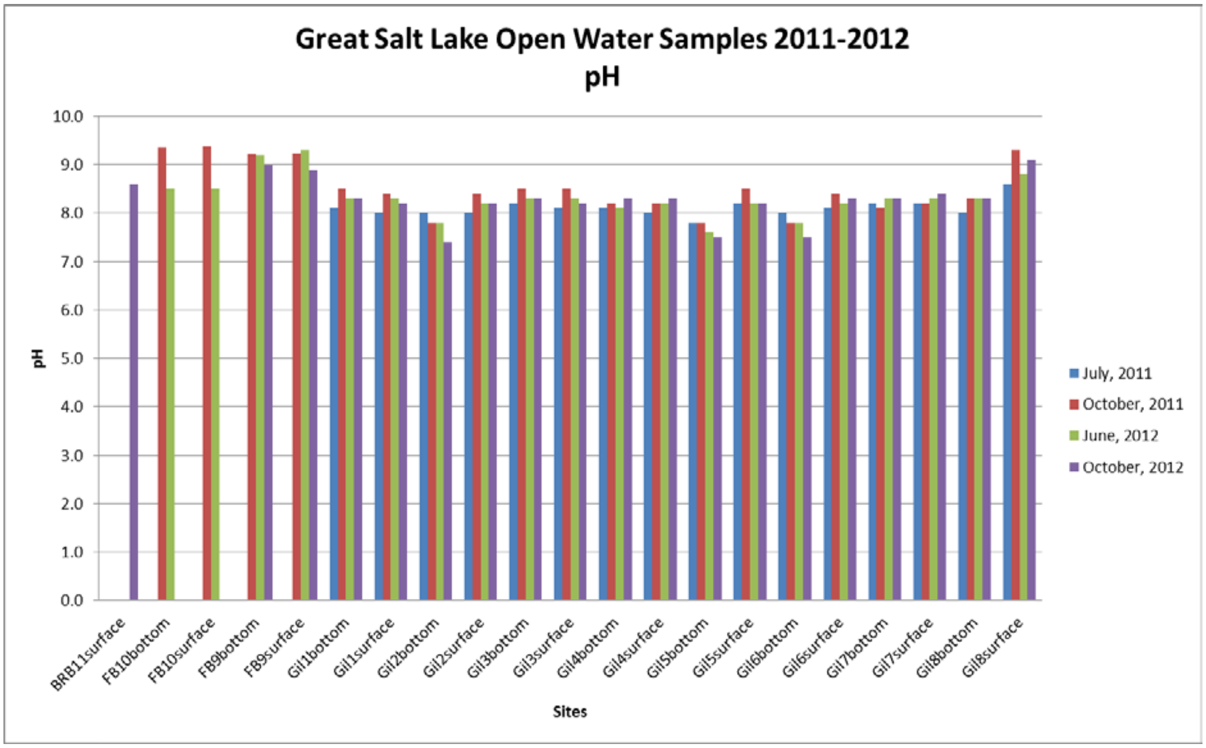

FIGURE 7-4. PH AT THE SURFACE AND BOTTOM OF THE WATER COLUMN AT EACH SITE IN GILBERT, FARMINGTON, AND BEAR RIVER BAYS.

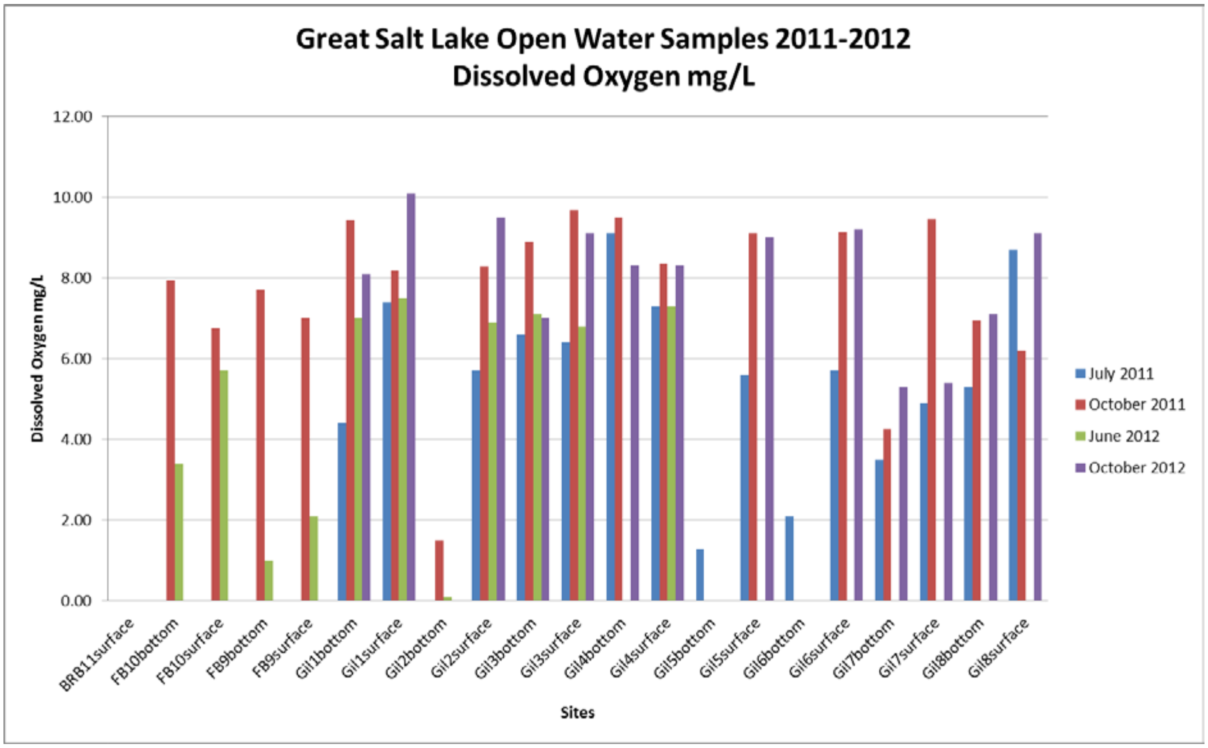

FIGURE 7-5. DO AT THE SURFACE AND BOTTOM OF THE WATER COLUMN AT EACH SITE IN GILBERT, FARMINGTON, AND BEAR RIVER BAYS.

TABLE 7-5. TEMPERATURE (°C) OF OPEN WATER SITES, PER SITE PER DATE.

	Temperature (°C)			
Great Salt Lake Open Water Sites	**July 2011**	**October 2011**	**June 2012**	**October 2012**
BRB11surface	NA	NA	NA	11.98
FB10bottom	NA	8.44	26.40	NA
FB10surface	NA	10.02	27.60	NA
FB9bottom	NA	7.28	21.20	12.40
FB9surface	NA	8.23	22.80	11.70
Gil1bottom	24.70	12.00	19.70	12.80
Gil1surface	25.60	13.38	20.20	12.50
Gil2bottom	17.50	16.47	15.30	19.50
Gil2surface	26.40	12.68	20.90	12.70
Gil3bottom	25.30	12.64	19.10	12.80
Gil3surface	26.80	12.72	19.30	13.90
Gil4bottom	25.50	12.54	NA	12.80
Gil4surface	27.50	10.96	20.40	12.10
Gil5bottom	20.50	17.37	17.10	18.70
Gil5surface	25.50	11.40	19.00	12.80
Gil6bottom	20.70	15.07	17.70	19.00
Gil6surface	27.60	12.52	21.30	12.60

	Temperature (°C)			
Great Salt Lake Open Water Sites	**July 2011**	**October 2011**	**June 2012**	**October 2012**
Gil7bottom	24.90	14.40	18.60	12.10
Gil7surface	25.70	13.20	18.60	11.70
Gil8bottom	26.10	10.67	19.70	12.80
Gil8surface	25.10	6.55	25.60	12.70
Average Farmington Bay temperature	**NA**	**8.49**	**24.50**	**12.05**
Average Gilbert Bay temperature	**24.71**	**12.79**	**19.50**	**13.84**
Average Gilbert Bay surface brine temperature	**26.28**	**11.68**	**20.66**	**12.63**
Average Gilbert Bay bottom temperature	**23.15**	**13.90**	**18.17**	**15.06**
Note: NA – Not available or applicable				

TABLE 7-6. PH OF OPEN WATER SITES, PER SITE PER DATE.

	pH			
Great Salt Lake Open Water Sites	**July 2011**	**October 2011**	**June 2012**	**October 2012**
BRB11surface	NA	NA	NA	8.6
FB10bottom	NA	9.4	8.5	NA
FB10surface	NA	9.4	8.5	NA
FB9bottom	NA	9.2	9.2	9.0
FB9surface	NA	9.2	9.3	8.9
Gil1bottom	8.1	8.5	8.3	8.3
Gil1surface	8.0	8.4	8.3	8.2
Gil2bottom	8.0	7.8	7.8	7.4
Gil2surface	8.0	8.4	8.2	8.2
Gil3bottom	8.2	8.5	8.3	8.3
Gil3surface	8.1	8.5	8.3	8.2
Gil4bottom	8.1	8.2	8.1	8.3
Gil4surface	8.0	8.2	8.2	8.3
Gil5bottom	7.8	7.8	7.6	7.5
Gil5surface	8.2	8.5	8.2	8.2
Gil6bottom	8.0	7.8	7.8	7.5

	pH			
Great Salt Lake Open Water Sites	**July 2011**	**October 2011**	**June 2012**	**October 2012**
Gil6surface	8.1	8.4	8.2	8.3
Gil7bottom	8.2	8.1	8.3	8.3
Gil7surface	8.2	8.2	8.3	8.4
Gil8bottom	8.0	8.3	8.3	8.3
Gil8surface	8.6	9.3	8.8	9.1
Average Farmington Bay pH	**NA**	**9.3**	**8.9**	**9.0**
Average Gilbert Bay pH	**8.1**	**8.3**	**8.2**	**8.2**
Average Gilbert Bay Surface pH	**8.2**	**8.5**	**8.3**	**8.4**
Average Gilbert Bay Bottom pH	**8.1**	**8.1**	**8.1**	**8.0**
Note: NA – Not available or applicable				

TABLE 7-7. DISSOLVED OXYGEN OF OPEN WATER SITES, PER SITE PER DATE.

	DO (mg/L)			
Great Salt Lake Open Water Sites	**July 2011**	**October 2011**	**June 2012**	**October 2012**
BRB11surface	NA	NA	NA	NA
FB10bottom	NA	7.94	3.40	NA
FB10surface	NA	6.75	5.70	NA
FB9bottom	NA	7.71	1.00	NA
FB9surface	NA	7.01	2.10	NA
Gil1bottom	4.40	9.44	7.00	8.10
Gil1surface	7.40	8.17	7.50	10.10
Gil2bottom	0.00	1.50	0.10	0.00
Gil2surface	5.70	8.28	6.90	9.50
Gil3bottom	6.60	8.90	7.10	7.00
Gil3surface	6.40	9.68	6.80	9.10
Gil4bottom	9.10	9.50	NA	8.30
Gil4surface	7.30	8.36	7.30	8.30
Gil5bottom	1.30	0.00	NA	0.00

	DO (mg/L)			
Great Salt Lake Open Water Sites	**July 2011**	**October 2011**	**June 2012**	**October 2012**
Gil5surface	5.60	9.10	NA	9.00
Gil6bottom	2.10	0.00	NA	0.00
Gil6surface	5.70	9.13	NA	9.20
Gil7bottom	3.50	4.27	NA	5.30
Gil7surface	4.90	9.46	NA	5.40
Gil8bottom	5.30	6.95	NA	7.10
Gil8surface	8.70	6.20	NA	9.10
Average Farmington Bay DO	**NA**	**7.35**	**3.05**	**NA**
Average Gilbert Bay DO	**5.25**	**6.81**	**6.10**	**6.59**
Average Gilbert Bay surface DO	**6.46**	**8.55**	**7.13**	**8.71**
Average Gilbert Bay bottom DO	**4.04**	**5.07**	**4.73**	**4.48**
Note: NA – Not available or applicable				

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 or metalloid and the concentration. In addition, the salinity of the water can affect how metals behave (i.e., transport, cycling, and storage). As was noted in the salinity section, some metals are more soluble at the lower redox potentials in anoxic water, and the concentrations of these metals were markedly increased in the anoxic deep brine layer as compared to the upper, more oxygenated layer of Gilbert Bay, where aquatic organisms reside.

For metals, the water column data were summarized with descriptive statistics and were compared to the Utah numeric water quality chronic criteria for the protection of fresh water[2] and EPA chronic criteria for the protection of salt water aquatic life[3]. However, these criteria were not developed for the aquatic life of GSL, nor are they applicable as regulatory criteria. Although EPA's 304(a) recommended numeric criteria and Utah's water quality standards are designed to protect a range of aquatic life that may not be present in

[2] http://www.rules.utah.gov/publicat/code/r317/r317-002.htm

[3] http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm

GSL, the criteria and standards are used here as a basis of comparison for the purpose of benchmarking observed lake concentrations against the potential for biological impacts and to further prioritize and screen pollutants based on their potential threat. Therefore, these criteria and standards may be overly protective for some segments and may not be suitable for the determination of designated use support, especially when salinity is greater than 3.5%.

Analyte	Fresh Water	Salt Water

For Bear River and Farmington Bays, when salinity is less than 3.5%, the fresh water criteria are likely appropriate as benchmarks. This is based on a preliminary review of the species known to inhabit these bays (see the Species List section); this review suggests that the resident organisms represent a freshwater ecosystem more than they do an salt water ecosystem. This supports the application of EPA's deletion procedure discussed in the Toxicological Testing and Pollutant Prioritization section of this chapter.

The fresh water chronic criteria for some metals (arsenic, cadmium, copper, and lead) are hardness-dependent and were adjusted using a hardness of 400 mg/L of calcium carbonate, the upper limit of the hardness criteria equation (GSL water exceeds 400 mg/L hardness). Translation of the fresh water chronic criteria from dissolved to total recoverable was used to compare in-lake data as outlined in Table 7-8. If no Utah or EPA numeric criteria were available for use as benchmarks, other sources including past GSL research, were used for comparison and are noted in the tables. Potential seasonal and annual trends will be evaluated in the future once more data is collected to support these statistical analyses.

	Total	Dissolved	Conversion[1]	Total	Dissolved	Conversion[1]
Arsenic (ug/L)	150	150	1	36	36	1
Cadmium[2] (ug/L)	0.76	0.64	$e^{0.7409(\ln(hardness)-4.719)}$	8.846	8.8	0.994
Copper[2] (ug/L)	30.5	29.3	$e^{0.845(\ln(hardness)-1.702)}$	TBT	3.1	0.83
Total mercury (ng/L)	0.9081	0.77	0.85	1.106	0.94	0.85
Methylmercury (ng/L)	NA	NA	NA	NA	NA	NA
Lead[2] (ug/L)	18.6	10.9	$e^{1.273(\ln(hardness)-4.705)}$		8.1	0.951
Selenium (ug/L)	5	4.6		TBT	71	0.998

Notes:

1. Based on total recoverable metal
2. Hardness dependent criteria. 400 mg/L hardness used. Used equations to convert dissolved metals standard to total recoverable metals
3. NA – Not available or applicable

TABLE 7-8.UTAH CHRONIC STANDARD FOR THE PROTECTION OF FRESH WATER AQUATIC LIFE AND EPA CHRONIC CRITERIA FOR THE PROTECTION OF SALT WATER AQUATIC LIFE CONVERTED FROM A DISSOLVED TO TOTAL CONCENTRATION USING THE CONVERSION EQUATION

CLASS 5A GILBERT BAY METALS CONCENTRATIONS IN THE WATER COLUMN, BRINE SHRIMP AND BIRD EGGS

Gilbert Bay Metals Concentrations in the Water Column

Table 7-9 shows descriptive statistics for water column concentrations of arsenic, copper, cadmium, lead, total mercury, methylmercury, selenium, and thallium in Gilbert Bay during the 2011–2012 monitoring period over all sites and depths. In addition, descriptive statistics are provided for the surface water samples in Table 7-10 and for the deep brine layer samples (sites Gil2bottom, Gil5bottom, and Gil6bottom) in Table 7-11. The average concentrations of metals in Gilbert Bay generally increased in concentration from the shallow layer to the deep brine layer sites.

TABLE 7-9. DESCRIPTIVE STATISTICS OF METALS CONCENTRATIONS AT ALL GILBERT BAY SITES OVER ALL DEPTHS DURING 2011 AND 2012.

Analyte	Average	Minimum	Maximum	Standard Deviation	Count	Fresh Water Aquatic Criteria	Salt Water Aquatic Criteria
Arsenic (ug/L)	77.852	27.900	157.000	25.760	64	150.00	36.0
Cadmium (ug/L)	0.046	0.010	0.280	0.065	64	0.76	8.8
Copper (ug/L)	2.553	0.175	15.000	2.742	64	30.50	3.1
Total mercury (ng/L)	9.866	1.150	47.300	13.541	57	12.00	940.0
Methylmercury (ng/L)	4.156	0.150	29.300	7.996	57	2.80[1]	NA
Lead (ug/L)	2.117	0.439	13.400	2.538	64	18.60	8.1
Selenium (ug/L)	0.379	0.197	0.776	0.113	64	4.60	71.0
Thallium (ug/L)	0.038	0.010	0.113	0.015	64	0.03[2]	17.0[2]

Notes:
1: Los Alamos National Laboratory, 2009 Tier II value for protection of aquatic life communities
2. ANZECC & ARMCANZ, 2000
3. NA = Not available or applicable

TABLE 7-10. DESCRIPTIVE STATISTICS OF METALS CONCENTRATIONS AT ALL GILBERT BAY SITES IN THE SURFACE WATER SAMPLES (0.2 M FROM SURFACE) DURING 2011 AND 2012.

Analyte	Average	Minimum	Maximum	Standard Deviation	Count	Fresh Water Aquatic Criteria	Salt Water Aquatic Criteria
Arsenic (ug/L)	67.063	27.900	100.000	20.783	32	150	36
Cadmium (ug/L)	0.020	0.010	0.046	0.013	32	0.76	8.8
Copper (ug/L)	1.825	0.880	3.750	0.602	32	30.5	3.1
Total mercury (ng/L)	3.562	1.230	10.300	2.108	31	12	940
Methylmercury (ng/L)	0.813	0.150	2.880	0.575	31	2.8[1]	
Lead (ug/L)	1.084	0.439	1.490	0.232	32	18.6	8.1

Selenium (ug/L)	0.362	0.197	0.756	0.106	32	4.6	71
Thallium (ug/L)	0.032	0.010	0.042	0.008	32	0.03[2]	17[2]

Notes:
1: Los Alamos National Laboratory, 2009 Tier II value for protection of aquatic life communities
2. ANZECC & ARMCANZ, 2000
3. NA = Not available or applicable

TABLE 7-11. DESCRIPTIVE STATISTICS OF METALS CONCENTRATIONS OF GILBERT BAY IN THE DEEP BRINE LAYER SITES (GIL2BOTTOM, GIL5BOTTOM, AND GIL6BOTTOM) DURING 2011 AND 2012.

Analyte	Average	Minimum	Maximum	Standard Deviation	Count	Fresh Water Aquatic Criteria	Salt Water Aquatic Criteria
Arsenic (ug/L)	113.367	85.100	157.000	19.555	12	150	36
Cadmium (ug/L)	0.155	0.060	0.280	0.084	12	0.76	8.8
Copper (ug/L)	5.621	0.175	15.000	5.353	12	30.5	3.1
Total mercury (ng/L)	38.900	26.400	47.300	8.186	9	12	940
Methylmercury (ng/L)	21.223	8.710	29.300	7.392	9	2.8[1]	
Lead (ug/L)	6.474	2.280	13.400	3.344	12	18.6	8.1
Selenium (ug/L)	0.488	0.348	0.776	0.142	12	4.6	71
Thallium (ug/L)	0.056	0.023	0.113	0.026	12	0.03[2]	17[2]

Notes:
1: Los Alamos National Laboratory, 2009 Tier II value for protection of aquatic life communities
2. ANZECC & ARMCANZ, 2000
3. NA = Not available or applicable

The average and standard deviation of arsenic concentrations in Gilbert Bay over all sites and depths during the monitoring period was 77.9 ± 25.7 µg/L (range of 27.9 to 157.0 µg/L). Arsenic concentrations doubled in the deep brine layer sites where the average arsenic concentration in the shallow layer was 67.1± 20.8 µg/L (range of 27.9 to 100.0 µg/L) increasing to 113.4 ± 19.6 µg/L (range of 85.1 to 157.0 µg/L) in the deep brine layer. For arsenic, the EPA-recommended salt waters chronic criterion of 36 µg/L is much lower than the fresh water criterion of 150 µg/L. Arsenic concentrations exceeded the salt water criterion in 97% of samples in Gilbert Bay (Figure 7-6). The remaining 3% of samples that did not exceed the recommended criterion were all from site Gil8, located at the culvert between Gilbert and Farmington Bays. Only one measurement of arsenic exceeded the fresh water aquatic criterion; it came from a sample obtained from the deep brine layer (site Gil2bottom).

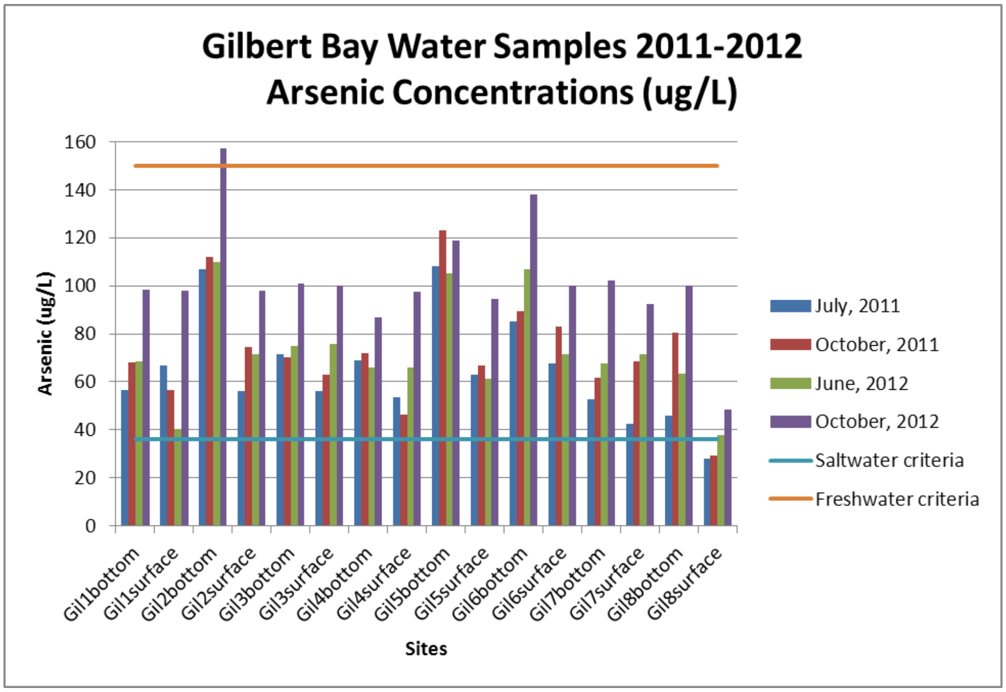

FIGURE 7-6. ARSENIC CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY

Over all sites and depths, average copper concentrations were 2.6 ± 2.7 µg/L (range of 0.175 to 15.000 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 µg/L ± 5.4 (range of 0.175 to 15.000 µg/L) in the deep brine layer. Copper concentrations exceeded the salt water criterion of 3.1 µg/L in 17% of total samples (Figure 7-7) and were mostly confined to the deep brine layer. No samples of copper exceeded the fresh water criterion.

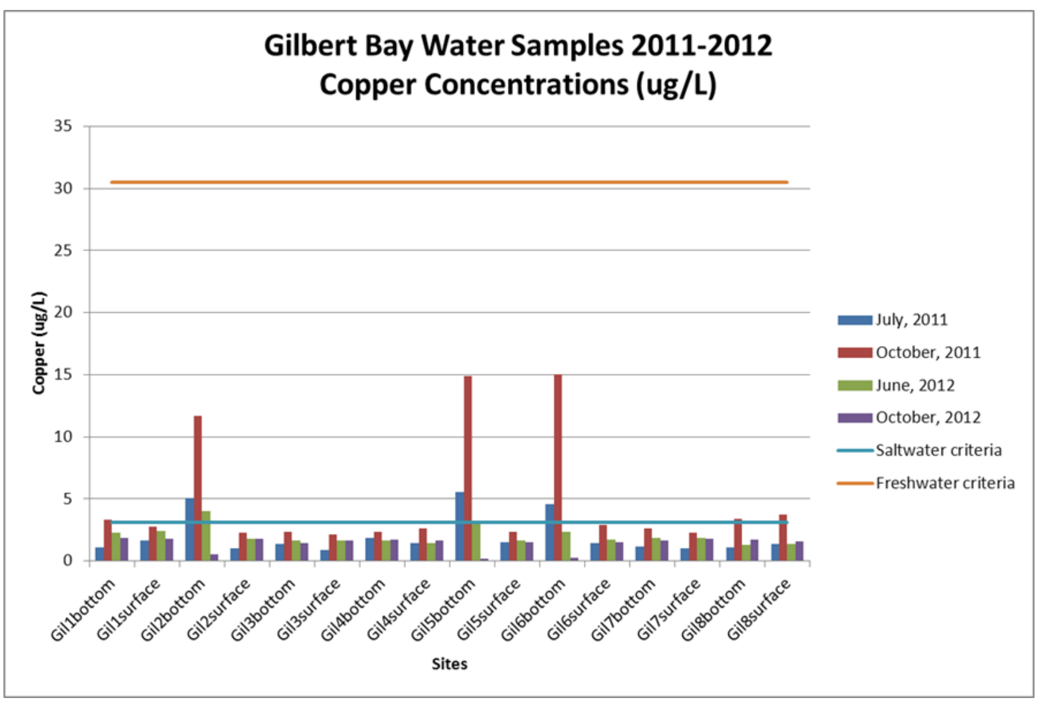

FIGURE 7-7. COPPER CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY.

A similar pattern was observed for lead, which averaged 2.1 ± 2.5 µg/L (range of 0.439 to 13.400 µg/L) over all sites and depths, and increased with depth from 1.1± 0.2 µg/L (range of 0.439 to 1.490 µg/L) in the shallow layer to 6.5 ± 3.3 µg/L (range of 2.28 to 13.40 µg/L) in the deep brine layer. Of the lead samples, 4% exceeded the salt water criterion of 8.1 µg/L, and all were located at sites Gil2bottom and Gil6bottom, where the deep brine layer was present (Figure 7-8). No samples of lead exceeded the fresh water criterion.

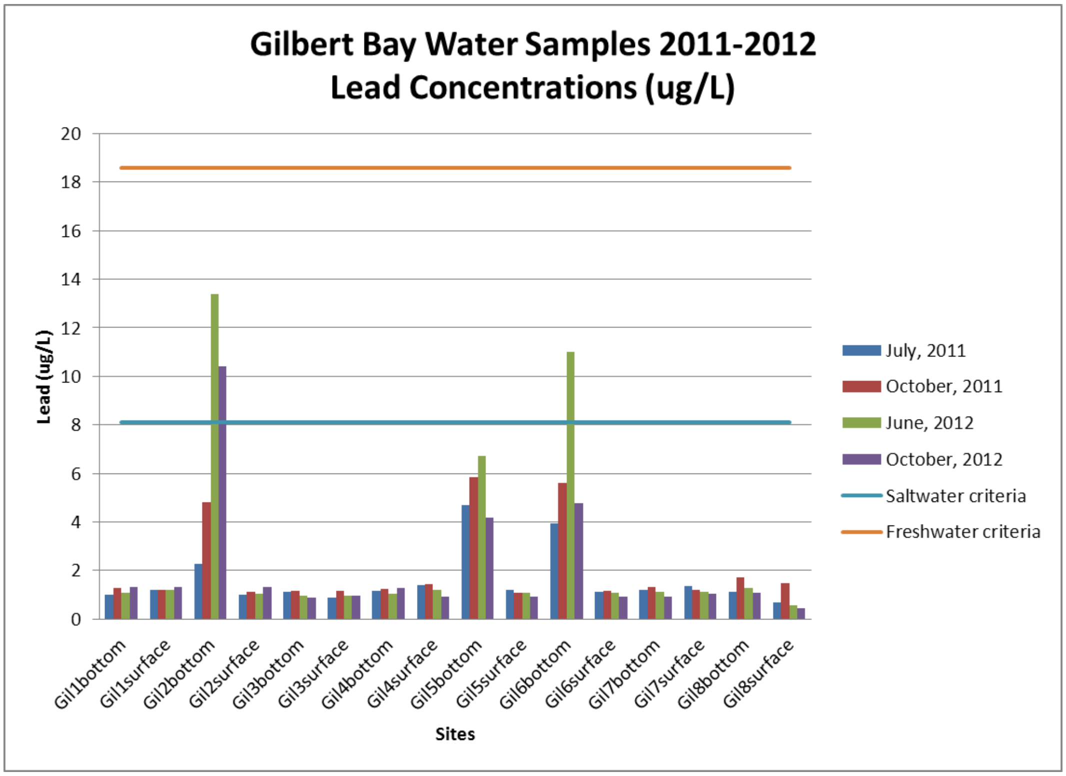

FIGURE 7-8. LEAD CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY.

Elevated mercury concentrations in the water column of Gilbert Bay have been well documented (Naftz et al., 2008; Darnall and Miles, 2009; Vest et al., 2008). Intensive studies began after 2003 when the USGS noted elevated methylmercury water column concentrations (Naftz et al., 2005). Subsequent research focused on mercury concentrations in the sediment and water column and the possible toxic exposure to and bioaccumulation in biota and humans (DWQ, 2011). The waterfowl consumption advisories for mercury in three species of duck (Cinnamon Teal, Northern Shoveler, and Common Goldeneyes) (Utah Waterfowl Advisories 2014) remain in place even though 2009 breast muscle tissue samples from Cinnamon Teals and Northern Shovelers were below the EPA screening level of 0.3 mg of mercury/kg for fish. As part of the BSP and other ongoing research, DWQ continues to measure mercury concentrations in the open waters of GSL, brine shrimp tissue, and shorebird eggs to assess bioaccumulation of methylmercury in the food web. Consistent with previous research, the highest concentrations of mercury in the water column were found in the deep brine layer of Gilbert Bay. During the 2011–2012 monitoring period, average total mercury concentrations in the shallow layer were 3.6 ± 2.1 ng/L (range of 1.23 to 10.30), and methylmercury concentrations were 0.8 ± 0.6 ng/L (range of 0.15 to 2.88). In contrast, the deep brine layer average total methylmercury concentrations were 38.9 ± 8.2 ng/L (range of 26.4 to 47.3) and 21.2 ± 7.4 ng/L (range of 8.7 to 29.3), respectively. When compared to Utah's total mercury fresh water aquatic criterion of 12 ng/L (based on protecting humans who consume fish), 19% of measurements exceeded the criterion, all of which occurred in the deep brine layer (Figures 7-9 and 7-10). For methylmercury, 10.5% of measurements exceeded the fresh water aquatic benchmark of 2.8 ng/L (Los Alamos National Laboratory, 2009). When compared to the EPA total mercury salt water aquatic criterion of 940 ng/L, none of the measurements, even in the deep brine layer, exceeded this criterion.

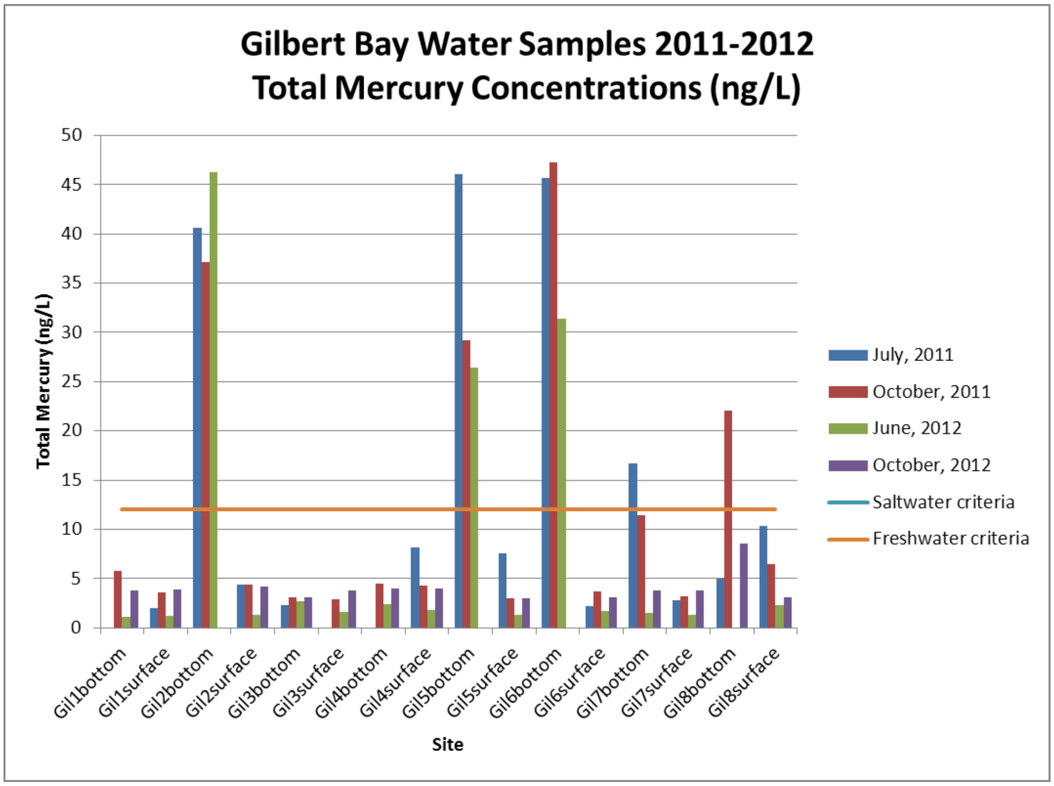

FIGURE 7-9. TOTAL MERCURY CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY.

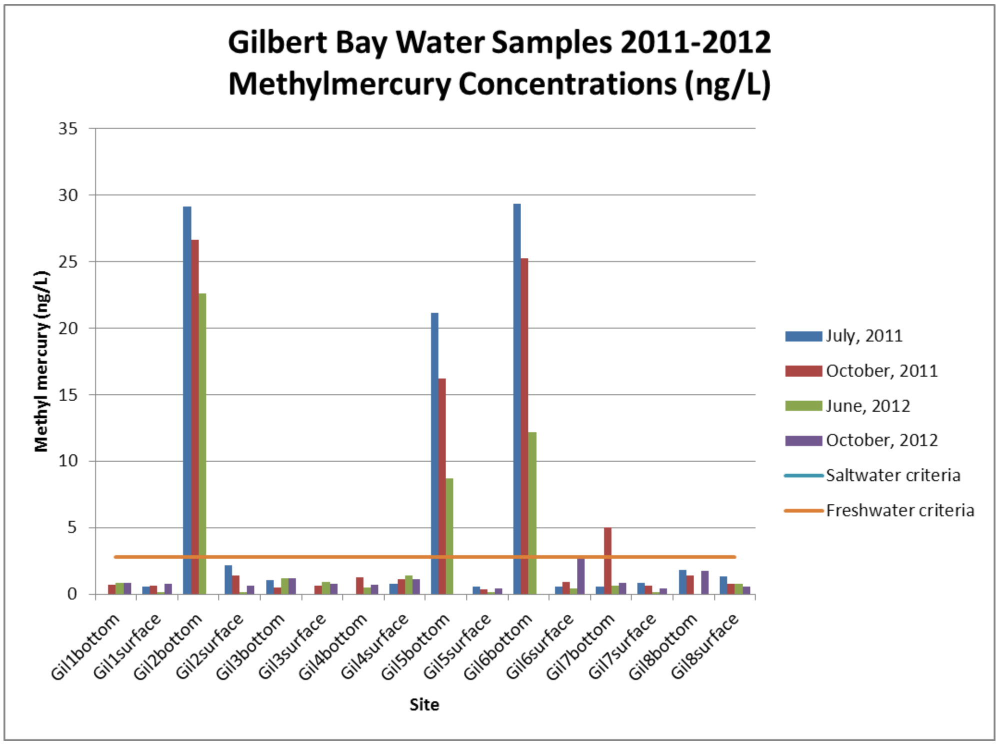

FIGURE 7-10. METHYLMERCURY CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY.

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 are estimated. The percentages of these measurements per analyte were 75% of cadmium samples, 98% of selenium samples, and 92% of thallium samples (DWQ, 2014a). None of the sample results for these analytes exceeded the fresh water or salt water criteria or benchmarks (see Figures 7-11, 7-12, and 7-13). Because 92% of the thallium samples were qualified as less than quantifiable, DWQ will begin measuring zinc concentrations instead of thallium in the future. The BSP mean selenium concentration of 0.379 ± 0.100 µg/L (range of 0.197 to 0.776 µg/L) was lower but was comparable to the mean selenium concentration of 0.584 µg/L (range of 0.297 to 0.899 µg/L) measured in 2006 and 2007 as part of the selenium standard research program (DWQ, 2007).

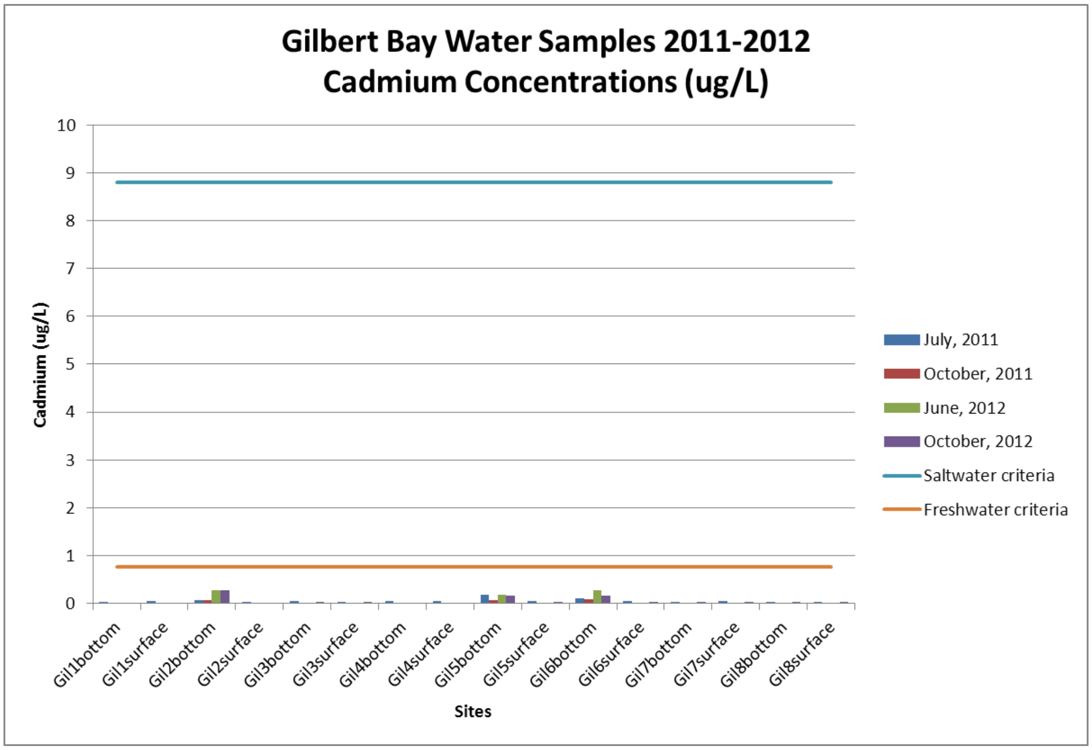

FIGURE 7-11. CADMIUM CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY.

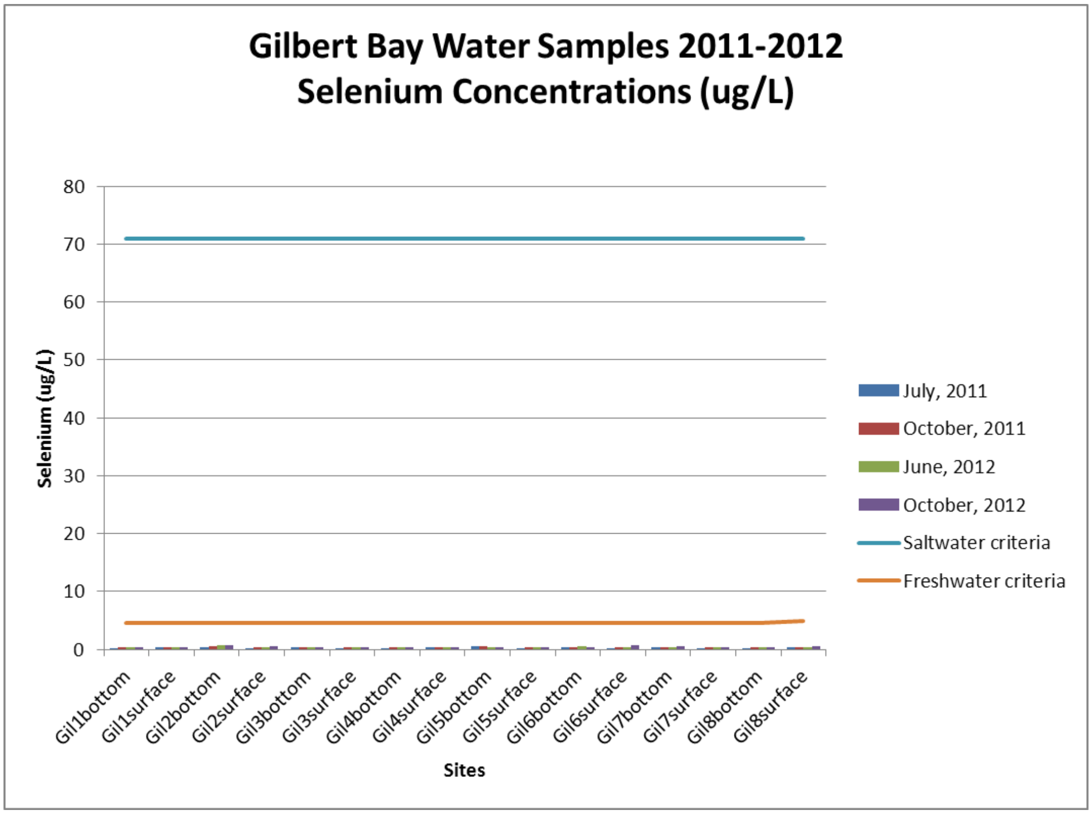

FIGURE 7-12. SELENIUM CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY.

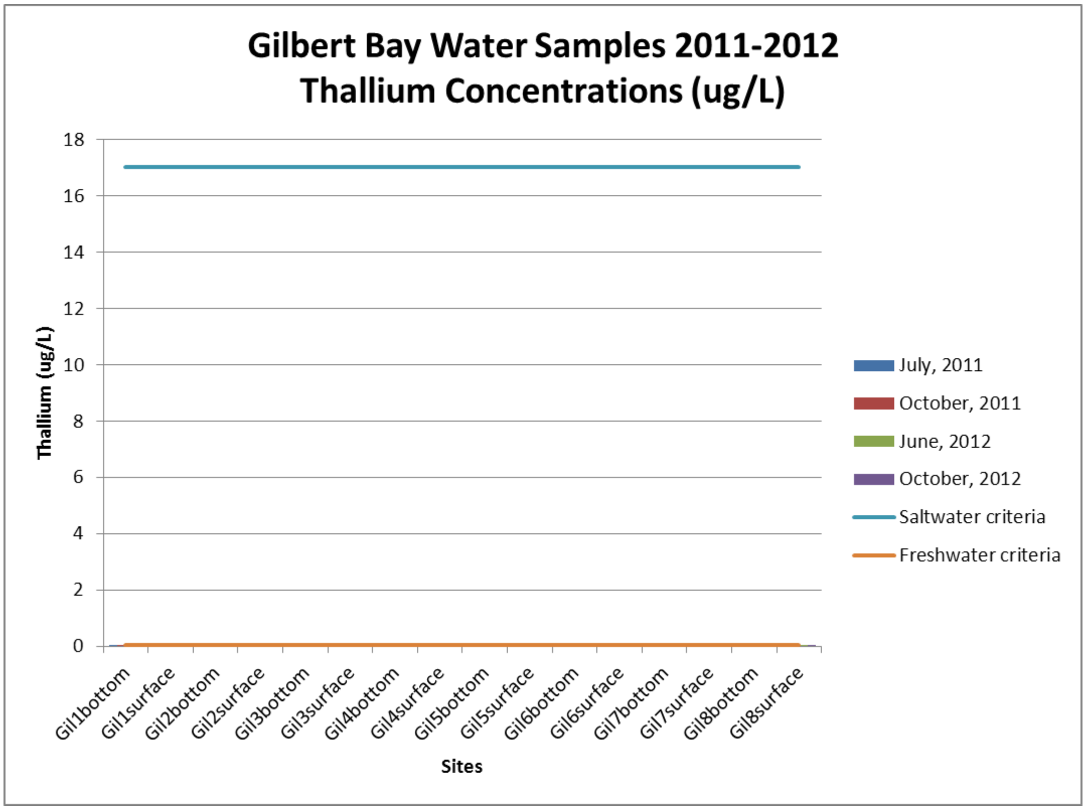

FIGURE 7-13. THALLIUM CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN GILBERT BAY.

Of the metals measured, arsenic, copper, methylmercury, and lead were ranked in order as highest priorities for toxicological testing of brine shrimp and brine flies necessary for the development of numeric water quality criteria (DWQ, 2013). For more detail, see the Toxicological Testing and Pollutant Prioritization section below.

Gilbert Bay Metals Concentrations in Brine Shrimp

Aquatic organisms take up metals from the water and food, which can result in concentrations in their bodies 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. As part of the BSP, metals in brine shrimp were assessed to evaluate dietary exposure to birds and monitor for increasing or decreasing trends. Brine flies were not sampled and the metals concentrations in these organisms remain a data gap.

A detailed effort was made by EPA, the U.S. Fish and Wildlife Service, USGS, and others to compile avian dietary effects levels for mercury (DWQ, 2011) and selenium (DWQ, 2007) to determine appropriate benchmarks to translate the narrative standard for GSL designated use support. Yet, the applicability of these benchmarks has not been rigorously evaluated, and they will not be used for a definitive assessment for this reporting cycle. Avian dietary effects levels for the other metals will also be compiled and used as a comparison as part of future efforts. The same difficulties with identifying appropriate benchmarks for GSL are anticipated for these other metals.

In all, 32 samples of brine shrimp were collected from Gilbert Bay during the 2011–2012 monitoring period and were analyzed for the following target analytes: arsenic, cadmium, copper, lead, total mercury, selenium, and thallium (Figures 7-14 through 7-20). Descriptive statistics are presented in Table 7-12. Mercury and selenium are discussed in more detail in the following paragraphs. Evaluations of the remaining metals concentrations in brine shrimp are deferred until comparison benchmarks are identified.

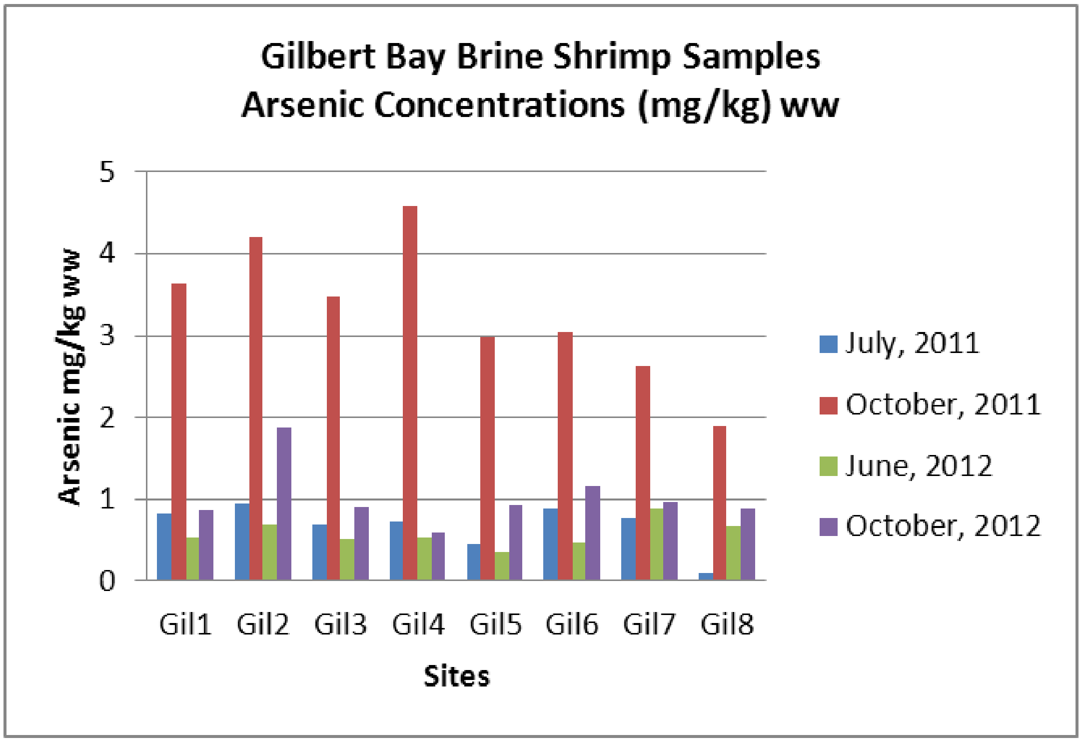

FIGURE 7-14. ARSENIC IN BRINE SHRIMP TISSUE AT EACH SITE IN GILBERT BAY.

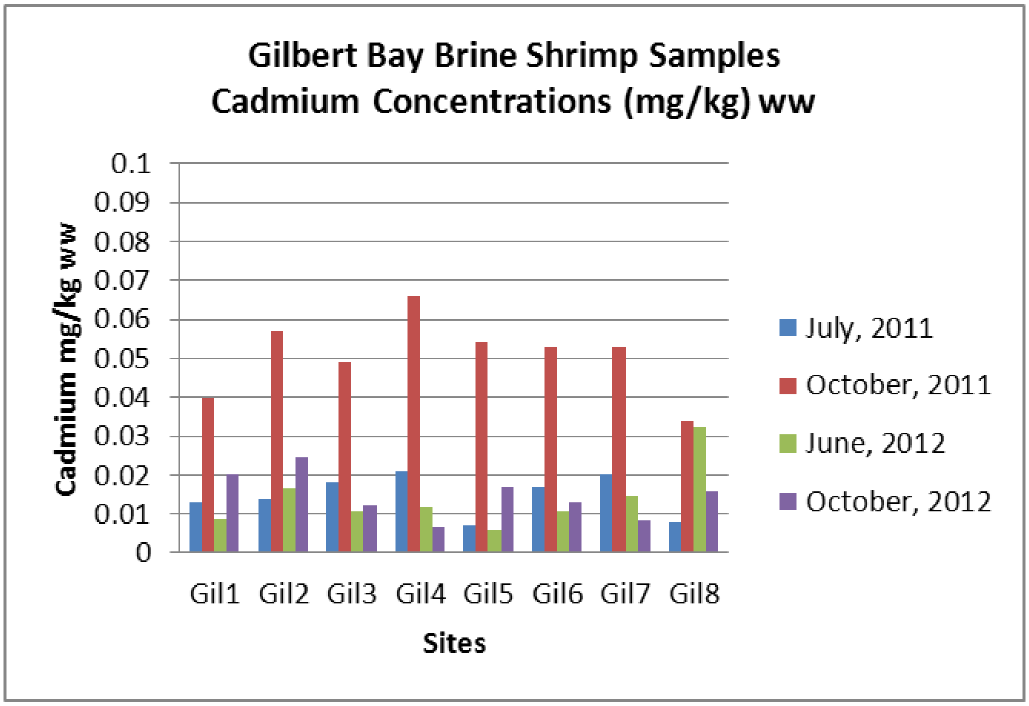

FIGURE 7-15. CADMIUM IN BRINE SHRIMP TISSUE AT EACH SITE IN GILBERT BAY.

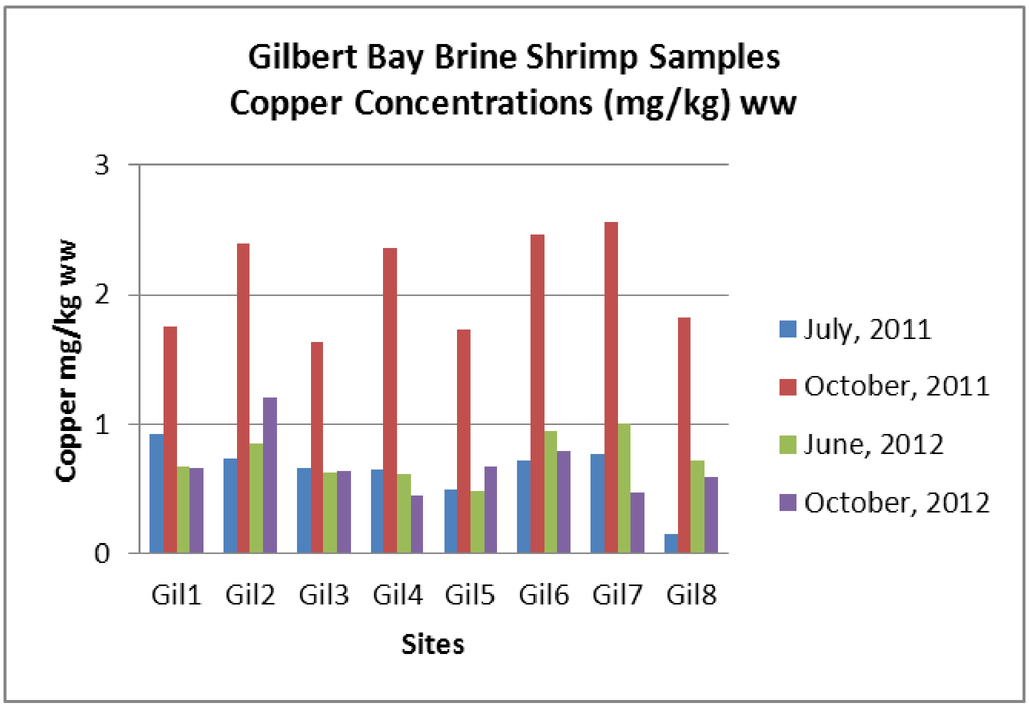

FIGURE 7-16. COPPER IN BRINE SHRIMP TISSUE AT EACH SITE IN GILBERT BAY.

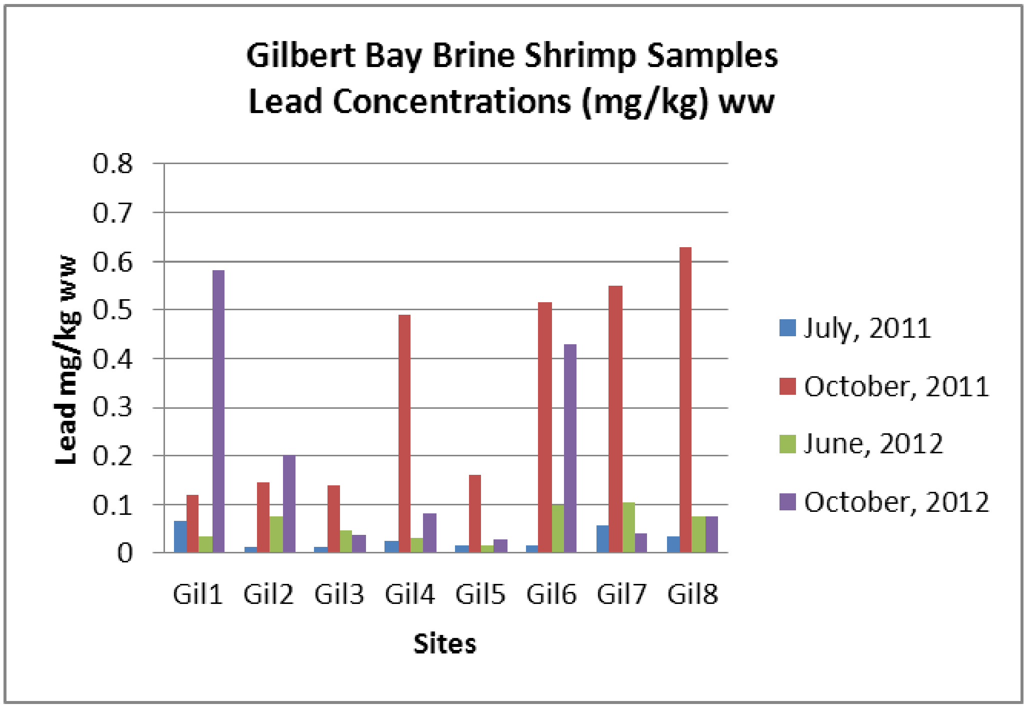

FIGURE 7-17. LEAD IN BRINE SHRIMP TISSUE AT EACH SITE IN GILBERT BAY.

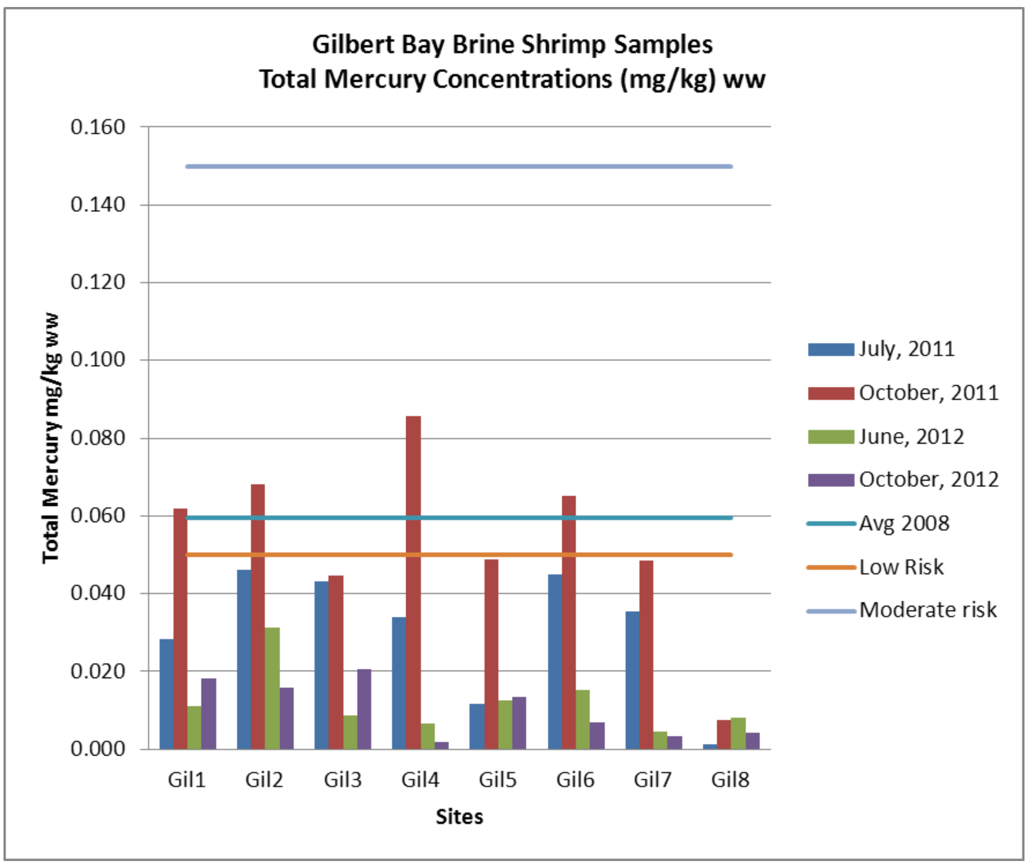

FIGURE 7-18. TOTAL MERCURY IN BRINE SHRIMP TISSUE AT EACH SITE IN GILBERT BAY COMPARED TO EVERS ET AL. (2004) RISK RANGES AND THE RESULTS OF THE 2008 ECOSYSTEM ASSESSMENT.

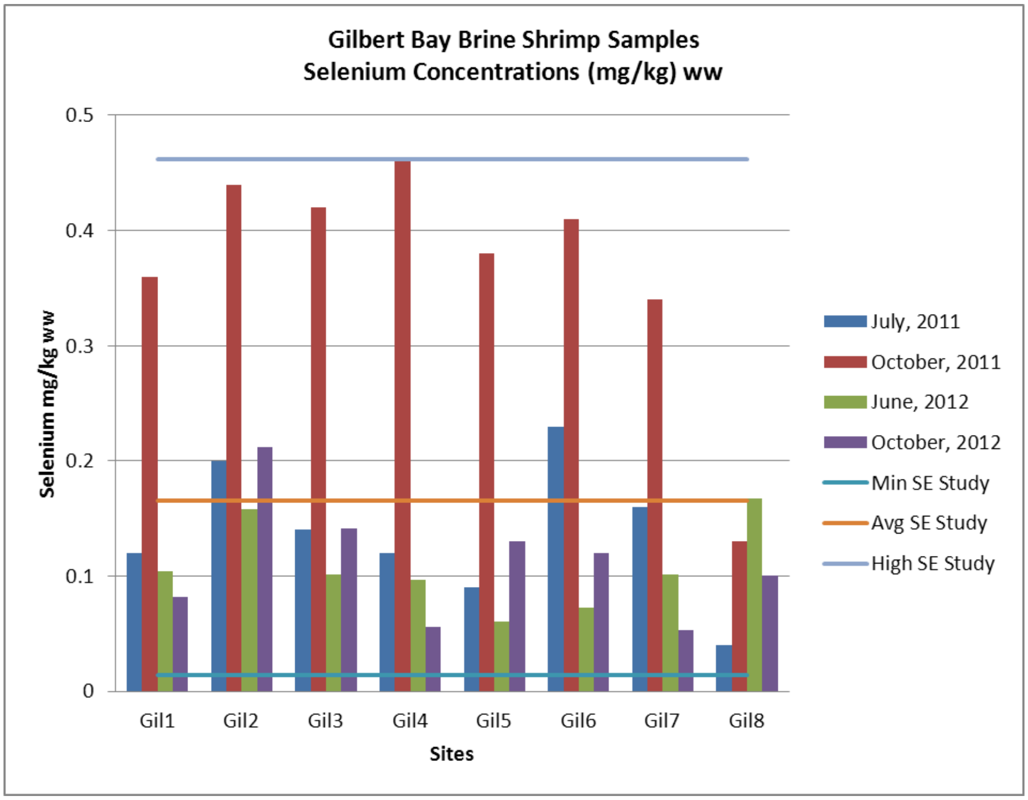

FIGURE 7-19. SELENIUM IN BRINE SHRIMP TISSUE AT EACH SITE IN GILBERT BAY COMPARED TO THE RESEARCH CONDUCTED AS PART OF THE SELENIUM STANDARD SETTING PROCESS.

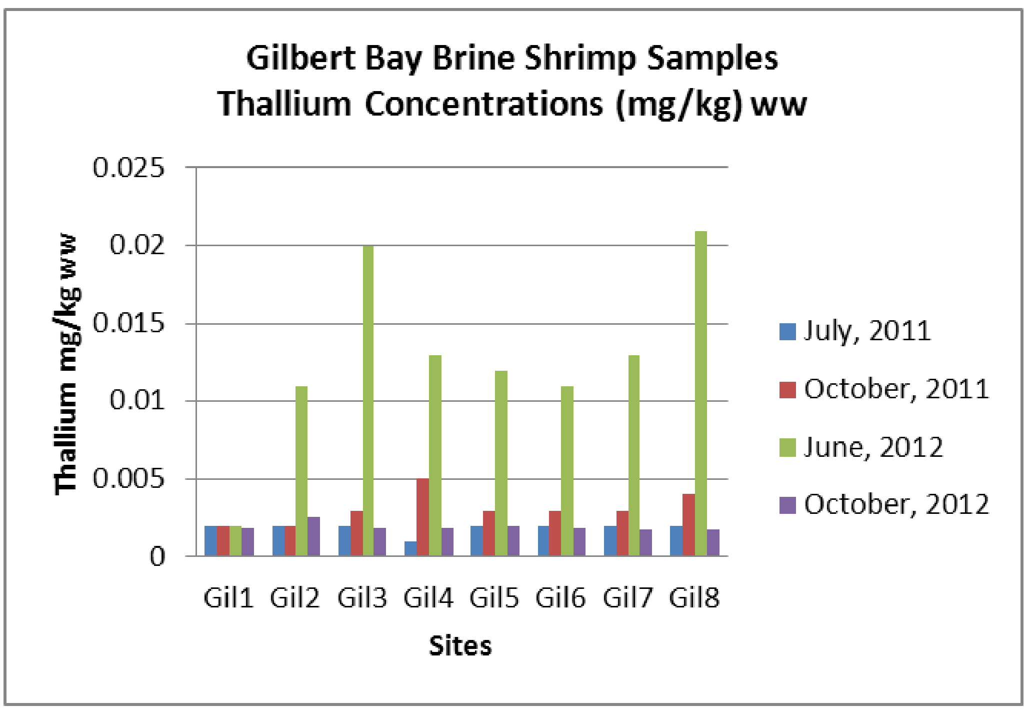

FIGURE 7-20. THALLIUM IN BRINE SHRIMP TISSUE AT EACH SITE IN GILBERT BAY.

TABLE 7-12. DESCRIPTIVE STATISTICS OF METALS IN BRINE SHRIMP TISSUE IN GILBERT BAY DURING 2011 AND 2012.

Analyte (expressed as wet weight)	Average	Minimum	Maximum	Standard Deviation	Count	Avian Dietary Effects Levels
Arsenic (mg/kg)	1.398	0.097	4.580	1.226	32	TBD
Cadmium (mg/kg)	0.024	0.006	0.066	0.018	32	TBD
Copper (mg/kg)	1.040	0.150	2.560	0.670	32	TBD
Total mercury (mg/kg)	0.027	0.001	0.086	0.023	32	Low risk in diet: < 0.05 mg/kg ww Moderate risk in diet: 0.05–0.15 mg/kg ww High risk in diet: 0.15–0.30 mg/kg ww Extra high risk in diet: >0.30 mg/kg ww
Lead (mg/kg)	0.155	0.011	0.630	0.192	32	TBD
Selenium (mg/kg)	0.181	0.040	0.460	0.128	32	TBD
Thallium (mg/kg)	0.005	0.001	0.021	0.005	32	TBD

Notes:

1. Effect on common loons (Evers et al., 2004)
2. TBD = To be determined

As part of the 2010 IR, Chapter 14: Great Salt Lake, Appendix A-1 presented an extensive literature review of benchmarks for mercury impairment in avian species. Evers et al. (2004) risk ranges were selected as interim benchmarks for mercury in dietary items that would pose a risk to avian wildlife as follows:

- Low risk in diet: 0–0.05 methylmercury mg/kg wet weight (ww)
- Moderate risk in diet: 0.05–0.15 methylmercury mg/kg ww
- High risk in diet: 0.15–0.30 methylmercury mg/kg ww
- Extreme high risk in diet: > 0.30 methylmercury mg/kg ww

Evers et al. (2004) risk ranges are based on methylmercury concentrations instead of total mercury concentrations. Methylmercury is the most toxic form of mercury to aquatic life and represents a portion of the total mercury. As part of the BSP, total mercury, instead of methylmercury, was analyzed in brine shrimp because it is a simpler and a more cost-effective measurement in biological tissues. Future analyses will include methylmercury for brine shrimp to address this data gap. Until these data are available, the assumption is that all of the measured mercury in brine shrimp is methylmercury. The fraction of total mercury that is methylmercury is variable but tends to decrease in lower trophic levels. The assumption that all of the mercury is methylmercury is likely a conservative one (Weiner and Heinz 2003). For total mercury, 87.5% of brine shrimp measurements were less than 0.05 mg/kg ww, below the low risk benchmark value and equivalent to a no-observed-adverse-effect level (Evers et al., 2004). Four measurements were greater than 0.50 mg/kg ww but less than 0.15 mg/kg ww, suggesting moderate risk.

In 2008 as part of the ecosystem assessment of mercury concentrations in GSL, 60 adult brine shrimp were analyzed for total mercury concentrations in Gilbert Bay (DWQ, 2011). The average brine shrimp concentration from the 2008 mercury ecosystem assessment was 0.059 mg/kg ww (range of 0.019 to 0.098

mg/kg ww) compared with the average concentration of 0.027± 0.020 mg/kg (range of 0.001to 0.086 mg/kg ww) as part of the 2011–2012 BSP results.

As part of the selenium water quality standard setting research conducted from 2006 to 2008, brine shrimp selenium concentrations were expressed as dry weight. For the purpose of the following comparisons, dry weight was converted to wet weight using the 2011–2012 average percentage of moisture in brine shrimp, which was 87%. The 2006–2008 average concentration of selenium in adult brine shrimp tissue was 0.16 mg/kg ww (range of 0.014 to 0.462 mg/kg ww,) compared to the BSP average concentration of 0.18 mg/kg ww (range 0.04 to 0.46 mg/kg ww).

Gilbert Bay Selenium and Mercury Concentrations in Bird Eggs

Selenium

The GSL selenium numeric water quality standard is a geometric mean of 12.5 mg/kg dry weight (dw) selenium based on the complete egg or embryo of aquatic-dependent birds that use the waters of Gilbert Bay (UAC R317-2-14). The standard was adopted by the Utah Water Quality Board in 2008 and approved by EPA in 2009, and is the first numeric standard adopted for the lake. Starting in 2010, DWQ contracted with Dr. John Cavitt from the Avian Ecology Laboratory of Weber State University to sample shorebird egg tissue for selenium, as outlined in the Sampling Design section of this report. As prescribed in the selenium standard setting process, the geometric mean dry weight selenium concentration from at least five eggs is compared to the selenium numeric water quality standard for designated use support. Table 7-13 provides descriptive statistics of selenium concentrations in bird egg tissue by date and location sampled.

TABLE 7-13. DESCRIPTIVE STATISTICS OF SELENIUM IN BIRD EGG TISSUE (MG/KG DRY WEIGHT) COMPARED TO THE SELENIUM NUMERIC STANDARD.

Date and Location Sampled	Geomean	Minimum	Maximum	Standard Deviation	Count	Gilbert Bay Selenium Numeric Standard[1]
07/27/2010 at Saltair	1.32	3.5	6.00	0.77	13	12.5 mg/kg dry weight
06/02/2011 at Bridger Bay, Antelope Island	1.56	1.38	1.84	0.19	5	
06/22/2011 at Farmington Bay Waterfowl Management Area[2]	2.54	2.28	2.83	0.21	5	
06/11/2012 at Ogden Bay Waterfowl Management Area[3]	1.46	1.13	2.03	0.33	9	
06/20/2012 at Antelope Island Causeway[3]	1.51	1.21	2.84	0.48	10	

Notes:

1. UAC R317-2-14
2. The selenium numeric water quality standard was established for Gilbert Bay. For Farmington Bay, the standard is used as a benchmark of avian risk.
3. Qualified as estimated. Did not meet the holding time requirement.

In June 2010, the geometric mean selenium concentration for 13 American Avocet and Black-necked Stilt eggs from Saltair was 4.30 ± 0.77 mg/kg dw (range of 3.5 to 6.0) (Cavitt et al, 2010). In June 2011, the geometric mean selenium concentration for five American Avocet eggs at Bridger Bay, Antelope Island, was 1.60 ± 0.19 mg/kg dw (range of 1.38 to 1.84) (Cavitt and Wilson, 2011). In June 2012, the geometric mean concentration of selenium in 10 American Avocet and Black-necked Stilt eggs collected from the Antelope Island Causeway and Ogden Bay Waterfowl Management Area was 1.50 ± 0.48 mg/kg dw (range of 1.21 to 2.84) and 1.50 ± 0.33 mg/kg dw (range of 1.13 to 2.03), respectively (Cavitt et al., 2012). In 2006, as part of the development of the selenium standard, 68 Black-necked Stilts and American Avocet eggs were analyzed for selenium concentrations. The geometric mean selenium concentration for eggs from that study was 2.40 mg/kg dw, which is similar to the 2011–2012 concentrations. The BSP average selenium concentrations for eggs were below the selenium water quality standard of 12.5 mg of selenium/kg egg tissue dw, and no single egg exceeded 12.5 mg/kg dw.

The standard also established incremental management responses at interim thresholds (UAC R317-2-14). At the observed concentration of less than 5.0 mg/kg dw, the action outlined in the standard is to continue routine monitoring, which is scheduled every other year as outlined in the BSP.

Mercury

In addition to selenium, DWQ and Weber State University sampled and analyzed egg tissue for mercury concentrations. Table 7-14 provides descriptive statistics of selenium concentrations in bird egg tissue by date and location sampled.

For the purpose of comparison, DWQ applied Evers et al. (2004) risk ranges for mercury egg concentrations that would indicate risk to avian wildlife as follows:

- Low risk in eggs: 0–0.5 mercury mg/kg ww
- Moderate risk in eggs: 0.5–1.3 mercury mg/kg ww
- High risk in eggs: 1.3–2.0 mercury mg/kg ww
- Extreme high risk in eggs: > 2.0 mercury mg/kg ww

Evers et al. (2004) risk ranges are based on data reported on a wet weight basis. Using the percentage of total solids per egg sample, dry weight mercury concentrations were converted to wet weight to make the comparison.

TABLE 7-14. DESCRIPTIVE STATISTICS OF MERCURY (HG) IN BIRD EGG TISSUE (MG/KG WW) COMPARED TO EVERS ET AL. (2004) RISK RANGES.

Date and Location Sampled	Mean	Minimum	Maximum	Standard Deviation	Count	Evers et al. Egg Tissue Risk Ranges[1]
06/02/2011 at Bridger Bay, Antelope Island	0.23	0.15	0.33	0.07	5	Low risk in eggs: 0–0.5 Hg mg/kg ww Moderate risk in eggs: 0.5–1.3 Hg mg/kg ww High risk in eggs: 1.3–2.0 Hg mg/kg ww Extreme high risk in eggs: >2.0 Hg mg/kg ww
06/22/2011 at Farmington Bay Waterfowl Management	0.34	0.21	0.42	0.08	5	

Date and Location Sampled	Mean	Minimum	Maximum	Standard Deviation	Count	Evers et al. Egg Tissue Risk Ranges[1]
Area						
06/11/2012 at Ogden Bay Waterfowl Management Area[2]	0.12	0.05	0.24	0.06	8	
06/20/2012 at Antelope Island Causeway[2]	0.15	0.04	0.38	0.11	10	
Notes: 1. Effect on common loons (Evers et al., 2004) 2. Qualified as estimated. Did not meet the holding time requirement						

In June 2011, the arithmetic mean mercury concentration for five American Avocet eggs at Bridger Bay, Antelope Island, was 0.20 ± 0.07 mg/kg ww (range of 0.14 to 0.33) (Cavitt and Wilson, 2011).

In June 2012, mean mercury concentrations in 10 American Avocet and Black-necked Stilt eggs collected from the Antelope Island Causeway and Ogden Bay Waterfowl Management Area were 0.15 ± 0.11 mg/kg ww (range of 0.04 to 0.38) and 0.12 ± 0.06 mg/kg ww (range of 0.05 to 0.24) (Cavitt et al., 2012).

The average mercury concentrations from eggs sampled in 2011 and 2012 are a low risk to avian wildlife according to Evers et al. (2004) risk ranges.

CLASS 5C BEAR RIVER BAY METALS CONCENTRATIONS IN THE WATER COLUMN

Table 7-15 shows the descriptive statistics of water column concentrations of arsenic, cadmium, copper, lead, total mercury, methylmercury, selenium, and thallium in Bear River Bay during the 2011–2012 monitoring period. Only two samples were collected in 2011 and 2012. For all analytes, none of the Bear River Bay samples exceeded the fresh water or salt water numeric aquatic life criteria (Figures 7-21 through 7-28).

TABLE 7-15. DESCRIPTIVE STATISTICS OF METALS CONCENTRATIONS AT THE BEAR RIVER BAY SITE BRB11, AT ALL DEPTHS, DURING 2011 AND 2012.

Analyte	Average	Minimum	Maximum	Standard Deviation	Count	Fresh Water Aquatic Criteria	Salt Water Aquatic Criteria
Arsenic (ug/L)	15.700	13.100	18.300	3.677	2	150.00	36.00
Cadmium (ug/L)	0.035	0.020	0.051	0.021	2	0.76	8.80
Copper (ug/L)	1.209	0.368	2.050	1.189	2	30.50	3.10
Total mercury (ng/L)	2.565	1.930	3.200	0.898	2	12.00	940.00
Methylmercury (ng/L)	0.685	0.499	0.870	0.262	2	2.80[1]	NA
Lead (ug/L)	0.170	0.148	0.192	0.031	2	18.60	8.10
Selenium (ug/L)	0.380	0.192	0.567	0.265	2	4.60	71.00

Analyte	Average	Minimum	Maximum	Standard Deviation	Count	Fresh Water Aquatic Criteria	Salt Water Aquatic Criteria
Thallium (ug/L)	0.015	0.013	0.017	0.003	2	0.03[2]	17.00[2]

Notes:
1: Los Alamos National Laboratory, 2009 Tier II value for protection of aquatic life communities
2. ANZECC & ARMCANZ, 2000
3. NA = Not available or applicable

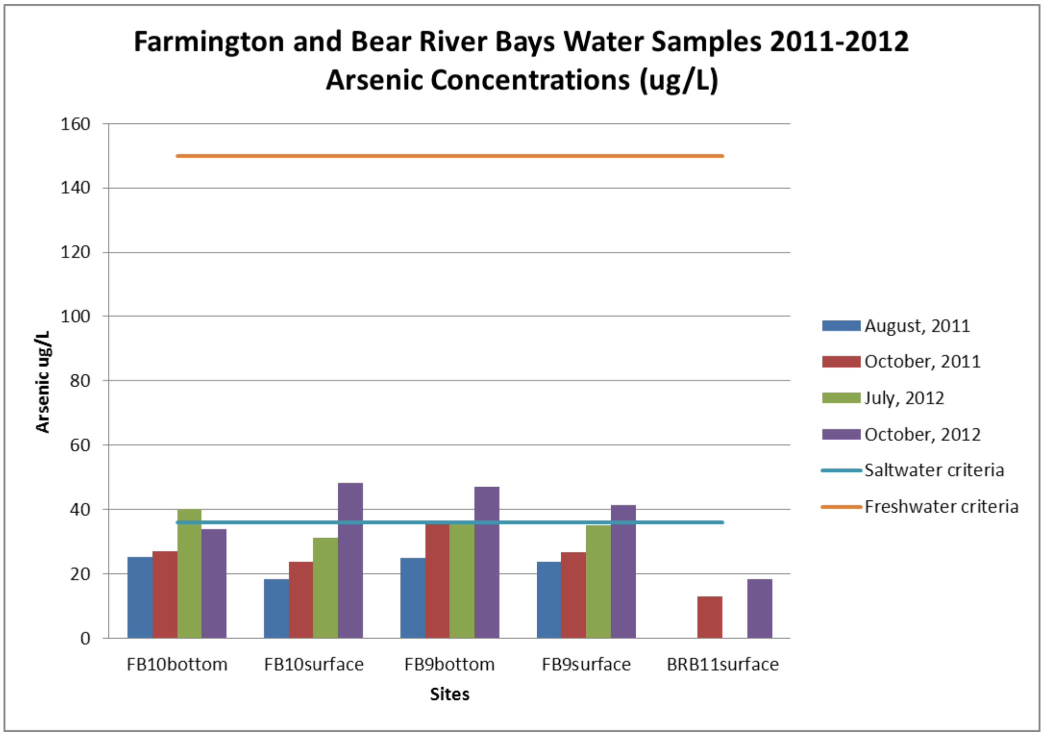

FIGURE 7-21. ARSENIC CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

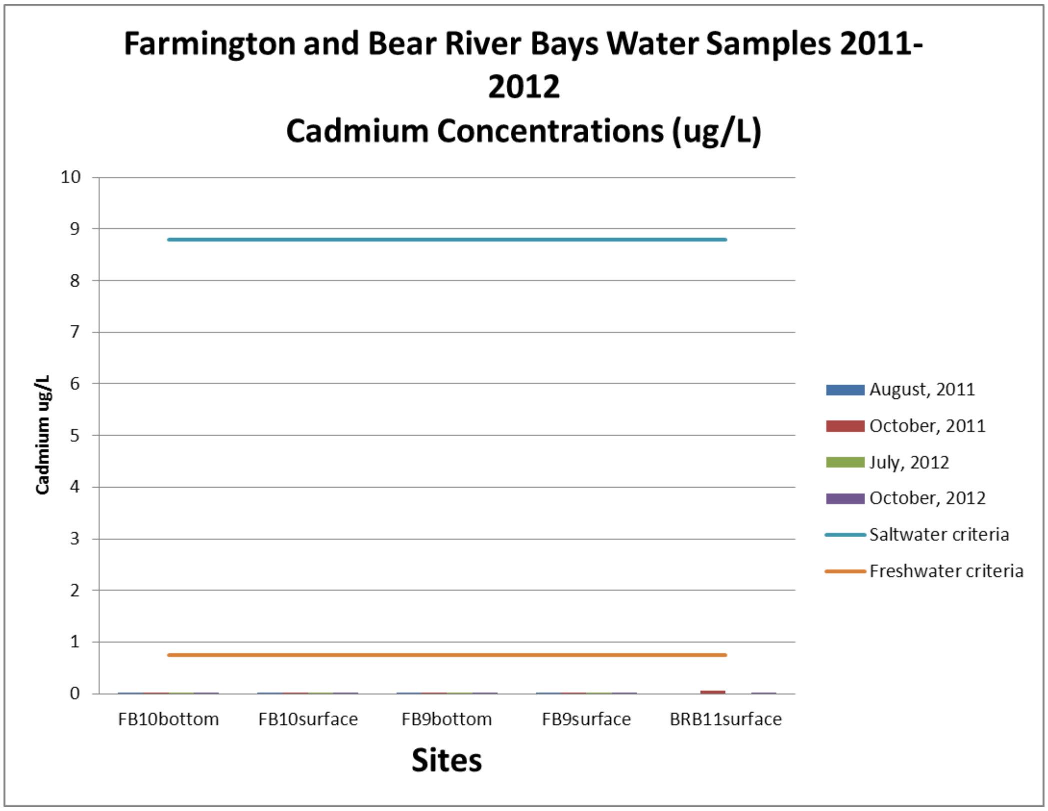

FIGURE 7-22. CADMIUM CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

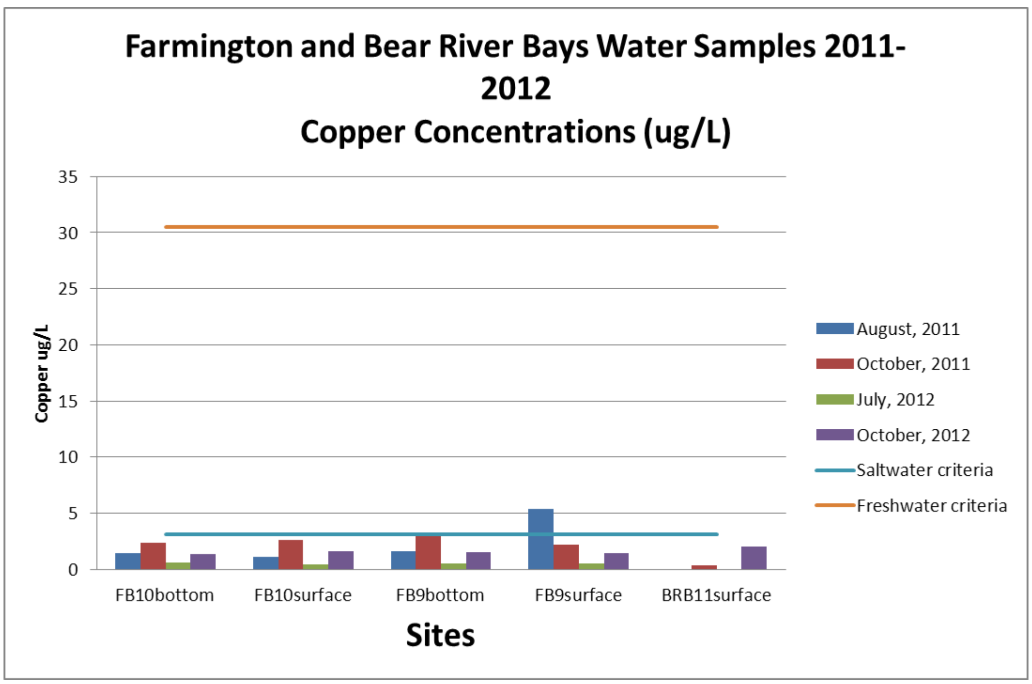

FIGURE 7-23. COPPER CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

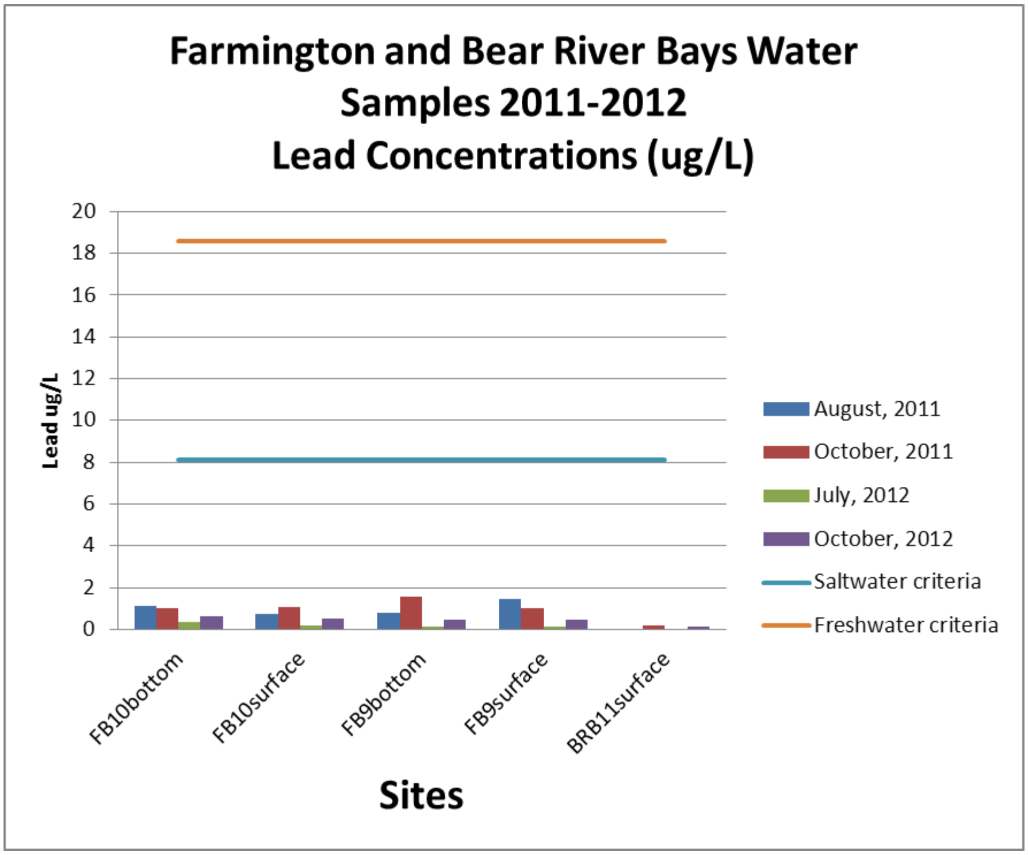

FIGURE 7-24. LEAD CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

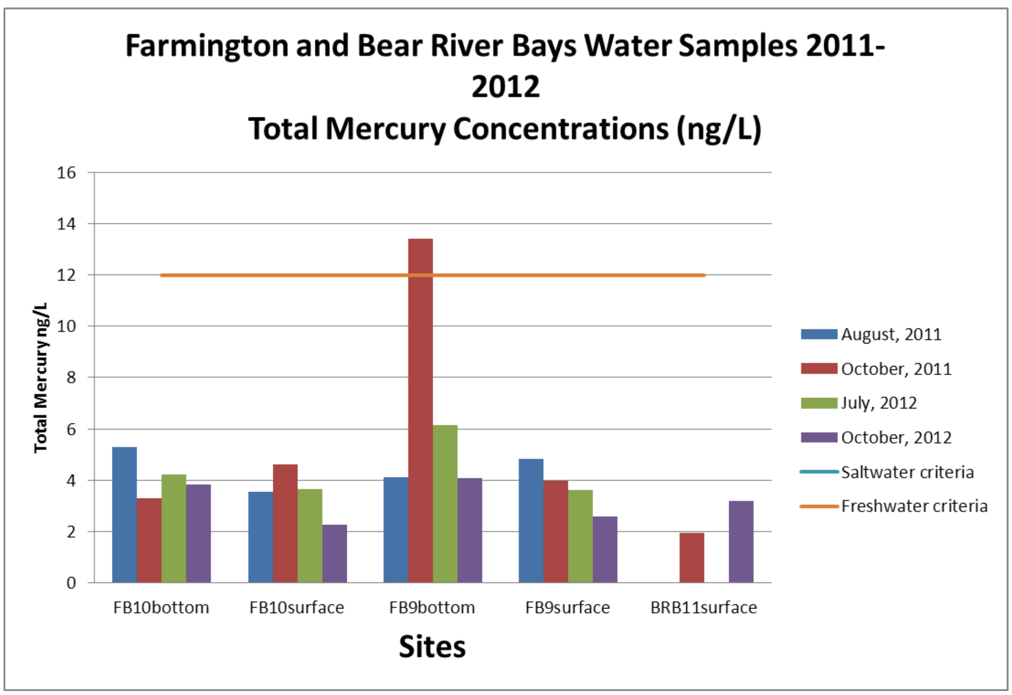

FIGURE 7-25. TOTAL MERCURY CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

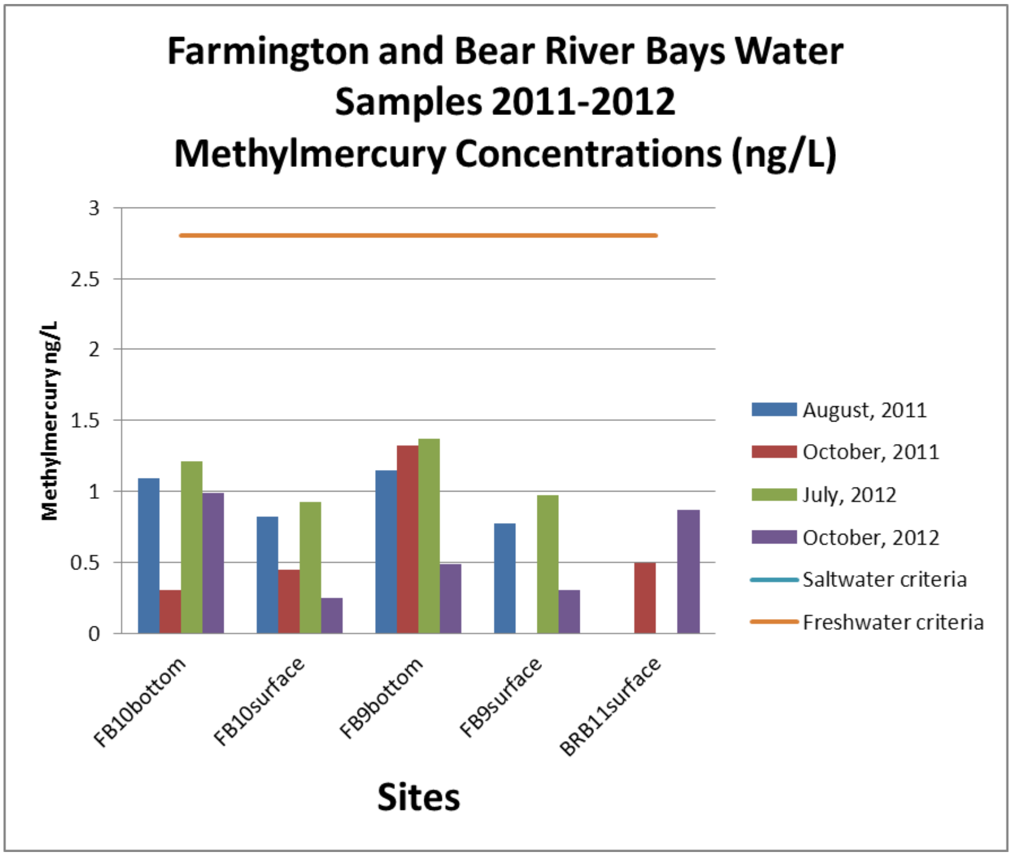

FIGURE 7-26. METHYLMERCURY CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

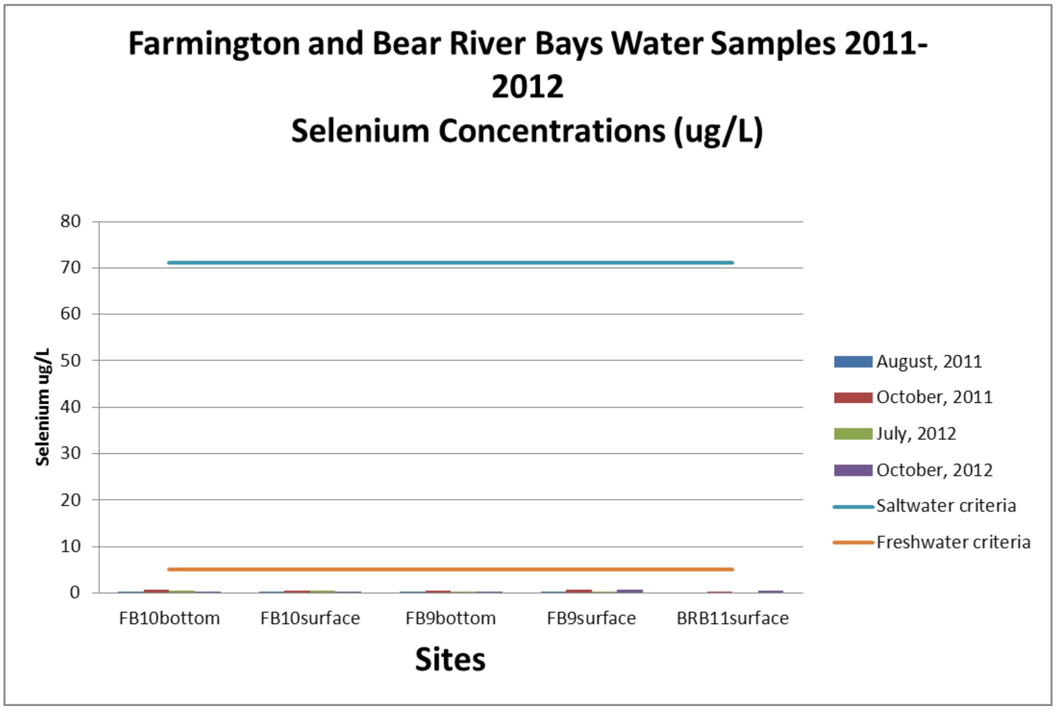

FIGURE 7-27. SELENIUM CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

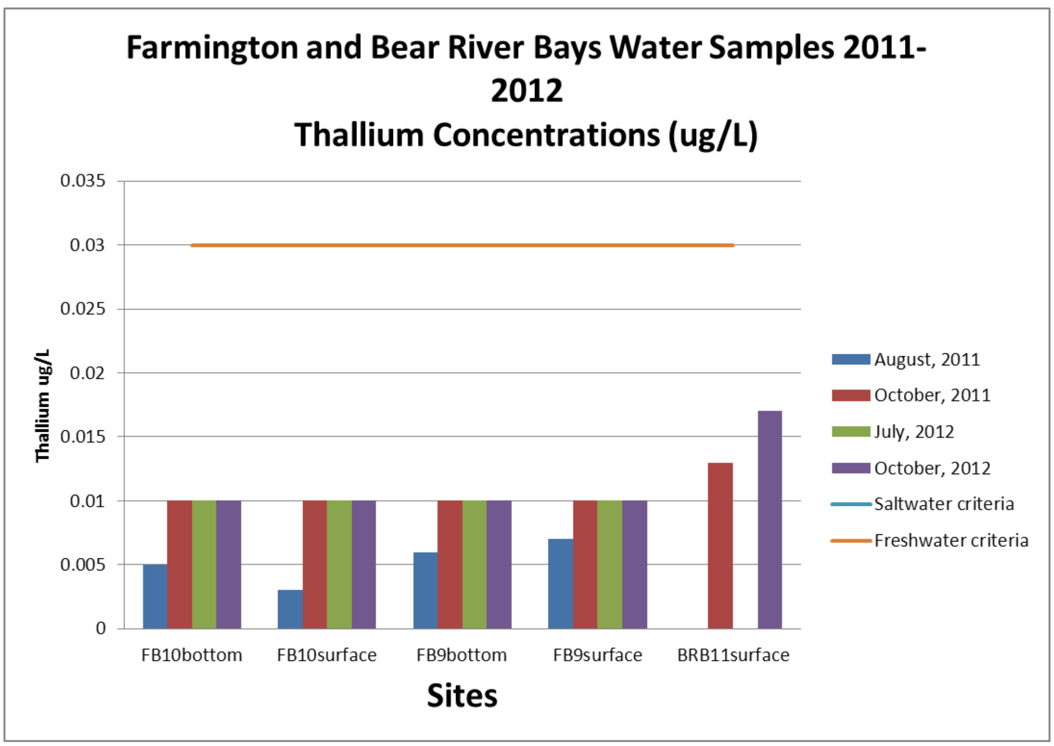

FIGURE 7-28. THALLIUM CONCENTRATIONS AT EACH SITE AND DEPTH (SHALLOW AND BOTTOM) IN FARMINGTON AND BEAR RIVER BAYS.

The average arsenic concentration and standard deviation in Bear River Bay over all sites and depths during the monitoring period was 15.7 ± 3.7 µg/L (range of 13.1 to 18.3 µg/L). The average copper concentration was 1.2 ± 1.2 µg/L (range of 0.368 to 2.050 µg/L). The average total mercury and methylmercury concentrations in Bear River Bay were 2.60 ± 0.90 µg/L (range of 1.93 to 3.20 µg/L) and 0.69 ± 0.26 (range of 0.499 to 0.870 µg/L), respectively. The average cadmium, lead, selenium, and thallium concentrations at Bear River Bay were 0.04 ± 0.02, 0.17 ± 0.03, 0.38 ± 0.27, and 0.02 ± 0.003 µg/L, respectively. None of these values exceed the fresh water or salt water aquatic chronic criteria. As discussed later in the Toxicological Testing and Pollutant Prioritization section, these criteria appear to be more appropriate as benchmarks for screening[4] support of GSL's designated uses.

CLASS 5D FARMINGTON BAY METALS CONCENTRATIONS IN THE WATER COLUMN AND BIOTA

Farmington Bay Metals Concentrations in the Water Column

Table 7-16 shows descriptive statistics of water column concentrations of arsenic, copper, cadmium, lead, total mercury, methylmercury, selenium, and thallium in Farmington Bay during the 2011–2012 monitoring period. Density stratification was present at site FB9 with a 6.3% difference in salinity between the shallow and bottom layers. However, the stratification is due to an intrusion of Gilbert Bay oxic water overlain by fresher Farmington Bay water. The average concentrations of metals at all sites in Farmington Bay did not increase with depth, as occurred in Gilbert Bay.

TABLE 7-16. DESCRIPTIVE STATISTICS OF METALS CONCENTRATIONS AT ALL FARMINGTON BAY SITES (FB9 AND FB10), AT ALL DEPTHS, DURING 2011 AND 2012.

Analyte	Average	Minimum	Maximum	Standard Deviation	Count	Fresh Water Aquatic Criteria	Salt Water Aquatic Criteria
Arsenic (ug/L)	32.431	18.400	48.200	8.780	16	150.00	36.00
Cadmium (ug/L)	0.015	0.006	0.025	0.007	16	0.760	8.800
Copper (ug/L)	1.734	0.467	5.400	1.229	16	30.50	3.100
Total mercury (ng/L)	4.590	2.250	13.400	2.532	16	12.00	940.00
Methylmercury (ng/L)	0.829	0.251	1.370	0.383	15	2.80[1]	NA
Lead (ug/L)	0.726	0.133	1.550	0.446	16	18.60	8.10
Selenium (ug/L)	0.414	0.235	0.608	0.112	16	4.60	71.00
Thallium (ug/L)	0.009	0.003	0.010	0.002	16	0.03[2]	17.00[2]

Notes:
1: Los Alamos National Laboratory, 2009 Tier II value for protection of aquatic life communities
2. ANZECC & ARMCANZ, 2000
3. NA = Not available or applicable

[4] Numeric criteria are legally enforceable. Benchmarks are surrogates for numeric criteria and are typically based on an incomplete toxicological characterization. The benchmarks used in this report are intended to more likely overestimate the potential for adverse effects than underestimate.

The average arsenic concentration in Farmington Bay over all sites and depths during the monitoring period was 32.4 ± 8.8 µg/L (range of 18.4 to 48.2 µg/L). Five out of 16 (31%) measurements exceeded the salt water criterion of 36 µg/L (see Figure 7-21). None of the arsenic samples exceeded the fresh water criterion.

The average copper concentration in Farmington Bay over all sites and depths during the monitoring period was 1.7 ± 1.2 µg/L (range of 0.467 to 5.400 µg/L). Of all measurements taken at Farmington Bay (16 total), only one—at site FB9surface in July 2011—exceeded the copper salt water criterion (see Figure 7-23), and none exceeded the fresh water criterion.

The average mercury concentration in Farmington Bay over all sites and depths during the monitoring period was 4.6 ± 2.5 ng/L (range of 2.25 to 13.40 ng/L). Of all measurements taken at Farmington Bay (16 total), only one—at site FB9bottom in October 2011—exceeded the total mercury fresh water criterion of 12 ng/L (see Figure 7-25). None exceeded the methylmercury fresh water benchmark for aquatic life (see Figure 7-26).

None of the cadmium, lead, selenium, or thallium measurements taken at Farmington Bay exceeded the fresh water or salt water criteria (see Figures 7-22, 7-24, 7-27, and 7-28).

Farmington Bay Selenium and Mercury Concentrations in Biota

In June 2011, five avian eggs were opportunistically collected from the Farmington Bay Wildlife Management Area (Cavitt and Wilson, 2011). These samples were analyzed for selenium and mercury concentrations (see Tables 7-13 and 7-14, respectively). The geometric mean selenium concentration was 2.50 ± 0.21 mg/kg dw (range of 2.28 to 2.83). Using the 12.5 mg/kg dw egg selenium standard set for Gilbert Bay as a benchmark, Farmington Bay selenium egg concentrations appear to be supporting the aquatic life uses. The mean mercury egg concentration was 0.33 ± 0.08 mg/kg ww (range of 0.21 to 0.42), which is considered low risk according to Evers et al. (2004) risk ranges for mercury egg concentrations that would indicate risk to avian wildlife.

Nutrient Concentrations

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 GSL are very different than in most waterbodies. Among other complications, the potential effects of nutrient enrichment on the aquatic life uses vary among the lake's bays. The hydrologic modifications of dikes and causeways restrict circulation from Farmington Bay to Gilbert Bay, potentially resulting in higher concentrations of nutrients in Farmington Bay and lower concentrations in Gilbert Bay. Another difficulty with assessing eutrophication effects is that special methods are required for nutrient analysis under hypersaline conditions. For instance, the USGS National Water Quality Laboratory performed an audit on the ammonia method in late 2012 and found that the results were not reproducible. In 2013, the laboratory used a new modified method for detecting ammonia. Ammonia data prior to 2013 are unusable and are not reported here.

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 and 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 two or three times per year from April to October (Belovsky et al., 2011). 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 (Belovsky et al., 2011).

In the fresher Farmington Bay, algal blooms occur most years, which leads to low DO levels as the algae decompose (Wurtsbaugh et al., 2012). Another concern with these blooms, which is currently under investigation, is whether the blooms are dominated by potentially toxic cyanobacteria[5]. High nutrient concentrations are partially responsible for these algal blooms, but the blooms are also known to be exacerbated by invertebrate-mediated trophic cascades. In areas of Farmington Bay with low salinity, predaceous bugs (*Tricorixa* sp.) can be found in extremely high concentrations. These bugs consume grazers, which in turn leads to increases in algae production (Wurtsbaugh, 1991). Algal productivity in Farmington Bay suggests an excess of nutrients, but Farmington Bay may be the delivery mechanism of vital nutrients to Gilbert Bay that support the algae, brine shrimp, brine flies, and birds in Gilbert Bay. Gilbert Bay primary and secondary productivity is nitrogen-limited in the warmer months (Belovsky et al., 2011). Further research regarding nutrient cycling between Farmington Bay and Gilbert Bay is needed to evaluate use support with regards to nutrients.

CLASS 5A GILBERT BAY NUTRIENT CONCENTRATIONS IN THE WATER COLUMN

In Gilbert Bay, there is a large difference in nutrient concentrations between the shallow layer and the deep brine layer, suggesting two pools of nutrients. The average dissolved phosphorus concentration in Gilbert Bay over all sites and depths during the monitoring period was 0.31 ± 0.28 mg/L (range of 0.05 to 1.61 mg/L) (Table 7-17). Average concentrations of dissolved (filtered) phosphorus in the shallow and deep brine layers were 0.18 ± 0.04 mg/L and 0.72 ± 0.12 mg/L, respectively (Figures 7-29 and Tables 7-18 and 7-19). On average, bay-wide, over all depths, 70% of total phosphorous is in the dissolved form. The average dissolved (filtered) nitrogen concentration in Gilbert Bay over all sites and depths during the monitoring period was 3.70 ± 1.62 mg/L (range of 2.53 to 9.07 mg/L). Concentrations of dissolved nitrogen in the shallow and deep brine layers averaged 2.90 ± 0.18 mg/L and 6.80 ± 1.28 mg/L, respectively (Figures 7-30). On average, bay-wide, over all depths, 91% of total nitrogen is dissolved. A total nitrogen to total phosphorous Redfield ratio (Redfield, 1934) equal to 1:9 supports the notion that Gilbert Bay is nitrogen-limited, as reported by Belovsky et al. (2011).

TABLE 7-17. DESCRIPTIVE STATISTICS OF NUTRIENT CONCENTRATIONS AT ALL GILBERT BAY SITES (GIL1–GIL8) AT ALL DEPTHS DURING 2011 AND 2012.

Nutrients	Average	Minimum	Maximum	Standard Deviation	Count
Phosphorous, unfiltered (mg/L)	0.431	0.189	2.95	0.460	64
Phosphorous, filtered (mg/L)	0.305	0.048	1.610	0.275	64
Total nitrogen, unfiltered (mg/L)	3.935	2.490	10.900	2.230	64
Total nitrogen, filtered (mg/L)	3.652	2.53	9.07	1.621	64
Chlorophyll *a* (ug/L)	11.780	0.004	128	21.876	64

[5] Intensive research on Farmington Bay nutrients, algal densities, speciation, and cyanobacteria was conducted in 2013 with anticipated results available by the next reporting cycle.

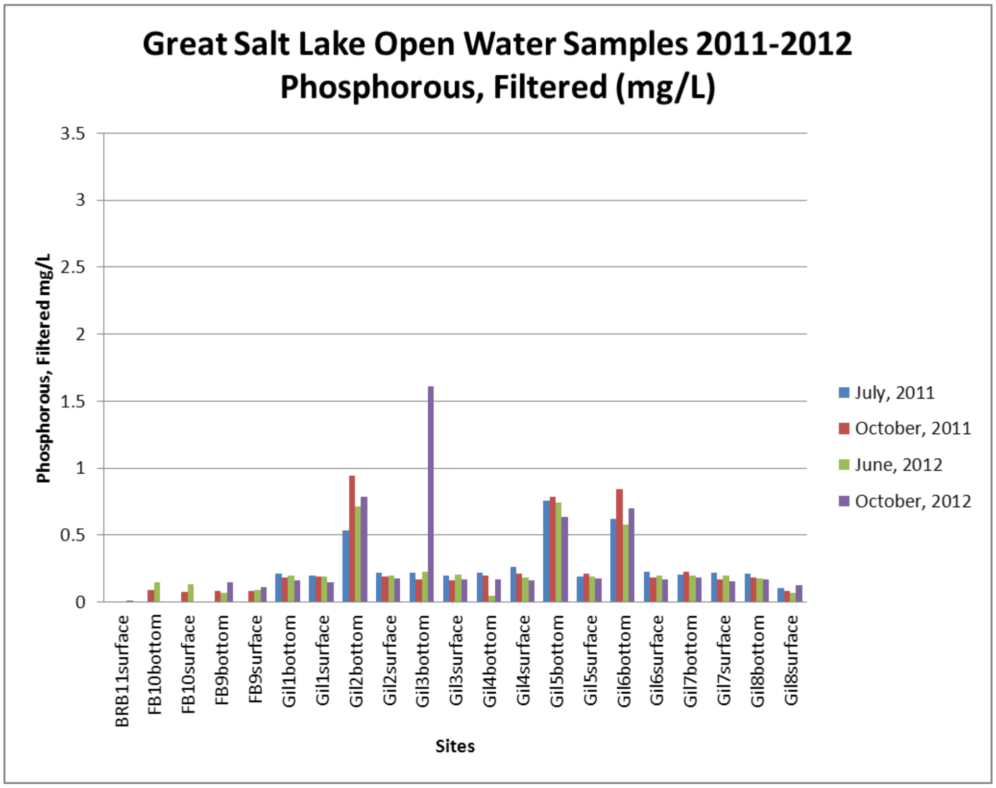

FIGURE 7-29. FILTERED PHOSPHORUS AT THE SURFACE AND BOTTOM OF THE WATER COLUMN AT EACH SITE IN GILBERT, FARMINGTON, AND BEAR RIVER BAYS.

TABLE 7-18. DESCRIPTIVE STATISTICS OF NUTRIENT CONCENTRATIONS AT ALL GILBERT BAY SITES (GIL 1 – GIL8) IN SURFACE WATER SAMPLES DURING 2011 AND 2012.

Nutrients	Average	Minimum	Maximum	Standard Deviation	Count
Phosphorous, unfiltered (mg/L)	0.239	0.189	0.342	0.039	32
Phosphorous, filtered (mg/L)	0.179	0.070	0.259	0.039	32
Total nitrogen, unfiltered (mg/L)	3.045	2.500	4.600	0.479	32
Total nitrogen, filtered (mg/L)	2.900	2.530	3.330	0.181	32
Chlorophyll *a* (ug/L)	11.740	0.004	128.000	27.855	32

TABLE 7-19. DESCRIPTIVE STATISTICS OF NUTRIENT CONCENTRATIONS AT ALL GILBERT BAY SITES (GIL 1 – GIL8) IN THE DEEP BRINE LAYER DURING 2011 AND 2012.

Nutrients	Average	Minimum	Maximum	Standard Deviation	Count
Phosphorous - unfiltered (mg/L)	1.041	0.632	1.460	0.226	12
Phosphorous - filtered (mg/L)	0.719	0.536	0.940	0.115	12
Total Nitrogen - unfiltered (mg/L)	8.002	4.090	10.900	2.343	12
Total Nitrogen - filtered (mg/L)	6.793	4.310	9.070	1.279	12
Chlorophyll a (ug/L)	43.297	0.025	134.000	36.175	15

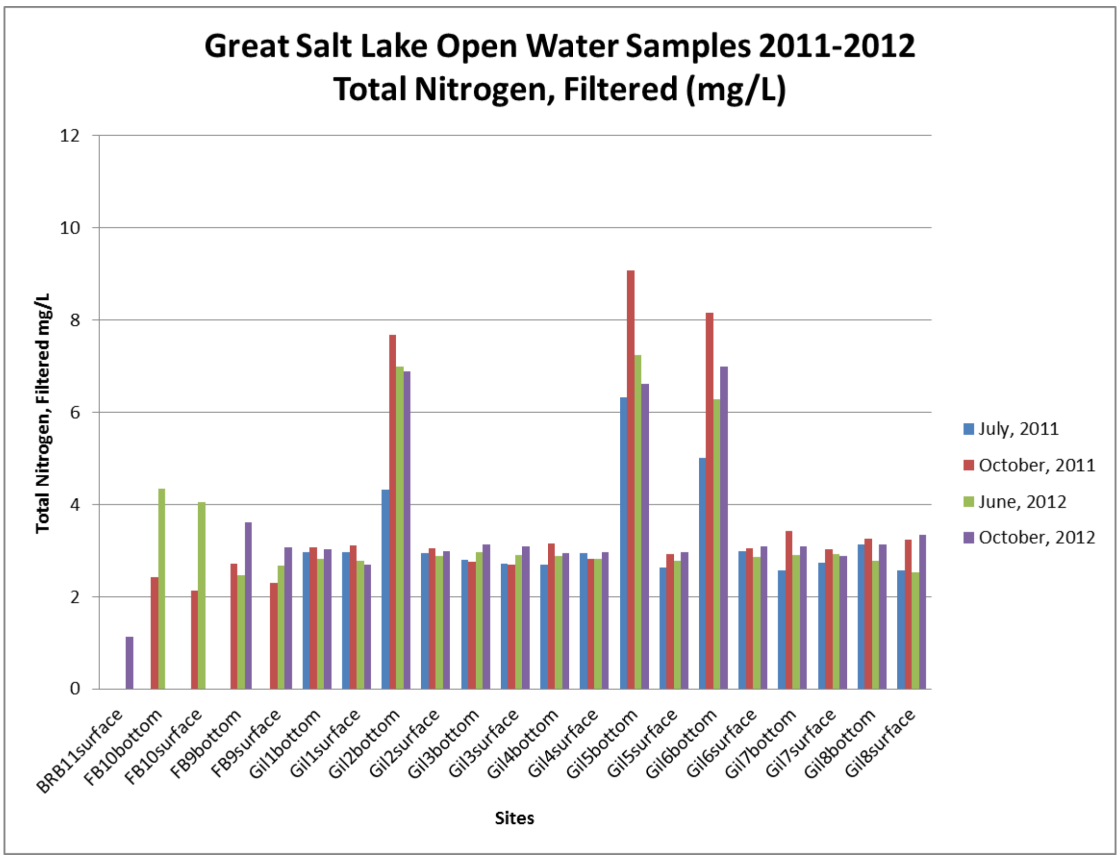

FIGURE 7-30. FILTERED TOTAL NITROGEN AT THE SURFACE AND BOTTOM OF THE WATER COLUMN AT EACH SITE IN GILBERT, FARMINGTON, AND BEAR RIVER BAYS.

Chlorophyll *a* concentrations are a surrogate measure of algal productivity and represent the amount of photosynthesizing algae in the water column. The average chlorophyll *a* concentration in Gilbert Bay over all sites and depths during the monitoring period was 11.8 ± 21.9 µg/L (range of 0.004 to 128.000 µg/L). The boom and bust cycle for algae in Gilbert Bay is reflected in the highly variable chlorophyll *a* concentrations. Concentrations of chlorophyll *a* in the shallow and deep brine layers averaged 11.7 ± 27.9 µg/L, and 43.3 ± 36.2 µg/L, respectively. The greatest concentrations of chlorophyll *a* occurred at site Gil8 located in the culvert between Farmington and Bear River Bays (Figure 7-31). The average chlorophyll *a* concentration at this site was 40.3 µg/L (range of 1.02 to 128.00 µg/L).

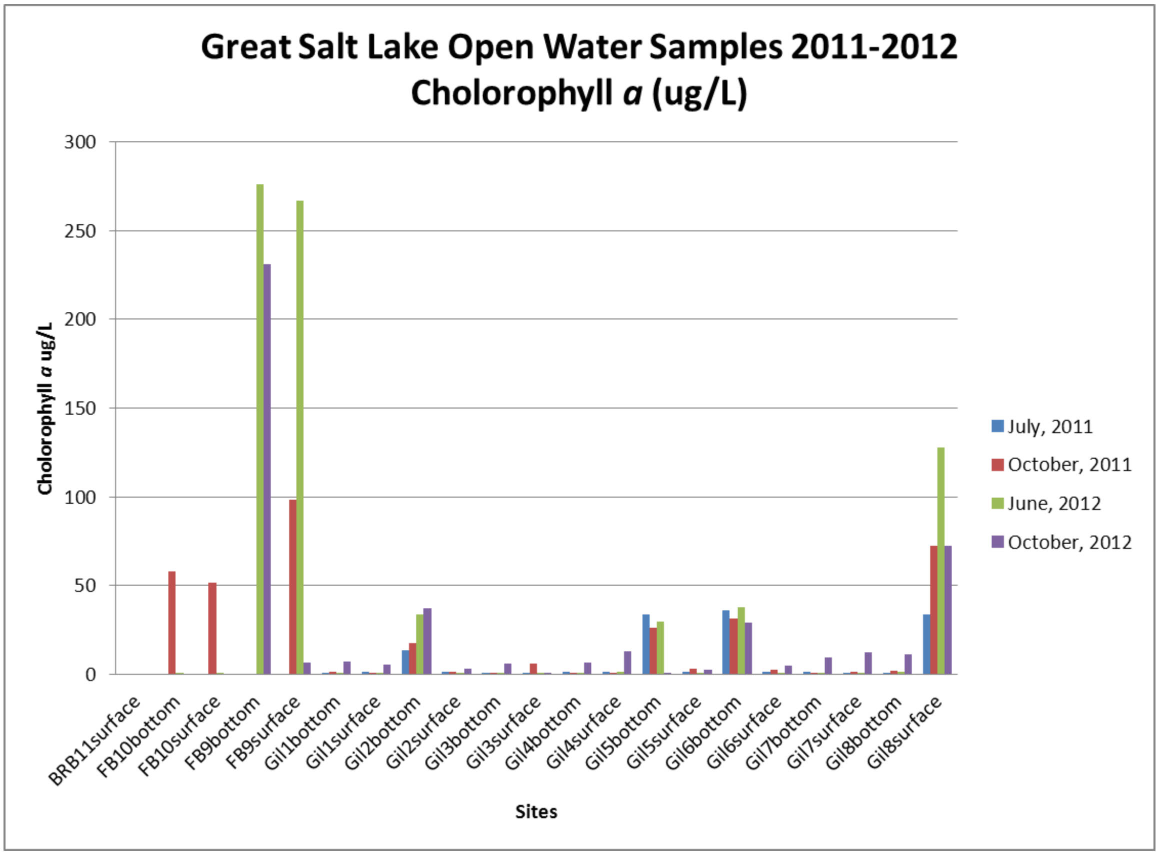

FIGURE 7-31. CHLOROPHYLL A AT THE SURFACE AND BOTTOM OF THE WATER COLUMN AT EACH SITE IN GILBERT, FARMINGTON, AND BEAR RIVER BAYS.

CLASS 5B BEAR RIVER BAY NUTRIENT CONCENTRATIONS IN THE WATER COLUMN

Only one usable sample of dissolved phosphorous and dissolved nitrogen was obtained for Bear River Bay during the 2011–2012 monitoring period. In October 2012, the dissolved phosphorous and dissolved nitrogen concentrations were 0.01 mg/L and 1.10 mg/L, respectively.

CLASS 5C FARMINGTON BAY NUTRIENT CONCENTRATIONS IN THE WATER COLUMN

The average dissolved phosphorus concentration in Farmington Bay over all sites and depths during the monitoring period was 0.10 mg/L ± 0.03 (range of 0.07 to 0.15 mg/L) (Table 7-20). The average dissolved nitrogen concentration in Farmington Bay over all sites and depths during the monitoring period was 3.00 ±

0.77 mg/L (range of 2.1 to 4.3 mg/L) (see Figures 7-29 through 7-31). The Redfield ratio (Redfield, 1934) of total nitrogen to total phosphorous was 11.2, suggesting that Farmington Bay is probably nitrogen limited but can sometimes be phosphorous limited.

TABLE 7-20. DESCRIPTIVE STATISTICS OF NUTRIENT CONCENTRATIONS AT ALL FARMINGTON BAY SITES (FB9 AND FB10) AT ALL DEPTHS DURING 2011 AND 2012.

Nutrients	Average	Minimum	Maximum	Standard Deviation	Count
Phosphorous, unfiltered (mg/L)	0.481	0.309	1.290	0.2930	10
Phosphorous, filtered (mg/L)	0.102	0.071	0.147	0.0304	10
Total nitrogen, unfiltered (mg/L)	5.375	4.410	6.690	0.8520	10
Total nitrogen, filtered (mg/L)	2.972	2.120	4.340	0.7710	10
Chlorophyll *a* (ug/L)	109.882	0.114	276.000	116.1450	9

The highest measured concentrations of chlorophyll *a* occurred at the Farmington Bay sites. The average chlorophyll *a* concentrations at these sites were 175.8 µg/L at FB9 (range of 6.65 to 276.00 µg/L) and 27.5 µg/L (range 0.114 to 57.700 µg/L) at FB10 (see Figure 7-31). According to Carlson's Trophic State Index, when chlorophyll *a* concentrations are greater than 56.0, the waterbody is classified as hypereutrophic, meaning it is a nutrient-rich lake with frequent algal blooms that can lead to low DO levels (Wurtsbaugh et al., 2012; Carlson 1977). Carlson's Trophic State Index may or may not be appropriate to Farmington Bay because it is a model of the biological productivity of a fresh water lake. In addition, Carlson (1977) specifically states that the method is used to describe the biological productivity of a waterbody and is not meant to rate a lake's water quality because of other mitigating site-specific factors (e.g., salinity or pH). At site FB10 in October 2011, salinity was 1.65% with an average chlorophyll *a* of 54.8 µg/L. The following June when salinity increased to 6.60%, the average chlorophyll *a* concentration decreased to 0.15 µg/L. Although salinity may influence phytoplankton, the observed relationship is probably more attributable to predation on phytoplankton grazers (Wurtsbaugh, 1991).

DEVELOPING NUMERIC CRITERIA FOR GREAT SALT LAKE

Background and Purpose

As outlined in Core Component 1of the 2012 Strategy, DWQ has developed a process to derive numeric criteria for all EPA priority pollutants[6] where existing data suggest a potential that pollutants may adversely affect GSL's designated uses, as determined in accordance with the requirements of 40 CFR 131.11(2). The critical initial step in prioritization and criteria development is identifying the composition and abundance of the expected biological organisms within each of the three salinity classes: hypersaline, marine, and fresh water. Next, DWQ will compile a comprehensive review of previously conducted toxicity studies for each pollutant and GSL-relevant species to supplement the data compiled for prioritizing the pollutants. The toxicity data will be reviewed to determine if biota in upper trophic levels (e.g., birds) are more sensitive to a given pollutant than biota in lower trophic levels (e.g., brine shrimp). If birds are more sensitive, then the criterion

[6] http://www.epa.gov/region1/npdes/permits/generic/prioritypollutants.pdf

will be based on protecting birds. Otherwise, a criterion based on other aquatic life in the bird's necessary food chain will be the goal. If the outcome of this determination is uncertain, then both tissue- and water-based criteria will be developed for both birds and aquatic organisms, respectively. The most protective of these criteria will be recommended for adoption as a numeric criterion for each salinity class.

For biomagnifying pollutants (e.g., mercury) that increase in concentration higher in the food web, the direct toxicity experienced by aquatic life in the water column may not reflect risk posed to species at higher trophic levels. Biomagnifying pollutants such as mercury will initially be tested for acute toxicity to brine shrimp and brine flies to confirm that biota in upper trophic levels (birds) are more sensitive than biota in the lower trophic levels.

Species List

For developing numeric criteria for GSL, an initial step is identifying the specific organisms in each bay that are currently present and those that would be considered "existing uses,"[7] meaning they were present on or after November 28, 1975. This list will define the specific aquatic and aquatic-dependent species relevant for each bay of GSL that must be protected. In addition, this list of species will help evaluate the extent to which EPA or Utah criteria are appropriate to GSL and where modifications to the available criteria are necessary. In 2011, a preliminary GSL species list was compiled from the literature and includes arthropods, rotifers, protozoans, bacteria, and algae in all the bays of GSL. The list includes the genus and species along with environmental factors that would influence the organisms' growth and reproduction including salinity, temperature, and pH. Once the species list is complete, the next step will be to characterize the life cycle of each organism found within GSL's bays to determine the environmental conditions (e.g., salinity, DO, and temperature) required for survival, growth, and reproduction. From this information, the viability of developing numeric criteria for different salinity classes as proposed in Core Component 1 of the Strategy will be assessed.

Toxicological Testing and Pollutant Prioritization

In accordance with EPA's 1984 *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (EPA 1984) and as outlined in Core Component 1 of the Strategy, toxicological testing is necessary to derive numeric water quality criteria for the protection of the aquatic wildlife designated use. As keystone species of GSL, brine shrimp and brine flies from Gilbert Bay were chosen as the test species for these initial assays. Brine shrimp are easily cultured in the laboratory and have been used as toxicity test organisms. Much less testing has been conducted for brine flies, and toxicity testing with these organisms will require method development. Acute toxicological tests will be performed in the first phase followed by chronic toxicity testing, dependent on resources. Funding for this research was granted to DWQ from the Utah Water Quality Board as a special request from the legislatively appointed Great Salt Lake Advisory Council.

Pollutants were prioritized for brine shrimp and brine fly toxicological testing using the 2011 and 2012 BSP data. The average concentrations of pollutants in the shallow and bottom layers of Gilbert Bay were compared to the EPA numeric water quality chronic criteria for the protection of freshwater and salt water aquatic wildlife or to other sources when available. Pollutants whose concentrations were higher relative to the

[7] http://www.rules.utah.gov/publicat/code/r317/r317-002.htm

comparison criteria were prioritized for testing. Other considerations for prioritization included whether the pollutant was present in point source discharges to GSL, the pollutant's amenability to regulatory controls, and the anticipated sensitivity of birds or aquatic organisms to the pollutant.

Based on these considerations, the pollutants selected for toxicological testing are, in order of priority, arsenic, copper, methylmercury, and lead. The prioritization of ammonia, cadmium, total mercury, selenium, thallium, zinc, and the remaining priority pollutants was deferred (DWQ, 2013).

After the GSL species list is completed, DWQ anticipates using the EPA deletion process as part of the recalculation procedure for deriving site-specific aquatic life numeric criteria for salinities equal to or less than salt water waters (EPA, 1994). For GSL waters with salinity greater than salt water, the criteria are anticipated to be based on GSL-specific species toxicity testing. DWQ expects that GSL will have fewer taxonomic families represented than were used to derive the national fresh water and salt water chronic criteria for protection of aquatic life. If sensitive species included in the derivation of the fresh water and salt water criteria are not present at GSL, application of the EPA's deletion procedure would result in criterion higher than the fresh water criterion. GSL species would have to be more sensitive for the criterion to be more stringent. The available toxicity data for brine shrimp and the limited data for brine flies suggest that these species are relatively tolerant of metals (DWQ, 2013). An exception would be if avian species are more sensitive to a pollutant than the aquatic biota, which was the case with selenium and will likely be the case for pollutants that biomagnify, such as methylmercury. This analysis supports the idea of using existing numeric criteria as screening or benchmark values. If the benchmark values are met, adverse effects to GSL biota are unlikely and the uses are likely supported. If the benchmark values are exceeded, additional data are required to evaluate the potential for adverse effects, and the support status is uncertain.

ASSESSMENTS AND DATA GAPS

Class 5A Gilbert Bay

The concentrations of selenium in Gilbert Bay are supportive of the uses because egg monitoring indicates that egg concentrations are well below the 12.5 mg/kg dw standard. In the absence of numeric criteria for other pollutants, the support status is less definitive. The absence of obvious effects in birds from water pollutants supports a finding that there are no severe impairments[8]. Brine shrimp populations remain vigorous, which also supports a finding that there are no severe impairments. However, these measures do not have a high degree of sensitivity, nor do they represent the complete ecosystem.

The comparison of GSL water concentrations to available aquatic chronic criteria provides another line of evidence. As previously discussed, GSL-specific criteria are unlikely to be more stringent than the fresh water and salt water chronic criteria used for comparison. For the metals assessed, Gilbert Bay water concentrations generally meet fresh water chronic criteria suggesting that the uses are supported by existing pollutant concentrations with the exception of arsenic and copper. The salt water chronic criteria were exceeded in 97% of the samples for arsenic and 17% of the samples for copper, which means that the use support status of these pollutant concentrations is indeterminate. The degree to which either salt water or fresh water chronic

[8] Bird populations at the lake experience high mortality rates during outbreaks of avian botulism or cholera. In 2013, at least 27 bald eagles died due to the West Nile virus.

criteria may be more stringent than necessary to protect the Gilbert Bay biota requires further investigation. The in-progress toxicity testing is specifically intended to address these uncertainties.

Methylmercury, especially in the deep brine layer, remains a focus of investigation. Although the results of the comparisons to salt water and fresh water criteria support a finding that the uses are protected, additional evaluations based on tissue concentrations were conducted because of the propensity of methylmercury to biomagnify and adversely impact higher trophic levels. Based on the currently available data, the elevated methylmercury concentrations appear to be limited to the deep brine layer that does not support higher-level organisms because of hypoxia and salinity. A potential exception is the methylmercury measured in 2004 and 2005 in the breast muscle tissue of the three waterfowl species for which there are human consumption advisories (Utah Department of Health 2005; 2006). These advisories remain in place, but more recent data suggest lower concentrations of methylmercury in waterfowl breast muscle tissue (DWQ, 2010). Reproduction, which is sensitive to the effects of methylmercury, is not threatened based on the limited number of eggs sampled for methylmercury (Cavitt et al., 2010; Cavitt and Wilson, 2011, 2012). In 2010–2012, USGS and the U.S. Fish and Wildlife Service conducted a significant study to assess the risk of mercury and selenium to breeding birds at the Bear River Migratory Bird Refuge. Over 1,000 eggs were collected, 131 of which were collected from GSL outside of the refuge boundaries. DWQ and EPA have funded the mercury and selenium analyses for these 131 eggs to provide a larger sample of eggs necessary to support more definitive use support conclusions.

DATA GAPS

The data gaps identified to assess Gilbert Bay's water quality support of the uses are as follows:

- Toxicity values for Gilbert Bay biota. Although a toxicity evaluation of the complete ecosystem (e.g., algae, brine flies, brine shrimp, and birds) is needed to support the development of numeric criteria, Gilbert Bay–specific toxicity values for individual species can support an impairment determination in the interim if lake concentrations exceed no-effects concentrations.
- Water quality data
- Nutrient budget
- Lake volume, circulation, and bay interconnectivity

Class 5B Gunnison Bay

Few data are available for either the water quality or biota of Gunnison Bay. The aquatic life (primarily halophilic bacteria) is limited by the extreme hypersaline waters (27% saline). DWQ anticipates that Gunnison Bay is a candidate for a use attainability analysis (UAA) if the salinity restricts the aquatic life or recreation designated uses to a condition that would be considered less than the federal Clean Water Act fishable/swimmable goal. Once access issues and additional resources are secured, monitoring will be established for Gunnison Bay to collect data necessary to inform the UAA.

DATA GAPS

The data gaps identified to assess Gunnison Bay's water quality support of the uses are as follows:

- Quality assurance, quality control procedures for hypersaline water with salinity greater than 20%
- Water quality data
- Resident species and life cycle

- Applicable comparison benchmarks or numeric criteria
- Lake volume, circulation, and bay interconnectivity

Class 5C Bear River Bay

For Bear River Bay, none of the metals sampled exceeded the EPA and Utah fresh water and/or salt water aquatic life criteria, suggesting that the uses are likely supported. Bear River Bay is the least saline of the four bays in GSL with historical salinity ranging from 1% to 5% (DWQ, 2010). A greater diversity of aquatic life, including, at times, fish, exists in this bay than in the saltier habitat of the rest of GSL. More information is needed on the conditions that support the biological assemblages of macroinvertebrates, zooplankton, algal communities, and fish to make an aquatic life use support determination. Included with the identification of species is information on their life cycles, including salinity tolerance. Once more water quality data are collected and the species list is completed, DWQ can identify remaining data gaps.

DATA GAPS

The data gaps identified to assess Bear River Bay's water quality support of the uses are as follows:

- Water quality data
- Resident species and life cycle
- Applicable comparison benchmarks or numeric criteria
- Lake volume, circulation, and bay interconnectivity

Class 5D Farmington Bay

For Farmington Bay, cadmium, lead, methylmercury, selenium, and thallium concentrations meet the fresh water and salt water criteria, suggesting that the uses are supported for these metals. Arsenic concentrations meet fresh water comparison criteria, but 16% of the samples exceeded the salt water criteria. Total mercury concentrations were less than the fresh water and salt water comparison criteria, with the exception of one sample that exceeded Utah's human health–based fresh water mercury criterion. Based on these comparisons, Farmington Bay designated uses are likely being supported with the possible exception of arsenic.

Based on Carlson's Trophic State Index, which is a fresh water classification, Farmington Bay is considered hypereutrophic and is characterized by frequent algal blooms that can deplete the DO from the water column (Carlson, 1977). However, Carlson points out that the index is not a conclusion on water quality due to site-specific mitigating factors such as salinity. In addition, although salinity may influence phytoplankton, the observed relationship is probably more attributable to predation on phytoplankton grazers (Wurtsbaugh, 1991). Farmington Bay may be the delivery mechanism of nutrients to downstream Gilbert Bay where the nutrients support algae that are consumed by brine shrimp and brine flies. A portion of these nutrients is ultimately exported from GSL via birds and the harvest of brine shrimp. Evidence suggests that for the last 200 years, Farmington Bay has always been a productive system and that its productivity has increased with anthropogenic development in the watershed (Leavitt et al., 2012). The observed historical increase in productivity appears to be mainly attributable to hydromodification through the construction of the Antelope Island causeway, canals, and dikes, and also, to a lesser extent, to increased influxes of nutrients (Leavitt et al., 2012). Salinity in Farmington Bay is more variable than that of other bays, resulting in an ecosystem that has presumably adapted to this variability. The effects of the nutrient concentrations on this system, whether beneficial or detrimental, have yet to be elucidated, and additional work is needed to characterize this ecosystem before a use support determination can be made. In 2013, synoptic studies were conducted on nutrients, metals, and cyanobacteria. The results of these studies will be reviewed, and remaining data gaps will be identified as part of the ongoing efforts to assess Farmington Bay.

DATA GAPS

The data gaps identified to assess Farmington Bay's water quality support of the uses are as follows:

- Water quality data
- Resident species list
- Cyanobacteria and cyanotoxin data
- Nutrient budget
- Applicable comparison benchmarks or numeric criteria
- Lake volume, circulation, and bay interconnectivity

Class 5E Transitional Waters

The Transitional Waters are from an elevation of approximately 4,208 feet to the open waters of GSL; they include streams, springs, drainage channels, wetlands, playas, mudflats, and alkali knolls. With the exception of impounded wetlands, most of the Transitional Waters are subject to periodic inundation by GSL when it rises.

DWQ's primary focus for assessing the Transitional Waters is the wetlands along the east side of the lake. The assessment of GSL's wetlands is presented in Chapter 4: Wetlands. The shorebird egg data discussed for Gilbert Bay were collected from the Transitional Waters; these data show support for the Gilbert Bay selenium standard and suggest support with regards to mercury concentrations. The 2012 egg sampling from the Transitional Waters that drain to Farmington Bay suggests that selenium concentrations are not impairing the uses in this area, but the support status for mercury concentrations is indeterminate. Other available data include water and sediment results collected from the southwest end of Gilbert Bay as part of a Utah Pollutant Discharge Elimination System permit for the Jordan Valley Water Conservancy District Southwest Groundwater Treatment Plant. The purpose of this monitoring was to ensure the proposed discharge will not adversely impact the Transitional Waters. Egg collection and analysis for establishing baseline conditions are also part of this monitoring, but birds have not nested in the vicinity of the discharge delta recently and no eggs were available.

DATA GAPS

The data gaps identified to assess the Transitional Waters' water quality support of the uses are as follows:

- Water quality data
- Resident species and life cycle
- Applicable comparison benchmarks or numeric criteria

LITERATURE CITED

Adler, R. 1999. Toward comprehensive watershed-based restoration and protection for Great Salt Lake. *Utah Law Review* 1:99–292.

Aldrich, W.T., and S.D. Paul. 2002. Avian Ecology of Great Salt Lake. In *Great Salt Lake: An Overview of Change,* edited by J. Gwynn, pp. 343–374. Utah Division of Natural Resources, Utah Geological Survey.

ANZECC & ARMCANZ. 2000. *An Introduction to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Canberra: Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Belovsky, G.E., D. Stephens, C. Perschon, P. Birdsey, D. Paul, D. Naftz, R. Baskin, C. Larson, C. Mellison, J. Luft, R. Mosley, H. Mahon, J.V. Leeuwen, and D.V. Allen. 2011. The Great Salt Lake Ecosystem (Utah, USA): long term data and a structural equation approach. *Ecosphere* 2(3)1–40.

Bioeconomics. 2012. *Economic Significance of the Great Salt Lake to the State of Utah*. Prepared for the State of Utah Great Salt Lake Advisory Council. Missoula, Montana: Bioeconomics, Inc.

Carlson, R. 1977. A trophic state index for lakes. *Limnology and Salt Waterography 22*(2):361–369.

Cavitt, J.F., and N. Wilson. 2011. *Concentrations of Selenium and Mercury in American Avocet Eggs at Great Salt Lake, Utah*. Ogden, Utah: Weber State University, Avian Ecology Laboratory.

Cavitt, J.F., J. Hall, L. Swenson, and N. Wilson. 2012. *Selenium and Mercury Concentrations of Shorebird Eggs at Great Salt Lake, Utah*. Ogden, Utah: Weber State University, Avian Ecology Laboratory.

Cavitt, J.F., M. Linford, and N. Wilson. 2010. *Selenium Concentrations in Shorebird Eggs at Great Salt Lake, Utah*. Ogden, Utah: Weber State University, Avian Ecology Laboratory.

Darnall, N.L., and A.K. Miles. 2009. Dynamics of mercury in eared grebes on Great Salt Lake. In *Saline Lakes around the world: unique systems with unique values. XV,* edited by A. Oren, D. Naftz, P. Palacios, and W. Wurtsbaugh. Logan, Utah: S.G. and Jessie E. Quinney Natural Research Library.

DWQ. 2007. *Development of a Selenium Standard for the Open Waters of the Great Salt Lake*. Utah Department of Environmental Quality. Salt Lake City, Utah: CH2M HILL.

———. 2010. *Utah 2010 Integrated Report:305(b) Assessment*. Salt Lake City : Utah Department of Environmental Quality.

———. 2011. *Ecosystem Assessment of Mercury in the Great Salt Lake, Utah 2008*. Salt Lake City: Utah Department of Environmental Quality.

———. 2012. *A Great Salt Lake Strategy*. Available at: **http://www.deq.utah.gov/locations/G/greatsaltlake/gslstrategy/docs/2014/04Apr/GreatSaltLakeWaterQualityStrategy040912v8jg.pdf**. Accessed September 19, 2014.

———. 2013. *Review Draft, Prioritization of Brine Shrimp and Brine Fly Bioassay Test Pollutants from Gilbert Bay, Great Salt Lake*. Salt Lake City: Utah Department of Environmental Quality.

———. 2014a. *Data Validation Report for the 2011-12 Great Salt Lake Baseline Sampling Plan Metals Data*. Salt Lake City: Utah Department of Environmental Quality.

———. 2014b. *Quality Assurance Project Plan for the Great Salt Lake Baseline Sampling Plan*. Salt Lake City: Utah Department of Environmental Quality.

EPA. 1984. *Guidelines for Deriving Numerical Aquatic Site-Specific Water Quality Criteria by Modifying National Criteria*. Springfield, Virginia: National Technical Information service.

———. 1994. Appendix L. Interim Guidance on Determination and Use of Water-Effect Rations for Metals. In *Water Quality Standards Handbook*, Second Edition. Available at: http://water.epa.gov/scitech/swguidance/standards/handbook/. Accessed September 18, 2014.

Evers, D.C., O. Lane, L. Savoy, and W. Goodale. 2004. *Assessing the impacts of methylmercury on piscivorous wildlife using a wildlife criterion value based on the common loon 1998-2003*. Report BRI2004-2005. Gorham, Maine: Biodiversity Research Institute.

Great Salt Lake Advisory Council. 2012. *Definition and Assessment of Great Salt Lake Health*. Prepared by SWCA Environmental Consultants and Applied Conservation.

Gwynn, J.W. (ed.). 2002. *Great Salt Lake: An Overview of Change*. Utah Department of Natural Resources, Utah Geological Survey.

Los Alamos National Laboratory. 2009. *Ecorisk Database (Release 2.4)* on CD.

Leavitt, P., L. Bunting, K. Moser, and C. Woodward. 2012. *Effects of Wastewater influx and hydrologic modification on algal production in the Great Salt Lake, UT*. Final report to DWQ.

Naftz, D., C. Angeroth, T. Kenney, B. Waddell, N. Darnall, S. Silva, S., C. Perschon, and J. Whitehead. 2008. Anthropogenic influences on the input and biogeochemical cycling of nutrients and mercury in Great Salt Lake, Utah, USA. *Applied Geochemistry* 1731–1744.

Naftz, D., B. Waddell, and D. Krabbenhoft. 2005. Mercury in air, water and biota from Great Salt Lake, UT: Reconnaissance phase results: Hg in deep brine layer. Poster presented at the American Society of Limnology and Oceanography meeting.

Redfield, A.C. 1934. On the proportions of organic derivations in sea water and their relation to the composition of plankton. In *James Johnstone Memorial Volume*, edited by R.J. Daniel, pp. 172–192. Liverpool, United Kingdom: University Press of Liverpool.

Utah Department of Health. 2005. *An Evaluation of Mercury Concentrations in Ducks from the Great Salt Lake Utah for 2004 and 2005*. Salt Lake City, Utah: Environmental Epidemiology Program, Utah Department of Health.

———. 2006. *An Evaluation of Mercury Concentrations in Ducks from the Great Salt Lake Utah for 2005-2006*. Salt Lake City, Utah: Environmental Epidemiology Program, Utah Department of Health.

Utah Division of Forestry, Fire and State Lands. 2013. *Final Great Salt Lake Comprehensive Management Plan and Record of Decision*. Salt Lake City Utah: Utah Department of Natural Resources, Division of Forestry, Fire and State Lands.

Utah Waterfowl Advisories. 2014. Utah Waterfowl Advisories website. Available at: http://www.waterfowladvisories.utah.gov/. Accessed September 19, 2014.

USGS. 2014. *Surface Water Monthly Statistics for Utah*. National Water Information System.

Vest, J.L., M.R. Conover, C.P. Perschon, J. Luft, and J.O. Hall. 2008. Trace Element Concentrations in Wintering Waterfowl from the Great Salt Lake, Utah. *Environmental Contamination and Toxicology*.

Weiner, K.D., and G. Heinz, G. 2003. Ecotoxicology of Mercury. In *Handbook of Ecotoxicology* (2nd ed.), edited by D. Hoffman. CRC Press.

Wurtsbaugh, W.A. 1991. Food-web modification by an invertebrate predator in the Great Salt Lake. *Oecologia* 168–175.

Wurtsbaugh, W., A. Marcarelli, and G. Boyer. 2012. *Eutrophication and Metal Concentrations in Three Bays of the Great Salt Lake*. Final Report to the Utah Division of Water Quality.