CHAPTER 7 GREAT SALT LAKE

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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 is well documented (Adler, 1999; Gwynn, 2002; Aldrich and Paul, 2002; Bioeconomics, 2012; SWCA, 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) bird tissue based on the complete egg/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 its associated food web further complicate the assessment efforts.

Utah's (freshwater) lakes 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. Utah's freshwater lakes and reservoirs can be assessed using methods developed for temperate lakes outside of Utah. No other lake in the world is comparable to GSL and therefore, assessment methods have to be created.

To develop the appropriate assessment methods to begin addressing these data gaps, the Utah Division of Water Quality (UDWQ) launched the *Great Salt Lake Water Quality Strategy* (hereafter Strategy) in 2012 that defines a comprehensive water quality approach for protecting GSL's recreation and aquatic wildlife designated uses (see http://www.deq.utah.gov/locations/G/greatsaltlake/strategy/index.htm). The Strategy defines a process to fill critical knowledge gaps, improve the precision and clarity of UDWQ's water quality management decisions, reduce regulatory uncertainty for regulated entities, and improve all partners' capacity to be stewards of lake water quality.

The Strategy contains 5 core components:

1. Numeric Water Quality Criteria Development
2. Strategic Monitoring and Research
3. Wetland Program Plan
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 (Core Component 2: Strategic Monitoring and Research)
- Development of a species list, prioritization of pollutants, and a work plan for toxicological testing (Core Component 1: Numeric Water Quality Criteria Development)
- 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 *Great Salt Lake Baseline Sampling Plan (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. Since there are only 2 years of quality assured data and the development of numeric criteria and/or the review of benchmarks is ongoing, this chapter of the *Integrated Report* 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 Integrated Reports and research carried out for UDWQ is incorporated by reference.

For the 2010 305(b) *Integrated Report* (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 both state law (UAC R317) and federal Clean Water Act (CWA) authority, UDWQ is entrusted with the responsibility to restore and maintain 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 (UAC R317-2-6) 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 the GSL's four major bays and the immediately adjacent wetlands. The designated uses assigned to all 5 classes (UAC R317-2-6.5) include 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):

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

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 haven't 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 UDWQ to employ a comprehensive approach to protecting GSL water quality. As outlined in the Strategy, UDWQ 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, UDWQ will continue to monitor and report pollutant concentrations in GSL's water, brine shrimp, and aquatic dependent bird 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*, UDWQ began routine targeted monitoring in 2011, following the direction of the Great Salt Lake Baseline Sampling Plan (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 environmental data collected are precise, accurate, representative, complete, and comparable for saline water (UDWQ, 2014). 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 the last several years of data 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 use of the data by UDWQ includes:

- Screening and refining the list of potential pollutants of concern in GSL and prioritizing pollutants for toxicological testing of key aquatic organisms, 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 305 (b) *Integrated Report*.
- 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 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 UDWQ from EPA's list of 126 "priority pollutants" (40 Code of Federal Regulations (CFR) Part 423 Appendix A) based on the perceived threat to GSL's designated uses and available funding for laboratory analyses allotted for the BSP. Table 2 lists the month/year and targeted bay, the media sampled (water, brine shrimp or bird egg) over the 2011-12 monitoring period.

In 2011 and 2012, water quality samples were collected in June and October at 11 sites in the open waters of GSL: 8 in Gilbert Bay, 2 in Farmington Bay and 1 in Bear River Bay (Figure 1 and Table 3). Gunnison Bay was not included due to access constraints and insufficient funding. Once these issues are resolved, UDWQ plans to incorporate routine monitoring of at least 2 sites in Gunnison Bay.

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 meters (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 a meter, 1 sample at the surface was taken. Field measurements documenting the temperature, pH, specific conductivity, dissolved oxygen, 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.

USGS Utah Water Science Center personnel collected the Gilbert Bay samples, Davis County Health Department personnel collected the Farmington Bay samples and UDWQ 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 obtain accurate readings. In 2012, the original site was moved north, but there wasn't enough water to sample in June. As a result, only 2 water column samples are available over both years.

The eggs of American avocets and/or black-necked stilts foraging along the shoreline of Gilbert Bay were sampled once per year in 2010, 2011, and 2012 per the Standard Operating Procedures. 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 its quality and usage against the acceptance and performance criteria set forth in the QAPP (UDWQ, 2014). 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 because the methylmercury concentration was greater than the total mercury concentration even though all QC 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 NWIS mapper at http://wdr.water.usgs.gov/nwisgmap/index.html. All the metals data resides with UDWQ in the Great Salt Lake Water Quality database and are available upon request.

Results and Discussion

Salinity, chemical stratification, and its effects on metal and metalloid concentrations

Each bay of Great Salt Lake has a distinct difference in salinity as was exhibited in both 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 that was much fresher at 4.1% (Figure 2 and Table 4). Bear River Bay is the least saline of the bays averaging 1 to 5% (UDWQ, 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) on October 2012, which equates to a salinity of approximately 0.05% which is freshwater (seawater 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, there was unseasonably warm weather that resulted in rapid significant snowmelt in the Wasatch Mountains. As a result, the elevation of Gilbert Bay rose 4 feet (elevation of 4195' to 4198') 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-NWIS, 2014). This unusually large freshwater input likely accounts for the lower salinity observed in 2011 when compared to 2012.

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 more dense water from Gunnison Bay (27% saline) is transported to Gilbert Bay and sinks to the bottom of the water column. From October 2011 to 2012, a deep brine layer was present at sites Gil2, Gil5 and Gil6. Overall, the average salinity in the shallow layer at these sites was 11.8% as compared to 18.2% in the deep brine

The deep brine layer has little to no oxygen (hypoxic and anoxic, respectively) which can lead to a lower redox potential than oxic waters which increases the solubility of some metals. As a result, the concentrations of arsenic, lead, copper, total mercury, and 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 creates conditions that are inhospitable to brine shrimp and brine flies, which reduces their direct exposure to the higher pollutant concentrations. However, exposure is not entirely eliminated because some mixing of the deep brine layer with the overlying oxic layer occurs (Belovsky et al., 2011).

Density stratification was also present at site Gil8 located at the culvert between Gilbert and Farmington Bay that showed an average 7% difference in salinity and in Farmington Bay at site FB9 with a 6.3% difference in salinity. The stratification at these sites is due to denser oxic Gilbert Bay water overlain by fresher Farmington Bay water. Density stratification at FB10 was not present.

Temperature, pH and Dissolved Oxygen

Over the 2011-12 monitoring period, the average temperature, pH and dissolved oxygen over all sites and depths in Gilbert Bay was 17.7°C, 8.2 and 6.2 milligrams per liter (mg/L), respectively (Figures 3, 4, and 5 and Tables 5, 6 and 7). Overall, Farmington Bay was cooler (15.6°C) more basic (pH 9.1) and was lower in water column dissolved oxygen (5.2 mg/L) than Gilbert Bay. On October 5, 2012 temperature and pH in Bear River Bay were 13.6°C and 8.8, respectively. 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 dissolved oxygen concentration of 0.5 mg/L. In Farmington Bay at site FB9, density stratification was present in October 2011 and June 2012, however, average dissolved oxygen levels did not decrease from the surface to the bottom of the water column as was seen in Gilbert Bay.

Metal and Metalloid (Metals) Concentrations

The effects of metals in water on aquatic organisms can range from necessary and beneficial to toxic, depending on the metal and the concentration. In addition, the salinity of the water can affect how metals behave (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 upper, more oxygenated layer of Gilbert Bay where aquatic organisms reside.

For each metal, the water column data were summarized with descriptive statistics and were compared to the Utah numeric water quality chronic criteria for the protection of freshwater[1] and Environmental Protection Agency (EPA) chronic criteria for the protection of ocean aquatic life[2]. However, these criteria were not developed for the aquatic life of GSL, nor are they applicable as regulatory criteria. 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 GSL. Instead, the Utah and EPA criteria 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, they may be overly protective for some segments and may not be suitable for the determination of designated use support, especially when salinities are greater than 3.5%.

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

For the hardness dependent metals (arsenic, cadmium, copper and lead), the fresh water chronic criteria 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 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.

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

Gilbert Bay metals concentrations in the water column

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

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

Table 9 shows descriptive statistics for water column concentrations of arsenic, copper, cadmium, lead, total mercury, methylmercury, selenium and thallium in Gilbert Bay over the 2011–12 monitoring period over all sites and depths. In addition, descriptive statistics are provided for the surface water samples in Table 10 and in the deep brine layer (sites Gil2bottom, Gil5bottom and Gil6bottom) in Table 11. The average concentrations of metals in Gilbert Bay generally increased in concentration from the shallow layer to the deep brine sites.

The average and standard deviation of arsenic concentrations in Gilbert Bay over all sites/depths over the monitoring period was 77.9 ± 25.7 ug/L (range from 27.9 to 157 ug/l). Arsenic concentrations doubled in the deep brine sites where the average arsenic concentration in the shallow layer was 67.1± 20.8 ug/L (range of 27.9 to 100 ug/L) increasing to 113.4 ± 19.6 ug/L (range of 85.1 to 157 ug/L) in the deep brine layer. For arsenic, the EPA recommended ocean chronic criterion of 36 ug/L is much lower than the freshwater criterion of 150 ug/L. Arsenic concentrations exceeded the ocean criterion in 97% of samples in Gilbert Bay (Figure 6). The remaining 3% of samples that did not exceed the recommended criterion were all at site Gil8, located at the culvert between Gilbert and Farmington Bay. Only 1 measurement of arsenic exceeded the freshwater aquatic criteria, which was obtained from a sample obtained from the deep brine layer (site Gil2bottom).

Over all sites and depths, average copper concentrations were 2.6 ± 2.7 ug/L (range of 0.175 to 15.0 ug/L). Copper concentrations increased with depth from 1.8 ± 0.6 ug/L (range of 0.88 to 3.75 ug/L) in the shallow layer to 5.6 ug/L ± 5.4 (range of 0.175 to 15 ug/L) in the deep brine layer. Copper concentrations exceeded the ocean criterion of 3.1 ug/L in 17% of total samples (Figure 8) and were mostly confined to the deep brine layer. No samples of copper exceeded the freshwater criterion.

A similar pattern was observed for lead that averaged 2.1 ± 2.5 ug/L (range 0.439 to 13.4 ug/L) over all sites and depths, and increased with depth from 1.1± 0.2 ug/L (range of 0.439 to 1.49 ug/L) in the shallow layer to 6.5 ± 3.3 ug/L (range of 2.28 to 13.4 ug/L) in the deep brine layer. Four percent of lead samples exceeded the ocean criterion of 8.1 ug/L and all were located at sites Gil2bottom and Gil6bottom where the deep brine layer was present (Figure 9). No samples of lead exceeded the freshwater criterion.

Elevated mercury concentrations in the water column of Gilbert Bay have been well documented (Naftz, et al., 2008a; Darnall & Miles, 2009; Vest, et al., 2008). Intensive studies began after 2003 when the USGS reported 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 and bioaccumulation to the biota and humans (UDWQ, 2011). The waterfowl consumption advisories for mercury in 3 species of duck (Cinnamon Teal, Northern Shoveler and Common Goldeneyes) (http://www.waterfowladvisories.utah.gov/) remain in place even though 2009 breast muscle tissue in

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, UDWQ continues to measure mercury concentrations in the open waters of GSL, in 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. Over the 2011-12 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 0.15 to 2.88). In contrast, the deep brine layer average total and methylmercury concentrations were 38.9 ± 8.2 ng/L (range of 26.4 to 47.3) and 21.2 ± 7.4 ng/L (range 8.7 to 29.3), respectively. When compared to the Utah's total mercury fresh water aquatic criterion of 12 ng/L that is based on protecting humans who consume fish, 19% of measurements exceeded the criterion, all of which occurred in the deep brine layer (Figures 10 and 11). For methylmercury, 10.5% of measurements exceeded the freshwater aquatic benchmark of 2.8 ng/L (LANL, 2009). When compared to the EPA total mercury ocean aquatic criterion of 940 ng/L, none of the measurements, even in the deep brine layer, exceeded this criterion.

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 percentage of these measurements per analyte was 75% of cadmium samples, 98% of selenium samples, and 92% of thallium samples (UDWQ, 2014). None of the sample results for these analytes exceeded the fresh or ocean criteria or benchmarks (Figures 7, 12 and 13). Since 92% of the thallium samples were qualified as less than quantifiable, UDWQ will begin measuring Zinc concentrations instead of thallium in the future. The BSP mean selenium concentration of 0.379 ± 0.1 ug/L (range 0.197 to 0.776 ug/L) was lower but comparable to the mean selenium concentration of 0.584 ug/L (range 0.297 to 0.899 ug/L) measured in 2006 and 2007 as part of the selenium standard research program (UDWQ, 2007).

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 (UDWQ, 2013). For more detail see the section on Pollutant Prioritization below.

Gilbert Bay metals concentrations in brine shrimp

Aquatic organisms take up metals from the water and food which can result in concentrations that exceed the concentrations in the surrounding water. Exposure to these pollutants can be transferred up the food chain from lower to higher trophic levels. In Gilbert Bay, brine shrimp and brine flies occupy a middle trophic level and their entire life cycle occurs within the lake. Brine shrimp and brine flies can absorb metals directly from the water or take up metals from the algae they feed upon. Predators such as birds can be exposed when they eat the shrimp or flies. 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, USFWS, USGS and others to compile avian dietary effects levels for mercury (UDWQ, 2011) and selenium (UDWQ, 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 yet and these benchmarks 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.

A total of 32 samples of brine shrimp were collected from Gilbert Bay over the 2011-12 monitoring period and were analyzed for the following target analytes; arsenic, cadmium, copper, lead total mercury, selenium and thallium (Figures 14-19). Descriptive statistics are presented in Table 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.

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

- Low risk in diet: 0 – 0.5 methylmercury mg/kg wet weight (ww)
- Moderate risk in diet: 0.5 – 0.15 methylmercury mg/kg wet weight
- High risk in diet: 0.15 - 0.30 methylmercury mg/kg wet weight
- Extreme High Risk in diet: > 0.30 methylmercury mg/kg wet weight

Evers 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 this data is 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 et al., 2003). For total mercury, 87.5% of brine shrimp measurements were less than 0.05 mg/kg ww, below the low risk benchmark value, equivalent to a no observed adverse effect level (Evers et al., 2004). Four measurements were greater than 0.5 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 (UDWQ, 2011). The average brine shrimp concentration from the 2008 mercury ecosystem assessment was 0.059 mg/kg ww (range 0.019 to 0.098 mg/kg ww) compared with the average concentration of 0.027± 0.02 mg/kg (range 0.001to 0.086 mg/kg ww) as part of the 2011-2012 BSP results (Figure 18).

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 2011-12 average percent moisture in brine shrimp of 87%. The 2006-2008 average concentration of selenium in adult brine shrimp tissue was 0.16 mg/kg ww (range 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) (Figure 19).

Gilbert Bay selenium and mercury concentrations in bird eggs

Selenium

The GSL selenium numeric water quality criterion is a geometric mean of12.5 mg/kg dry weight (dw) selenium based on the complete egg/embryo of aquatic-dependent birds that use the waters of Gilbert Bay (UAC R317-2-14). The criterion was adopted by the Utah Water Quality Board in 2008 and approved by EPA in 2009 and is the first numeric criterion adopted for the lake. Starting in 2010, UDWQ 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 5 eggs is compared to the selenium numeric water quality standard for designated use support. Table 13 provides descriptive statistics of selenium concentrations in bird egg tissue by date and location sampled and Table 14 provides the same information for mercury concentrations.

In June 2010, the geometric mean selenium concentration for 13 American Avocet and Black-necked stilt eggs from Saltair was 4.3 ± 0.77 mg/kg dw (range 3.5 to 6) (Cavitt et al, 2010). In June 2011, the geometric mean selenium concentration for 5 American Avocet eggs at Bridger Bay, Antelope Island was 1.6 ± 0.19 mg/kg dw (range 1.38 to 1.84) (Cavitt et al, 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 1.5 ± 0.48 mg/kg dw (range 1.21 to 2.84) and 1.5 ± 0.33 mg/kg dw (range 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 egg selenium concentration from that study was 2.4 mg/kg dw, similar to the 2011-2012 egg concentrations. The BSP average selenium egg concentrations 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 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, UDWQ/Weber State University sampled and analyzed egg tissue for mercury concentrations. For the purpose of comparison, UDWQ applied Evers et al. (2004) risk ranges for mercury egg concentrations that would indicate risk to avian wildlife as:

- Low risk in eggs: 0 – 0.5 Hg mg/kg wet weight
- Moderate risk in eggs: 0.5 – 1.3 Hg mg/kg wet weight
- High risk in eggs: 1.3 - 2.0 Hg mg/kg wet weight
- Extreme High Risk in eggs: >2.0 Hg mg/kg wet weight

Evers' risk ranges are based on data reported on a wet weight basis. Using percent total solids per egg sample, dry weight mercury concentrations were converted to wet weight to make the comparison.

In June 2011 the arithmetic mean mercury concentration for 5 American Avocet eggs at Bridger Bay, Antelope Island was 0.2 ± 0.07 mg/kg ww (range of 0.14 to 0.33) (Cavitt et al, 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 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' risk ranges.

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

Tables 15 show the descriptive statistics of water column concentrations of arsenic, copper, cadmium, lead, total mercury, methylmercury, selenium, and thallium in Bear River Bay over the 2011 – 12 monitoring period. Only 2 samples were collected in 2011 and 2012. For all analytes, none of the Bear River Bay samples exceeded the freshwater or ocean numeric aquatic life criteria (Figures 20 - 27).

The average arsenic concentration and standard deviation in Bear River Bay over all sites/depths over the monitoring period was 15.7 ± 3.7 ug/L (range from 13.1 to 18.3 ug/l). The average copper concentration was 1.2 ± 1.2 ug/L (range from 0.368 to 2.05 ug/l). The average total and methylmercury concentration in Bear River Bay were 2.6 ± 0.90 ug/L (range from 1.93 to 3.2 ug/l) and 0.69 ± 0.26 (range from 0.499 to 0.870 ug/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 ug/L respectively. None of these values exceeded the freshwater or ocean 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[3] 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

Tables 16 shows descriptive statistics of water column concentrations of arsenic, copper, cadmium, lead, total mercury, methylmercury, selenium, and thallium in Farmington Bay over the 2011 – 12 monitoring period. Density stratification was present at site FB9 with a 6.3% difference in salinity between the shallow and bottom layer. 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.

The average arsenic concentration in Farmington Bay over all sites/depths over the monitoring period was 32.4 ± 8.8 ug/L (range from 18.4 to 48.2 ug/l). Five out of 16 (31%) measurements exceeded the ocean criterion of 36 ug/L (Figure 20). None of the arsenic samples exceeded the freshwater criterion.

The average copper concentration in Farmington Bay over all sites/depths over the monitoring period was 1.7 ± 1.2 ug/L (range from 0.467 to 5.4 ug/l). Out of all measurements taken at Farmington (16 total), only 1 exceeded the copper ocean criterion at site FB9surface in July, 2011 (Figure 22) and none exceeded the freshwater criterion.

The average mercury concentration in Farmington Bay over all sites/depths over the monitoring period was 4.6 ± 2.5 ng/L (range from 2.25 to 13.4 ng/l). Out of all measurements taken at Farmington Bay (16 total), only 1 exceeded the total mercury freshwater criterion of 12 ng/L occurring at site FB9bottom in October, 2011 (Figure 24). None exceeded the methylmercury freshwater benchmark for aquatic life (Figure 25).

[3] Benchmarks, screening values, and indicators are used synonymously in this document. 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.

None of the cadmium, lead, selenium or thallium measurements taken at Farmington Bay exceeded the freshwater or ocean criteria (Figures 21, 23, 26 and 27).

Farmington Bay selenium and mercury concentrations in biota

In June 2011, 5 avian eggs were opportunistically collected from the Farmington Bay Wildlife Management Area (Cavitt et al., 2011). These samples were analyzed for selenium and mercury concentrations (Tables 13 and 14 respectively). The geometric mean selenium concentration was 2.5 ± 0.21 mg/kg dw (range 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 0.21 to 0.42) 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 are different among the lake’s bays. The hydrologic modifications of dikes and causeways restrict circulation from Farmington to Gilbert Bay potentially resulting in higher concentrations of nutrients in Farmington Bay and lower concentrations in Gilbert Bay. 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. The laboratory has utilized a new modified method for detecting ammonia in 2013. Ammonia data prior to 2013 is 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/nutrients available. Algal abundance can rapidly increase when brine shrimp abundance is low and then rapidly decrease as brine shrimp abundance increases. This boom and bust cycle typically occurs 2 to 3 times per year from April to October (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 dissolved oxygen 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[4]. 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*) can be found at 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 and Gilbert Bays is needed to evaluate use support with regards to nutrients.

CLASS 5A GILBERT BAY NUTRIENTS IN THE WATER COLUMN

In Gilbert Bay, there is a large difference in nutrient concentrations between the shallow and deep brine layer suggesting two pools of nutrients. The average dissolved phosphorus concentration in Gilbert Bay over all sites/depths over the monitoring period was 0.31 ± 0.28 mg/L (range from 0.05 to 1.61 mg/l) (Table 17). Average concentrations of dissolved phosphorus in the shallow and deep brine layers were 0.18 ± 0.04 mg/l and 0.72 ± 0.12 mg/L, respectively (Figures 28 and 29 and Tables 18 and 19). On average, bay-wide, over all depths, 70% of total phosphorous is in the dissolved form. The average dissolved nitrogen concentration in Gilbert Bay over all sites/depths over the monitoring period was 3.7 ± 1.62 mg/L (range from 2.53 to 9.07 mg/l). Concentrations of dissolved nitrogen in the shallow and deep brine layers were an average 2.9 ± 0.18 mg/l and 6.8 ± 1.28 mg/l, respectively (Figures 30 and 31). On average, bay-wide, over all depths, 91% of total nitrogen is dissolved. The total nitrogen to total phosphorous ratio of 9 supports that Gilbert Bay is nitrogen limited as reported by Belovsky et al. (2011) (Redfield, 1934).

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/depths over the monitoring period was 11.8 ± 21.9 ug/L (range from 0.004 to 128 ug/l). The boom – 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 were an average 11.7 ± 27.9 ug/l, and 43.3 ± 36.2 ug/L, respectively. The greatest concentrations of chlorophyll *a* occurred at site Gil8 located in the culvert between Farmington and Bear River Bays (Figure 32). The average chlorophyll *a* concentration at this site was 40.3 ug/L (range 1.02 to 128 ug/L).

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

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

Only 1 usable sample of dissolved phosphorous and nitrogen was obtained for Bear River Bay over the 2011-12 monitoring period. In October, 2012, the dissolved phosphorous and nitrogen concentrations were 0.01 mg/L and 1.1 mg/L, respectively.

CLASS 5C FARMINGTON BAY NUTRIENT CONCENTRATIONS IN THE WATER COLUMN

The average dissolved phosphorus concentration in Farmington Bay over all sites/depths over the monitoring period was 0.10 mg/L ± 0.03 (range from 0.07 to 0.15 mg/l) (Table 20). The average dissolved nitrogen concentration in Farmington Bay over all sites/depths over the monitoring period was 3.0 ± 0.77 mg/L (range from 2.1 to 4.3 mg/l) (Figures 28-31). The ratio of total nitrogen to total phosphorous was 11.2 suggesting that Farmington Bay is probably nitrogen limited but can sometimes be phosphorous limited (Redfield, 1934).

The highest measured concentrations of chlorophyll *a* occurred at the Farmington Bay Sites. The average chlorophyll *a* concentrations at these sites were 175.8 ug/L at FB9 (range 6.65 to 276 ug/L) and 27.5 ug/L (range 0.114 to 57.7 ug/L) at FB10 (Figure 31). According to Carlson's Trophic State Index, when chlorophyll *a* concentrations are greater than 56, the waterbody is classified as hypereutrophic; a nutrient-rich lake with frequent algal blooms that can lead to low dissolved oxygen levels (Wurtsbaugh et al., 2012; Carlson 1977). Carlson's Trophic Index may or may or may not be appropriate to Farmington Bay because it is a model of the biological productivity of a freshwater lake. In addition, Carlson 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, pH). At site FB10 in October, 2011 salinity was 1.65% with an average chlorophyll *a* of 54.8 ug/L. The following June when salinity increased to 6.6%, the average chlorophyll *a* concentration decreased to 0.15 ug/L. While salinity may influence phytoplankton, the observed relationship is probably more attributable to predation on phytoplankton grazers (Wurtsbaugh, 1991).

DEVELOPMENT OF NUMERIC WATER QUALITY CRITERIA

Background and Purpose

As outlined in the Strategy, Core Component 1, UDWQ has developed a process to derive numeric criteria for all EPA priority pollutants[5] where existing data suggest a potential, as determined in accordance with the requirements of 40 *Code of Federal Regulations* (CFR) 131.11(2), to adversely affect GSL's designated uses. 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 freshwater. Next, UDWQ will compile a comprehensive review of previously conducted toxicity studies for

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

each pollutant and GSL relevant species to supplement the data compiled for prioritizing the pollutants. The toxicity data will be reviewed to determine if upper trophic levels (i.e., birds) are more sensitive to the pollutant than lower trophic levels (e.g., brine shrimp). If birds are more sensitive, then the criterion 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 upper trophic levels (birds) are more sensitive than 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,"[6] which occurred 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 national 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 (salinity, dissolved oxygen, temperature, etc.) 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 USEPA (1984) *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* and as outlined in the Strategy (Core Component 1) 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

[6] http://www.rules.utah.gov/publicat/code/r317/r317-001.htm#T1

been used as toxicity test organisms. Much less experience is available 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 UDWQ 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 layer of Gilbert Bay were compared to the EPA numeric water quality chronic criteria for the protection of freshwater and ocean aquatic wildlife or other sources when available. Pollutants whose concentrations were higher relative to the 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.

The outcome of the screening of pollutants for toxicological testing was, in order of priority: arsenic, copper, methylmercury, and lead. The prioritization of ammonia, cadmium, total mercury, selenium, thallium, and zinc and the remaining priority pollutants were deferred (UDWQ, 2013).

After the GSL species list is completed, UDWQ 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 ocean waters (EPA, 1994). For GSL waters with salinity greater than ocean water, the criteria are anticipated to be based on GSL-specific species toxicity testing. UDWQ expects that GSL will have less taxonomic families represented than were used to derive the national freshwater and ocean water chronic criteria for protection of aquatic life. If sensitive species included in the derivation of the fresh water and ocean criteria are not present at GSL, application of the EPA's deletion procedure would result in criterion higher than the, for instance, freshwater criterion. Great Salt Lake species would have to be more sensitive for the criterion to be more stringent. The available toxicity data for brine shrimp and limited data for brine flies suggest that these species are relatively tolerant of metals (UDWQ, 2013). An exception would be if avian species are more sensitive to a pollutant than the aquatic biota such as was the case with selenium and likely will be the case for pollutants that biomagnify, such as methylmercury. This analysis supports using existing numeric criteria as screening or benchmark values. If the benchmarks are met, adverse effects to GSL biota is unlikely and the uses are likely supported. If the benchmarks values are exceeded, additional data is 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 frank (obvious) effects in birds attributable to water pollutants supports no severe impairments[7]. Brine shrimp populations remain vigorous which also supports 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 is unlikely to be more stringent than the freshwater and ocean chronic criteria that were used for comparison. For the metals assessed, Gilbert Bay water concentrations generally meet freshwater chronic criteria suggesting that the uses are supported by existing pollutant concentrations with the exception of arsenic and copper. The ocean 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 ocean or fresh water chronic 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 ocean and freshwater criteria supports 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 which doesn't support higher-level organisms because of hypoxia and salinity. A potential exception is the methylmercury measured in the breast muscle tissue in 2004 and 2005 of the three waterfowl species that resulted in human consumption advisories. These advisories remain in place but more recent data suggests lower concentrations of methylmercury in waterfowl breast muscle tissue (UDWQ, 2009). Reproduction, a sensitive toxic effect of methylmercury, is not threatened based on the limited number of eggs sampled for methylmercury (Cavitt et al., 2010; 2011; 2012). In 2010 through 2012, the USGS in partnership with the USFWS 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 with 131 of the eggs being collected from GSL outside of the refuge boundaries. UDWQ and EPA have funded the mercury and selenium analyses for 131 of these eggs to provide a larger sample of eggs necessary to support more definitive use support conclusions.

[7] 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.

DATA GAPS

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

- 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

Class 5B Gunnison Bay

Little 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). UDWQ 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:

- Quality assurance and quality control procedures for hypersaline water with salinities greater than 20%
- Water quality data
- Resident species and life cycle
- Applicable comparison benchmarks or numeric criteria

Class 5C Bear River Bay

For Bear River Bay, none of the metals sampled exceeded the EPA and Utah fresh and/or ocean aquatic life criteria suggesting that the uses are likely supported. Bear River Bay is the most fresh of the Bays in GSL with historical salinity ranging from 1 to 5% (UDWQ, 2010). A greater diversity of aquatic life exists in this Bay than the saltier habitat in the lake including at times, fish. 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 is collected and the species list is completed, UDWQ can identify remaining data gaps.

DATA GAPS

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

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

Class 5D Farmington Bay

For Farmington Bay, cadmium, lead, methylmercury, selenium, and thallium concentrations meet the freshwater and ocean criteria which suggests that the uses are supported for these metals. Arsenic concentrations meet freshwater comparison criteria but 16% of the samples exceeded the ocean criteria. Total mercury concentrations were less than the freshwater and ocean comparison criteria with the exception of one sample that exceeded Utah's human health-based freshwater 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, a freshwater classification, Farmington Bay is considered hypereutrophic characterized by frequent algal blooms that can deplete the dissolved oxygen 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, while 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 they 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. There is evidence that for the last 200 years, Farmington Bay has always been a productive system but 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 to a lesser extent, by increase influxes of nutrients (Leavitt et al., 2012). Salinity in Farmington Bay is more variable than the 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 prior to making a use support determination. 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:

- Water quality data
- Resident species list
- Cyanobacteria and cyanotoxin data
- Nutrient budget

- Applicable comparison benchmarks or numeric criteria

Class 5E Transitional Waters

The Transitional Waters are from an elevation of approximately 4208' to the open waters of GSL and includes streams, springs, drainage channels, wetlands, playas, mudflats, and alkali knolls. With the exception of the impounded wetlands, most of the Transitional Waters are subject to periodic inundation by GSL when the lake rises.

UDWQ'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 of this IR. The shorebird egg data discussed for Gilbert Bay were collected from the Transitional Waters and show support for the Gilbert Bay selenium standard and suggests support with regards to mercury concentrations. The 2012 Farmington Bay Transitional Waters egg sampling suggests that selenium concentrations are not impairing the uses 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 UPDES 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 is 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 wetland's water quality support of the uses are:

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

REFERENCES

Adler, R. (1999). Toward comprehensive watershed-based restoration and protection for Gresat Salt Lake. *Utah Law Review*.

Aldrich, W. T., & Paul, S. D. (2002). Avian Ecology of Great Salt Lake. In J. Gwynn (Ed.), *Great Salt Lake: An Overview of Change* (pp. 343-374). UDNR, UGS.

Belovsky, G. E., Stephens, D., Perschon, C., Birdsey, P., Paul, D., Naftz, D., et al. (2011). The Great Salt Lake Ecosystem (Utah, USA): long term data and a structural equation approach. *Ecosphere*.

Bioeconomics. (2012). *Economic Significance of the Great Salt Lake to the State of Utah*. Salt Lake City: Final Report to the Great Salt Lake Advisory Council.

Carlson, R. (1977). A trophic state index for lakes. *Limnology and Oceanography, 22*(2), 361-369.

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

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

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

SWCA Environmental Consultants and Applied Conservation (2012). *Definition and Assessment of Great Salt Lake Health*. Prepared for the Great Salt Lake Advisory Council.

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

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

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

Laboratory, L. A. (2009). *Ecorisk Database (Release 2.4) on CD*.

Leavitt, P., Bunting, L., Moser, K., & Woodward, C. (2012). *Effects of Wastewater influx and hydrologic modification on algal production in the Great Salt Lake, UT*. Final Report to the Utah Division of Water Quality.

Naftz, D., Angeroth, C., Kenney, T., Waddell, B., Darnall, N., Silva, S., et al. (2008a). Anthropogenic influences on the imput and biogeochemical cycling of nutrients and mercury in Great Salt Lake, Utah, USA. *Appied Geochemistry*, 1731-1744.

Naftz, D., Waddell, B., & Krabbenhoft, D. (2005). *Mercury in air, water and biota from Great Salt Lake, UT:Reconnaissance phase results: Hg in deep brine layer*. ASLO poster.

Quality, U. D. (2014). *Quality Assurance Project Plan for the Great Salt Lake*. Utah Department of Environmental Quality, Salt Lake City, UT.

Redfield, A. C. (1934). On the proportions of organic derivations in sea water and their relation to the composition of plankton. In R. J. Daniel (Ed.), *James Johnstone Memorial Volume* (pp. 172-192). University Press of Liverpool .

Utah Department of Health (2005). *An Evalutation of Mercury Concentrartions in Ducks from the Great Salt Lake Utah for 2004 and 2005*. Environmental Epidemiology Program, Utah Department of Health, Salt Lake City, UT.

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

Utah Division of Forestry, Fire and State Lands (2013). *Final Great Salt Lake Comprehensive Management Plan and Record of Decision*. Utah Department of Natural Resources. Salt Lake City, UT: Prepared by SWCA Environmental Consultants.

Utah Division of Water Quality (2007). *Development of a Selenium Standard for the Open Waters of the Great Salt Lake*. Utah Department of Environmental Quality. Salt Lake City, UT: Prepared by CH2M Hill.

Utah Division of Water Quality (2010). *Utah 2010 Integrated Report:305(b) Assessment*. Utah Department of Environmental Quality, Salt Lake City, UT.

Utah Division of Water Quality (2011). *Ecosystem Assessment of Mercury in the Great Salt Lake, Utah 2008*. Utah Department of Environmental Quality, Salt Lake City, UT.

Utah Division of Water Quality (2013). *Review Draft, Prioritization of Brine Shrimp and Brine Fly Bioassay Test Pollutants fro Gilbert Bay, Great Salt Lake*. Utah Department of Environmental Quality, Salt Lake City, UT.

Utah Division of Water Quality (2014). *Data Validation Report for the 2011-12 Great Salt Lake Baseline Sampling Plan Metals Data*. Utah Department of Environmental Quality, Salt Lake City, UT.

United States Environmental Protection Agency (1984). *Guidelines for Deriving Numerical Aquatic Site-Specific Water Quality Criteria by Modifying National Criteria*. Sprigfield, VA: National Technical Information service.

United States Environmental Protection Agency (1994). *Water Quality Standards Handbook: Second Ed. Appendix L*. USEPA.

United States Fish and Wildlife Service (2009). *Assessment of Contaminants in the Wetlands and Open Waters of the Great Salt Lake, Utah 1996-2000*. USFWS.

United States Geological Survey(2014). *Surface Water Monthly Statistics for Utah*. National Water Information System.

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

Weiner, Krabbenhoft, D., & Heinz, G. (2003). Ecotoxicology of Mercury. In D. Hoffman (Ed.), *Handbook of Ecotoxicology* (2nd ed.). CRC Press.

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

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