APPENDIX A-2

DRAFT GREAT SALT LAKE ASSESSMENT FOR MERCURY

PART 2 - 2010 ECOLOGICAL RISK ASSESSMENT APPROACH

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1. INTRODUCTION

As described in USEPA (1998) *Guidelines for Ecological Risk Assessment*, an ecological risk assessment is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. The process is used to systematically evaluate and organize data, information, assumptions, and uncertainties in order to help understand and predict the relationships between stressors and ecological effects in a way that is useful for environmental decision making.

For GSL, the assessment considers chemical stressors such as mercury. Ecological risk assessments are developed within a risk management context to evaluate human-induced changes that are considered undesirable. Changes often considered undesirable are those that alter important structural or functional characteristics or components of ecosystems. An evaluation of adverse effects may include a consideration of the type, intensity, and scale of the effects as well as the potential for recovery. The acceptability of adverse effects is determined by risk managers. Descriptions of the likelihood of adverse effects may range from qualitative judgments to quantitative probabilities. Although risk assessments may include quantitative risk estimates, quantitation of risks is not always possible. It is better to convey conclusions (and associated uncertainties) qualitatively than to ignore them because they are not easily understood or estimated.

Ecological risk assessments for GSL can be used to predict the likelihood of future adverse effects, e.g., a future discharge containing mercury, or evaluate the likelihood that effects are caused by past exposure to stressors, e.g., existing mercury concentrations in GSL are adversely affecting wildlife.

The ecological risk assessment process is based on two major elements: characterization of effects and characterization of exposure. These provide the focus for conducting the three phases of risk assessment: problem formulation, analysis, and risk characterization.

In problem formulation, the purpose for the assessment is articulated, the problem is defined, and a plan for analyzing and characterizing risk is determined. Initial work in problem formulation includes the integration of available information on sources, stressors, effects, and ecosystem and receptor characteristics. From this information two products are generated: assessment endpoints and conceptual models. Either product may be generated first (the order depends on the type of risk assessment), but both are needed to complete an analysis plan, the final product of problem formulation.

Analysis is directed by the products of problem formulation. During the analysis phase, data are evaluated to determine how exposure to stressors is likely to occur (characterization of exposure) and, given this exposure, the potential and type of ecological effects that can be expected (characterization of ecological effects). The first step in analysis is to determine the strengths and limitations of data on exposure, effects, and ecosystem and receptor characteristics. Data are then analyzed to characterize the nature of potential or actual exposure and the ecological responses under the circumstances defined in the conceptual model.

The products from these analyses are two profiles, one for exposure and one for stressor response. These products provide the basis for risk characterization. During risk characterization, the exposure and stressor-response profiles are integrated through the risk characterization process. Risk characterization includes a summary of assumptions, scientific uncertainties, and strengths and limitations of the analyses. The final product is a risk description in which the results of the integration are presented, including an interpretation of ecological adverse effects and descriptions of uncertainty and lines of evidence.

Although problem formulation, analysis, and risk characterization are presented sequentially, ecological risk assessments are frequently iterative. Something learned during analysis or risk characterization often leads to a reevaluation of problem formulation or new data collection and analysis.

2. PROBLEM FORMULATION

2.1 MANAGEMENT GOALS, OBJECTIVES, AND OPTIONS

Management Goals are statements about the desired condition of ecological values of concern (USEPA, 1998). The management goals driving this assessment come from DWQ rules. The management goals (R317-2-6) for GSL are in part[1] to maintain GSL water quality to support:

- Waterfowl, shore birds and other water-oriented wildlife including their necessary food chain in Gilbert Bay.
- Waterfowl, shore birds and other water-oriented wildlife including their necessary food chain in Gunnison Bay.
- Waterfowl, shore birds and other water-oriented wildlife including their necessary food chain in Bear River Bay.
- Waterfowl, shore birds and other water-oriented wildlife including their necessary food chain in Farmington Bay.
- Waterfowl, shore birds and other water-oriented wildlife including their necessary food chain in transitional waters.

If GSL does not support these uses, then GSL is impaired.

Management Objectives define what must be true in order for the management goals to be met and provide the foundation for management decisions. Mercury is the primary concern and the management objectives are to prevent toxic levels of mercury in water, sediment and biota for each of the geographic areas defined above.

Management Options determine the means to obtain the management goals and assist the ecological risk assessor with scoping the assessment. Management options relevant to DWQ to prevent toxic levels of mercury from accumulating in GSL include:

- No further action because mercury from GSL is not impairing the use.
- Implement voluntary actions to reduce mercury inputs to the lake or actions that would reduce mercury methylation rates.
- Implement the Total Maximum Daily Load (TMDL) process
    - Identify mercury sources to GSL.
    - Control mercury additions to the lake with UPDES permit limits.
    - Implement best management practices to control mercury inputs from nonpoint sources.
    - Implement controls to reduce methylation rates of mercury.
    - Physically remove mercury from the lake.

[1] The designated beneficial uses for GSL also include primary and secondary recreation.

2.2 ASSESSMENT ENDPOINTS

Assessment endpoints (USEPA, 1998) are explicit expressions of the actual environmental value that is to be protected, operationally defined by an ecological entity and its attributes. Assessment endpoints are critical to problem formulation because they structure the assessment to address management concerns and are central to conceptual model development.

Once ecological values are selected as potential assessment endpoints, they need to be operationally defined. Two elements are required to define an assessment endpoint. The first is the identification of the specific valued ecological entity. This can be a species (e.g., brine shrimp), a functional group of species (e.g., herbivorous waterfowl), a community (e.g., benthic invertebrates), an ecosystem (e.g., GSL), a specific valued habitat (e.g., wetlands), or other entity of concern. The second is the characteristic about the entity of concern that is important to protect and potentially at risk. Thus, it is necessary to define what is important for

brine shrimp (e.g., saline waters free of toxic contaminants), a lake (e.g., mercury cycling), or wetlands (e.g., food source free of toxic contaminants for waterfowl). For an assessment endpoint to serve as a clear interpretation of the management goals and the basis for measurement in the risk assessment, both an entity and an attribute are required.

The following assessment endpoints are proposed for GSL include:

- survival, growth, and reproduction of algae used by brine shrimp and brine flies,
- survival, growth, and reproduction of brine shrimp,
- survival, growth and reproduction or brine flies,
- survival, growth, and reproduction of waterfowl, and
- survival, growth, and reproduction of shorebirds.

The next step is to develop testable hypotheses. These hypotheses were selected based on the premise that mercury is toxic to these receptors and can affect survival, growth, or reproduction. Methyl mercury has been measured in GSL water, sediment, and biota. The hypotheses for this assessment are:

- Mercury present in GSL water, sediment, and biota is adversely affecting the survival, growth, or reproduction of brine shrimp.
- Mercury present in GSL water, sediment, and biota is adversely affecting the survival, growth, or reproduction of brine flies.
- Mercury present in GSL water, sediment, and biota is adversely affecting the survival, growth, or reproduction of waterfowl.
- Mercury present in GSL water, sediment, and biota is adversely affecting the survival, growth, or reproduction of shorebirds.

To conclude that GSL is impaired requires that only one of these entities be adversely affected by mercury from GSL.

2.3 SELECTING MEASURES

For the assessment plan described in the appendix included in the 2008 IR, we proposed to identify both *direct* and *indirect* indicators of the GSL ecosystem health. Thereby, multiple lines of evidence and measures were to be used to determine whether the beneficial uses are at risk. In this iteration, the same lines of evidence and measures are proposed but are put in the framework described by *Guidance for Conducting Ecological Risk Assessments* (USEPA, 1998). USEPA (1998) uses the *direct* and *indirect* terms in a similar way but in reference to effects. Direct and indirect effects from USEPA (1998) are easiest to define by example. A *direct effect* would be mercury reducing the survival of brine shrimp. An *indirect effect* would be the reduced number of brine shrimp causing reduced growth in Eared Grebes who feed on brine shrimp.

There are three categories of measures (USEPA, 1998). Measures of effect are measurable changes in an attribute of an assessment endpoint or its surrogate in response to a stressor to which it is exposed. Measures of exposure are measures of stressor existence and movement in the environment and their contact or co-occurrence with the assessment endpoint. Measures of ecosystem and receptor characteristics are measures of ecosystem characteristics that influence the behavior and location of entities selected as the assessment endpoint, the distribution of a stressor, and life history characteristics of the assessment endpoint or its surrogate that may affect exposure or response to the stressor.

2.3.1 Algae

Measures of effects for algae potentially include observations of reduced populations, increases in nuisance algae, or bioassays where algae were exposed to mercury and survival, growth, or reproduction are measured. Mercury is known to adversely affect algae (Harriss et al., 1970) but most work has focused on the tendency of algae to accumulate mercury and be a source of exposure to higher trophic levels. Bioassays using algae species indigenous to GSL could be conducted. GSL algae populations are known to be significantly affected by grazing and salinity (Wurtsbaugh, 1995). GSL fluctuations of algal population due to mercury are unlikely to be detectable due to the fluctuations from these other factors.

Measures of exposure include measurements of methyl mercury in GSL water and sediment. No studies on the concentration of mercury in GSL algae were found but based on the mercury measurements from the water column and studies conducted elsewhere, GSL algae is expected to contain mercury. The algae complete their life cycle in GSL, so the source of any Hg is GSL.

Algae is an essential food source for higher trophic levels in GSL including brine shrimp and brine flies, although different types of algae are preferred by each. Brine shrimp graze primarily on phytoplankton. Brine flies graze on the periphyton and use bioherms (carbonates formed by blue-green algae) as a substrate for their chrysalis. Mercury concentrations can increase with trophic level, so the higher trophic levels may be a more sensitive indicator of adverse effects from mercury.

2.3.2 Brine Shrimp

Measures of effects for brine shrimp potentially include observations of reduced populations or bioassays where brine shrimp are exposed to mercury and survival, growth, or reproduction are measured. Pandey and MacRae (1991) measured a lowest-observed-adverse-effects-concentration (LOAEC) of 0.1 µM (≈ 0.2 mg/l) for several forms of organic mercury, the lowest concentration tested. Bioassays could be conducted using GSL water and brine shrimp. GSL brine shrimp populations are known to be significantly affected by season, the availability of algae, salinity, predation, and harvesting. Field observations of fluctuations in brine shrimp population due to mercury exposure are unlikely to be detectable due to the fluctuations from these other factors.

Measures of exposure include measurements of mercury in GSL water, phytoplankton, and brine shrimp. Brine shrimp complete their life cycle in GSL and methyl mercury has been detected in GSL water and mercury in brine shrimp confirming that the exposure pathway is complete. The term brine shrimp includes cysts, napulii, juvenile and adult brine shrimp that are different life stages from youngest to oldest, respectively. Brine shrimp are also an important food source for many birds, so mercury concentrations in brine shrimp tissues will help elucidate threats to higher trophic levels.

2.3.3 Brine Flies

Measures of effects for brine flies potentially include observations of reduced populations or bioassays where brine flies are exposed to methyl mercury and survival, growth, or reproduction are measured. Bioassays are unavailable but could be conducted. Brine fly populations are known to be significantly affected by seasons, the availability of algae, predation, and salinity. Field observations of fluctuations of brine fly populations due to mercury exposure are unlikely to be detectable due to the fluctuations from these other factors. Other aquatic

invertebrates for which data is available may be suitable surrogates to extrapolate methyl mercury toxicity.

Measures of exposure include measurements of mercury in GSL brine flies, water, periphyton, and phytoplankton. Brine flies complete their life cycle at GSL and methyl mercury has been detected in GSL water and sediment and the exposure pathway is presumed to be complete. Brine flies are also an important source of food for birds and other animals that may be at a greater risk due to the previously noted tendency for mercury to bioaccumulate.

2.3.4 Waterfowl

Measures of effects for waterfowl potentially include observations of reduced populations or reproductive impairments, or studies where waterfowl are exposed to methyl mercury and survival, growth, or reproduction are measured.

Due to the migratory nature of waterfowl, field observations of variations in population would be difficult to conduct or interpret (http://wildlife.utah.gov/gsl/waterbirdsurvey/eagr.htm). Large die-offs periodically occur at GSL due to avian cholera that further complicates any field population studies (UDWR, 2010). A field study on GSL was conducted where Cinnamon Teal eggs were examined. No adverse effects were observed but the mercury concentrations in cinnamon teal eggs were generally below the literature benchmarks. USFWS (2009) measured mercury from 1996 to 2000 in Forster's terns and great blue heron eggs and chicks at Farmington Bay. No toxic effects were observed even though the concentrations for some individuals were higher than literature benchmark levels for frank (obvious) health effects in birds (Heinz 1974, Barr 1986, and Scheuhammer 1997).

Many field and laboratory studies have been conducted on the effects of mercury on waterfowl. Appendix A of the 2008 IR presents a mercury assessment logic diagram and decision rules to guide the collection and interpretation of benchmarks and data. In Part 1, Tables 2, 3, 4, and 5 of this assessment, research of mercury toxicity to aquatic birds including observed growth, survival, or reproduction, and the concentrations of mercury in diet, eggs, blood, and liver collected to date is presented. Evers et al. (2004) extensive research of mercury toxicity in Loons provided risk ranges for mercury concentrations in diet, eggs, and blood as a comparison. The applicability of these studies to GSL has not been evaluated in detail but will be prior to applying to GSL waterfowl.

GSL differs from many of the studies in the literature where methyl mercury toxicity was measured because of selenium co-occurring with mercury at GSL. Mercury and selenium can be antagonistic in avian species, i.e., less than additive toxicity (*e.g.*, El-Begearm et al. 1977; Heinz and Hoffman, 1998; Yang et al., 2008). The primary mechanism of antagonism is hypothesized to be the result of mercury and selenium binding in addition to other mechanisms (Parizek, 1978; Yang et al., 2008). In contrast to the mercury:selenium antagonism observed in adult birds, Heinz and Hoffman (1998) conducted a controlled feeding study of methyl mercury and selenium effects on mallard duck eggs. The author's concluded that methyl mercury and selenium were more toxic to mallard duck embryos than either methyl mercury or selenium alone. In mammals, the form of selenium has been shown to be important for the degree of antagonism (Magos et al., 1978; Lemire and Mergler, 2009). At GSL, mercury and selenium are accumulated differently in avocets, goldeneyes, eared grebes, and seagulls (Santolo and Ohlendorf, 2008). These differences may reflect differing species-specific toxicokinetics or different exposure regimes.

A detailed review of the toxicological literature will be conducted as part of future efforts with the goal of deriving a no-observed-effects concentration to compare with the available tissue data.

Waterfowl are in the upper trophic levels for GSL and exposures are expected to be higher than at the lower trophic levels. GSL waterfowl feed on the available algae and invertebrates that include brine flies, brine shrimp, and coroxids in addition to potentially foraging in areas other than GSL. Some waterfowl, like eared grebes, feed predominantly on brine shrimp.

Measures of exposure include measurements of mercury in GSL waterfowl, water, sediment, algae, and invertebrates. Methyl mercury was detected in GSL water and brine shrimp that indicates the exposure pathway is complete for waterfowl feeding on brine shrimp or contacting GSL water. Concentrations of mercury measured in Common Goldeneye ducks from GSL are among the highest measured (Vest et al., 2008; USFWS, 2009). The concentrations of mercury in Common Goldeneye duck tissues increase from when the birds first arrive in the fall to winter further supporting that the exposure pathway at GSL is complete. Mercury concentrations subsequently decreased later in the season in Common Goldeneye ducks for reasons that are unclear.

The majority of waterfowl at GSL are residents for part of the year. Some species, like cinnamon teal nest at GSL. All of the waterfowl are mobile except when molting prevents flight, e.g., eared grebes. The portion of the mercury burden in waterfowl that is from the GSL is currently unknown. However, adverse effects from mercury have to be attributable to GSL exposures to make an impairment decision for GSL as identified in the management goals.

Several lines of evidence will be considered for evaluating what portion of the mercury exposures is attributable to GSL:

- Is the species a year-round resident or migratory?
- What is the composition of the diet and in what areas of GSL do they forage? What are the concentrations of mercury in waterfowl before and after they migrate?

The literature will also be reviewed for studies where the uptake and depuration rates of methyl mercury in waterfowl were measured. With applicable data, the portion of methyl mercury burden attributable to GSL can be modeled.

A comparison of the literature benchmarks (Part 1, Tables 2 through 5) with the mercury burdens in GSL waterfowl (Part 1, Tables 6 through 9) suggests that adverse effects from mercury exposures are possible and further investigation is warranted. Only one species needs to be adversely affected from GSL mercury exposures to support an impairment decision. However, more than one species may need to be evaluated because for instance, the species with the highest exposures may not be the species that are the most sensitive to methyl mercury's effects. Data gaps in either the measures of exposures or measures of effects may preclude basing an impairment conclusion on a single species.

2.3.5 Shorebirds

Measures of effects for shorebirds potentially include observations of reduced populations or reproductive impairments, or studies where shorebirds are exposed to methyl mercury and survival, growth, or reproduction are measured.

Due to the migratory nature of shorebirds, field observations at GSL of reductions in population would be difficult to conduct or interpret. A field study at GSL was conducted where herring gull colonies at GSL were compared to a reference site (Conover and Vest, 2008). Mercury and selenium were measured in muscle, liver, and eggs. The mercury concentrations measured in some individuals were higher than literature benchmark levels for frank (obvious) health effects in birds (Heinz 1974, Barr 1986, and Scheuhammer 1997). However, no reproductive effects were observed. One out of 73 eggs collected was not viable and 100 examined chicks appeared normal. However, Conover and Vest (2008) note that herring gulls may not be as sensitive to mercury as other shorebirds or waterfowl.

Many field and laboratory studies have been conducted on the effects of mercury on shorebirds. Appendix A of the 2008 IR presents a mercury assessment logic diagram and decision rules to guide the collection and interpretation of benchmarks and data. In Part 1, Tables 2, 3, 4, and 5 of this assessment, research of mercury toxicity to aquatic birds including observed growth, survival, or reproduction, and the concentrations of mercury in diet, eggs, blood, and liver collected to date is presented. Evers et al. (2004) extensive research of mercury toxicity in Loons provided risk ranges for mercury concentrations in diet, eggs, and blood as a comparison. The applicability of these studies to GSL has not been evaluated in detail but will be prior to applying to GSL shorebirds.

For the measures of effects, shorebirds are similar to waterfowl and the discussion in Section 2.3.4 applies to shorebirds and is not repeated here.

Shorebirds are in the upper trophic levels for GSL and exposures are expected to be higher than at the lower trophic levels. Shorebirds will feed on the available invertebrates that include brine flies, brine shrimp, and coroxids. Shorebirds may also significant exposures from incidental ingestion of contaminated sediment.

Measures of exposure include measurements of mercury in GSL shorebirds, water, sediment, and invertebrates. Mercury has been detected in all of these media confirming that the exposure pathway is likely complete. Limited data for mercury concentration in black-necked stilts, snowy plovers, great blue herons, Forster's tern, and American avocets are available (USFWS, 2009). In these studies, no obvious toxic effects were observed.

Shorebirds are mobile and may be migratory. The portion of the mercury burden measured in shorebirds that is from the GSL is currently unknown. However, for an impairment decision as identified in the management goals, adverse effects from mercury has to be attributable to GSL exposures.

Similar to the waterfowl discussed in Section 2.4.4, the same lines of evidence will be considered for evaluating what portion of the exposures to methyl mercury exposure is attributable to GSL.

A comparison of the literature benchmarks where mercury toxicity was observed with the mercury burdens in GSL shorebirds suggests that adverse effects are possible and further investigation is warranted. Only one species needs to be adversely affected from GSL mercury exposures to support a decision of an impairment decision. However, a single species may be inadequate. Species with the highest exposures may not be the same as the species that are the most sensitive to methyl mercury's effects. Data gaps in either the measures of exposures or measures of effects may preclude basing an impairment conclusion on a single species.

3. FUTURE EFFORTS

The management goal is to determine if GSL is impaired because of mercury. Short term efforts will focus on evaluating the data that is currently available that may or may not be sufficient for determining whether GSL is impaired. Short term efforts include:

- Develop a conceptual site model that is a graphical display of the movement of mercury through the ecosystem.
- Compile all available analytical data.
- Identify the most sensitive receptors. If the most sensitive receptors are protected, all of the receptors will be protected.
- Identify methods to identify the contribution of GSL to mercury burden of waterfowl and shorebirds.
- Evaluate literature benchmarks for applicability to GSL waterfowl and shorebirds if GSL is a significant source of mercury exposures.
- Refine measures of exposures and effects.
- Identify data gaps and any future research needs.

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