9.0 Key Observations and Conclusions

Section 4.0 of this report summarized the objectives of the research program as questions to be answered by the program. Those five key questions (illustrated in Figure 4-1) were documented by the Data Quality Objectives for the overall program (CH2M HILL, 2006) and framed the development of the seven research projects the Science Panel identified to answer the central question of:

What is the acceptable waterborne concentration of selenium that prevents impairment of the beneficial uses of the open waters of Great Salt Lake?

This section summarizes key observations and conclusions made by the Science Panel as a result of the research program.

9.1 Key Observations

The following observations were made in relation to the five questions that guided development of the research projects (see Figure 4-1):

1. **Are significant ecological effects occurring in aquatic wildlife? If so, to which ones and at which locations? What are the associated selenium concentrations in tissues (including bird blood, liver, and eggs)?**

   As previously discussed, the Science Panel identified the two critical endpoints for protection of beneficial uses of the open waters of Great Salt Lake as: (1) reproductive success (that is, reproductive endpoints) and (2) body condition (that is, non-reproductive endpoints) of birds using the open waters. The Science Panel re-phrased question number 1 as follows to account for the two critical endpoints and agreed to these answers:

   - Have any adverse effects been observed in the reproductive endpoints for aquatic wildlife due to selenium that were investigated as part of this program?

     No egg hatchability or teratogenic effects (that is, deformities) were observed in gulls, avocets, or stilts associated with the open waters of Great Salt Lake. The geometric mean selenium concentration observed for gulls was 2.89 µg Se/g and for shorebirds it was 2.72 µg Se/g. These values are similar to the 85^{th} to 90^{th} percentile of background levels and consistent with a non-contaminated site (Skorupa and Ohlendorf, 1991). We did find one egg (out of total number of 133 sampled) with a selenium concentration of 9.2 µg Se/g at the KUCC outfall that is above the lower 95-percent confidence limit (6.4 µg Se/g) but below the median (12.5 µg Se/g) of the mallard EC_{10} for egg hatchability.

   - Have any adverse effects been observed in non-reproductive endpoints (for example, body condition) in aquatic wildlife due to selenium that were investigated as part of this program?

A determination cannot be made at this time due to confounding variables and insufficient data; however, elevated concentrations of selenium and mercury were found in bird blood and livers. This may indicate that some of these birds are using selenium to detoxify mercury.

- The Science Panel determined that the reproductive endpoint is considered the most sensitive endpoint for selenium on Great Salt Lake and will be the basis for the selenium water quality standard for open waters of the lake. Non-reproductive endpoints will require additional research before they can be used in assessing the water quality standard.
- Selenium concentrations in water; sediment; food chain items; and bird liver, blood, and eggs were measured and summarized in Section 5.0 of this report.

2. **What is the relative importance (based on selenium concentrations and their availability) of various food-chain exposure pathways for aquatic wildlife?**
    - Bird diets were determined by Project 1 (Cavitt 2008a, Conover 2008a) and summarized in Section 5.0 of this report.
    - Although some birds (such as gulls and goldeneyes) are known to consume food items from offsite locations (such as fresh water sources along Great Salt Lake), gulls and shorebirds associated only with open waters of Great Salt Lake were feeding mainly upon brine shrimp (gulls) and brine fly larvae (shorebirds). The assumption in the Bioaccumulation Model is that all birds consume only items they can obtain from the open waters of Great Salt Lake. This represents a conservative scenario where birds are consuming the food item with the most likely food chain link on Great Salt Lake for selenium.
    - It is assumed that California gulls consume a diet of 100 percent brine shrimp and shorebirds consume a diet of 100 percent brine fly larvae. Shorebirds are also assumed to inadvertently consume shore-zone sediment as 5 percent of their diet.
    - Various alternatives were incorporated into the Bioaccumulation Model to allow the user to explore and evaluate effects from various combinations of bird diets.

3. **What are the transfer factors that describe relationships between selenium concentrations in water column, in bird diets, and the concentrations found in bird eggs?**
    - Transfer factors, regression equations, and other methods were developed to describe the relationships of selenium concentration in the water column and bird diet and eggs. The recommended transfer relationships are incorporated into the Bioaccumulation Model. The Model allows the user to select from various relationships and/or change transfer factors if desired.
    - The MSTF model should be used to model uptake of selenium by brine shrimp. This model was developed using site-specific data that follow the uptake of selenium by brine shrimp from water through seston (i.e., brine shrimp food source).

- Until more data are collected, the estimate of selenium in brine fly larvae and adults should be determined through a ratio relating brine fly selenium concentrations to adult brine shrimp concentrations.
- The Bioaccumulation Model was developed from data collected from Great Salt Lake during a study period when waterborne selenium concentrations were observed to range between 0.4 and 0.8 µg Se/L. The BAF and selected MS-TF models for the transfer for selenium from water to bird diet best represent this range. These models extrapolate values so there is less confidence in the accuracy of predicted values outside of this range. These models may overpredict concentrations in brine shrimp for waterborne selenium concentrations above 0.8 µg Se/L. The Science Panel also noted that the Bioaccumulation Model should not be used for waterborne selenium concentrations higher than 2.5 µg Se/L.
- Relationships for shorebirds are site-specific and are the best understood from information we have. For implementation of the water quality standard, relationships for shorebirds should be used. Specifically, the Shorebird Regression Model should be used to model selenium transfer between bird diet and eggs for shorebirds and the Gull Transfer Factor Model for gulls. These models represent site-specific conditions and are combined in the Bioaccumulation Model as the Great Salt Lake-specific Model.

4. What are the most important processes that affect the partitioning, cycling, and release of selenium in the Great Salt Lake open waters?

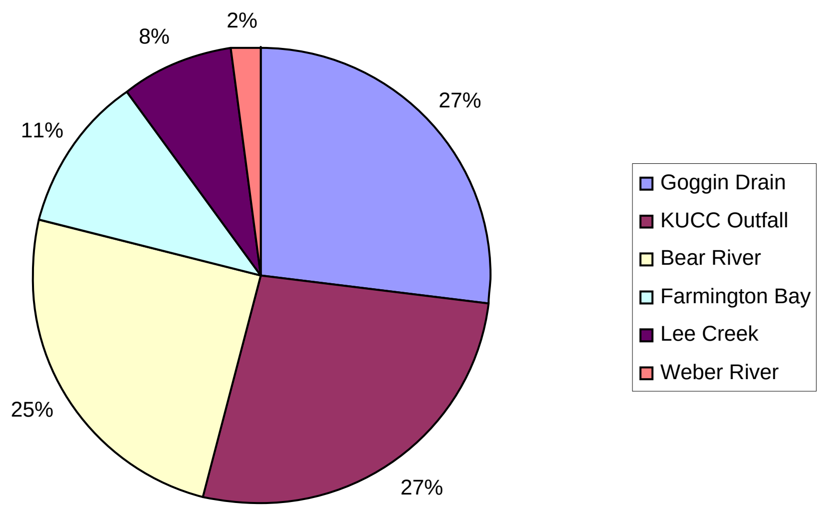
- Volatilization was demonstrated to be the major mechanism of selenium removal from Great Salt Lake (geometric mean of 2,108 kilograms per year [could range between 820 and 5,240 kilograms per year]). Permanent sedimentation follows as the second-most-important mechanism for selenium removal (geometric mean of 520 kilograms per year [could range between 45 and 990 kilograms per year]). Other mechanisms include shallow zone particulate sedimentation, deep brine layer dissolution and resuspension, and brine shrimp cyst removal.
- A possible loss of about 880 kilograms per year (geometric mean [could range between 0 and 1,600 kilograms per year]) through the railroad causeway from the South Arm to the North Arm was estimated from a few, discrete sampling events. This estimate is uncertain and warrants further work to verify.
- Most selenium was present in the dissolved phase but selenium concentrations were relatively higher in the particulate fraction of the deep brine layer.
- The measured loss fluxes more than balance the measured annual load (1,480 kilograms per year) during the study period. The observed increase in total selenium concentration during the study period indicates that some selenium loads have not yet been measured or that some losses are overestimated and further monitoring is needed.
- Long-term cycling of selenium within Great Salt Lake was not fully addressed by this program due to the insufficient length of the study period.

- Significant variability in results was observed, but these data represent the best available information. Further work will be required to allow for accurate predictions of future waterborne selenium concentrations.

5. What are the sources of waterborne selenium entering Great Salt Lake, and what is the relative significance of the various sources?

- Water quality sampling and flow measurements for six tributaries to Great Salt Lake identified the following selenium loads to the lake (total of 1,540 kilograms over the 15-month study period) (see Figure 9-1)

FIGURE 9-1
Tributary Selenium Loads



- A review of the literature identified the possibility that dry and wet atmospheric deposition could contribute a significant load of selenium to Great Salt Lake. No data from Great Salt Lake are available; however, this load could be as high as 596 kilograms per year using relationships from the literature. Therefore, the selenium load attributable to atmospheric deposition could be greater than any single tributary.
- While lake water levels generally decreased during the study period, waterborne selenium concentrations were observed to increase. This indicates that potential selenium sources have not yet been measured or that some of the losses are overestimated. Possible additional sources could be: (1) unmeasured surface inflows, (2) submarine groundwater discharges, (3) lake sediment pore water diffusion into the overlying water column, and (4) wind-blown dust that is deposited directly on the lake surface.
- Because of the anomalies observed in the overall mass balance of selenium in Great Salt Lake, further work is needed to better understand the mass balance of selenium in the lake.

9.2 Conclusions

The central question the research program was to answer was:

> *What is the acceptable waterborne concentration of selenium that prevents impairment of the beneficial uses of the open waters of Great Salt Lake*?

To answer that question, information gathered through the research program was used to develop the Bioaccumulation Model that can be used by the State of Utah to relate selenium concentrations between water and bird food items and eggs. The following general conclusions were made by the Science Panel as answers to the central question:

1. The water quality standard should be a tissue-based standard, based upon the selenium concentration found in the eggs of birds using the open waters of Great Salt Lake.
2. A selenium water quality standard that prevents impairment for aquatic wildlife of Great Salt Lake lies within the range of 6.4 to 16 mg Se/kg for bird eggs (See Fact Sheet in Appendix B). Tables 9-1 and 9-2 illustrate the best estimate of reduction in egg hatchability associated with selenium concentrations in mallard eggs and vice versa.

TABLE 9-1
Egg Selenium Concentration vs. Best Estimate of Reduction in Mallard Egg Hatchability

	Best Estimate of Reduction in Mallard Egg Hatchability		
Egg Selenium Concentration (mg Se/kg dw)	**Most Likely**	**Best Case (2.5% chance of occurring)**	**Worst Case (2.5% chance of occurring)**
6.4	2%	<1%	10%
8.2	3%	<1%	15%
12	10%	4%	26%
14	14%	5%	31%
16	21%	10%	38%

NOTE:
The range of egg selenium concentrations identified for consideration by the Science Panel in November 2006 is 6.4-16 mg Se/kg dw. See also Ohlendorf 2003 and *Fact Sheet: Recommended Guidelines for a Water Quality Standard for Selenium in Great Salt Lake*.

TABLE 9-2
Reduction in Mallard Egg Hatchability vs Best Estimate of Egg Selenium Concentration

Egg Selenium Concentration (mg Se/kg dw)	Best Estimate of Reduction in Mallard Egg Hatchability		
	Most Likely	95% Confident Value is Within This Range	
1%	5.7	1.6	9.4
3%	8.2	3.0	12
5%	9.8	4.1	14
10%	12	6.4	16
20%	16	10	20
50%	27	21	31

NOTE:
Reference: Ohlendorf, 2003

3. For implementation, the waterborne concentration of selenium associated with the water quality standard will be derived from the Bioaccumulation Model. Tables 9-3 and 9-4 present possible outcomes from the Bioaccumulation Model.

TABLE 9-3
Possible Outcomes for Shorebirds from the Bioaccumulation Model

Egg Concentration (mg Se/kg dw)	Shorebird Diet Concentration (mg Se/kg dw)	Water Column Concentration (µg Se/L)
Measured Concentrations from Great Salt Lake 2006/2007		
2.7	1.7	0.6
Predicted Values		
6.4	3.1	1.5
9.5	4.6	2.2
12	6.0	2.8
14	7.0	3.3
16	7.9	3.7

NOTE:
Reference: Bioaccumulation Model v.4.2

TABLE 9-4
Possible Outcomes for Gulls from the Bioaccumulation Model

Egg Concentration (mg Se/kg dw)	Shorebird Diet Concentration (mg Se/kg dw)	Water Column Concentration (µg Se/L)
Measured Concentrations from Great Salt Lake (2006/2007)		
2.9	4.2	0.6
Predicted Values		
6.4	9.2	1.5
9.5	14	2.1
12	18	2.8
14	21	3.2
16	24	3.6

NOTE:
Reference: Bioaccumulation Model v. 4.2

4. Given the uncertainties of the current understanding of selenium cycling in Great Salt Lake, the bioaccumulative nature of selenium, the need to incorporate both waterborne and tissue-based selenium concentrations, and the desire to proactively protect and manage the water quality of Great Salt Lake, the Science Panel developed a concept for a tiered approach to implementing the selenium water quality standard. The approach described in Section 8.0 assumes the use of the Bioaccumulation Model developed as part of this program to relate water, diet, and egg concentrations. The approach implements various trigger concentrations for water, diet, and egg concentrations that increase monitoring levels and management options if and when actual selenium concentrations increase. The Science Panel recommends that the State of Utah implement a similar tiered approach for monitoring, assessment and management options to ensure the selenium water quality standard is not exceeded.
5. The final water quality standard that prevents impairment of the beneficial uses of the open waters of Great Salt Lake will represent a level of protectiveness (that is, not exceeding a specified level of predicted reduction of egg hatchability) recommended by the Steering Committee and selected by the Water Quality Board.
6. Each Science Panel member prepared a brief position statement providing their individual recommendation for a water quality standard. This statement includes the recommended basis for the standard (all are tissue-based) selenium concentration, associated level of protection, and brief rationale for the recommendation. These position statements were forwarded to the Steering Committee and Water Quality Board for consideration (see Appendix M).
7. The Science Panel recommended additional investigations to provide for long-term verification and validation of the conclusions from this research program. These investigations are summarized in Section 8.0 of this report.

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