EXECUTIVE SUMMARY

SELENIUM PROGRAM

GREAT SALT LAKE WATER QUALITY STUDIES

Development of a Selenium Standard for the Open Waters of Great Salt Lake

STATE OF UTAH

DEPARTMENT OF ENVIRONMENTAL QUALITY

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MAY 2008

Acknowledgements

The selenium program would not have been possible without valuable contributions from the following people and organizations as well as countless others who supported the development and completion of this effort:

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William O. Moellmer
Theron Miller
Ying-Ying Macauley
Jodi Gardberg

North Davis Sewer District

Kevin Cowan

Science Panel

William Moellmer, Utah Division of Water Quality
Theron Miller, Utah Division of Water Quality
Joseph Skorupa, U.S. Fish and Wildlife Service
Theresa Presser, U.S. Geological Survey
Anne Fairbrother, Parametrix, Inc.
William Adams, Rio Tinto
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David L. Naftz, U.S. Geological Survey
Don Leonard, Utah Artemia Association
Jim Huizingh, Morton Salt
Kelly Payne, Kennecott Utah Copper
Richard Bay, Jordan Valley Water Conservancy District
Leland Myers, Central Davis Sewer District
Maunsel Pearce, Great Salt Lake Alliance
Robert W. Adler, University of Utah
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Other Advisors

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Thomas W. Way, U.S. Geological Survey

Executive Summary

Great Salt Lake is of vital importance to resident and migratory birds, local recreation, and the brine shrimp and mineral industries. In response to this importance, and in response to increasing development pressures within the lake's watershed, the State of Utah (through the Department of Environmental Quality, Division of Water Quality [DWQ]) initiated a program to support the development of a site-specific, numeric water quality standard for selenium for the open waters of the lake. Those waters are currently protected for their beneficial uses through the application of the narrative standard in the state water quality standards (State of Utah, R317-2-7).

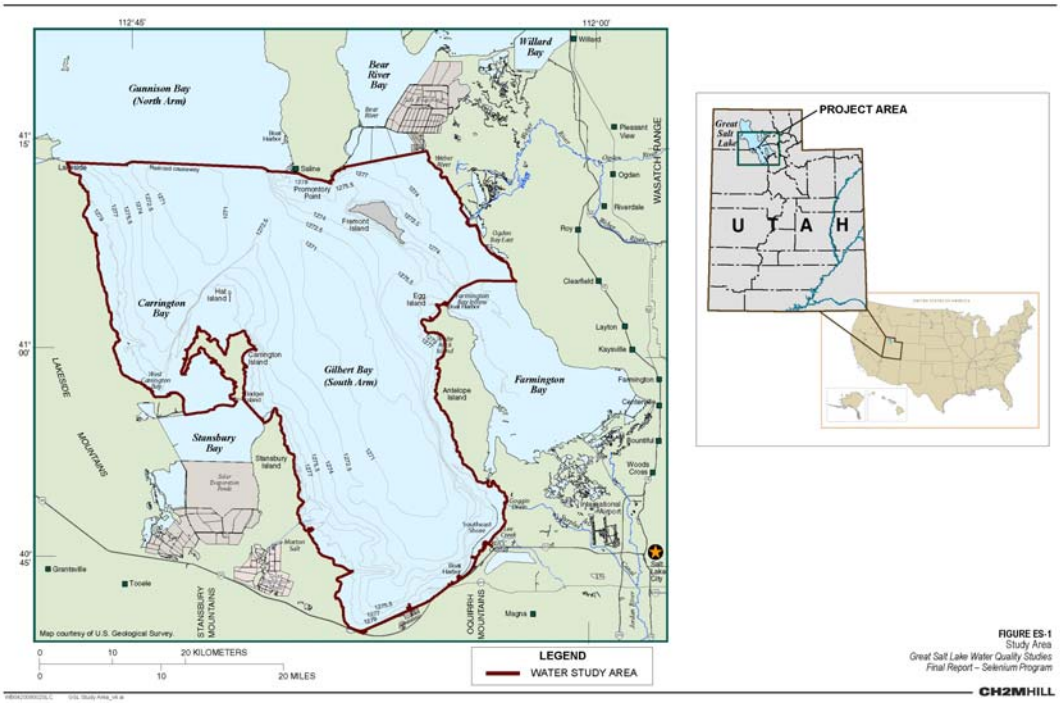
This report describes the overall program for development of the selenium standard and focuses specifically on the research program conducted to provide information to support that standard.

Background

Study Area

Figure ES-1 shows the study area referred to as the "open waters of Great Salt Lake" for this project. This area is commonly referred to in the literature as Gilbert Bay or the South Arm and includes Ogden Bay and Carrington Bay. Farmington Bay, Gunnison Bay (also known as the North Arm), Bear River Bay, Willard Bay, and Stansbury Bay are not included in the study area.

FIGURE ES-1
Great Salt Lake Study Area



Need for a Site-Specific Standard

The DWQ has specified appropriate beneficial uses for waters of the State and protects those uses through the development and enforcement of water quality standards. Due to the unique geochemistry of Great Salt Lake, the application of national fresh-water selenium water quality criterion to Great Salt Lake is inappropriate (EPA 1987, 2004). The open waters of Great Salt Lake have instead historically been protected for their beneficial uses through the application of a narrative clause in the State water quality standards (R317-2-7). Any discharges directly to the lake are required to meet background concentrations in the lake, or the State has required the discharger to complete site-specific studies to establish a numeric standard that is protective of the lake's beneficial uses (Ostler, 2004).

Beneficial Uses of Waters of Great Salt Lake

1. Primary Contact Recreation
2. Secondary Contact Recreation
3. Waterfowl, Shorebirds, and Other Water-oriented Wildlife
4. Aquatic Food Organisms
5. Mineral Extraction

Kennecott Utah Copper Corporation (KUCC) completed studies from 2000 to 2002 that recommended a site-specific water quality standard for selenium to be included as part of their Utah Pollution Discharge Elimination System (UPDES) discharge permit to Great Salt Lake (Brix et al., 2004). These studies identified a proposed "de facto" chronic numeric standard for selenium in Great Salt Lake of 27 micrograms of selenium per liter (µg Se/L). The DWQ currently uses this selenium concentration in assessing and enforcing the Kennecott UPDES discharge permits to Great Salt Lake (DWQ Fact Sheet, 2004a).

Recent proposals for new discharges of wastewater to Great Salt Lake led to a recommendation that the DWQ complete additional research to verify that the discharge of wastewaters containing selenium is not harmful to the Great Salt Lake ecosystem. The DWQ convened the Great Salt Lake Water Quality Steering Committee, consisting of key stakeholders, and an expert Science Panel in 2004. Their role was to investigate and recommend a new, site-specific water quality standard for selenium for the open waters of Great Salt Lake.

Program Development

The DWQ developed a public involvement, consultation, and coordination program (including the Great Salt Lake Water Quality Steering Committee, the Science Panel, and a public involvement program) and developed a technical program (including analytical methodologies, a conceptual model for selenium in Great Salt Lake, threshold values, and the research program) to address the need for a site-specific standard. Development of analytical methodologies and a conceptual model that characterizes selenium cycling in the study area were completed first. These were essential precursors to the research program because of the need to be able to analyze for selenium in the highly saline waters of the lake (historic measurements of waterborne selenium concentrations ranged from 20 to 200 µg Se/L) and to provide a framework for definition of information needs (that is, research) for establishment of the water quality standard.

The simplified conceptual model for selenium cycling in the open waters of Great Salt Lake (Figure ES-2) includes three primary components: (1) selenium in the upper food chain, (2) selenium in the lower food chain, and (3) selenium in the water and sediment. Due to the

bioaccumulative nature of selenium, selenium in the system is generally recognized to originate at the "bottom" of the conceptual model (that is, from selenium in the water and sediment [abiotic component]) and move "up" through the lower food chain (food web component) and into the upper food chain (birds).

FIGURE ES-2
Simplified Conceptual Model for Selenium Cycling in Great Salt Lake

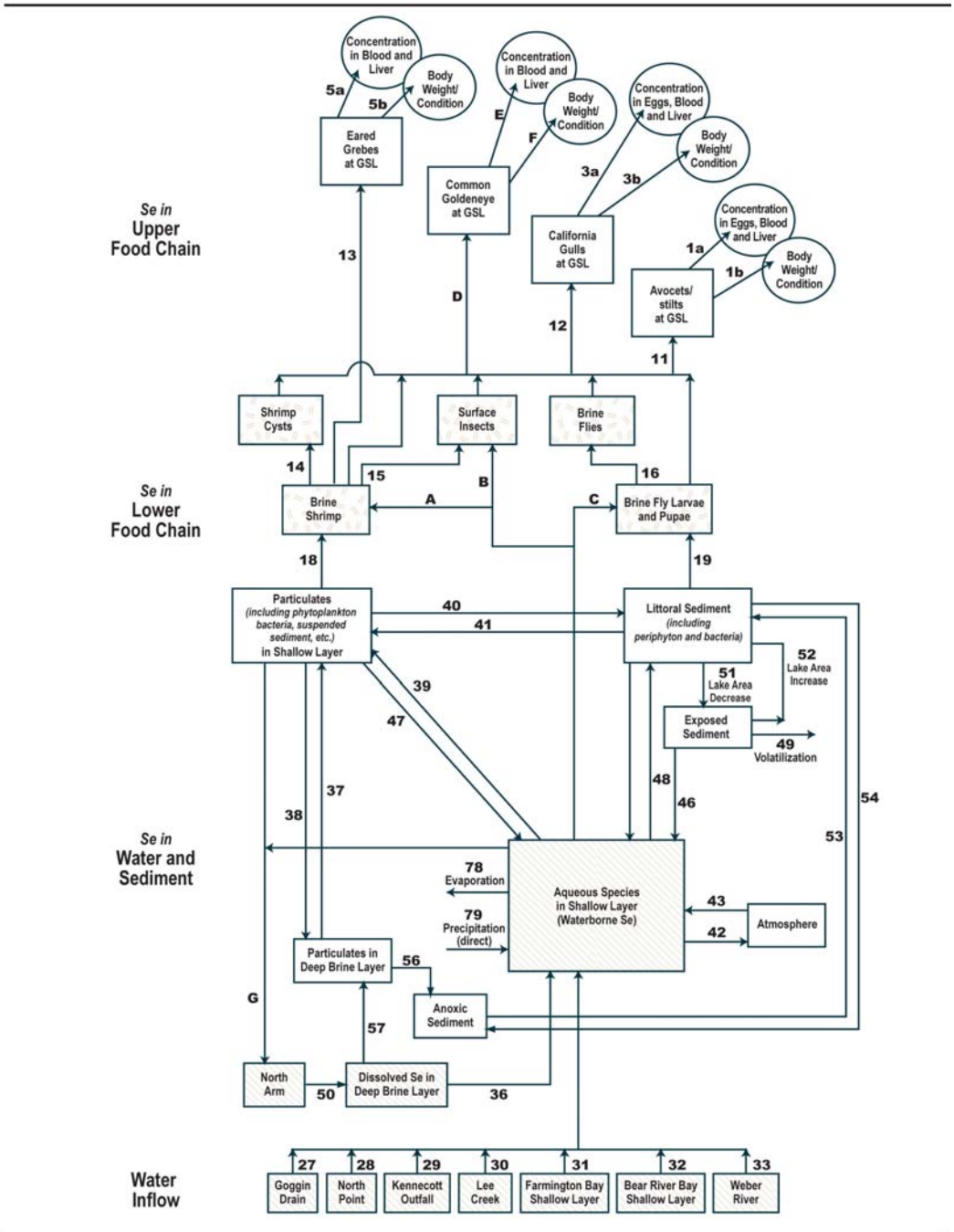


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FIGURE ES-2
Simplified Conceptual Model for Selenium Cycling
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

Critical Endpoints to be Protected for Open Waters of Great Salt Lake

1. Reproductive Success of Birds
2. Body Condition of Overwintering oand Migrating Birds

Through development of the conceptual model (Johnson et al., 2006), the Science Panel concluded that successful reproduction and body condition of birds were the two most sensitive, or critical, endpoints to be protected in preventing impairment of the beneficial uses of the study area. These critical endpoints, as represented by the reproductive success of California gulls, American avocets and black-necked stilts (species using Great Salt Lake for nesting) and the body condition of eared grebes and common goldeneyes (species using Great Salt Lake during fall migration and over-wintering, respectively), would be the focus for the research program.

Toxicity threshold values for the exposure of birds to selenium at Great Salt Lake (i.e., the concentration where effects of selenium are observed) are necessary for the development of a water quality standard that is protective for them. Based on available information, the Science Panel agreed that the most significant exposure of birds occurs through their diet (brine shrimp and/or brine flies), and that the best-documented and most readily monitored effects are those on reproductive success (particularly egg hatchability). The Science Panel agreed in November 2006 to define a range of selenium concentrations in bird diet items and eggs that could serve as the basis for evaluation in the research program and development of the water quality standard.

The range of values the Science Panel recommended for consideration for the water quality standard is defined by the EC_{10} for bird diet items and eggs as defined in Ohlendorf 2003. This summary of toxicological studies showed that we can have 95 percent confidence that a 10 percent reduction (called an "EC_{10}") in egg hatchability of mallards will occur between 3.6 and 5.7 milligrams per kilogram (mg Se/kg) with the highest probability that it will occur at 4.9 mg Se/kg (mg/kg equals parts per million [ppm]). There is only a very small chance (2.5 percent) that the low or high values in the ranges provided are the true concentration where a 10-percent effect, or reduction in egg hatchability, occurs. A similar 10 percent reduction in egg hatchability in mallards will occur between 6.4 and 16 mg Se/kg with the highest probability that it will occur at 12 mg Se/kg. Table ES-1 shows this range of selenium concentrations in the diet and eggs and the associated best estimates for percent reduction in egg hatchability for mallards for each selenium concentration (see Table ES-1).

TABLE ES-1
Selenium Concentration Ranges and Associated Reduction in Egg Hatchability

Diet Selenium (mg /kg)	Reduction in Hatchability	Egg Selenium (mg/kg)	Reduction in Hatchability
3.6	3%	6.4	2%
4.9	10%	12	10%
5.7	18%	16	21%

The Science Panel determined that selection of the actual water quality standard within these ranges is a question of what level of protection the State of Utah wishes to afford. It is a question of philosophy rather than science and should be determined by the Steering Committee and Water Quality Board rather than the Science Panel. The Science Panel and

Steering Committee agreed that the Science Panel would not provide an outright recommendation for a water quality standard but would 1) recommend a range of values with associated levels of reduction in hatchability and 2) provide individual recommendations of Science Panel members for a water quality standard. These items would be offered by the Science Panel for consideration by the Steering Committee and Water Quality Board.

Objectives

Using the conceptual model for selenium, the Science Panel developed a series of specific questions that would further their understanding of selenium cycling in Great Salt Lake and help them develop their recommendation for a selenium water quality standard. The central question the research program was to resolve was stated as: "*What is the acceptable waterborne concentration of selenium that prevents impairment of the beneficial uses of the open waters of Great Salt Lake?*" Figure ES-3 illustrates five study questions that were developed to answer the central question and how they relate to the development of the research program.

FIGURE ES-3
Program Questions Relative to Projects

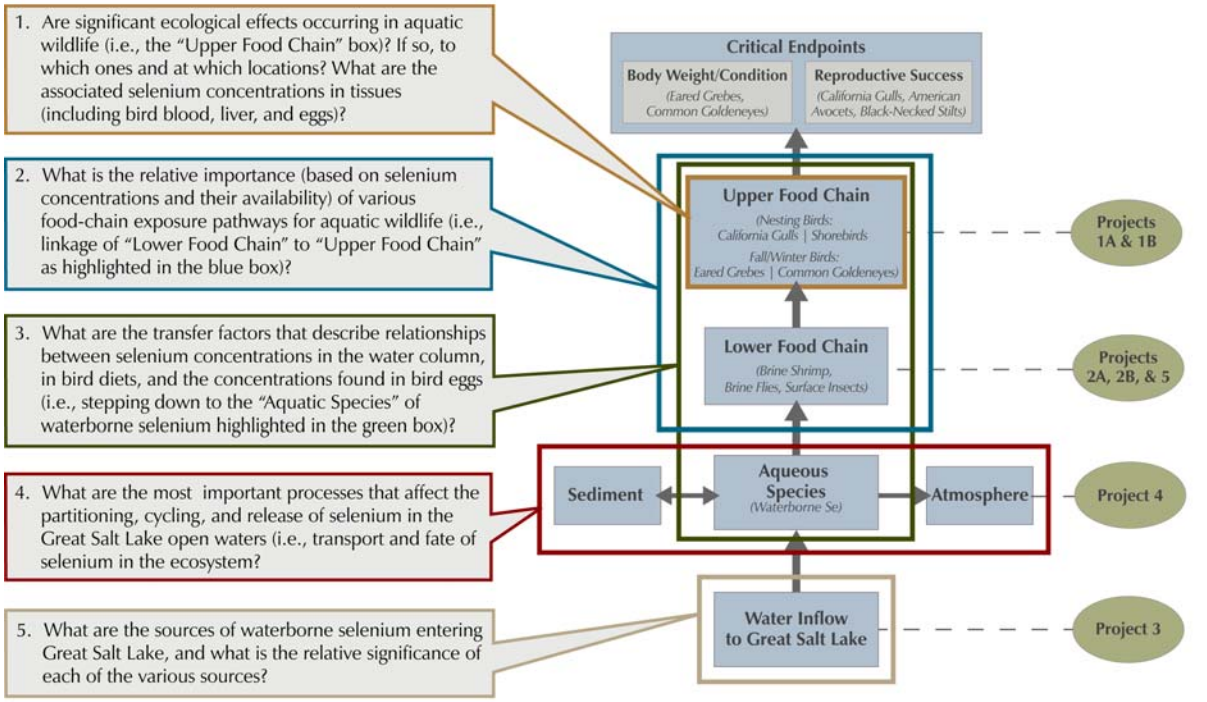

FIGURE ES-3
Program Questions Relative to Projects
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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Research Projects

Seven projects were completed in 2006, 2007, and 2008. Detailed project data quality objectives, workplans, and standard operating procedures are found in the Se*lenium Program Manual* (CH2M HILL, 2006). Detailed project background, objectives, methods, and results

were documented in each project's final report. Data and observations were integrated into a quantitative model and synthesis report as described in this document. The following projects were initiated in 2006:

- Project 1A – Determine the concentration and effect of selenium in shorebirds through the sampling of adult birds, eggs, diet, water, and sediment
- Project 1B – Determine the concentration and effect of selenium in California gulls through the sampling of adult birds, eggs, diet, water, and sediment. Determine the concentration and effect of selenium in eared grebes and common goldeneyes through the sampling of adult birds when they arrive at Great Salt Lake and before leaving the lake
- Project 2A – Synoptic survey of selenium in periphyton and brine fly larvae from the benthic zone (that is, lake bottom)
- Project 2B – Synoptic survey of selenium in water, seston (that is, suspended material including algae), and brine shrimp
- Project 3 – Measurement and modeling of selenium loads to Great Salt Lake
- Project 4 – Measurement of selenium flux to and from sediment and atmosphere

A review of initial data collected for each of the projects in 2006 identified the need for additional studies to be completed in 2007. These include:

- Project 1A – Repeat a subset of the 2006 sampling program in 2007 with the addition of analysis of samples for mercury
- Project 1B – Repeat a subset of the 2006 sampling program in 2007 with the addition of analysis of samples for mercury and the sampling of a gull colony at a freshwater location
- Project 2B – Continue 2006 sampling program through July 2007
- Project 4, Volatilization – Directly measure volatilization on the open waters of Great Salt Lake to verify estimates of selenium loss to the atmosphere
- Project 4, Sedimentation – Collect additional shallow and deep sediment cores to verify sedimentation rates and permanent burial of selenium in sediment
- Project 5 – Complete kinetic studies in the laboratory to define the transfer of selenium from water and diet to brine shrimp

Results

The following represents a brief summary of key results from each project.

Project 1 – Upper Food Chain

Shorebirds

American avocets and black-necked stilts were found to have a mixed diet of invertebrates from both fresh water and saline water sources along the shoreline of Great Salt Lake (Cavitt,

2008a, 2008b). Brine fly larvae were found to be the most likely food chain link for selenium; selenium concentrations in food items ranged between 0.3 and 3.8 micrograms of selenium per gram (µg Se/g) with an overall mean selenium concentration in food items of 1.7 µg Se/g (all selenium concentrations for tissue and sediment are expressed on dry-weight basis in this report).

Banding an American Avocet (Recurvirostra americana) at Ogden Bay

Selenium concentrations found in shorebird blood and livers were higher than expected based on concentrations found in food sources and bird eggs (selenium concentrations in bird blood and livers are generally expected to be more similar to those found in the bird's diet and eggs than indicated by results for these shorebirds). Further investigation and analysis of the datasets concluded that the most likely explanation for the higher-than-expected blood selenium concentrations was exposure to elevated mercury concentrations in Great Salt Lake. Selenium may play a role in mercury detoxification (that is, it counteracts the toxic effects of mercury) for individuals with high mercury levels.

Despite elevated levels of selenium found in adult tissues, egg selenium concentrations were relatively low and ranged between 1.2 and 9.2 µg Se/g in individual eggs, with an overall mean egg concentration of 2.7 µg Se/g (68 eggs collected). Breeding (nest) success ranged between 94 and 97 percent. These success rates were considered consistent with what would be expected for non-contaminated sites.

The data collected during the 2006 and 2007 breeding seasons suggest that the selenium concentration found in water samples, food chain invertebrates, and eggs at Antelope Island and Ogden Bay were low and within typical background levels reported elsewhere. Elevated selenium levels found at Saltair are likely due to freshwater inflows from the KUCC outfall.

California gull at Saltair (Larus californicus)

Gulls, Grebes, and Ducks

Most California gulls collected from three colonies on Great Salt Lake (68 percent) consumed exclusively brine shrimp (Conover et al, 2008a). Others ate a mixture of other invertebrates, fish, and garbage. Adult brine shrimp were found to be the most likely food chain link for selenium in gulls. Egg selenium concentrations ranged from 2.0 to 4.3 µg Se/g, with an overall mean selenium concentration in eggs of 2.9 µg Se/g. Of 72 eggs collected, only one had no embryo development and none exhibited embryo malposition or deformities. None of the 100 chicks that were examined exhibited teratogenesis (deformities). Similar to the shorebirds, selenium concentrations found in gull blood and livers were higher than expected based on concentrations found in their food sources and eggs. Further investigation

and analysis of the datasets concluded that the most likely explanation for the higher-than-expected blood selenium concentrations was exposure to elevated mercury concentrations in Great Salt Lake. Bird body weight was not correlated to blood or liver selenium concentrations. Despite elevated selenium levels found in gull blood and livers, selenium was not found to impair gull health or reproduction.

Eared Grebe (Podiceps nigricolis)

Eared grebes collected during the fall of 2006 were found to eat primarily brine shrimp (Conover et al, 2008b). Selenium concentrations found in grebe blood and livers were higher than expected. Further investigation and analysis of the datasets concluded that the most likely explanation for the higher-than-expected blood selenium concentrations was exposure to elevated mercury concentrations in Great Salt Lake. Measures of body condition such as mass of body, liver, pancreas, and spleen were not correlated to selenium or mercury. There was a positive relationship between selenium and body mass that is undoubtedly a result of physiological characteristics of the grebe. The birds gain weight during their fall migration stay on the lake, and while they are there, they also accumulate more selenium from their food. Confounding variables and insufficient data did not allow a determination to be made regarding the effect of selenium and mercury on the body condition of eared grebes.

Common Goldeneye (Bucephala clangula)

Selenium and mercury levels in common goldeneye collected in 2005 and 2006 were higher than expected (Conover et al, 2008c). Similar to the results for other species previously described, further investigation and analysis of the datasets concluded that exposure to elevated mercury concentrations in Great Salt Lake were the most likely explanation for the higher-than-expected blood selenium concentrations. Body mass and liver mass were not correlated to selenium or mercury in the blood or liver. Fat mass was negatively correlated with selenium concentrations in liver and mercury concentrations in liver and blood. Selenium and mercury concentrations were found to increase during the wintering period. Confounding variables and insufficient data did not allow a determination to be made regarding the effect of selenium and mercury on the body condition of common goldeneyes.

Project 2 – Lower Food Chain

Benthic Zone (Bottom of the Lake)

Brine fly larvae and pupae were sampled from biostromes (also called stromatolites, which are hard underwater structures) and shore-zone sediments from locations near the northern and southern ends of Antelope Island (Wurtsbaugh, 2007). Samples of biostromes, sediment, and adult brine flies were also collected. Brine flies were found to be much more abundant on biostromes than on nearby sand or mud substrates. Concentrations were found to increase from larvae (1.3 µg Se/g) to pupae (1.5 µg Se/g) to adult flies (1.8 µg Se/g). The limited number of samples did not provide adequate information to develop a predictive relationship between selenium in brine fly food sources, sediment, and the brine fly tissue.

Collecting Brine Flies near Antelope Island (Photo courtesy Wayne Wurtsbaugh)

Pelagic Zone (Water Column of the Lake)

Data on brine shrimp and lake characteristics included data on water quality, seston chemistry, chlorophyll concentrations, algal cell counts, complete density estimates of brine shrimp by life stage, and brine shrimp and seston selenium content (Marden, 2007, 2008). Brine shrimp and phytoplankton exhibited characteristics indicative of a generally "healthy" population. Selenium concentrations in water were not significantly variable spatially but changed seasonally, with a net increase of 0.1 to 0.2 µg Se/L for the lake water column for the period of study. The mean waterborne selenium concentration for 2006 and 2007 was 0.6 µg Se/L. Similarly, seston and brine shrimp selenium concentrations variably increased over the period of study. No statistically significant relationships were found between brine shrimp selenium concentrations and those in water or seston. The geometric mean for selenium concentrations in adult brine shrimp in 2007 was 4.3 µg Se/g and for brine shrimp nauplii/cysts was 2.4 µg Se/g.

Filtering seston from the watercolumn on Great Salt Lake (photo courtesy Brad Marden)

Project 3 – Selenium Loads

Six gages were operated on tributaries to Great Salt Lake for water quality sampling and flow measurements, and standard U.S. Geological Survey (USGS) models (LOADEST) were used

to produce daily loading estimates over the period of record (Naftz et al., 2008). Total estimated selenium load was 1,540 kilograms (kg) over the full 15-month study period, with an annual (May 2006 to April 2007) load of 1,480 kg. The KUCC outfall and Goggin Drain contributed the greatest proportion of loads among sites (27 percent each), although the Bear River contributed an almost equal amount (25 percent). Loads from Farmington Bay, Weber River, and Lee Creek comprised the remaining measured load. The greatest total loads over time at all sites occurred during May 2006. Most of the influent selenium was in the dissolved phase as selenate ($Se6^{+}$). Measurements at the railroad causeway separating the North and South Arms of the lake indicated a possible net positive flow and selenium load from south to north over the period of record with a mean loss from the south arm of about 2.4 kg Se per day (800 kg per year).

USGS gauge at KUCC outfall (10172650)

The mean waterborne selenium concentration for the study area increased over the 15-month period of the study and exceeded the change in concentration (0.17 µg Se/L) that could be expected from the simple addition of influent loads. The mean waterborne selenium concentration for unfiltered lake water samples collected as part of this project was 0.60 µg Se/L. Additional unmeasured sources of selenium could account for as much as 1,500 kg of additional load during the 2006 through 2007 period.

Project 4 – Selenium Flux

Data collected in this project provided a great amount of detail about in-lake geochemical processes and yielded estimates of important losses of selenium from the water column (Johnson et al., 2008). The project provided baseline characterizations of selenium in the water column, including the upper, mixed layer, and the deep brine layer, as well as in sediments and as volatile compounds exiting the lake in vapor phase. Measurements of selenium in lake water showed that most of it was present in the dissolved phase but that selenium concentrations were relatively higher in the particulate fraction of the deep brine layer. The average selenium concentration for unfiltered water samples collected as part of this project was 0.64 ± 0.28 µg Se/L and for filtered water samples 0.49 ± 0.25 µg Se/L.

Collecting sediment core on Great Salt Lake (photo courtesy Bill Johnson)

Volatilization of selenium from surface waters was discovered to be a major loss process for selenium from the water column and, although highly variable, probably accounts for a net loss of selenium more than four-fold greater than that attributed to sediment burial. The total selenium estimated to be lost to the atmosphere was 2,108 kg (estimated uncertainty range is 1,380 to 3,210 kg per year).

The permanent sedimentation flux was estimated to be 520 kg per year with an uncertainty range of 45 to 990 kg per year. Downward sedimentation fluxes were highest where influenced by the Bear River inflow, and were lowest in the shallow brine layer located near the northwest-southeast axis of the study area. Sediment accumulation rates were greater in the deep brine layer than in shallow brine layer areas, suggesting that re-suspension accounted for most of the sediment accumulation at depth.

Combined volatilization and sedimentation fluxes out of Great Salt Lake total to about 2,628 kg per year based upon the geometric means. Volatilization was demonstrated to be the major mechanism of selenium removal from Great Salt Lake. The measured loss fluxes more than balanced the measured annual load (1,480 kg 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 of the losses may be overestimated. Further monitoring is needed to better define the selenium mass balance in Great Salt Lake.

Project 5 – Brine Shrimp Kinetics Study

Brine Shrimp (Artemia franciscana) (Photo courtesy Martin Grosell)

Detailed laboratory studies were completed to determine selenium accumulation rates in brine shrimp from water and diet (Grosell, 2008). Initial studies found that higher salinities reduced feeding by the brine shrimp and reduced their uptake of selenium directly from water, so a salinity of 100 g/L was used for experiments.

The results revealed clear saturation kinetics response at waterborne concentrations below 10 µg Se/L. Between 10 and 20 µg Se/L in water there was a "knee" in the brine shrimp response pattern. Much higher values of bioaccumulation were associated with water concentrations up to 40 µg Se/L. Higher water values (up to 80 µg Se/L) demonstrated decreased bioaccumulation, possibly due to selenium regulation by the brine shrimp. The studies also showed that low food concentrations (below 10 µg Se/g in algae) produced selenium assimilation efficiencies as high as 90 percent. Higher selenium concentrations in algae produced slightly lower assimilation efficiencies.

The final result of the study was a two-part model that adds waterborne and dietary exposures to produce an estimate of bioaccumulated selenium in brine shrimp.

Quantitative Conceptual Model Development

A quantitative model was developed to integrate project data into the conceptual model developed previously by Johnson et al. (2006). The quantitative conceptual model was developed with two components—a Mass Balance Model and a Bioaccumulation Model.

Mass Balance Model

A modified mass balance approach was used to link measured and estimated Great Salt Lake concentrations of selenium in various media into a model that would be responsive to changing ambient conditions. The basic concept is to sum all input and removal mechanisms to estimate a waterborne selenium concentration for the study area. Measured lake and influent selenium concentrations and loads were compiled as monthly geometric mean values, whenever possible. Modeled water column loads and concentrations step through time on a monthly average time step. The model is meant to predict water column concentrations and therefore relies on both external loads (tributaries, atmospheric deposition) as well as internal loading (remineralization from seston and sediments).

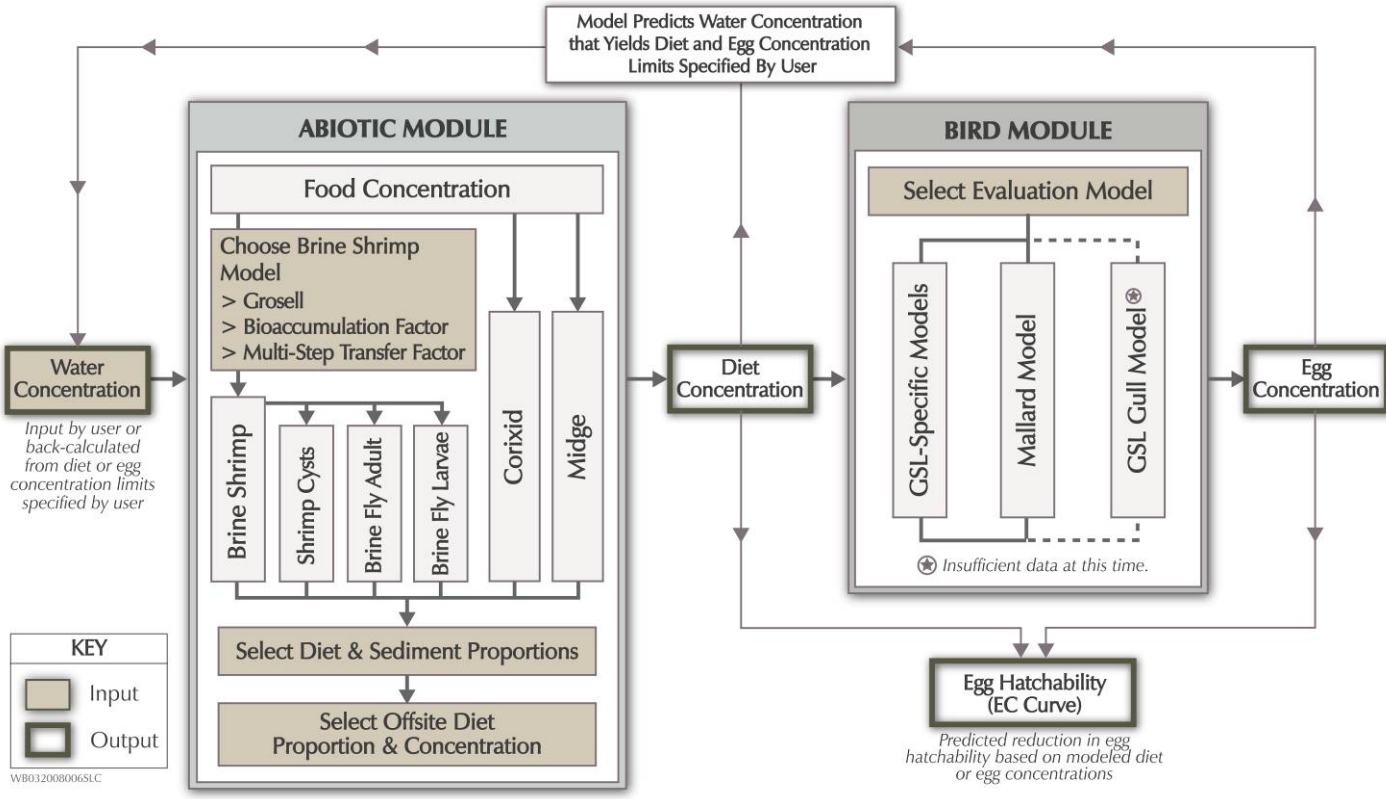
The technique of sequentially computing mass balances produced a relatively good match to measured values. At the end of the 15-month measurement period, the predicted water column monthly total selenium concentrations were low by an average of 0.04 µg Se/L (7 percent). A remaining unmeasured total was noted in the reports of Johnson et al. (2008) and Naftz et al. (2008) as evidence for a significant, unmeasured load. In particular, lake water column concentrations during the 2006 through 2007 period were generally observed to rise during a relatively dry year of reduced stream loading. Data are insufficient to resolve the uncertainty in the dataset and resolve questions about long-term patterns of lake assimilation of selenium. The Science Panel recommended that additional monitoring be conducted to build and improve upon the current model (potentially building a fully dynamic model) to allow for more accurate examination of scenarios for future conditions.

Bioaccumulation Model

A Bioaccumulation Model was developed from data collected from Great Salt Lake to describe the transfer of selenium from water and sediment up through the food web and into bird eggs. The Model allows the user to estimate diet and egg selenium concentrations from an assumed waterborne selenium concentration. The model also allows the user to back-calculate a waterborne selenium concentration from an assumed diet or egg selenium concentration. Resulting waterborne, diet, and egg concentrations are listed and plotted upon egg and diet toxicity curves to illustrate potential effects of selenium on egg hatchability (Ohlendorf, 2003).

The Bioaccumulation Model is composed of a series of relationships that describe the transfer of selenium from water up through the food chain. The transfer factors and regression equations that represent these relationships were developed from data collected from Great Salt Lake as part of the research program. The user has the flexibility to select from numerous options to evaluate the sensitivity and results from alternative transfer relationships and bird diet combinations. Figure ES-4 illustrates inputs, outputs, and the general flow of logic of the Bioaccumulation Model.

FIGURE ES-4
Bioaccumulation Model Flow Chart



Key Observations

The Science Panel has made the following observations to answer the questions identified in Figure ES-3.

1. **Are significant ecological effects occurring in aquatic wildlife? If so, to which ones and at which locations?** The Science Panel rephrased this question as follows to account for the two critical endpoints previously described:

   - 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 were observed in gulls, avocets, or stilts using 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 85th to 90th 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 µg Se/g) of the 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 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), 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 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 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 these relationships. 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 Multi-step, Transfer Factor (MS-TF) 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 through seston.
- 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.
- 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 (GTF) Model for gulls. These models represent site-specific conditions.

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 kg/yr [could range between 820 and 5,240 kg/yr]). Permanent sedimentation follows as the second-most-important mechanism for selenium removal (geometric mean of 520 kg/yr [could range between 45 and 990 kg/yr]). Other mechanisms include shallow zone particulate sedimentation, deep brine layer dissolution and resuspension, and brine shrimp cyst removal.

- A possible loss of about 800 kg per year (geometric mean [could range from 0 to 1,600 kg/yr]) 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 kg 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.

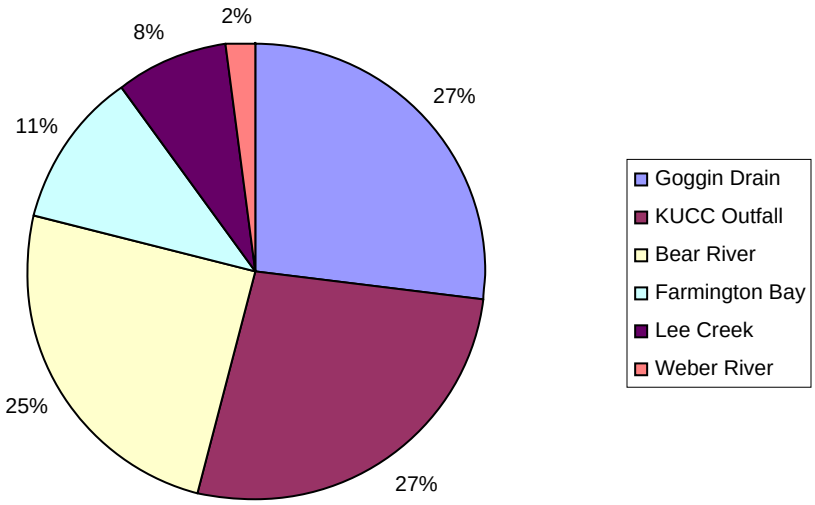
5. What are the sources of waterborne selenium entering Great Salt Lake, and what is the relative significance of the various sources?

- Water quality sampling and flow measurements for six tributaries to the Great Salt Lake identified the following selenium loads to the lake (total of 1,540 kg over the 15-month study period). See Figure ES-5.[1]

- 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 kg/yr using relationships from the literature. Therefore, the selenium load attributable to atmospheric deposition could be greater than any single tributary.

[1] The study period was during the drought of 2006-2007.

FIGURE ES-5
Tributary Selenium Loads



- 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.

Recommendations

The Science Panel recommendations include the following:

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. The standard will be evaluated based upon the geometric mean of eggs sampled in the course of one nesting season at locations where birds are dependent upon 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 16.5 mg Se/kg for bird eggs (See Fact Sheet, *Recommended Guidelines for a Water Quality Standard for Selenium in Great Salt Lake*).
3. 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. Individual recommended values were as follows:

- 12 – 13 mg Se/kg ..... 6 Science Panel members (most likely value for EC_{10})
- 10.4 mg Se/kg ..... 1 Science Panel member
- 5 mg Se/kg ..... 1 Science Panel member
- Abstained ..... 1 Science Panel member, agency policy did not allow member to make recommendation

4. For implementation, the waterborne concentration of selenium associated with the water quality standard will be derived from the Bioaccumulation Model.

5. 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 has developed a concept for a tiered approach to implementing the selenium water quality standard. The approach assumes the use of the Bioaccumulation Model developed as part of this program to relate water, diet and egg concentrations. 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. The objectives of the approach are to perform the following:

   - Monitor Great Salt Lake to assess trends in selenium concentrations and determine whether they are approaching or exceeding the water quality standard in eggs, using water and diet (measured in brine shrimp and estimated in brine flies by a "translation factor") as indicators of whether the standard is likely to be exceeded in the egg
   - Address current uncertainty in modeled bioaccumulation relationships by validating expected bioaccumulation with new data for water or diet concentrations and, if appropriate, egg selenium and hatchability
   - Evaluate trigger selenium concentrations that initiate various monitoring, assessment and management actions identified in the assessment framework
   - Evaluate the lake with respect to the numeric water quality standard for selenium
   - Initiate management actions to mitigate further increases in selenium concentration if an upward trend is observed

   The approach implements various trigger concentrations for water, diet, and egg selenium that increase monitoring levels and management options if and when actual selenium concentrations increase.

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. Given the uncertainties of the current understanding of the Great Salt Lake ecosystem, it is prudent to identify potential actions DWQ could take to verify and validate the current model, the new water quality standard, and future permit limits. It is recommended that the DWQ consider the following, noting that some of these recommendations are incorporated into the proposed assessment framework:

   - The highest priority research need identified by the Science Panel was to verify the transfer of selenium between the water column and brine shrimp for waterborne concentrations of 0.5 – 5.0 µg Se/L. The current Bioaccumulation Model includes two relationships (BAF and MSTF models) developed from Great Salt Lake data that describe this transfer; however, both were created from a dataset represented by waterborne concentrations of 0.4 – 0.8 µg Se/L. Further studies would verify these site-specific relationships for higher ranges of waterborne selenium concentrations.

   - Periodically reassess the current conceptual model and update it with any new scientific information, as appropriate. The objective of continual reassessments of the model is to improve upon the accuracy of current relationships used in the Bioaccumulation and Mass Balance Models to minimize current uncertainties.

   - Monitor brine shrimp selenium concentrations and waterborne selenium concentrations at predetermined intervals throughout Great Salt Lake. The objective is to improve on the current understanding of the transfer of selenium from the water to these diet items and assess long-term trends.

   - Complete additional collocated sampling of brine fly larvae and adults and sediment and water. Current brine fly levels are based on a "translation factor" developed from limited brine fly data and brine shrimp data.

Brine shrimp sampling on Great Salt Lake (photo courtesy Brad Marden)

   - Complete additional egg sampling studies that relate transfer of selenium from diet to eggs. The objective is to provide additional data points that will improve the statistical power of the current Great Salt Lake Shorebird Model (that is, the regression equation developed from data collected to date) and Great Salt Lake Gull Model (currently not used for lack of observed relationship).

   - Continue monitoring tributary inflows and selenium loads to Great Salt Lake in conjunction with lake water column concentrations. The objective is to understand long-term trends, identify other potential selenium sources, and improve upon the current mass balance model. Special emphasis should be placed upon understanding flow inputs/outputs to the North Arm as very little information describing these processes is currently available.

   - Evaluate other potential sources of selenium to Great Salt Lake.

- Sample atmospheric deposition of selenium to verify assumptions made in the Mass Balance Model. The objective of this study is to measure both wet and dry atmospheric deposition of selenium and other pertinent meteorological parameters at Great Salt Lake to quantify actual atmospheric selenium loads to Great Salt Lake.
- Conduct a one-time study to determine selenium concentrations in phalaropes when they arrive at Great Salt Lake and before their departure during their season of peak abundance at the lake. The objective of this study is to identify any potential effects of selenium upon their body condition and ability to migrate.
- Conduct further studies to evaluate the potential effects of selenium on non-reproductive endpoints in birds. Confounding variables and insufficient information available during the completion of this project did not allow for a determination of effects due to selenium on those endpoints for Great Salt Lake birds.
- Conduct further studies to understand the potential interaction of selenium and mercury and their effects on aquatic birds using open waters of Great Salt Lake.
- Verify waterborne selenium concentrations at the outer limit of point-source discharge mixing zones at predetermined intervals. The objective is to verify current mixing zone assumptions and potential effects to beneficial uses in these zones.
- Continue verifying discharge concentrations per permit requirements.

FINAL REPORT

SELENIUM PROGRAM

GREAT SALT LAKE WATER QUALITY STUDIES

Development of a Selenium Standard for the Open Waters of Great Salt Lake

STATE OF UTAH

DEPARTMENT OF ENVIRONMENTAL QUALITY

DIVISION OF WATER QUALITY

CH2MHILL

CWECS

MAY 2008

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1.0 Introduction

Great Salt Lake is of vital importance to resident and migratory birds, local recreation, and the brine shrimp and mineral industries. In recognition of this importance, and in response to increasing development pressures within the lake's watershed, the State of Utah initiated a program to complete research supporting the development of a site-specific selenium numeric water quality standard for the open waters of Great Salt Lake. This document summarizes this program and its recommendations.

This section of this document describes the physical setting of Great Salt Lake, the study area, lake conditions during the study period, and this document's organization.

1.1 Physical Setting

Great Salt Lake is a uniquely dynamic terminal lake located adjacent to a rapidly growing metropolitan area in northern Utah (refer to Figure 1-1). Its approximate watershed area is 21,540 square miles, extending over three states, with an estimated population exceeding 1.9 million people in 2003. Population in the watershed is expected to increase by almost 75 percent by the year 2030 (Governor's Office of Planning and Budget, 2005). Changes in land use, hydrology, and water quality as a result of this population growth will add further dimensions of complexity to the lake's dynamics.

Great Salt Lake is the largest remnant of the ancient Lake Bonneville, which existed from about 32,000 to 14,000 years ago and once covered about 20,000 square miles of western Utah, eastern Nevada, and southern Idaho. A natural dam gave way about 16,000 years ago, resulting in a large flood that drained much of Lake Bonneville. Increased evaporation over the following millennia has led to the present-day Great Salt Lake, occupying the lowest depression in the Great Basin. As is characteristic of terminal lakes, Great Salt Lake has no outlet; water that flows in can only evaporate or percolate into the substrate.

Great Salt Lake is the sixth-largest lake in the United States and the world's fourth-largest terminal lake. It varies significantly in size and depth as a result of changes in inflow from precipitation, tributaries, and groundwater, as well as from losses through evaporation. At a lake elevation of 4,200 feet, the lake is about 75 miles long and 30 miles wide, and has about 335 miles of shoreline. It occupies more than 1,700 square miles and contains more than 15 million acre-feet (or almost 5 trillion gallons) of water. Great Salt Lake's shallow depths (its maximum depth is about 35 feet) and its gradually sloping shoreline result in dramatic surface area variations with any increase or decrease in lake level. Lake levels fluctuated more than 20 feet between 1873 and 1963, which had elevations of 4,211.5 and 4,191.35 feet, respectively. The lake's surface area fluctuated between 938 and 2,500 square miles in that same period (Hahl and Handy, 1969). The lake level rose 20.5 feet after 1963 to reach its record high level of 4,211.85 feet on June 3, 1986. The net rise between 1982 and 1986 was 12.2 feet (Arnow and Stephens, 1987).

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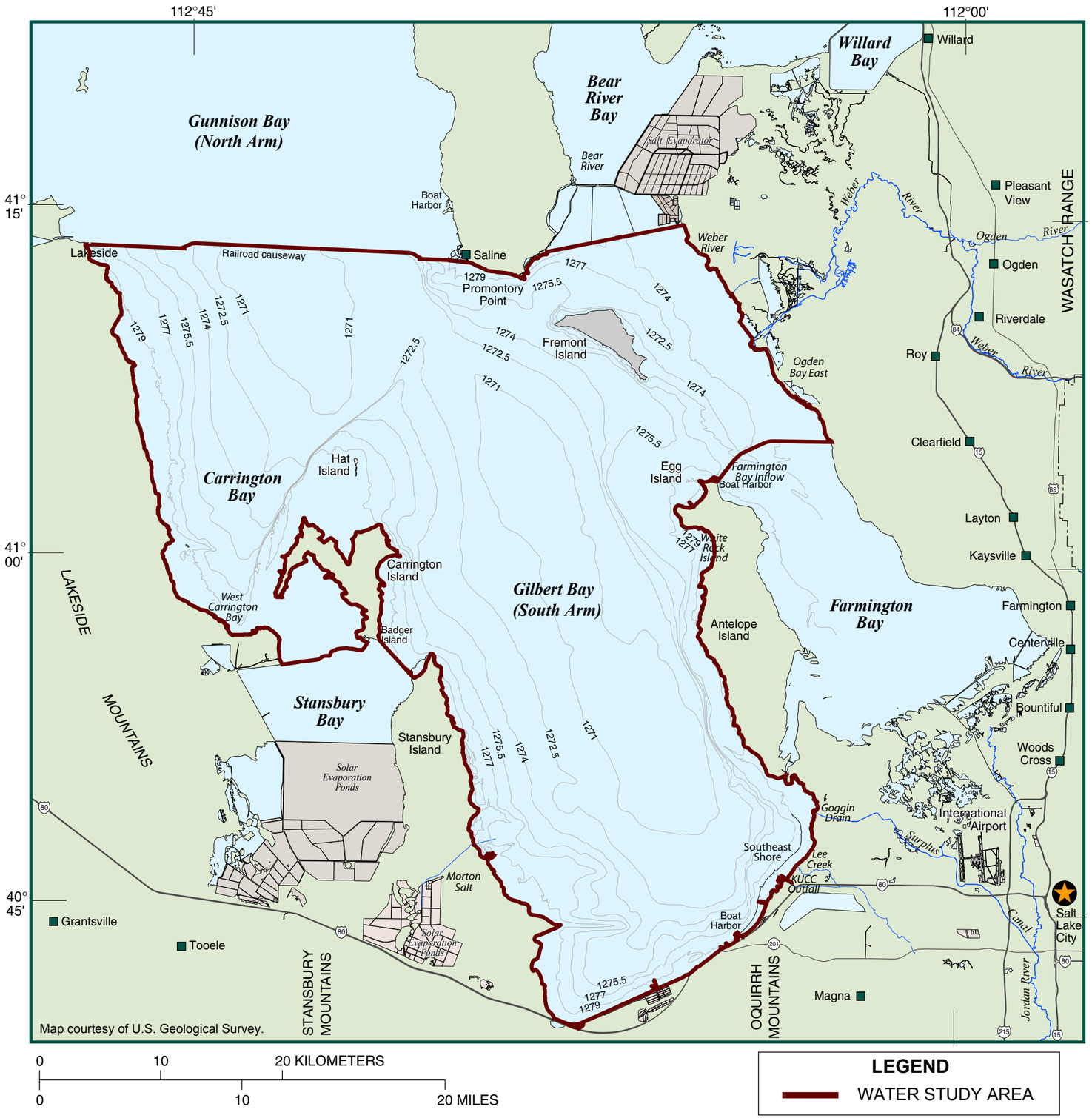

FIGURE 1-1
Study Area
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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On average, 2.9 million acre-feet of water and 2.2 million tons of salt enter Great Salt Lake each year. The vast majority of lake inflow typically comes from three drainages: the Jordan River (9 percent), Weber River (13 percent), and Bear River (39 percent). Additional inflow comes from groundwater (3 percent), direct precipitation (31 percent), and other minor east-side streams (5 percent) (Arnow and Stephens, 1987). Because the lake's only substantial water loss mechanism is evaporation, minerals, salts, and sediments from the watershed accumulate in Great Salt Lake. This results in lake water that is typically three to five times more salty than sea water and creates a unique habitat for biota that have adapted to and rely on the Great Salt Lake ecosystem.

1.2 Resources Dependent on Great Salt Lake

Great Salt Lake's unique yet harsh conditions are significant to the ecology and economy of the region and Western Hemisphere. Each of the lake's resources—including bird habitat, people, the mineral industry, and brine shrimp harvesters—maintains a fragile balance with the ecology of Great Salt Lake, often dependent on the annual conditions of the lake for its scale, diversity, and economic value.

Millions of birds use the lake as they migrate from breeding grounds as far away as the arctic to wintering areas as far away as Argentina. For example, up to 1 million Wilson's phalaropes (*Phalaropus tricolor*), or more than two-thirds of the world's population, annually migrate through Great Salt Lake as they travel from the near arctic to the high Andes (Jehl, 1988; Colwell and Jehl, 1994). The magnitude of the Wilson's phalarope population was a primary factor in the designation of Great Salt Lake as one of six sites within the Western Hemisphere's Shorebird Reserve Network in the United States (Aldrich and Paul, 2002). Over half of the world's population of eared grebes (*Podiceps nigricollis*) use Great Salt Lake for up to 4 months during fall migration (Jehl, 1988), and in 2007 their population on Great Salt Lake exceeded 2.5 million birds (N. Darnall, personal communication, October 15, 2007). Great Salt Lake hosts the largest nesting colony of American white pelicans (*Pelecanus erythrorhynchos*) west of the continental divide (King and Anderson, 2005) and the largest breeding population of California gulls (*Larus californicus*) in the world (Aldrich and Paul, 2002).

Opportunities for recreation abound on and around Great Salt Lake. Thousands of people visit the lake annually to enjoy sailing, hiking, hunting, and watching the diverse bird life. Along the lake are two state parks, numerous state wildlife refuges, and one federal wildlife refuge. Waterfowl hunting alone was estimated to be almost an $8-million industry in 1998 (Isaacson et al., 2002).

As a result of the minerals left behind by evaporation, Great Salt Lake is home to a burgeoning mineral industry that is perhaps the Great Salt Lake industry with the greatest impact on Utah's economy (Isaacson et al., 2002). Several mineral extraction companies currently operating on Great Salt Lake generated a total of about 2.8 million tons of sodium chloride, potassium sulfate, magnesium chloride, magnesium metal, chlorine gas, and other products—all estimated to be worth about $300 million in 1995 (Gwynn, 1997). This represents about 16 percent of the annual value of all minerals produced in 1995 in Utah (U.S. Geological Survey [USGS], 1995).

Great Salt Lake produces a significant portion of the world's supply of brine shrimp cysts. Commercial harvest on the lake began in 1952, and the lake has become an internationally renowned source of cysts for their quality as feed for the aquaculture and ornamental fish industry. The market value is estimated to average $8 to 11 million annually with an estimated peak value of $58 million in 1995. The annual harvest from Great Salt Lake is often limited by biological factors rather than market forces (Isaacson et al., 2002).

1.3 Study Area

Figure 1-1 shows the study area referred to as the "open waters of Great Salt Lake" for this project. This area is commonly referred to in the literature as Gilbert Bay or the South Arm, and includes Ogden Bay and Carrington Bay within its area (Gwynn, 1987). Farmington Bay, Gunnison Bay (also known as the North Arm), Bear River Bay, Willard Bay, and Stansbury Bay are not included in the study area.

The study area is generally bounded by the shoreline as defined by the current lake water level but an area no greater than as represented by the lake's bed elevation of 4,202 feet (Moellmer, 2007, personal communication). The Union Pacific Railroad Causeway separates Gilbert Bay from Gunnison Bay and Bear River Bay. The Antelope Island Causeway and Island Dike Road at the southern end of Antelope Island separate Gilbert Bay from Farmington Bay. A series of evaporation pond dikes separate Gilbert Bay from what was historically known as Stansbury Bay.

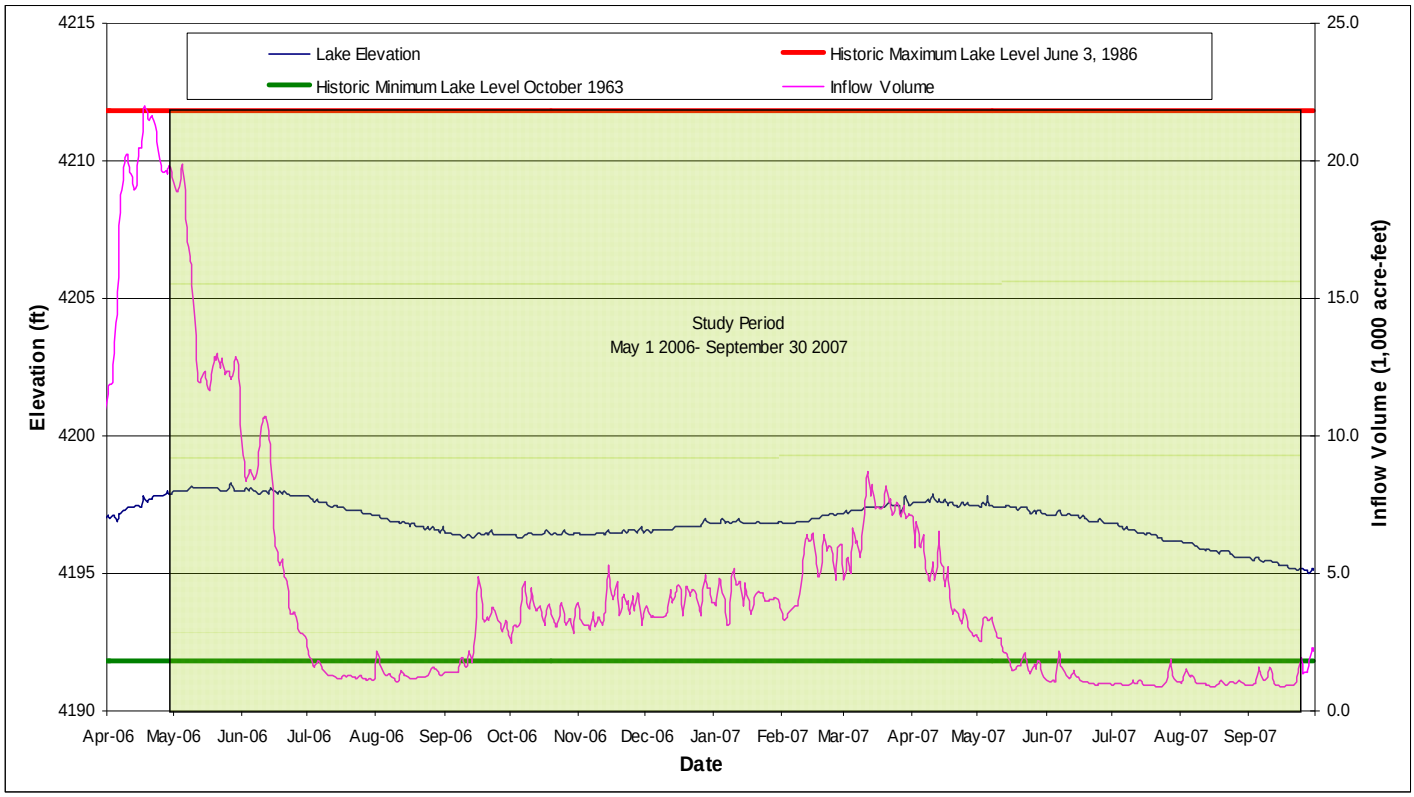
1.4 Lake Conditions during the Study Period

As previously described, Great Salt Lake is a uniquely dynamic water body dependent on a wide variety of variables that affect its physical characteristics. While an objective of this selenium program is to characterize the cycling of selenium in Great Salt Lake, it is important to understand the context of the research in terms of the historic variability of the lake and its watershed. Field studies for this program began in May 2006 and generally ended in September 2007.

1.4.1 Lake Level

The lake elevation for the study period, as measured at the USGS station at Saltair (USGS 10010000 Great Salt Lake at Saltair Boat Harbor, Utah), varied from 4,198.0 feet on May 1, 2006 to 4,195.1 feet on September 30, 2007 (see Figure 1-2). The maximum lake elevation in the study period was 4,198.3 feet (May 27, 2006) and the minimum elevation was 4,195.0 feet (September 28, 2007). As noted earlier in Section 1.1, the lake elevation has historically fluctuated more than 20 feet with a maximum elevation of 4,211.85 feet in 1986 and a minimum elevation of 4,191.85 feet in 1963.

FIGURE 1-2
Lake Elevation and Inflow Volume throughout Study Period



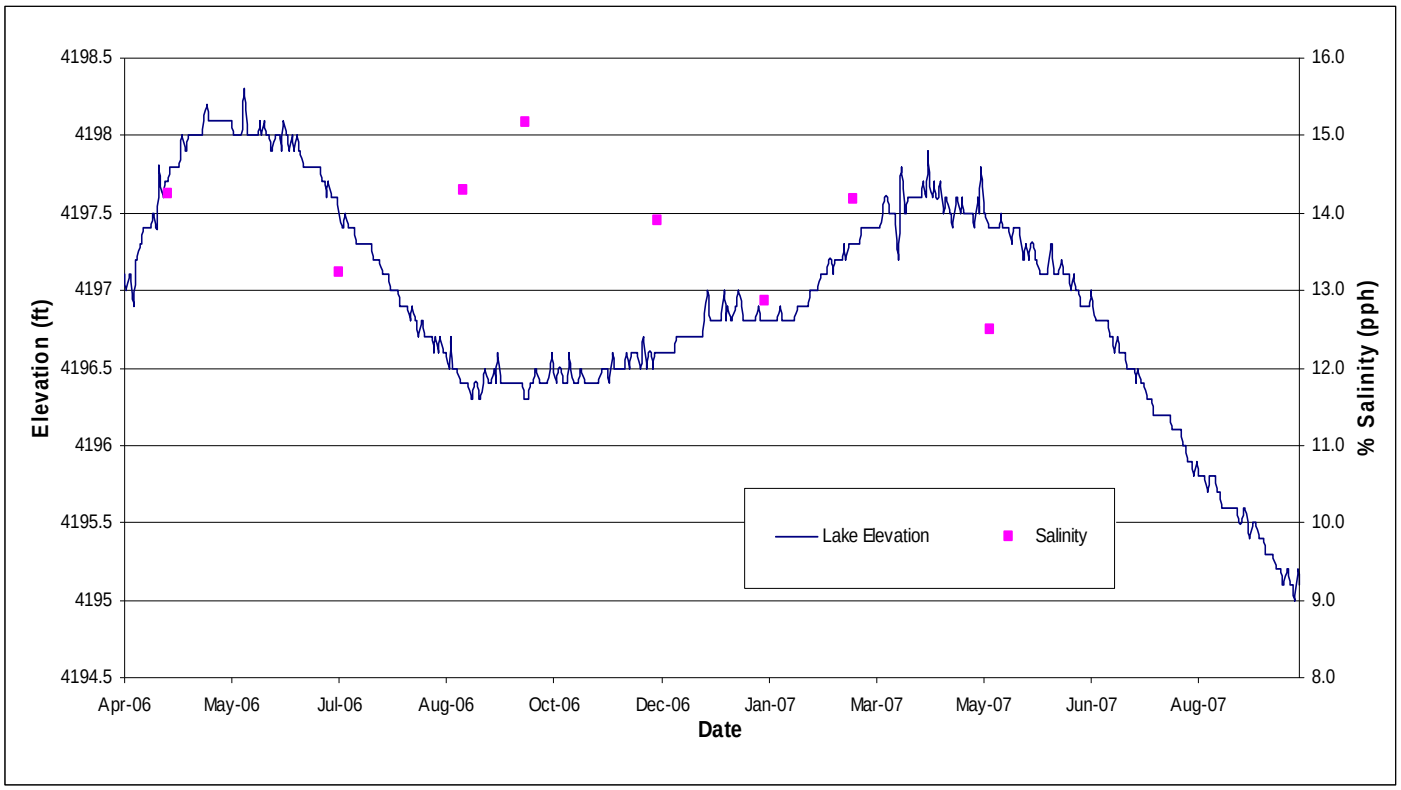
1.4.2 Surface Area and Volume

The surface area and water volume of the study area for the study period varied from an area of 743 square miles and volume of 8,273,227 acre-feet on May 1, 2006 to an area of 659 square miles and volume of 6,908,632 acre-feet on September 30, 2007 (as estimated from the elevation/volume relationship of Baskin [2005]). This represents a reduction in surface area of about 11 percent and a reduction in volume of about 16 percent over the study period. The lake's surface area varied between 2,500 and 938 square miles between 1873 (similar elevation as in 1986) and 1963, respectively (Hahl and Handy, 1969).

1.4.3 Salinity

The USGS monitors the salinity of Great Salt Lake at 16 locations on a monthly basis. The salinity for the study period, as measured by the USGS, varied from 14.2 percent in April 2006 to 12.5 percent in May 2007. The maximum measured salinity in the study period was 15.2 percent and the minimum measured salinity was 12.5 percent. See Figure 1-3 for salinity values plotted along with lake elevations for the study period. The lake's salinity generally varies inversely with lake level and has historically varied between 5.6 percent in 1986 to 28 percent in 1963 (Arnow and Stephens, 1987).

FIGURE 1-3
Lake Elevation and Salinity

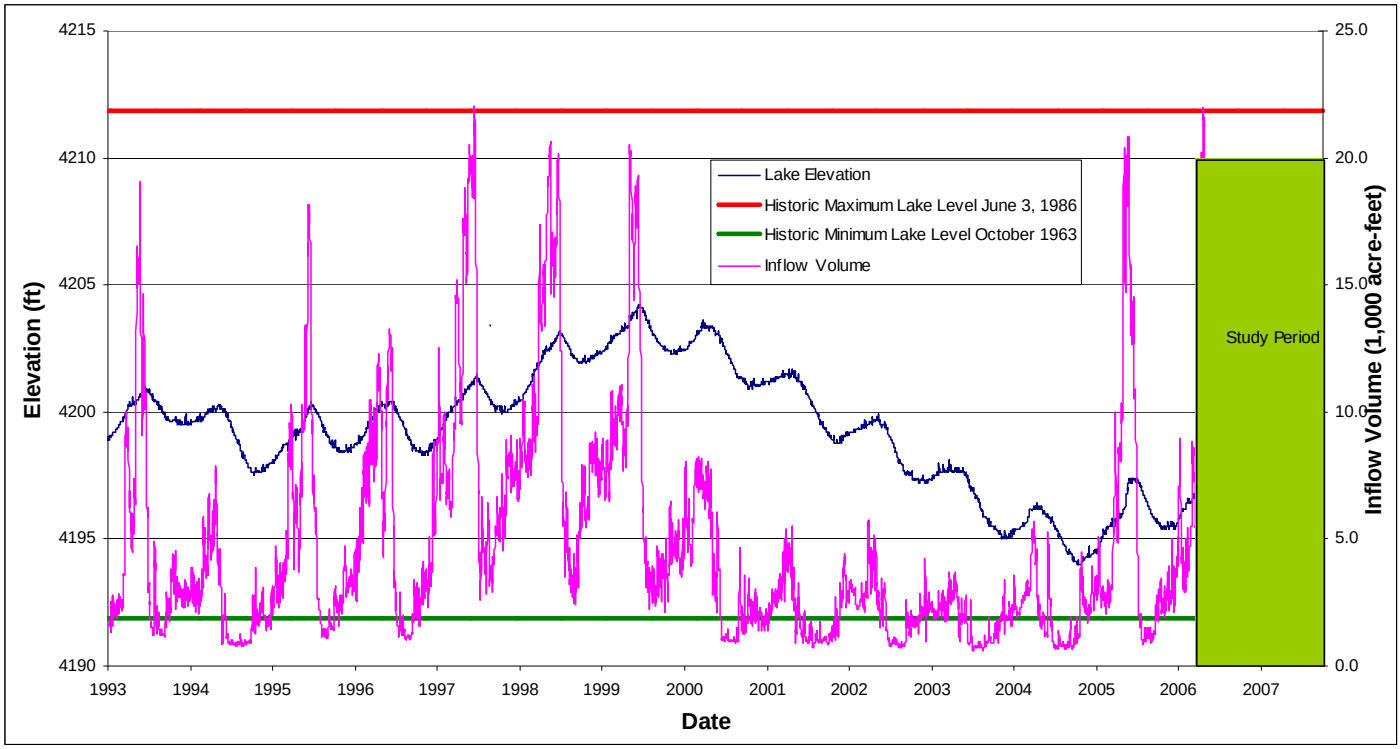


1.4.4 Hydrology

The elevation, size, and salinity of Great Salt Lake vary largely as a result of changes in inflow from precipitation, tributaries, and groundwater, as well as from losses through evaporation. Understanding the watershed's recent hydrologic regime helps to place the lake's response during the study period in context.

The study period (May 2006 through September 2007) provided a unique opportunity to understand the dynamics of Great Salt Lake during a dry period of the hydrologic cycle. The two indices used by the State of Utah to define and compare cumulative drought events, the Palmer Drought Severity Index (PDSI) and the Palmer Hydrologic Drought Index (PHDI), indicate that the watershed moved into a drought condition during the study period (Utah Division of Water Resources, 2007). Great Salt Lake's watershed had a PDSI and PHDI in May 2006 that indicated "moderately moist" to "very moist" conditions in the watershed. This is consistent with the generally "wet" water years of 2005 and 2006. Throughout the study period, however, conditions consistently became drier within the watershed and the PDSI and PHDI at the end of the study period in September 2007 indicated "severe drought" to "extreme drought" condition in the watershed (National Oceanic and Atmospheric Administration, 2007). These effects of the dry cycle can also be observed in Figure 1-4; lake levels generally decreased during the study period as inflow volumes decreased. While the effects of a drought period upon the cycling of selenium in Great Salt Lake are not understood, it is certainly a variable that affects the dynamics of the lake.

FIGURE 1-4
Lake Elevation and Inflow Volume 1993 to 2007



1.5 Document Organization

The remainder of this document is divided in the following sections:

- Section 2.0 provides the historical background of the project, regulatory framework, and need for a numeric site-specific water quality standard.
- Section 3.0 describes the development of the Utah Division of Water Quality's (UDWQ's) public involvement, consultation, and coordination program and the development of the overall selenium program.
- Section 4.0 defines the objectives for the overall selenium program and for each of the individual projects.
- Section 5.0 provides a summary of the program's quality assurance protocol and the results and conclusions for each of the seven projects.
- Section 6.0 provides a summary of the considerations, assumptions, and methodology used to develop a quantitative model of selenium cycling in the open waters of Great Salt Lake.
- Section 7.0 provides a summary of the results of the conceptual model for each of the alternatives selected by the Science Panel.
- Section 8.0 identifies considerations and recommendations for implementation of a new selenium water quality standard for the open waters of Great Salt Lake.

- Section 9.0 provides a summary of this report and offers conclusions based on the presented information.
- Section 10.0 provides references cited in this document.

Final reports and other pertinent technical memoranda prepared as part of this program are included in the appendices of this document.

- Appendix A, Conceptual Model for Selenium Cycling in the Great Salt Lake
- Appendix B, Recommended Guidelines Fact Sheet and Threshold Values Memoranda
- Appendix C, Project 1A - Shorebirds
- Appendix D, Project 1B – Gulls, Grebes, Ducks
- Appendix E, Project 2A - Benthic Zone and Brine Flies
- Appendix F, Project 2B - Pelagic Zone and Brine Shrimp
- Appendix G, Project 3 - Selenium Loads to the Lake
- Appendix H, Project 4 - Selenium Flux within and from the Lake
- Appendix I, Project 5 - Brine Shrimp Kinetics Study
- Appendix J, Data Validation Report
- Appendix K, Avian Blood Memo
- Appendix L, Evaluation of Mercury Concentrations in Birds Collected from Great Salt Lake, 2006 and 2007
- Appendix M, Science Panel White Papers

2.0 Program Background

2.1 Historical Perspective

Great Salt Lake and its shores have been the subject of management deliberations arguably since the first Mormon pioneers settled near its shores in 1847. These deliberations historically centered primarily upon resource use and allocation. Increasing development of those resources in the latter part of the 20th century shifted that focus towards defining the ecological resources of Great Salt Lake and protecting them. What was first considered a relatively simple ecosystem composed of algae, brine shrimp, brine flies, and bird life, was discovered to be a very complex and dynamic ecosystem. It rapidly became apparent that the lack of a comprehensive database describing the complex ecosystem made it very difficult to make management decisions resulting in its protection (Atwood et al., 1999).

State and federal agencies historically have collected a significant amount of information characterizing lake level fluctuations, water balance, and salt balance throughout Great Salt Lake. While appropriate for some management decisions, additional information was needed to understand the ramifications of those decisions on the Great Salt Lake ecosystem. The State of Utah completed the Great Salt Lake Comprehensive Management Plan in 1997 and updated it again in 2000 (UDNR, Great Salt Lake Planning Team, 2000). The State of Utah initiated the Great Salt Lake Ecosystem Project in 1994 to work towards understanding the ecology of Great Salt Lake (Stephens and Birdsey, 2002).

The Ecosystem Project and other efforts have worked to understand:

- How the algal growth rate, competitive interactions, abundance, and species composition fluctuate as they relate to salinity, temperature, and nutrient influxes
- How brine shrimp survival and reproduction fluctuate with salinity, temperature, nutrient influxes, algal abundance and species composition, and predation from other zooplankton
- Great Salt Lake bird species—both their numbers and how they use lake resources
- The complex limnology of Great Salt Lake as it relates to salinity, temperature, lake levels, water balance and mixing, and contaminant and nutrient influxes

It has been found that these processes do not operate independently but interact and seem to vary—sometimes significantly—from year to year (Atwood et al., 1999). These studies confirmed that Great Salt Lake's ecosystem is unique and much more complex than previously thought.

2.2 Existing Regulatory Framework

The federal Water Pollution Control Act Amendments of 1972—also known as the Clean Water Act—established the institutional structure for the U.S. Environmental Protection Agency (EPA) to regulate discharges of pollutants into the waters of the United States,

establish water quality standards, conduct planning studies, and provide funding for specific grant projects. The Clean Water Act has been amended by Congress several times since 1972. The EPA has provided most states with the authority to administer many of the provisions of the Clean Water Act.

The UDWQ has specified appropriate beneficial uses for waters of the State and achieve and protect those uses through the development and enforcement of water quality standards (40 *CFR* §131.11). Due to the unique geochemistry of Great Salt Lake, the application of national fresh-water selenium water quality criteria to Great Salt Lake is inappropriate (EPA 1987, 2004). The open waters of Great Salt Lake have instead been protected for their beneficial uses through the application of the following narrative criteria clause in the State water quality standards (R317-2-7):

> *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.*

The beneficial uses designated for Great Salt Lake are listed in R317-2-6, Use Designations and summarized in Table 2-1.

TABLE 2-1
Beneficial Uses of Waters of Great Salt Lake

Beneficial Use
Primary Contact Recreation
Secondary Contact Recreation
Waterfowl, Shorebirds, and Other Water-Oriented Wildlife
Aquatic Food Chain Organisms
Mineral Extraction

The narrative standard has been implemented by the State of Utah in part through requiring that any discharges to fresh water tributaries must meet fresh water numeric water quality standards. Any discharges directly to Great Salt Lake are required to meet background concentrations in the lake, or the State has required the discharger to complete site-specific studies to establish a protective numeric standard (Ostler, 2004).

Kennecott Utah Copper Corporation completed studies from 2000 to 2002 establishing a site-specific water quality standard for selenium that would be included as part of their Utah Pollution Discharge Elimination System (UPDES) discharge permit to Great Salt Lake (Brix et al., 2004). These studies evaluated the potential bioaccumulation of selenium in aquatic-dependent birds (such as shorebirds and waterfowl) from their diet of brine shrimp,

and indicated that the bird diet (for example, brine shrimp) should not exceed 5 milligrams of selenium per kilogram (mg Se/kg) to be protective. Applying that dietary selenium threshold for aquatic birds to the relationship between water and brine shrimp tissue levels resulted in an estimate of 27 micrograms selenium per liter (µg Se/L) as a safe concentration in water for this exposure pathway. Therefore, the narrative standard is interpreted to mean that a "de facto" chronic numeric standard for selenium in Great Salt Lake is 27 µg Se/L. This is the value the UDWQ currently uses in assessing and enforcing UPDES discharge permits to Great Salt Lake (UDWQ fact sheet, 2004a).

2.3 Need for a Site-Specific Standard

Mining and other activities in the southwestern Salt Lake Valley have resulted in groundwater with elevated sulfate concentrations that threaten the integrity of an important municipal water supply. Under federal Superfund Law and provisions of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), the State of Utah and its partners developed a joint proposal to develop and construct a groundwater extraction and treatment project, with groundwater remedial functions, to provide treated municipal-quality water to the public in southwestern Salt Lake Valley. The proposed reverse osmosis (RO) treatment processes that remove the contaminants also generate a concentrated brine requiring disposal.

Some of the RO concentrate was initially proposed to be discharged to the Jordan River. A UPDES discharge permit to do so was obtained from the State of Utah. Under its UPDES permit, remaining RO concentrate was to be recycled by the Kennecott Utah Copper Corporation with excess water discharged to Great Salt Lake. As a result of public comments focusing primarily upon selenium concentrations in the RO concentrate, the UPDES permit for discharge to the Jordan River was withdrawn and efforts were renewed to find an alternative disposal location for concentrate waters to be produced from the treatment process (Jordan Valley Water Conservancy District, 2006).

After evaluating 15 alternatives, the stakeholder forum recommended that discharge of the concentrate to Great Salt Lake be considered following additional research and verification that discharge of such concentrate will not be harmful to the Great Salt Lake ecosystem. Selenium was the primary constituent of concern. The State of Utah subsequently convened the Great Salt Lake Water Quality Steering Committee (Steering Committee), consisting of key stakeholders similar in structure to the stakeholder forum discussed previously, and an expert Science Panel to recommend a new selenium water quality standard for the Great Salt Lake. Information developed from that process will serve as the basis for further public comment and to determine if regulatory approval of a UPDES permit for discharge of the concentrate to Great Salt Lake is feasible. The stakeholder forum is expected to reconvene and make its final recommendation after a site-specific water quality standard is in place (Jordan Valley Water Conservancy District, 2006).

2.4 Development of a Site-Specific Standard

Site-specific water quality standards that reflect the unique biota, habitat, and geochemistry of a water body are allowed by federal and state regulations. The Clean Water Act provides states with the opportunity to adopt water quality standards that are "…modified to reflect

site specific conditions" (40 *CFR* §131.11[b][1][ii]). Site-specific standards are intended to account for species composition and water quality characteristics at the site and result in better levels of protection to aquatic life at the site than national criteria. The State of Utah rules also provide for the development of site-specific numeric water quality standards:

> *The Board may allow site-specific modifications based upon bioassay or other tests performed in accordance with standard procedures determined by the Board* (State of Utah, 2007b).

Federal regulations require that states submit to the EPA the "methodologies used for site-specific criteria development, any general policies applicable to water quality standards, and any revisions to the standards" (40 *CFR* §131.20[c]). In addition, water quality criteria must be based on "sound scientific rationale" (40 *CFR* §131.11). Lastly, states should establish numeric standards "based on Clean Water Act Section 304(a) Guidance modified to reflect site-specific conditions, or other scientifically defensible methods" (40 *CFR* §131.11[ii],[iii]; see also the EPA's Water Quality Standards Handbook [1994], Chapter 3, Water Quality Criteria).

The approach for development of a site-specific standard for selenium in the open waters of Great Salt Lake is atypical for several reasons. The EPA typically derives water quality criteria for aquatic organisms (that is, it does not directly address aquatic-dependent wildlife), the EPA applies toxicity data that are based on water-column concentrations and result in direct effects on test organisms (that is, it does not directly address dietary exposure), and it derives criteria that are presented as water column concentrations (Wuerthele, 2004). For selenium in Great Salt Lake, there are a number of factors that are not ideally addressed by the typical EPA protocol, such as the following:

- Selenium is a bioaccumulative toxicant, with dietary exposure as a key pathway.
- Chronic selenium criteria, therefore, are appropriately presented as threshold tissue-based values.
- Although the aquatic community in Great Salt Lake is rather limited, it is an important resource for aquatic-dependent birds.
- For Great Salt Lake, potential effects on aquatic-dependent birds must be a key consideration in standard development.
- The chemistry of Great Salt Lake is unique.

Furthermore, the EPA's typical approach to aquatic life criteria development requires a minimum dataset with data to include a range of functional groups and sensitive taxa (such as a salmonid, a second recreationally or commercially important fish family, another aquatic vertebrate, a planktonic crustacean [for example, cladoceran], a benthic crustacean [for example, amphipod, an aquatic insect, etc.]) to derive acute and chronic criteria (Wuerthele, 2004).

The current national ambient water quality criteria (EPA, 1987) are based on a number of studies at Belews Lake, North Carolina, with the chronic criterion set at 5 µg Se/L (total recoverable selenium). More recently (EPA, 2004), EPA has proposed draft criteria that are based on whole-body fish tissue (chronic value equals 7.91 µg Se/g dry weight) based on a winter stress study with bluegill. That chronic value is not appropriate for

Great Salt Lake for a number of reasons (absence of fish, etc.), so the site-specific standard must be based on conditions applicable to the lake (as described in Section 3.0).

Past efforts to develop water quality standards for selenium for Great Salt Lake have focused on dietary exposure as a key pathway to waterfowl and shorebirds that feed there. As described previously, this is due to the bioaccumulative nature of selenium, and resulted in a suggested chronic selenium criterion that was expressed as a threshold tissue-based value (Brix et al., 2004). Potential effects of selenium concentrations in these kinds of birds will play an important role in the development of a new Great Salt Lake site-specific selenium standard. Given the unique chemistry and limited dataset describing the Great Salt Lake's ecology, site-specific selenium standards will have to consider other factors, such as the following (Wuerthele, 2004):

- A key aquatic organism will need to be identified for which a tissue-based value may be developed.
- A tissue-based toxicity threshold value for the aquatic organism will need to be evaluated and determined that will protect wildlife dependent on that aquatic organism as a food resource.
- The evaluation should include an assessment of whether the whole-body toxicity threshold value will be protective of critical endpoints in wildlife, such as reproductive success.
- A relationship will need to be derived to allow the translation of a tissue-based toxicity threshold concentration to a water column concentration. This will be required for use as a basis for regulating discharges to Great Salt Lake.
- Accurate and precise methods will be needed to measure selenium in Great Salt Lake water and in tissues of aquatic organisms.

Pursuant to the lack of an adequate understanding of the fate of selenium in Great Salt Lake and the requirements identified above, the State of Utah initiated the current program to complete the requisite scientific research to develop a numeric water quality standard for the open waters of Great Salt Lake.

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3.0 Program Development

This section summarizes the development of the UDWQ's public involvement, consultation, and coordination program—including the Steering Committee, the Science Panel, and a public involvement program—and the development of the overall selenium program (including analytical methodologies, a conceptual model for selenium in Great Salt Lake, threshold values, and the research program).

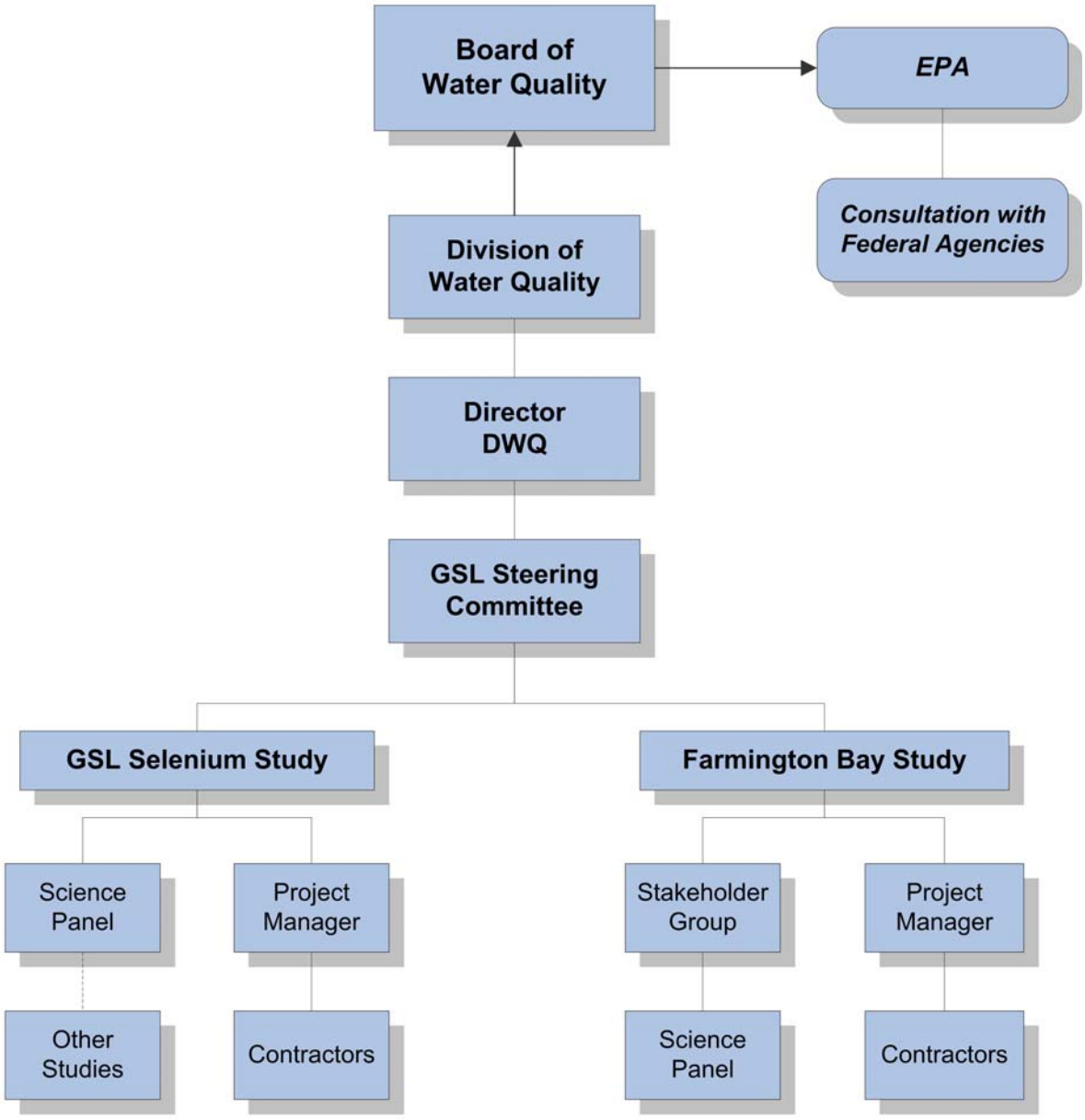
3.1 Public Involvement, Consultation, and Coordination

It was the objective of the UDWQ for the selenium program to be an inclusive and transparent process where input was actively solicited from a broad range of interests and incorporated into the decision-making process. Representatives from federal and state regulatory and resource agencies, other public entities, conservation organizations, recreation groups, and industrial users of the lake would not simply be informed of progress but would be actively involved in developing and recommending a new water quality standard to the State Water Quality Board. To that end, the UDWQ formed the Steering Committee and the expert Science Panel. These two groups were responsible for instituting and developing the selenium program described in this document. A public involvement strategy was integrated to also incorporate input from the general public.

3.1.1 Great Salt Lake Water Quality Steering Committee

The UDWQ formed the Steering Committee to recommend site-specific numeric water quality standards for Great Salt Lake to the State Water Quality Board. The standards are to be developed in such a way that they (1) prevent impairment of the lake's beneficial uses and (2) sustain the natural resources of the lake and associated wetlands (UDWQ, 2004a). The intent is for the Steering Committee to begin with the development of a water quality standard for selenium for the open waters of Great Salt Lake and then move to other constituents/contaminants as required. The Steering Committee currently also oversees a program to define and determine whether Farmington Bay's beneficial uses are impaired. Figure 3-1 illustrates the organizational structure for the Great Salt Lake Water Quality Studies program.

FIGURE 3-1
Organizational Structure



Members of the Steering Committee were originally identified by the UDWQ to represent the wide spectrum of interests in Great Salt Lake. The UDWQ worked with various prospective members to ensure the Steering Committee would fairly represent the broadest range of stakeholders. Table 3-1 identifies the 16 current members of the Steering Committee, their alternates, and the groups they represent. The Steering Committee had its first meeting on August 18, 2004, and has met at monthly or quarterly intervals as required since then. Steering Committee meeting dates, times, and locations were distributed to the members and posted on the Web site as soon as the dates were known, typically a month before the meeting. Meeting agendas and any related review materials were distributed via e-mail. An e-mail list (e-mail group that included the Steering Committee members and other interested individuals from the public) was established to facilitate the distribution of

materials and communications. All meetings are advertised on the project Web site, announced to all interested stakeholders by e-mail, and open and free for the public to attend. Overall, 24 meetings were held throughout the selenium program from August 18, 2004 to May 2, 2008.

TABLE 3-1
Great Salt Lake Water Quality Steering Committee Members, their Affiliations, and Alternates

Members	Alternates
Dave Grierson Utah Department of Natural Resources/Forestry Fire and State Lands Representing State Government	No alternate designated
Clay Perschon Utah Department of Natural Resources/Division of Wildlife Resources Representing State Government	John Luft DNR/Division of Wildlife Resources Representing State Government
Karen Hamilton U.S. EPA, Region 8 Representing Federal Government	Jim Berkley U.S. EPA, Region 8 Representing Federal Government
Nathan Darnall U.S. Fish and Wildlife Service/Utah Field Office Representing Federal Government	Larry Crist U.S. Fish and Wildlife Service/Utah Field Office Representing Federal Government
David Naftz U.S. Geological Survey Representing Federal Government	Robert Baskin U.S. Geological Survey Representing Federal Government
Don Leonard Utah Artemia Association Representing Aquaculture	No alternate designated
Jim Huizingh Morton Salt Representing Industry	Tom Tripp US Magnesium, LLC Representing Industry
Kelly Payne Kennecott Utah Copper Representing Industry	Reed Bodell Kennecott Utah Copper Representing Industry
Richard Bay Jordan Valley Water Conservancy District Representing Municipalities	Mark Attencio Jordan Valley Water Conservancy District Representing Municipalities
Leland Myers Central Davis Sewer District Representing Publicly Owned Treatment Works	Jill Houston Central Davis Sewer District Representing Publicly Owned Treatment Works
Maunsel Pearce Great Salt Lake Alliance Representing Conservation Organizations	Bruce Waddell Great Salt Lake Alliance Representing Conservation Organizations
Chris Montague The Nature Conservancy of Utah Representing Conservation Organizations	Lynn de Freitas Friends of the Great Salt Lake Representing Conservation Organizations

TABLE 3-1
Great Salt Lake Water Quality Steering Committee Members, their Affiliations, and Alternates

Members	Alternates
Richard West West Side Associated Duck Clubs Representing Duck Clubs	Richard N. Gilbert Ambassador Duck Club Representing Duck Clubs
Delane McGarvey Representing Local Government	Florence Reynolds Salt Lake City Department of Public Utilities Representing Local Government
Richard Sprott Department of Environmental Quality Representing State Government	Bill Sinclair Utah Department of Environmental Quality Representing State Government
Walt Baker DEQ/Division of Water Quality Representing State Government	Leah Ann Lamb DEQ/Division of Water Quality Representing State Government

Source: *List of Great Salt Lake Steering Committee Members and Alternates*, April 17, 2008

The specific objectives of the Steering Committee are to (UDEQ, 2004a):

- Create a partnership among stakeholders, including industry, government agencies, and nongovernmental organizations to:
  - Gain broad acceptance of process and results
  - Provide access to expertise and experience
  - Provide multiple funding sources
- Conduct a transparent public process by:
  - Identifying stakeholders
  - Receiving input
  - Sharing results
  - Seeking consensus
- Establish, at the beginning of the process, and maintain a scientific advisory panel to:
  - Identify gaps in scientific understanding of the lake chemistry and ecology
  - Advise the Steering Committee on funding applications
  - Prioritize water quality parameters of concern
  - Define and approve work plans for scientific studies
  - Provide for independent peer review of scientific studies
  - Recommend science-based numeric standards to the Steering Committee
- Sponsor and guide scientific research by:
  - Defining study objectives (for example, fate, bioaccumulation, toxicity)
  - Securing funding
  - Specifying or sponsoring development of appropriate study methods
  - Sponsoring data collection
  - Reporting results

- Adhere to federal and state statutes, regulations, and guidelines for standards development when:
  - Coordinating with EPA Region 8 on process for developing site-specific standards
  - Using results and recommendations of scientific research to determine appropriate numeric standards
  - Recommending numeric standards to Utah Water Quality Board for incorporation into the state Water Quality Administrative Rules

The Steering Committee works together using a consensus-building approach. A quorum is defined as two-thirds of the committee. A vote of two-thirds is required to accept procedural proposals and a supermajority of 75 percent is required for approval of proposals of a substantive nature. A supermajority of 75 percent of the committee is defined as a point where consensus has been achieved and is required for a recommendation to be forwarded to the Utah Water Quality Board. If a supermajority cannot be reached, then position papers for all opinions will be forwarded to the Utah Water Quality Board.

3.1.2 Science Panel

The Science Panel was formed by the Steering Committee to provide technical guidance, oversight, and review of required research for the selenium program, and recommend a water quality standard. While many members of the Steering Committee have significant technical expertise, the nine members of the Science Panel were carefully selected based upon their specific technical expertise and experience rather than the interests they represent. A core group of five panel members, including Dr. Joseph Skorupa/U.S. Fish and Wildlife Service, Dr. Theresa Presser/U.S. Geological Survey, Dr. William Adams/Rio Tinto, Dr. Anne Fairbrother/Parametrix, Inc., and Bill Wuerthele, were selected based upon their national expertise and experience addressing selenium in aquatic ecosystems. The cochairmen of the Panel, Dr. William Moellmer and Dr. Theron Miller—both representing the Utah Department of Environmental Quality—bring significant local experience with Great Salt Lake and state regulations. Dr. Don Hayes and Brad Marden also bring significant expertise of Great Salt Lake limnology, aquatic biology, and wetlands to the Science Panel.

The Steering Committee's charge to the Science Panel is as follows (UDEQ, 2004c):

- Review goals, objectives, decision-making procedures, and Science Panel Charges, and recommend adjustments
- Review membership and recommend adjustments or additional expertise needed
- Prepare scope of work for a consultant/contractor to:
  - Gather and review existing literature on features of the Great Salt Lake ecosystem
  - Gather and review pertinent site-specific and outside data on ecotoxicology of selenium
  - Gather and review pertinent site-specific and relevant outside data to define the lake chemistry (for example, the chemistry and fate of selenium through the upper

water column, brine layer, sediment, atmosphere, and biota) and evaluate the potential variance associated with water levels and atmospheric conditions

- Provide for independent peer review of scientific studies, as needed
- Identify gaps in scientific understanding that must be addressed to develop the standard
- Specify appropriate sampling and laboratory methodologies for selenium in Great Salt Lake, its tributaries, and discharges
- Prioritize other water contaminants of concern and suggest methods to include in present study, provided that such activities do not interfere with the development of a selenium standard
- Prioritize and recommend (to the Steering Committee) the research needed
- Assist the Steering Committee and the UDWQ in the following:
  - Selection of research contractors
  - Periodic review of contractors and work plans
  - Recommend atom of funding sources
- Interpret literature and results of site-specific scientific studies and agree on conclusions toward the standard
- Periodically report to the Steering Committee on progress and significant findings
- Recommend standard(s) to the Steering Committee
- Review and comment on methodologies and media needed for continued monitoring of selenium accumulation in the Great Salt Lake ecosystem

The Science Panel meeting dates were generally developed in coordination with the members, and dates, times, and locations were distributed to the Steering Committee and public as soon as the dates were known. Meeting agendas and any related review materials were distributed among the Science Panel via e-mail and the meeting agendas were distributed to the Steering Committee and public via e-mail. All meetings were advertised on the project Web site, were announced to all interested stakeholders by e-mail, and were open and free for the public to attend. Science Panel meetings were often held in Salt Lake City with conference calls held monthly to facilitate project communication and coordination. Printouts of meeting handout materials were provided at each meeting. These materials were also posted on the Web site after the meeting. Throughout the selenium program, the Science Panel held 11 meetings and 17 conference calls from November 9, 2004 to May 2, 2008.

The Science Panel members determined that while they can and will address questions of a scientific nature, they cannot address questions of a philosophical or political nature. The Science Panel proposed to the Steering Committee, and received approval from the Committee at its March 21 through 23, 2007 meeting, to forward a recommended palette of values for a water quality standard to the Steering Committee to evaluate. The delivery of a range of values replaced the original intent of the delivery of one recommended specific

value for a water quality standard. Science Panel members will also provide "white papers" with their individual recommendations to assist in the Steering Committee's deliberations.

3.1.3 Public Involvement Program

Public involvement is a process by which interested and affected individuals, organizations, agencies, and government entities are consulted to participate in a decision-making process. Due to the complexity of issues involved in development of the selenium program and the diversity of interests with a stake in protection of Great Salt Lake, an extensive public involvement effort was conducted. The goal of this effort for the selenium program was to understand and address public concerns and issues and to develop the selenium program so that it addressed these concerns and issues.

To meet the goal of the public involvement effort, an open and objective approach to the selenium program was developed. Through a variety of public involvement activities, such as Steering Committee meetings, facilitating public participation in project meetings, and information materials, the State solicited public input for preparation of the selenium program. The public involvement approach developed for the selenium program was to facilitate a two-way exchange of information.

Overall, the approach to public involvement consisted of the following three main components:

- **The Steering Committee should address overall technical assumptions and policy issues.** The public involvement approach was integrated closely with the Steering Committee on overall technical assumptions and policy issues. The Steering Committee includes a diverse group of stakeholders from federal, state, and local regulatory, resource, and public agencies, as well as interested nongovernmental organizations. The Steering Committee brings a diverse array of expertise and knowledge of different scientific and policy issues that may shape the selenium program.

- **Technical approach and deliberations should be open and transparent to the public.** Transparency and the ability to participate were essential in developing the public's trust in the integrity of the effort. The UDWQ facilitated the means for the public to be invited to and participate in all Steering Committee and Science Panel meetings and conference calls. All reference, planning, and work products were made available for public consumption after Science Panel review and acceptance.

- **Public outreach is vital in addressing local concerns and issues.** The public provides a unique view of the concerns and issues that may not be provided by other stakeholder groups. The public is generally concerned about a wide variety of issues, whereas stakeholder groups may be focused on a set of specific issues. Therefore, the means were implemented to solicit input from the general public. These means included public Steering Committee and Science Panel meetings, e-mailed updates and notices to a list of interested parties, meeting handouts, and extensive project materials made available on the Web site at www.deq.utah.gov/issues/GSL_WQSC/index.htm.

This open and objective approach sought to involve a diverse group of individuals in all aspects and levels of the development of the selenium program.

3.2 Program Development

Figure 3-2 summarizes the process the Steering Committee developed for the selenium program (UDWQ, 2004d). Dates on this chart were updated to reflect the most recent available information. As previously discussed and illustrated in Figure 3-2, significant interaction between the Steering Committee, the Science Panel, and investigators was critical in developing and completing the aggressive program. An extensive program of research projects was envisioned to serve as the basis for the water quality standard; however, two tasks were identified as essential preliminary steps for the foundation of those projects: (1) development of analytical methodologies and (2) development of a conceptual model that characterizes selenium cycling in the open waters of Great Salt Lake. Subsequently, toxicity threshold values were developed in conjunction with the projects to frame the palette of values for the water quality standard that would be evaluated. This section describes the development of these three tasks and how they were used to shape the projects completed as part of the research program.

3.2.1 Analytical Methodologies

Various analytical methods have historically been used for analysis of water from Great Salt Lake. Recent analytical results for selenium have ranged from about 1 µg/L using hydride generation atomic absorption (HGAA) spectrometry to about 120 µg/L using graphite furnace atomic absorption (GFAA) spectrometry. Much of the variability is likely from interferences caused by the extreme salinity, high and variable total dissolved solids (TDS), and alkaline nature of Great Salt Lake waters. A practical analytical method that met sensitivity criteria, required minimal sample dilution, tolerated high TDS, minimized spectral interferences, and was simple and reliable was needed to help establish a baseline of selenium data for Great Salt Lake.

Under the direction of the Science Panel, UDWQ initiated a round-robin study among seven laboratories in 2004 to compare ambient selenium concentrations and low-level spike recoveries in Great Salt Lake water. This round-robin study is described in detail by Moellmer et al. (2007). Sample water from Great Salt Lake was collected from depths of 1 meter and 7 meters and filtered using a 0.45-micrometer membrane filter. Samples were sent to a third-party laboratory for preparation of replications and spiking. A total of 36 samples were sent to each of seven laboratories that used different analytical methods including conventional inductively coupled plasma—mass spectrometry (ICP-MS), passive and dynamic collision/reaction cell ICP-MS, octopole reaction cell ICP-MS (ORC ICP-MS), GFAA, and HGAA.

Two methods, HGAA and ORC ICP-MS, provided results that were adequately consistent and accurate as determined from spike recoveries. The other methods yielded significant positive bias and unusable results. As a result, the Science Panel identified HGAA as the only current method suitable for use in the selenium program. ORC ICP-MS is another possible method that may be used but will require further evaluation. Further, the Science Panel asked that all historic Great Salt Lake selenium water quality data that were not developed using HGAA or ORC ICP-MS be evaluated and potentially qualified as unsuitable for use. The Science Panel asked that water samples collected as part of the selenium program be analyzed using HGAA.

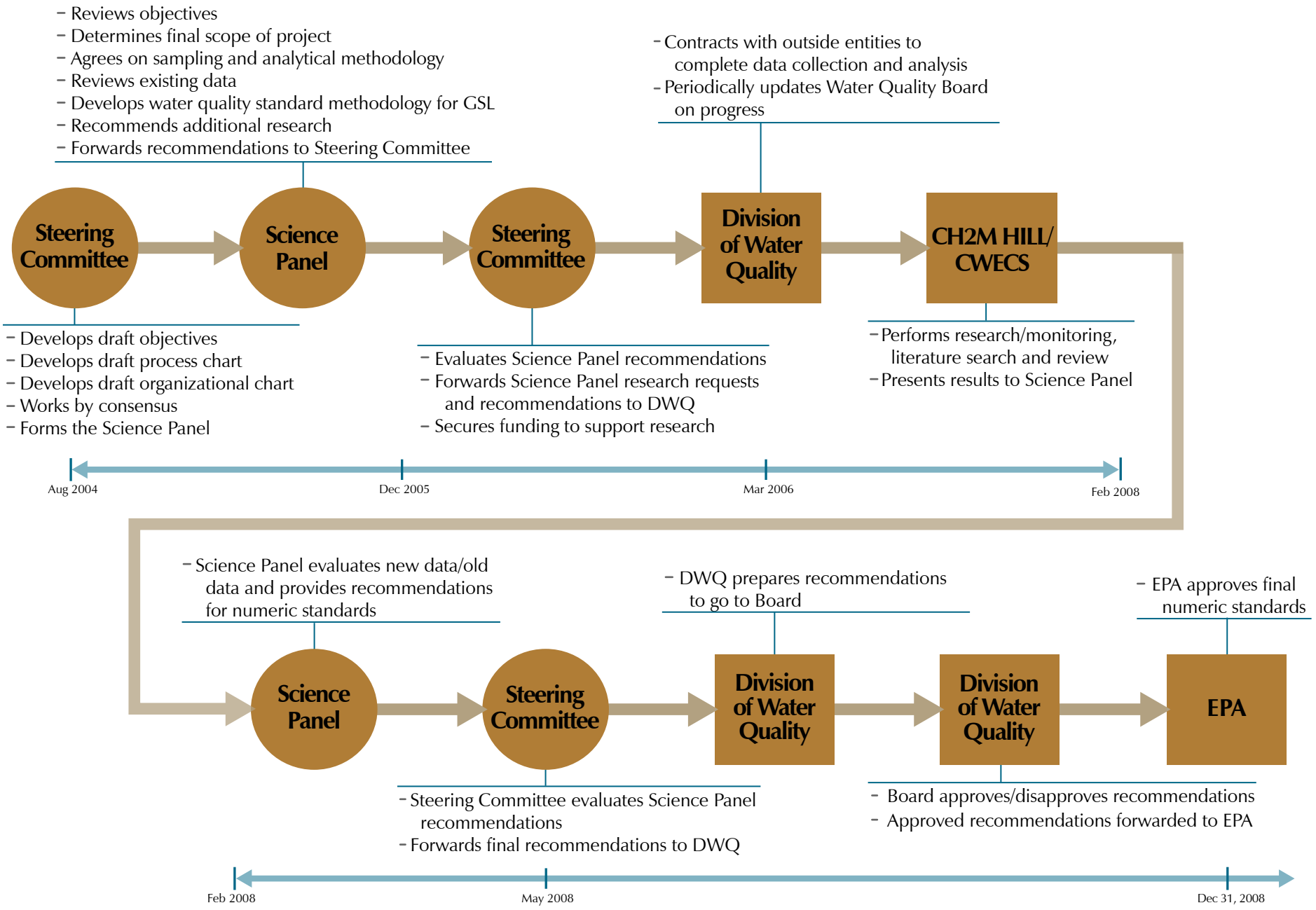


FIGURE 3-2
Process Chart for the Selenium Program
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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3.2.2 Conceptual Model

An essential element to understanding the cycling of selenium in the Great Salt Lake ecosystem is the development of a conceptual model. The purpose of the conceptual model is to qualitatively illustrate the physical processes and relationships regulating the movement of selenium through the ecosystem. It provides a visual representation of Great Salt Lake's cause-and-effect relationships that is useful for identifying those areas where more study is required. The Science Panel's objective was to develop a conceptual model that would assist them in defining research projects and serve as the basis for a quantitative model describing the system.

The Science Panel worked with Drs. Bill Johnson, Mike Conover, Wayne Wurtsbaugh, and Jack Adams to develop the Conceptual Model for Selenium Cycling in Great Salt Lake (Johnson et al., 2006). That report is included in Appendix A for reference. It used available information to characterize selenium cycling in Great Salt Lake, summarize the trophic transfer of selenium through the food chain, and describe the biogeochemical cycling of selenium below the food chain. The conceptual model was divided into five components: (1) selenium in the upper food chain, (2) selenium in the lower food chain, (3) selenium in the shallow layer of Great Salt Lake, (4) selenium in the deep layer and sediment, and (5) selenium in the water as characterized by loading to the lake. Each component was illustrated with a qualitative flow chart and included accompanying text summarizing the underlying assumptions and supporting references. The draft final version of this conceptual model served as the basis for the Science Panel's understanding of Great Salt Lake selenium cycling, identification of projects to be conducted, and an understanding of the endpoints that might be used for the development of a water quality standard.

A simplified conceptual model was developed with the Science Panel in October 2006 to characterize these critical endpoints and the elements of the original conceptual model that the selenium program would focus upon in defining quantitative relationships (such as transfer of selenium through the food chain). Figure 3-3 illustrates the simplified conceptual model and includes only three main components rather than the original five: (1) selenium in the upper food chain, (2) selenium in the lower food chain, and (3) selenium in the water and sediment. This revised model was used by the Science Panel to integrate results of the research completed for the selenium program and to develop quantitative relationships among individual components of the ecosystem.

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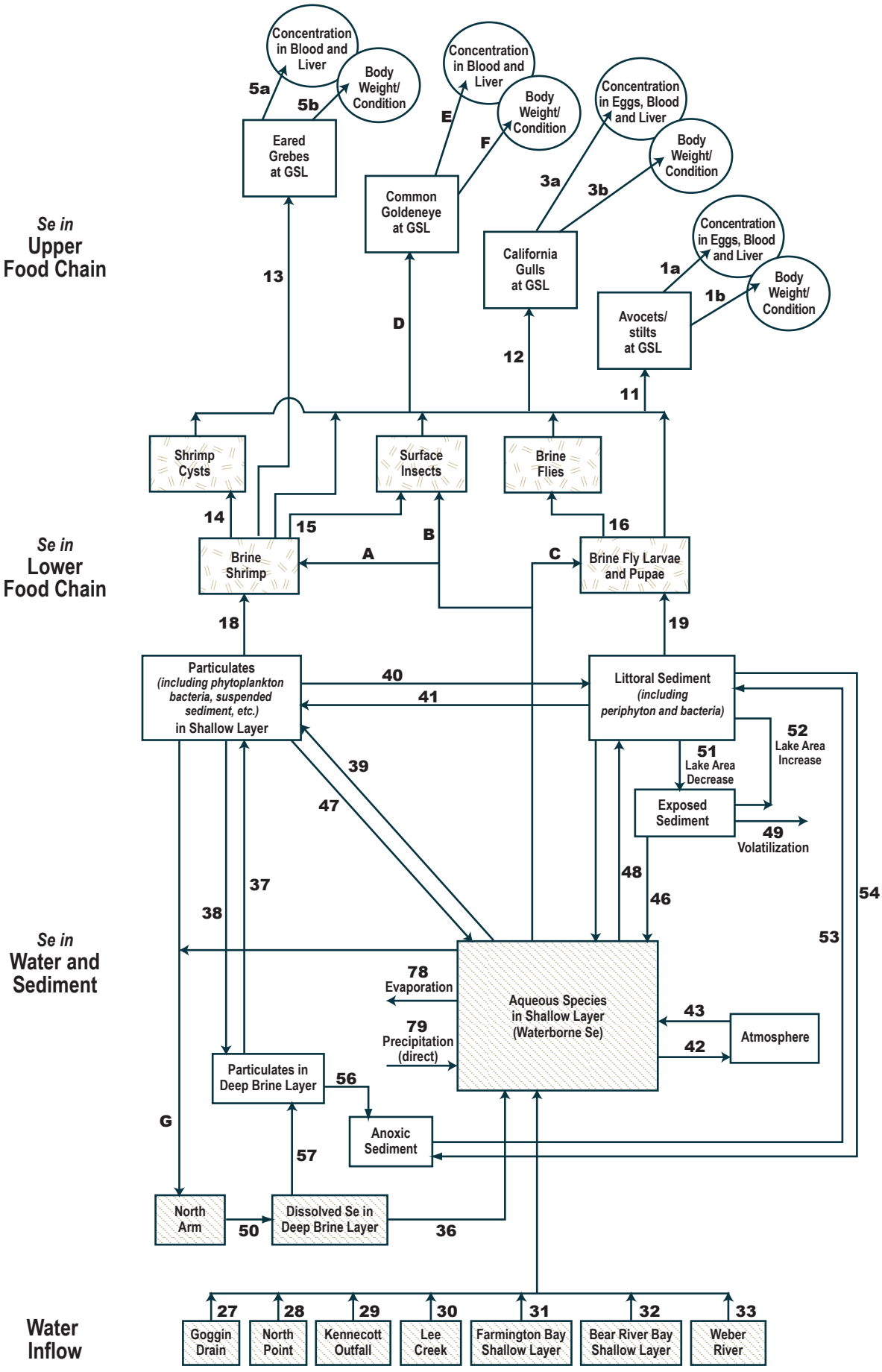

WB042008002SLC GSL_Delineation-of-Projects.ai

FIGURE 3-3
Simplified Conceptual Model for Selenium Cycling
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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3.2.3 Toxicity Threshold Values

Critical Endpoints

It is generally recognized that the most significant exposure of birds to selenium occurs through their diet and that the best-documented and most readily monitored effects are those on reproductive success (particularly egg hatchability). The conceptual model (Johnson et al., 2006) suggested various species of birds that are known to breed on Great Salt Lake (for example, black-necked stilt, American avocet, Franklin's gull, California gull, and snowy plover). The conceptual model also suggested that various species of birds (for example, eared grebe, northern shoveler, and common goldeneye) feed extensively on the open water during migration or while overwintering on Great Salt Lake but do not breed on Great Salt Lake. The sensitive endpoint for these birds was surmised to be mass wasting that would inhibit successful migration or survival during the winter months. The Science Panel agreed that bird diet (brine shrimp and/or brine flies) was the key pathway to the two most sensitive, or critical, endpoints in birds that depend on the open waters of Great Salt Lake: (1) reproductive success and (2) body condition. These critical endpoints (particularly reproductive success) were the focus of the research conducted during 2006 and 2007, and the more sensitive and more readily monitored of the two represents what the water quality standard will be developed to protect, as described in the following sections.

Development of Threshold Values

Toxicity threshold values for the exposure of birds to selenium at Great Salt Lake are necessary for the development of a water quality standard that is protective of these endpoints. A toxicity (or threshold) value is defined as the exposure level or dose of a substance above which toxicity or adverse effects can occur, and below which toxicity or adverse effects are unlikely to occur. The threshold value for the birds' diet as well as bird tissue (for example, in eggs) determines the protective limit for selenium in these endpoints. These values were evaluated as part of the overall conceptual model to determine what selenium concentrations in the water column would be protective of those threshold values. The Science Panel identified the following key considerations for the threshold values:

- It is generally recognized that the most significant exposure of birds occurs through their diet.
- The best-documented and most readily-monitored effects are those on reproductive success (particularly egg hatchability, assessed indirectly for Great Salt Lake on the basis of selenium concentrations in food-chain organisms and bird eggs).
- Laboratory studies with mallards provide the best available data to evaluate avian exposure and effects; because the mallard is relatively sensitive to the effects of selenium, using those threshold values builds in conservatism so that the result can be considered protective of other species.
- The 95 percent confidence interval (CI) on the mean selenium concentrations in mallard diet and eggs associated with the 10 percent effect concentration (EC_{10}) for egg hatchability (explained in the following paragraphs) defines a range of values that would be reasonably protective for birds nesting at Great Salt Lake.

- Two technical memoranda in Appendix B provide a summary and discussion of potential threshold values identified by Science Panel members for consideration in establishing a water quality standard for selenium in the open waters of Great Salt Lake.
- The degree of protectiveness to be applied by the State in setting the water quality standard is not known, and there is not complete understanding of the sensitivity of the Great Salt Lake system to selenium; thus, the Science Panel identified a range of values to be used in modeling and derivation of a potential standard

From the available information, the Science Panel initially (in November 2006) narrowed the values to be considered by identifying "working values" for the ranges of acceptable selenium concentrations in bird diets and eggs. For both diet and eggs, the Science Panel selected the ranges of selenium concentrations provided by Ohlendorf (2003); they include the 95 percent CI (also referred to as the 5 percent lower confidence limit [LCL] and the 95 percent upper confidence limit [UCL]) for the mean selenium concentration that is associated with a 10 percent reduction (called an EC_{10}) in the hatchability of mallard eggs. While the U.S. Fish and Wildlife Service is no longer able to respond in writing to requests for species lists and concurrence with "no effect" determinations, no federally listed threatened and/or endangered species are known to use the open waters of Great Salt Lake (Nathan Darnall, personal communication with Bill Moellmer, October 4, 2007).

Laboratory toxicological studies (Heinz et al., 1987, 1989; Heinz and Hoffman, 1996, 1998; Stanley et al., 1994, 1996) have shown that an EC_{10} in egg hatchability in mallards occurs when the diet contains selenium concentrations between 3.6 and 5.7 mg Se/kg and when the egg contains selenium concentrations between 6.4 and 16 mg Se/kg (all concentrations in bird diets or eggs mentioned in this document are expressed on dry-weight basis). This range is also known as the 95 percent CI. Essentially, there is 95 percent confidence that the mean dietary or egg selenium concentration that causes a 10 percent reduction of egg hatchability is within the identified ranges, which are illustrated in Figures 3-4 and 3-5. The statistical analysis indicates the greatest probability of a 10-percent hatchability reduction is associated with a 4.9 mg Se/kg in the diet and 12 mg Se/kg in the egg. There is only a very small chance that the low or high values in the ranges defined as the 95-percent CI are the true concentration where 10-percent hatchability reduction occurs.

FIGURE 3-4
Mallard Egg Hatchability versus Control as a Function of Selenium Concentration in Diet

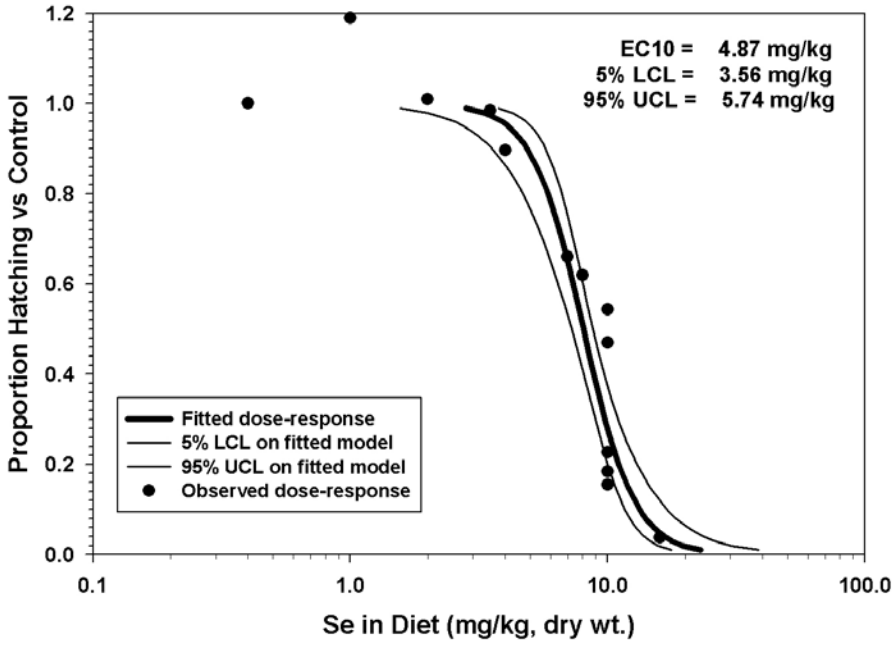
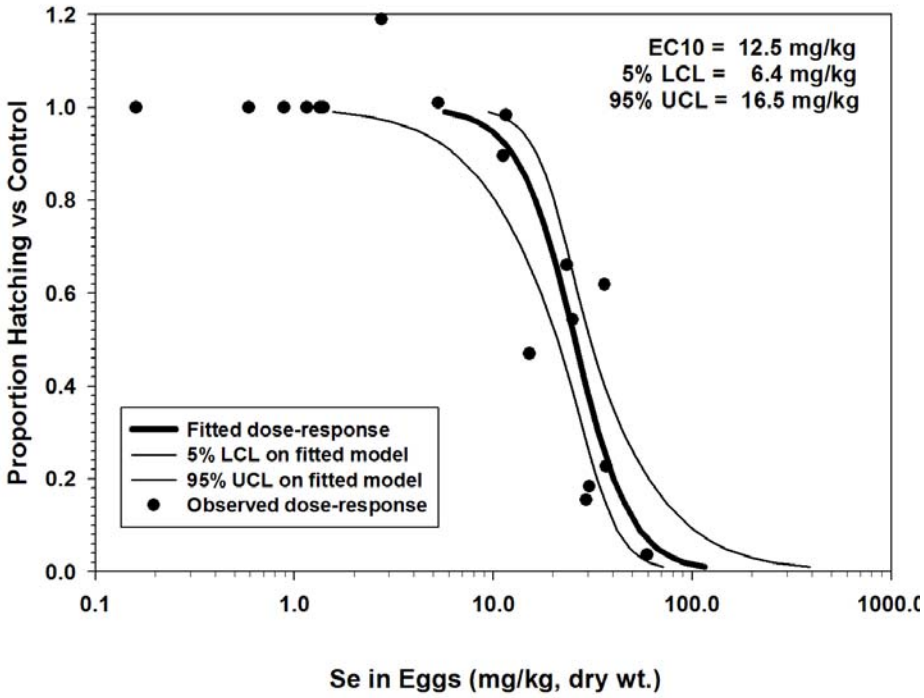


FIGURE 3-5
Mallard Egg Hatchability versus Control as a Function of Selenium Concentration in Eggs



At the July 31 to August 1, 2007 Science Panel meeting, Joe Skorupa suggested an alternative method of communicating the selected threshold values that de-emphasizes the EC_{10} terminology. Those values (shown in Table 3-2) relate the mean, LCL, and UCL as a selenium concentration in the diet or in bird eggs to the degree of reduction in egg hatchability (as percent reduction) associated with those selenium concentrations. For each concentration, the table lists the "maximum likelihood" value that is the best estimate of the expected decrease in hatchability. The table also lists the reduction in hatchability that can be expected to occur (as the best estimates of best case and best estimates of worst case) for the corresponding concentrations. The best case and worst case estimates are the range of the absolute least to the absolute most reduction that is associated with the Selenium concentration, with 95 percent confidence that the level of effect falls within that range. In each case, the probability of the extremes occurring is very low (2.5 percent chance of occurring).

TABLE 3-2
Hatchability Reduction Estimate

Se Concentration (mg Se/kg)	Best Estimate of Reduction in Hatchability		
	Best Case	Maximum Likelihood	Worst Case
	Diet		
3.6	<1%	3%	10%
4.9	4%	10%	24%
5.7	10%	18%	32%
	Egg		
6.4	<1%	1.5%	10%
12	3.5%	10%	26%
16	10%	21%	38%

The Science Panel requested that the upper and lower 95 percent CI as well as the mean value for the EC_{10} initially be used in the development of the quantitative model of the ecosystem. Using the upper and lower bounds of the accepted range would assist the Science Panel in evaluating the sensitivity of Great Salt Lake to selenium.

Basis for Selection of Threshold Values

As previously mentioned, the dietary selenium EC_{10} for mallards was reported as 4.9 milligrams per kilogram (mg/kg), with 95 percent CI of 3.6 to 5.7 mg/kg based on reproductive toxicity (egg hatchability) (Ohlendorf, 2003). The EC_{10} was estimated by fitting a logistic regression model (Figure 3-4). Similar to the dietary values calculated by Ohlendorf (2003) for reproductive toxicity for mallards, the EC_{10} in eggs was reported as 12.5 mg/kg, with 95 percent CI of 6.4 to 16.5 mg/kg (Figure 3-5). This EC_{10} also was estimated by fitting a logistic regression model to the results of the six laboratory studies with mallards.

Other statistical methods and adjustments were discussed by the Science Panel; however, the consensus was that this range of values, as defined by Ohlendorf, would be used for consideration of the water quality standard.

3.2.4 Research Program

Using the draft final version of the conceptual model (Johnson et al., 2006), the Science Panel derived the following nine priority projects to assist in furthering their understanding of selenium cycling in Great Salt Lake and to develop their recommendation for a selenium water quality standard:

- Identify bird species breeding on the lake; identify nesting populations and locations
- Analyze remaining water samples archived at the USGS
- Develop a request for proposals (RFP) to collect eggs for breeding birds (for example, black-necked stilts, American avocets, shovelers, etc.); complete synoptic survey of the lake to sample brine flies and brine shrimp
- Develop an RFP to synthesize available selenium data for water, biota, and sediments of Great Salt Lake
- Develop an RFP to determine the mass load of selenium to Great Salt Lake (for example, characterize flows and water concentrations for main sources of water to the lake)
- Develop an RFP to determine the fate of selenium in Great Salt Lake (for example, define the transfer to the sediments and flux from sediment to and from the water column)
- Review the existing conceptual model and evaluate the need to expand it
- Develop a report summarizing the round-robin study
- Evaluate the need to sample eared grebes in the fall

This list was condensed by the Science Panel into the following four projects that were issued in an RFP in January 2006:

- **Project 1**—Determine ambient selenium concentrations in water, brine shrimp, brine flies, and bird eggs; determine stomach contents of nesting birds
- **Project 2**—Design and conduct a selenium concentration synoptic survey in the water and brine shrimp within Gilbert Bay
- **Project 3**—Determine selenium loadings from point sources and rivers to Gilbert Bay of Great Salt Lake
- **Project 4**—Develop a selenium transfer/flux model between the sediments and water column

The specific objectives and workplans for each project were the subject of significant discussion during the first quarter of 2006. While the intent of each project largely remained the same, the methods, media to be sampled, and period of sampling were adjusted based upon additional information and suggestions provided by the principal investigators and discussion with the Science Panel. The final objectives and workplans are summarized in

Section 4.0 and are included in CH2M HILL's 2006 *Selenium Program Manual* and on the Web site. The four projects evolved into the six projects started in 2006 as described in the following paragraphs. Figure 3-6 illustrates the relationship between the six projects and the simplified conceptual model.

- **Project 1A**—Determine the concentration and effect of selenium in shorebirds through the sampling of adult birds, eggs, diet, water, and sediment
- **Project 1B**—Determine the concentration and effect of selenium in California gulls through the sampling of adult birds, eggs, diet, water, and sediment; determine the concentration and effect of selenium in eared grebes and common goldeneyes through the sampling of adult birds when they arrive at Great Salt Lake and prior to leaving the lake
- **Project 2A**—Synoptic survey of selenium in periphyton and brine fly larvae from the benthic zone
- **Project 2B**—Synoptic survey of selenium in water, seston, and brine shrimp from the pelagic zone
- **Project 3**—Measurement and modeling of selenium loads to Great Salt Lake
- **Project 4**—Measurement of selenium flux to and from sediment and atmosphere

A review of initial data collected for each of the projects in 2006 identified the need for additional studies. The Science Panel requested, and the Steering Committee approved, the following study objectives for 2007:

- **Project 1A**—Repeat a subset of the 2006 sampling program in 2007 with the addition of analysis for mercury
- **Project 1B**—Repeat a subset of the 2006 sampling program in 2007 with the addition of analysis for mercury and the sampling of a gull colony at a freshwater location
- **Project 2B**—Continue 2006 sampling program through July 2007
- **Project 4, Volatilization**—Directly measure volatilization on the open waters of Great Salt Lake to verify estimates
- **Project 4, Sedimentation**—Collect additional shallow and deep sediment cores to verify sedimentation rates and permanent burial of selenium in sediment
- **Project 5**—Complete kinetic studies in the laboratory to define the transfer of selenium from water and diet to brine shrimp

Further, the Science Panel requested, and the Steering Committee approved, the integration of data and observations from these projects into a quantitative model and report as described in this document.

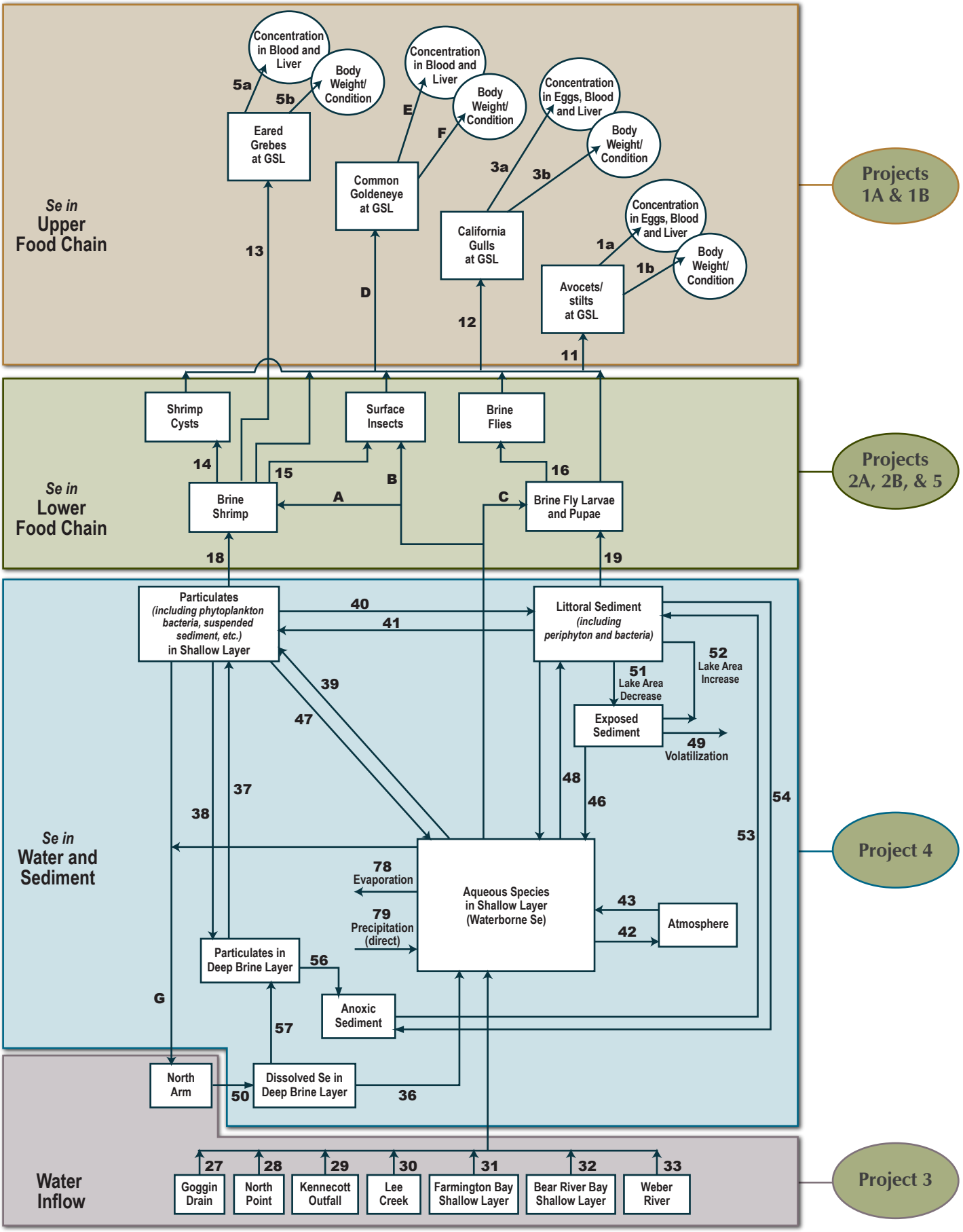


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FIGURE 3-6
Delineation of Projects within the Conceptual Model
Great Salt Lake Water Quality Studies
Draft Report – Selenium Program

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4.0 Program Objectives

This section defines the objectives for the overall selenium program and for each of the individual projects.

4.1 Program Objectives

The UDWQ's objective is to define a site-specific, numeric water quality standard for selenium that prevents impairment of the beneficial uses of the open waters of Great Salt Lake. This was to be accomplished through the development of a selenium study program intended to enable the Steering Committee to recommend a standard to the Utah Water Quality Board. As such, the selenium program was designed to complete the appropriate studies (identified by the Science Panel) and evaluation needed to support such a recommendation.

4.1.1 Data Quality Objectives

The EPA has prepared a data quality objectives (DQOs) process (EPA, 2000, 2006) that serves as a useful tool in assessing what questions must be answered (or decisions that need to be made), what information is available to answer those questions, what additional information is needed, how that information will be collected, and how it will be used in making decisions as related to development of a selenium standard for the open waters of Great Salt Lake. Implementation of the DQOs process in the selenium program, along with use of the previously developed conceptual model, helped describe how the physical, chemical, and ecological components of the environment are related, as well as provided the rationale and context for the work that would be done. The DQOs described the objectives and overall approach for conducting studies to support development of the standard and provided more specific information about the work to be done under each of the individual projects. The DQOs developed for the program and for each of the original six projects active in 2006 are included in the Program Manual; DQOs were developed subsequently for the laboratory kinetic studies with brine shrimp. The listed questions and objectives posed in each project's DQOs are included in the following sections.

4.1.2 Program Questions

The central question for the selenium program to resolve can be stated as follows:

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

More specific questions that support this overall decision were developed to help define the individual projects completed as part of the program. Figure 4-1 illustrates how these questions relate to the development of the program's seven projects.

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

2. What is the relative importance (based on selenium concentrations and their availability) of various food-chain exposure pathways for aquatic wildlife (i.e., linkage of "Lower Food Chain" to "Upper Food Chain" as highlighted in the blue box)?

3. What are the transfer factors that describe relationships between selenium concentrations in the water column, in bird diets, and the concentrations found in bird eggs (i.e., stepping down to the "Aquatic Species" of waterborne selenium highlighted in the green box)?

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

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

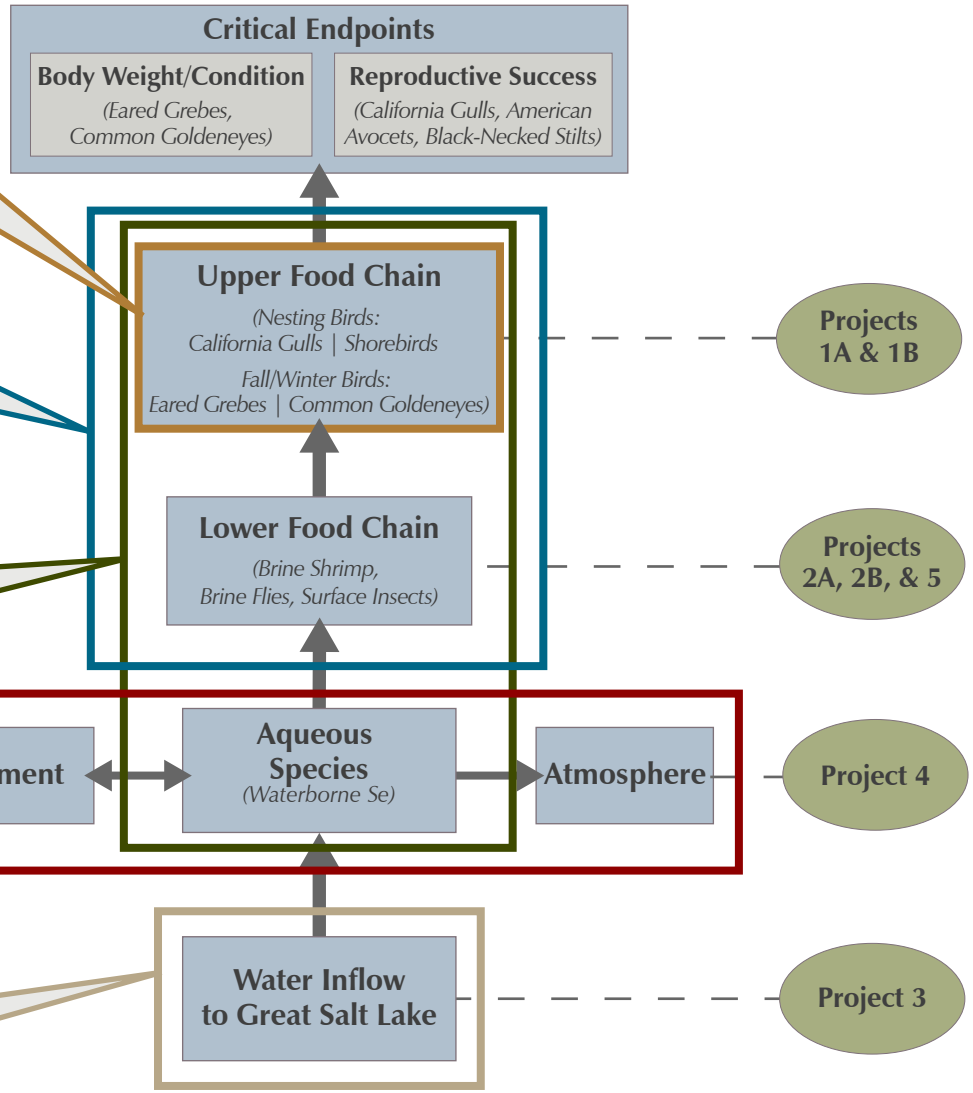

FIGURE 4-1
Program Questions Relative to Projects
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2 Project Objectives

As described in Section 3.0, each of the selenium program's studies was initially identified and prioritized by the Science Panel through an evaluation of the conceptual model, available information, and discussion with principal investigators. A key element in developing and refining the work plan for each project was definition and discussion of each project's objectives and targeted questions to be answered. The project's DQOs, work plan, and standard operating procedures (SOPs) were subsequently developed and revised per Science Panel input. This section summarizes the objectives and questions for each project, and it illustrates which components of the conceptual model were to be addressed by each project.

Project DQOs, workplans, and SOPs for the six initial projects are included in the *Selenium Program Manual*. Detailed discussion of project background, objectives, methods, and results are found in each project's final report, and included in Appendices C through I of this document.

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4.2.1 Project 1A, Concentration and Effects of Selenium in Shorebirds

Principal Investigator: Dr. John Cavitt, Weber State University

Project Objectives (2006)

- Determine ambient selenium concentrations in water, sediment, brine shrimp, brine flies, and unidentified food items in nesting shorebird foraging areas, bird eggs, bird blood, and bird livers
- Determine stomach contents of nesting birds
- Determine if selenium concentrations affect reproductive success of American avocets and black-necked stilts at Great Salt Lake

Project Objectives (2007)

- Determine ambient selenium concentrations in brine fly larvae and in American avocet eggs
- Determine stomach contents of nesting birds
- Verify 2006 selenium concentrations by determining selenium and mercury concentrations in nesting American avocet blood and liver

Project Questions

The guiding questions for Project 1A include the following:

- What do the shorebirds eat at Great Salt Lake, and what are the transfer factors for selenium from the diet to bird eggs?
- Are significant ecological effects occurring in American avocets and black-necked stilts? If so, to which ones and at which locations?
- What are the associated selenium concentrations in bird eggs, blood, and liver?

To understand the potential effects of selenium on shorebirds at Great Salt Lake, the following questions needed to be addressed:

- What is the diet of American avocets and black-necked stilts at Great Salt Lake?
- What is the ambient concentration of selenium in the water and macro-invertebrates consumed by shorebirds?
- What is the concentration of selenium within the liver and blood of American avocets and black-necked stilts?
- What is the concentration of selenium within the eggs of American avocets and black-necked stilts?
- What is the hatching success of American avocet and black-necked stilt eggs?

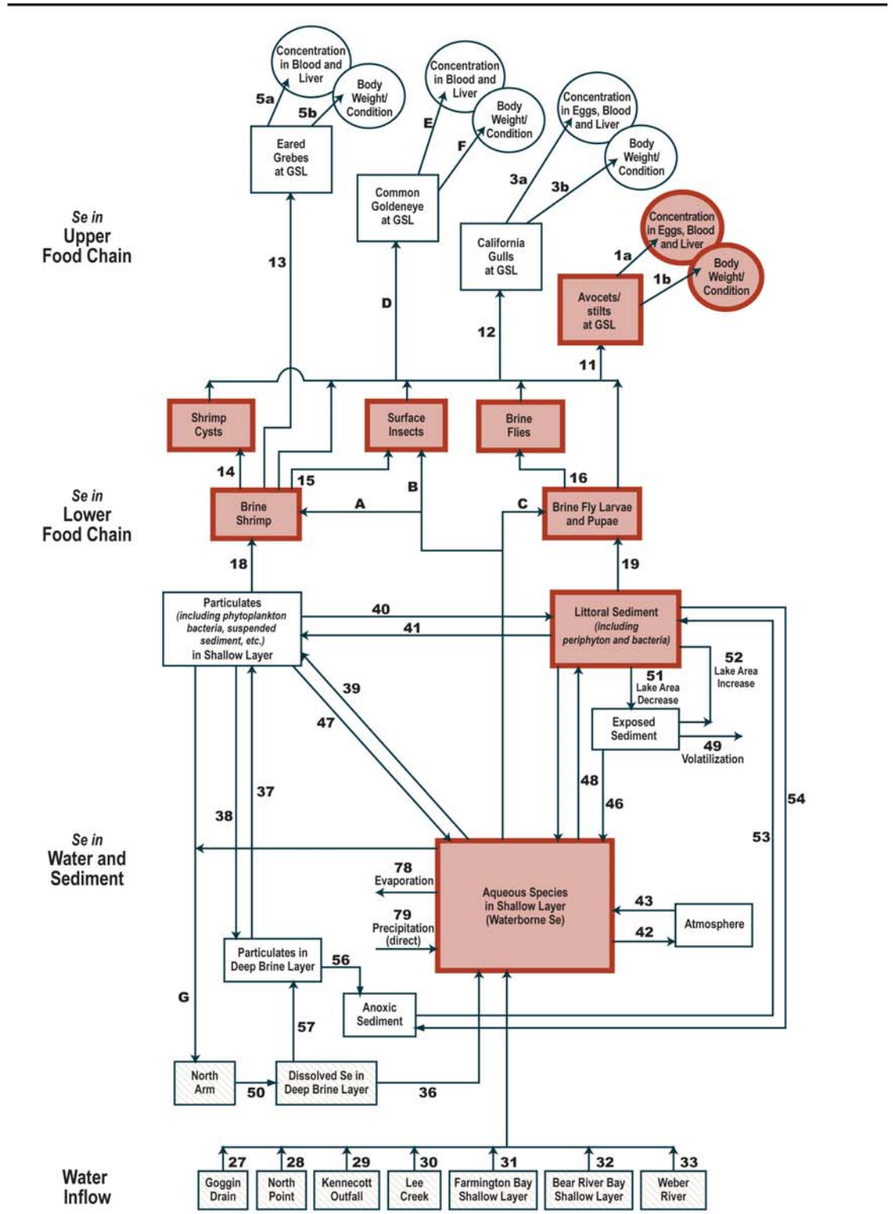

FIGURE 4-2
Project 1A – Shorebirds
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.2 Project 1B, Concentration and Effects of Selenium in Gulls, Grebes, and Ducks

Principal Investigator: Dr. Mike Conover, Utah State University

Project Objectives (2006)

- Determine stomach contents of nesting birds and ambient selenium concentrations in water, sediment, brine shrimp, brine flies, and other identified food items in nesting California gull foraging areas and in bird eggs, blood, and livers
- Determine if selenium concentrations affect reproductive success of California gulls at Great Salt Lake
- Determine selenium concentrations in eared grebes during the fall and male common goldeneyes during the winter, and determine if selenium concentrations affect body condition of those birds

Project Objectives (2007)

- Determine body condition, diet, and ambient selenium concentrations in blood and liver of nesting California gulls from two salt water colonies (Hat Island and Great Salt Lake Minerals) and a "fresh" water colony (Neponset Reservoir)
- Compare blood/liver selenium concentrations and diet found in crop of sampled birds from different nesting sites and opportunistically sample brine shrimp in area where gulls are feeding to link diet to blood and liver selenium levels

Project Questions

The guiding questions for Project 1B include the following:

- What are the transfer factors for selenium from the diet to bird eggs?
- Are significant ecological effects occurring in California gulls, eared grebes, or common goldeneye? If so, to which ones and at which locations?
- What are the associated selenium concentrations bird eggs, blood, and livers?

To understand the potential effects of selenium on these birds at Great Salt Lake, the following questions needed to be addressed:

- Where do California gulls nest and forage within Great Salt Lake and what is the diet of nesting gulls?
- What are the ambient selenium concentrations in the water, sediment, and diet items at the foraging sites of nesting California gulls in Great Salt Lake?
- What are the associated selenium concentrations in nesting California gulls (blood and liver), a random sample of gull eggs, gull eggs with dead or abnormal embryos, and deformed gull chicks?
- What are selenium concentrations in adult eared grebes staging on Great Salt Lake when they first arrive and right before they leave, and how does body condition of grebes relate to selenium concentrations in their tissues?
- What are selenium concentrations in overwintering ducks (adult male common goldeneye), and how does body condition of ducks relate to selenium concentrations in their tissues?

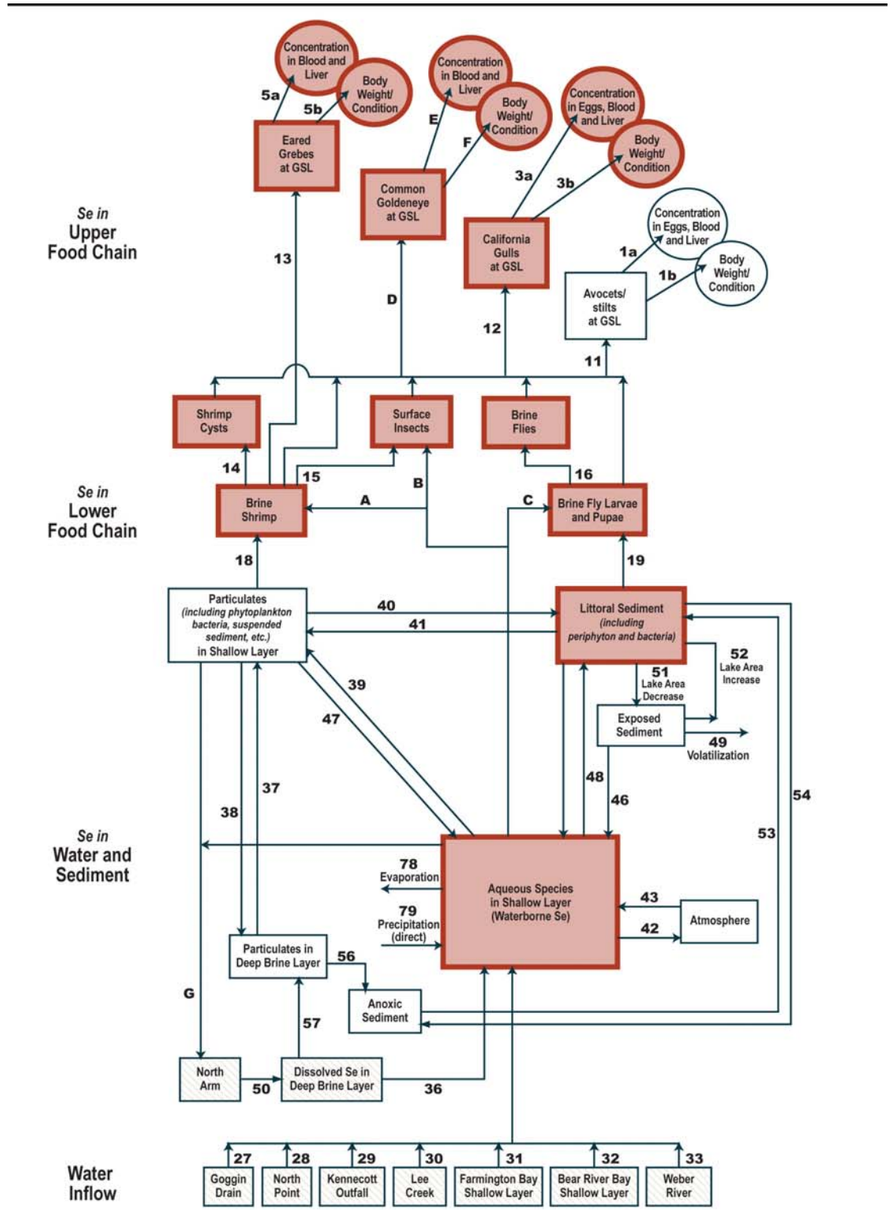

FIGURE 4-3
Project 1B – California Gulls, Eared Crebes, Common Goldeneye
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.3 Project 2A, Synoptic Survey of Selenium in Periphyton and Brine Fly Larvae from the Benthic Zone

Principal Investigator: Dr. Wayne Wurtsbaugh, Utah State University

Project Objectives

Determine the importance of the benthic food web for bioaccumulation of selenium in birds by:

- Developing methods to sample the benthic zone of the lake
- Determining chlorophyll concentrations in periphyton and selenium concentrations in periphyton brine fly larvae and detritus found on sand, mud, and biostromes (stromatolite) substrates in Great Salt Lake as well as in adult brine flies
- Determining ambient selenium concentrations in co-located water and substrate samples

Project Questions

The guiding question for Project 2A was:

- What are the transfer factors for selenium from the benthic zone (water and sediment) to the brine fly component of the food web?

To understand the potential effects of selenium on the benthic zone and food web of Great Salt Lake, the following questions needed to be addressed:

- Can brine fly larvae and pupae be sampled quantitatively using a SCUBA-operated vacuum sampler on stromatolite substrates?
- Can soft substrates be sampled quantitatively using a Ponar dredge?
- What is the time cost for each of these sampling procedures?
- What is the selenium content in periphyton/detrital material?
- What is the selenium content in brine fly larvae and adults?
- What is the selenium content in the overlying water above the benthic substrates?

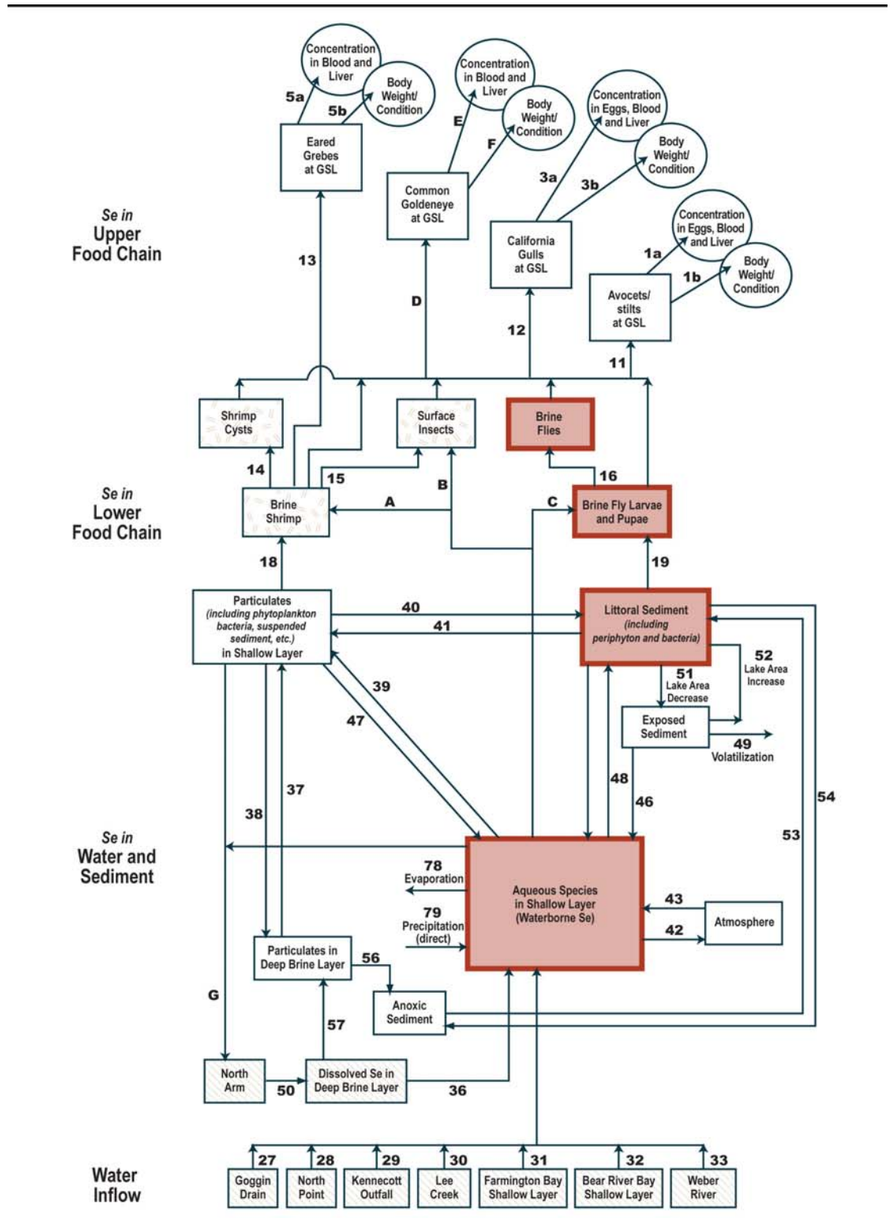

FIGURE 4-4
Project 2A – Benthic Zone
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.4 Project 2B, Synoptic Survey of Selenium in Water, Seston, and Brine Shrimp

Principal Investigator: Brad Marden, Parliament Fisheries, LLC

Project Objectives (2006)

This project evaluated the trophic transfer of selenium within food webs from water to particulate matter (seston) to brine shrimp (*Artemia franciscana)* through the following objectives*:*

- Document the temporal and spatial characteristics of total selenium concentrations in water and correlate with seston and brine shrimp tissue selenium concentrations
- Correlate isotopic nitrogen (15N) and carbon (13C) levels in seston with selenium concentrations in brine shrimp tissue to identify dietary sources
- Monitor primary production indicators (chlorophyll a concentration) and record brine shrimp population dynamics (all life stages)
- Document algal population abundance and diversity over time

Project Objectives (2007)

This project was extended to collect samples through July 2007 with the same objectives as in 2006.

Project Questions

The guiding question for Project 2B was:

- What are the transfer factors for selenium from the pelagic zone (water and seston) to the brine shrimp component of the food web?

To understand the potential effects of selenium on the pelagic zone and food web of Great Salt Lake, the following questions needed to be addressed:

- What are the concentrations of selenium in Great Salt Lake water, seston, and brine shrimp tissue?
  - What is the correlation between waterborne concentrations of selenium and levels found in seston and brine shrimp?
  - What is the potential dietary selenium risk to avian species from consuming brine shrimp (not part of Marden's study)?
- What are the temporal and spatial patterns of isotopic carbon (13C) and nitrogen (15N) in particulate organic matter and brine shrimp tissue as may be indicative of dietary sources?
  - Do 13C and 15N correlate with selenium concentrations in particulate organic matter and brine shrimp?
  - Do selenium, 13C, and 15N in brine shrimp correlate with seston abundance (surrogate forphytoplankton abundance)?
  - Do the stable isotope fractions in diet indicate discrete sources of selenium that account for brine shrimp tissue levels of selenium? Do the sources supporting the brine shrimp body-burdens of selenium vary seasonally?
- What are the population size, age-structure, and biomass of brine shrimp in Great Salt Lake?
  - What is the total selenium load in Great Salt Lake brine shrimp population (How do changing brine shrimp tissue concentrations of selenium and the abundance of adults or cysts correlate with avian consumers and avian seasonality and nesting at Great Salt Lake?)?

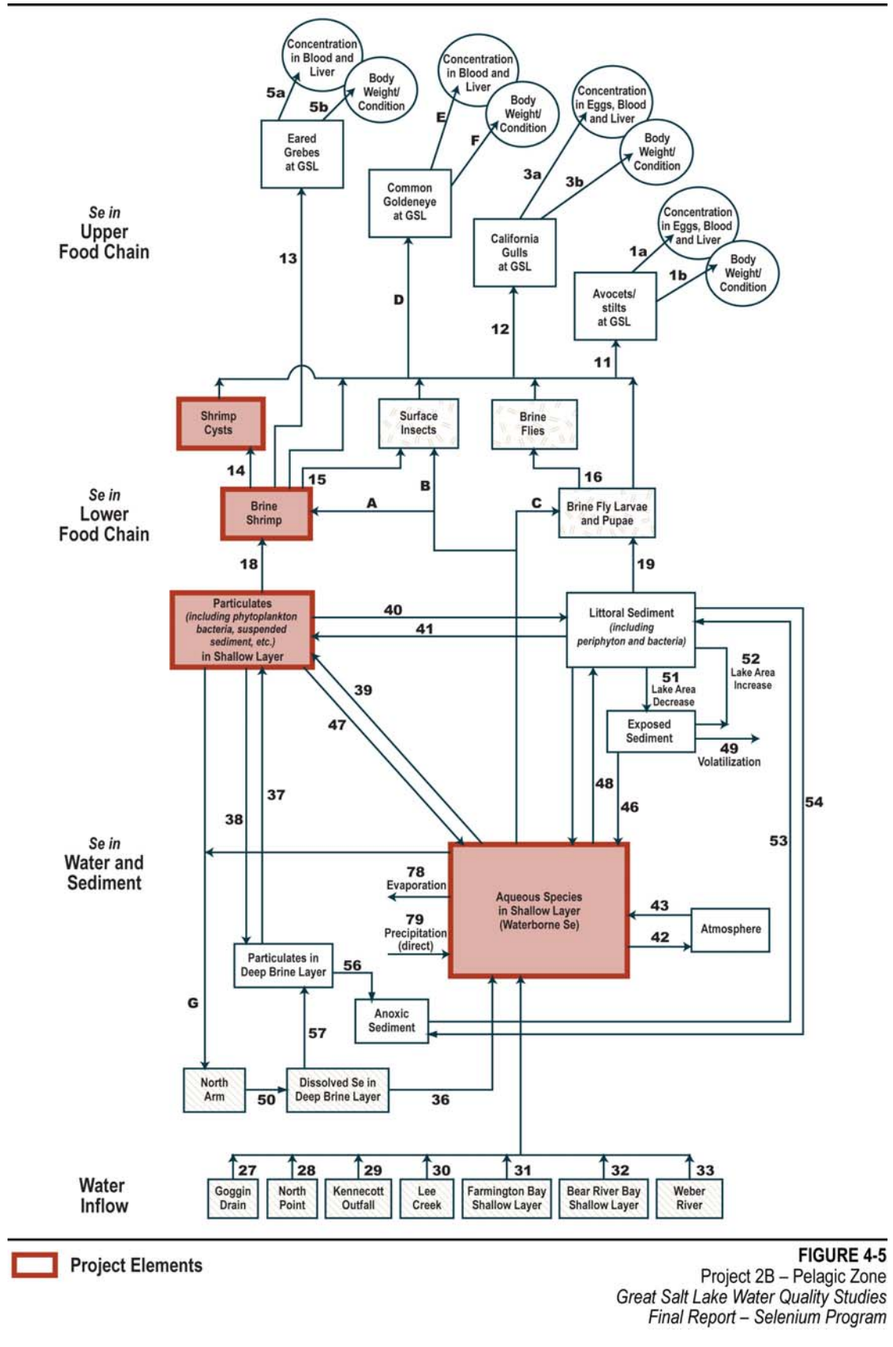

FIGURE 4-5
Project 2B – Pelagic Zone
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.5 Project 3, Measurement of Selenium Loads to Great Salt Lake

Principal Investigator: Dr. David Naftz, USGS, Dr. Bill Johnson, University of Utah

Project Objectives

Most rivers that flow into Great Salt Lake are monitored by the USGS with respect to discharge and concentration of chemical constituents. Unfortunately, all of the established gaging sites are located significant distances upstream of where the outflow actually enters the open waters of Great Salt Lake. Significant changes in the selenium concentration, as well as other chemical constituents, can occur between the established gaging stations and where the inflow enters into the open waters of the lake.

The objective of this project was to establish new stream gaging station locations that facilitate the measurement of selenium loads entering the open waters of Great Salt Lake. Data gathered from the new gaging infrastructure were used to model mean daily selenium loads from all surface water inflow sources to Great Salt Lake. The modeling results were used to determine an annual selenium budget for the open waters of Great Salt Lake. For purposes of this project, it was assumed that loading from groundwater and atmospheric deposition was negligible.

Project Questions

The guiding question for Project 3 was:

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

To understand the relative significance of each of the potential sources of selenium to Great Salt Lake, the following questions needed to be addressed:

- What is the potential selenium load from the following sources?
  - Farmington Bay
  - Bear River Bay
  - Goggin Drain
  - Weber River
  - Lee Creek
  - Kennecott Utah Copper outfall
  - North Arm flow through Union Pacific Railroad Causeway
  - Morton Salt Outfall
  - Great Salt Lake Minerals outfall
- What are the seasonal and geographic variations in selenium loadings with respect to seasonal biological cycles in the Great Salt Lake ecosystem?

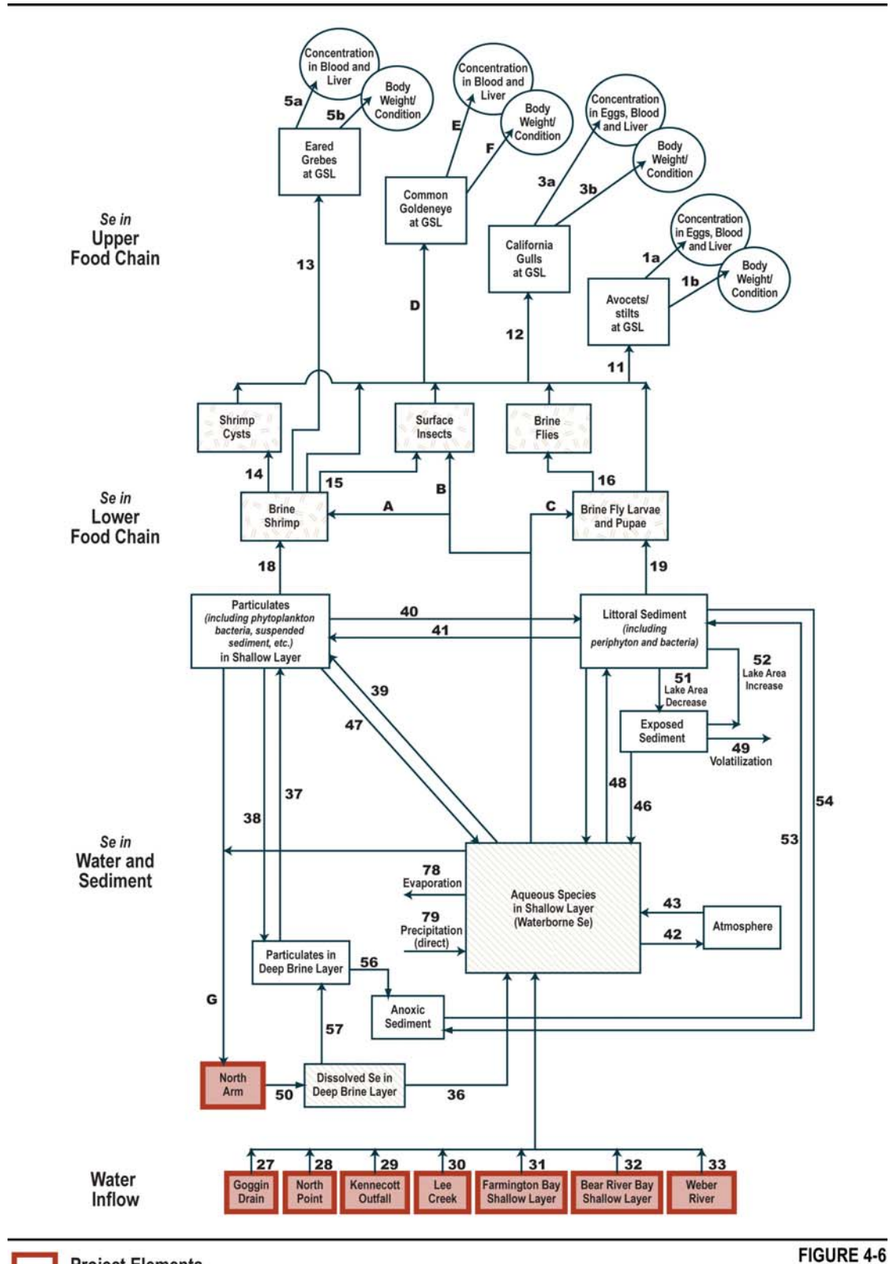

FIGURE 4-6
Project 3 – Selenium Loads
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.6 Project 4, Measurement of Selenium Flux

Principal Investigators: Dr. Bill Johnson, University of Utah; Dr. David Naftz, USGS

Project Objectives

The selenium inputs determined in Project 3 must be balanced against selenium outputs, which are expected to occur mainly via two mechanisms: (1) release of selenium vapor to the atmosphere; and/or (2) permanent burial of selenium in the sediment. These output fluxes cannot be estimated from published literature because these two release processes in Great Salt Lake have not been heavily investigated. Furthermore, the existing literature for other systems does not address a system of the size, salinity, vertical and spatial heterogeneity, and temporal variability as represented in Great Salt Lake.

The objective of Project 4 was to complete appropriate measurements to:

- Estimate the flux rates of volatilization, ebullition, and permanent burial via sedimentation
- Estimate the effects re-suspension and re-solubilization of selenium have in mass balance to the water column
- Estimate the potential internal selenium load to the water column from rising lake levels

Project Questions

The guiding question for Project 4 was:

- What are the most important processes that affect the partitioning, cycling, and release of selenium in Great Salt Lake open waters (that is, where does the selenium go once it is in Great Salt Lake)?

To understand the partitioning, cycling, and release of selenium in Great Salt Lake, the following questions needed to be addressed:

- What are the rates of selenium removal via volatilization and ebullition from Great Salt Lake?
- What is the rate of permanent sequestration of selenium via sedimentation?
- Do transient events or ongoing processes re-suspend and re-solubilize selenium into the water column to an extent that has biological significance?
- Do lake level rises re-introduce selenium into the water column to an extent that has biological significance?

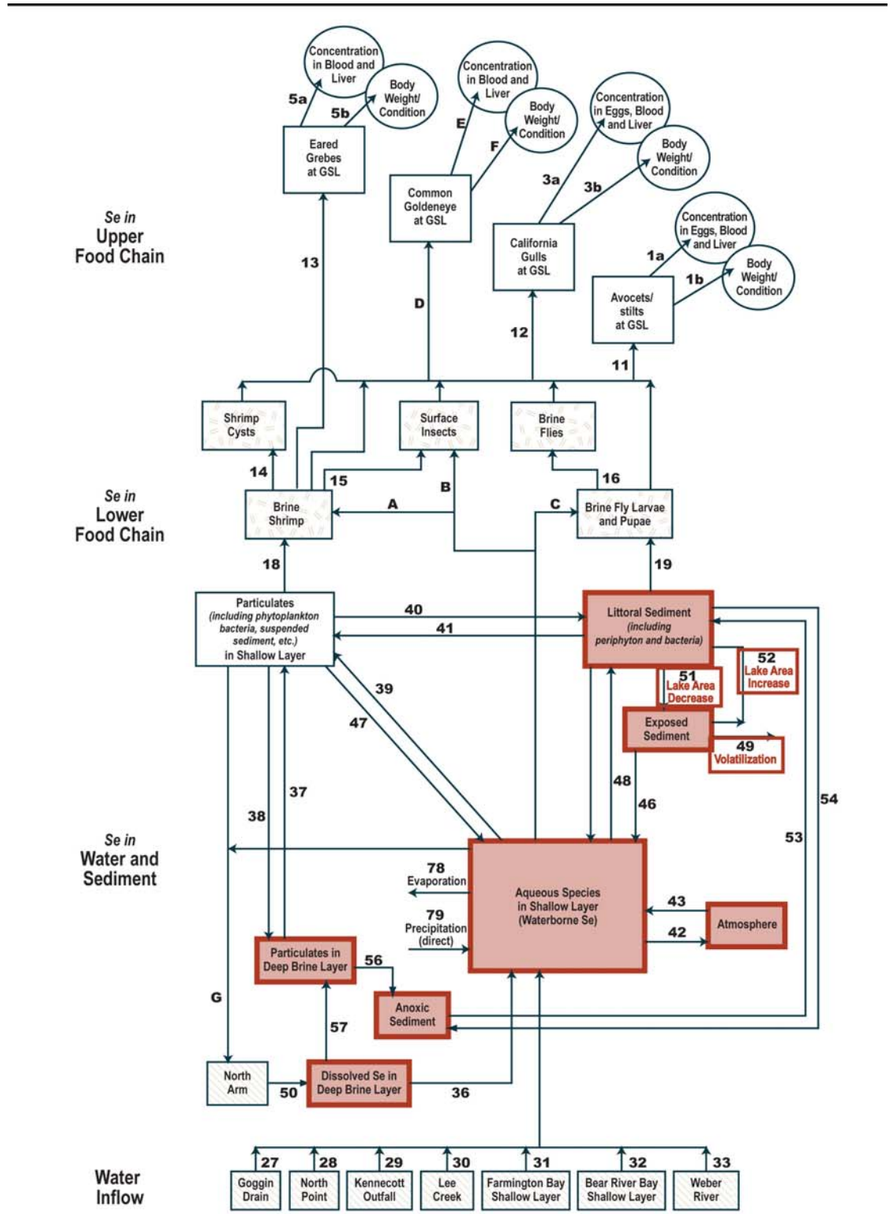

FIGURE 4-7
Project 4 – Selenium Flux
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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4.2.7 Project 5, Predictions of Selenium Accumulation in ***Artemia franciscana*** under Conditions Realistic for the Populations Residing in the Great Salt Lake (Brine Shrimp Kinetics)

Principal Investigator: Dr. Martin Grosell, University of Miami

Project Objectives

The primary objective for Project 5 was to provide reliable predictions of selenium accumulation in brine shrimp under conditions realistic for the populations residing in Great Salt Lake.

This general objective was addressed by pursuing the following specific objectives:

1. Determine the influence of salinity on selenium uptake and feeding rate by brine shrimp
2. Determine selenium uptake rates in brine shrimp from dissolved selenium concentrations in artificial Great Salt Lake water (uptake kinetics)
3. Determine dietary selenium intake and subsequent selenium assimilation efficiency in brine shrimp fed a diet of selenium-loaded algae cells (*Dunaliella viridis*)
4. Determine selenium elimination rates from brine shrimp following selenium accumulation from elevated ambient concentrations
5. Model selenium accumulation in brine shrimp based on the results from Objectives 1 through 3 to provide predictions of selenium accumulation during realistic exposure scenarios
6. Determine the "knee" of the dissolved selenium accumulation rate curve in brine shrimp
7. Investigate possible regulation of selenium accumulation in brine shrimp during prolonged exposure to selenium

Project Questions

The guiding question for Project 5 was:

- What are the transfer factors for selenium from water and algae to the brine shrimp component of the food web as determined under laboratory conditions?

To understand the transfer of selenium from water and algae to brine shrimp, the following questions needed to be addressed:

- What is the influence of salinity on selenium uptake and feeding rate by brine shrimp?
- What are the uptake kinetics, assimilation efficiencies, and elimination rates for brine shrimp in artificial Great Salt Lake water and shrimp fed a diet of selenium-loaded algae cells?
- What is the "knee" of the dissolved selenium accumulation rate curve in brine shrimp?
- How can we predict how selenium will accumulate in brine shrimp during realistic exposure scenarios?

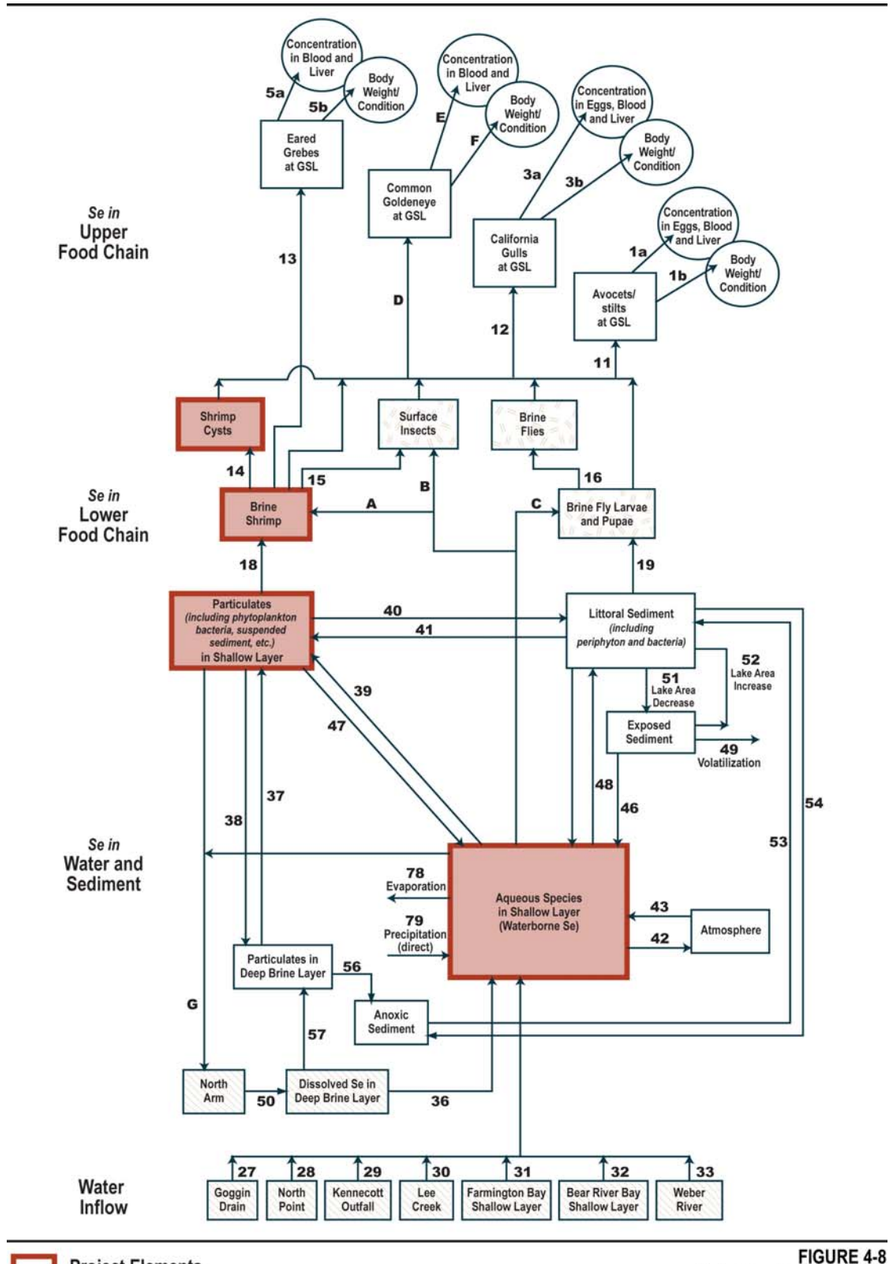

FIGURE 4-8
Project 5 – Great Salt Lake
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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5.0 Program Results

The previous section defined the objectives of the seven research projects identified by the Science Panel. This section provides a summary of the program's quality assurance protocol and the results and conclusions for each of the seven projects.

5.1 Quality Assurance

Quality assurance and collaboration were essential to enabling successful completion of the selenium program. DQOs, workplans, data, and summary reports were developed through a collaborative approach involving principal investigators, CH2M HILL, and the Science Panel. Each document was reviewed and discussed numerous times to ensure the project team was in consensus with the approach, results, and observations. Conditions that warranted changes in approach were reviewed and approved by the project team. Documents developed as part of the selenium program were reviewed by the project team and approved by the Science Panel prior to release to the public.

A detailed *Quality Assurance Project Plan* (CH2M HILL, 2006) was developed to define the process through which the environmental data would be collected for the selenium program to ensure they would be of the appropriate quality to achieve the DQOs defined for the program and each project. The *Quality Assurance Project Plan* also discusses specific protocols for sampling, sample handling and storage, chain of custody, laboratory analyses, data handling, data management, and data evaluation and assessment. It also specifies requirements for performance evaluations, corrective actions, and preventive maintenance of equipment.

5.2 Pending Results

A few final reports have not been received but are imminent and will be submitted as addendums to the existing reports. Results from Project 2B for brine shrimp, water, and seston during 2007 are included here as preliminary tables, but the final interpretive report for all 2006 through 2007 has not yet been received. A final report for Project 5, Brine Shrimp Kinetics Study, is due shortly once final experiments requested by the Science Panel have concluded. These experiments were intended to verify and provide additional detail to the information already in hand.

5.2.1 Summary of Results

Detailed workplans were developed by each project's principal investigator in conjunction with CH2M HILL and the Science Panel to reflect the project's DQOs (see Section 4.0). The *Selenium Program Manual* includes project DQOs, workplans, and SOPs for the six initial projects (CH2M HILL, 2006). Detailed discussion of project background, objectives, methods, and results are found in each project's final report, included in Appendices C through I of this document. Field and laboratory studies were initiated in May 2006 and generally ended in September 2007. Field and laboratory work for Projects 3 and 5

continued into the first quarter of 2008. Each principal investigator documented the methods used and results of the study, and provided discussion of and conclusions from the project in a final summary report. The project reports are included in the appendices. This section provides a summary of the results and observations for each project.

5.2.2 Project 1A, Concentration and Effects of Selenium in Shorebirds

Weber State University's Dr. John Cavitt completed the sampling program for Project 1A over two nesting seasons (2006 and 2007). The following provides a summary of data and results from Cavitt's reports, *Concentration and Effects of Selenium on Shorebirds* (Cavitt, 2008b) and *Selenium and Mercury Concentrations in Breeding Female American Avocets at Ogden Bay* (Cavitt, 2008b), both found in Appendix C.

2006 Sampling Season

Collections. Adult American avocets, avocet eggs, water, sediment, and dietary samples were collected from each of three colonies at Great Salt Lake (Antelope Island, Ogden Bay, and Saltair) (see Figure 5-1), and adult black-necked stilts and stilt eggs were collected from the Ogden Bay site. Of the three colonies, the Antelope Island colony was the only true open-water site; the Ogden Bay colony is where the Weber River flows into the lake along the eastern shore and the Saltair colony is adjacent to the Kennecott Utah Copper Corporation outfall on the southern shore.

Adult tissue analysis. Five American avocets were collected from each of three colonies at Great Salt Lake, and five black-necked stilts were collected from the Ogden Bay site. Selenium concentrations in blood and liver (shown in Table 5-1) were not different between stilts and avocets, between sexes, or among sites. Blood and liver selenium concentrations had a significant positive relationship when all samples were combined, but not for avocets alone (from all colonies), or for avocets from Antelope Island or Saltair. Overall mean blood selenium concentration was 29 micrograms per gram (µg/g) and ranged from 12 to 68 µg/g (n = 19; geometric mean = 27; 95 percent CI [on the arithmetic mean] = 22 - 36 µg/g); overall mean liver selenium concentration was 19 µg/g and ranged from 8.3 to 40 µg/g (n = 20; geometric mean = 18; 95 percent CI = 15 - 23 µg/g).

TABLE 5-1
Summary of Statistics for Selenium Analysis (µg/g dry weight) for Shorebirds
Collected at Great Salt Lake, 2006

Colony	Tissue	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Antelope Island	Blood	4	19.7	3.8	1.9	16	23	19.5
Ogden Bay	Blood	10	36.0	16.5	5.2	20	68	33.1
Saltair	Blood	5	23.5	8.8	3.9	12	34.7	22.1
Antelope Island	Liver	5	12.3	3.1	1.4	8.3	16	11.9
Ogden Bay	Liver	10	20.6	9.5	3.0	11	40	18.8
Saltair	Liver	5	23.6	8.7	3.9	15	38	22.5
Antelope Island	Egg	21	2.3	0.4	0.1	1.6	2.9	2.2
Ogden Bay	Egg	39	2.3	0.7	0.1	1.2	3.6	2.2
Saltair	Egg	8	5.6	2.3	0.8	2.9	9.2	5.1

Body mass. There was no significant difference between body mass of males and females. Although there was a significant negative relationship between liver selenium concentration and body mass, body mass was not significantly related to blood selenium.

Diet. The diet of American avocets varied by location. Avocets at Antelope Island, where there are no freshwater sources, had 100 percent brine flies in their digestive tracts. At Ogden Bay, avocet digestive tracts contained 66 percent midges, 20 percent brine flies, and the remaining 14 percent various other invertebrates. Avocets from Saltair contained 40 percent midges, 36 percent brine flies, and the remaining 24 percent were various other invertebrates. Black-necked stilt digestive tracts from Ogden Bay contained 50 percent various beetles, 30 percent water boatmen, and 20 percent brine flies.

Selenium concentrations in invertebrates ranged from 0.3 µg/g in snails from Ogden Bay to 3.8 µg/g in brine flies from Saltair; however, brine fly selenium concentration did not significantly differ among sites.

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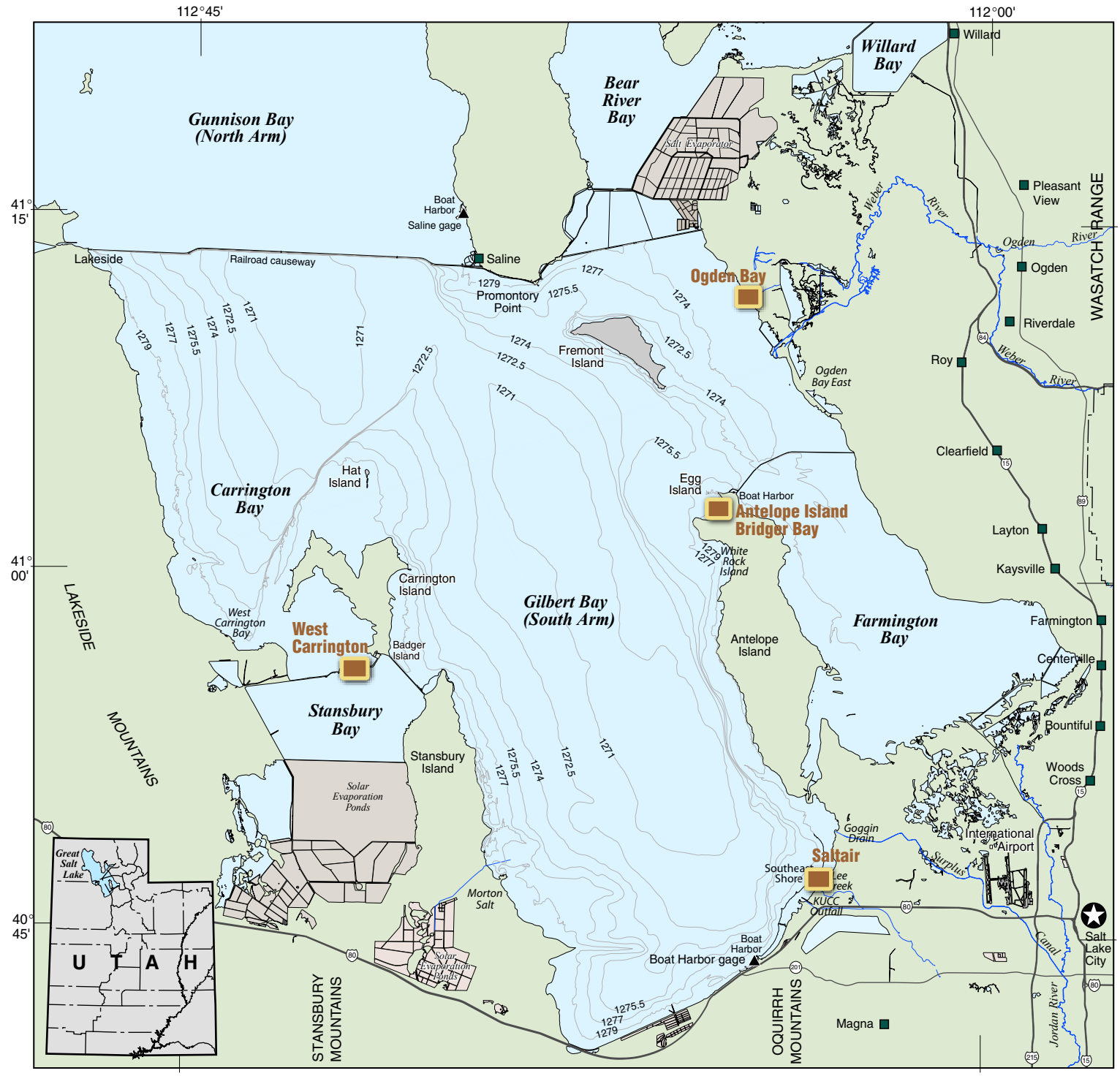

FIGURE 5-1
Project 1A – Shorebirds Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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Water and sediments. Three water and three sediment samples were collected from each colony site. The selenium concentration in water collected from Saltair (mean = 34 µg/L) was significantly higher than in water collected from the other sites (Antelope Island mean = 0.29 µg/L and Ogden Bay mean = 0.22 µg/L). Sediment selenium was also higher (P = 0.07) at Saltair (mean = 1.7 µg/g) than from Antelope Island (mean = 0.4 µg/g) and Ogden Bay (mean = 0.4 µg/g).

Breeding productivity. Breeding (nest) success at Antelope Island was 0.94 with predation as the most common cause of nest failure (50 percent); at Ogden Bay, nest success was 0.97 and the most common cause of nest failure was flooding (nearly 50 percent); and at Saltair, no young were produced due to flooding.

Egg collection, examination, and selenium analysis. Seventy eggs (53 avocet and 17 stilt) were collected, and 68 were analyzed for total selenium (see Table 5-1). No abnormalities were observed in embryos. Mass of American avocet eggs did not differ among sites. The median selenium concentration in eggs from Saltair (n = 8, median = 5.4 µg/g) was significantly higher than median concentrations in those from Antelope Island (n = 21, median = 2.2 µg/g) and Ogden Bay (n = 39, median = 2.5 µg/g). Overall mean egg selenium concentration was 2.7 µg/g and ranged from 1.2 to 9.2 µg/g (n = 68; geometric mean = 2.4; 95 percent CI [on the arithmetic mean] = 2.3 – 3.0 µg/g).

2007 Sampling Season

Collections. Adult American avocets, avocet eggs, and diet samples were collected in 2007 from Ogden Bay (see Figure 5-1).

Breeding productivity. At the Ogden Bay breeding colony, 231 nests were initiated during 2007 and only 19 nests produced young. This was mostly due to losses from two flooding events and nest abandonment.

Adult collection and tissue analysis. Four female American avocets were trapped on their nests at the Ogden Bay colony. The Ogden Bay colony is located where the Weber River flows into the lake along the eastern shore. Elevated blood and liver selenium concentrations were found in all avocets, shown in Table 5-2. There was no significant relationship between blood and liver selenium concentrations in these birds. Selenium concentrations tended to be higher in avocets collected from Ogden Bay in 2006 than in 2007 (P = 0.08), but liver selenium was similar between years. Mercury concentrations in blood and liver, shown in Table 5-2, were not significantly associated with selenium concentrations. Body mass was not significantly associated with either mercury or selenium in blood or liver in these four birds.

TABLE 5-2
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for American Avocets (Shorebirds)
Collected at Great Salt Lake, 2007

Colony	Tissue	*n*	Mean	95% CI[2]	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium									
Ogden Bay	Blood	4	17.3	8.4 - 26	5.6	2.8	12.0	23.0	16.6
Ogden Bay	Liver	4	13.3	8.7 - 18	2.9	1.4	11.0	17.0	13.0
Ogden Bay	Egg[1]	4	2.2	1.7 - 2.6	0.3	0.1	1.8	2.4	2.1
Mercury									
Ogden Bay	Blood	4	0.9	0.7 - 1.1	0.1	0.1	0.7	1.0	0.9
Ogden Bay	Liver	4	2.0	1.2 - 2.7	0.5	0.2	1.7	2.7	1.9
Ogden Bay	Egg[1]	4	0.3	0.08 - 0.5	0.1	0.1	0.1	0.4	0.3

NOTES:
[1] Pooled egg selenium and mercury.
[2] Based on arithmetic mean.

Egg collection, examination, and selenium analysis. Eleven eggs were collected from the four nests where females were trapped, and two eggs were collected from the oviducts of females that were captured on their nests. Selenium results for eggs from each nest were pooled and the mean egg selenium for each nest was used in the analyses. There was a trend towards a positive relationship between blood and egg selenium ($P = 0.07$) but no relationship was observed between liver and egg selenium, based on blood and liver selenium from females trapped on the nests and mean egg selenium from each nest. In addition, no relationship was observed between mercury in blood or liver and egg mercury concentrations. Selenium and mercury concentrations in eggs collected from oviducts of two females were similar to those in eggs from their nests.

Invertebrate analysis. Selenium concentration in a sample of brine fly larvae was 1.6 µg/g and in a sample of adult flies it was 1.2 µg/g. Mercury concentration was 0.1 µg/g in the adults and below the method detection limit in larvae.

5.2.3 Project 1B, Concentration and Effects of Selenium in Gulls, Grebes, and Ducks

The sampling program for Project 1B was largely completed by Utah State University's Dr. Michael Conover over two nesting seasons, 2006 and 2007. Gulls were sampled in both 2006 and 2007. Eared grebes were sampled in the fall of 2006. Goldeneye samples were collected in the 2005 through 2006 fall to winter season. The following provides a summary of data and results from Conover et al. (2008a, 2008b, and 2008c) found in Appendix D.

California Gulls

Collections. Adult California gulls, eggs, water, sediment, and diet samples were collected from three colonies in both 2006 (Hat Island, Antelope Island, and Great Salt Lake Minerals

[GSLM]) and 2007 (Hat Island, GSLM, and an offsite freshwater colony at Neponset Reservoir) (see Figure 5-2).

Food analyses for adults. Of the gulls collected from Great Salt Lake colonies, only one contained more than a single kind of food item (60 percent brine shrimp, 35 percent corixids, and 5 percent midges). Most of the others contained 100 percent brine shrimp (about 75 percent); fewer contained brine fly larvae (7 percent) or corixids (7 percent) in their digestive tracts. Besides brine shrimp, brine flies, and corixids, they had also eaten midge larvae, earthworms, carp, and various types of garbage. Only gulls from GSLM contained corixids and midge larvae. The eight gulls from Neponset Reservoir that had food in their esophagus had fed on garbage and terrestrial insects.

Food items collected from GSLM and Hat Island were analyzed for selenium and mercury. Selenium concentrations in brine shrimp were highest at the Hat Island colony. Mercury levels in brine shrimp were similar between GSLM and Hat Island colonies. Brine shrimp collected by Dr. Conover during 2006 contained higher selenium concentrations than samples collected from the same colonies during 2007.

Selenium analyses of adults collected during 2006 through 2007. Because no male-female differences were found in blood or liver selenium concentrations, results from males and females were combined. Selenium concentrations in gulls eating various food items also were not different. Among individual gulls, selenium concentrations in blood and liver were highly correlated.

Among gulls collected from different colonies, a significant difference in the concentration of selenium in blood was found, but not in livers. In both 2006 and 2007, selenium concentrations were highest in blood of gulls collected at the GSLM colony, which is near where water from the Bear River flows into Great Salt Lake, and lowest in gulls from the Antelope Island colony in 2006 and Hat Island in 2007. Gulls from the Hat Island colony had intermediate concentrations of selenium in 2006 and Neponset gulls had intermediate levels of selenium in 2007, as shown in Table 5-3. This pattern of the highest selenium concentrations being recorded at the GSLM colony was true for selenium concentrations in blood, liver, eggs, and sediment, although differences among colonies were significant only for blood. For gulls collected at the GSLM colony, those collected during 2006 had higher selenium concentrations in their blood than those from 2007 ($F = 4.57$; $d.f. = 1, 22$; $P = 0.04$), but selenium levels in their livers were similar ($F = 0.59$; $d.f. = 1, 22$; $P = 0.59$). Overall mean blood selenium concentration (both years and all locations combined) was 17 µg/g and ranged from 4.8 to 46 µg/g ($n = 71$; geometric mean = 15; 95 percent CI [on the arithmetic mean] = 14.7 - 19.1 µg/g). Overall mean liver selenium concentration was 8.2 µg/g and ranged from 3.9 to 15 µg/g ($n = 71$; geometric mean = 7.8; 95 percent CI = 7.6 - 8.8 µg/g).

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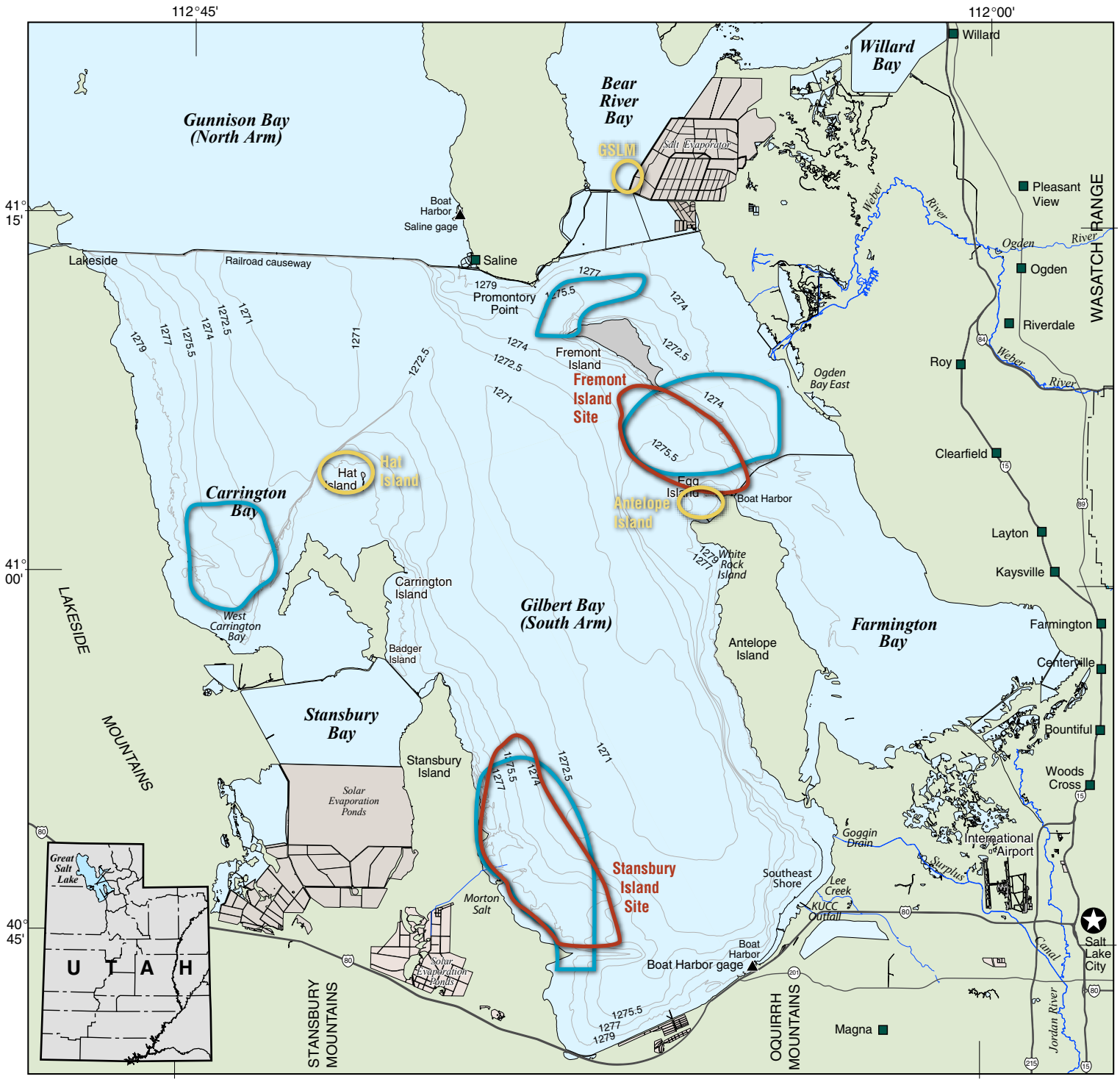

FIGURE 5-2
Project 1B – Gull, Eared Grebe, and Goldeneye Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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TABLE 5-3
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for California Gulls Collected at Great Salt Lake, 2006 and 2007

Colony	Tissue	Year	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium									
Antelope Island	Blood	2006	12	13.9	6.2	1.8	6.4	25.0	12.6
Great Salt Lake Minerals	Blood	2006	11	25.1	10.5	3.2	5.0	37.0	22.1
Great Salt Lake Minerals	Blood	2007	12	20.9	11.9	3.4	8.7	45.7	18.2
Hat Island	Blood	2006	12	16.0	6.9	2.0	6.3	29.0	14.6
Hat Island	Blood	2007	12	10.7	5.0	1.4	4.8	23.0	9.8
Neponset	Blood	2007	12	15.5	7.9	2.3	5.0	32.2	13.8
Antelope Island	Liver	2006	12	7.3	2.4	0.7	4.0	13.0	7.0
Great Salt Lake Minerals	Liver	2006	11	9.2	2.9	0.9	3.9	13.0	8.8
Great Salt Lake Minerals	Liver	2007	12	9.3	3.3	1.0	6.2	15.0	8.8
Hat Island	Liver	2006	12	7.8	2.2	0.6	5.6	13.0	7.6
Hat Island	Liver	2007	12	7.2	1.4	0.4	4.7	9.7	7.1
Neponset	Liver	2007	12	8.3	2.4	0.7	5.6	13.0	8.0
Antelope Island	Egg	2006	11	2.8	0.5	0.2	2.1	4.1	2.7
Great Salt Lake Minerals	Egg	2006	11	3.4	0.5	0.2	2.6	4.3	3.3
Hat Island	Egg	2006	11	2.8	0.5	0.2	2.0	3.4	2.8
Neponset	Egg	2007	12	2.8	0.5	0.1	2.2	3.8	2.7
Mercury									
Great Salt Lake Minerals	Blood	2007	12	3.0	2.1	0.6	0.6	7.6	2.3
Hat Island	Blood	2007	12	3.0	0.9	0.3	0.6	4.3	2.7
Neponset	Blood	2007	12	1.3	1.0	0.3	0.2	3.2	0.8
Great Salt Lake Minerals	Liver	2007	12	4.2	3.3	0.9	0.6	9.9	3.0
Hat Island	Liver	2007	12	5.6	2.4	0.7	0.8	9.8	4.9
Neponset	Liver	2007	12	2.4	2.0	0.6	0.3	5.9	1.6
Neponset	Egg	2007	12	0.3	0.2	0.1	0.1	0.7	0.2

Mercury analyses of adults during 2007. Blood selenium concentrations were correlated with mercury levels in blood but not livers. Selenium concentrations in livers were not correlated with mercury levels in either the blood or the liver.

Mercury concentrations in blood and liver were similar in gulls collected from the Hat Island and GSLM colonies. However, gulls from Neponset Reservoir had significantly lower mercury concentrations in blood and liver than gulls from Hat Island and GSLM colonies.

Body mass. Male gulls were significantly heavier than female gulls and neither male nor female body mass was significantly correlated with selenium or mercury in blood or liver.

Selenium and mercury analyses of water and sediment. Only single water and sediment samples were analyzed from each colony. Waterborne selenium concentration was higher at Hat Island than at the other Great Salt Lake colonies in 2006 but not in 2007.

Selenium and mercury analyses of eggs. Selenium concentrations did not differ among eggs collected from the different Great Salt Lake colonies. The overall mean selenium concentration in eggs was 2.9 µg/g and ranged from 2.0 to 4.3 µg/g (n = 45; geometric mean = 2.9; 95 percent CI [on the arithmetic mean] = 2.8 - 3.1 µg/g). Mercury was analyzed only for eggs from Neponset Reservoir in 2007. Mean mercury concentration in these eggs was 0.26 µg/g and ranged from 0.07 to 0.70 µg/g (n = 12; geometric mean = 0.21; 95 percent CI = 0.14 - 0.38 µg/g).

Analyses of eggs and chicks for viability and deformities. Among the sample of 24 eggs randomly sampled from 3-egg clutches during the late incubation period from Great Salt Lake colonies (72 eggs total), all contained developing late-incubation stage embryos except a single egg that came from the GSLM colony. No embryo deformities were found in any eggs collected or 100 newly hatched chicks observed in the colonies.

Eared Grebes

Collections. Eared grebes were collected in September and November 2006 from near Antelope Island and near Stansbury Island (see Figure 5-2).

Food analyses. All grebes had a mass of feather fragments and brine shrimp cysts in their gizzard but individual food items in the gizzard could not be identified. Identification of other food items was limited to items in the birds' esophagus. During September, grebes fed primarily on adult brine shrimp and adult brine flies. During November, food items in the grebes were almost entirely adult brine shrimp.

Selenium and mercury analyses. Selenium concentrations in livers (Table 5-4) were lower in grebes collected in September than in November and they were also lower in grebes collected near Antelope Island than those collected near Stansbury Island. Juveniles had lower selenium concentrations than adults but concentrations in males and females were not different. In blood, selenium concentrations differed only by collection site (Antelope Island blood selenium was lower than in blood from Stansbury Island birds). Mercury concentration in the blood of grebes was lower in those collected in September than in November and lower in birds collected near Antelope Island than in those from near Stansbury Island. Juveniles had lower blood mercury than adults but males and females were not different.

TABLE 5-4
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for Eared Grebes
Collected at Great Salt Lake, 2006

Location	Tissue	Month	Age	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium										
Antelope Island	Blood	Sept	Adult	6	24.8	11.0	4.5	6.8	36.3	21.9
Antelope Island	Blood	Sept	Juv	6	15.3	15.9	6.5	0.3	45.9	7.6
Antelope Island	Blood	Nov	Adult	4	14.0	3.2	1.6	10.3	17.8	13.7
Antelope Island	Blood	Nov	Juv	7	12.9	5.3	2.0	1.1	16.1	10.2
Stansbury Island	Blood	Sept	Adult	4	16.9	9.8	4.9	7.7	25.6	14.6
Stansbury Island	Blood	Sept	Juv	6	16.6	9.4	3.9	6.8	32.7	14.6
Stansbury Island	Blood	Nov	Adult	8	35.5	12.1	4.3	22.2	55.3	33.8
Stansbury Island	Blood	Nov	Juv	2	28.7	4.2	3.0	25.7	31.7	28.5
Antelope Island	Liver	Sept	Adult	6	13.6	2.7	1.1	10.7	16.8	13.3
Antelope Island	Liver	Sept	Juv	9	7.7	2.2	0.7	5.0	11.9	7.5
Antelope Island	Liver	Nov	Adult	5	7.5	0.7	0.3	7.0	8.7	7.4
Antelope Island	Liver	Nov	Juv	10	7.2	0.5	0.2	6.4	8.2	7.1
Stansbury Island	Liver	Sept	Adult	4	10.5	6.8	3.4	5.6	20.3	9.1
Stansbury Island	Liver	Sept	Juv	11	8.1	2.1	0.6	5.5	12.7	7.8
Stansbury Island	Liver	Nov	Adult	13	21.8	4.1	1.1	17.2	28.4	21.4
Stansbury Island	Liver	Nov	Juv	2	21.0	4.5	3.2	17.8	24.2	20.8
Mercury										
Antelope Island	Blood	Sept	Adult	6	5.3	1.8	0.8	3.2	8.2	5.1
Antelope Island	Blood	Sept	Juv	6	4.8	3.7	1.5	0.1	8.6	2.2
Antelope Island	Blood	Nov	Adult	4	4.1	0.7	0.3	3.2	4.7	4.1
Antelope Island	Blood	Nov	Juv	7	3.2	1.5	0.6	0.1	4.3	2.0
Stansbury Island	Blood	Sept	Adult	4	5.5	0.9	0.4	4.8	6.7	5.5
Stansbury Island	Blood	Sept	Juv	6	6.7	1.8	0.7	3.5	8.6	6.4
Stansbury Island	Blood	Nov	Adult	8	14.3	1.9	0.7	11.5	18.0	14.2
Stansbury Island	Blood	Nov	Juv	2	12.3	4.3	3.1	9.3	15.4	11.9
Stansbury Island	Liver	Sept	Adult	4	6.9	2.7	1.4	4.6	10.5	6.5
Stansbury Island	Liver	Sept	Juv	6	12.2	10.1	4.1	4.5	32.2	9.9
Stansbury Island	Liver	Nov	Adult	9	15.4	6.2	2.1	5.9	28.0	14.2
Stansbury Island	Liver	Nov	Juv	1	17.9	–	–	17.9	17.9	17.9

When all birds were combined, mean selenium concentration in blood was 21 µg/g, and concentrations ranged from 0.3 to 55 µg/g (*n* = 43; geometric mean = 16; 95 percent CI [on the arithmetic mean] = 17 – 25 µg/g); in liver it was 12 µg/g and ranged from 5.0 to 28 µg/g (*n* = 60; geometric mean = 13; 95 percent CI = 10 – 14 µg/g). Mean mercury concentration in blood was 6.9 µg/g and concentrations ranged from 0.05 to 18 µg/g (*n* = 43; geometric mean = 4.9; 95 percent CI = 5.6 – 8.4 µg/g); in liver it was 13 µg/g and ranged from 4.5 to 32 µg/g (*n* = 20; geometric mean = 11; 95 percent CI = 9.4 – 16 µg/g). When all grebes were included, there were significant positive relationships between selenium concentrations in blood and liver and between selenium and mercury concentrations in blood. When juvenile males, adult males, juvenile females, and adult females collected in November were analyzed separately, selenium concentrations in blood were correlated with selenium concentrations in liver in all sex and age groups. In males, selenium concentrations in the liver and blood were correlated with mercury levels in blood but not mercury levels in livers. In females, selenium concentrations were not associated with mercury concentrations.

When all grebes were combined, a positive relationship was seen between body mass and selenium concentrations in blood and liver and mercury concentrations in liver. This association is undoubtedly a result of increased mass of the birds while they were on the lake and the increased selenium and mercury concentrations in the late-season birds. When only grebes collected in November were considered and each age and sex group was analyzed separately, body mass was not correlated with selenium or mercury concentrations with one exception—mass of juvenile females was highly positively correlated with mercury blood levels.

Common Goldeneyes

Collections. Common goldeneyes were collected in two general areas (Fremont Island and Stansbury Island) in November through December 2005 and January through March 2006 (see Figure 5-2).

Selenium and mercury analyses. Selenium and mercury concentrations, shown in Table 5-5, in both livers and blood did not vary by age, but collection site (Fremont Island versus Stansbury Island) affected selenium concentrations in liver and also mercury concentrations in both liver and blood. When all birds were combined, mean selenium concentration in blood was 17 µg/g and concentrations ranged from 1.1 to 33 µg/g (*n* = 40; geometric mean = 14; 95 percent CI [on the arithmetic mean] = 14 – 19 µg/g); in livers the mean for selenium was 15 µg/g and concentrations ranged from 3.6 to 34 µg/g (*n* = 40; geometric mean = 13; 95 percent CI = 13 – 18 µg/g). Mean mercury concentration in blood was 14 µg/g and concentrations ranged from 0.6 to 30 µg/g (*n* = 40; geometric mean = 12; 95 percent CI = 12 – 17 µg/g); in liver the mean was 39 µg/g and concentrations ranged from 1.6 to 114 µg/g (*n* = 40; geometric mean = 11; 95 percent CI = 30 – 48 µg/g).

TABLE 5-5
Summary Statistics for Selenium and Mercury Analyses (µg/g dry weight) for Common Goldeneyes
Collected at Great Salt Lake, November–December 2005 and January–March 2006

Location	Tissue	Month	*n*	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Selenium									
Fremont Island	Blood	Nov	1	4.3	–	–	4.3	4.3	4.3
Fremont Island	Blood	Dec	9	14.7	6.0	2.0	7.8	28.0	13.8
Fremont Island	Blood	Jan	9	20.6	8.0	2.7	11.0	33.0	19.3
Stansbury Island	Blood	Nov	1	3.5	–	–	3.5	3.5	3.5
Stansbury Island	Blood	Dec	1	7.8	–	–	7.8	7.8	7.8
Stansbury Island	Blood	Feb	8	19.4	4.3	1.5	13.0	24.0	18.9
Stansbury Island	Blood	Mar	11	16.4	9.1	2.7	1.1	32.0	12.5
Fremont Island	Liver	Nov	1	5.8	–	–	5.8	5.8	5.8
Fremont Island	Liver	Dec	9	9.4	3.0	1.0	5.7	14.0	8.9
Fremont Island	Liver	Jan	9	17.4	6.4	2.1	7.2	25.2	16.2
Stansbury Island	Liver	Nov	1	4.4	–	–	4.4	4.4	4.4
Stansbury Island	Liver	Dec	1	5.5	–	–	5.5	5.5	5.5
Stansbury Island	Liver	Feb	8	18.6	3.5	1.2	11.0	22.1	18.3
Stansbury Island	Liver	Mar	11	18.7	9.4	2.8	3.6	34.0	15.6
Mercury									
Fremont Island	Blood	Nov	1	2.2	–	–	2.2	2.2	2.2
Fremont Island	Blood	Dec	9	8.5	2.9	1.0	3.4	13.4	7.9
Fremont Island	Blood	Jan	9	14.2	3.5	1.2	9.0	19.0	13.8
Stansbury Island	Blood	Nov	1	4.6	–	–	4.6	4.6	4.6
Stansbury Island	Blood	Dec	1	8.5	–	–	8.5	8.5	8.5
Stansbury Island	Blood	Feb	8	17.5	3.7	1.3	13.2	23.2	17.2
Stansbury Island	Blood	Mar	11	19.4	10.1	3.0	0.6	30.0	13.6
Fremont Island	Liver	Nov	1	2.8	–	–	2.8	2.8	2.8
Fremont Island	Liver	Dec	9	14.4	7.7	2.6	5.4	30.0	12.8
Fremont Island	Liver	Jan	9	36.9	14.3	4.8	10.8	59.1	33.6
Stansbury Island	Liver	Nov	1	5.1	–	–	5.1	5.1	5.1
Stansbury Island	Liver	Dec	1	11.6	–	–	11.6	11.6	11.6
Stansbury Island	Liver	Feb	8	51.2	15.8	5.6	23.0	71.2	48.6
Stansbury Island	Liver	Mar	11	60.1	35.8	10.8	1.6	114.0	38.9

Significant relationships were identified between selenium concentrations in liver and selenium in blood or mercury concentrations in liver; selenium and mercury in blood and liver were all highly correlated with each other. Body mass and liver mass, shown in Table 5-6, were not correlated with concentrations of selenium or mercury in either blood or

liver. Fat mass was negatively correlated with selenium concentrations in liver, mercury concentrations in liver, and mercury concentrations in blood.

Among Fremont Island ducks, selenium and mercury concentrations in both liver and blood samples varied by collection date; but this was not true for Stansbury Island ducks. Body mass, liver mass, and fat mass did not vary by collection date for either Fremont Island or Stansbury Island ducks.

TABLE 5-6
Summary Statistics for Body Mass, Liver Mass, and Fat Mass (grams wet weight) for Common Goldeneyes Collected at Great Salt Lake, November–December 2005 and January–March 2006

Location	Month	n	Mean	Std. Dev.	Std. Error	Min.	Max.	Geometric Mean
Body Mass								
Fremont Island	Nov	1	1150.0	–	–	1150.0	1150.0	1150.0
Fremont Island	Dec	9	1120.4	106.6	35.6	962.0	1246.0	1115.8
Fremont Island	Jan	9	1105.9	85.6	28.5	1038.0	1254.0	1103.1
Stansbury Island	Nov	1	1094.0	–	–	1094.0	1094.0	1094.0
Stansbury Island	Dec	1	1191.0	–	–	1191.0	1191.0	1191.0
Stansbury Island	Feb	8	1052.4	73.9	26.1	954.0	1159.0	1050.1
Stansbury Island	Mar	11	1048.7	71.3	21.5	921.0	1155.0	1046.5
Liver Mass								
Fremont Island	Nov	1	27.0	–	–	27.0	27.0	27.0
Fremont Island	Dec	9	35.2	6.6	2.2	26.0	48.0	34.7
Fremont Island	Jan	9	32.4	7.1	2.4	23.0	47.0	31.8
Stansbury Island	Nov	1	42.0	–	–	42.0	42.0	42.0
Stansbury Island	Dec	1	36.0	–	–	36.0	36.0	36.0
Stansbury Island	Feb	8	26.3	3.5	1.2	22.0	32.0	26.0
Stansbury Island	Mar	11	32.8	5.8	1.7	23.0	43.0	32.3
Fat Mass								
Fremont Island	Nov	1	17.0	–	–	17.0	17.0	17.0
Fremont Island	Dec	9	14.2	7.8	2.6	5.4	28.4	12.5
Fremont Island	Jan	9	10.6	3.1	1.0	6.1	14.8	10.2
Stansbury Island	Nov	1	9.5	–	–	9.5	9.5	9.5
Stansbury Island	Dec	1	19.0	–	–	19.0	19.0	19.0
Stansbury Island	Feb	8	8.3	5.3	1.9	4.9	20.7	7.4
Stansbury Island	Mar	11	7.8	5.6	1.7	3.7	21.1	6.5

5.2.4 Project 2A, Synoptic Survey of Selenium in Periphyton and Brine Fly Larvae from the Benthic Zone

The sampling program for Project 2A was completed by Utah State University's Dr. Wayne Wurtsbaugh during 2006. The following provides a summary of data and results from Wurtsbaugh's *Preliminary Analyses of Selenium Bioaccumulation in Benthic Food Webs of the Great Salt Lake, Utah* (2007), found in Appendix E.

Brine fly larvae and pupae were sampled from biostromes and shore-zone sediments from locations near the northern and southern ends of Antelope Island (Bridger Bay and Gilbert South) during June 2006. The periphyton algae of the biostromes and the bulk sediment were also characterized for selenium content and a new sampling method for brine flies on biostromes proved to be a useful tool for work in Great Salt Lake. Through additional tests performed in April 2007, it was confirmed that acid digestion of the biostrome calcareous material provided the best measure of periphyton selenium, undiluted by the inorganic matrix. Acidified biostrome periphyton selenium concentrations exceeded those of nearby surface sediments, and both were significantly higher than either sand or unacidified biostromes. In total, Wurtsbaugh estimated that about 90 percent of the lake's selenium mass is contained in the top 2 cm of lake sediment and biostrome material (see Wurtsbaugh, 2007, Table 5).

The limited number of biostrome, sediment, and larvae/pupae samples did not provide adequate information to develop a predictive relationship between the selenium in brine fly food sources and the brine fly tissue. Therefore, geometric mean values of the selenium concentrations in acidified biostromes, shore-zone sediment, and brine fly larvae and pupae were taken from this study to incorporate into the food web model. Brine fly larvae were found to be much more abundant on the biostrome structures than on nearby sand or mud substrates, and it is appropriate that the selenium in biostrome periphyton be used in the model as the representative food for the larvae.

Selenium concentrations in the brine flies ranged from 0.9 to 2.0 micrograms of selenium per gram (μg Se/g) and varied between life stages and sites. Concentrations increased from larvae (1.3 μg Se/g) to pupae (1.5 μg Se/g), and this difference was significant (P less than 0.05). Concentrations were higher in adult flies (1.8 μg Se/g) than in pupae, but there were insufficient samples (three) to determine if this was significant. A two-way analysis of variance indicated that the brine flies in Bridger Bay (1.6 μg Se/g) had significantly higher concentrations of selenium than did those in Gilbert South (1.3 μg Se/g) (P less than 0.001).

Figure 5-3 shows a map of brine fly and biostrome sampling locations. Table 5-7 summarizes selected results.

TABLE 5-7
Key Brine Fly Results from 2006–2007 Great Salt Lake Studies: Ranges of Values

	Water concentrations (µg Se/L)	Sediment concentrations (µg Se/g dw)	Tissue concentrations (µg Se/g dw)
Water/sediment	0.37 – 0.43	1.4 – 9.8	
Brine fly larvae			0.9 – 1.5
Brine fly pupae			1.1 – 2.0
Brine fly adults			1.8 – 1.9
Biostrome periphyton			0.9 – 2.2

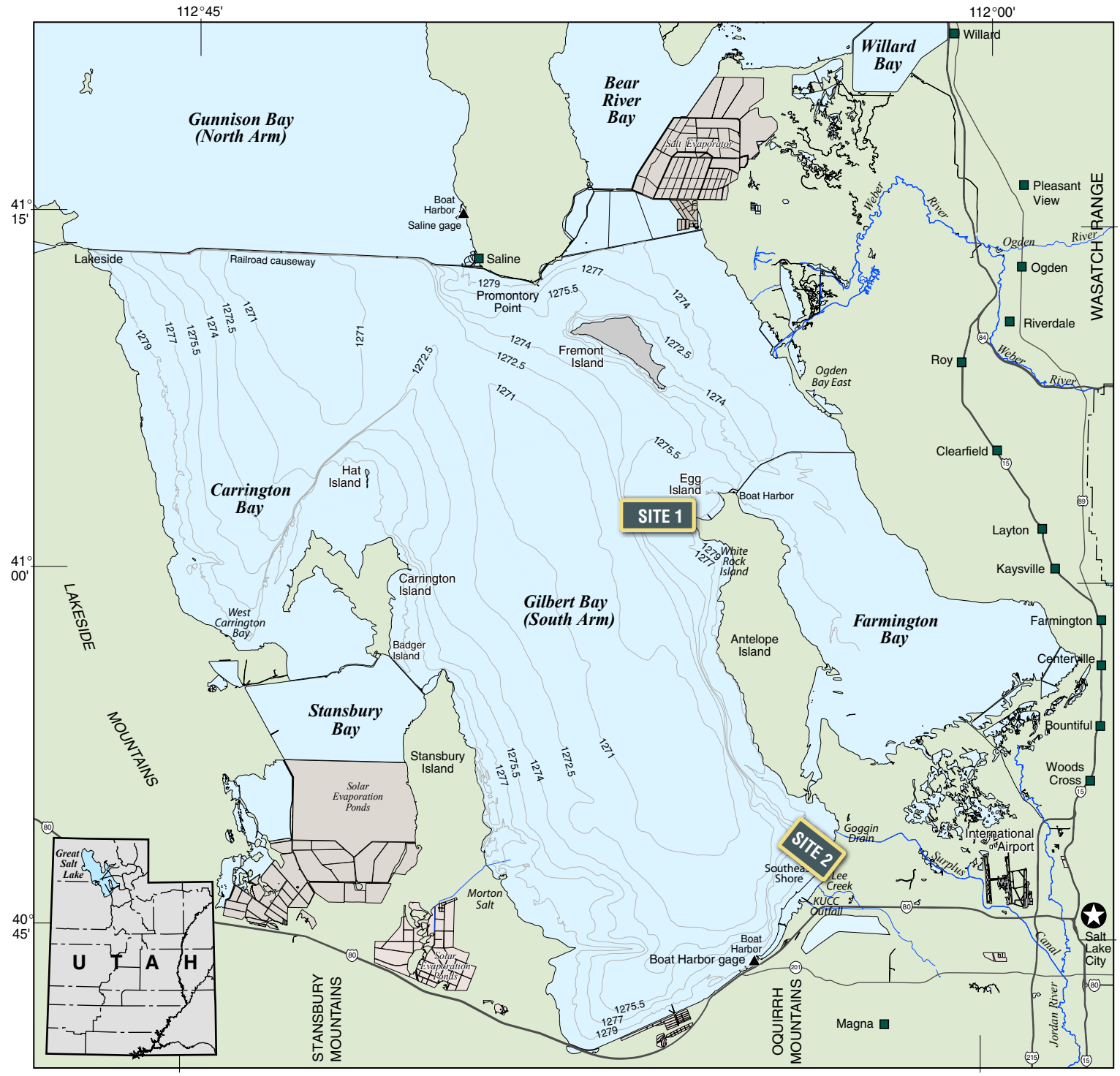

FIGURE 5-3
Project 2A – Benthic Zone Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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5.2.5 Project 2B, Synoptic Survey of Selenium in Water, Seston, and Brine Shrimp

The sampling program for Project 2B was completed by Brad Marden during 2006 and 2007. The following provides a summary of data and results from Marden's *Project 2B: Synoptic Survey of the Pelagic Zone: Selenium in Water, Seston, and Artemia* (originally with 2006 results, only) and his 2007 update found in Appendix F. The final 2006 through 2007 summary report of all data is still pending.

Brad Marden's data on brine shrimp and lake characteristics included data on water quality, seston chemistry, chlorophyll concentrations, algal cell counts, complete density estimates of brine shrimp by life stage, and brine shrimp selenium content.

The brine shrimp displayed a characteristic seasonal cycle of abundance during the 2006 through 2007 data collection period that is typical of a generally "healthy" population. The phytoplankton was also found to be typical of the lake, with the midsummer community dominated by the chlorophyte *Dunaliella* sp. Selenium concentrations in water were not significantly variable spatially but changed seasonally, with a net increase of 0.1 to 0.2 µg Se/L for the lake water column over the period of study. Similarly, seston and brine shrimp selenium concentrations variably increased over the period of study. However, no statistically significant relationships were found between brine shrimp selenium concentrations and those in water or seston in the 2006 result summary or in the analysis of data from combined years. The 2007 results indicated more elevated brine shrimp tissue selenium concentrations than 2006. Those 2007 values (upper ends of ranges, Table 5-8) were all analyzed from filters in contrast to the values from 2006, without the use of filters, that never exceeded 3.5 mg Se/kg dry weight (dw). The change in methods and subsequent shift to higher brine shrimp concentrations suggest that the 2007 brine shrimp values should be used as most representative of current lake conditions.

Figure 5-4 shows a map of sampling locations for the brine shrimp study. Table 5-8 summarizes selected results.

TABLE 5-8
Brine Shrimp Results from 2006–2007
Great Salt Lake Studies: Ranges of Values

	Water concentrations (µg Se/L)	Tissue concentrations (µg Se/g dw)
Water	0.398 – 0.899	
Adults/Juveniles		0.31 – 7.1
Nauplii and cysts		0.09 – 5.4
Seston		0.29 – 4.5

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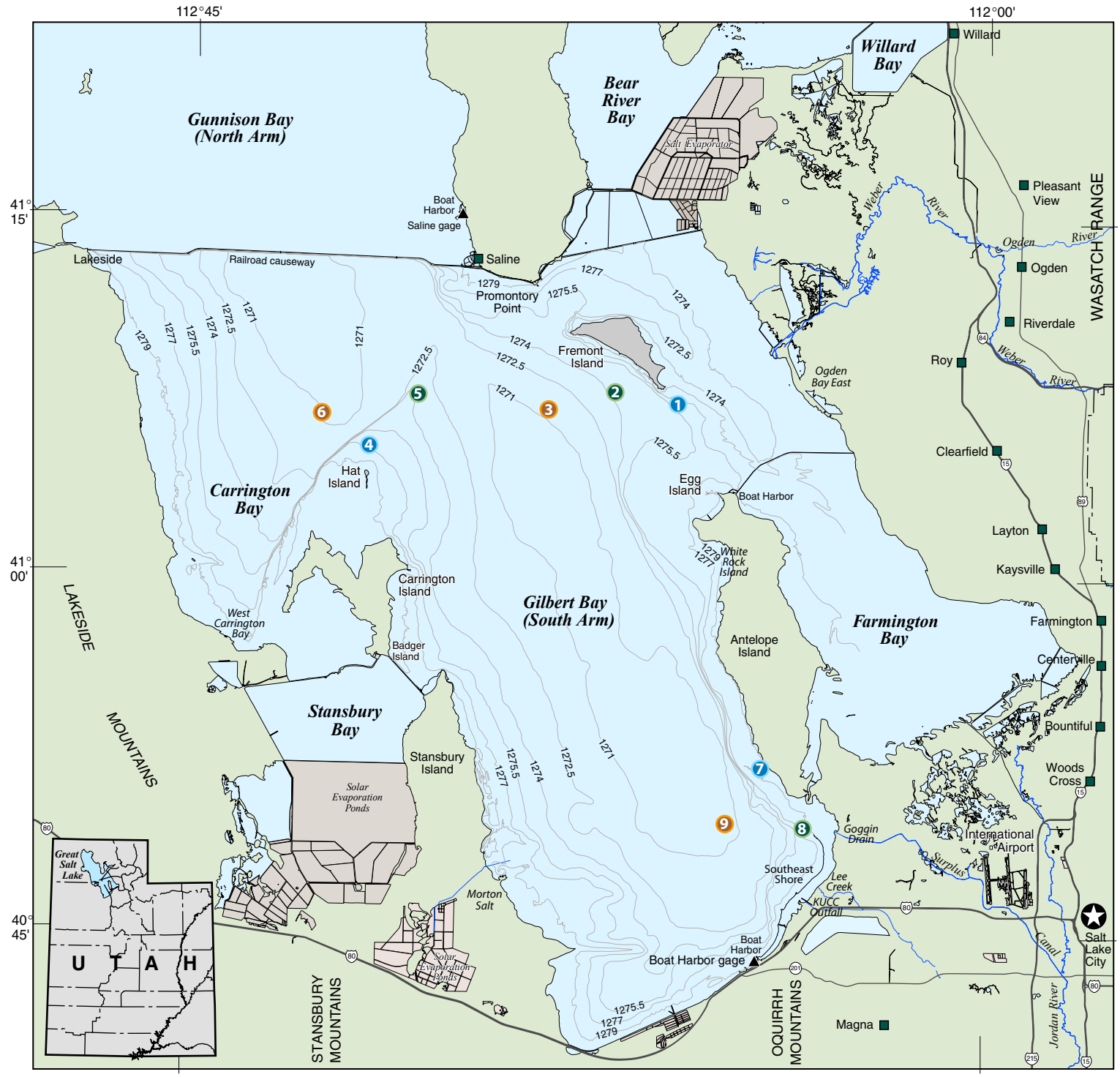

LEGEND

- 1 - 3 Meter Deep Location
- 5 - 6 Meter Deep Location
- 8 - 9 Meter Deep Location

FIGURE 5-4
Project 2B – Pelagic Zone Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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5.2.6 Project 3, Measurement of Selenium Loads to Great Salt Lake

The sampling program for Project 3 was completed by the USGS's Dr. David Naftz over a 15-month period in 2006 and 2007. The following provides a summary of data and results from USGS's *Estimation of selenium loads entering the south arm of Great Salt Lake, Utah: Final Report* (Naftz et al., 2008), found in Appendix G.

Six gages were operated for water quality sampling and flow measurements, and standard USGS models (LOADEST) were used to match statistically significant loading models to the measured loads at each gage to produce daily loading estimates over the period of record. Total estimated selenium influent load was 1,540 kg, with an annual (May 2006 to April 2007) load of 1,480 kg over the full 15-month study period. The Kennecott Utah Copper Corporation outfall and Goggin Drain contributed the greatest proportion of loads among sites (27 percent each), although the Bear River contributed an almost equal amount (26 percent). The Farmington Bay outlet site measured the combined flow northward to the main lake out of Farmington Bay. The Weber River gage measured one branch of the Weber River and did not measure the entire flow. Loads from the Weber River were corrected for the total river volume of water. The greatest total loads over time at all sites occurred during May 2006. Most of the influent selenium was in the dissolved phase as selenate ($Se6^{+}$), which was determined by subtraction of selenite ($Se4^{+}$) from total amount of dissolved selenium in the samples. Measurements at the railroad causeway partially separating the north and south arms of the lake indicated a net positive flow and selenium load from south to north over the period of record with a mean loss from the south arm of 2.4 kg Se/day.

The mean selenium concentration in the south arm of the lake increased over the 15-month period of the study and exceeded the change in concentration (0.17 µg Se/L) that could be expected from the simple addition of influent loads. Additional unmeasured sources of selenium could account for as much as 1,500 kg of additional load during the 2006 through 2007 period.

Table 5-9 summarizes selected project findings. Figure 5-5 shows the map of sampling locations.

TABLE 5-9
Project 3 Data Summary

Site	15-mo. Stream Loading (kg) (n)	Se Speciation (% selenite) (2 samples ea)	Causeway Loads to North (kg/day) (5 samples)	In-lake Increase in Conc. (µg Se/L) (46 samples)	Estimated Increase in Lake Conc. from streams (µg Se/L)
Bear River	400 (42)	17 – 27			
Weber River	54 (12)	30 – 33			
Goggin Drain	420 (41)	22 – 33			
Lee Creek	120 (14)	22 – 28			
Kennecott outfall	420 (134)	1.8 – 5.1			
Farmington Bay	170 (47)	14 – 20			
Causeway			2.4		
In-lake				0.16 – 0.34	0.17

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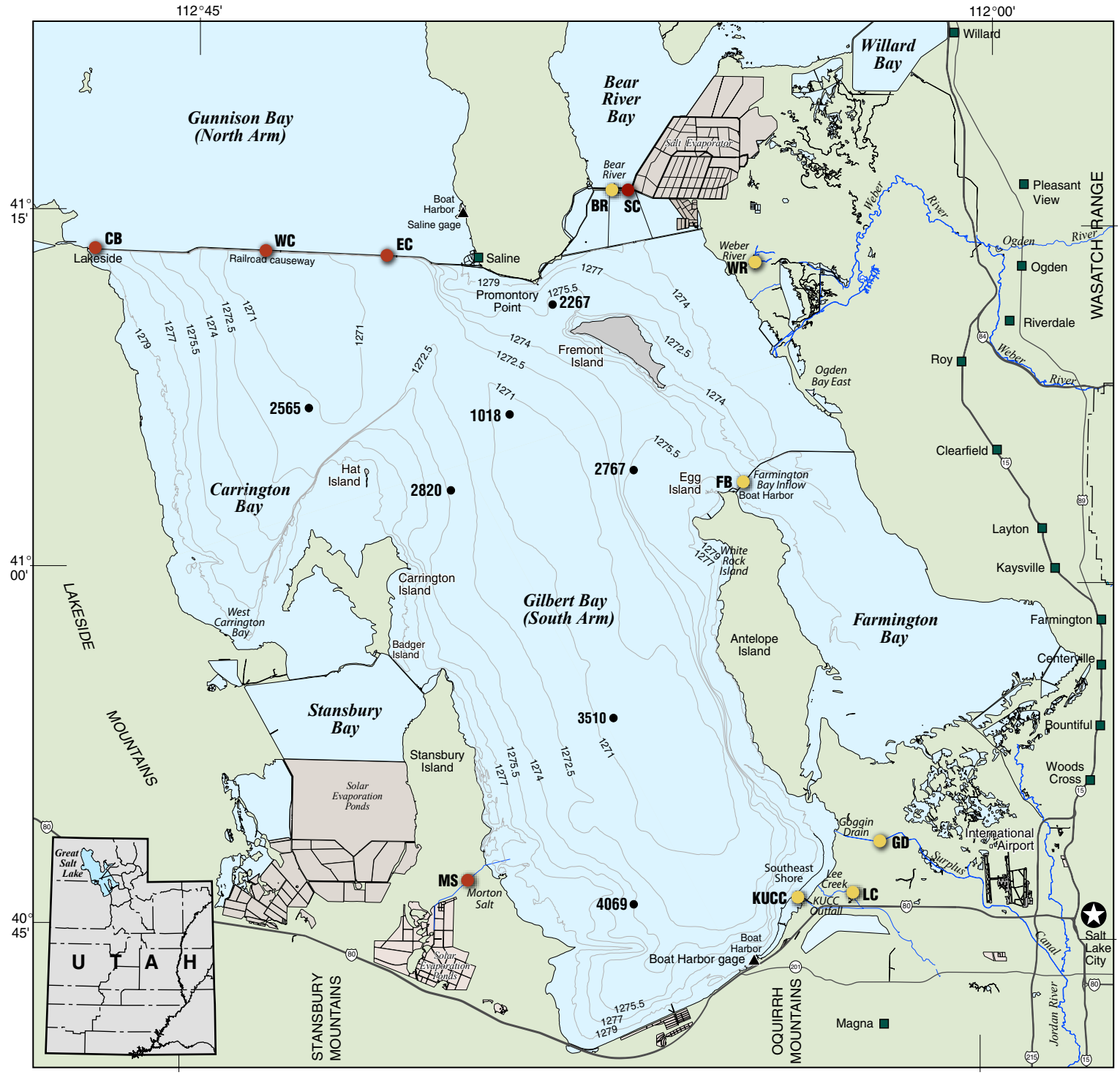

Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1980, 1984
Universal Transverse Mercator projection, zone 12

LEGEND

- AA — Non-continuous Stream Gage and Sample Collection Site
- AA — Continuous Stream Gage and Sample Collection Site
- 4069 — Lake Monitoring Site

FIGURE 5-5
Project 3 – Selenium Load Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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5.2.7 Project 4, Measurement of Selenium Flux

The University of Utah's Dr. Bill Johnson completed the sampling program for Project 4 in 2006 and 2007. The following provides a summary of data and results from Johnson's *Estimation of selenium removal fluxes from the south arm of the Great Salt Lake, Utah: Final Report* (Johnson et al., 2008), found in Appendix H.

Project 4 provided a great amount of detail about in-lake geochemical processes and yielded estimates of important losses of selenium from the water column as well as estimates of gains through remobilization from particulate phases. Project 4 also provided baseline characterizations of selenium in the water column, as found in the upper, mixed layer, and the deep brine layer, as well as in sediments and as volatile compounds exiting the lake in vapor phase. Measurements of water showed that most selenium was present in the dissolved phase but that selenium concentrations were relatively higher in the particulate fraction of the deep brine layer. A net increase in water column selenium concentrations was measured during the study at some stations and was reported in the *Estimation of selenium loads entering the south arm of Great Salt Lake* report (Appendix G).

Sediment traps, cores, and bed sediment samples were collected and the material was analyzed for major and minor elements, including selenium. Radioisotope analyses were used to characterize sediment age by depth and sediment accumulation rates. The subsequent results yielded estimates of sedimentation rates and permanent sediment burial of selenium.

Volatilization of selenium from surface waters was discovered to be a major loss process for selenium from the water column and, although highly variable, probably accounts for a net loss of selenium more than 4-fold greater than that attributed to sediment burial. The estimates of volatilization required the measurement of total gas pressure, dissolved volatile species of selenium, direct estimates of flux from an *in situ* floating chamber, and modeled estimates of surface flux based on measurements of volatile selenium concentration gradients, water temperature, and wind speed during the 2006 through 2007 period.

Sedimentation fluxes were measured using sediment traps at several sites but appeared to be dominated by resuspension of surface sediments in the deep brine layer traps. In addition, the shallow sediment trap near the Bear River showed excessively high sedimentation rates attributable to riverine flux of sediments into the lake. However, other shallow sediment trap locations yielded sediment trap results useful in characterizing water column sedimentation loss rates uncomplicated by resuspension or tributary inputs. Those latter results were compiled as seasonal totals. Total sedimentation of selenium from the shallow layers was estimated as 383 kg over the year of measurement.

Thermistor string results revealed frequent displacement of the anoxic deep brine layer associated with seiches brought about by strong wind events. As a result, the seiches produced changing spatial patterns of anoxia overlying the lake's sediments. In theory, the seiches would affect resuspension of sediments as well as selenium remobilization and dissolution related to changing oxygenation of the overlying water. However, laboratory batch tests of sediment exposed to aerated or anoxic conditions did not reveal a significant potential for selenium remobilization from surface sediments through this route.

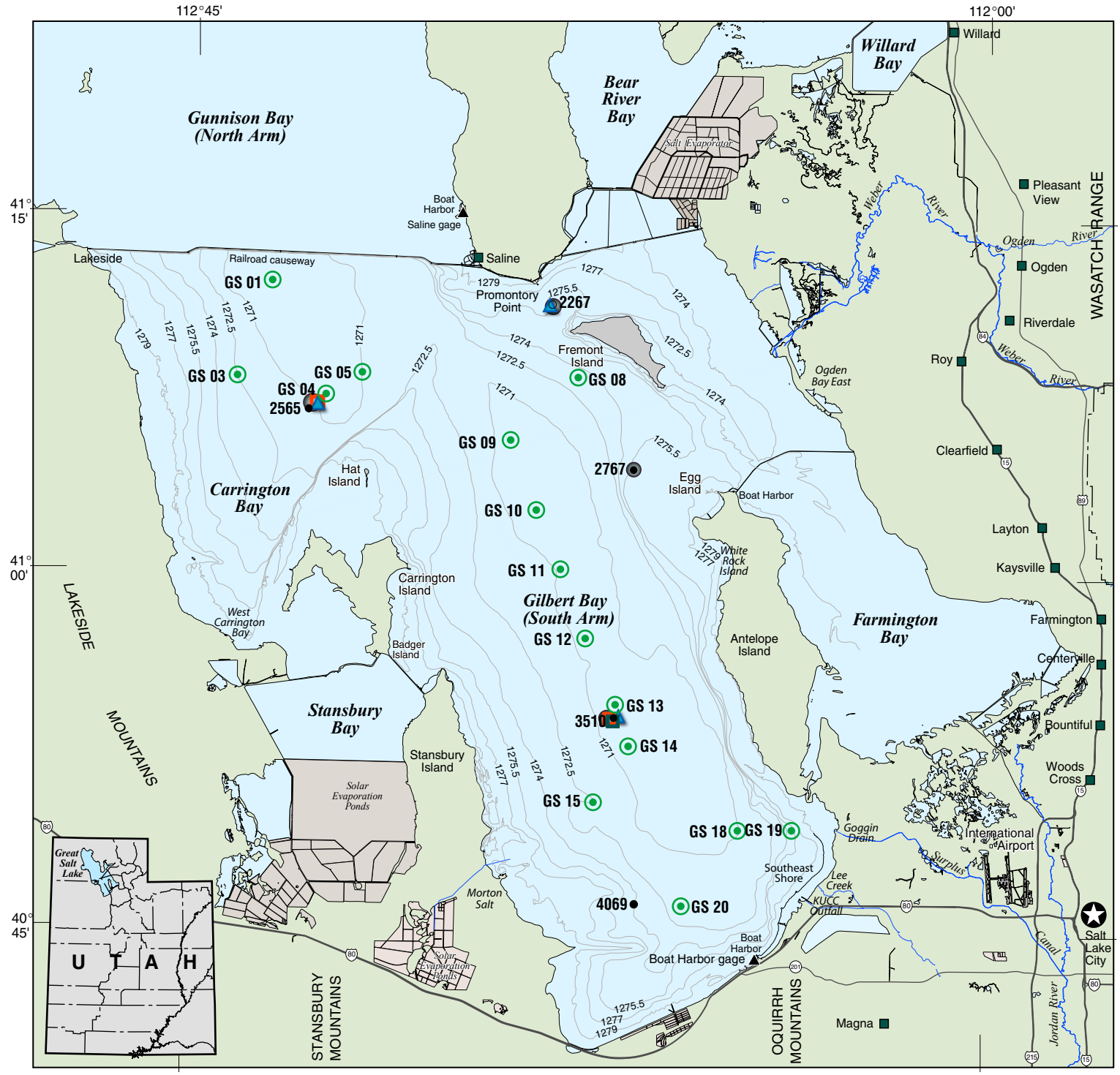
However, in addition to periodic and common wind-driven seiche movements of the deep brine layer, an overall shrinking of the areal coverage of the layer was observed during the 2006 through 2007 period. Johnson estimated that the newly exposed lake bottom sediments might have yielded as much as 25 kg of selenium to the water column during this period of DBL shrinkage.

In total, the mean estimates of various components of lake-wide mass balance of selenium over the study period, as reported by Johnson, include the following:

- Volatilization: 2,108 kg per year (estimated range is 1,380 to 3,210 kg per year)
- Permanent Sedimentation: 520 kg per year (estimated range is 45 to 990 kg per year)
- Shallow zone particulate sedimentation: 383 kg per year (estimated from his results)
- Deep brine layer dissolution and resuspension (internal loading): 25 kg per month (does not multiply to yearly value)
- Brine shrimp cyst removal: 28 kg per year (estimated range is 10 to 48 kg per year), median
- Selenium residence time in the lake: 3 to 5 years (knowing gain and loss terms)

The variability of each estimate was reported, as well.

Figure 5-6 shows sampling points. Table 5-10 lists selected findings from the study.



Base from U.S. Geological Survey digital data, 1:100,000, 1978, 1979, 1980, 1984
Universal Transverse Mercator projection, zone 12

NOTE: ALL LOCATIONS ARE APPROXIMATE.

LEGEND

- Dissolved Gas
- Sediment Cores
- Sediment Trap / Water Samples
- Thermistor Staging
- ADCP
- 4069 Lake Monitoring Site

FIGURE 5-6
Project 4 – Selenium Flux Sampling Locations
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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TABLE 5-10
Project 4 Data Summary

Parameter	Se Concentration or Flux Estimate	Number of Samples
Raw water	0.25 – 3.11 µg/L	126
Filtered water	0.21 – 2.77 µg/L	126
Surface sediment (ooze)	0.83 +/- 0.36 mg/kg	12
Mineral sediment	1.19 +/- 0.22 mg/kg	12
Shallow-layer Sedimentation rates	$1.25*10^{-9}$ – $5.52*10^{-8}$ g/cm^2/yr	7
Permanent burial rates	500 kg/yr (weighted from all zones)	8
Volatilization	1,380 – 3210 kg/yr	23

5.2.8 Project 5, Brine Shrimp Kinetics Study

Dr. Martin Grosell at the University of Miami conducted this study to address specific objectives about brine shrimp selenium assimilation and bioaccumulation. The following provides a summary of data and results from Grosell 2007a and 2007b found in Appendix I. Dr. Grosell's final report is pending.

An initial objective of the study was to determine the variation in brine shrimp feeding rate as a function of salinity. The results suggested that optimal feeding rates could best be studied at 100 grams per liter (g/L) salinity. Higher salinities produced reduced feeding rates and reduced uptake of selenium directly from water.

The second objective investigated the uptake of selenium by brine shrimp after 24-hour exposures at a variety of ambient waterborne selenium concentrations. The results revealed clear saturation kinetics response at waterborne concentrations below 10 µg Se/L. Between 10 and 20 µg Se/L in water there was a "knee" in the brine shrimp response pattern. Much higher values of bioaccumulation were associated with water concentrations up to 40 µg Se/L. Higher water values (up to 80 µg Se/L) demonstrated decreased bioaccumulation, possibly due to selenium regulation by the brine shrimp.

In addition, the study involved feeding Se-75-labeled algae to brine shrimp over 1-hour exposures to estimate ingestion and assimilation efficiencies. The experiment produced a series of graphical relationships that can be used to specify assimilation efficiencies as a function of dietary selenium concentration. Low food concentrations (below 10 µg Se/g dw in algae) produced selenium assimilation efficiencies as high as 90 percent. Higher selenium concentrations in algae produced slightly lower assimilation efficiencies, leveling off near 75 percent in the 60 to 80 µg Se/g dw algae range.

Martin Grosell also presented the results of exposures showing the uptake of selenium by algae (*Dunaliella viridis*) in water containing from 1 to 50 µg Se/L (nominal concentrations) and subsequent feeding of algae containing radio-labeled selenium to Great Salt Lake brine shrimp. All waterborne selenium exposures of algae showed an initial period of rapid uptake over about 5 to 7 days, followed by an apparent depuration period lasting until

about day 20, and then relatively constant tissue concentrations in algae that were exposure-dependent.

The final result of the study was a two-part model that adds waterborne and dietary exposures to produce an estimate of bioaccumulated selenium in brine shrimp. The final predictive model was based on uptake from water and food, computed separately. Predictions from water took the form of two scenarios. The first was a linear relationship between selenium in water and brine shrimp tissue for waterborne concentrations less than 2 µg Se/L. The second scenario described a logistic equation applicable for waterborne concentrations over 2 µg Se/L. The first scenario was chosen for Great Salt Lake modeling because it most closely matched field conditions.

The second part of the model described dietary exposure. The data describe an exponential decay, with assimilation efficiencies ranging from near 100 percent at low food concentrations to about 80 percent for all food concentrations over about 20 µg Se/g dw. Two tables (the two scenarios) were provided at the end of the report predicting steady-state brine shrimp tissue concentrations as would be estimated from Grosell's equations given a choice of water (vertical axis) or dietary (horizontal axis) concentrations. Scenario 1, for low waterborne concentrations within the ranges observed at Great Salt Lake, was chosen as the calculating equations as incorporated into the mass balance and exposure model.

6.0 Quantitative Conceptual Model Development

This section provides a summary of the considerations, assumptions, and methodology used to develop a quantitative conceptual model of selenium cycling in the open waters of Great Salt Lake.

The simplified conceptual model for selenium cycling in the open waters of Great Salt Lake (refer to Figure 3-3) is composed of three primary components: (1) selenium in the upper food chain, (2) selenium in the lower food chain, and (3) selenium in the water and sediment. Due to the bioaccumulative nature of selenium, it is generally recognized to originate at the "bottom" of the conceptual model—that is, from selenium in the water and sediment (abiotic component)—and move "up" through the conceptual model through the lower food chain (food web component), and into the upper food chain (birds component). The development of the quantitative model is discussed first for the Abiotic and Food Web component of the model and then for the Birds component.

6.1 Mass Balance Model

6.1.1 Water Mass Balance

A modified mass balance approach was used to link measured and estimated Great Salt Lake concentrations of selenium in various media into a model that would be responsive to changing ambient conditions. The basic concept of the Mass Balance Model is to include all input and removal mechanisms to estimate a waterborne selenium concentration for the study area. Measured lake and influent selenium concentrations and loads were compiled as monthly geometric mean values, whenever possible. Modeled water column loads and concentrations step through time on a monthly average time step. The concept is to capture seasonal variability whenever possible. The model is meant to predict water column concentrations and therefore relies on both external loads (tributaries, atmospheric deposition) as well as internal loading (remineralization from seston and sediments).

The mass balance prediction for average water column loads can be depicted as:

EQUATION 1
Mass Balance for Average Water Column Load

$$\text{Se-lake}_{t1} = \text{Se-lake}_{t0} + (\text{Influent}_{t1}\ \text{Se} + \text{AtmDep}_{t1}\ \text{Se} + \text{Mineralized}_{t1}\ \text{Se}) - (\text{Volatilized}_{t1}\ \text{Se} + \text{Buried}_{t1}\ \text{Se} + \text{Brine shrimp harvest}_{t1}\ \text{Se})$$

Where:

- t0 and t1 are sequential months.
- Influent selenium sums the net load contributions from tributaries and estimated losses to the north lake for any given month as derived from Naftz et al. (2008).

- AtmDep selenium is an estimate, placeholder value for atmospheric deposition load directly onto the lake's surface, based on 0.5 multiplied by the Chesapeake Bay wet selenium deposition rate and all of the Chesapeake Bay dry deposition rate (annual rate divided by 12) (EPA, 1996). The assumption is that atmospheric deposition to the nonlake area of the watershed is captured in watershed runoff and is already included.
- Mineralized selenium load was estimated as shallow sedimentation rates minus permanent sediment burial rates. The difference between the two represents selenium that is sinking but not being permanently buried and is therefore being remineralized through any wide variety of sediment processes (diagenesis, resuspension, water column dissolution, etc.). It is recognized that net flux could be into or from the sediments for any given period of time.
- Volatilized selenium was estimated as the mean annual, lake-wide loss of volatile selenium provided by Johnson et al. (2008), divided by 12 to yield simple, monthly estimates. These values could be greatly improved through the estimation of monthly values based on temperature, volatile selenium concentrations in water, and wind speed measurements. Volatilization is strongly associated with such seasonally varying parameters as wind speed and temperature, which means that accurate modeling of this important variable (volatilization) must take those meteorological factors into account.
- Buried selenium was the estimated annual permanent sediment burial rate for the lake divided by 12 to produce monthly loss values.
- Brine shrimp harvest was estimated as the weight removed times the average cyst concentrations, following the methods of Johnson et al. (2008). Brine shrimp removal was allocated as an annual value that was equally divided among the months of third and fourth calendar quarters (the timing of actual harvest).

The components of the above mass balance equation were summed as loads and divided by lake volume to yield lakewide average selenium concentrations. Monthly average volumes were estimated using the elevation/volume relationship for the south lake of Baskin (2005) and the USGS Water Resources Division online record of lake elevation at the Saltair station (USGS 10010000 Great Salt Lake at Saltair Boat Harbor, Utah).

The technique of sequentially computing mass balances produced a relatively good match to measured values. At the end of the 15-month measurement period the predicted water column monthly total selenium concentrations were low by an average of 0.04 µg/L (7 percent). A remaining unmeasured total was noted in the reports of Johnson et al. (2008) and Naftz et al. (2008) as evidence for a significant, unmeasured load. In particular, lake water column concentrations during the 2006 through 2007 period were generally observed to rise during a relatively dry year of reduced stream loading. Future monitoring efforts should make an effort to include currently unmeasured but potentially significant contributors to load, such as atmospheric deposition (only estimated from literature values here) and groundwater.

6.1.2 Sediment

Sediments from shallow water depth—but away from shore and those underlying the deep brine layer—provided characterizations useful for tracking particle sedimentation and remineralization (Johnson et al., 2008) but were not used as measures of direct exposure to

invertebrates and birds. Instead, sediments in the immediate shore zone (shorebird wading depth) were assumed to provide direct exposure to brine fly larvae, other insects, and for incidental consumption by shorebirds. Dry-weight sediment concentrations of total selenium were corrected based on the salt content of the water in the wet sediment using the methodology described by Johnson et al. (2008) for deeper water sediments. Shore-zone sediment concentrations were assumed to vary directly with waterborne concentrations in the long term and were therefore modeled as a simple 1:1 relationship to water on a monthly basis. Surface sediment concentrations may be expected to lag in concentration response to changes in the overlying water but the duration of the lag is unknown.

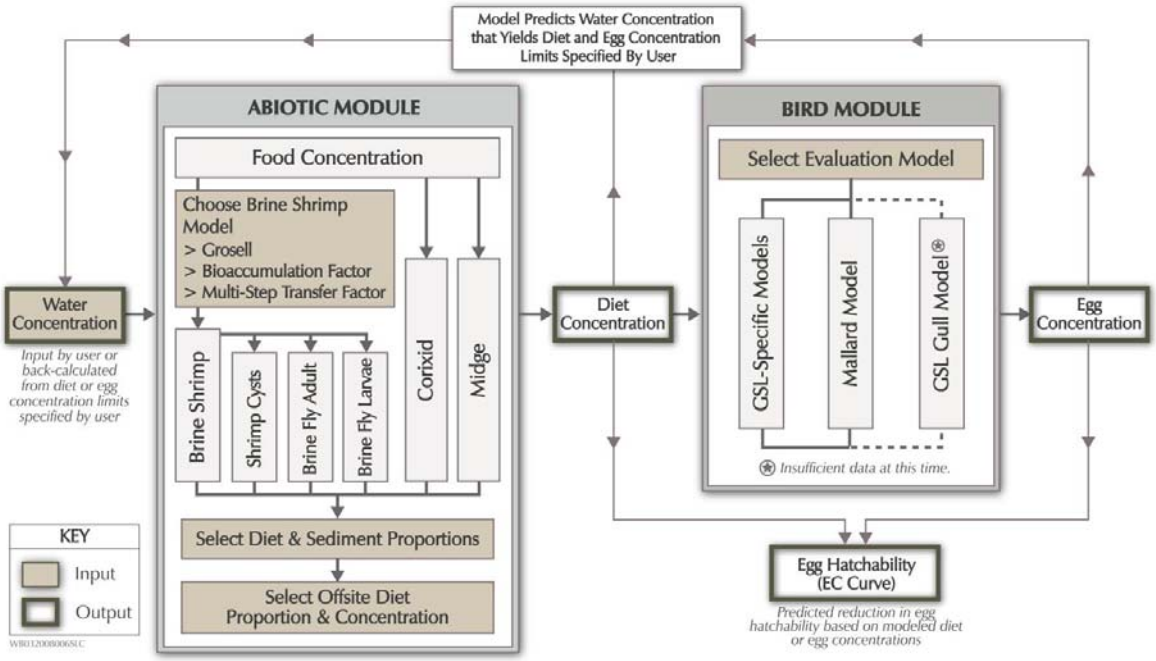
For this and all other modeled parameters, the mass balance model is designed to examine scenarios of possible future conditions that would be representative of a new, altered, steady-state condition. Data are insufficient to resolve the uncertainty in the dataset and resolve questions about long-term patterns of lake assimilation of selenium. The Science Panel recommended that additional monitoring be conducted to build and improve on the current model (potentially building a fully dynamic model) to allow for more accurate examination of scenarios for future conditions.

6.2 Bioaccumulation Model

A Bioaccumulation Model was developed to allow the user to estimate diet and egg selenium concentrations from an assumed waterborne selenium concentration. The model also allows the user to back-calculate a waterborne selenium concentration from an assumed diet or egg selenium concentration. Resulting waterborne, diet, and egg concentrations are listed and plotted upon egg and diet toxicity curves to illustrate potential effects of selenium on egg hatchability (Ohlendorf, 2003).

The Bioaccumulation Model is composed of a series of relationships that describe the transfer of selenium from water up through the food chain. The transfer factors and regression equations that represent these relationships were developed from data collected from Great Salt Lake as part of the research program. The user has the flexibility to select from numerous options to evaluate the sensitivity and results from alternative transfer relationships and bird diet combinations. Figure 6-1 illustrates inputs, outputs, and the general flow of logic of the Bioaccumulation Model.

FIGURE 6-1
Bioaccumulation Model Flow Chart



6.2.1 Bird Dietary Item Tissue Concentrations

The first part of the Bioaccumulation Model links measured biota tissue concentrations for the invertebrate food items to the water and sediment concentrations in which they were reared. The concept is that future, modeled tissue selenium concentrations could be estimated from modeled water and sediment values and knowledge of the existing relationships between invertebrate tissue selenium and concentrations in the ambient media. Measured brine fly tissue concentrations were taken from Cavitt (2007, 2008a) and Wurtsbaugh (2007), brine shrimp concentrations were compiled from the reports of Conover (2008a) and Marden (2007), and selenium concentrations in periphyton from biostromes were reported by Wurtsbaugh (2007). A limited number of other insect tissue selenium concentrations from 2006 were available from Conover et al. (2008a).

All invertebrate concentrations were summarized as monthly geometric means. None of the invertebrate species showed significant differences with spatial areas of the lake and the values used in the model are representative of lake-wide averages.

Brine fly selenium concentrations were examined for statistically significant relationships between fly tissue concentrations and periphyton algae or sediment concentrations, but there were few paired values and no statistically significant relationships. Selenium concentrations in brine flies (adults and larvae) and brine shrimp cysts were modeled with the assumption of a 1:1 relationship with changing brine shrimp concentrations (ultimately, modeled from waterborne concentrations). Periphyton algae (as measured on biostromes) were similarly assumed to vary in a 1:1 relationship with waterborne total selenium concentrations. Thus, insect food items for birds were assumed to vary directly and positively with changing lake water concentrations on a monthly basis.

In contrast, brine shrimp selenium concentrations could be quantitatively related to dissolved selenium in water and total seston (water column particulates) selenium concentrations using several modeling approaches (Figures 6-2 and 6-3). First, brine shrimp tissue concentrations were modeled based on a simple modification of Grosell's laboratory results (Grosell, 2007a, 2007b) for feeding experiments with Great Salt Lake brine shrimp fed *Dunaliella viridis*, the dominant Great Salt Lake algal food used by brine shrimp (listed as Grosell model in the Bioaccumulation Model). The modeled brine shrimp tissue concentrations were computed based on monthly estimates of dissolved selenium in water and the selenium concentrations in seston (surrogate measure for food). Grosell's Scenario 1 (based on waterborne concentrations less than 2.5 µg Se/L) was used for these estimates. Second, adult brine shrimp concentrations were based on the lake-derived Bioaccumulation Factor (listed as BAF model in the Bioaccumulation Model) of 6,720 as the ratio of brine shrimp tissue selenium concentrations to total concentrations of selenium in water. The third estimating method (listed as Multi Step – Transfer Factor [MS-TF] model in the Bioaccumulation Model) was to estimate seston from dissolved waterborne concentrations of selenium (K_d of 1,579) and brine shrimp from seston (Transfer Factor of 5.022). All methods tended to overestimate the measured brine shrimp selenium concentrations, with the monthly average differences being 1.3, 0.67, and 0.36 mg Se/kg dw for the Grosell, BAF, and MS-TF methods, respectively, over all months of measurement. Figure 6-2 shows a comparison of the monthly predictions versus measured average values.

In a comparative presentation of water, brine fly, and brine shrimp concentrations as documented from 17 studies of saline lakes and ponds, brine shrimp concentrations showed a probable "background" value of less than 2 mg Se/kg but ranged up to 110 mg Se/kg dw (J. Skorupa, personal communication). The lowest waterborne concentrations (below 5 µg Se/L) tended to have the highest water-to-brine-shrimp transfer factors (up to 3,400). The transfer factors at Great Salt Lake (6,720) are almost twice those ratios but representative of lower water column concentrations (those observed at Great Salt Lake are near the lowest in the comparative study). Site-specific conditions at Great Salt Lake may contribute to unusually elevated bioavailability and transfer of selenium to brine shrimp as compared to other lakes and ponds.

FIGURE 6-2
Measured vs. Modeled Brine Shrimp
Monthly Geometric Means

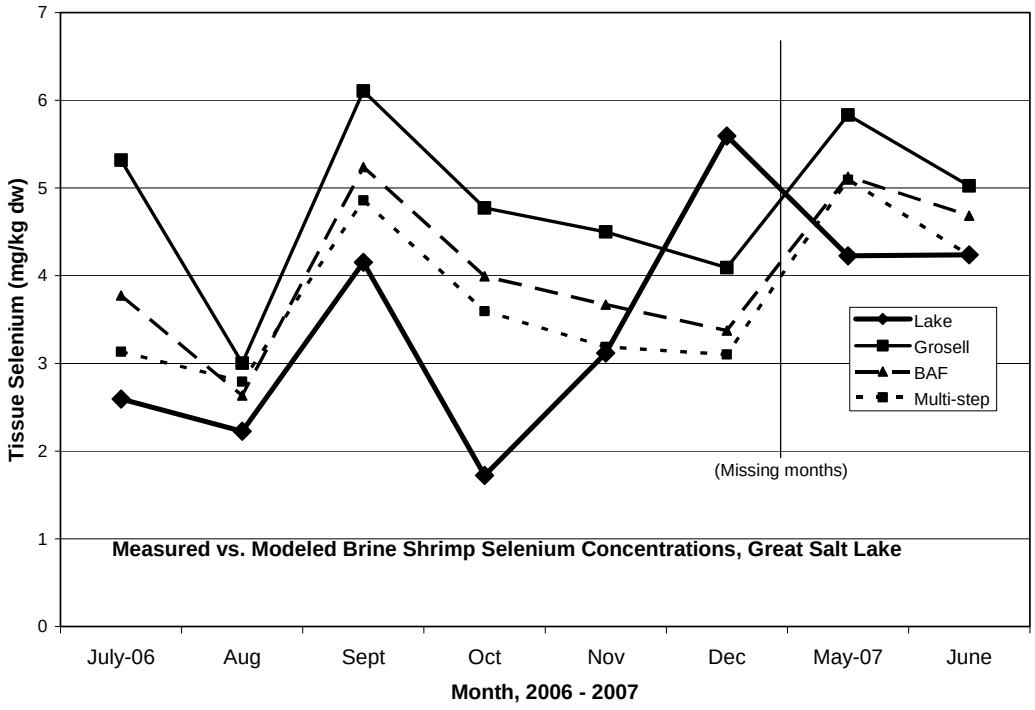


Figure 6-2 shows measured brine shrimp monthly geometric mean selenium concentrations versus modeled tissue levels predicted from Grosell's equations, a BAF factor from water, or an MS-TF from water to seston to shrimp.

6.3 Birds

Data from sampling and analysis of invertebrates (previously described) and birds at Great Salt Lake in 2006 and 2007 were used to develop selenium transfer relationships through the food web to birds and their eggs. Weighting factors (proportional composition of the diet) were developed based on food-habit studies conducted in 2006 by Conover et al. (2008a) and Cavitt (2008a) and additional samples collected in 2007 (Cavitt, 2008b; Conover et al., 2008a, 2008b, 2008c). Where site-specific data did not exist for Great Salt Lake (for example, assumed background selenium concentrations), data from other studies was used.

Detailed dietary, home range, and measured selenium accumulation data for gulls, stilts, and avocets (Cavitt 2008a; Conover et al., 2006) were used to develop regression equations and transfer and weighting factors for the Great Salt Lake food chain. Transfer factors were based on available measured selenium concentrations from Great Salt Lake biological studies.

Species-specific diet data were used to model selenium accumulation for each bird species (that is, the California gull [*Larus californicus*], black-necked stilt [*Himantopus mexicanus*], American avocet [*Recurvirostra americana*], eared grebe [*Podiceps nigricollis*], and common goldeneye [*Bucephala clangula*]). The percent of onsite foraging for each species was

determined from published foraging ranges and site-specific information, such as where on Great Salt Lake they tended to nest (for the breeding species).

The analytical techniques used in the models are based on a series of linear and log-linear relationships and transfer factors among environmental variables. In each case, assumptions are made about the underlying distribution of the data and the appropriateness of the relationship in explaining covariance of the variables. As is to be expected from environmental sampling data, there is much unexplained variation in the predictions, even in cases of statistically significant relationships. However, the basic assumption of the models is that the predictive relationships are all descriptive of underlying causal relationships.

Water, sediment, and invertebrate selenium concentrations for the avian portion of the model are taken from the abiotic/invertebrate portion of the model, which was previously discussed. The avian model uses the results of the abiotic/invertebrate model to estimate selenium transfer through the food web to gull and shorebird blood, liver, and eggs, and to grebe and goldeneye blood and liver.

After evaluating the model using all species and data, the Science Panel determined the reproductive endpoints were the most sensitive. Confounding variables and insufficient data did not allow a determination to be made regarding the effect of selenium and mercury on the body condition of eared grebes and common goldeneyes. The Science Panel discontinued further development of a model using eared grebes and common goldeneyes and this portion of the model was removed from the Bioaccumulation Model. Further discussion of the eared grebe and common goldeneye portion of the model is not included herein.

Modeling from diet to blood and liver selenium concentration remains in the model but is not used to estimate reproductive endpoints. In addition, since the model is for the open waters of Great Salt Lake, it was decided that diets would be 100 percent brine shrimp for gulls and that shorebird diets would be 100 percent brine fly larvae; however, the model still allows users to input varying composition of diet for gulls and shorebirds, insofar as concentrations in those dietary items are available. The brine fly selenium concentrations (adult and larvae) are based on a ratio of brine shrimp to brine fly selenium concentrations as discussed above.

A gull regression model was attempted to relate gull diet and egg selenium concentrations. However, a gull model could not be developed because of the small number of co-located gull diet and egg samples collected and the possibility that there is only a weak association between gull colonies and brine shrimp that were sampled. Regression models were developed from Great Salt Lake shorebird data and laboratory toxicological studies on mallards. The Shorebird Regression Model is site-specific; therefore, the Science Panel recommends its use for shorebirds. The gull transfer factor is site-specific; therefore, the Science Panel recommends its use for gulls.

6.3.1 Statistics

Simple regressions were used in developing equations based on measured parameters (from studies previously described) to be used for predicting future selenium concentrations in birds or their eggs. The model uses primarily the mean and 95 percent lower and upper

confidence intervals on the mean. ANOVA was used to measure the quality of the models (Zar, 1974; SAS Institute, 1996). All means are geometric means unless otherwise noted. Measured selenium concentrations were log-transformed due to the positive skewing of selenium data. Comparisons between measured selenium (see summary statistics in Section 5) and modeled selenium were made via ANOVA or the Student's *t*-test of log-transformed values (Zar, 1974; SAS Institute, 1996).

6.3.2 Avian Model

When there were enough data, regression was used to describe associations between diet and egg selenium concentrations, based on available measured selenium values from Great Salt Lake biological sampling (that is, from invertebrate to egg). The upper food chain was modeled using results of gull studies conducted by Conover et al. (2008a), and shorebird studies conducted by Cavitt (2008a, 2008b). Colocated water, sediment, and invertebrate samples were used to estimate selenium concentrations at the six sites where gulls and shorebirds were sampled during 2006, and the geometric mean of these was used to estimate the lakewide concentrations.

Weighting Factors

Selenium accumulation was weighted in three ways: (1) proportional composition of the diet for each species was based on food habits as determined from studies at Great Salt Lake that identified the proportions of the various dietary items in a species' diets; (2) home ranges or colony locations were determined from studies at Great Salt Lake or estimated from other studies and used to determine the proportion of onsite foraging for various species; and (3) an estimate of percent of offsite (or "background") food consumed was used.

The following diets described are listed in order of those found most often to least often for each species. In mixed diets, the proportions are approximated because there was generally a range of composition (proportions) among birds of that species. The demonstration model uses the first diet for each species; however, the model allows manipulation of the proportions of dietary items for all species.

Three shorebird diets were found in field studies at Great Salt Lake (Cavitt, 2007a):

1. 100 percent brine fly
2. 66 percent midge, 20 percent brine fly, 14 percent corixid
3. 40 percent midge, 36 percent brine fly, 24 percent corixid

Four gull diets were found in field studies at Great Salt Lake (Conover et al., 2006):

1. 100 percent brine shrimp
2. 100 percent brine fly
3. 100 percent corixid
4. 60 percent brine shrimp, 35 percent corixid, and 5 percent midge larvae

For eared grebes, four diets were found:

1. 100 percent brine shrimp
2. 100 percent brine fly
3. 60 percent brine shrimp, 40 percent brine fly

4. 60 percent brine shrimp, 30 percent brine fly, 10 percent corixid

Common goldeneyes fed on a variety of food items in Great Salt Lake but the proportions in individual birds collected are not known. Sixty-five percent of the goldeneyes collected contained brine fly larvae, five percent contained brine shrimp, 30 percent contained brine shrimp cysts, 40 percent contained wetland seeds, and 25 percent contained freshwater invertebrates. The following diets are in order of the percent of goldeneyes collected with the food item observed in their digestive tract, not the proportion in their diets:

1. 100 percent brine fly larvae
2. 100 percent wetland plant seeds
3. 100 percent brine shrimp cysts
4. 100 percent freshwater invertebrates
5. 100 percent brine shrimp

Transfer Factors

Simple numerical transfer factors were used for all steps that did not have a significant regression relationship or for which available data did not allow for the use of a regression equation. The transfer factors were based on spatially and temporally paired invertebrate and bird samples collected during 2006 (Equations 2, 3, and 4).

EQUATION 2
Transfer Factor for Diet Selenium to Blood Selenium

$$\text{Blood [Se]} = (\text{GM Blood [Se]} / \text{GM Diet [Se]})$$

EQUATION 3
Transfer Factor for Diet Selenium to Liver Selenium

$$\text{Liver [Se]} = (\text{GM Liver [Se]} / \text{GM Diet [Se]})$$

EQUATION 4
Transfer Factor for Diet selenium to Egg Selenium

$$\text{Egg [Se]} = (\text{GM Egg [Se]} / \text{GM Diet [Se]})$$

Diet Calculation

Selenium concentrations that were based on invertebrate samples colocated with bird or egg samples were used to determine weighting factors or regression equations from diet to tissue or diet to egg selenium. Dietary concentrations then used in the model were attained from the abiotic/invertebrate to biotic model as described above. Proportions of dietary items were then entered in the model and a diet was then estimated (Equation 5).

EQUATION 5
Diets for all Birds and Models were calculated from Abiotic/Invertebrate to Biotic Model Results

$$\text{Diet [Se]} = \text{Food Item [Se]} \times \text{proportion food item(s) in the diet}$$

In addition to the diet, birds eating invertebrates such as brine flies that live in the sediment are expected to incidentally ingest some sediment. The model calculates 0.05 fraction

sediment in addition to the diet proportion. The sediment concentration is calculated in the abiotic/invertebrate model and the percent of sediment ingested can be manipulated in the model.

6.3.3 Reproductive Effects

A general model for estimating egg selenium concentration from dietary concentration was developed from mallard feeding studies summarized by Ohlendorf (2003) and on which the threshold values are based (see Section 3.2.3). These data showed a significant positive relationship (r^2 = 0.89, $F_{1,17}$ = 128, P less than 0.01) between diet and egg selenium concentrations in mallards. This regression equation (Equation 6) was compared to specific models (one for American avocets [Equation 7] and one for California gulls [Equation 8]) developed from colocated diet and egg samples collected from Great Salt Lake. The general model based on feeding studies where birds were exposed to a constant dietary selenium concentration under standardized conditions has the steepest slope. The specific models for avocets and gulls are based on only a few samples. The avocet model initially had only four paired samples collected as part of this program.

EQUATION 6
General Equation (Diet Selenium to Egg Selenium) Derived from Mallard Feeding Studies

$$\text{Egg Se (µg/g dw)} = 0.787 + 3.267 \times \text{Diet Se (µg/g dw)}$$

EQUATION 7
American Avocet Diet-to-Egg Selenium Equation Based on Co-located Diet and Egg Samples from Great Salt Lake

$$\text{Avocet Egg Se (µg/g dw)} = -1.34 + 2.52 \times \text{Diet Se (µg/g dw)}$$

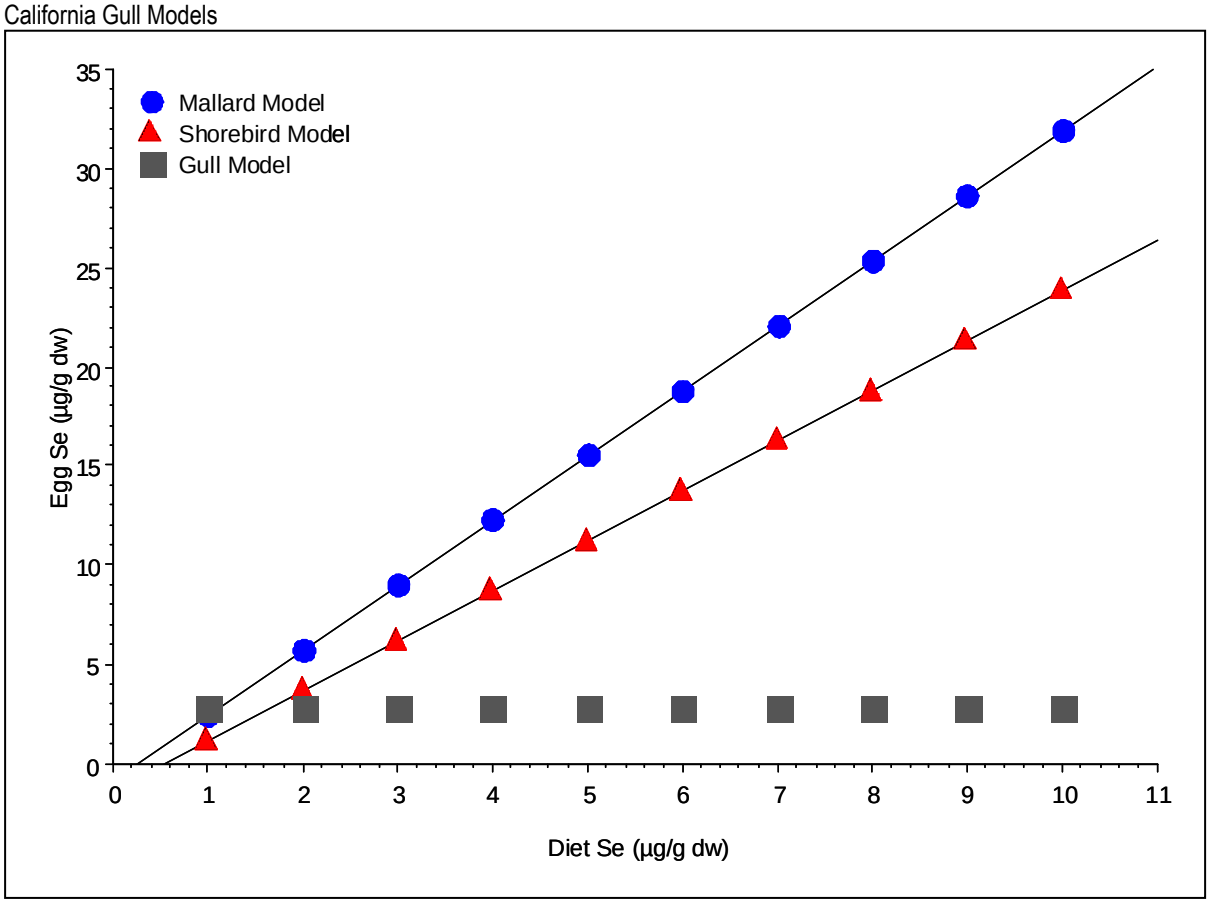
EQUATION 8
California Gull Diet-to-Egg Selenium Equation Based on Co-located Diet and Egg Samples from Great Salt Lake

$$\text{Gull Egg Se (µg/g dw)} = -2.83 + 0.003 \times \text{Diet Se (µg/g dw)}$$

It is likely that birds primarily feed on invertebrates near their nests and that there is an association between selenium concentrations in invertebrates that are associated with a colony location and the birds in that colony. In other species, invertebrates collected from near the nest sites had similar selenium concentrations to invertebrates being fed to the young in the nest (Santolo, 2007). The avocet model (Equation 7) primarily uses food items (invertebrates) that are associated (r^2 = 0.79, $F_{1,3}$ = 7.3, P = 0.11) with sediment from each location and show a similar slope to the generalized model (Figure 6-3). However, this was not the case with gulls because they do not feed on static resources at a colony but reflect a more dynamic relationship with Great Salt Lake water and therefore have only a weak association with the colony locations. The gull model (Equation 8) is based on brine shrimp for three locations and invertebrates from the Neponset Reservoir location, and it does not show a significant relationship (r^2 = 0.001, $F_{1,3}$ = 0.001, P = 0.9757). This is possibly because even though the brine shrimp were collected from the locations where the gull eggs were collected, they are not tightly associated with the locations. Thus, the Science Panel concluded that the gull regression model should not be used or included in the Bioaccumulation Model until further data is collected that improves the relationship. When

the slopes of these models are compared, the general and shorebird models show similar slopes (Figure 6-3). The shorebird model is site-specific to Great Salt Lake; therefore the Science Panel recommends that it be used instead of the generalized mallard model for shorebirds. It should be noted that the Shorebird Model does overpredict egg selenium concentrations if used for gulls. The Shorebird Model should not be used for gulls.

FIGURE 6-3
Comparison of General Diet-to-Egg Selenium (Based on Mallard Studies) and Specific American Avocet and California Gull Models



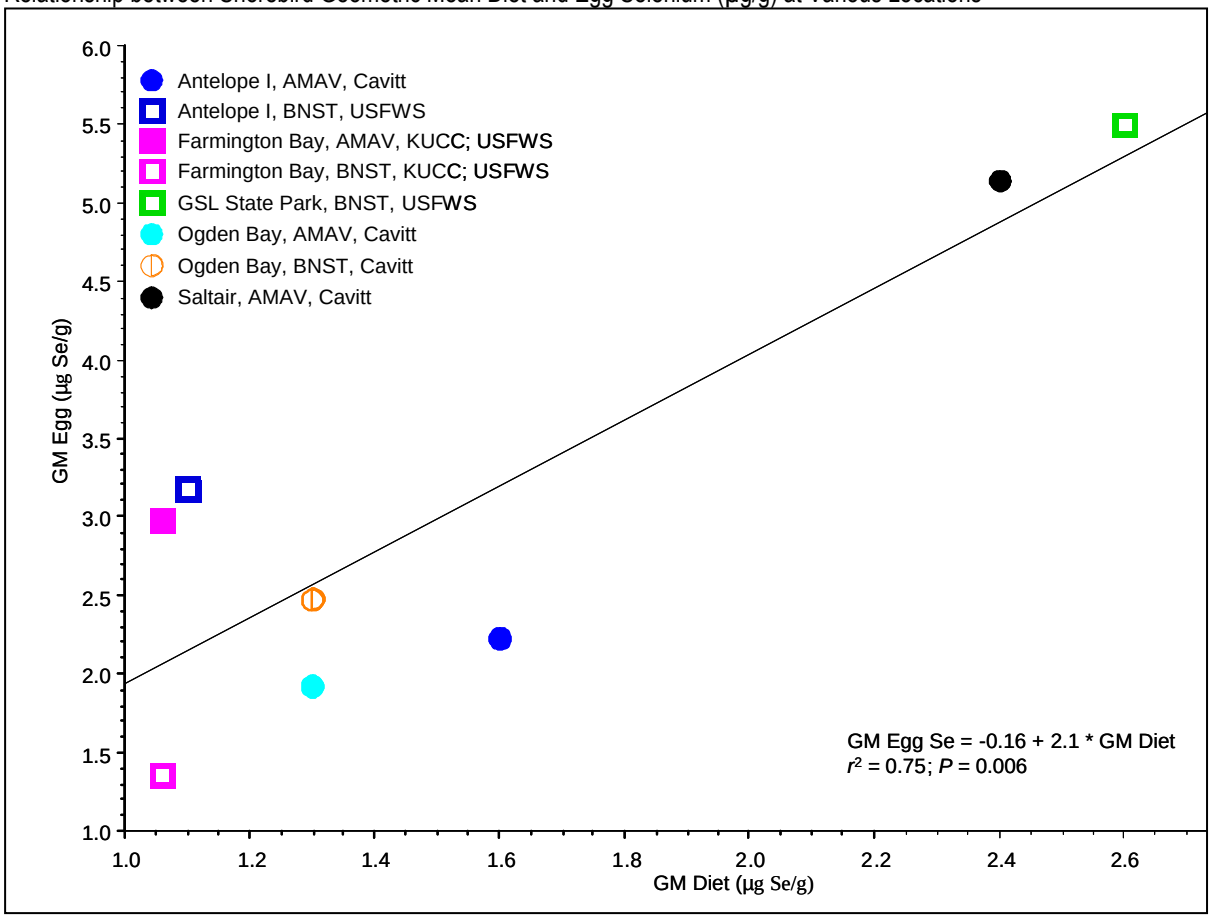
To increase the number of data points used in the shorebird diet-to-egg selenium regression model, spatially colocated samples collected from Great Salt Lake by the U.S. Fish and Wildlife Service (USFWS) and from Farmington Bay by EP&T (for Kennecott Utah Copper Corporation [KUCC]) were used. Assumptions that the egg and diet data were spatially co-located were made. Table 6-1 shows the data that was added to the sample results of diet and eggs collected for the project (Cavitt, 2007a).

TABLE 6-1
Additional Data Used in Shorebird Regression Model

Location	Species	GM Se (µg/g)	Mean (µg/g)	Collected by
Antelope Island	Brine fly adults and larvae	1.1	1.1	USFWS
Farmington Bay	Brine fly adults and corixids	1.1	1.1	USFWS
GSL State Park	Brine shrimp	2.6	2.7	USFWS
Antelope Island	Black-necked stilt eggs	3.2	3.2	USFWS
Farmington Bay	Black-necked stilt eggs	1.4	1.4	KUCC
Farmington Bay	American avocet eggs	2.9	3.3	KUCC
GSL State Park	Black-necked stilt eggs	5.5	5.6	USFWS

There was only a single invertebrate sample collected at Saltair so it was not used. Diet samples were collected in 1995 and 2005 from Farmington Bay and shorebird eggs were collected in 1995. The assumption was made that diet concentrations did not change significantly. Diet and eggs from Antelope Island were collected in 1996. Invertebrates and bird eggs were collected from Great Salt Lake State Park in 1997.

FIGURE 6-4
Relationship between Shorebird Geometric Mean Diet and Egg Selenium (µg/g) at Various Locations



The Shorebird Model (Equation 9) was selected by the Science Panel over the Mallard Model as the preferred bioaccumulation model because it is site-specific, shorebirds are less sensitive than mallards (using the Mallard Model for shorebirds would significantly overpredict egg concentrations), and the form of selenium used in the mallard studies creates a more conservative transfer factor than is observed on Great Salt Lake. The Gull Transfer Factor Model was selected by the Science Panel over the Shorebird and Mallard Models for use with gulls because it is site-specific and gulls appear to be less sensitive than shorebirds or mallards (using the Shorebird or Mallard Models for gulls significantly overpredicts egg concentrations for gulls). It should be noted that the Science Panel has more confidence in the shorebird relationships due to the colocated diet and egg samples collected for shorebirds. Preference should be given to the shorebird component of the Bioaccumulation Model until more is known about gull diet/egg relationships. The Shorebird Model and Gull Transfer Factor Model were combined into one option called the GSL-specific Model in the Bioaccumulation Model. Both the GSL-specific and Mallard Models are included in the Bioaccumulation Model for comparison. In addition, future co-located sampling should continue to improve this model.

EQUATION 9
Shorebird Diet-to-Egg Selenium Equation Based on Co-located Diet and Egg Samples from Great Salt Lake

$$\text{Shorebird Egg Se (µg/g dw)} = -0.16 + 2.1 \times \text{Diet Se (µg/g dw)}$$

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7.0 Quantitative Conceptual Model Results

This section provides a summary of results from the quantitative conceptual model described in Section 6.0.

7.1 Introduction

A quantitative conceptual model, described in Section 6.0 of this report, was developed to integrate the observations and data collected as part of the research program in 2006 and 2007 to allow a user to relate water, diet, and egg selenium concentrations in Great Salt Lake. The model includes two components: (1) Mass Balance Model and (2) Bioaccumulation Model. Each of these components includes various inputs, outputs, and alternatives from which the user may select.

The Science Panel agreed that a selenium water quality standard that prevents impairment of beneficial uses of open waters of Great Salt Lake would be defined by a waterborne or tissue concentration that is represented within a range of 3.6 through 5.7 mg Se/kg for bird diet and 6.4 through 16 mg Se/kg for eggs. This range was selected as the basis for evaluation in the research program and largely frames the alternatives considered by the Science Panel. While numerous alternatives are discussed herein, the model allows the user to select his or her own custom scenarios to complete sensitivity analyses and estimate results. The user should use caution as the model was developed from data from a specific period in time (May 2006 through July 2007) for the conditions present in Great Salt Lake during that time. The following presents a summary of results from the quantitative conceptual model.

7.2 Mass Balance Model

As described in Section 6.0, the Mass Balance Model was constructed to link measured and estimated selenium loads, loss fluxes, and internal cycling to estimate waterborne selenium concentrations for Great Salt Lake. The model estimates waterborne selenium concentrations from the data collected and allows the user to create a custom scenario to evaluate. Guidelines are included within the model to describe the uncertainty of data collected and estimated. It should be noted that the Science Panel expressed caution in the use of the Mass Balance Model as it represents conditions from only 12 months of data. Further work is needed before the model can be used to predict future conditions and account for long-term cycling of selenium in Great Salt Lake.

Table 7-1 shows measured and modeled waterborne concentrations for 2006 and 2007. Predictions averaged within 0.388 µg Se/L of measured values on a monthly basis and were very close (0.003 µg/L) for an annual average, indicating the general ability of the model to mimic field conditions.

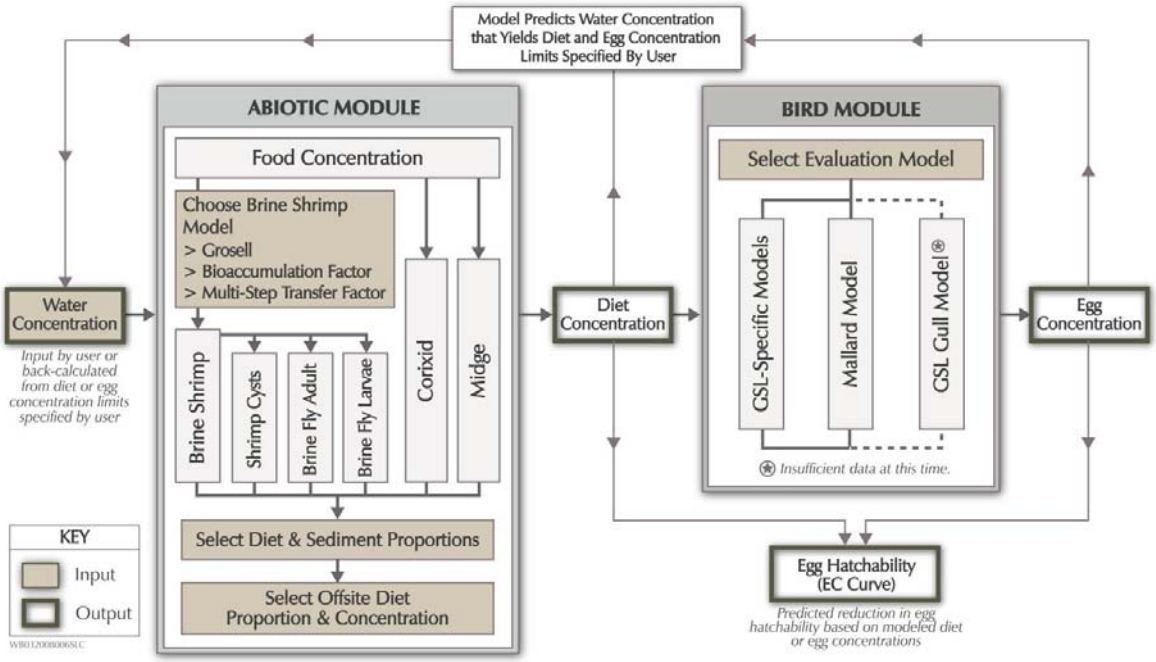
TABLE 7-1
Measured versus Modeled Monthly Average Total Selenium Concentrations in Water (µg Se/L)

	Annual Average	July 06	Aug. 06	Sept. 06	Oct. 06	Nov. 06	Dec. 06	Jan. 07	Feb. 07	Mar. 07	Apr. 07	May 07	June 07
Measured	0.600	0.396	0.780	0.614	0.569	0.525	0.566	0.608	0.649	0.690	0.773	0.705	0.717
Modeled	0.597	0.562	0.392	0.780	0.594	0.546	0.502	0.548	0.595	0.631	0.670	0.763	0.697
Measured - Modeled	0.003	-0.166	0.388	-0.166	-0.025	-0.021	0.064	0.060	0.054	0.059	0.103	-0.058	0.020

7.3 Bioaccumulation Model

The Bioaccumulation Model (also described in Section 6.0) was constructed to allow the user to estimate bird diet and egg selenium concentrations from an assumed waterborne selenium concentration (see Figure 7-1). The model also allows the user to back-calculate a waterborne selenium concentration from an assumed bird diet or egg selenium concentration. The model may be thought to generally have two steps in relating selenium concentrations: (1) water to diet and (2) diet to egg. Each step has various inputs, outputs, and alternatives from which the user may select. The following provides a comparison of alternative relationships used in each of these two steps as well as a summary of estimated bird diet and egg selenium concentrations from an assumed waterborne selenium concentration and vice versa.

FIGURE 7-1
Bioaccumulation Model Flow Chart



7.3.1 Water to Diet

The calculation of a bird diet concentration from an assumed waterborne concentration (and vice versa) includes numerous inputs and alternatives that the user may select. The Science Panel has decided to assume that all birds consume only items they can obtain from the open waters of Great Salt Lake. Further, they have assumed that gulls consume a diet of 100 percent brine shrimp and shorebirds consume a diet of 100 percent brine fly larvae and 5 percent sediment. While the user may change these diet combinations, all results presented herein rely upon these assumptions.

Selenium concentrations for brine shrimp cysts and brine fly larvae and adults are derived from a relationship that relates their selenium concentration directly to the selenium concentration in adult brine shrimp. Thus, the estimated bird diet selenium concentration used for the water quality standard depends on the relationship selected by the user to estimate the selenium concentration in brine shrimp.

Three relationships that relate an assumed waterborne concentration to the brine shrimp concentration are included in the Bioaccumulation Model. These relationships are described in Section 6.0 and are as follows: (1) Grosell's Model (developed from laboratory studies relating selenium concentrations in water and algae to adult brine shrimp), (2) BAF (bioaccumulation factor relating total selenium concentration in water directly to adult brine shrimp), and (3) MS-TF (a multi-step transfer factor model that relates total to dissolved selenium concentration in water to seston [brine shrimp food source] and then from seston to adult brine shrimp). Each relationship is unique and generates a different result. Figure 7-2 illustrates how results from the three relationships compare.

After a review of each of the models, the Science Panel decided to use the MS-TF relationship for recommending the water quality standard. As described in Section 6.0, the MS-TF relationship comes closest to predicting brine shrimp selenium concentrations on a monthly basis for the study period (see Figure 6.2) and its mechanistic, multi-step process most closely resembles the transfer of selenium from water to brine shrimp in Great Salt Lake.

7.3.2 Diet to Egg

The Bioaccumulation Model includes two alternatives to estimate egg selenium concentrations from bird diet concentrations (and vice versa): the GSL-specific Model option (including the Shorebird Model [a regression model developed from collocated shorebird diet and egg samples) and Gull Transfer Factor Model [a direct ratio between the geometric means of gull diet and egg concentrations]) and the Mallard Model (a regression model developed from six toxicological studies completed in the laboratory using mallards). As described in Section 6.0, other relationships were also developed but not included as alternatives in the Bioaccumulation Model. These other relationships include the Gull Model (a regression model developed from gull food items and eggs) and shorebird transfer factor (a direct ratio between the geometric mean of shorebird diet and egg concentrations).

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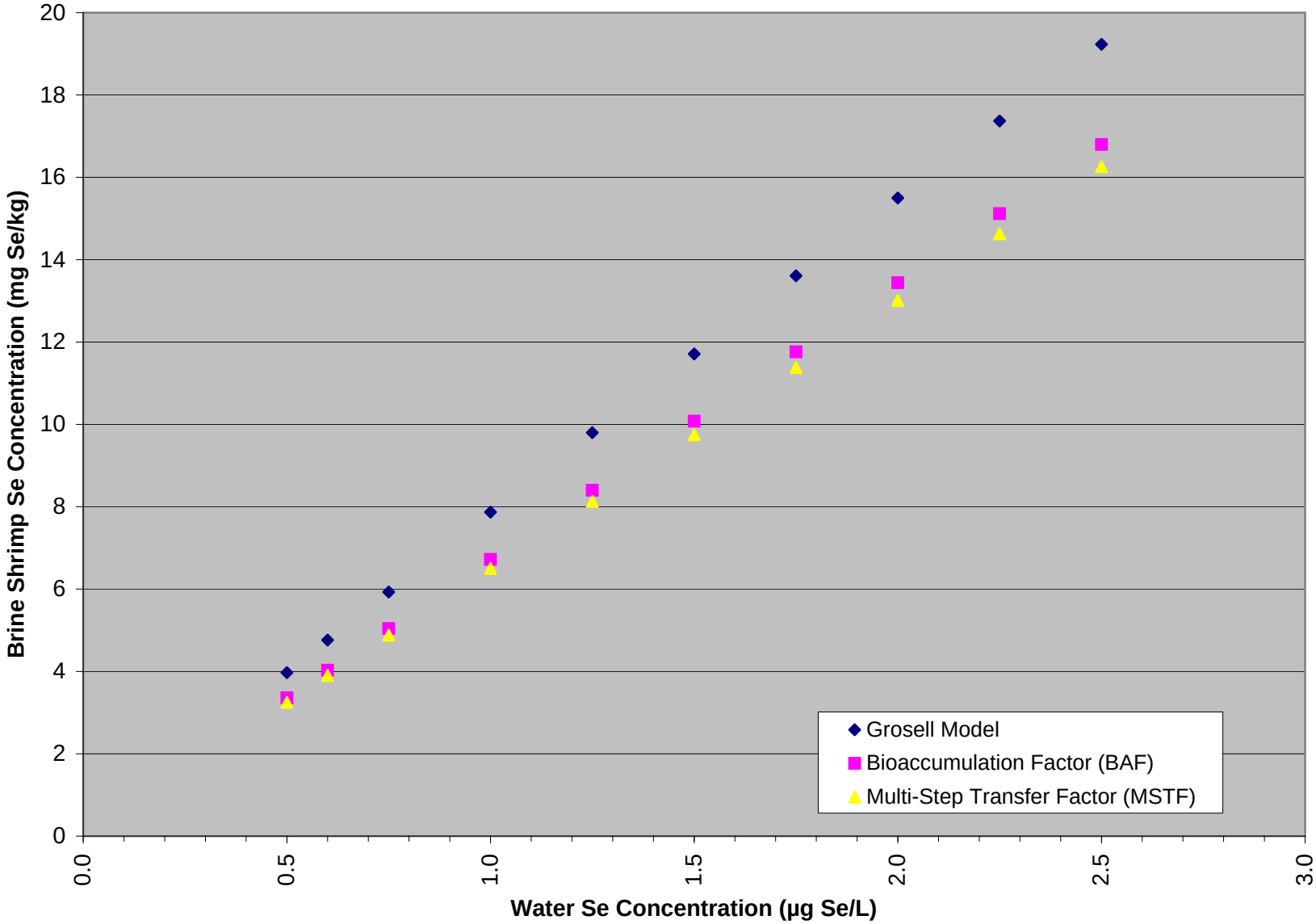
FIGURE 7-2
Comparison of Three Brine Shrimp Models



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The Science Panel decided to eliminate the Gull Model from consideration at this time due to a lack of relationship between diet and egg selenium concentrations for gulls from Great Salt Lake. Further research is needed before the Gull Model may be applied for decision-making purposes. The shorebird transfer factor provides a useful relationship, although relationships based upon regression equations are generally considered to be more representative of datasets. As such, the Science Panel decided to include only the GSL-specific Model and Mallard Model as options in the Bioaccumulation Model.

Figure 7-3 illustrates a comparison of the Shorebird Model, Mallard Model, and shorebird transfer factor relationships for shorebirds. Figure 7-4 illustrates a comparison of the Shorebird Model, Mallard Model, and gull transfer factor relationships for gulls. Both figures illustrate estimates of egg selenium concentration from a waterborne selenium concentration.

The Mallard Model is generally more conservative (that is, it generally estimates a higher egg selenium concentrations than the Shorebird Model does for a given bird diet selenium concentration). The Shorebird and Mallard Models both estimate higher egg selenium concentrations than are estimated by the two transfer factor relationships. The Science Panel decided to use the Shorebird Model as the preferred relationship for shorebirds because it is site-specific and more representative of Great Salt Lake than the generalized Mallard Model. The Science Panel decided to use the gull transfer factor model as the preferred relationship for gulls because it is site-specific and more representative of gulls on Great Salt Lake than the Shorebird Model or the generalized Mallard Model. The Shorebird Model estimates higher egg selenium concentrations for gulls than observed on Great Salt Lake. The transfer factors illustrated in Figures 7-3 and 7-4 and discussed in the following subsection are considered useful complements to the regression models for some purposes. Thus, the Science Panel decided to use the GSL-specific Model for recommending the water quality standard.

7.3.3 Variability of Modeling Terms

Table 7-2 shows the variability in monthly values as used in creating the selenium food web model (that is, water to diet). Various values of these parameters could be substituted into the model to examine effects on "downstream" (including higher trophic level) calculated values. For example, entering 25th or 75th percentile water values instead of means would affect predictions of selenium concentrations in sediment, seston, invertebrate dietary items, and bird eggs. Entering new dietary item values would affect the estimation of concentrations in bird eggs.

It should be noted that the Bioaccumulation Model should <u>not</u> be used for waterborne selenium concentrations greater than 2.5 µg Se/L. Further, the Bioaccumulation Model was developed using data collected during the 2006 through 2007 study period. Waterborne selenium concentrations for the study period ranged from 0.4 to 0.8 µg Se/L. Predictions of bird diet and egg selenium concentrations for waterborne selenium concentrations greater than 0.8 µg Se/L should be used with caution.

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FIGURE 7-3

Comparison of Three Shorebird Egg Models

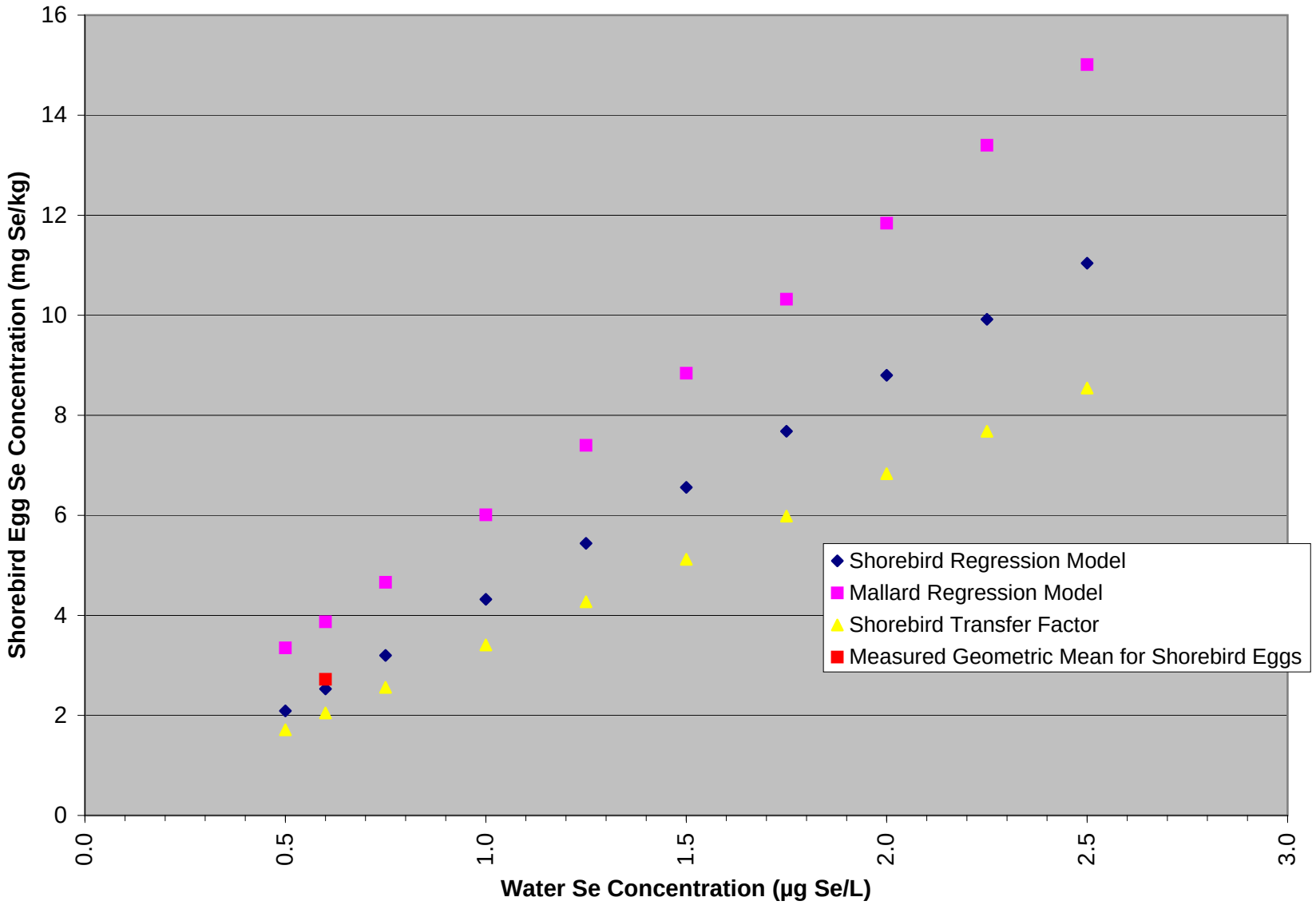

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FIGURE 7-4

Comparison of Three Gull Egg Models

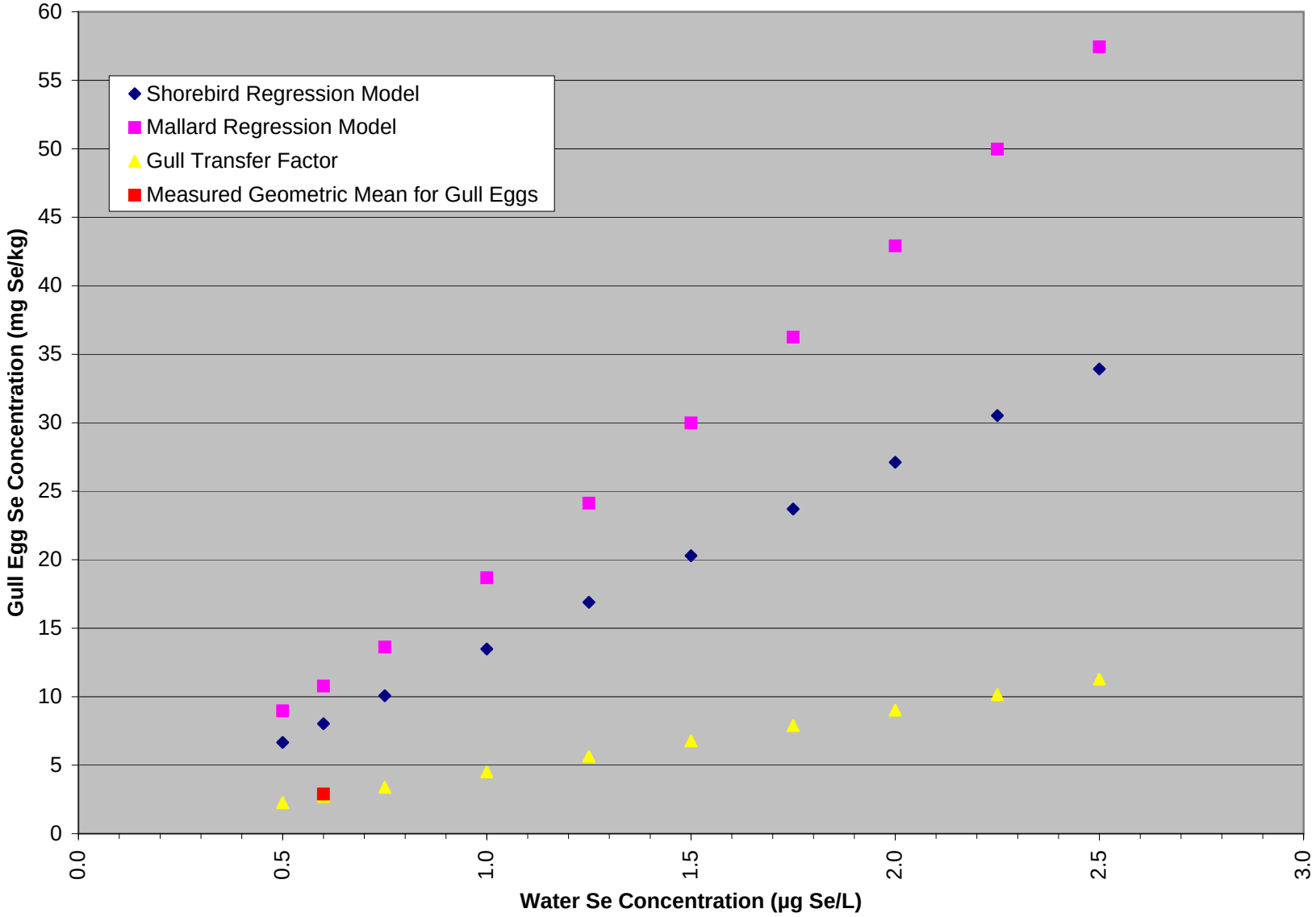

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TABLE 7-2
Variability of Monthly Geometric Means Used as Modeling Terms*

Term	Mean	Range (low/high)	25 Percentile Value	Median (50 percentile)	75 Percentile Value	Upper 95% Upper Confidence Limit of Mean	Lower 5% LCL of mean
Total Se concentration in water (µg/L)	0.634	0.374/0.873	0.512	0.648	0.759	0.737	0.533
Dissolved Se concentration in water (µg/L)	0.497	0.278/0.773	0.376	0.514	0.584	0.594	0.399
Seston (mg Se/kg dw)	0.950	0.419/2.945	0.651	0.893	0.1.345	1.474	0.426
Periphyton (mg Se/kg dw)	0.977	0.630/1.20	0.630	1.100	1.200	1.733	0.221
Adult brine flies (mg Se/kg dw)	1.933	1.200/3.100	1.650	1.800	2.200	2.589	1.277
Adult brine shrimp (mg Se/kg dw)	3.425	1.42/6.555	2.6514	3.722	4.7094	4.171	2.679

NOTE:
*Except for brine shrimp, which are modeled based on water and seston means and bioaccumulation equations from the laboratory study.

7.3.4 Summary of Results

Table 7-3 provides a summary of estimated bird diet and egg concentrations from assumed waterborne selenium concentrations. The range of waterborne selenium concentrations included in Table 7-3 spans 0.5 to 2.5 µg Se/L. The table includes estimates of diet selenium concentration using all three brine shrimp relationships. The table also includes estimates of egg selenium concentration for the four different diet-to-egg relationships using only the MS-TF brine shrimp relationship.

The geometric mean for waterborne selenium concentrations for the study period was 0.6 µg Se/L. The geometric mean for shorebird egg selenium concentrations was 2.72 mg Se/kg and for gull egg selenium concentrations was 2.89 mg Se/kg. As summarized in Table 7-3, the resulting estimated egg selenium concentration using 0.6 µg Se/L for water was 2.53 mg Se/kg for shorebird eggs and 2.71 mg Se/kg for gull eggs (this assumes the Science Panel's recommendation of using the MS-TF brine shrimp model and GSL-specific Model are used). The estimated egg selenium concentration for shorebirds was within 8 percent of the measured geometric mean, whereas the estimated egg selenium concentration for gulls was within 6 percent of the measured geometric mean.

Table 7-4 provides a summary of estimated waterborne and diet selenium concentrations from assumed egg selenium concentrations. The range of egg selenium concentrations included in Table 7-4 spans 3.0 to 16.5 mg Se/kg. A mean egg selenium concentration of 3.0 mg Se/kg has been identified as a likely background level for eggs (Skorupa and

Ohlendorf, 1991). The geometric mean for shorebird egg selenium concentrations in this research program was 2.72 mg Se/kg. The geometric mean for gull egg selenium concentrations in this research program was 2.89 mg Se/kg. The Science Panel identified the range of 6.4 to 16 mg Se/kg as the range to be considered for the water quality standard.

Table 7-5 provides a summary of estimated selenium concentrations for water and diet for assumed egg concentrations within the range identified by the Science Panel and using the relationships selected by the Science Panel.

TABLE 7-3

Diet and Egg Concentrations Calculated from Assumed Water Concentration

From Bioaccumulation Model v 4.3

Water Concentration	Estimates for Diet Concentrations (mg/kg)				Estimates for Egg Concentrations (mg/kg)					
	Brine Shrimp Model			BF larvae from MS-TF BS Model	Shorebird Model		Mallard Model		Shorebird	Gull
(µg/L)	Grosell	BAF	MS-TF		Shorebird	Gull	Shorebird	Gull	Transfer Factor	Transfer Factor
0.5	4.0	3.4	3.3	1.1	2.1	6.7	3.4	9.0	1.7	2.3
0.6	4.8	4.0	3.9	1.3	2.5	8.0	3.9	11	2.0	2.7
0.8	5.9	5.0	4.9	1.6	3.2	10	4.7	14	2.6	3.4
1.0	7.9	6.7	6.5	2.1	4.3	13	6.0	19	3.4	4.5
1.3	9.8	8.4	8.1	2.7	5.4	17	7.4	24	4.3	5.6
1.5	12	10	9.8	3.2	6.6	20	8.8	30	5.1	6.8
1.8	14	12	11	3.7	7.7	24	10	36	6.0	7.9
2.0	16	13	13	4.3	8.8	27	12	43	6.8	9.0
2.3	17	15	15	4.8	9.9	31	13	50	7.7	10
2.5	19	17	16	5.3	11	34	15	57	8.5	11

NOTES:

Mean values for study period: water = 0.6 µg/L, shorebird diet = 1.7 mg/kg, shorebird egg = 2.7 mg/kg, gull diet (from Conover) = 4.2 mg/kg, gull egg = 2.9 mg/kg

GSL during period when we collected co-located bird diet/egg samples had a water concentration closer to 0.4 µg/L

Used the MS-TF brine shrimp model to estimated egg concentrations.

Used default values prescribed by Science Panel for bird diet mix (100 percent brine shrimp for gulls, 100 percent brine fly larvae for shorebirds with 5 percent sediment)

Shorebird and Gull transfer factors are not alternatives available on Bioaccumulation Model main page but are found within the Bird Model tabs

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TABLE 7-4

Water and Diet Concentration Calculated from Assumed Egg Concentration

From Bioaccumulation Model v 4.3

Comparison of Shorebird & Mallard Models to Relate Egg to Diet Concentration for Shorebirds									
Egg Concentration	Estimate for Diet Concentration Shorebird Model	Estimate for Diet Concentration Mallard Model	Estimates for Water Concentrations (µg/L) Brine Shrimp Model					
			Grosell		BAF		MS-TF	
(mg/kg)	(mg/kg)	(mg/kg)	Shorebird	Mallard	Shorebird	Mallard	Shorebird	Mallard
3.0	1.5	0.9	0.6	0.4	0.7	0.4	0.7	0.4
4.7	2.3	1.6	0.9	0.6	1.1	0.7	1.1	0.8
6.4	3.1	2.3	1.2	0.9	1.4	1.0	1.5	1.1
9.5	4.6	3.4	1.8	1.4	2.1	1.6	2.2	1.6
13	6.0	4.5	2.4	1.8	2.7	2.0	2.8	2.1
15	7.0	5.2	2.8	2.0	3.2	2.3	3.3	2.4
17	7.9	5.8	3.2	2.3	3.6	2.6	3.7	2.7

Comparison of Gull Transfer Factor & Mallard Models to Relate Egg to Diet Concentration for Gulls								
Egg Concentration	Estimate for Diet Concentration		Estimates for Water Concentrations (µg/L) Brine Shrimp Model					
	Gull Transfer Factor (GTF)	Mallard Model	Grosell		BAF		MS-TF	
(mg/kg)	(mg/kg)	(mg/kg)	GTF	Mallard	GTF	Mallard	GTF	Mallard
3.0	4.3	0.9	0.5	0.1	0.6	0.1	0.7	0.1
4.7	6.8	1.6	0.9	0.2	1.0	0.2	1.0	0.3
6.4	9.2	2.3	1.2	0.3	1.4	0.3	1.4	0.4
9.5	14	3.4	1.8	0.4	2.0	0.5	2.1	0.5
13	18	4.5	2.3	0.6	2.7	0.7	2.8	0.7
15	21	5.2	2.7	0.7	3.1	0.8	3.2	0.8
17	24	5.8	3.1	0.7	3.5	0.9	3.7	0.9

NOTE:

Used default values prescribed by Science Panel for bird diet mix (100 percent brine shrimp for gulls, 100 percent brine fly larvae for shorebirds with 5 percent sediment)

Geometric means for samples collected as part of this research program: shorebird eggs - 2.7 mg/kg, gull eggs - 2.9 mg/kg, gull diet - 4.2

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TABLE 7-5

Water and Diet Concentration Calculated from Assumed Egg Concentration

From Bioaccumulation Model v 4.3

Egg Concentration (mg/kg)	Estimate for Diet Concentration (mg/kg)	Estimate for Water Concentration (µg/L)
Shorebirds		
6.4	3.1	1.5
9.5	4.6	2.2
12.5	6.0	2.8
14.5	7.0	3.3
16.5	7.9	3.7
Gulls		
6.4	9.2	1.4
9.5	13.7	2.1
12.5	18.0	2.8
14.5	20.9	3.2
16.5	23.8	3.7

NOTE:

Assumes the use of Shorebird Model for shorebirds, Gull Transfer Factor Model for gulls and MS-TF Brine Shrimp Model for both species.

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8.0 Implementation Issues

This section identifies considerations and recommendations for implementation of a new selenium water quality standard for the open waters of Great Salt Lake.

8.1 Considerations

Implementation of the site-specific standard for the open waters of Great Salt Lake will need to be based on a number of considerations that are specific to the goals for the standard. Studies conducted to date have provided estimates of the loading of selenium from various sources to the lake, the transport and fate of the selenium within the lake (including transfer among the lake's abiotic and biotic "compartments"), losses from the water column (permanent sequestration in sediment and emissions by volatilization), and exposure and potential effects in birds that feed on invertebrates from the lake. There are a number of uncertainties about the mass balance of selenium in the system and concentrations of selenium in field-collected dietary items (as described in Sections 5 and 7), especially because of the short time frame of the data on which the model is based. Thus, it seems essential that monitoring conducted for assessment of selenium status in the lake and its biota should include sampling of water, bird food items, and eggs that can be used to validate the model.

Other important considerations include the following:

- The conversion of the egg-based selenium standard to appropriate water- and diet-based "trigger" values for implementation of the standard.
- Whether a mixing zone should be considered for discharges to the lake, and how that mixing zone should be defined
- Specifically, what the physical boundaries for application of the standard should be (Wuerthele 2004)
- Whether the "lake" should be defined chemically (that is, waters exceeding a certain salinity, perhaps 75 parts per thousand, where brine shrimp and brine flies would be the predominant invertebrates in the lake), given the variations in the physical boundaries over time

Because the standard is based on predictive modeling, assessment monitoring will be essential and should include concentrations of selenium in water and in invertebrates that serve as food sources for aquatic-dependant birds. Both brine shrimp and brine flies are important food resources for aquatic-dependant birds of the open waters of the lake (although other invertebrates also are important for those birds, those other invertebrates are found mainly in areas with lower salinities near freshwater inflows). In addition, periodic assessment of selenium concentrations in bird eggs also would be warranted if concentrations in invertebrates increase from current levels. Frequency of sampling and locations for monitoring sites will need to be determined.

Reproductive success is the most critical endpoint for the protection of birds using the open waters of Great Salt Lake. A secondary critical endpoint is adequate body condition of birds so they can successfully migrate or survive the winter. For implementation purposes, and based on the information that is currently available, it is assumed that a water quality standard protective of the reproductive success of aquatic-dependent birds will also be protective of migratory non-nesting species, such as eared grebes and over-wintering ducks. However, further study of the effects of selenium on seasonally resident or migratory non-breeding birds (such as phalaropes in addition to grebes and ducks) seems warranted. In addition, there seem to be significant interactions between selenium and mercury (which is found at elevated concentrations in some components of the lake ecosystem) that influence bioaccumulation of selenium and resultant tissue concentrations in biota.

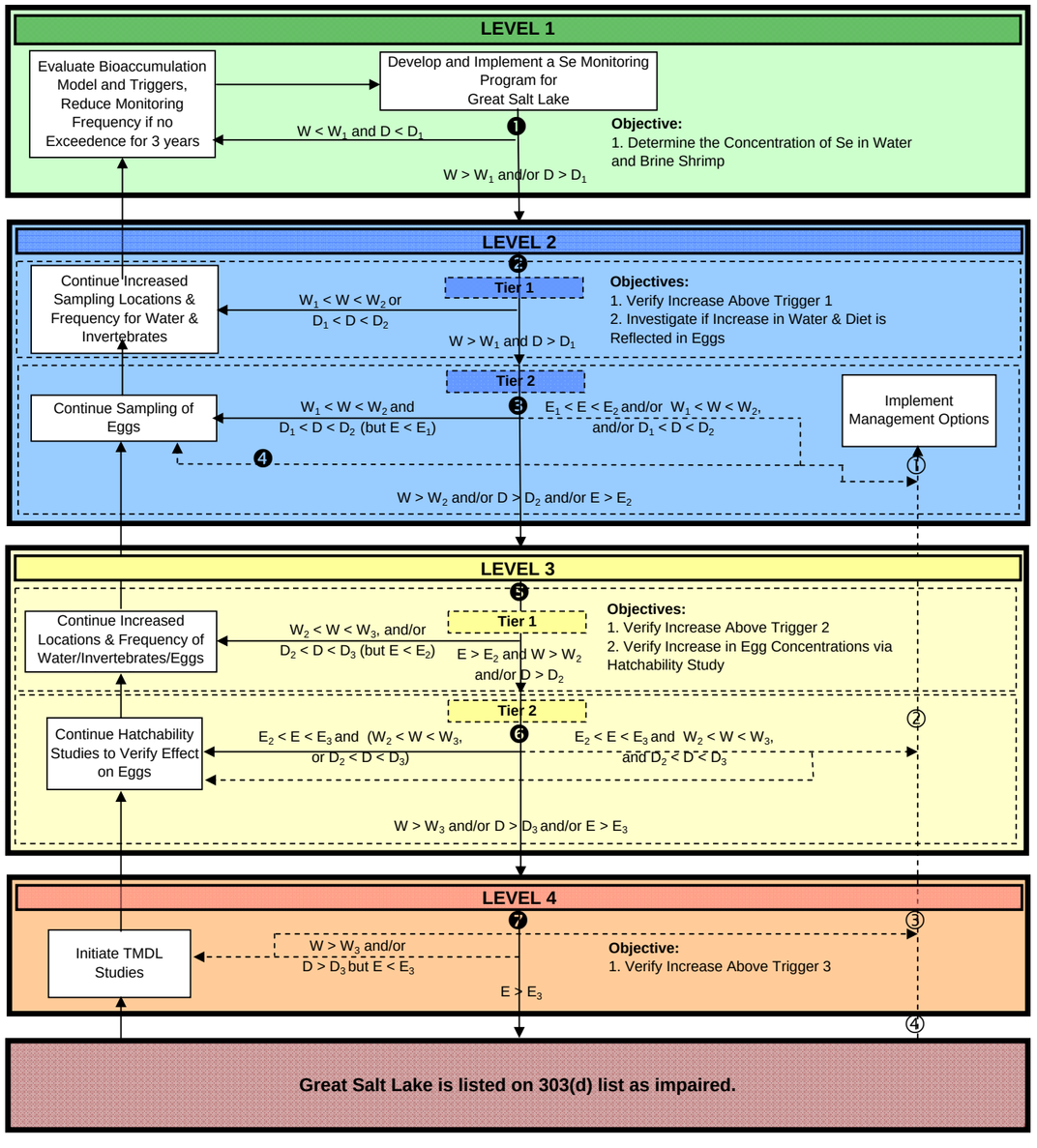
The Science Panel has identified dietary and egg selenium concentrations representing thresholds for statistically significant effects on egg hatchability (see Section 3.5). The following is assumed:

- The egg threshold will be used to identify a water column concentration corresponding to egg concentrations that will protect avian endpoints and serve as a standard, but the dietary concentration will be an important focus of the assessment monitoring. The Science Panel concluded that there is more certainty in the predicted effect of egg selenium concentrations on Great Salt Lake birds than diet selenium concentrations; therefore, the standard will be based only on the egg selenium concentration.
- The standard will address water quality of open waters and not that in open channels or pipelines discharging to the lake.
- Based on the selected water quality standard (including biological and water media), it will be necessary to develop discharge permits for implementation of the standard.

8.2 Assessment and Management Framework

The Science Panel has discussed various alternatives for implementing a water quality standard for selenium in the open waters of Great Salt Lake throughout the execution of this program. 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 has developed a concept for a tiered approach to implementing the selenium water quality standard. The approach assumes the use of the Bioaccumulation Model developed as part of this program to relate water, diet, and egg concentrations. Figure 8-1 illustrates the proposed framework of this approach. The final framework may be revised by UDWQ and the Water Quality Board after the water quality standard is established.

FIGURE 8-1
Recommended Assessment and Management Framework for Selenium (Se) in Great Salt Lake
Great Salt Lake Water Quality Studies Final Report - Selenium Program



Objective for Each Level

Level 1	Determine the concentration of Se in water and brine shrimp.
Level 2	Verify increase above Trigger 1. Investigate if increase in water & diet is reflected in eggs.
Level 3	Verify increase above Trigger 2. Verify increase in egg concentrations via hatchability study.
Level 4	Verify increase above Trigger 3.

Sampling Programs:

- ❶ Sample water and brine shrimp at four locations semi-annually.
- ❷ Increase sampling of water and brine shrimp to eight locations on quarterly basis.
- ❸ Add sampling of eggs at two locations for two bird species on annual basis.
- ❹ Increase sampling of eggs to three locations for two bird species on annual basis.
- ❺ Increase sampling of water and brine shrimp to eight locations on monthly basis, eggs at three locations for two bird species on annual basis.
- ❻ Add completion of hatchability study for one bird species on annual basis.
- ❼ Expand hatchability study to two bird species on annual basis.

Management Options

- ① Require Antidegradation Review Level II for all new discharges.
- ② Implement caps on Se loads from existing point discharges.
- ③ Initiate preliminary studies for load reductions
- ④ Implement load reduction and declare impairment.

Definitions

W_1: Trigger 1 for water concentration
W_2: Trigger 2 for water concentration
W_3: Trigger 3 for water concentration
D_1: Trigger 1 for diet concentration
D_2: Trigger 2 for diet concentration
D_3: Trigger 3 for diet concentration
E_1: Trigger 1 for egg concentration
E_2: Trigger 2 for egg concentration
E_3: Trigger 3 for egg concentration

Trigger 3 represents the site-specific numeric water quality standard; this may be a water or tissue-based concentration.

Scenarios for Consideration

ALL VALUES LISTED IN SCENARIOS FOR CONSIDERATION ARE SUBJECT TO CHANGE BY SCIENCE PANEL.

Scenario No.	Matrix	Conc. Units	Trigger 1 Conc.	Trigger 1 EC	Trigger 2 Conc	Trigger 2 EC	Trigger 3 Conc	Trigger 3 EC	Remarks
1	Water Diet Egg	ppb ppm ppm	3	Bckgrnd	4.7		6.4	$EC_{1.5}$	Uses LCL for EC_{10} as trigger for impairment and background level for initial action.
2	Water Diet Egg	ppb ppm ppm	3	Bckgrnd	6.4	$EC_{1.5}$	12	EC_{10}	Uses EC_{10} as trigger for impairment and background level for initial action.
3	Water Diet Egg	ppb ppm ppm	6.4	$EC_{1.5}$	9.2	EC_5	12	EC_{10}	Uses EC_{10} as trigger for impairment and LCL for EC_{10} for initial action.
4	Water Diet Egg	ppb ppm ppm	6.4	$EC_{1.5}$	12	EC_{10}	16	EC_{21}	Uses UCL for EC_{10} as trigger for impairment and LCL for EC_{10} for initial action.

Note:
1. These scenarios are offered for consideration. Trigger 3 to be determined by water quality standard.
2. EC values determined from Ohlendorf 2003.
3. Egg concentration of 3ppm used as background level of Se (Skorupa & Ohlendorf 1991).

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The intent of the approach is for analytical results to be summarized by statistical measures of lake-wide results for each medium that is sampled (for example, geometric mean of analytical results for annual water and diet samples and from one nesting season for egg samples). The UDWQ will begin at Level 1 and use the defined criteria to determine the actions to be implemented for the following year.

The tiered approach was developed to address the following objectives:

- Monitor Great Salt Lake to assess trends in selenium concentrations and determine whether they are approaching or exceeding the water quality standard in eggs, using water and diet (measured in brine shrimp and estimated in brine flies by a "translation factor") as indicators of whether the standard is likely to be exceeded in eggs
- Address current uncertainty in modeled bioaccumulation relationships by validating expected bioaccumulation with new data for water and diet concentrations and, if appropriate, egg selenium and hatchability
- Evaluate trigger selenium concentrations that initiate various monitoring, assessment and management actions identified in the assessment framework
- Evaluate the lake with respect to the numeric water quality standard for selenium
- Initiate management actions to mitigate further increases in selenium concentration if an upward trend is observed

The approach implements various trigger concentrations for water, diet, and egg selenium that increase monitoring levels and management options if and when actual selenium concentrations increase.

It is assumed that the water quality standard will be a tissue-based standard that is protective of the most sensitive endpoint for Great Salt Lake's beneficial uses—reproductive success for birds using the open waters of Great Salt Lake. As such, impairment of the water body will be defined by an observed selenium concentration in eggs. Selenium concentrations in water or diet are indicative of expected effects; however, a measure of selenium in eggs can be related to hatchability success with more confidence than a measure of selenium in water or diet items. It is assumed that the Bioaccumulation Model will be used to relate egg selenium concentrations to corresponding water and diet selenium concentrations. These water selenium concentrations can then be used to develop required discharge permits.

The rationale of using selenium concentration in eggs as the water quality standard is supported by work of Skorupa and Ohlendorf (1991) showing that selenium concentrations in eggs can be most directly associated with exposure of the embryo and resultant effects on its viability/development. Waterborne and diet selenium determine the *potential* and not the *actual* selenium bioaccumulation in eggs. There are many variables, each with its own uncertainty, that affect extrapolation from waterborne or dietary selenium levels to the exposure endpoint (embryo), as illustrated in Figure 8-2. Only one variable affects extrapolation from egg selenium levels to egg hatchability—species sensitivity to selenium. This was the basis for selecting an egg concentration for the recommended selenium water quality standard for the open waters of Great Salt Lake. The Bioaccumulation Model was

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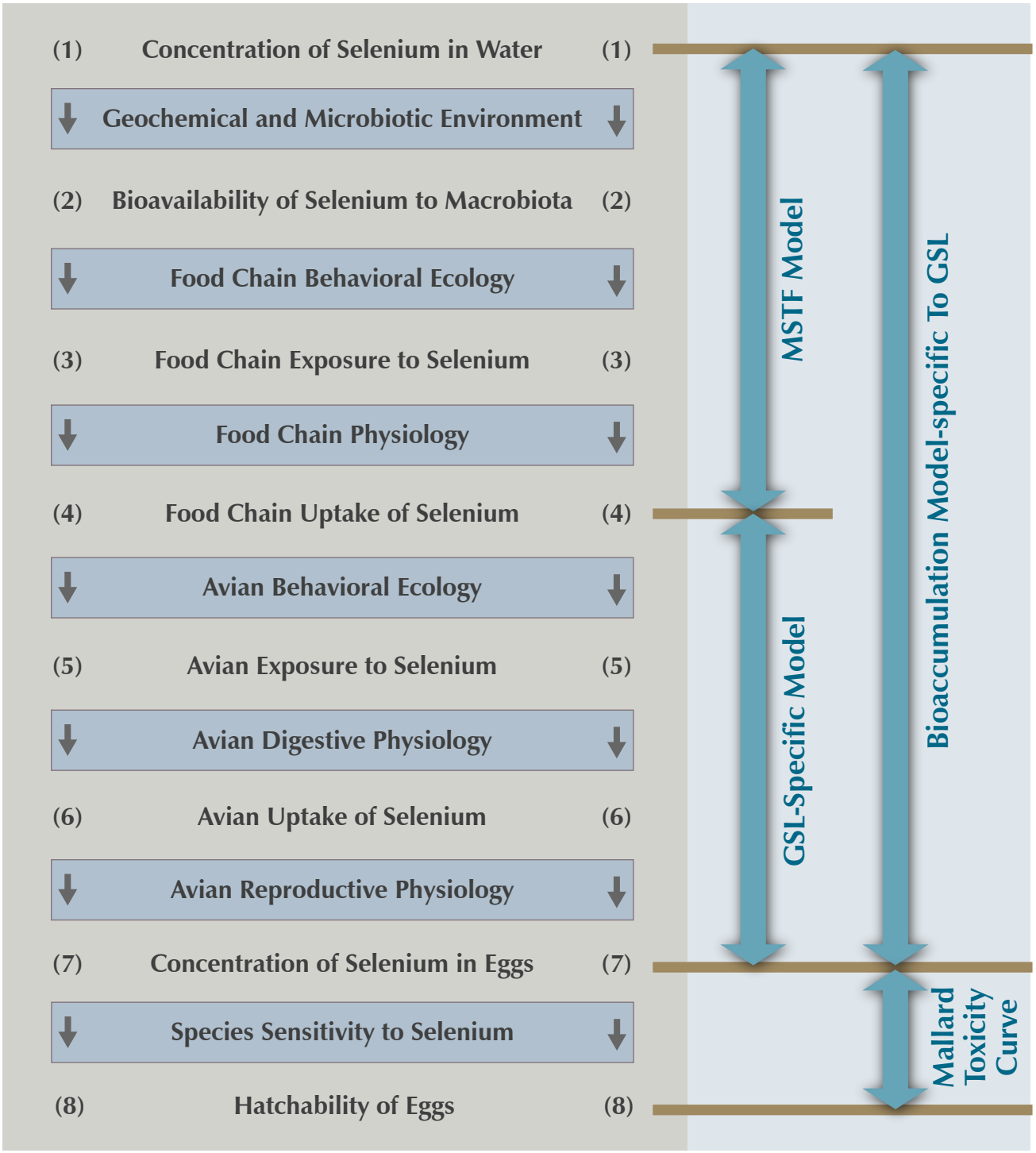

Source: Adapted from Skorupa & Ohlendorf, 1991.

FIGURE 8-2
Major Variables Potentially Confounding the Relationship Between Waterborne and Egg Selenium
Great Salt Lake Water Quality Studies
Final Report – Selenium Program

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selected by the Science Panel to address the transfer of selenium between water and bird egg and to predict an egg selenium concentration. The mallard selenium toxicity curve for eggs (Ohlendorf, 2003) was selected by the Science Panel to represent the effect of selenium in eggs upon reduction in egg hatchability.

As previously described, waterborne selenium concentrations that correspond to diet and egg concentrations will be back-calculated using the Bioaccumulation Model developed as part of this program. The monitoring program described by the approach will be used to continually assess and improve upon the relationships included in the bioaccumulation model and the trigger levels included in the approach. The increasing levels of monitoring and implementation of management options, when necessary, are intended to provide a more robust and defensible dataset to confirm an apparent upward trend in selenium concentrations as well as provide a means to mitigate the upward trend, if one occurs. The level of protection that defines the trigger level for each of the tier levels will be based upon the levels of protection recommended by the Steering Committee and decided by the Water Quality Board.

The Great Salt Lake waterborne concentration used for implementation of UPDES permits is expected to be back-calculated from the egg concentration that relates to the expected level of effect defining impairment. This level of effect will be determined by the Steering Committee and Water Quality Board.

8.3 Long-term Verification

A water quality standard defined for Great Salt Lake will be subject to revision at least every 3 years and more frequently if deemed appropriate. For example, an update may be appropriate if there is a change in beneficial uses, water quality changes (for example, reaching levels of potential impairment), or new scientific information on the cycling of selenium in Great Salt Lake becomes available. Given the uncertainties of our current understanding of the Great Salt Lake ecosystem, it is prudent to identify potential actions the UDWQ could take to verify and validate the current model, the new water quality standard, and future permit limits. It is recommended that the UDWQ consider the following:

1. The highest priority research need identified by the Science Panel was to verify the transfer of selenium between the water column and brine shrimp for waterborne concentrations of 0.5 to 5.0 µg Se/L. The current Bioaccumulation Model includes two relationships (BAF and MS-TF models) developed from Great Salt Lake data that describe this transfer; however, both were created from a dataset represented by waterborne concentrations of 0.4 to 0.8 µg Se/L. Predictions using these models of brine shrimp selenium concentrations from waterborne concentrations greater than 0.8 µg Se/L should be used with caution. The Grosell model (Grosell, 2008) was developed in the laboratory for waterborne concentrations of 0 to 2.5 µg Se/L; however, comparisons with data from other water bodies indicate that selenium concentrations in brine shrimp may be over-predicted. Further studies would verify these site-specific relationships.

2. Periodically reassess the current conceptual model and update it with any new scientific information, as appropriate. The current model is based largely upon only 15 months of data. It is recognized that the lake is a dynamic lake and the current model does not account for long-term trends. The objective of continual reassessments of the model is to improve upon the accuracy of current relationships used in the bioaccumulation and mass balance models to minimize current uncertainties.

3. Monitor brine shrimp (tissue selenium concentrations and waterborne selenium concentrations) at predetermined intervals (1 time, 2 times, 4 times, etc. per year) throughout Great Salt Lake. The frequency and number of sampling locations would depend on the assumed homogeneity of brine shrimp and waterborne selenium concentrations throughout the lake. The objective is to improve upon the current understanding of the transfer of selenium from the water to these diet items and long-term trends. While the bioaccumulation model and recommended monitoring program emphasize brine shrimp as the primary diet item for birds, additional information is needed to improve upon the current understanding of selenium concentrations in brine flies. Thus, until that information becomes available, selenium concentrations in brine flies will be estimated using a "translation factor" based on measured brine shrimp selenium concentrations.

4. Complete additional collocated sampling of brine fly larvae and adults and sediment and water. Current brine fly levels are based on a "translation factor" developed from limited brine fly data and brine shrimp data. Additional measurements should be made to improve this "translation factor" or develop a new relationship as brine flies are also an important food source for birds using the open waters of Great Salt Lake.

5. Complete additional egg sampling studies that relate transfer of selenium from diet to eggs. The objective is to provide additional data points that will improve the statistical power of the current Great Salt Lake Shorebird Model (that is, the regression equation developed from data collected to date). Another objective is to further develop the Great Salt Lake Gull Regression Model.

6. Continue monitoring tributary inflows and selenium loads to Great Salt Lake in conjunction with lake water column concentrations. The objective is to understand long-term trends, identify other potential selenium sources, and improve upon the current mass balance model. Long-term flow records will provide benefits beyond the assessment of selenium in Great Salt Lake, as this information is important for any study where the mass balance of water inputs to the lake and outputs to sediment, biota, or the atmosphere is required. Special emphasis should be placed upon understanding flow inputs/outputs to the North Arm as very little information describing these processes is currently available.

7. Sample atmospheric deposition of selenium to verify assumptions made in the mass balance model. Current deposition rates in the model are based solely upon literature values from other locales. The objective of this study is to measure both wet and dry atmospheric deposition of selenium and other pertinent meteorological parameters at Great Salt Lake to quantify actual atmospheric selenium loads to Great Salt Lake.

8. Evaluate other potential sources of selenium to Great Salt Lake such as lake sediment pore water diffusion into the overlying water column, submarine groundwater discharge or wind blown dust that is deposited directly onto the lake surface.

9. Conduct a one-time study to determine selenium concentrations in phalaropes when they arrive at Great Salt Lake and before their departure during their season of peak abundance at the lake. Phalaropes were not studied as part of this project but were identified as another bird species that relies heavily upon the open waters of Great Salt Lake for their food source. The objective of this study is to identify any potential effects of selenium upon their body condition and ability to migrate.

10. Conduct further studies to evaluate the potential effects of selenium upon non-reproductive endpoints in birds. Confounding variables and insufficient information available during the completion of this project did not allow for a determination of effects due to selenium on those endpoints for Great Salt Lake birds. More information is needed to understand the diet composition of migratory birds and potential effects of selenium upon successful fall migration and survival of over-wintering birds using the open waters of Great Salt Lake.

11. Conduct further studies to understand the potential interaction of selenium and mercury and their effects on aquatic birds using open waters of Great Salt Lake.

12. Verify waterborne selenium concentrations at the outer limit of mixing zones at predetermined intervals. This should apply to current discharges at the shore and to submerged outfalls. The objective is to verify current mixing zone assumptions and potential effects to beneficial uses in these zones.

13. Continue verifying discharge concentrations per permit requirements.

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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 85th to 90th 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.

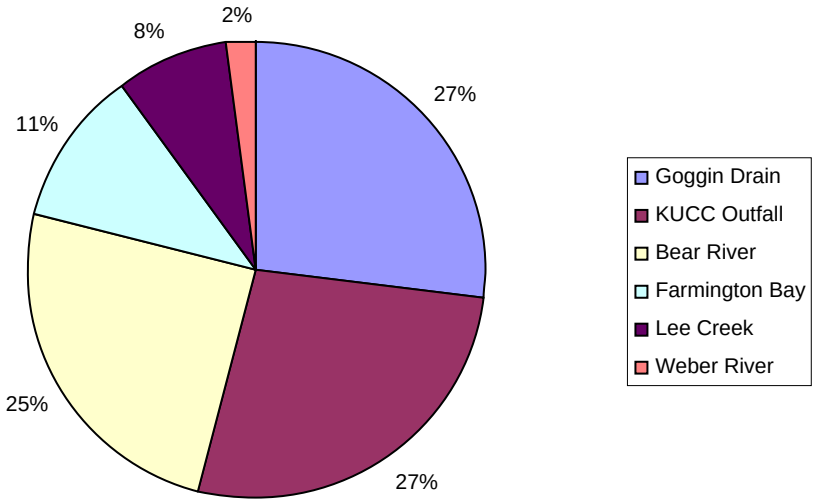
- Long-term cycling of selenium within Great Salt Lake was not fully addressed by this program due to the insufficient length of the study period.

- 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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Contents

Conceptual Model for Selenium Cycling in the Great Salt Lake

Prepared for the Division of Water Quality
of the Utah Department of Environmental Quality

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Conceptual model for selenium cycling in the Great Salt Lake

This document describes a conceptual model for selenium cycling in the Great Salt Lake. The document consists of four parts:

Introduction to the problem & Overview

During the Fall of 2005 a panel of nationally recognized scientists in the area of selenium environmental toxicology and geochemistry was convened to work with local scientists and engineers to develop a conceptual model to guide development of investigations in support of determining an open water selenium standard for the Great Salt Lake. The expert panel included Dr. Anne Fairbrother (U.S. Environmental Protection Agency), Dr. Joseph Skorupa (U.S. Fish & Wildlife Service, Dr. William Adams (Rio Tinto, Inc), Dr. Theresa Presser (U.S. Geological Survey), and William Wuerthle (U.S. Environmental Protection Agency). The local scientists and engineers who worked with the expert panel in development of the conceptual model were Drs. William Johnson and Jack Adams (University of Utah), and Drs. Michael Conover & Wayne Wurtsbaugh (Utah State University).

Motivation

The motivation to determine a selenium standard for the open water of the Great Salt Lake (GSL) derives from public concern for a plan to allow disposal of reverse osmosis (RO) concentrate in the GSL. The concentrate would contain elevated concentrations of major and trace elements, including selenium. The need for reverse osmosis treatment of groundwater arises from sulfate contamination in the confined aquifer emanating from the Kennecott evaporation ponds.

Existing GSL selenium standard

The open water of the GSL is protected for its current beneficial uses (Class 5) through the application of the narrative criteria clause which states that it is unlawful "to discharge … any waste or other substance in such a way as will be or may become offensive …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". Due to the highly individual nature of the Great Salt Lake, the Utah Department of Environmental Quality (DEQ) has not yet identified numeric water quality standards specific to the Great Salt Lake.

Conceptual model to guide standard development

The development of an open water standard for selenium requires a working knowledge of the biological significance of existing selenium concentrations in the Great Salt Lake, as well as a working understanding of the likely changes in these concentrations over time given existing and proposed loads to the system. This "working knowledge" is being represented in a conceptual model that accounts for selenium in various "stocks" in the system (e.g. water, sediment, biota) and the "flow" of selenium between stocks (e.g., precipitation and settling, volatilization, bioconcentration). The conceptual model is presently descriptive, but will serve as the basis for a semi-quantitative model that will be fed by data accumulated during subsequent investigations.

Loads

The existing selenium loads to the GSL are not well characterized. The most prevalent source of selenium nationally is irrigation of marine deposits of Cretaceous to Tertiary age. Marine deposits of Cretaceous to Tertiary age are not prevalent in the Great Salt Lake Basin (Hintze, 2005), and are restricted mainly to the Bear River Watershed. However, the Bear River is the dominant source of water to the GSL and since the GSL is a terminal lake, evaporative concentration of selenium increases the risk of elevated selenium concentrations within the GSL system. Other actual and potential sources of selenium to the GSL include mine tailings and refinery wastes, respectively.

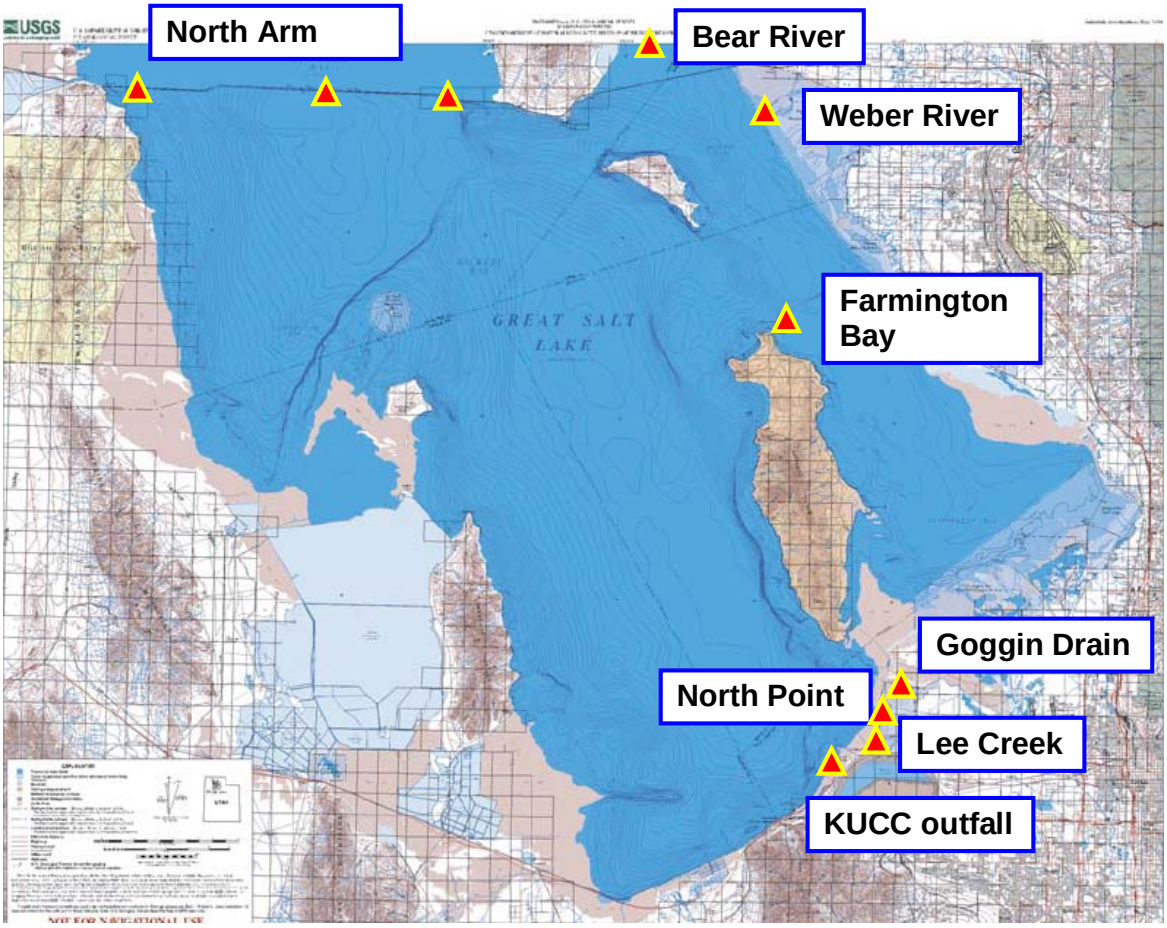
Challenges to analytical methodologies

The hypersaline water of the Great Salt Lake presents an exceptional challenge to existing analytical techniques used to measure selenium in water. A preliminary "round robin" survey of samples from several depths (one location) demonstrated that only a limited set of analytical methods can reliably quantify selenium in this system. The round robin, which was based on a single sampling location, is encouraging in that it indicates that approximately 0.7 ppb selenium exists in the water column; a value that is not expected to yield deleterious effects in biota. However, it must be stressed that the open water of the Great Salt Lake cannot be represented by a sample from a single location, or a particular time, as elaborated below.

Accumulated record

The degree to which selenium is sequestered in non-bioavailable compartments or forms in the GSL is central to the assessment of the long-term effects of selenium loads to the GSL. The long-term accumulation of selenium in the GSL is recorded in its accumulating sediments. Collection and analysis of sediment cores from lakes and reservoirs provides a record of long-term water quality trends. Measurable concentrations of most trace elements and selected organic compounds are often associated with fine particulates in the water column, which settle and may accumulate at the lake bottom. The U.S. Geological Survey (USGS) lake cores in Farmington Bay suggest pre-1900s selenium concentrations around 0.4 μg/g; with possible increases of 4- to 5-fold thereafter (Dr. David Naftz, personal communication). The cause of the increase has not been investigated, and may reflect either increased selenium loads, or selenium loss from the deeper (older) sediments with time. The significance of potential increased selenium accumulation depends on the long-term bioavailability of accumulated selenium. Hence, the goal of understanding the distribution of existing and additional selenium loads within the GSL system requires the development of a conceptual model that comprehensively describes selenium cycling within the existing GSL ecosystem. The conceptual model is needed to guide prediction of how pathways may vary with climate-induced changes (e.g. salinity, redox

conditions, etc.), and to provide metrics indicating the degree of confidence with which the various components of the cycle are understood.



Dynamics of the GSL ecosystem
Comprehensive determination of selenium cycling in this system requires an understanding of the following attributes of selenium cycling that will be elucidated in the conceptual model:

a) The storage compartments of selenium in the system
b) The residence times of selenium within these compartments
c) The pathways between these compartments.
d) The fluxes of selenium between these compartments

The comprehensive conceptual model for selenium cycling in the GSL system allows decision makers to identify areas where improved understanding of processes is required prior to determination of a standard for the open water of the GSL. However, the complexity of the GSL system will likely identify more potential investigations than can be supported financially or completed in the time allotted. Hence, decision makers will need to rank identified areas of need relative to the ultimate goal of support of beneficial use of the GSL system. There are two major considerations in development of the conceptual model:

a) The GSL system is spatially diverse, being comprised by four distinct bays and two layers. The limited connections between the bays yield major differences in salinity among their waters. These bays are also frequently stratified vertically. Gilbert Bay has a deeper anoxic zone that does not generally "turn over" on an annual basis and is more saline than the overlying shallower zones. Farmington Bay also frequently has a deep brine layer that is believed to be mixed periodically during strong wind events (Dr. Wayne Wurtsbaugh, personal communication). Due to variation in salinity (and hence density) with depth, the flow between spatial compartments can be bi-directional flow, such that the deeper hypersaline layer flows oppositely to the overlying water.
b) The GSL system is temporally dynamic, due to seasonal and inter-annual variations in runoff from the Wasatch and Uinta Mountains to the east. Variability in runoff controls salinity, shoreline location, and lake depth. Due to the shallowness of the GSL, wind events are also important drivers of flow between compartments in the GSL. Wind events also influence vertical mixing of the deep anoxic layer into the overlying water column. Greater than 60% of the lake area is oxic, but a significant portion is underlain by an anoxic deep brine layer. In Farmington Bay, a wind event was observed to mix the deep brine layer into the total water column making the entire water column anoxic for two days (Dr. Wayne Wurtsbaugh, personal communication). The lateral extent of the deeper anoxic zone appears to expand and shrink on a seasonal basis, potentially exposing sediments to a combination of chemically reducing and oxidizing conditions on an annual basis. The temporal dynamics of selenium cycling in the GSL system is also biologically driven since the abundances of particular organisms shift from season to season.

Biogeochemical fluxes

The vertical spatial variability of the GSL system requires special consideration since it is likely across this vertical gradient that selenium moves from the geochemical to the biological system. In short, microorganisms in the water column “make their living” by facilitating the trade of electrons between elements. In this process, selenium may be chemically reduced when an oxidized form of selenium sorbs to a particle and settles to the deeper anoxic zone. In contrast, reduced selenium may be oxidized when reduced forms are re-suspended into the oxic zone. The same issue applies to lake area variations, which may expose anoxic sediment to air, or may submerge oxic sediment beneath the anoxic deep brine layer. The deeper anoxic zone in the GSL has some of the highest sulfate reduction rates measured in a natural system (Dr. David Naftz, USGS, personal communication), suggesting that transformation of selenium in this system is significant (based on the similarities of selenium and sulfur chemistry).

A potential release mechanism of selenium from the GSL and sediments is the buoyant transport (upward) of bubbles of reduced volatile selenium (e.g. methylated selenides). The flux of volatile selenium in the Great Salt Lake is unknown. The rate of this transfer is likely temporally variable in response to variations in salinity and temperature, each of which control speciation and the solubility of organic selenium species.

Into the food chain

The tie between biogeochemical cycling and the food chain occurs at the level of microorganisms. Brine shrimp and brine fly larvae are expected to take up selenium via the

microorganisms on which they feed. The brine shrimp and brine flies are in turn the major food sources to birds in the open water. Hence, the development of an open water standard involves the execution of surveys to measure selenium concentrations in water, microorganisms, brine shrimp, and brine flies. Notably, preliminary monthly data taken during the summer by Dr. William Adams (Rio Tinto) suggests factor of two increases in selenium concentrations in brine shrimp at the south end of the Great Salt Lake during the month of July. This period roughly coincides with depleted $\delta^{15}N$ (the heavy isotope of nitrogen) measured by Dr. David Naftz (USGS, personal communication). Possible reasons for the observed large seasonal shift could be a seasonal change in food source from green to blue green algae or a shift to a benthic food source growing on the extensive areas of stromatolites/bioherms in the GSL.

Toxic endpoints

The development of an open water standard must of course occur with reference to sensitive species at the top of the food chain, i.e. birds in the case of the Great Salt Lake. Among the birds present on the Great Salt Lake, three species were chosen: one as a representative of migratory species, and two as representatives of species that breed on the Great Salt Lake.

Eared grebes were chosen to represent migratory species on the basis that The Great Salt Lake and Mono Lake are the only two lakes in the western U.S. supporting the population of eared grebes in the fall season. Furthermore, while they reside on the Great Salt Lake, the eared grebes eat only brine shrimp (99.7% of diet) (Dr. Michael Conover, personal communication). Viability of offspring is likely not a sensitive endpoint for this species since the high rate of Se depuration for birds likely resets their selenium concentration within weeks of change in diet, and egg laying occurs about 90 days following departure from the Great Salt Lake (in the fall). Since eared grebes must consume on the order of 13,000 shrimp per day during their stay to support their migration from the Great Salt Lake (Dr. Michael Conover, personal communication), a potential selenium toxic endpoint for this species is inadequate build-up of mass for migration. However, in other avian species, e.g. mallards, the level of selenium required to impair adult health has been demonstrated to be higher than that required to impair reproduction (Dr. Joseph Skorupa, personal communication), suggesting that resources should be focused on the toxic endpoints associated with reproduction.

Avocets/stilts and northern shovelers were chosen to represent species that breed on the Great Salt Lake. Their diet contains a high concentration of brine flies, brine shrimp, or corixids, thereby making them most at-risk relative to other over-wintering birds in terms of selenium burden. Furthermore, sufficient numbers of eggs can be easily obtained for these species, and in the case of avocets/stilts their foraging area restricted to relatively short distances. A disadvantage of avocets is their relatively low sensitivity to Se. An advantage of shovelers is that toxicity data from mallards may be transferable. A disadvantage of shovelers is that a portion of the population may be year round, but other portions may be transient, and they may not rely heavily on the Great Salt Lake for diet since they nest at the interface between fresh and salt water.

Momentum

The conceptual model illustrates the critical pathway of selenium from water, to microorganisms, to brine shrimp and brine flies, to birds, and to their eggs. Surveys of selenium concentrations

within these “stocks” will yield bio-accumulation factors for selenium between these “stocks” and will thereby support the back-calculation of an open water standard. An interim standard can likely be developed over the course of a single year. However, based on the conceptual model, the confidence in this standard would be greatly enhanced by surveys performed over multiple years in order to account for characteristic year-to-year variation in the Great Salt Lake system. In order to better predict the long-term trajectories of selenium concentrations in this system, additional surveys are needed to determine selenium loads to the system in a fashion that accounts for year-to-year variation. Furthermore, selenium particulate fluxes into and out of sediment, and selenium vapor fluxes upward through (and exiting) the system, need to be examined in order to determine the significance of accumulated sediments as long term sinks or sources of selenium.

Framework of the model and underlying assumptions

The conceptual model for selenium cycling in the Great Salt Lake system includes two major domains:

1) trophic transfer of selenium upward through the food chain
2) biogeochemical cycling of selenium "below" the food chain, which is dynamically influenced by hydrologic processes (variations in runoff and evaporation).

For both domains, the boundary of the conceptual model coincides with the effective boundaries of Gilbert Bay, i.e. the open water of the Great Salt Lake west of Farmington Bay, west of the Weber River input, and south of Promontory Point (Bear River Bay) and the North Arm.

This boundary places wetlands processes outside the boundaries of the conceptual model. However it is well recognized that wetlands processes govern the concentration of selenium entering into Gilbert Bay from Farmington Bay and other areas outside the boundaries of the conceptual model.

An important consideration is the potential export of selenium from within the conceptual model boundaries to wetlands during high elevations of the Great Salt Lake. The effects of this "violation" of the model boundaries are mitigated by the following conditions:

1) during high elevations of the Great Salt Lake the present wetlands become hypersaline and effectively become equivalent to the open water of the Great Salt Lake (the freshwater-hypersaline interface is moved outward)
2) the water quality standard in these inundated wetlands would carry the 3D numeric criteria, which may be less than the open water standard of the Great Salt Lake.

Given these conditions, the conceptual model boundaries allow the mass transfer of selenium and water to Gilbert Bay to be idealized one-way (into Gilbert Bay). This simplification allows the complexities of selenium cycling in the wetlands to be considered separately from the complexities of selenium cycling in Gilbert Bay.

The conceptual model that follows focuses on selenium cycling in Gilbert Bay.

Trophic transfer of selenium within food chain

The food chain in the Great Salt Lake system is relatively simple. For birds, food sources available directly from the lake are restricted to brine shrimp, brine shrimp cysts, brine flies, brine fly larvae, and water column insects (i.e. corixids).

Although corixids are known from freshwater environments, corixids can be found in Gilbert at salinities up to 160 g/L (salinity). Although many of the corixids observed at high salinities have likely have been washed in from less saline environments, observations demonstrate corixids may be present in significant numbers in the saline waters of Gilbert Bay (Dr. Wayne Wurtsbaugh, personal communication).

Simplifying assumptions are required to define compartments and physical mass transfer processes in a tractable model. Below we articulate simplifying assumptions that yield a tractable, albeit still complex, model.

Simplifying assumptions

1) The Se cycle can be separated into trophic transfer "within" the food chain versus physical mass transfer and chemical transformation "below" the food chain. The underlying assumption is that exposures to Se for organisms "higher" than phytoplankton in the shallow layer and periphyton and bacteria in the littoral sediment are predominantly via diet. Hence, the conceptual model treats direct physicochemical partitioning of selenate and selenite to "higher" organisms as negligible relative to uptake of organic selenium via predation. This assumption is justified by the fact that dietary exposure is the dominant route of exposure for many organisms (Toll et al., 2005; Brix et al., 2005).
2) An exception to the above assumption is physicochemical uptake of selenate and selenite by plants, which in turn influences aqueous selenium concentrations. The conceptual model boundaries effectively eliminate the need to consider influences of plants on selenium cycling. In contrast, the influence of plants is likely a very important consideration in selenium cycling in Farmington Bay.
3) Dietary uptake of Se by "higher" organisms is predominantly in the form of organic Se. Dietary uptake of inorganic Se is negligible for "higher" organisms.
4) Incorporation of inorganic Se into the food chain occurs predominantly at the level of periphyton and bacteria in the littoral sediment and phytoplankton in the shallow layer.
5) Only phytoplankton in the shallow layer, and periphyton and bacteria in the littoral sediment, are grazed by brine shrimp and brine fly larvae. Hence, the phytoplankton in the shallow layer, and periphyton and bacteria in the littoral sediment act as the gateway between the geochemical cycling and the food chain. The bacteria in the deep brine layer and anoxic sediment mediate Se cycling, but are not directly significant to higher food chain organisms.
6) Brine shrimp diet may vary dynamically. Potential food sources for brine shrimp other than phytoplankton include purple sulfur bacteria located at the interface between the Shallow Layer and Deep Brine Layer, and bioherm algae located on the lake bottom where the deep brine layer is absent (Littoral Sediment). The purple sulfur bacteria are photosynthetic and oxidize H_2S exsolved from the Deep Brine Layer, and may therefore also oxidize volatile selenium compounds and accumulate selenium. That brine shrimp foraging is dynamic is suggested by measured peak selenium concentrations in brine shrimp during July (Dr. William Adams of Rio Tinto) which qualitatively corresponds to depletion of $\delta^{15}N$ in brine shrimp (measured by Dr. David Naftz of USGS). These changes are likely coincident with depleted phytoplankton concentrations (as a result of brine shrimp grazing the phytoplankton). The combined observations suggest that the brine shrimp graze on other food sources during July; or alternatively, the phytoplankton are depleted in selenium during July. Brad Marden (Artemia Association) suggests that weekly monitoring is needed, since brine shrimp and algae populations fluctuate significantly on a weekly basis.
7) A tentative link is also included between phytoplankton and birds. Dr. Joe Skorupa (USFWS) has expressed discomfort with the absence of an avian species that exploits the

phytoplankton directly. This tentative link is added as a reminder of the need to assess this absence. However, Dr. Mike Conover suggests that no GSL birds eat single-cell phytoplankton because these organisms are just too small. Some algae species form dense colonies (floating mats, etc.), that are sufficiently large (several grams wet weight) for some ducks that are primarily herbivores (e.g., wigeon) and geese to pick up and eat. These algae species probably do not occur in the pelagic areas of the GSL. The algae can be significant at times in Farmington Bay. However, in most herbaceous birds, algae make up only a small part of their diet due to lack of nutritional value.

Among the birds present on the Great Salt Lake, three species were chosen as representative of migratory species, and species that breed on the Great Salt Lake. The food supply for most birds (corixids, brine flies, brine shrimp) collapses in November when the GSL becomes too cold. Many species, e.g. grebes, stilts, avocets, plovers, phalaropes, and gulls leave by December. Some species, e.g. ring-billed and California gulls and ducks (e.g., common goldeneyes) over-winter on the GSL and probably migrate directly to the breeding ground. Birds that breed on the Great Salt Lake include avocets, stilts, Franklin's gulls, California gulls, and snowy plovers.

Grebes

Eared grebes were chosen as a "sentinel" (indicator) species on the basis that while on the GSL, they only eat brine shrimp (99.7% of diet). Feathers, corixids and brine flies each make up about 0.1% of their total diet according to research by Dr. Mike Conover, and work by Dr. Don Paul. Their length of stay on the GSL is known from Dr. Mike Conover's data.

Toxic endpoint

The most sensitive endpoint is considered to be mass wasting, since it may result in unsuccessful migration. Reproductive impairment is likely not a sensitive endpoint for this species since the high rate of Se depuration for birds likely resets Se concentration within weeks of change in diet, and egg laying occurs about 90 days following departure from the Great Salt Lake (in the fall). Reproductive impairment is not considered a sensitive endpoint for grebes that use the Great Salt Lake in the spring due to the short residence time of the birds on the lake during this period.

The level of Se to impair adult health is higher than that required to impair reproduction. Heinz (1996) provides a summary of mallard work, and recommends a dietary value of 10 ppm, dw, to protect adult mallards from adverse effects. Ohlendorf (2003) reported that the dietary EC10 for reproductive impairment in mallards was 4.87 ppm, dw, with 95% confidence boundaries of 3.56 - 5.74 ppm, dw. Given that the value of 4.87 ppm is an EC10, not the expected LOAEL, and that one really should allow for inter-species variability in sensitivity. Dr. Skorupa advocates using the lower confidence boundary value of ca. 3.5 ppm. He suggests that this is consistent with Wilber's (1980) comprehensive review of selenium toxicology in Clinical Toxicology, 17:171-230, wherein he noted that the chronic toxic dose for "hens" ranged from 3.5 - 10 ppm. Presumably part of the variation in that range is due to different endpoints evaluated by different studies and also presumably the reproductive endpoints would have yielded the lower boundary of the range cited by Wilber (1980). Dr. Skorupa indicates that all parties agree now that the EC10 for mallard egg hatchability data is about 12 ppm (Adams et al. 2003; Ohlendorf, 2003). Furthermore, Ohlendorf (2003) reported that the 95% confidence

boundary on that EC10 estimate was 6.4 - 16.5 ppm, dw. For the same reasons as outlined above, Dr. Skorupa advocates an EC10 of about 6 ppm. He suggests that the wisdom of this is further reinforced by a recent paper that reported about an EC15 control-adjusted effect in egg hatchability for spotted sandpipers at an average egg selenium concentration of 7.3 ppm, dw (Harding et al., 2005).

The bird most likely to be at-risk from loss of mass (or decreased gain of mass) due to selenium effects while on the GSL is the eared grebe:

1) some of the highest Se concentrations at Kesterton reservoir were found in this species
2) they eat only brine shrimp, brine flies, and corixids while on the GSL
3) these birds are always at the edge of what is nutritionally possible (i.e., having enough energy to migrate from the GSL to the Salton Sea)
4) there are mass downings of eared grebes migrating from the GSL during some years that result in the deaths of thousands of grebes. The cause of these downings is not clear, however some attribute the downings to snow storms (Jehl, 1993).

Uncertainty in depuration rate

Selenium accumulation and depuration rates are rapid. Studies indicate that it would take about 2.5 months (71 days) for waterfowl to return to background selenium levels once they leave a source, but they would be below effects levels of 10 ppm (w:w) in about 8 - 10 days (e.g. Heinz et al., 1990; Yamamoto et al., 1998; Heinz, 1996; Wilson et al., 1997).

However, selenium accumulates to high levels in preen glands and does so fairly rapidly (e.g., from ca. 4 ppm ww to ca. 20 ppm ww in ca. 60 days in one study of small shorebirds). The feathers concurrently also increase rapidly in Se content from preen gland (uropygial gland) secretions being applied to the feathers. Selenium concentrations in these feather must have been introduced via the exterior since the feathers were fully grown (i.e., hard penned) and therefore no longer had any vascular connection to pathways for metabolic (i.e., internal) deposition of Se (e.g. Goede and De Bruin, 1986; Goede and DeBruin, 1984).

A factor of 2-4 increased selenium burdens in eared grebes relative to other species at the Tulare Basin is observed despite equivalent diets for these birds (Dr. Joseph Skorupa, personal communication). This enhanced selenium concentration in eared grebes may reflect the effect of ingestion of feathers.

Avocets/stilts

Avocets and stilts were chosen on the basis that these birds breed on the Great Salt Lake, and their diets contain a high concentration of brine flies, brine shrimp, or corixids, thereby making them most at-risk relative to other over-wintering birds in terms of selenium burden. Furthermore, sufficient numbers of eggs can be obtained easily for this species, and their foraging area is restricted to relatively short distances.

A disadvantages of avocets is their relatively low sensitivity to Se.

Toxic endpoint
The most sensitive endpoint for the avocets/stilts is considered reproductive impairment (reduced egg hatchability) since these species breed at the Great Salt Lake.

Northern Shovelers

This species was chosen on the basis that it is an over-wintering species whose diet mostly comes from the GSL during the winter (probably cysts, but this not definitively determined). Dr. Mike Conover has a large sample of shovelers that were collected on the GSL on December 1 (n= 90) and on March 1 (n =30) 2005. These samples are frozen and could be processed to determine their condition and Se concentrations. Dr. Conover also dragged duck nests along the GSL marshes for several years and is certain that shoveler nests can be found. Sampling for deformed or normal ducklings likely not possible since upon hatching, Shoveler ducklings are led by the hens deep into the marshes where it is impossible to find them.

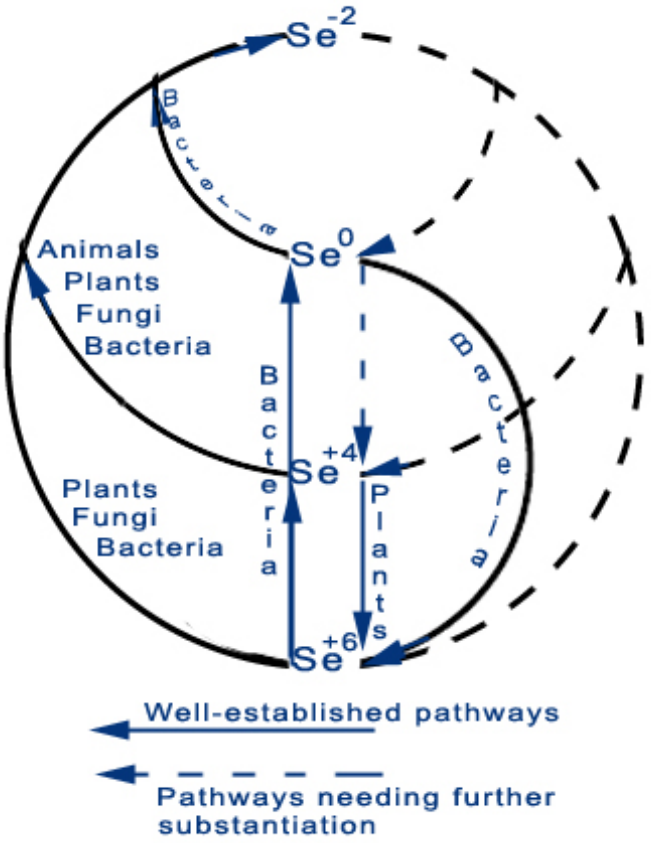
An advantage of shovelers is that toxicity data from mallards may be transferable. A disadvantage of shovelers is that a portion of the population may be year round, but other portions may be transient. They may not rely heavily on the Great Salt Lake for diet since they nest at the interface between fresh and salt water.

Toxic endpoint
The most sensitive endpoint is considered egg hatchability since these species breed at the Great Salt Lake.

Note: Dr. Clay Perschon (Utah Division of Wildlife Resources) does not agree with the choice of northern shoveler, since this species does not appear to use the lake extensively. Dr. Perschon suggests use of the common goldeneye, since they appear to use the lake extensively (brine shrimp and brine flies). However, a weakness of this approach is that common goldeneyes do not nest on the Great Salt Lake, so this would require designation of a different toxic endpoint relative to northern shovelers.

Biogeochemical cycling of selenium "below" the food chain

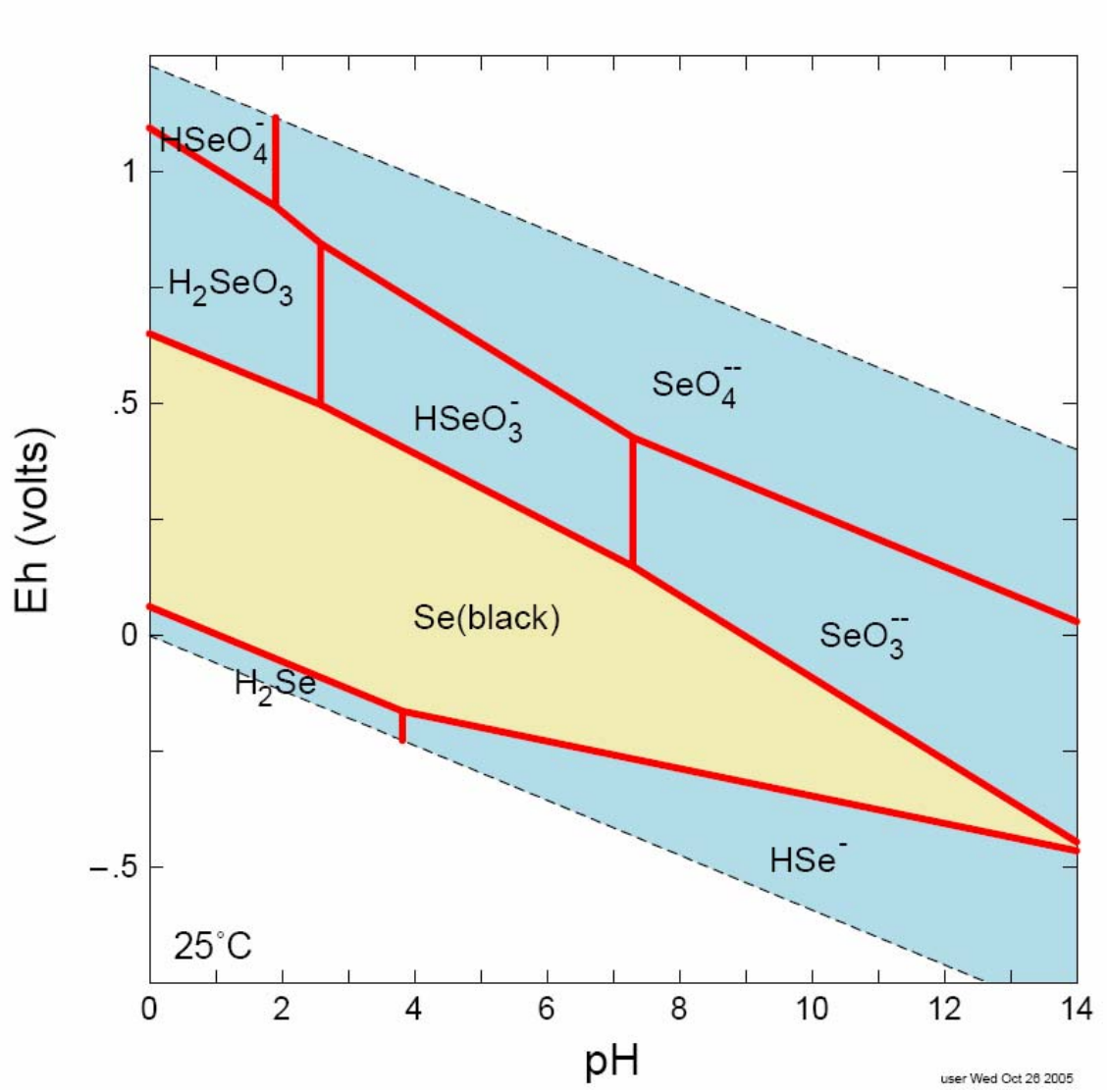
Expected selenium species in the Great Salt Lake fall into five categories: organic selenium Se(-II), selenide Se(-II), elemental selenium Se(0), selenite Se(+IV) (SeO_3^{2-}), and selenate Se(VI) (SeO_4^{2-}). If one lumps organic and volatile selenium, the pathways relating these species to one another can be generalized as shown below:



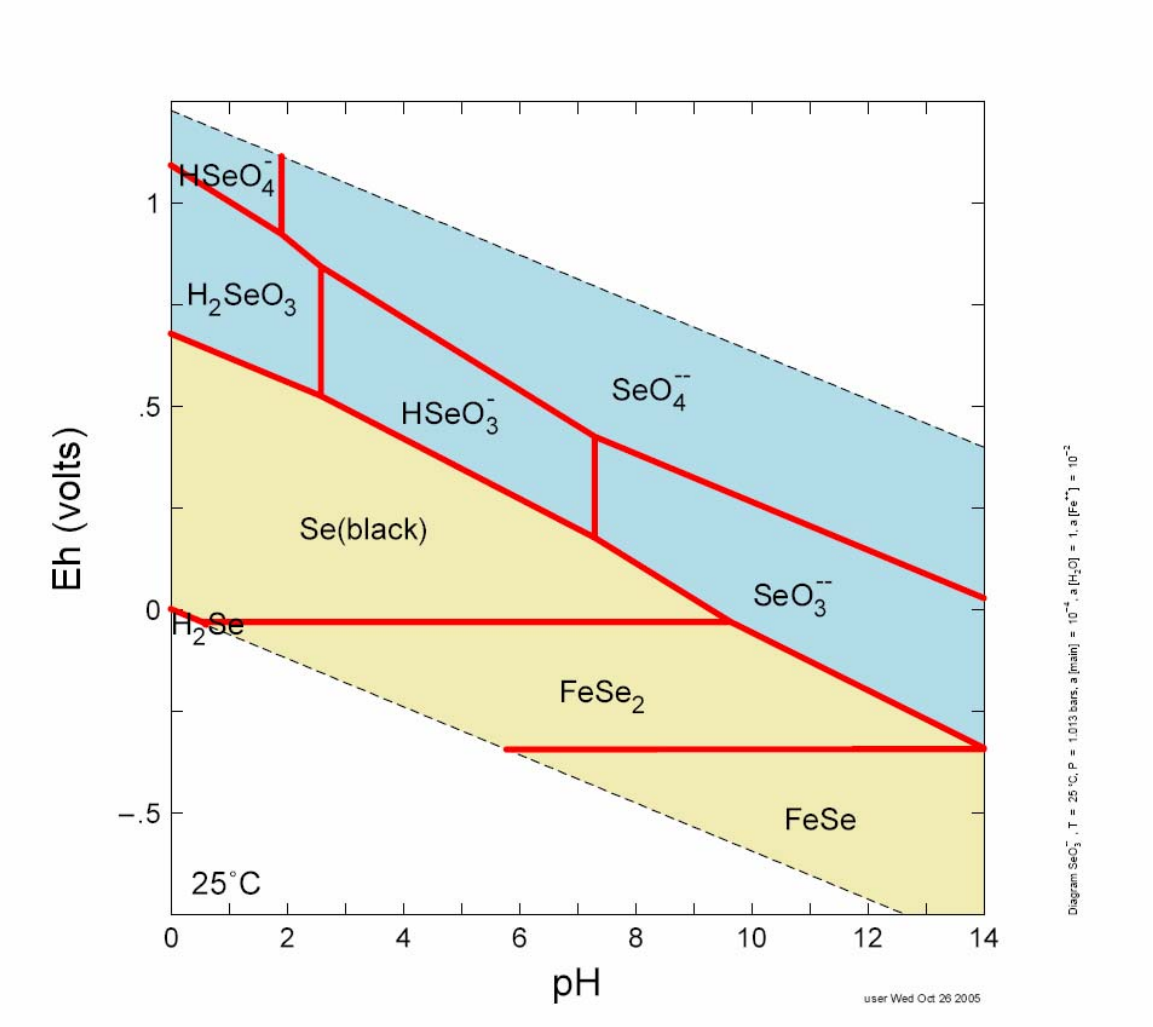
The figure above concisely describes the biologically mediated redox processes controlling Se behavior in the environment. Progress from the figure above toward a functioning semi-quantitative conceptual model requires identification of specific compartments in which the above processes occur, and also requires identification of processes governing physical mass transfer of Se between compartments.

Many of the simplifying assumptions below are derived from the expected speciation of selenium in water with salinities far below that of the Great Salt Lake. The expected speciation in the Great Salt Lake cannot be determined at this time via geochemical models due to the lack of information for activity coefficients under the hypersaline conditions of the Great Salt Lake.

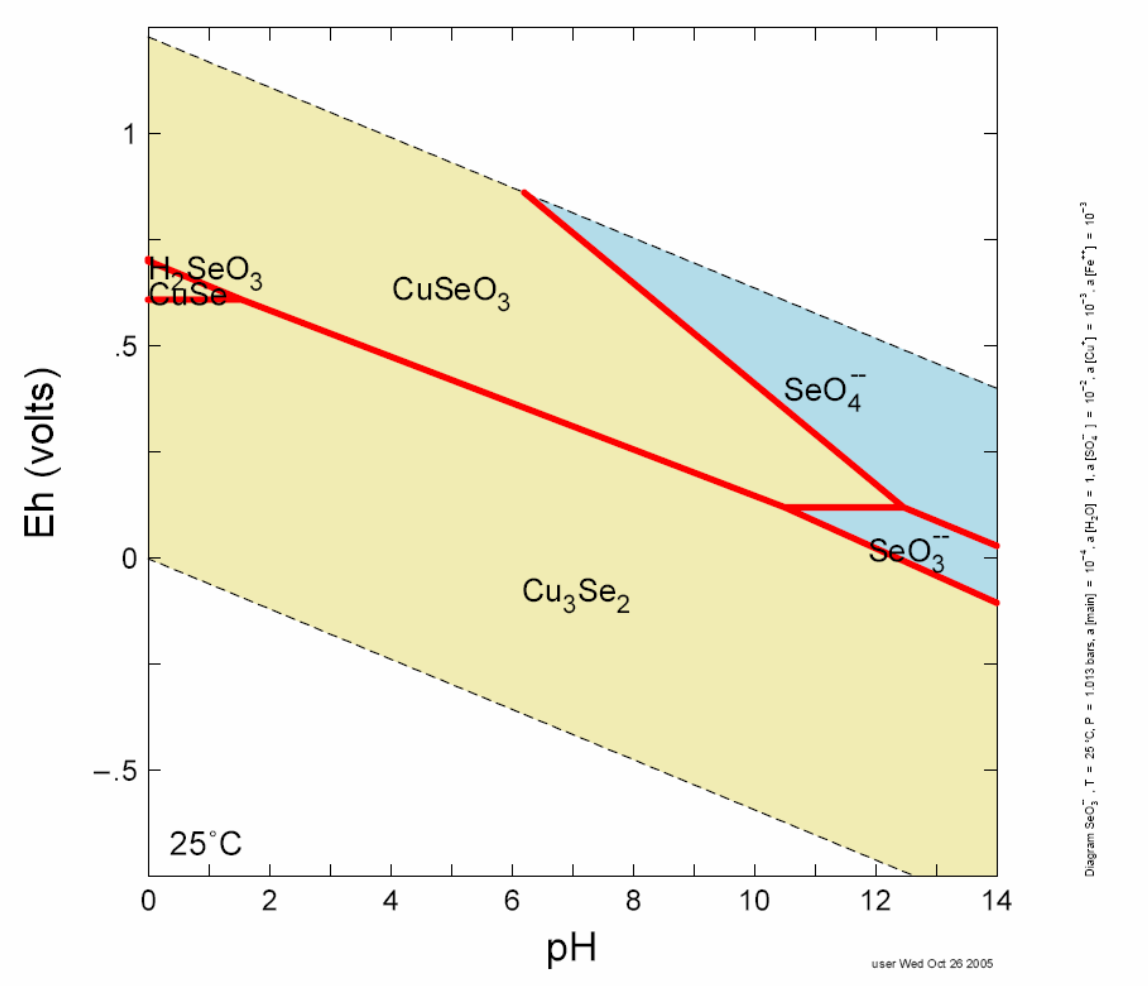
Equilibrium speciation diagrams using activity coefficients from less saline waters are used here as a tentative starting point. Equilibrium speciation of selenium is shown as a function of pH (negative log of proton activity) and p*e* (negative log of electron activity) in the figure below developed using Geochemist's Workbench. The x-axis on this diagram demonstrates increasing pH from left to right. The y-axis on this diagram illustrates increasingly oxidizing conditions from bottom to top. The boundaries on the system represent the stability boundaries for water, which reacts to form oxygen at the top boundary, and forms hydrogen gas at the bottom boundary. The biogeochemical environment of the Great Salt Lake is therefore constrained within these boundaries.



It should also be noted that forms of particulate selenium other than elemental selenium are expected due to the presence of trace metals in the concentrated water of the Great Salt Lake. For example, addition of iron alters the particulates that should be formed, whereas the stability of the relatively oxidized aqueous species is largely unaffected.



However, addition of dissolved sulfate and copper to the water yields additional particulate phases and important decreases in the stability fields of the aqueous species (as shown below).



Important limitations & need for direct measurement

It is important to note that these stability fields depend on the aqueous activities of selenium and the trace metals. The activities used in these diagrams do not reflect hypersaline conditions, due to a lack of activity coefficients for selenium and trace metals in these systems. Hence, direct measurements to determine actual selenium speciation is crucial to understanding the mechanisms governing the aqueous selenium concentrations in the Great Salt Lake.

Furthermore, the stability diagrams reflect equilibrium conditions, whereas formation of particulate phases may entail kinetic processes that allow aqueous species to exist in a metastable state.

Simplifying assumptions

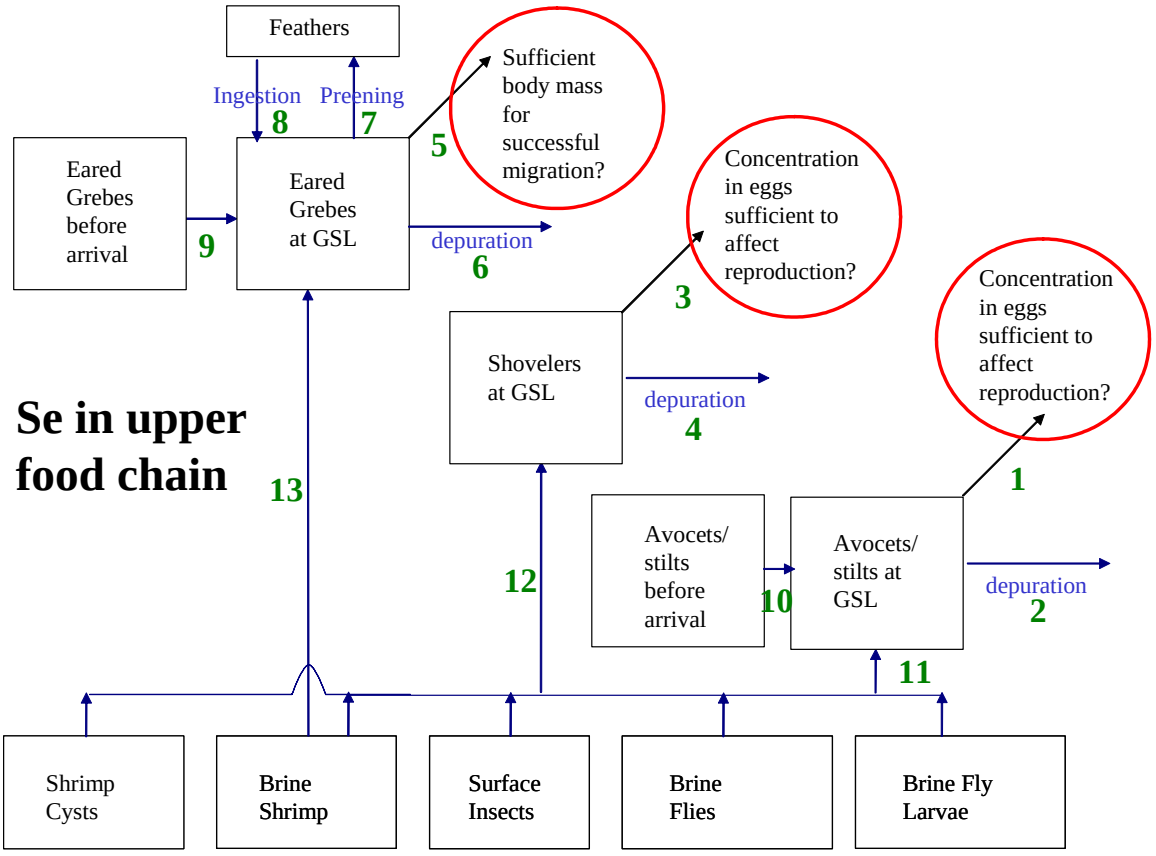
8) Selenium can be represented by five predominant lumped species:
    a. non-volatile organic selenium (organic Se in figures below)
    b. volatile organic and inorganic selenium (H_2Se in figures below)
    c. elemental selenium (Se^0)
    d. selenite (SeO_3^{2-})
    e. selenate (SeO_4^{2-})

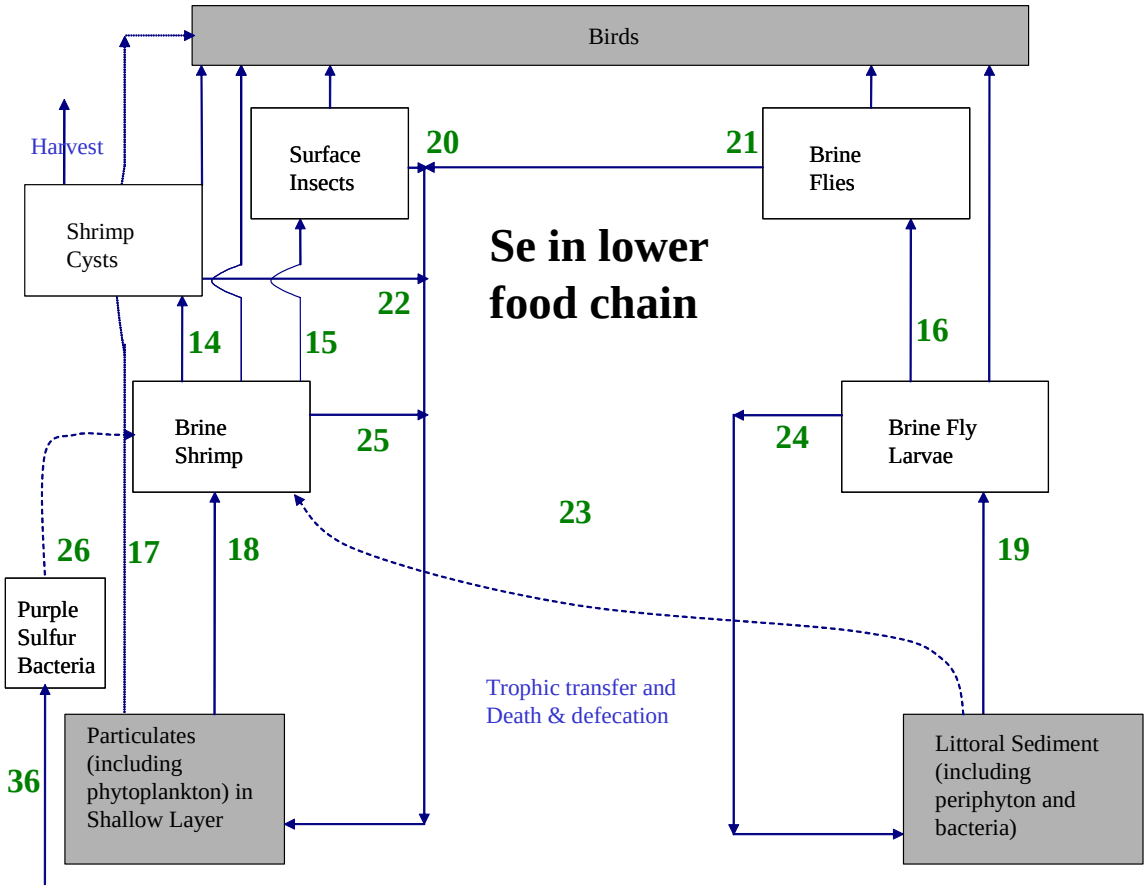
9) Physicochemical mass transfer processes (e.g. adsorption, desorption, precipitation, settling, volatilization, dissolution, and redox transformation) predominantly occur below the food chain, and these processes can be neglected within the food chain.
10) The cycling processes occurring in the oxidized layers (Shallow Layer, Littoral Sediment, and Exposed Sediment) are: 1) oxidation to selenate and selenite (from species with relatively-reduced Se); 2) reduction to selenite (from selenate); and 3) uptake of selenate, selenite, and organic selenium by phytoplankton, periphyton, and bacteria.
11) The cycling processes occurring in the reduced layers (Deep Brine Layer, Anoxic Sediment) are: 1) reduction to selenite, elemental selenium, volatile selenium (methyl and di-hydrogen selenides), and hydrogen selenide (from species with relatively oxidized Se); and 2) uptake of selenite, organic selenium, and hydrogen selenide by phytoplankton, periphyton, and bacteria.
12) Note that the hydrogen-selenide complex (HSe^-) is not volatile, and this complex is expected (rather than di-hydrogen selenide) for the pH range of the GSL (although no activity coefficients exist for Se in hypersaline water, so we know this only approximately).
13) Atmospherically deposited selenium is assumed to be in the form of selenate, selenite, and elemental selenium.
14) The "particulate" phases include organic and mineral matter. The organic matter includes organisms and feces, which may settle or be re-suspended.
15) Se input from the North Arm is introduced only to the Deep Brine Layer as reduced species since the dense North Arm water becomes the deep brine layer in Gilbert Bay.
16) MagCorp, Inc. was not considered a significant contributor of selenium to Gilbert Bay.

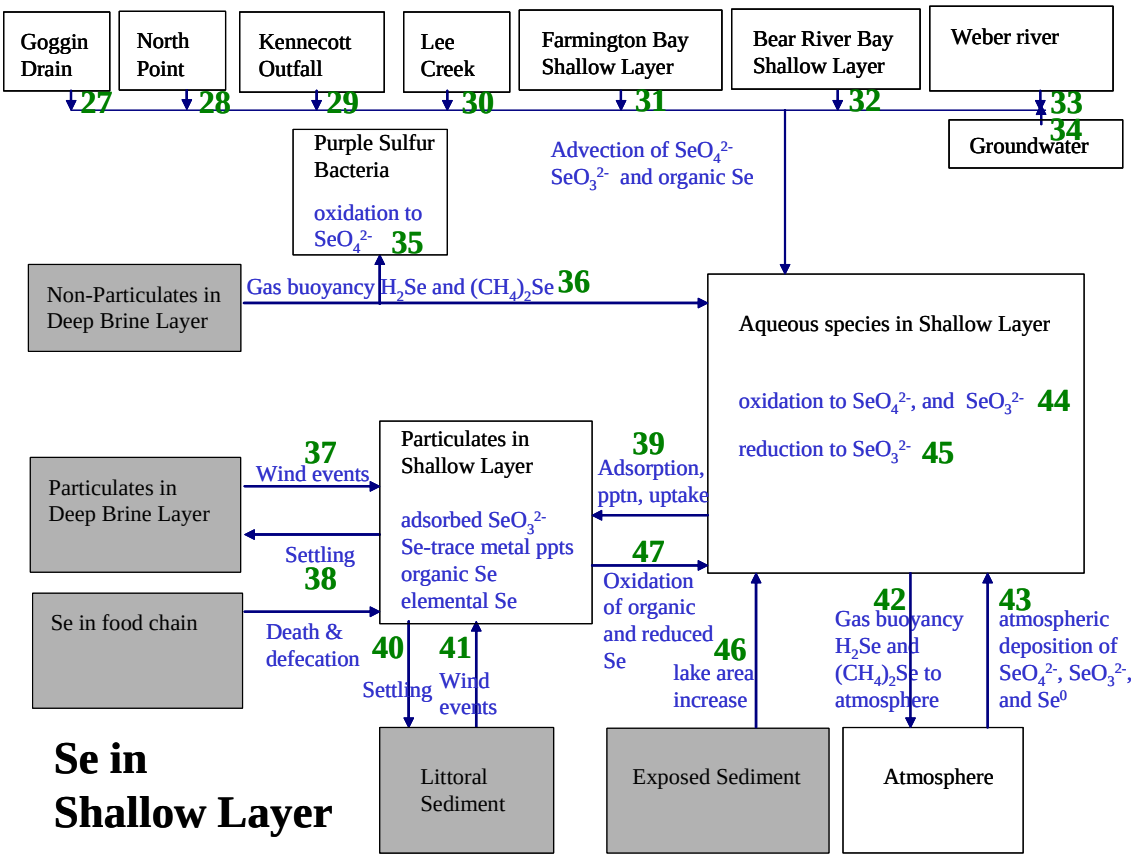
Note that influences on flows such as light, salinity, pH, dissolved oxygen, nutrients, etc. are NOT explicitly tracked in the model, but rather will be reflected in daily to seasonal variations in the flows depicted in the model.

The final layer concerns the stocks and flows of water in order to track seasonal evaporative concentration and dilution of selenium species.

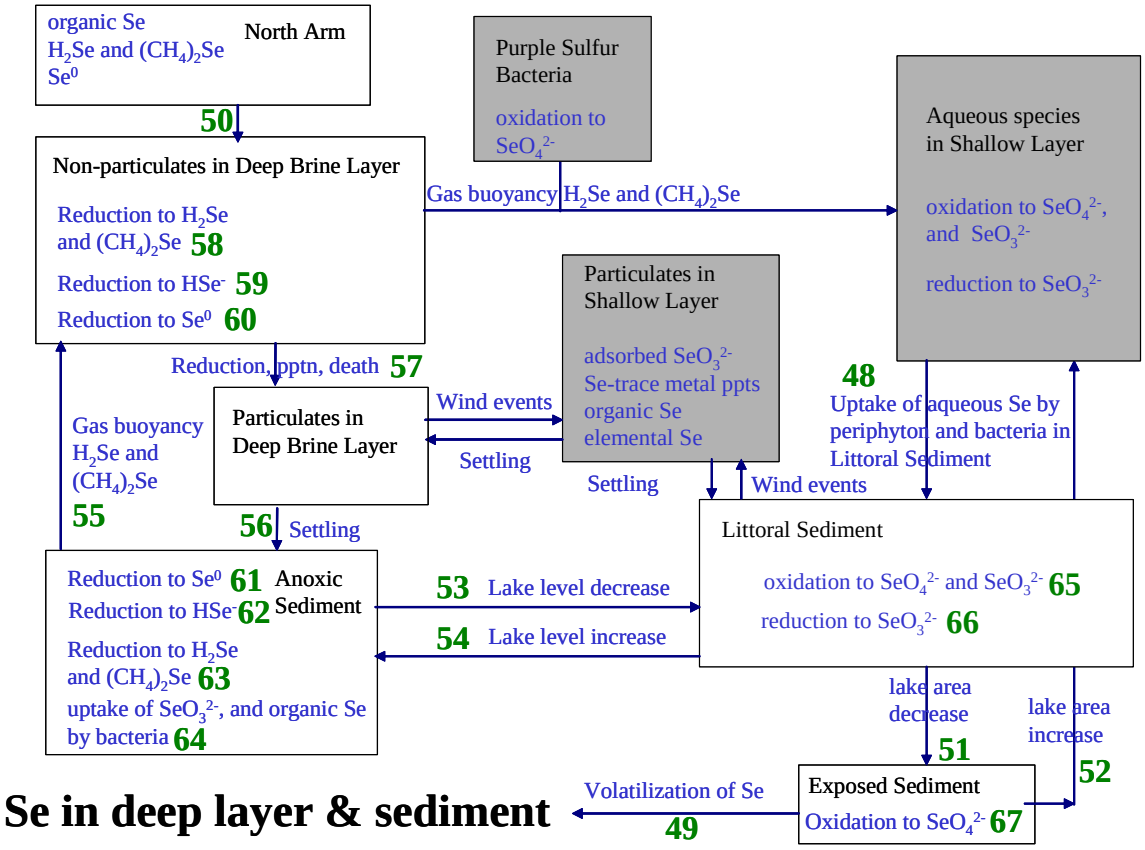
Visual depiction of conceptual model



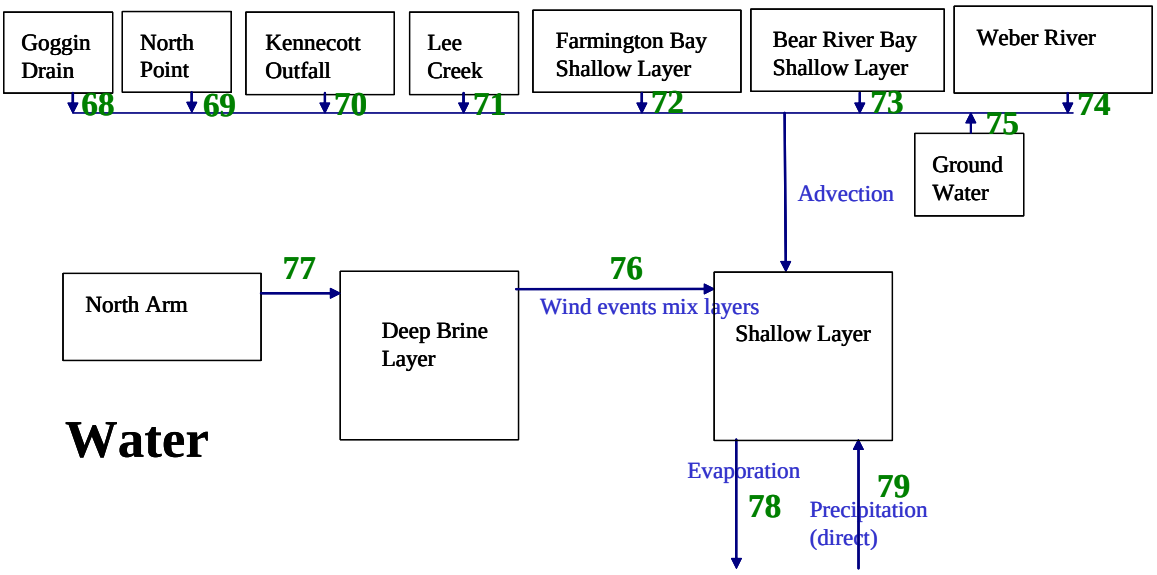

Birds
Harvest
Surface Insects
20
21
Brine Flies
Shrimp Cysts
Se in lower food chain
22
14
15
16
Brine Shrimp
25
24
Brine Fly Larvae
23
26
17
18
19
Purple Sulfur Bacteria
Trophic transfer and Death & defecation
36
Particulates (including phytoplankton) in Shallow Layer
Littoral Sediment (including periphyton and bacteria)



Se in Shallow Layer



Se in deep layer & sediment


Goggin Drain
North Point
Kennecott Outfall
Lee Creek
Farmington Bay Shallow Layer
Bear River Bay Shallow Layer
Weber River
68
69
70
71
72
73
74
75
Ground Water
Advection
North Arm
77
Deep Brine Layer
76
Wind events mix layers
Shallow Layer
Water
Evaporation
78
79
Precipitation (direct)

Conceptual model supporting references

The supporting references are provided in the context of the corresponding process in the conceptual model, each number below refers to a labeled process in the conceptual model:

1) **Se transfer from adult avocets/stilts to eggs**: Dr. Anne Fairbrother indicates that development of a literature review on toxicological effects is unnecessary since the EPA is now developing a comprehensive review based on work at the San Francisco Bay. This will be available in the near future. The appropriate egg selenium threshold for toxicity to offspring is hotly debated (Fairbrother et al., 2000; Skorupa, 1999; Fairbrother et al., 1999). Fairbrother et al. argue for a threshold of 16 ppm ww egg selenium as protective of chicks, whereas Skorupa argues for 6 ppm ww egg selenium as protective of embryo mortality effects.
2) **Selenium depuration from avocets/stilts**: This process would be subsumed into measured transfer of Se from avocet/stilt adults to their eggs (1 above). Depuration values are available from the literature for various birds. Selenium accumulation and depuration rates are rapid. Studies indicate that it would take about 2.5 months (71 days) for birds to return to background selenium levels once they leave a source, but they would be below effects levels of 10 ppm ww in about 8-10 days: (e.g. Heinz et al., 1990; Yamamoto et al., 1998; Heinz, 1996; Wilson et al., 1997).
3) **Se transfer from adult shovelers to eggs**: see (1).
4) **Selenium depuration from northern shovelers**: This process would be subsumed into measured transfer of Se from shoveler adults to their eggs (3 above). See also (2)
5) **Se influence on eared grebe mass loss**: The level of Se to impair adult health is higher than that required to impair reproduction. Heinz (1996) provides a summary of mallard work, and recommends a dietary value of 10 ppm, dw, to protect adult mallards from adverse effects. Ohlendorf (2003) reported that the dietary EC10 for reproductive impairment in mallards was 4.87 ppm, dw, with 95% confidence boundaries of 3.56 - 5.74 ppm, dw. Given that the value of 4.87 ppm is an EC10, not the expected LOAEL, and that one really should allow for inter-species variability in sensitivity. Dr. Skorupa advocates using the lower confidence boundary value of ca. 3.5 ppm. He suggests that this is consistent with Wilber's (1980) comprehensive review of selenium toxicology in Clinical Toxicology, 17:171-230, wherein he noted that the chronic toxic dose for "hens" ranged from 3.5 - 10 ppm. Presumably part of the variation in that range is due to different endpoints evaluated by different studies and also presumably the reproductive endpoints would have yielded the lower boundary of the range cited by Wilber (1980). Dr. Skorupa indicates that all parties agree now that the EC10 for mallard egg hatchability data is about 12 ppm (Adams et al., 2003; Ohlendorf, 2003). Furthermore, Ohlendorf (2003) reported that the 95% confidence boundary on that EC10 estimate was 6.4 - 16.5 ppm, dw. For the same reasons as outlined above, Dr. Skorupa advocates an EC10 of about 6 ppm. He suggests that the wisdom of this is further reinforced by a recent paper that reported about an EC15 control-adjusted effect in egg hatchability for spotted sandpipers at an average egg selenium concentration of 7.3 ppm, dw (Harding et al., 2005).
6) **Selenium depuration from eared grebes**: The relatively quick depuration of Se from eared grebes effectively resets Se concentrations within several weeks of migration, and

breeding occurs about 90 days following departure from the GSL. Hence, offspring would not reflect Se conditions at the GSL. See also (2)

7) **Se concentration in eared grebe preen oil**: Selenium accumulates to high levels in preen glands and does so fairly rapidly (e.g., from ca. 4 ppm ww to ca. 20 ppm ww in ca. 60 days in one study of small shore birds). The feathers concurrently also increase rapidly in Se content from preen gland (uropygial gland) secretions being applied to the feathers because the feathers were fully grown (i.e., hard penned) and therefore no longer had any vascular connection to pathways for metabolic (i.e., internal) deposition of Se (e.g. Goede and De Bruin, 1986; Goede and DeBruin, 1984).
8) **Se ingestion via ingestion of feathers by eared grebes**: A factor of 2-4 increased selenium burdens in eared grebes relative to other species at the Tulare Basin is observed despite equivalent diets for these birds (Dr. Joseph Skorupa, personal communication). This enhanced selenium concentration in eared grebes may reflect the effect of ingestion of feathers.
9) **Se concentration in eared grebe upon arrival at GSL**: unknown. Dr. Joe Jehl has stored carcasses that may be helpful.
10) **Se concentration in avocets/stilts upon arrival at GSL**: unknown
11) **Avocet/stilt diet (mass consumption source and rate) while at GSL**: avocets and stilts on the GSL primarily consume brine shrimp and brine flies. However, the relative importance of each in their diets is unknown. The amount of each that is consumed daily is also unknown (Dr. Michael Conover, personal communication).
12) **Northern shoveler diet (mass consumption source and rate) while at GSL**: unknown. Dr. Conover has recently started conducting research on this topic for Utah Division of Wildlife Resources.
13) **Eared grebe diet (mass consumption source and rate) while at GSL**: Eared grebes eat brine shrimp (99.7% of diet). Feathers, corixids and brine flies each make up about 0.1% of their total diet according to research by Dr. Mike Conover, and work by Dr. Don Paul.
14) **Selenium transfer from brine shrimp to shrimp cysts**: Cyst production rate is a function of adult shrimp density, temperature and phytoplankton food level (Wurtsbaugh 1995; Gliwicz et al. 1995; Wurtsbaugh & Gliwicz, 2001). Selenium deposition in cysts or eggs of Artemia is not know. Cysts have high lipid concentrations, and since selenium does not concentrate in lipids, selenium concentrations might be low in the cysts (Dr. W. Wurtsbaugh comments). Brad Marden knows of references to support. Brad Marden has archived cyst samples.
15) **Selenium transfer from brine shrimp to surface insects**: Corixid (surface insect) densities are low in Gilbert Bay, so this transfer is likely minimal (Dr. W. Wurtsbaugh comment). Brad Marden has not observed corixids in open water at salinities above 90 parts per thousand. High corixid densities are found in Farmington Bay and likely in Bear River Bay at moderate salinities (Dr. W. Wurtsbaugh comment). Corixid feeding on Artemia has been documented in Marcarelli et al. (2003). Laboratory predation experiments showed that corixids could eat 14-34 brine shrimp per day at temperatures of 20 °C, depending on the age and size of the shrimp. With the density of corixids found in Farmington Bay there was a potential to eat 20% of the adult and 60% of the juvenile brine shrimp (Dr. W. Wurtsbaugh, personal communication).
16) **Selenium transfer from brine fly larvae to brine flies**: Some selenium would remain in the cast of the metamorphosing and emerging brine flies, and thus would not transfer

directly up the food chain to birds. Quantitative importance unknown (Dr. W. Wurtsbaugh comment). Dr. Harry Ohlendorf predicts a loss of ~30% based on damselfly samples.

17) **Se transfer from phytoplankton in shallow layer to birds**: According to Dr. Mike Conover, no GSL birds eat single-cell phytoplankton that dominate throughout the Great Salt Lake; they are just too small. Some algae species form dense colonies (floating mats, etc.), that are sufficiently large (several grams wet weight) for some ducks that are primarily herbivores (e.g., wigeon) and geese to pick up and eat. These algae species probably do not occur in the pelagic areas of the GSL. The algae can be significant at times in Farmington Bay. However, in most herbaceous birds, algae make up only a small part of their diet due to lack of nutritional value.
18) **Se transfer from Shallow Layer particulates (including phytoplankton) in shallow layer to brine shrimp**: Brine shrimp grazing is a function of shrimp size, temperature and phytoplankton density. Clearance rates (R, mL/individual shrimp/day) of the water column at 20 °C: $R = 5.45\ L^{1.82}$, where L equals the shrimp length in mm (Reeve 1963). At an adult density of 4/L, 100% of the water column can be cleared of algae each day (Dr. W. Wurtsbaugh comment). Uptake efficiency of selenium by brine shrimp is unknown, but efficiencies of 41-53% have been noted for other zooplankton feeding on phytoplankton (Schlekat et al. 2004). Selenium not taken up would be voided in feces and sedimented. Schlekat et al. (2004) found depuration rates of selenium by zooplankton of 12-25% per day. Fisher et al. (2000) provide a model of Se uptake by marine phytoplankton and incorporation into zooplankton. Brad Marden also knows of references to support. Brad Marden suggests that a weekly frequency of sampling is needed. Booms and crashes occur on weekly basis, based on secchi disk and algal cell count measurements. Given the large fetch and resuspension of sediments by wind action, there could be sizeable numbers of inorganic particles in the water column. The shrimp are not good at discriminating, so they would graze on these and it is possible that adsorbed Se could be stripped off.
19) **Se transfer from periphyton, detritus, and bacteria in littoral sediment to brine fly larvae**: Not known. Selenium transfer rates to benthic invertebrates in other systems have been analyzed several times (Horne, 1991; Alaimo et al., 1994; Besser et al., 1996; Lemly, 1997; Wang et al,. 1999; May et al., 2001; Schlekat et al., 2002; Peterson et al., 2002) and benthic organisms can take up Se from algae, detritus and the sediments themselves. Herbst (in Review) found that brine flies in saline ponds did not contain Se, whereas brine shrimp and corixids did, whereas brine flies did contain Se at Kesterson (Dr. Harry Ohlendorf, personal communication). Besser et al. (1996) found that planktonic food webs bioconcentrated selenium more than benthic ones, but a model by Baines et al. (2002) indicated that Se would move up the food web more effectively via benthic organisms. Sulfate competitively inhibits uptake of selenium by organisms (Forsythe et al., 1994; Bailey et al., 1995; Wu and Guo, 2002; Brix et al., 2004), and thus in high-sulfate systems like the Great Salt Lake, Se uptake may be less than in fresher systems.
20) **Flux of Se in dead surface insects to Particulates in Shallow Layer**: The residence time in th water column during settling is extremely short, such that this flux can be ignored (Dr. W. Wurtsbaugh comment).

21) **Flux of Se in dead brine flies to Particulates in Shallow Layer**: It is likely that the settling rate of brine flies would be sufficiently high to drive them directly to the sediments (Dr. W. Wurtsbaugh comment).
22) **Flux of Se in shrimp cysts to Particulates in Shallow Layer**: Unknown.
23) **Possible transfer from periphyton and bacteria in littoral sediment to brine shrimp**: Microbes capable of selenium reduction and accumulation either externally or internally could possibly transfer fairly large amounts of selenium, in the elemental form, to any organism that actively or passively consumes these microbes. Decaying plant matter provides sufficient glucose and glucose metabolic by-products to elicit selenium reduction in localized areas within the littoral sediment environment by diverse populations of microbes. Various microbes, including some algae, are capable of selenium reduction and accumulation or just selenium accumulation in diverse environments, including aerobic, micro-aerophilic, or anaerobic environments. The following references provide parameters important in selenium transfer and indicate the importance of potential selenium transfer to the brine shrimp (Saiki and Lowe, 1987; Sanders and Gilmore, 1994; Besser et al., 1989; Sherr et al., 1988; Wheeler et al., 1982; Riedel et al., 1991; Rassoulzadegan and Sheldon, 1986; Fenchel and Finlay, 1990).
24) **Flux of Se in dead brine fly larvae to Littoral Sediment**: unknown
25) **Flux of Se in dead brine shrimp to Particulates in Shallow Layer:** It is likely that the settling rate of brine shrimp would be sufficiently high to drive them directly to the sediments (Dr. W. Wurtsbaugh comment).
26) **Flux of Se from purple sulfur bacteria to brine shrimp**: Due to mixing that almost certainly occurs at regular intervals at the upper layer of the chemocline, brine shrimp would not necessarily have to venture into the anoxic environment to feed on substantial amounts of the purple sulfur bacteria. Purple sulfur bacteria move reduced sulfur and possibly some selenium from a reduced state to an oxidized state using CO_2 in an anaerobic environment. Purple sulfur bacteria (*Ectothiorhodospiraceae*) and green sulfur bacteria (*Chlorobiaceae*), mainly use sulfide and other inorganic sulfur compounds. In turn, *Desulfovibrio* reduces SO_4^{-2} to H_2S, and provides H_2S for the green and purple sulfur bacteria. Since H_2S is volatile and has quite a high solubility coefficient, the H_2S produced by the anaerobic *Desulfovibrio* in the column can move up through the column where it can serve as an energy source for the sulfur oxidizing bacteria. Since sulfide and light occur in opposing gradients, the phototrophic green and purple sulfur bacteria often grow only in a rather narrow zone of overlap, but can reach very high densities within this zone. The following references indicate the potential for selenium transport to the brine shrimp (Saiki and Lowe, 1987; Sanders and Gilmore, 1994; Besser et al., 1989; Sherr et al., 1988; Wheeler et al., 1982; Riedel et al., 1991; Rassoulzadegan and Sheldon, 1986; Fenchel and Finlay, 1990). It is not known if brine shrimp in the Great Salt Lake descend into the chemocline to feed on the purple sulfur bacteria. When food in the shallow layer is very low in summer, shrimp could go into the upper layer of the chemocline for short intervals (nearly anoxic) and feed on the bacteria (Dr. W. Wurtsbaugh comment).
27) **Transfer of selenate, selenite, and organic selenium from Goggin Drain**: Measurements of total selenium concentrations available from Kennecott.
28) **Transfer of selenate, selenite, and organic selenium from North Point Canal**: Measurements of total selenium concentrations available from Kennecott.

29) **Transfer of selenate, selenite, and organic selenium from Kennecott outfall**: Measurements of total selenium concentrations available from Kennecott.
30) **Transfer of selenate, selenite, and organic selenium from Lee Creek**: Measurements of total selenium concentrations available from Kennecott.
31) **Transfer of selenate, selenite, and organic selenium from Farmington Bay**: Samples downstream of wetlands have been accumulating at USGS; analyses needed.
32) **Transfer of selenate, selenite, and organic selenium from Bear River Bay**: Se could be moderately high in waters from Bear River watershed (Hamilton and Buhl, 2005). Samples downstream of wetlands have been accumulating at USGS; analyses needed.
33) **Transfer of selenate, selenite, and organic selenium from Weber River**: Samples downstream of wetlands have been accumulating at USGS, analyses needed.
34) **Transfer of selenate, selenite, and organic selenium from ground water**: Estimate required.
35) **Se transfer from Deep Brine Layer to purple sulfur bacteria**: **Purple sulfur bacteria** (*Ectothiorhodospiraceae*) and **green sulfur bacteria** (*Chlorobiaceae*), mainly use sulfide and other inorganic sulfur or selenium compounds. In an anaerobic environment, using CO_2 as a carbon source, the green and purple sulfur bacteria oxidize H_2S to SO_4^{-2} or HSe^- to selenite and/or selenate during photosynthesis. *Desulfovibrio* sp. in this environment can reduce SO_4^{-2} or oxidized selenium compounds to H_2S and HSe^-. No literature was found that quantifies this type of transfer.
36) **Vapor transfer of Se from Deep Brine Layer to Shallow Layer**: Oyamada et al. (1991) and Neumann et al. (2003) provide references on production of gas phase selenium by bacteria. The generation of volatile selenium has been observed in a range of soils and sediments (Zhang and Frankenberger, 2002; Chau et al., 1976; Azaizeh et al., 1997; Frankenberger and Karlson, 1988; Frankenberger and Karlson, 1994; Pilon-Smits et al., 1999; Oremland et al., 1986, 1989, 1990, 1994; Steinberg et al., 1990; Zawislanski et al., 2001; Zawislanski, 1996). No references were found quantifying volatile selenium flux at the interface between anoxic brine and suboxic hypersaline waters.
37) **Re-suspension transfer of particulate Se species from Deep Brine Layer to Shallow Layer**: DYRSEM model of Imberger (URL) group can be implemented to predict these transports.
38) **Settling transfer of particulate Se species from Shallow Layer to Deep Brine Layer**: Here particulates are defined as any phase that settles. Settling rates of live and dead phytoplankton are highly variable, ranging from meters/day to mm/day (Reynolds 1984). Larger taxa, particularly diatoms, sink quickly whereas small bacterial-sized ones will not sink at all. The dominant phytoplankton in Gilbert Bay (*Dunelliela*) is flagellated and will not sink while alive. Most transport of organic particulate matter will be via fecal material of brine shrimp. Settling rates of these feces is unknown (Dr. W. Wurtsbaugh comments). According to sediment flux measurements conducted in sediments and wetland environments, particulate selenium in wetland and sediment systems range from <2.5% to 25% of the total selenium flux. Notably selenium deposits were generally highest in sediments and marsh layers in the upper 15 cm. The differentiation of various particulate forms of selenium: selenium bound to organic macromolecules, selenium bound to organic particulates, elemental particulate selenium, selenium adsorbed to mineral particles, etc. requires implementation of advanced size fractionation techniques such as field flow fractionation (Zhang et al., 2004; Johnson et al., 2000).

39) **Adsorption, precipitation, and uptake by phytoplankton of aqueous Se species to yield particulate Se species in the Shallow Layer**: Dr. Anne Fairbrother suggests Williams et al. (1994) for uptake of selenate by algae. Fisher and Wente (1993) describe mineralization rates of Se in marine phytoplankton. Baines et al. (2004) point out that Se uptake by phytoplankton is highly light dependent. See Doyle et al. (1995) for additional insights. Neumann et al. (2003) describe rapid metabolism of selenate to volatile dimethylselenide, but this process was inhibited by sulfate. Selenium is concentrated in the particle phase relative to the aqueous phase by factors ranging from ten to thousands. Theresa Presser suggests that these concentration factors are too variable to borrow from literature, and need to be measured. Dr. Wayne Wurtsbaugh notes: Fisher et al. (2000) provide a model of Se uptake by marine phytoplankton and subsequent incorporation into zooplankton. Baines et al. (2004) point out the light dependence of metals (including Se) by phytoplankton. Nishri et al. (1999) describe Se uptake by phytoplankton and its incorporation into dissolved organic matter. See also 54 (reduction of selenium in shallow layer) and 47 (adsorption, precipitation, and uptake by phytoplankton of aqueous Se species to yield particulate Se species in the Shallow Layer).
40) **Settling of Particulate Se in Shallow Layer to Littoral Sediment**: This process includes detrital material from sinking seston, and from periphyton that have died, as well as minerals. Settling rates of live and dead phytoplankton are highly variable, ranging from meters/day to mm/day (Reynolds 1984). Larger taxa, particularly diatoms, sink quickly whereas small bacterial-sized ones will not sink at all. The dominant phytoplankton in Gilbert Bay (*Dunelliela*) is flagellated and will not sink while alive. Most transport of organic particulate matter will be via fecal material of brine shrimp. Settling rates of these feces are unknown (Dr. W. Wurtsbaugh comments). See also 54 (reduction of selenium in shallow layer) and 47 (adsorption, precipitation, and uptake by phytoplankton of aqueous Se species to yield particulate Se species in the Shallow Layer).
41) **Re-suspension transfer of Particulate Se from Littoral Sediment to Shallow Layer**: Resuspension of particulate material and nutrients/Se in the interstitial water is thought to be important in the Salton Sea (G. Schladow-UC Davis, personal communication to W. Wurtsbaugh). The larger fetch of the GSL is likely to make re-suspension even more important.
42) **Vapor transfer of Se from Shallow Layer to atmosphere**: Volatilization of selenium from seawater and other high salinity aquatic settings is a well-observed phenomenon indicating significant potential for this process to be important in the selenium budget for the Great Salt Lake. Volatilization increases with the addition of organics, and increases with pH above 7. In many articles, selenite produced higher volatilization of selenium than did selenate, which emphasizes the importance of selenium species on selenium pathways and fluxes. Direct measurement of dissolved gas pressures would allow determination of the potential significance of selenium fluxes by this mechanism (Chau et al., 1976; Amouroux and Donard, 1996; Azaizeh et al., 1997; Atkinson et al., 1990; Barkes and Fleming, 1974; de Souza et al., 1998; Fleming and Alexander, 1972; Frankenberger and Karlson, 1988; Frankenberger and Karlson, 1994; Oremland and Zehr, 1986; Pilon-Smits et al., 1999; Zhang and Frankenberger, 2002; Zieve and Peterson, 1985)

43) **Atmospheric transfer of selenium to Shallow Layer**: No references were found on this topic. We do not expect a substantial amount of selenium to be transferred from the atmosphere to the GSL environments modeled.

44) **Oxidation of various reduced Se species to selenate and selenite in the Shallow Layer**: Some inorganic forms of selenium have been reported to be oxidized by microorganisms. *Micrococcus selenicus* isolated from mud (Breed et al. 1957), a rod-shaped bacteria isolated from soil (Lipman and Waksman, 1923), and a purple bacterium (Sapozhnikov, 1937) have been reported to oxidize Se^0 to SeO_4^{2-}. Strains of *Bacillus megaterium* from top soil in river alluvium can oxidize elemental selenium to selenite and selenate; the red amorphous elemental selenium is more readily transformed than the grey elemental selenium. Additionally, *Acidithiobacillus ferrooxidans* (formerly *Thiobacillus ferrooxidans*) is able to oxidize copper selenide as a sole energy source and can also oxidize other selenium species to elemental selenium (Torma and Habashi, 1972). Reduced selenium species that are transported to the shallow layer will be oxidized according to oxidation-reduction equilibria. The significance of this process is uncertain. Since oxidized selenium species are soluble, this process potentially re-mobilizes selenium. The transport of reduced selenium species to the shallow layer may occur via re-suspension of sediment, lake area fluctuation, etc. Determination of the significance of this process requires measurement of selenium fluxes in response to sediment re-suspension and lake area fluctuation.

45) **Reduction of selenate to selenite in shallow layer**: Selenium reduction can occur in all GSL environments including aerobic environments and reduction of selenate to selenite is a natural transformation by many bacteria that are able to reduce selenate to elemental selenium (Doran and Alexander, 1977; Oremland et al., 1989; Lortie et al., 1992; Steinberg et al., 1990; Zarate**,** 2001; Zawislanski and Zavarin, 1996). Quite a number of inorganic selenium compounds can be reduced by microorganisms. *Micrococcus* sp. have been demonstrated to reduce Se^0 to HSe^- and *Desulfovibrio* sp. can reduce selenite to Se^0 (Woolfolk and Whitney, 1962). A great variety of bacteria, actinomycetes, and fungi have been shown to reduce selenate and selenite to elemental selenium (Bautista and Alexander, 1972; Sarret et al. 2005; and Zalokar, 1953). Despite being in the same chemical family, selenite can be reduced directly to elemental selenium while sulfite cannot be reduced to S^0, but is reduced to H_2S implying different enzymatic reduction mechanisms. *Desulfovibrio desulfuricans* has been shown to reduce selenate to selenide (Zehr and Oremland, 1987). With some microorganisms, sulfate can inhibit the reduction of selenate, suggesting that this mechanism in at least some microorganisms may be similar. In *Escherichia coli* and other microbes like some *Bacillus* sp. and *Pseudomonas* sp., reduction of selenate and selenite to elemental selenium via glucose metabolism results in elemental selenium being deposited on the cell surface rather than building up in the cytoplasm (Gerrard et al., 1974). Other microbial reductions of selenate and selenite can result in incorporation of selenide into organic compounds such as selenomethonine (Ahuluwalia et al., 1968) or accumulation of elemental selenium internally. Other soil microbes reduce selenate or selenite to dimethylselenide (Fleming and Alexander, 1972; Doran and Alexander, 1977). Reduction of selenate and selenite by a wide variety of microbes represents a detoxifying mechanism in some and a form of respiration in others and is nutritionally required by a number of bacteria, plants, and animals.

46) **Transfer of oxidized Se from Exposed Sediment to Shallow Layer via lake area increase**: Naftz et al. (2005) provide flux rates of Se into water during re-flooding of wetlands.
47) **Oxidation of organic and reduced particulates to oxidized non-particulate species in the Shallow Layer**: Some inorganic forms of selenium have been reported to be oxidized by microorganisms. *Micrococcus selenicus* isolated for mud (Breed et al. 1957), a rod-shaped bacteria isolated from soil (Lipman and Waksman, 1923), and a purple bacterium (Sapozhnikov, 1937) have been reported to oxidize Se^0 to SeO_4^{2-}. Strains of *Bacillus megaterium* from top soil in river alluvium can oxidize elemental selenium to selenite and selenate; the red amorphous elemental selenium is more readily transformed than the grey elemental selenium. Additionally, *Acidithiobacillus ferrooxidans* (formerly *Thiobacillus ferroxidans*) is able to oxidize copper selenide as a sole energy source and can also oxidize other selenium species to elemental selenium (Torma and Habashi, 1972).
48) **Uptake of aqueous Se by periphyton and bacteria in Littoral Sediment**: Bacteria that reduce selenium and accumulate selenium on their exterior membranes produce submicron sized particles of selenium bound to their surface that could be released into the aqueous environment – it may be possible for these same microbes to bind particulate selenium from the littoral environment. In any event, microbes with bound selenium – internal and external – could be responsible for movement of selenium in this environment and to the next higher level in the food chain. The references provided indicate that a number of variables are important in the transfer of selenium from sediments to bacteria and that this transfer must be balanced with the production of dimethylselenide and concentration of selenium in the water column (Zarate**,** 2001; Doran and Alexander, 1977; Barkes and Fleming, 1974).
49) **Volatilization of Se from Exposed Sediment**: see Frankenberger & Karlson (1995)
50) **Transfer of Se from North Arm to Deep Brine Layer**:
51) **Transfer of selenate, selenite, and organic Se from littoral sediment to Exposed Sediment via lake level decrease**: Estimation required.
52) **Transfer of selenate from Exposed Sediment to Shallow Layer via lake level increase**: Estimation required.
53) **Transfer of reduced Se from Anoxic Sediment to Littoral Sediment via lake level decrease**: Estimation required.
54) **Transfer of selenate, selenite, and organic Se from Littoral Sediment to Anoxic Sediment via lake level increase**: Estimation required.
55) **Vapor transfer of reduced selenium from Anoxic Sediment to Deep Brine Layer**: Blum et al. (1998) describe new halobacteria that reduce selenate to selenite and elemental Se.
56) **Settling transfer of particulate Se species from Deep Brine Layer to Anoxic Sediment**: Particulate matter in deep brine layer is very high, either because the high salt content "pickles" the material, thus slowing decomposition, and/or because the high density water is heaver than the settling particles, thus maintaining material in suspension (Dr. W. Wurtsbaugh comment).
57) **Transfer of Se from non-particulates in Deep Brine Layer to Particulates in Deep Brine Layer via reduction, precipitation**: Hockin and Gadd (2003) describe linked

redox precipitation of sulfur and selenium under anaerobic conditions by sulfate-reducing bacteria.

58) **Reduction to vapor Se in Deep Brine Layer**: Quite a number of inorganic selenium compounds can be reduced by microorganisms. *Micrococcus* sp. have been demonstrated to reduce Se^0 to HSe^- and *Desulfovibrio* sp. can reduce selenite to Se^0 (Woolfolk and Whitney, 1962). A great variety of bacteria, actinomycetes, and fungi have been shown to reduce selenate and selenite to elemental selenium (Bautista and Alexander, 1972; Sarret et al., 2005; and Zalokar, 1953). Despite being in the same chemical family, selenite can be reduced directly to elemental selenium while sulfite cannot be reduced to S^0, but is reduced to H_2S implying different enzymatic reduction mechanisms. *Desulfovibrio desulfuricans* has been shown to reduce selenate to selenide (Zehr and Oremland, 1987). With some microorganisms, sulfate can inhibit the reduction of selenate, suggesting that this mechanism in at least some microorganisms may be similar. In *Escherichia coli* and other microbes like some *Bacillus* sp. and *Pseudomonas* sp., reduction of selenate and selenite to elemental selenium via glucose metabolism results in elemental selenium being deposited on the cell surface rather than building up in the cytoplasm (Gerrard et al., 1974). Other microbial reductions of selenate and selenite can result in incorporation of selenide into organic compounds such as selenomethonine (Ahuluwalia et al., 1968) or accumulation of elemental selenium internally. Other soil microbes reduce selenate or selenite to dimethylselenide (Fleming and Alexander, 1972; Doran and Alexander, 1977). Reduction of selenate and selenite by a wide variety of microbes represents a detoxifying mechanism in some and a form of respiration in others and is nutritionally required by a number of bacteria, plants, and animals.

59) **Reduction to HSe- in Deep Brine Layer**: Blum et al. (2001) describe a novel bacterium growing in anoxic water that respires selenate to selenite and elemental Se. It is quite possible that the deep brine layer of the GSL would contain these organisms. See also (58).

60) **Reduction to elemental Se in Deep Brine Layer**: See (58).

61) **Reduction to elemental Se in Anoxic Sediment**: Most selenium reduction may occur before selenium reaches the anaerobic sediments. The anaerobic sediments may primarily act as a sink for accumulation of reduced forms of selenium (Doran and Alexander, 1977; Leatherbarrow et al., 2005; Oremland et al., 1990; Oremland, 1994; Oremland et al., 1989; Zawislanski and Zavarin; 1996; Steinberg and Oremland, 1990). See also (67).

62) **Reduction to HSe^- in Anoxic Sediment**: According to the references reviewed, this should be an important pathway for selenium transformation in the GSL. No transformation rates in the literature were available that could be directly related to the GSL environment. Environmental variables such as high amounts of excess sulfate and nitrate, for example, will in part determine selenium reduction pathways and the form and fate of the precipitated product(s). However, selenate reduction should be achievable under a broad range of environmental conditions (Zehr and Oremland, 1987; Zawislanski and Zavarin, 1996; Zawislanski et al., 2001). See also (59).

63) **Reduction to vapor Se in Anoxic Sediment**: See (58).

64) **Uptake of selenite, organic Se, and other reduced Se by bacteria in Anoxic Sediment**: According to the references reviewed, uptake of organic selenium and other

reduced selenium forms is expected to be significant in the GSL anoxic sediments. Uptake of selenite may occur at higher rates in other GSL environments. As in most references that indicate rates of selenium transformations, no rates were available that were directly applicable to the GSL environment (Zehr, and Oremland, 1987; Sanders and Gilmore, 1994; Doran and Alexander, 1977). See also (58, 61).

65) **Oxidation to selenate and selenite in Littoral Sediment**: Some inorganic forms of selenium have been reported to be oxidized by microorganisms. *Micrococcus selenicus* isolated for mud (Breed et al. 1957), a rod-shaped bacteria isolated from soil (Lipman and Waksman, 1923), and a purple bacterium (Sapozhnikov, 1937) have been reported to oxidize Se^0 to SeO_4^{2-}. Strains of *Bacillus megaterium* from top soil in river alluvium can oxidize elemental selenium to selenite and selenate; the red amorphous elemental selenium is more readily transformed than the grey elemental selenium. Additionally, *Acidithiobacillus ferrooxidans* (formerly *Thiobacillus ferroxidans*) is able to oxidize copper selenide as a sole energy source and can also oxidize other selenium species to elemental selenium (Torma and Habashi, 1972). Reduced selenium species that are transported to the Littoral Sediment will be oxidized. Since oxidized selenium species are soluble, this process potentially re-mobilizes selenium. The transport of reduced selenium species to the shallow layer may occur via re-suspension of sediment, lake area fluctuation, etc. Determination of the significance of this process requires measurement of selenium fluxes in response to sediment re-suspension and lake area fluctuation.
66) **Reduction to selenite in Littoral Sediment**: See (45 and 48).
67) **Oxidation to selenite in Exposed Sediment**: See (47) and (65).
68) **Transfer of water from Goggin drain**: Data available from Kennecott.
69) **Transfer of water from North Point canal**: Data available from Kennecott.
70) **Transfer of water from Kennecott outfall**: Data available from Kennecott.
71) **Transfer of water from Lee Creek**: Data available from Kennecott.
72) **Transfer of water from Farmington Bay**: Data available from USGS.
73) **Transfer of water from Bear River Bay**: Data available from USGS.
74) **Transfer of water from Weber River**: Data available from USGS.
75) **Transfer of water from ground water**: Estimates required.
76) **Transfer of water from Deep Brine Layer**: Estimates required.
77) **Transfer of water from North Arm to Deep Brine Layer**: Estimates required.
78) **Evaporation**: Data available from variety of federal, state, and academic sources.
79) **Precipitation**: Data available from variety of federal, state, and academic sources.

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Threshold Values for Selenium in Great Salt Lake: Selections by the Science Panel

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DATE: February 28, 2007

PROJECT NUMBER: 341055.PP.QC

The purpose of this technical memorandum is to provide a summary and documentation of the Science Panel's discussions relative to toxicity thresholds for exposure of birds to selenium at the Great Salt Lake. It is generally recognized that the most significant exposure of birds occurs through their diet, and that the best-documented and most readily-monitored effects are those on reproductive success (particularly egg hatchability). Thus, much of the focus of this technical memorandum is on those exposures and endpoints, because they can be most readily applied toward establishment of a site-specific water quality standard for selenium in the open waters of the Great Salt Lake.

Before the Science Panel meeting on November 29-30, 2006, I prepared a technical memorandum (Subject: Threshold Values for Selenium in Great Salt Lake; dated November 28) to provide the following:

- a summary of potential threshold values identified by Science Panel members for consideration in establishing a water quality standard for selenium in the open waters of the Great Salt Lake, and
- supporting documentation and literature provided by Panel members to be used as the basis of discussion by the Panel.

Bill Adams, Anne Fairbrother, Theresa Presser, and Joe Skorupa provided input concerning threshold values to be considered and sent supporting literature (either as citations or copies of publications), in addition to providing their views on the threshold values themselves. The entire Panel discussed that material and related information from other sources on November 30. From the available information, the Panel narrowed the ranges of values for bird diets and eggs to those listed in Tables 1 and 2 (Attachment A [tables modified from the compilation of field and laboratory data presented in Table 15 of Presser and Luoma, 2006]) and then identified "working values" for the ranges of acceptable selenium concentrations in bird diets and in bird eggs (those shaded in the tables). It is understood that the values will likely be refined during future phases of work (including consideration of site-specific

data currently being generated by the Great Salt Lake research effort) and discussion related to establishing a site-specific standard for Great Salt Lake.

A previous draft of this technical memorandum (dated December 8) provided a brief summary of the threshold values that were selected by the Panel during those discussions. For both diet and eggs, the ranges of selenium concentrations selected by the Panel are the lower and upper 95 percent confidence intervals (95% CIs; also referred to as the 5 percent lower confidence limit [LCL] and the 95 percent upper confidence limit [UCL]) for the mean selenium concentration that is associated with a 10 percent reduction (i.e., the 10 percent effect concentration or EC_{10}) in the hatchability of mallard eggs. Those values were reported by Ohlendorf (2003), based on the analysis of data from six laboratory studies (Heinz et al. 1987, 1989; Heinz and Hoffman 1996, 1998; Stanley et al. 1994, 1996). Essentially, there is 95 percent confidence that the mean dietary or egg selenium concentration that causes a 10 percent reduction of egg hatchability is within the identified ranges, which are illustrated in the figures below.

The Panel agreed by consensus that the 95% CIs on mean selenium concentrations in mallard diet and eggs associated with the EC_{10} for egg hatchability would be reasonably protective for birds nesting at the Great Salt Lake, and that the ranges of values represented by the 95% CIs included the concentrations proposed by various Panel members for consideration. Rationale supporting selection of the 95% CIs is provided by the previous technical memorandum (dated November 28) and through discussion at the Panel meeting.

Panel members provided comments on the December 8 draft version of this technical memorandum summarizing threshold values (Attachment B), and Bill Adams provided further data analyses of effect levels in diets and eggs of mallards that are included in this revised draft. Additional considerations and qualifications about the selected dietary and egg concentrations are presented below in the Discussion section.

All concentrations in bird diets or eggs mentioned below are expressed on dry-weight basis.

Selenium in Bird Diets

The dietary selenium EC_{10} for mallards was reported as 4.87 mg/kg, with 95% CIs of 3.56 to 5.74 mg/kg based on reproductive toxicity (egg hatchability) (Ohlendorf 2003). The EC_{10} of 4.87 mg/kg was estimated by fitting a logistic regression model (Figure 1). It should be noted, however, that the mallard studies used a "dry diet" that had about 10 percent moisture. Ohlendorf (2003) used the reported dietary selenium concentrations without adjustment for that moisture content, but an upward adjustment of the values (by 11 percent) would be appropriate to account for the moisture content of the duck diet.

In Adams et al. (2003), hockey-stick regression was used to model relationships between egg selenium concentrations and adverse effects in order to derive toxicity thresholds, such as EC_{10} values. Hockey-stick regression is a model that has been used elsewhere to define a threshold when an underlying background level of response is unrelated to the dose (see Adams comments in Attachment B). Thus, such a model may be relevant to naturally occurring elements that are essential to birds and a wide variety of other organisms and particularly useful for elements such as selenium, which has a narrow range between levels that are essential and those that are toxic to birds so that variance around the inflection point (threshold) in the model is small. As shown in Figure 2 below, a threshold clearly

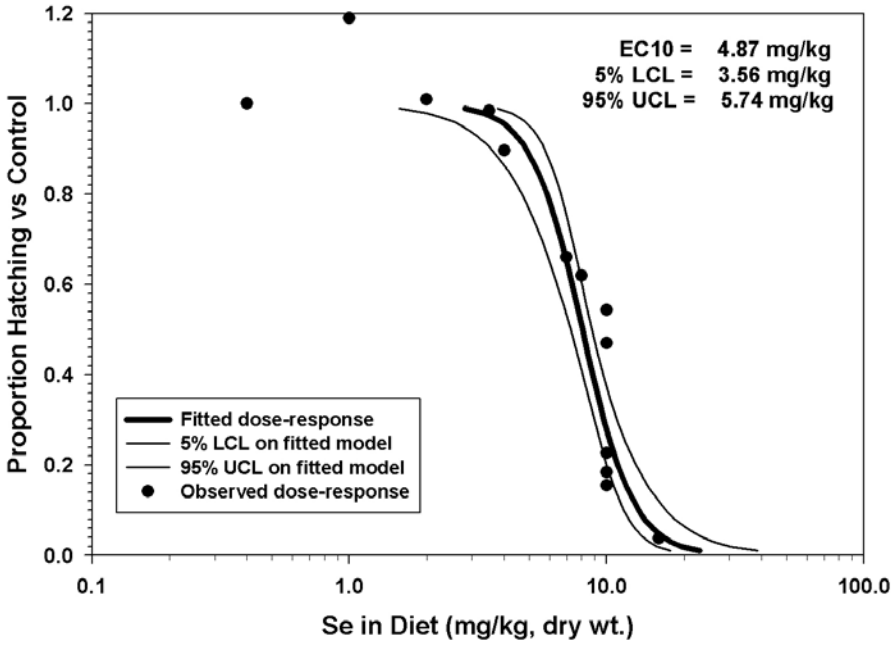

Figure 1. Mallard egg hatchability vs control as a function of selenium concentration in diet.

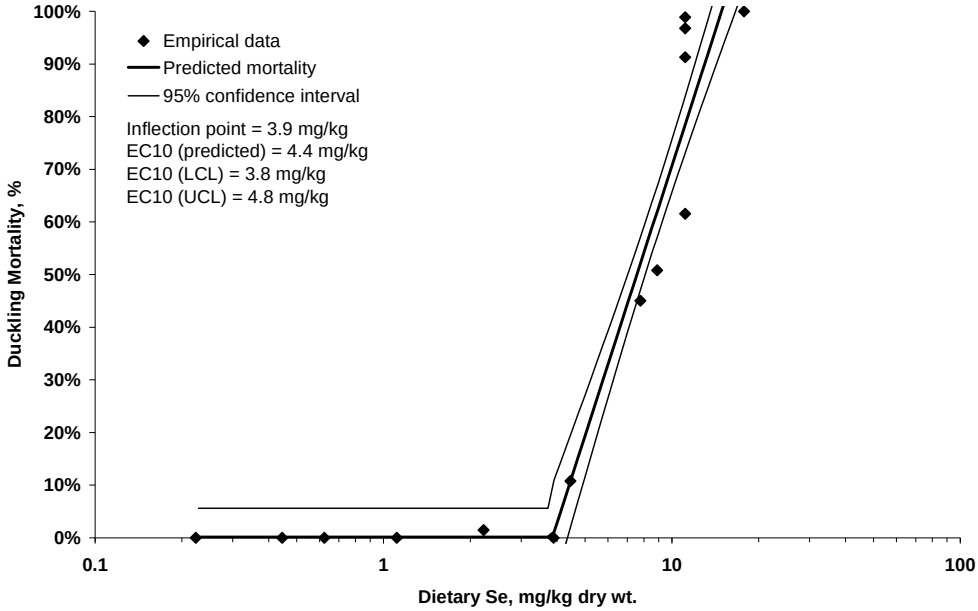

Figure 2. Hockey stick regression of laboratory mallard duckling mortality versus dietary selenium.

appears to exist when dietary selenium is plotted versus duckling mortality (which incorporated the cumulative effects of fertilization success and hatchability). The inflection point occurs at a dietary selenium concentration of 3.9 mg/kg. (The Discussion section below describes uncertainty around the inflection point.) The predicted EC_{10} is 4.4 mg/kg (just slightly above the inflection point) and the 95% CI around the predicted EC_{10} ranges from 3.8 to 4.8 mg/kg. The predicted EC_{10} of 4.4 mg/kg is slightly lower than Ohlendorf's (2003) EC_{10} of 4.9 mg/kg, and the 95% CI is narrower using hockey stick regression than when using logistic regression.

Selenium in Bird Eggs

Similar to the dietary values calculated by Ohlendorf (2003) for reproductive toxicity for mallards, the EC_{10} in eggs was reported as 12.5 mg/kg, with 95% CIs of 6.4 to 16.5 mg/kg (Figure 3). The EC_{10} of 12.5 mg/kg was estimated by fitting a logistic regression model to the results of the six laboratory studies with mallards.

As noted in Table 2, the EC_{10} for duckling mortality, as reported in Adams et al. (2003), ranged from 12 to 16 mg/kg (see Adams comments in Attachment B). These EC_{10} values are based on a synthesis of laboratory studies in which the final endpoint was duckling mortality (the same effects data used in the dietary EC_{10} evaluation with hockey-stick regression above) and the range of EC_{10} values reflects different statistical approaches for analyzing the data. An adaptation from Figure 3 in Adams et al. (2003) is provided below (Figure 4), with the 95% CI included. As shown, the inflection point occurs at an egg selenium concentration of 9.8 mg/kg, with a predicted EC_{10} comparable to that derived by Ohlendorf (2003). (See Discussion for comments concerning uncertainty around the inflection point.) However, the 95% CI using hockey-stick regression is much narrower (9.7 to 13.6 mg/kg) than that derived by Ohlendorf using logistic regression (6.4 to 16.5 mg/kg). Given that there is a clear egg-selenium threshold at which effects begin to be observed, a unimodal model, such as logistic regression, may result in exaggerated confidence intervals, particularly in the tails.

Discussion

Additional discussion is presented below concerning the basis for selection of threshold values, uncertainty surrounding the hockey-stick regression inflection points, hormetic effects of selenium, and other qualifications and points discussed during the Panel meeting in November, as reflected in comments from Panel members (Attachment B).

Basis for Selection of Threshold Values

The Science Panel can choose a scientifically-based threshold value or acceptable "benchmark" concentration based on the consensus confidence limits described by analysis of available data (presented above), but ultimately, a choice of numbers from within the consensus confidence limits for regulatory purposes is not a scientific decision. Choices of a specific number or numbers from within those confidence ranges are philosophical/legal decisions that depend on how precautionary the State of Utah wants to be (a matter of philosophy) and on how much potential for legal liability the State is comfortable with exposing itself to. The key decision the State must make is whether they want to regulate to a "NEC" (no effects concentration, which is not the same as a NOEC [no observed effects

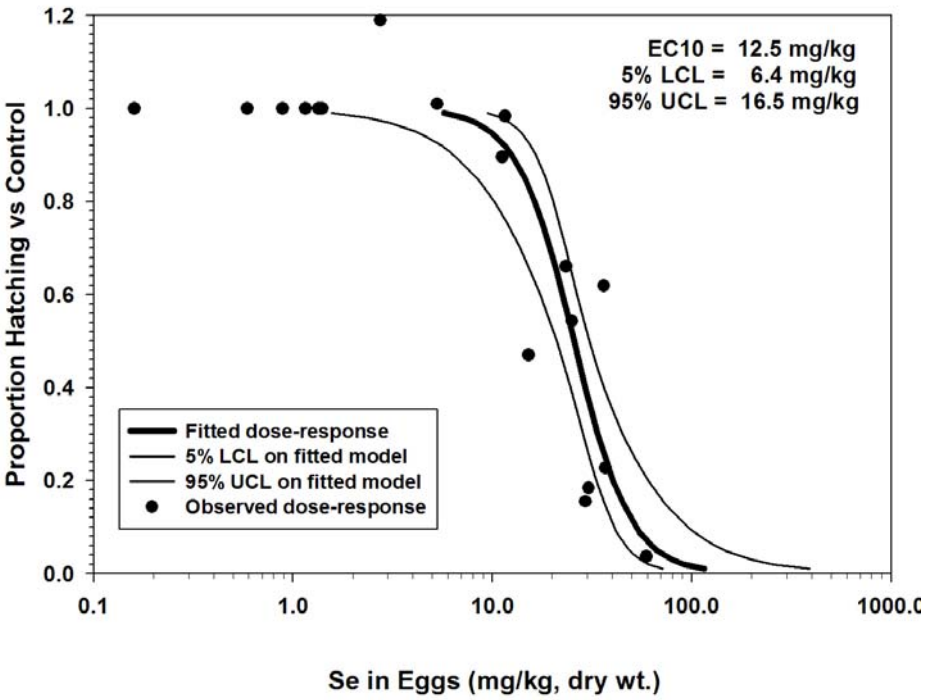

Figure 3. Mallard egg hatchability vs control as a function of selenium concentration in eggs.

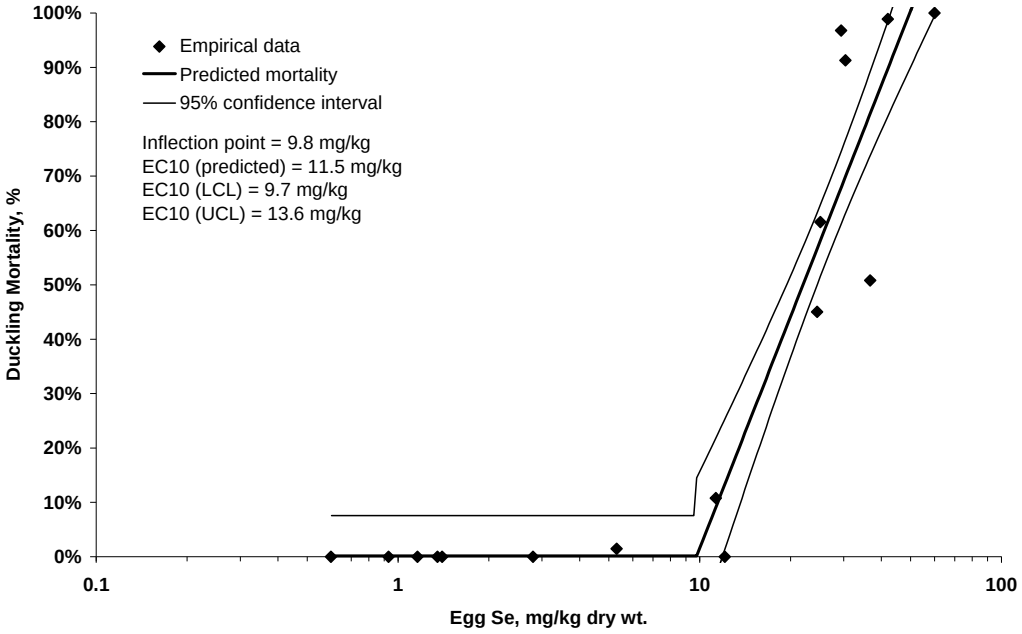

Figure 4. Hockey stick regression of laboratory mallard duckling mortality versus egg selenium.

concentration]) standard or to some version of a "tolerably toxic" standard such as an EC_{10}, an EC_{20}, or an EC_{05}, etc.

Conceptually, a benchmark concentration is defined as the location on the exposure-response curve that is the threshold between absence and presence of a given effect or endpoint (i.e., the threshold between an EC_{00} and an EC_{01} concentration [see: www.epa.gov/ecotox/ecossl/pdf/ecossl_attachment_3-2.pdf; p. A-6]). Benchmark concentrations are estimated as the lower 95 percent confidence boundary on the EC_{10} (see: Meister and Van Den Brink [2000], pp. 114-116 in particular; and USEPA [2000]).

Uncertainty Surrounding the Hockey-Stick Regression Inflection Points

To determine the inflection point between the hockey-stick "blade" and "handle", or any parameter in the model, initial parameter values are input to the software program SPlus® and an iterative technique is used to search for more exact parameter values that will minimize the sum of squared deviations between the observed effects data and effects values predicted by the model. Variance in the estimate of the inflection point value is affected by the spacing of the measured X values as well as the scatter or trend in Y values in the vicinity of the estimated inflection point. If, for example, there are few measured dietary selenium concentrations near the predicted inflection point, the uncertainty in the location of the inflection point will be greater because it will be difficult to determine the exact concentration at which the inflection point occurs (i.e., it could be between two of the measured values). Uncertainty around the predicted Y (EC) values at the predicted inflection point is affected by the number of Y values and the scatter of the Y values at that particular X value (which, when calculating the confidence interval around Y, is assumed to be estimated without error). Thus, both the spacing of the measured X values and the variance in the response variable affects the uncertainty around the inflection point. The tighter spacing and less ambiguous effects response after the inflection point causes the 95% CI around the dietary selenium-based inflection point (3.0 to 4.9 mg/kg) to be narrower than that for the egg selenium-based inflection point (6.4 to 14.9 mg/kg).

However, although there is uncertainty surrounding the inflection point, use of the best estimate of the inflection point results in the best fit of the regression model to the data. In Figure 4, for example, if the inflection point occurred at either end of the 95% CI of egg selenium concentration (6.4 to 14.9 mg/kg dry wt.) one can easily visualize that the fit of the regression to the data points above the inflection point would not pass through the measured values in the same way.

Hormetic Effects of Selenium

Consideration of the hormetic effects of selenium may result in lowering of thresholds (for hormetic substances and endpoints one has to distinguish between valid control responses and hormetic deficiency responses before a valid baseline to compare toxic responses against can be identified). The hormetic bias in the data used for the Ohlendorf (2003) regressions has not yet been fully considered by the Science Panel. If such consideration were to result in changes, those changes could only be in the direction of a downward shifting of the threshold confidence limits. (For example, preliminary unpublished analyses that adjusted for hormetic effects in the mallard data yielded a revised EC_{10} for diet of

4.1 mg/kg, with a 95% CI of 1.3 to 5.8 mg/kg, and a revised EC_{10} for eggs of 9.22 mg/kg, with a 95% CI of 4.11 to 13.07 mg/kg.).

Other Qualifications and Points Discussed

The Panel also discussed the following additional qualifications and points relative to toxicity threshold values:

- Applicability of laboratory data to field situations is not certain (note that field data were retained in compilation of egg-selenium concentrations in Table 2), and it is important to collect site-specific field data on selenium concentrations in bird eggs (e.g., current data gathering effort at the Great Salt Lake).
- Applicability of mallard data to species at Great Salt Lake is uncertain, because relative sensitivity of all species nesting there is not known.
- Threshold values discussed are for the hatchability endpoint (based on diet and avian egg) but non-reproductive adverse effects endpoints (e.g., avian blood endpoint) also may be important. However, interpretive values for selenium in avian blood are not available; although selenium concentrations in blood indicate exposure of the birds, that endpoint is not considered useful for setting a water quality standard.
- Phalaropes are seasonally numerous at the Great Salt Lake and should be added to the list of species to be monitored because they represent species with a feeding rate that is a large percentage of body weight (affecting energy consideration in determining wildlife criterion).

Recommended Next Steps

The issues summarized in this technical memorandum should be discussed/considered further by the Panel, particularly to refine the selection of threshold values for bird diets and eggs with respect to effects documented elsewhere (in field and laboratory studies) and considering the results being developed through research at the Great Salt Lake. In parallel, it will be important to know what level of protectiveness the State and EPA will apply in the development of the site-specific standard for selenium on the Great Salt Lake (i.e., EC_{20}, EC_{10}, EC_{05}, etc.) so that the Science Panel can most effectively make recommendations that can be applied toward that purpose.

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ATTACHMENT A

Tables

TABLE 1
Diet Concentrations

mg/kg	Approach or Site	Effects	Species	Reference(s)
4.87 **(CI 3.56 - 5.74)**	Synthesis of lab Data	Hatchability in mallards (10% effect level/95% confidence boundaries)	Mallard	Ohlendorf 2003
4.4 (CI 3.8 - 4.8)	Synthesis of lab data	EC_{10} for duckling mortality	Mallard	Bill Adams analyses presented in Attachment B
3.85 - 7.7 (diet based on 10% moisture)	Lab	Reduced hatching success in mallards (33% at 7.7 µg/g); reduced growth and weight in hatchlings	Mallard	Stanley et al. 1996
7.7 (diet based on 10% moisture)	Lab	Reduction in number of surviving mallard ducklings produced per female	Mallard	Stanley et al. 1996
8.8 4.4/6.2 (diet based on 10% moisture)	Lab	8.8 - LOAEL, 4.4 - NOAEL, 6.2 - Geometric Mean Reduction (17%) in survival of mallard ducklings; mean decrease (43%) in number of 6-day-old ducklings	Mallard	Heinz et al. 1989
6	Lab	Adverse effect on body condition of male American kestrels	American Kestrels	Yamamoto and Santolo, 2000
7.7 - 8.8 (diet based on 10% moisture)	Lab	Dietary threshold of teratogenic effects in mallards; above upper threshold, rate of deformity rises sharply	Mallard	Stanley et al. 1996
7.7 - 8.8 (diet based on 10% moisture)	Lab	Dietary threshold of mallard duckling mortality (parental exposure)	Mallard	Stanley et al. 1996

Note: Highlighted cells are the threshold values for bird diets identified by consensus of the Science Panel on November 30, 2006.

TABLE 2
Egg Concentrations

mg/kg (dry wt.)	Approach or Site	Effects	Species	Reference(s)
12.5 **(CI 6.4 - 16.5)**	Synthesis of lab data	Hatchability in mallards (10% effect level/95% confidence boundaries)	Mallard	Ohlendorf 2003
10	Synthesis of lab data	NOAEL	Mallard	Adams et al. 2003
12 - 16	Synthesis of lab data	EC_{10} for duckling mortality	Mallard	Adams et al. 2003
9	Synthesis of lab data	Impaired clutch viability (8.2% effects level)	Mallard	Lam et al. 2005
8.2 (or 7.3) (egg based on 73% moisture)	Field	16% depression in egg viability **(*7.3 in paper*)**	Spotted Sandpiper	Harding et al. 2005
6	Synthesis of field data	Threshold (3% effect level) of hatchability	Stilts	Skorupa, 1998; Skorupa, 1999
5.1 (egg based on 78.4% moisture)	Field	15% depression in egg viability	American dipper	Harding et al. 2005

Note: Highlighted cells are the threshold values for bird eggs identified by consensus of the Science Panel on November 30, 2006.

ATTACHMENT B

Comments on December 8, 2006, Draft Technical Memorandum

ATTACHMENT B

Comments on December 8, 2006, Draft Technical Memorandum

Comments of Bill Adams

Following are comments on Harry Ohlendorf's draft technical memorandum to the Great Salt Lake Science Panel entitled *Threshold Values for Selenium in Great Salt Lake: Selections by the Science Panel* (December 8, 2006).

Selenium in Bird Diets

As noted in the draft memorandum, the mallard studies used in Ohlendorf (2003) as the basis for a dietary selenium EC10 in birds was based on a "dry diet" containing about 10% moisture. Although the moisture content of the mallard diet was low, we recommend that standard convention should be used to properly adjust the dietary selenium concentrations to a dry weight basis. The equation for the wet weight-to-dry weight conversion is included in Attachment 1 to this memorandum.

In Adams et al. (2003), hockey-stick regression was used to model relationships between egg selenium concentrations and adverse effects in order to derive toxicity thresholds, such as EC10 values. Hockey-stick regression is a model that has been used to define a threshold when an underlying background level of response is unrelated to the dose. Thus, such a model may be relevant to naturally occurring elements that are essential to birds and a wide variety of other organisms and particularly useful for elements such as selenium, which has a narrow range between levels that are essential and levels that are toxic to birds so that variance around the inflection point (threshold) in the model is small. As shown in Figure 1 below, a threshold clearly appears to exist when dietary selenium is plotted versus duckling mortality (which incorporated the cumulative effects of fertilization success and hatchability). The inflection point occurs at a dietary selenium concentration of 3.9 mg/kg dry wt. (please see discussion at end of comments concerning uncertainty around the inflection point). The predicted EC10 is 4.4 mg/kg dry wt. (just slightly above the inflection point) and the 95% confidence interval around the predicted EC10 ranges from 3.8 to 4.8 mg/kg dry wt. The predicted EC10 of 4.4 mg/kg dry wt. is slightly lower than Harry Ohlendorf's EC10 of 4.9 mg/kg dry wt., but the 95% confidence interval is narrower using hockey stick regression.

Selenium in Bird Eggs

As noted in Table 2 of the draft memorandum, the EC10 for duckling mortality, as reported in Adams et al. (2003), ranged from 12-16 mg/kg dry wt. These EC10 values are based on a synthesis of laboratory studies in which the final endpoint was duckling mortality (the same effects data used in the dietary EC10 evaluation above) and the range of EC10 values reflects different statistical approaches for analyzing the data. An adaptation from Figure 3 in Adams et al. (2003) is provided below, with the 95% confidence interval included. As

shown, the inflection point occurs at an egg selenium concentration of 9.8 mg/kg with a predicted EC10 comparable to that derived by Harry Ohlendorf (please see discussion at end of comments concerning uncertainty around the inflection point). However, the 95% confidence interval using hockey stick regression is much narrower (9.7 to 13.6 mg/kg dry wt.) than that derived by Harry using logistic regression (6.4-16.5 mg/kg dry wt.). Given that there is a clear egg selenium threshold at which effects begin to be observed, a unimodal model, such as logistic regression, may result in exaggerated confidence intervals, particularly in the tails.

Uncertainty Surrounding the Hockey-Stick Regression Inflection Points

To determine the inflection point between the hockey-stick "blade" and "handle", or any parameter in the model, initial parameter values are input to the software program SPlus® and an iterative technique is used to search for more exact parameter values that will minimize the sum of squared deviations between the observed effects data and effects values predicted by the model. Variance in the estimate of the inflection point value is affected by the spacing of the measured X values as well as the scatter or trend in Y values in the vicinity of the estimated inflection point. If, for example, there are few measured dietary selenium concentrations near the predicted inflection point, the uncertainty in the location of the inflection point will be greater because it will be difficult to determine the exact concentration at which the inflection point occurs (i.e., it could be between two of the measured values). Uncertainty around the predicted Y (EC) values at the predicted inflection point is affected by the number of Y values and the scatter of the Y values at that particular X value (which, when calculating the confidence interval around Y, is assumed to be estimated without error). Thus, both the spacing of the measured X values and the variance in the response variable affects the uncertainty around the inflection point. The tighter spacing and less ambiguous effects response after the inflection point causes the 95% confidence interval around the dietary selenium-based inflection point (3.0 to 4.9 mg/kg dry wt.) to be narrower than that for the egg selenium-based inflection point (6.4 to 14.9 mg/kg dry wt.).

However, although there is uncertainty surrounding the inflection point, use of the best estimate of the inflection point results in the best fit of the regression model to the data. In Figure 2, for example, if the inflection point occurred at the either end of the 95% confidence interval of egg selenium concentration (6.4 to 14.9 mg/kg dry wt.) once can easily visualize that the fit of the regression to the data points above the inflection point would not pass through the measured values in the same way.

Figure 1. Hockey stick regression of laboratory mallard duckling mortality versus dietary selenium.

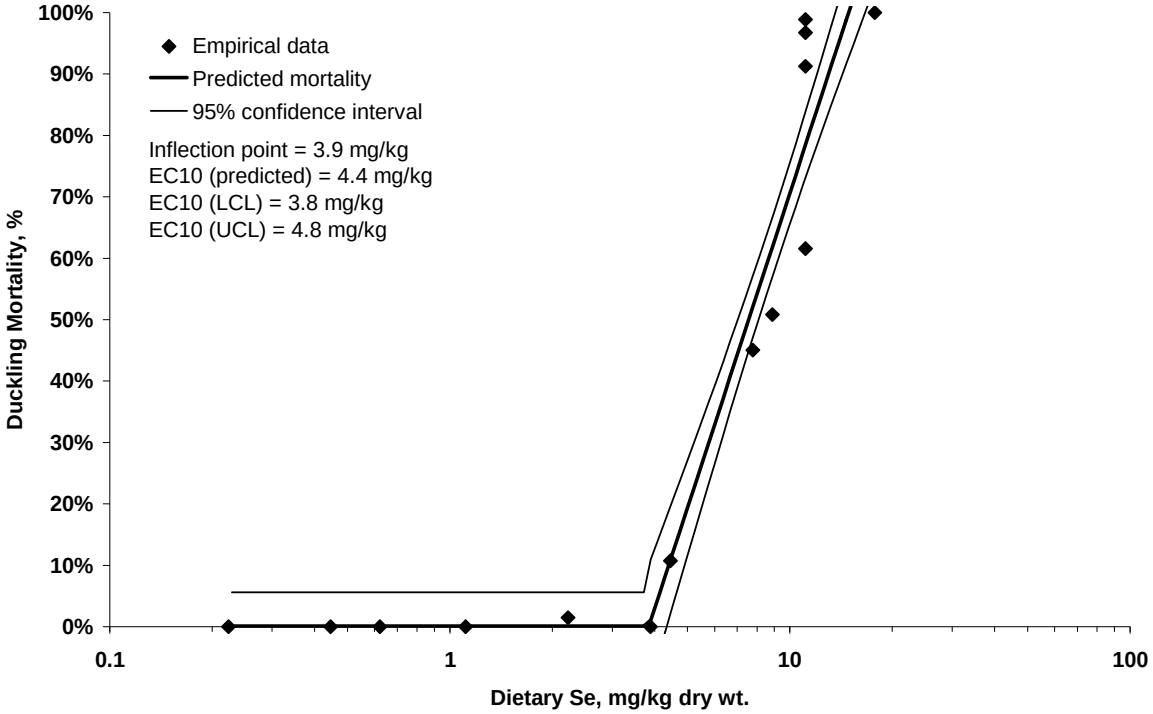
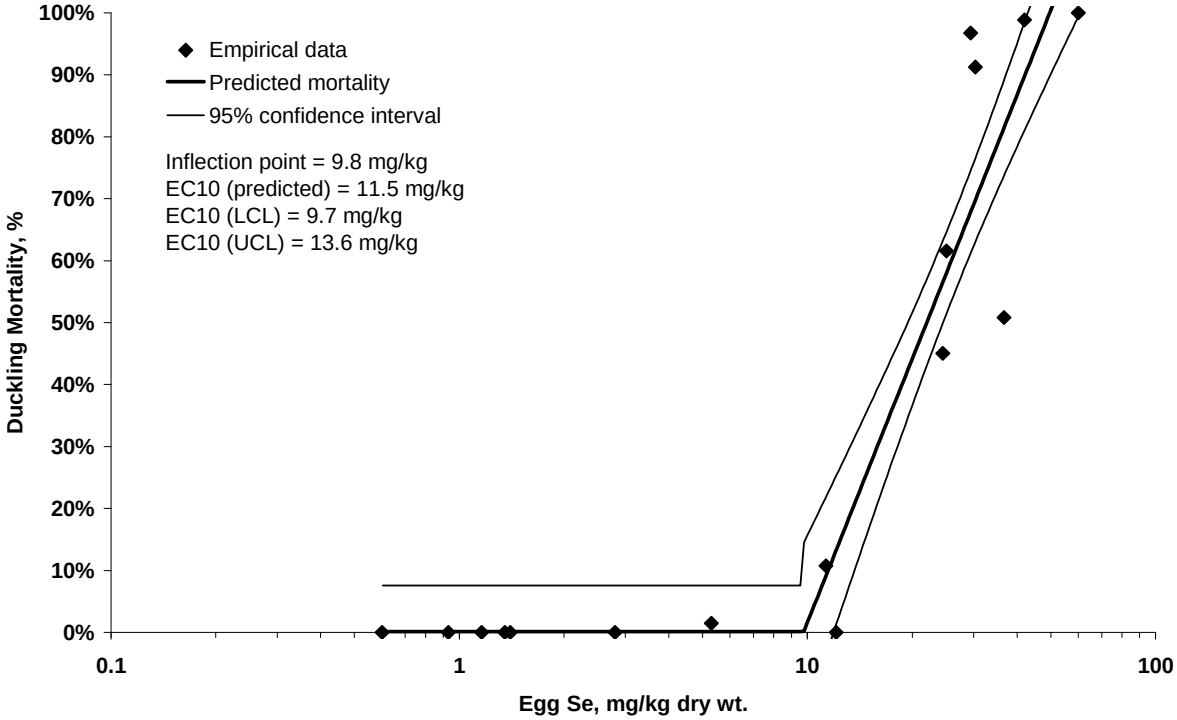


Figure 2. Hockey stick regression of laboratory mallard duckling mortality versus egg selenium.



ATTACHMENT 1

WET WEIGHT-TO DRY WEIGHT CONVERSION FOR DIETARY SELENIUM CONCENTRATIONS IN MALLARD STUDIES

$$\text{Dry Weight Concentration} = \frac{\text{Wet Weight Concentration}}{f_{solids}}$$

Where: f_{solids} = fraction solids in diet (i.e., 0.9 in a diet containing 10% moisture)

Comments of Anne Fairbrother

I realize that I am late (the last?) on providing comments and feedback on the report you pulled together from our last Salt Lake City meeting on threshold values. I was sort of hoping to see the data from Bill Adams' re-analysis of the dose-response before replying... Absent that, here are my thoughts and comments.

I think you did an appropriate job pulling together what was discussed at the meeting in regard to diet and egg threshold levels. However, the more I look at the data in regard to selenium uptake and effects, the more convinced do I become that we are dealing with a threshold phenomenon, likely because of the essential nature of the element. I do believe that the mean value for the EC10 that was selected for both endpoints is likely to remain pretty much the same regardless of what dose-response model is used, but the standard error about the mean may be different. Likely it will be smaller when using a threshold model since a logistic model tends to spread out the CI's at its tails. So, for now, I am willing to approve the document as a report of what was discussed at the meeting, but not as a final say on what we have agreed to for the EC10 and its confidence intervals.

Comments of Theresa Presser

Suggested additions to threshold discussion write-up of 12/8/06:

1) Page 1: Note that compilation of data for consideration was adapted from Presser and Luoma (2006), table 15.

2) Page 1: Note that in addition to laboratory data, a compilation of field data for egg concentrations was retained.

3) Page 1: Note that any final determination must take into account site-specific data currently being generated by the Great Salt Lake research effort.

4) Page 2 wording: "The panel agreed by consensus that the 95% CIs on mean selenium concentrations in mallard diet and eggs would be reasonably protective for birds nesting at the Great Salt Lake, and the range of values included the concentrations proposed by various panel members for consideration. Rational supporting selection of the 95% CIs is provided by the previous technical memorandum and through discussion at the panel meeting."

    a) Did you mean here the 95% CIs on the mean EC10 for hatchability?

    b) The phrase "would be reasonably protective for birds nesting at the Great Salt Lake" does not adequately convey all parts of the extensive discussion that took place. I did not perceive that a consensus had been reached as to protectiveness, only that a consensus had been reached as to the interpretation of data from mallard lab experiments. Therefore, I suggest incorporating into the wording of a summary statement the following qualifications and points that were discussed at the meeting:

        1) Applicability of lab data to field situations (note retention of compilation of field data in table 2 and current data gathering effort at the Great Salt Lake; points 2 and 3 listed above)

        2) Applicability of mallard data to species at Great Salt Lake (sensitivity issue)

        3) Applicability of hatchability endpoint (diet and avian egg) and non-reproductive adverse effects endpoints (e.g., avian blood endpoint)

        4) Level of protection and precautionary regulation as exemplified by benchmark concentration regulation. Specifically add excerpt from page 8 of 11/28/06 memo as clarification of 95% CI: "Conceptually, a benchmark concentration is defined as the location on the exposure-response curve that is the threshold between absence and presence of a given effect or endpoint, i.e., the threshold between an EC00 and an EC01 concentration (see: www.epa.gov/ecotox/ecossl/pdf/ecossl_attachment_3-2.pdf; p. A-6)….. Benchmark concentrations are estimated as the lower 95% confidence boundary on the EC10 (see: Meister, R., and P.J. Van Den Brink. 2000. The analysis of laboratory toxicity experiments. Pages 99-118 in T. Sparks (ed.), Statistics in Ecotoxicology. John Wiley & Sons, LTD, New York, NY: [pp 114-116 in particular]; and see: USEPA. 2000. Benchmark Dose Technical Guidance

Document. [External Review Draft]. EPA/630/R-00/001. U.S. Environmental Protection Agency, Washington, DC)."

5) Addition of phalarope to list of species to be monitored to represent species with a feeding rate that is a large percentage of body weight (energy consideration in determining wildlife criterion).

6) Potential lowering of thresholds through consideration of hormesis data (for hormetic substances and endpoints one has to distinguish between valid control responses and hormetic deficiency responses before a valid baseline to compare toxic responses against can be identified).

5) References: Add Presser and Luoma, 2006.

6) Table 1:"Bill Adams suggestion" needs to be documented as how his entry differs from entry #1 in table 1.

Comments of Joe Skorupa

In Table 1 I don't believe the science panel wanted the value of 4.87 to be presented in bold type, only the confidence limits (for comparison see Table 2 where I think you have it the way the science panel intended).

Adjusting for 10% moisture would result in an 11% increase in the dietary values, not an upward adjustment of 10% as stated.

I didn't feel like your draft write-up adequately conveyed our (sci. panel's) discussion concerning the fact that, ultimately, a choice of numbers from within the consensus confidence limits is not a scientific decision. That confidence range is as far as science can bring us... choosing a specific number or numbers from within those confidence ranges are philosophical/legal decisions that depend on how precautionary the State of Utah wants to be (a matter of philosophy) and on how much potential for legal liability the State is comfortable with exposing itself to. The key decision the State must make is whether they want to regulate to a "NEC" (no effects concentration... which is not the same as a NOEC) standard or to some version of a "tolerably toxic" standard such as an EC-10, or EC-20, or EC-05 etc.

Finally, I think on the scientific side of things we would be remiss in our duty as experts not to include some discussion indicating that the issue of hormetic bias in the data used for the Ohlendorf (2003) regressions has not yet been fully considered by the science panel (at Bill Adams request to defer it so that he could preview Beckon's SETAC presentation before I presented any of it to the panel... although it seemed to be acceptable to everyone to see Kennecott's U. of Wyoming presentation without any opportunity for anyone other than Bill A. to preview it... seems like a double standard to me), and that if such consideration were to result in changes, those changes could only be in the direction of a downward shifting of the threshold confidence limits.

For example, remember that the analysis that Brad Sample re-ran to adjust for hormetic effects in the mallard data yielded a revised EC-10 for diet of 3.7 ppm ww [4.1 ppm dw] with a 95% confidence interval of 1.15 - 5.18 ppm ww [1.3 - 5.8 ppm dw] and a revised EC-10 for eggs of 9.22 ppm dw with a 95% confidence interval of 4.11 - 13.07 ppm dw.

Threshold Values for Selenium in Great Salt Lake: Refined Selections by the Science Panel

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DATE: October 17, 2007

PROJECT NUMBER: 341055.P7.05

The purpose of this technical memorandum is to provide a summary and documentation of the Science Panel's further discussions during the recent Panel meetings (March 21 to 22, 2007, and July 31 to August 1, 2007) relative to refining toxicity thresholds for exposure of birds to selenium at the Great Salt Lake (GSL), and to define some of the terms used. During the most recent meetings, the Panel continued its review of available information to determine threshold values that should be considered for development of the site-specific standard for selenium in the open waters of GSL. Previous considerations are summarized in the following two technical memorandums: Subject: Threshold Values for Selenium in Great Salt Lake, dated November 28, 2006; and Subject: Threshold Values for Selenium in Great Salt Lake: Selections by the Science Panel, dated February 28, 2007.

Briefly, key considerations for the threshold values are as follows:

- It is generally recognized that the most significant exposure of birds occurs through their diet.
- The best-documented and most readily-monitored effects are those on reproductive success (particularly egg hatchability, assessed indirectly for GSL on the basis of selenium concentrations in food-chain organisms and bird eggs).
- Laboratory studies with mallards provide the best available data to evaluate avian exposure and effects; because the mallard is relatively sensitive to the effects of selenium, using those threshold values builds in conservatism so that the result can be considered protective of other species.
- The 95% lower confidence interval (CI) on the mean selenium concentrations in mallard diet and eggs associated with the EC_{10} for egg hatchability (explained below) would be reasonably protective for birds nesting at the GSL.

- The previous technical memoranda provide a summary and discussion of potential threshold values identified by Science Panel members for consideration in establishing a water quality standard for selenium in the open waters of the GSL.
- The degree of protectiveness to be applied by the State in setting the water quality standard is not known, and there is not complete understanding of the sensitivity of the GSL system to selenium; thus, the Panel is considering a range of values to be used in modeling and derivation of a potential standard.

From the available information, the Panel initially (in November 2006) narrowed the values to be considered by identifying "working values" for the ranges of acceptable selenium concentrations in bird diets and eggs. For both diet and eggs, the Panel selected the ranges of selenium concentrations provided by Ohlendorf (2003); they include the 95% CI (also referred to as the 5% lower confidence limit [LCL] and the 95% upper confidence limit [UCL]) for the mean selenium concentration that is associated with a 10% reduction (i.e., the 10% effect concentration or EC_{10}) in the hatchability of mallard eggs. The Panel selected the EC_{10} as the appropriate endpoint because it is conventionally used as an endpoint in toxicological studies and the related literature, and it represents a lower limit of sensitivity for assessment of effects at a population level.

For bird diets, the 95% CI = 3.56 to 5.74 mg Se/kg (mean = 4.87 mg Se/kg); in bird eggs, the 95% CI = 6.4 to 16.5 mg Se/kg (mean = 12.5 mg Se/kg). (All concentrations in bird diets or eggs mentioned in this technical memorandum are expressed on dry-weight basis.) Those values were based on the analysis of data from six laboratory studies (Heinz et al. 1987, 1989; Heinz and Hoffman 1996, 1998; Stanley et al. 1994, 1996). Essentially, there is 95% confidence that the mean dietary or egg selenium concentration that causes a 10% reduction of egg hatchability is within the identified ranges, which are illustrated in Figures 1 and 2.

At the July 31 to August 1 meeting, Joe Skorupa suggested an alternative way of communicating the selected threshold values that de-emphasizes the EC_x terminology. Those values, shown in Table 1, relate the mean, LCL, and UCL as a selenium concentration in the diet or in bird eggs to the degree of reduction in egg hatchability (as percent reduction) associated with those selenium concentrations. For each concentration, the table lists the range of reduction in hatchability that can be expected to occur. The range represents the least to the most reduction that is associated with the selenium concentration, with 95% confidence that the level of effect falls within that range. The table also lists the "maximum likelihood" value for each concentration; that value is the best estimate of the expected decrease in hatchability.

Basis for Selection of Threshold Values

As mentioned above, the dietary selenium EC_{10} for mallards was reported as 4.87 mg/kg, with 95% CI of 3.56 to 5.74 mg/kg based on reproductive toxicity (egg hatchability) (Ohlendorf 2003). The EC_{10} was estimated by fitting a logistic regression model (Figure 1). Similar to the dietary values calculated by Ohlendorf (2003) for reproductive toxicity for mallards, the EC_{10} in eggs was reported as 12.5 mg/kg, with 95% CI of 6.4 to 16.5 mg/kg (Figure 2). This EC_{10} also was estimated by fitting a logistic regression model to the results of the six laboratory studies with mallards.

Supportive/Corroborative/Other Considerations

The Panel considered two approaches to hockey-stick regression and also the possible effects of hormesis as ways of modifying the results of the logistic regression model described above, but decided they should be considered informational and corroborative, rather than as providing a basis for adjustment of the values given above. Hockey-stick regression and hormesis results are briefly described below. In addition, the Panel also discussed other considerations, such as the degree of protectiveness the State may want to take into account in setting the standard as well as several additional qualifications, during its meetings.

Hockey-stick Regression

Adams et al. (2003) used hockey-stick regression to model relationships between egg selenium concentrations and adverse effects in order to derive toxicity thresholds, such as EC_{10} values. (Hockey-stick regression is discussed in more detail in the technical memorandum of February 2007.) As shown in Figure 3, a threshold clearly exists when dietary selenium is plotted versus duckling mortality (which incorporates the cumulative effects of fertilization success and hatchability). The inflection point occurs at a dietary selenium concentration of 3.9 mg/kg (Table 2). The predicted EC_{10} is 4.4 mg/kg (just slightly above the inflection point) and the 95% CI around the predicted EC_{10} ranges from 3.8 to 4.8 mg/kg.

The hockey-stick analysis described above was based on data that were adjusted for the response of "control" ducks in the studies. When the data were not adjusted (normalized) on the basis of the control birds, the inflection point was 3.2 mg/kg (Figure 4 and Table 2), slightly lower than the LCL for logistic regression (3.6 mg/kg; Figure 1) or the inflection point when data were normalized for response of controls (3.9 mg/kg; Figure 3 and Table 2).

For eggs, an adaptation from Figure 3 in Adams et al. (2003) is provided below as Figure 5, with the 95% CI included. As shown in the figure and in Table 3, the inflection point occurs at an egg selenium concentration of 9.8 mg/kg, with a predicted EC_{10} comparable to that derived by Ohlendorf (2003). However, the 95% CI using hockey-stick regression is much narrower (9.7 to 13.6 mg/kg) than that derived by Ohlendorf using logistic regression (6.4 to 16.5 mg/kg). When data are not adjusted (normalized) for the response of the "control" mallards, the inflection point is 6.7 mg/kg (Figure 6 and Table 3). This is near the LCL for logistic regression (6.4 mg/kg; Figure 2) and lower than the inflection point when data were normalized for response of controls (9.8 mg/kg; Figure 5 and Table 3).

Overall, the Panel considered the results of the hockey-stick regression analyses to corroborate the use of the EC_{10} (and associated CI) from logistic regression, rather than indicating a need to adjust those threshold values.

Hormetic Effects of Selenium

Consideration of the hormetic effects of selenium may result in lowering of thresholds (for hormetic substances and endpoints, one has to distinguish between valid control responses and hormetic deficiency responses before a valid baseline to compare toxic responses against can be identified). The hormetic bias in the data used for the Ohlendorf (2003)

regressions was discussed by the Science Panel. If modifications were to be made on the basis of hormetic effects, those changes could only be in the direction of a downward shifting of the threshold confidence limits. (Preliminary unpublished analyses that adjusted for hormetic effects in the mallard data yielded a revised EC_{10} for diet of 4.1 mg/kg, with a 95% CI of 1.3 to 5.8 mg/kg, and a revised EC_{10} for eggs of 9.22 mg/kg, with a 95% CI of 4.11 to 13.1 mg/kg.)

The Panel agreed that the available information does not indicate a need to modify the range of values presented in Table 1 for use in modeling and evaluation of avian exposure and effects. Instead, hormesis, like hockey-stick regression, is a factor the Panel will consider but the ranges of values in Table 1 are considered adequate for that purpose.

Desired Degree of Protectiveness

The Science Panel can choose a scientifically-based threshold value or acceptable "benchmark" concentration based on the consensus confidence limits described by analysis of available data (presented above), but ultimately, a choice of numbers from within the consensus confidence limits for regulatory purposes is not a scientific decision. Choices of a specific number or numbers from within those confidence ranges are philosophical/legal decisions that depend on how precautionary the State of Utah wants to be (a matter of philosophy) and on how much potential for legal liability the State is comfortable with exposing itself to. This issue is discussed in more detail in the technical memorandum of February 2007.

Other Qualifications and Points Discussed

The Panel also discussed several additional qualifications and points relative to toxicity threshold values. The principal ones included the applicability of laboratory data to field situations, applicability of mallard data to species at GSL, importance of non-reproductive adverse effects endpoints, and possible effects on phalaropes or other seasonally numerous birds with smaller body weight (and consequently a higher feeding rate) at the GSL. However, in the end, the Panel agreed to focus primarily on those species for which information was available or for which assessment could be more readily completed.

Recommended Next Steps

The threshold values summarized in this technical memorandum (Table 1) should be used for purposes of modeling and evaluation toward development of the recommended standard. In parallel, it will be important to know what level of protectiveness the State and USEPA will apply in the development of the site-specific standard for selenium on the GSL (i.e., EC_{10}, LEL, UCL, or some other value) so that the Science Panel can most effectively make recommendations that can be applied toward that purpose.

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Tables

TABLE 1
Range of Values for Use in Modeling and Evaluation
Threshold Values for Selenium in Great Salt Lake: Refined Selections by the Science Panel

Concentration	95% Effects	Maximum Likelihood
Diet		
3.6 ppm	< 1% - 10%	3%
4.9 ppm	4% - 24%	10%
5.7 ppm	10% - 32%	18.5%
Egg		
6.4 ppm	< 1% - 10%	1.5%
12.5 ppm	3.5% - 26.5%	10%
16.5 ppm	10% - 37.5%	21%

TABLE 2
Hockey-stick Regression Results for the Bird Diet Endpoint
Threshold Values for Selenium in Great Salt Lake: Refined Selections by the Science Panel

	Inflection Point	LCL	EC_{10}	UCL
Data adjusted for control	3.9	3.8	4.4	4.8
Data not adjusted for control	3.2			

Note: EC_{10}, LCL, and UCL for data without adjustment for control not calculated due to varying confidence interval.

TABLE 3
Hockey-stick Regression Results for the Bird Egg Endpoint
Threshold Values for Selenium in Great Salt Lake: Refined Selections by the Science Panel

	Inflection Point	LCL	EC_{10}	UCL
Data adjusted for control	9.8	9.7	11.5	13.6
Data not adjusted for control	6.7			

Note: EC_{10}, LCL, and UCL for data without adjustment for control not calculated due to varying confidence interval.

Figures

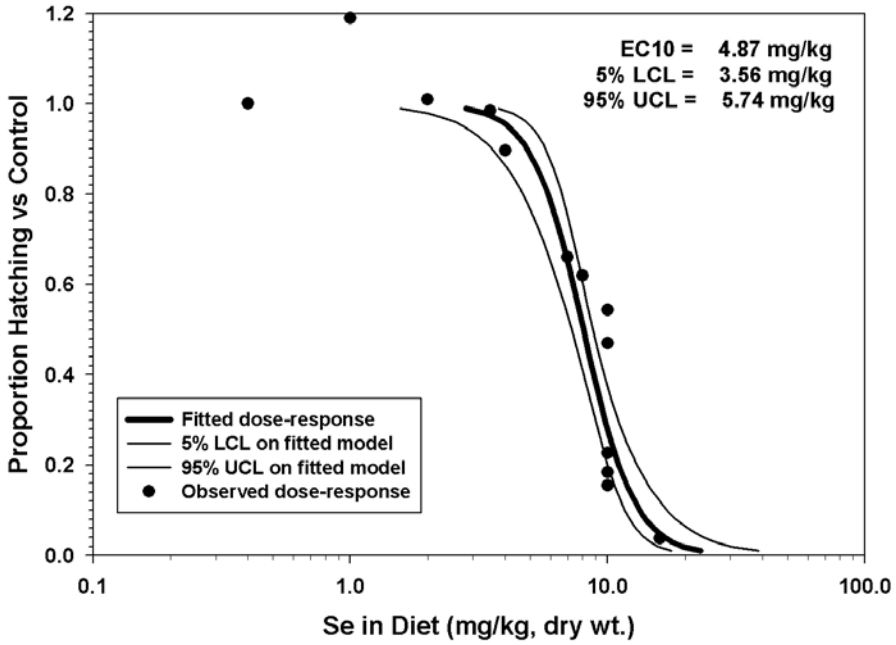

FIGURE 1
Mallard Egg Hatchability versus Control as a Function of Selenium Concentration in Diet

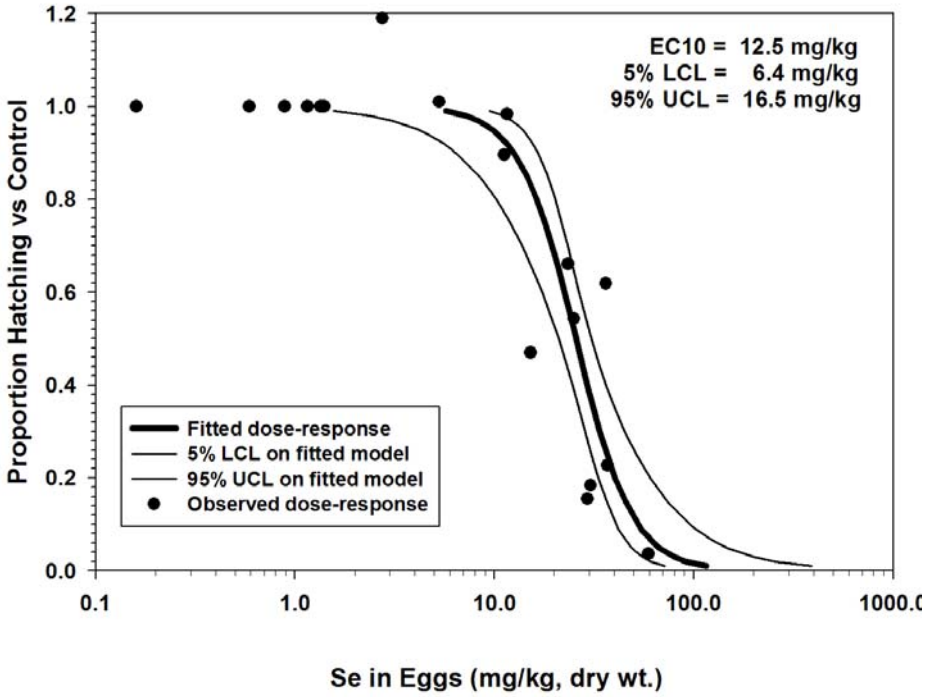

FIGURE 2
Mallard Egg Hatchability versus Control as a Function of Selenium Concentration in Eggs

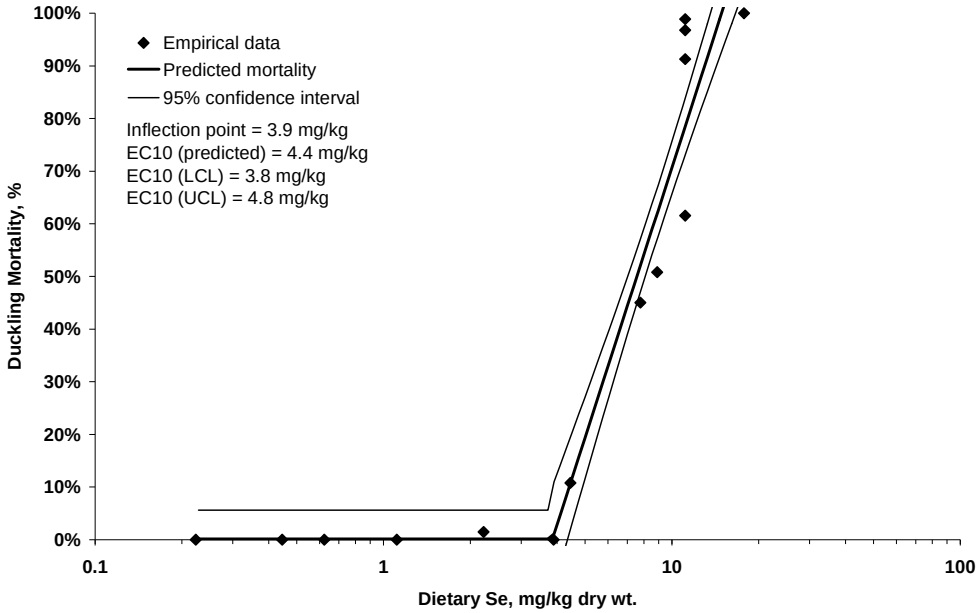

FIGURE 3
Hockey-stick Regression of Laboratory Mallard Duckling Mortality versus Dietary Selenium

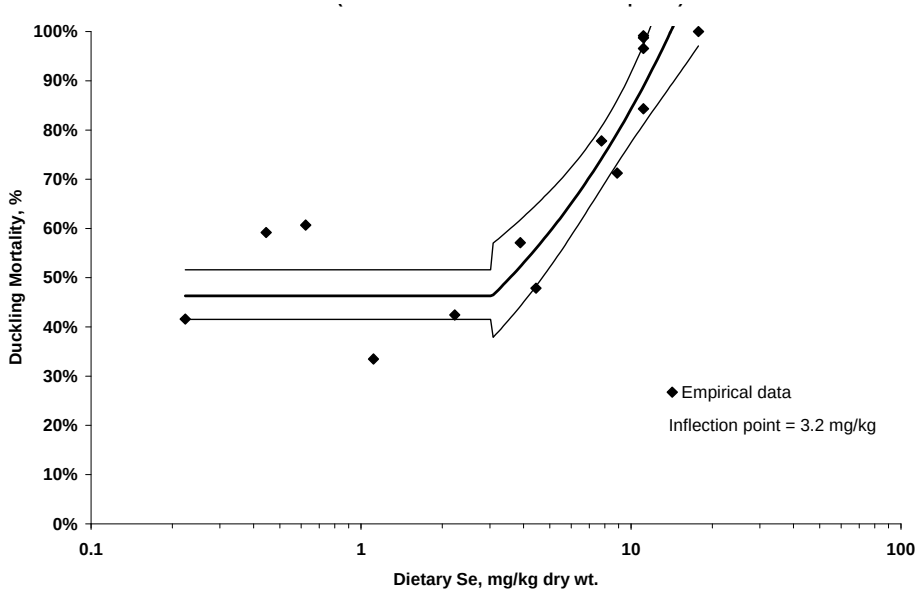

FIGURE 4
Hockey-stick Regression of Laboratory Mallard Duckling Mortality versus Dietary Selenium
(data not normalized for control response)

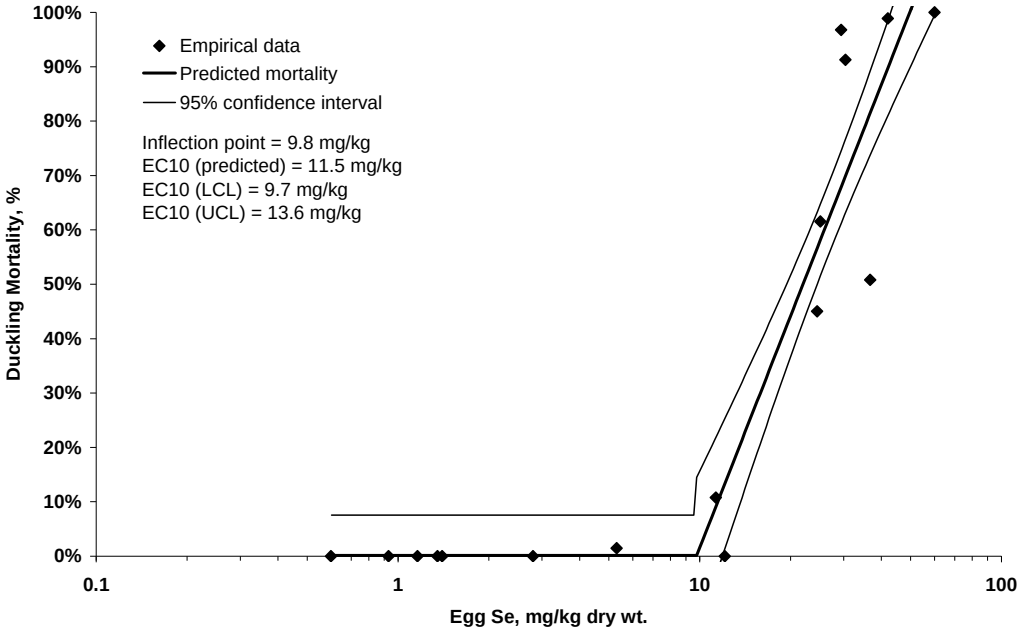

FIGURE 5
Hockey-stick Regression of Laboratory Mallard Duckling Mortality versus Egg Selenium

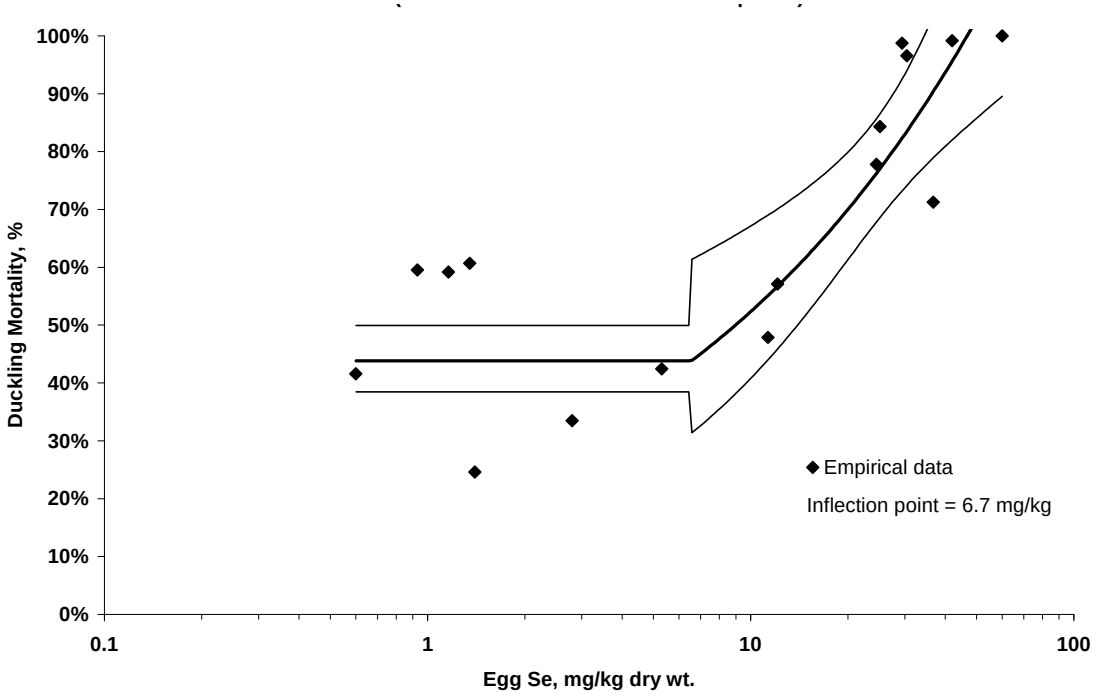

FIGURE 6
Hockey-stick Regression of Laboratory Mallard Duckling Mortality versus Egg Selenium
(data not normalized for control response)

FACT SHEET

Recommended Guidelines for a Water Quality Standard for Selenium in Great Salt Lake

The State of Utah formed a Science Panel in 2004 to study selenium (Se) in the open waters of Great Salt Lake (GSL). This fact sheet presents the Science Panel's recommended guidelines for a water quality standard for Se. A Steering Committee, comprised of various GSL stakeholders, will review the Science Panel's recommendations and define a site-specific, numeric water quality standard for Se that prevents impairment of the beneficial uses of the open waters of GSL.

Science Panel's Recommended Guidelines

It is the opinion of the Science Panel that a Se water quality standard that prevents impairment for aquatic wildlife of GSL lies within the following ranges:

- 3.6 to 5.7 mg Se/kg (mg/kg = parts per million) for bird diet items
- 6.4 to 16 mg Se/kg for bird eggs

The recommended guidelines are subject to the following qualifications and precautions:

- There is uncertainty in the guidelines, as reflected by the range of Se concentrations
- The guidelines would be applied by back-calculating from tissue concentrations to estimate a corresponding water concentration
- The Panel recognizes the need for conservatism in application of the guideline that will be recommended

What is the basis for this recommendation?

- **Why do the guidelines focus on birds?** Birds are likely the most sensitive to Se:
  - » The water quality standard will be developed to protect birds that feed primarily on open waters of GSL
  - » Exposure of birds to Se is mainly through their diet
- **How does Se affect birds?** The best-documented, most sensitive, and most readily monitored effect of Se on birds is reproductive success:
  - » Other endpoints such as body condition for migratory birds or adult mortality are important, but related Se concentrations are undetermined at this time
  - » Reproductive success is considered more sensitive than those other endpoints
- **How is the effect of Se on reproductive success studied?** Se concentration in eggs can be directly related to expected reproductive success (i.e., egg hatchability) through the use of field- or laboratory-derived relationships:
  - » Success is measured by egg hatchability (i.e., the number of eggs incubated full term that hatch vs. those that don't hatch)
  - » Field studies require extensive monitoring, eggs are sacrificed when sampled, and sampling of eggs is possible only during the nesting season (about a 2-month period)
  - » Laboratory studies describe the relationship between Se concentration in bird diet, eggs, and reproductive success
- **If collecting eggs is difficult, is there another way to link Se to reproductive success?** Field-collected food items can be used to represent the bird diet to estimate Se concentration in eggs and predict reproductive success:
  - » Samples of food items can be obtained throughout the year (though spring nesting season is most important)
  - » It is easier to obtain routine samples of food items than to sample eggs
- **What is the basis for linking Se in eggs and diet to reproductive success?** Laboratory studies provide the best available data for relating Se levels in bird diets or eggs to effects on reproductive success:
  - » Panel reviewed the literature for best data describing Se effects on egg hatchability
  - » Data set identified is from six laboratory studies of mallards fed a selenomethionine-augmented diet relating Se concentration in diet and eggs to egg hatchability
  - » Panel agreed to use values from Ohlendorf (2003)[1] to establish the range
- **Why use data for mallards, which do not nest on open waters of GSL?** Mallards as a species are more sensitive to Se than other species that commonly nest at GSL:
  - » Field studies show that birds that typically use saline, or salt water, non-marine habitats (e.g., avocets and snowy plover) seem to be less sensitive than closely related species typical of freshwater habitats (e.g., stilts and killdeer)[2]

- » Mallards are a freshwater species; thus, using mallard data **builds conservatism**, or a safety factor, into any water quality standard
- » The best available data set for Se effects on egg hatchability are for mallards

- **How do we link bird diet and egg concentrations to the water?** Research for the GSL Se Program included development of a model that characterizes the transfer of Se from water to the birds' diet and then to the birds' eggs:
  - » Allows the development of a water concentration from specific diet and egg Se concentrations (by back-calculation)

How does the range of diet and egg selenium concentrations represent levels of protection?

The Science Panel has determined that selenium-related impairment for the open waters of GSL should be defined by hatching success of birds commonly nesting on the lake. Toxicological studies have shown that a 10% reduction (called an "EC_{10}") in egg hatchability of mallards occurs when the diet contains selenium concentrations between 3.6 and 5.7 mg/kg and selenium concentrations in eggs are between 6.4 and 16 mg/kg. This range of selenium concentrations in the diet and eggs and associated reductions in egg hatchability are shown in the table below. The statistical analysis indicates the greatest probability that a 10% hatchability reduction is associated with a 4.9 mg/kg diet and 12 mg/kg in the egg. There is only a very small chance that the low or high values in the ranges provided are the true concentration where a 10% effect occurs.

Diet Selenium (mg /kg)	Reduction in Hatchability	Egg Selenium (mg/kg)	Reduction in Hatchability
3.6	3%	6.4	2%
4.9	10%	12	10%
5.7	18%	16	21%

The Steering Committee will recommend to the Utah Water Quality Board the level of hatchability reduction that should be allowed before impairment is declared. The standard will be directly linked to that reduction.

What does the ECx mean?

- ECx is the effect concentration (in the diet or egg) at which X% of the eggs that are incubated to full term do not hatch because of Se exposure (i.e., 100 - X% of the eggs hatch successfully despite Se exposure of the hen)
- Each range of values (diet or egg) is determined from a toxicity (or exposure effects) curve established in the laboratory[1]
- The curve helps define the effect, in this case a certain percentage (X%) of eggs not hatching, for a given Se concentration
- When birds are exposed to the ECx in the diet, or concentrations reach the ECx in the eggs, up to an additional X% hatching failure may occur (there are other causes that also naturally contribute to hatching failure)
- The population significance of this failure depends on other losses (e.g., predation, flooding of nests, etc.)

What does the ECx NOT mean?

- It does NOT mean that X% of the overall bird population using GSL will die
- The ECx being used considers hatching success and does not apply to other endpoints, such as effects on the adult population:
  - » Hatching success is a more sensitive endpoint than adult survival

What will the Science Panel provide to the Steering Committee?

- Recommended guidelines that relate tissue and water concentrations to a level of protection (ECx)
- Technical documentation of studies used to develop a model that relates Se in water to bird diet and then to bird eggs
- A palette of values relating tissue Se concentrations to water Se concentrations
- Recommendations for the water quality standard from each Science Panel member

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2. U.S. Department of the Interior (USDI). 1998. *Guidelines for Interpretation of the Biological Effects of Selected Constituents in Biota, Water, and Sediment*. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, Bureau of Indian Affairs, National Irrigation Water Quality Program Information Report 3.

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PROJECT 1A: CONCENTRATION AND EFFECTS OF SELENIUM ON SHOREBIRDS AT GREAT SALT LAKE, UTAH

OCTOBER 1, 200

PROJECT 1A: CONCENTRATION AND EFFECTS OF SELENIUM ON SHOREBIRDS AT GREAT SALT LAKE, UTAH

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INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972 (i.e. the Clean Water Act) mandated that each state identify the beneficial uses of its water bodies and establish water quality standards to protect those uses. The Great Salt Lake (GSL) is well known as one of North America's most important inland shorebird sites. At least 22 species of shorebirds utilize the GSL during migration and another eight species nest in habitats associated with the lake. The breeding populations of American Avocets (*Recurvirostra americana;* AMAV) and Black-necked Stilts (*Himantopus mexicanus*; BNST) are among the highest in North America (Aldrich and Paul 2002). Consequently, the GSL is recognized as a site of hemispheric importance within the Western Hemisphere Shorebird Reserve Network (Andres et al. 2006). Because of the lake's importance to shorebirds, as well as other waterbirds, aquatic wildlife habitat is listed as a beneficial use of the GSL. However, numeric water quality standards do not exist for the GSL.

A recent proposal by the Southwest Jordan Valley Groundwater Project to dispose of reverse osmosis concentrate within the south arm of the GSL has led to public concern over potential selenium contamination. Selenium (Se) is a toxic trace element that may disrupt avian development, and increase mortality (Ohlendorf et al. 1988, 1989). This concern has brought a renewed focus on the need for numeric water quality standards.

The transfer of Se into the GSL food chain occurs at the level of microorganisms and phytoplankton (Johnson et al. 2006). These organisms are consumed by both brine shrimp (*Artemia* spp.) and brine flies (*Ephydra* spp.), which in turn are likely a major component of shorebird diets within the GSL (Cavitt 2006). The development of a water quality standard requires the knowledge of current Se levels found within the water, sediments, macro-invertebrates, and shorebirds. This background information should also be coupled with the biological significance of these existing Se concentrations (e.g. effects on egg hatchability).

I compiled these data for two common shorebird species breeding at GSL, the AMAV and BNST. The objectives of this study included the following:

- Determine the diet of American Avocets and Black-necked Stilts at Great Salt Lake
- Measure the ambient concentration of Se in the water, sediment, and macro-invertebrates consumed by shorebirds
- Measure the concentration of Se within the blood and liver of American Avocets and Black-necked Stilts
- Measure the concentration of Se within the eggs of American Avocets and Black-necked Stilts
- Determine the hatchability, and breeding productivity of American Avocets and Black-necked Stilts

METHODS

Data were collected for this study from late April until August 2006.

Study sites

An aerial survey of the Great Salt Lake was flown on April 23, 2006. A flight pattern was chosen so that the southern shoreline, western shoreline, and eastern shoreline could be surveyed for aggregations of AMAV and BNST. This was followed by ground surveys (walking, ATV) and boat surveys (hovercraft) to refine and pinpoint study site locations (4/24/2006 – 5/12/2006).

Figure 1. Study sites monitored for this project during the 2006 breeding season.

As a result of these surveys, the following study areas were identified (Figure 1):

- *Antelope Island, Bridger Bay* – This study site is located at Bridger Bay adjacent to Antelope Island State Park. AMAV were observed foraging around a submerged roadway in the bay at water depths of approximately 60cm. No freshwater sources are found in the area. The study site is located at 41°02.662' N 112°15.857'W.

- *Ogden Bay* – This study site is located at the Ogden Bay Waterfowl Management Area along the eastern shore of the Great Salt Lake. AMAV and BNST were observed in large numbers during the surveys. Freshwater from the Weber River flows into the bay at this location and attracts large numbers of shorebirds and waterfowl. The study site is located at 41°12.038' N 112°14.597'W.

- *Saltair* – This study site is located along the south shore of the Great Salt Lake. The site receives freshwater inflows from the Kennecott wastewater discharge. Several AMAV pairs and one BNST pair were observed foraging in this location. The study site is located at 40°46.116' N 112°10.466'W.

- *West Carrington* – This area is the western-most study site and is located northwest of Badger Island. AMAV were observed foraging in salt water of ~ 10cm in depth. The coordinates of this study location are 40°56.037' N 112°36.588'W. No freshwater sources were observed in the area.

Adult collections for tissue and dietary analyses

Adult AMAV and BNST were randomly collected by shotgun (USFWS Permit # MB043593-0; UT Division of Wildlife Resources COR# 1COLL7037) at Antelope Island, Ogden Bay, and Saltair after ~ 15min. of active foraging. Following the collection, birds were dissected in the field. The mouth and pharynx were rinsed with 80% ethanol and the wash collected into plastic containers. In addition, the esophagus, proventriculus and ventriculus were each removed and stored in separate containers with 80% ethanol. Blood was collected from a ventricle of the heart using a sterile syringe and then placed within a 1.8-ml Nalgene® cryogenic vial. Each vial was labeled, and placed on ice until returned to the laboratory. A lobe of the liver (~ 5g) was removed, weighed, labeled and placed in a Whirl-pak® bag and stored on ice until returned to the laboratory. All liver and blood samples were frozen upon return to the laboratory and until shipment for analysis of total selenium content. All blood samples were analyzed as whole blood.

Gut contents were removed and food items identified to family and order using Merritt and Cummins (1984) and Voshell (2002). Invertebrates were counted and volumes determined for each taxon by water displacement. Data from samples were summarized as aggregate % volume.

Invertebrate samples

Food-item sampling areas (FISAs) were located from the point birds were first detected foraging, to the point where the adult was collected. Invertebrates within the FISAs were collected using sweep nets (Figure 2), sorted by taxon and life stage (i.e., larvae, pupae and adult), weighed, placed in ® bags and frozen for total selenium analysis. Every attempt was made to collect at three points within each FISA and to collect ~5g per taxon/life stage.

Figure 2. Sweep sampling for invertebrates at Ogden Bay Waterfowl Management Area.

Water and sediment samples

One to five water samples were collected from each FISA. Each water sample was a composite sample with 20% of the sample coming from each of five different sites systematically distributed across the FISA. Water was filtered through a 1-mm mesh to remove large items from the sample and stored at room temperature. After 48 hours, the water was then decanted into a Nalgene® bottle, to separate the water sample from any sediment, and shipped for analysis of total selenium content.

Three sediment samples were collected for each colony with a hand corer (5.08 cm diameter, 10 cm depth). The sediment sample was a composite sample with 20% of the composite sample coming from each of five sediment core samples collected from five sites

systematically distributed across each FISA. The sediment sample was stored under refrigeration until shipped for analysis of total Se.

Breeding productivity

Each study site was visited every three to four days from late April until early August to locate and monitor nests. Nests were located by either systematic searches of potential nesting sites or by observing the behavior of adults. We recorded the location of each nest with Magellan Explorist 100 Global Positioning System (GPS) unit. To facilitate relocating nests in dense colonies, each nest was marked with a 10-cm wooden tag, placed in the ground at the edge of the nest so only the top 3-4cm was visible (Figure 3). A unique nest identification number was written on each tag with permanent marker.

Because shorebirds lay only 1 egg/day, the laying date of first eggs (clutch initiation date) was determined by back-dating when nests were found prior to clutch completion. Clutch size was assigned for a nesting attempt only when the same number of eggs was recorded on two consecutive visits and there was evidence that incubation had commenced (i.e., adult behavior and egg temperature). Clutch initiation dates were also estimated for nests located after clutch completion and in which young successfully hatched. The incubation stages of nests found with complete clutches were estimated by egg flotation, which allowed for the prediction of hatching date.

The status of extant nests was determined by visitations every 3-4 days until either eggs hatched or the nest failed. Nests were defined as successful if at least one young hatched and survived to nest-leaving. Nests were presumed successful if eggs disappeared near the expected date of hatching and there was evidence of a successful hatching. This evidence included the presence of young, the presence of eggshell tops and bottoms near the nest, egg shell fragments ~1-5mm in size and detached egg membrane within the nest lining (Mabee 1997, Mabee et al. 2006). A failed nest was classified as depredated if all eggs disappeared prior to the expected date of nest-leaving and there was no basis for weather- or flood-induced mortality. Further evidence of egg depredation included eggshell pieces in the nest (> 5mm in size), and yolk within the nest material.

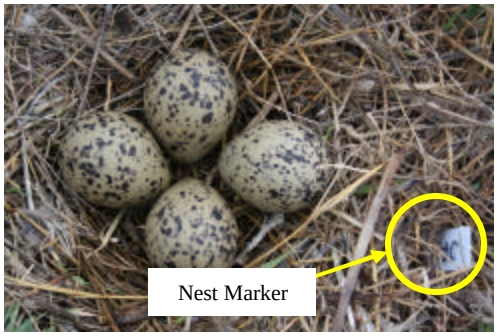

Figure 3. American Avocet nest illustrating nest marker used to uniquely identify nests.

For each nest we recorded the following information: date of clutch initiation, maximum number of eggs, clutch size, date of hatching, number of eggs hatched, number of young produced, and nest fate. From these data I was able to calculate hatchability, daily nest survival rate and nesting success. Hatchability of eggs is defined as the proportion of eggs present at hatching time that produce young (Koenig 1982). Consequently, eggs taken by nest predators or those flooded are not included in the calculation. Hatchability was calculated as # eggs hatched/# full term eggs in the nest. For nests where eggs were

removed for Se analysis, the formula was # eggs hatched /(# full term eggs in the nest - # eggs removed).

I examined nesting success by estimating daily survival rates (DSR) and their associated SE according to Mayfield's (1961, 1975) method as modified by Johnson (1979) and Hensler and Nichols (1986). The DSR (s) and the corresponding Mayfield estimator of nesting success (P_2) are calculated as:

$$P_2 = s^h = (1 - \frac{N_u}{E})$$

Where E = the total number of exposure days, N_u = total number of unsuccessful nests, and h = the mean laying period plus incubation period for successful clutches.

Variation in DSR between sites was compared using the program CONTRAST (Sauer and Williams 1989). The program is based on establishing variance-covariance matrices that contrast two or more DSRs and then comparing their differences with a chi-square distribution.

Egg collections / dissections

Eggs were collected to determine the incidence of embryo malpositions and malformations and to determine the concentration of selenium. A single, uncracked egg was randomly collected from a subset of nests early in the incubation period, from a subset of nests late in the incubation period and from dropped eggs found within colonies. Dropped eggs are defined as, "eggs laid on the ground without evidence of scraping" (Robinson et al. 1997). Because nest failure can be quite high at study sites, we collected dropped eggs to ensure there was a sufficient sample for analysis in the event of colony failure. Eggs were marked with a unique identification number, placed in an egg carton and transported to the laboratory. The nest identification number, GPS coordinates of the nest, number of eggs in the nest and estimated incubation stage were also recorded. All eggs were refrigerated upon arrival at the laboratory and dissected within 7 days. Each egg was weighed, and measured (maximal length and breadth) with calipers. A small window was cut at the blunt end of each egg just above the air cell. The stage of development, position of the embryo and condition were noted. Fertility of each egg was determined by the presence of a blastodisc. The normal position of the embryo during the later stages of development is with the head in the blunt end of the egg, with the head under the right wing and with the bill pointed toward the air cell. Malpositions were classified according to Romanoff and Romanoff 1972 as:

I. head between thighs,
II. head in small end of egg,
III. head under left wing,
IV. embryo rotated so that the bill not directed toward air cell,
V. feet over head,
VI. bill over right wing

The condition of the embryo was also noted, including absence of eyes and of limbs or limb buds; presence and number of digits on the feet; evidence of internal hemorrhage, edema, brain swelling, or failure of the body wall to completely close. When embryos were not present, the yolk was examined for the presence of a blastodisc. Egg contents were then placed in Nalgene® containers, labeled and frozen until shipment for analysis of total selenium.

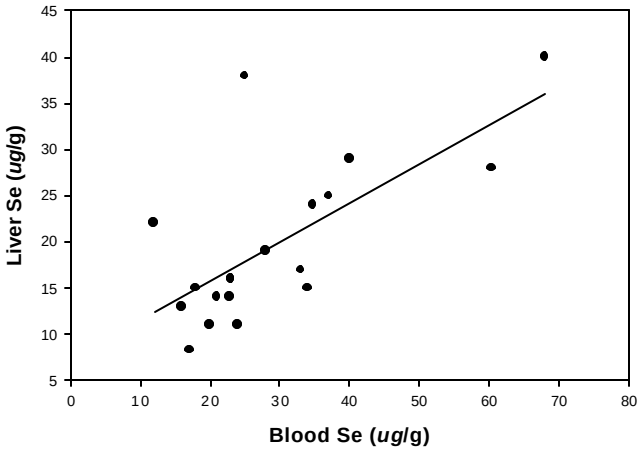

Figure 4. Relationship between blood and liver Se concentrations (µg/g dw) for both AMAV and BNST ($F_{1,18}$= 15.29, r^2 = 0.474, *P* = 0.001; 2 data points occur at the same position, 23 µg/g blood, 16 µg/g liver)

RESULTS

Because free-living birds vary in tissue moisture (e.g. Tieleman and Williams 2002, Tieleman et al. 2003), all tissue results reported below are on a dry-weight basis.

Adult tissue analysis

A total of 15 AMAV (5 each from Antelope Island, Ogden Bay, and Saltair) and 5 BNST (Ogden Bay) were collected for both dietary analysis and to examine total Se concentrations (µg/g dw) in liver and blood tissues (see Appendices 1 and 2 for data sets). I was unable to collect blood from one AMAV (6106-4-AML) taken at Antelope Island; thus, the number of blood samples included in AMAV analyses is only 14.

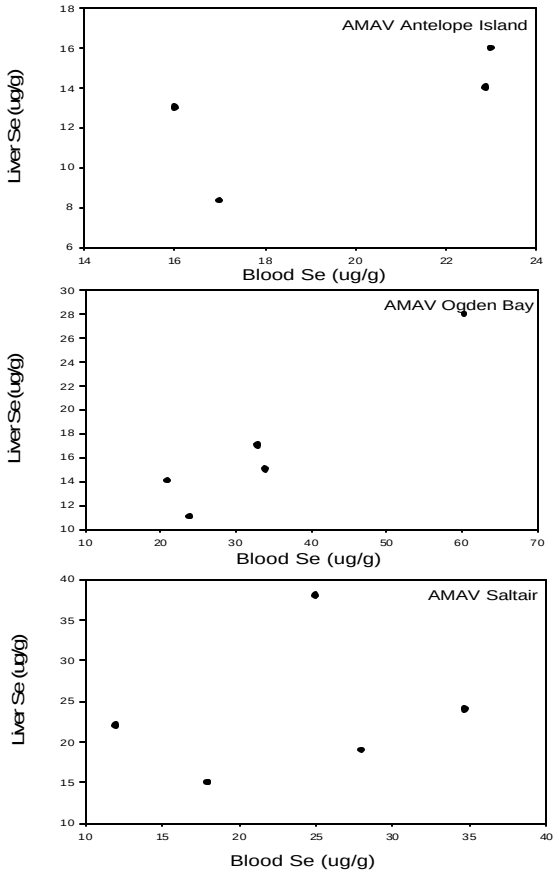

Figure 5. Relationship between blood and liver Se concentrations (µg/g dw) for AMAV by site. See text for statistics.

There was no significant relationship between the log-transformed concentrations of Se in the blood and liver for AMAV ($F_{1,13}$= 2.5, r^2 = 0.172, *P* = 0.140), but there was a significant positive relationship for BNST ($F_{1,4}$= 58.01, r^2 = 0.951, *P* = 0.005) and for both species combined ($F_{1,18}$= 15.29, r^2 = 0.474, *P* = 0.001; Figure 4). This suggests that for BNST both samples are reflective of current body

burden and dietary exposure. If the same data are examined on a site by species basis (Figures 5 and 6), there is a significant relationship between the Se concentration in the blood and liver for AMAV and BNST at Ogden Bay (AMAV - $F_{1,4}$= 36.23, r^2 = 0.924, *P* = 0.009; BNST - $F_{1,4}$= 58.01, r^2 = 0.951, *P* = 0.005), but not for AMAV at Antelope Island ($F_{1,3}$= 1.95, r^2 = 0.495, *P* = 0.297) or Saltair ($F_{1,4}$= 0.169, r^2 = 0.053, *P* = 0.709).

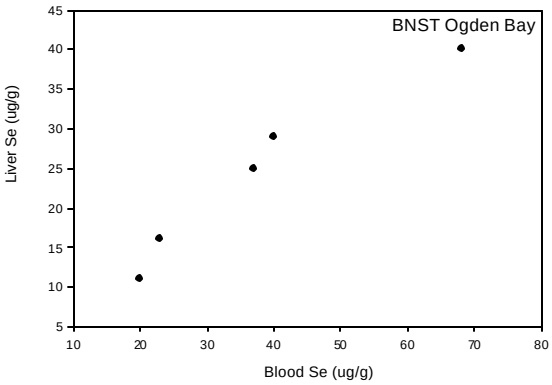

Figure 6. Relationship between blood and liver Se concentrations (µg/g *dw*) for BNST at Ogden Bay ($F_{1,4}$= 58.01, r^2 = 0.951, *P* = 0.005).

The mean blood and liver Se concentrations did not differ significantly between species (blood *t* = -1.54, *df* = 17, *P* = 0.141; liver *t* = -1.47, *df* = 18, *P* = 0.159; Figure 7). However, I have treated each species separately in the remaining analyses because the number of BNST in the analysis is small and they were restricted to a single site.

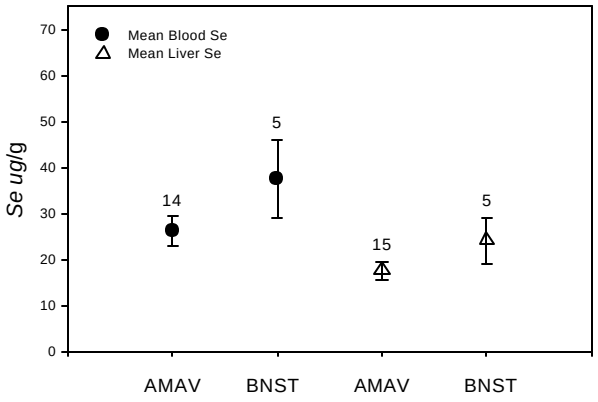

Figure 7. Mean ± std error of tissue Se concentrations (µg/g *dw*; (blood *t* = -1.54, *df* = 17, *P* = 0.141; liver *t* = -1.47, *df* = 18, *P* = 0.159).

AMAV adults had high blood Se concentrations (Figure 8), ranging from 12 - 60 µg/g *dw*. Likewise, liver Se concentrations were also high (Figure 9), ranging from 8.3 - 38 µg/g *dw*. There were no significant differences in blood Se concentration among sites ($F_{2,14}$ = 2.276, *P* = 0.149; Figure 8); however, adults collected from Ogden Bay tended to have a higher mean concentration relative to the other sites. The concentration of Se in AMAV liver tended to be higher at Saltair relative to either Ogden Bay or Antelope Island, although not significantly at α = 0.05 ($F_{2,14}$ = 3.79, *P* = 0.053). Males and females did not differ in blood Se concentration (*t* = -0.592, *df* = 12, *P* = 0.565), liver Se concentration (*t* = -1.733, *df* = 13, *P* = 0.107) or body mass (*U* = 11, *df* = 14, *P* = 0.170). There was a significant negative relationship between liver Se concentration and body mass (*r* = -0.54, *P* = 0.038; Figure 10A), but

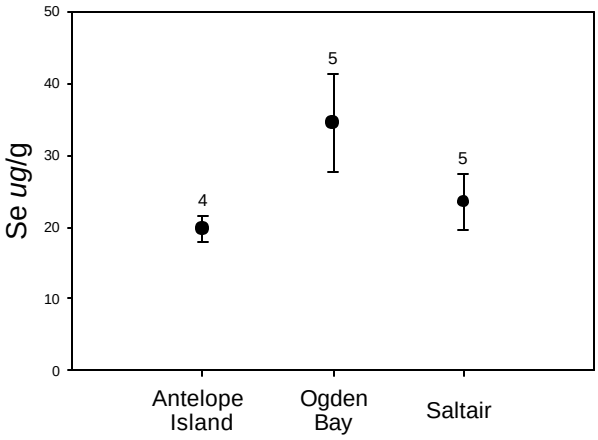

Figure 8. Mean ± std error AMAV blood Se concentration (µg/g *dw*) at each site sampled ($F_{2,14}$ = 2.276, *P* = 0.149).

no relationship with blood Se concentration (r = -0.04, P = 0.90).

BNST adults had high blood Se concentrations (Figure 6, 7), ranging from 20-68 µg/g *dw*. Liver Se concentrations were also high (Figure 6, 7) ranging from 11 - 40 µg/g *dw*. Since BNST were found nesting only at Ogden Bay, site comparisons could not be made for this species. The body mass of BNST tended to be lower for those birds with higher liver Se concentration (r = -0.826, P = 0.085; Figure 10B), and higher blood Se concentration (r = -0.796, P = 0.11) although not significantly. Since only a single female was collected, differences in Se tissue concentrations between sexes could not be tested.

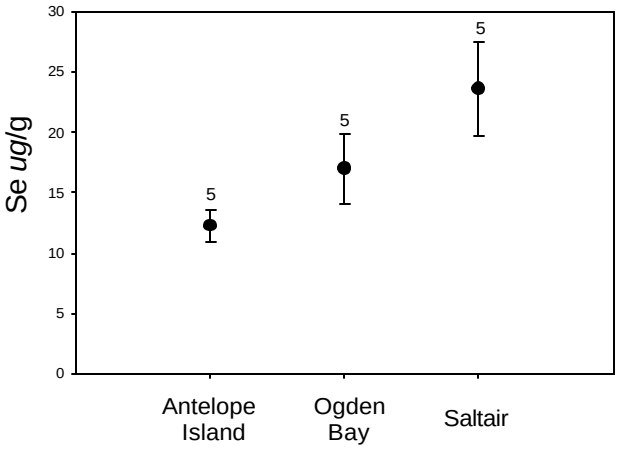

Figure 9. Mean ± std error AMAV liver Se concentration (µg/g *dw*) at each site sampled ($F_{2,14}$ = 3.79, P = 0.053) . Data provided in Appendix 1 and 2.

Diet

The diet of AMAV varied among sites. At Antelope Island, 100% of the food items recovered from the digestive tract (mouth, esophagus, proventriculus) were brine flies (Ephydridae; Figure 11). Seeds were recovered from the ventriculus of four individuals (Figure 12). At Ogden Bay, 66% of the aggregate volume of food items recovered were midges (Chironomidae) and 20% brine flies (Figure 11). At Saltair a larger proportion of brine flies (36%) were consumed at Ogden Bay but less than at Antelope Island (Figure 11).

BNST diets at Ogden Bay were somewhat more varied and included water boatmen (Corixidae), brine flies and beetles (Coleoptera; indicated by mandibles, and exoskeletons, Figure 13). The diets of each individual together with the corresponding tissue Se concentrations and body mass are presented in Appendices 1 and 2.

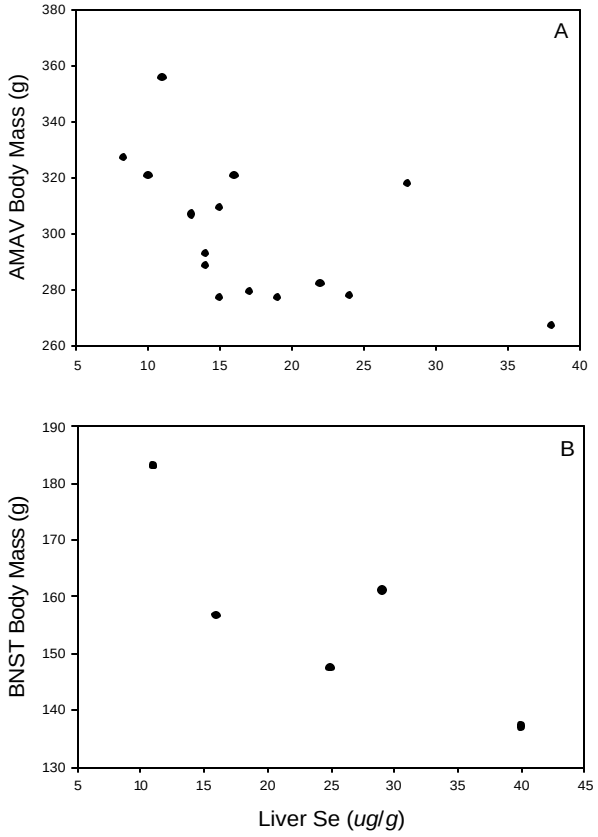

Figure 10. Relationship between AMAV (A- r = -0.54, P = 0.038) and BNST (B - r = -0.826, P = 0.085) body mass (g) and liver Se concentration (µg/g *dw*). Data provided in Appendix 1 and 2.

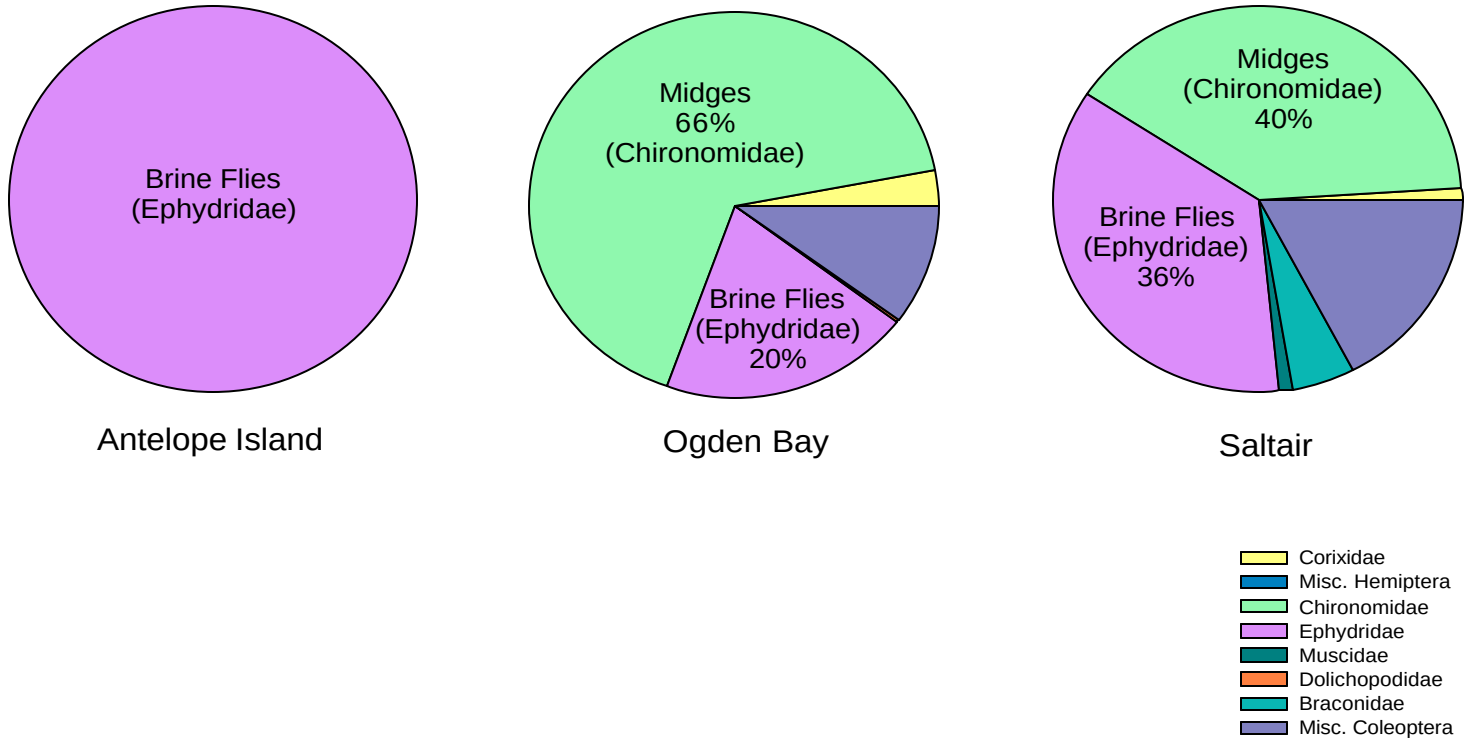

Figure 11. Aggregate % volume of food items recovered from AMAV digestive tracts (mouth, esophagus, and proventriculus) at each site.

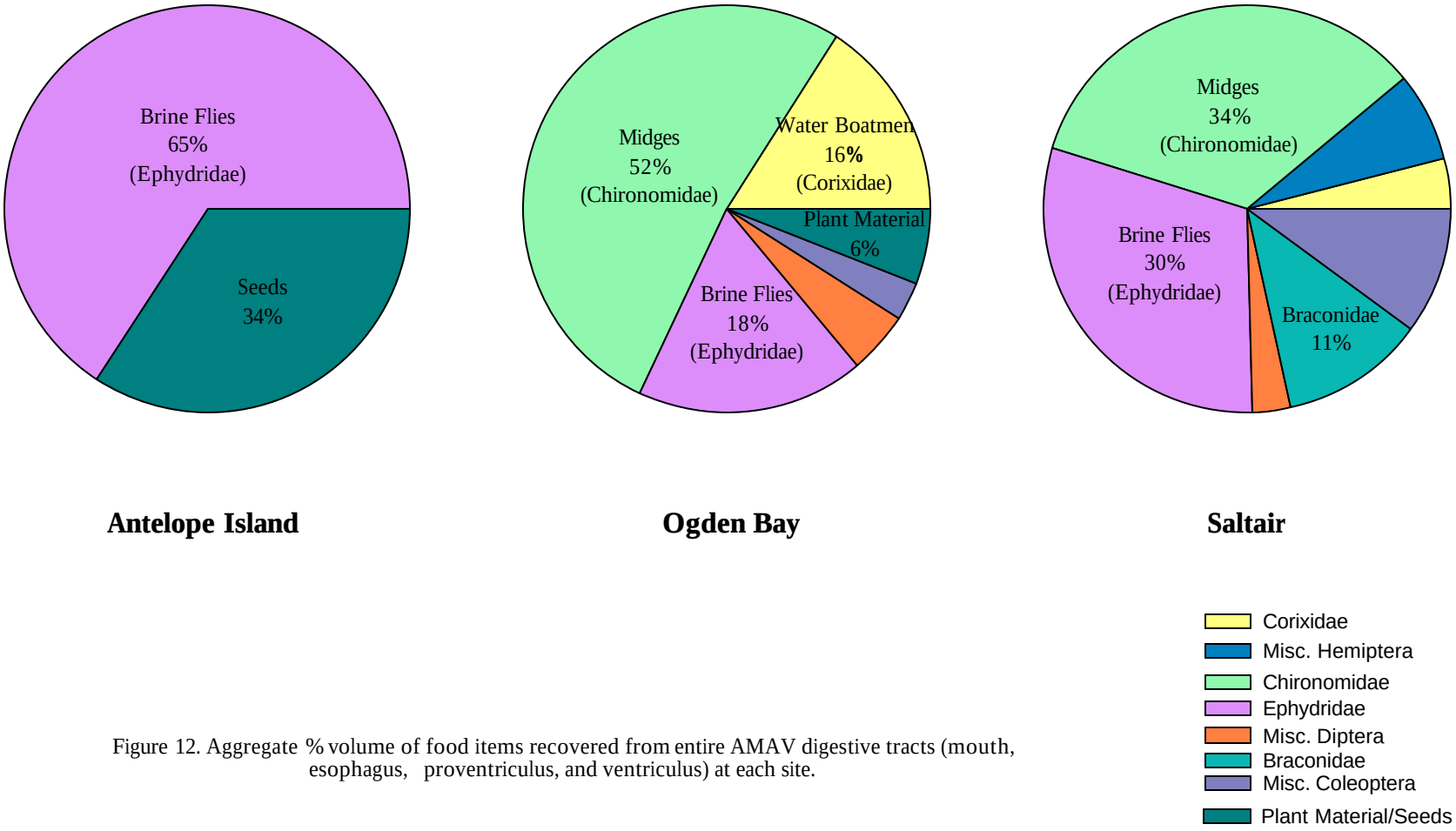

Figure 12. Aggregate % volume of food items recovered from entire AMAV digestive tracts (mouth, esophagus, proventriculus, and ventriculus) at each site.

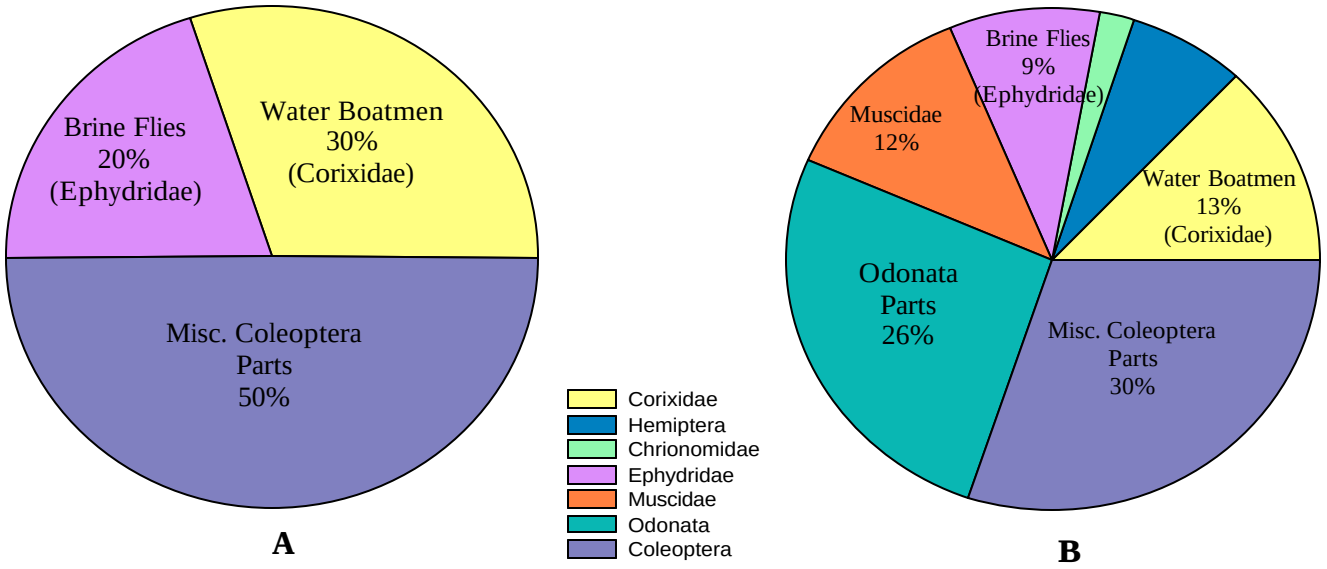

Figure 13. Aggregate % volume of food items recovered from BNST digestive tracts at Ogden Bay
A - mouth, esophagus, and proventriculus
B - mouth, esophagus, proventriculus and ventriculus

Invertebrates

The concentration of Se in invertebrates sampled ranged from 0.3 μg/g *dw* in snails at Ogden Bay to 3.8 μg/g *dw* in brine flies collected at Saltair. There were no significant differences in Se concentrations among stages of the brine fly life cycle (adult, larvae, pupae; $H = 2.61$, $df = 2$, $P = 0.271$). Consequently, all stages are considered together to compare among sites.

Brine fly Se concentration did not differ significantly among sites, yet individuals collected at Saltair tended to have a higher mean concentration relative to either Antelope Island or Ogden Bay ($F_{2,15} = 3.40$, $P = 0.065$). The Se concentrations of all invertebrates collected are reported in Appendix 3.

Water and sediments

The Se content of water samples taken from Saltair were significantly higher than those taken from either Antelope Island or Ogden Bay ($H = 7.2$, $df = 2$, $P = 0.004$; Figure 14). Although sediment samples did not differ significantly, a similar trend existed with Saltair having a greater median Se content relative to either Antelope Island or Ogden Bay ($H = 7.7$, $df = 2$, $P = 0.07$; Figure 15). The data sets for each sample are presented in Appendix 4.

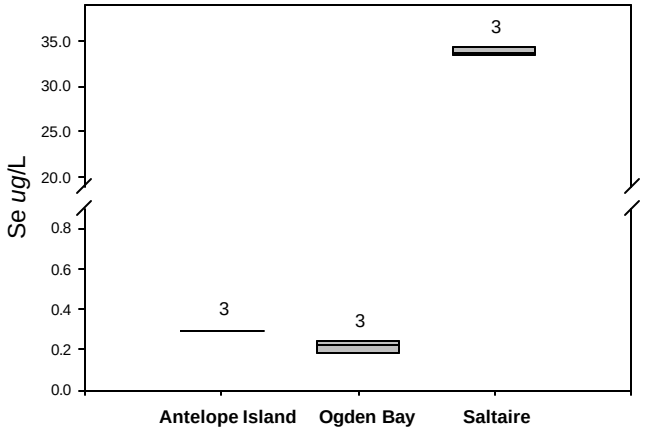

Figure 14. Median Se concentration of water samples collected at each site ($H = 7.2$, $df = 2$, $P = 0.004$).

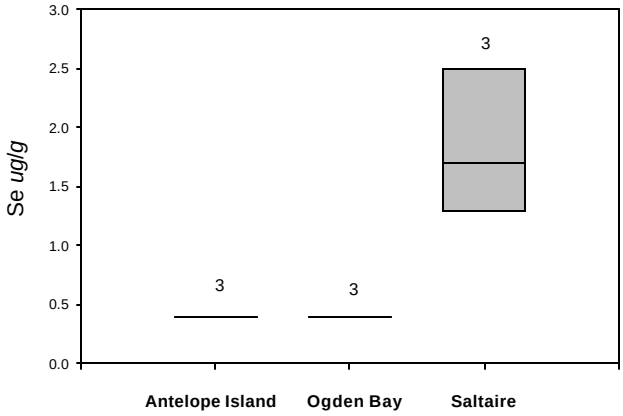

Figure 15. Median Se concentration of sediment samples collected at each site ($H = 7.7$, $df = 2$, $P = 0.07$).

Breeding productivity

Antelope Island, Bridger Bay - A total of 196 AMAV nests were identified and monitored throughout the breeding season at the Antelope Island Bridger Bay site (Figure 1 and 16). Two Snowy Plover (*Charadrius alexandrinus*) were also identified at this site (Figure 16). First eggs were laid at this site on 5/15, and the last young hatched on 7/13. The median date of clutch initiation for this colony was 6/9. A total of 669 eggs were laid with an average clutch size of 3.78 eggs/nest (range 2-5 eggs; modal clutch size= 4; Table 1). The site produced a total of 293 young with an average of 3.42 young produced per successful nest (Table 1). The hatchability of eggs was 0.94.

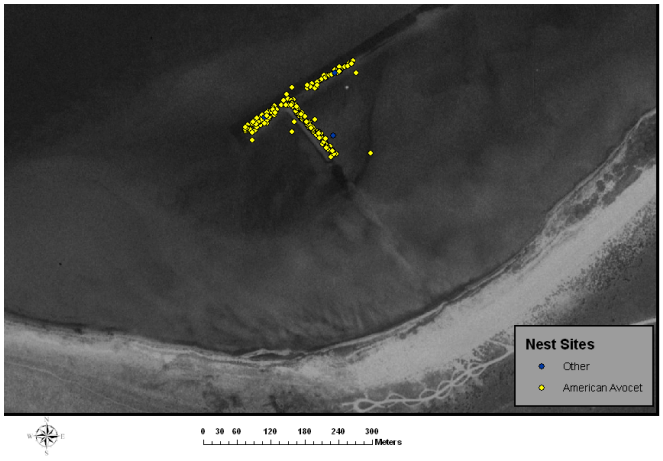

Figure 16. Nest site locations at Antelope Island, Bridger Bay. Nest sites are located along an old road bed.

The most common source of nest failure at this site was attributed to nest predation (50%, Figure 17). These nests were found with large egg shell fragments and occasionally with holes pecked into the side. California Gulls (*Larus californicus*) were consistently observed near the colony and have been seen taking both AMAV eggs and young at other locations (Robinson et al. 1997, Cavitt personal observation). The second most important source of nest failure was due to unknown causes (28%). These nests were also likely nest depredations but insufficient evidence was available to assign a fate to the nest.

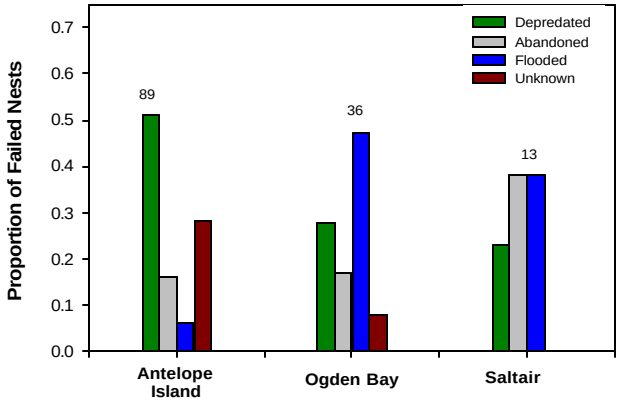

Figure 17. Causes of AMAV nest failure at each site.

The daily survival rate of nests at the Antelope Island site was 0.972 ± 0.003. This corresponds to a Mayfield nesting success estimate of 0.472.

Table 1. Productivity data collected for each study site (mean clutch size, hatchability and average number of young to nest leaving ± standard error).

Site	Species	Total Eggs Laid (total nests)	Clutch Size (n)	Hatchability (#nests/#eggs)	Total Young Produced	Average # Young Leaving/Nest (n)
Antelope Island	AMAV	669 (196)	3.77 ± 0.05 (90)	0.94 ± 0.01 (86/308)	293	3.42 ± 0.08 (86)
Ogden Bay	AMAV	296 (90)	3.77 ± 0.08 (44)	0.97 ± 0.02 (40/138)	137	3.34 ± 0.10 (41)
	BNST	137 (39)	3.84 ± 0.09 (19)	1.0 ± 0 (18/58)	70	3.33 ± 0.10 (21)
Saltair	AMAV	32 (13)	4.0 ± 0 (2)	-	0	-

Ogden Bay - A total of 90 AMAV and 39 BNST nests were identified and monitored throughout the breeding season at the Ogden Bay site (Figure 1 and 18). Nests of other species located at Ogden Bay included, two Mallards (*Anas platyrhynchos*), three Redheads (*Aythya americana*), two Wilson's Phalaropes (*Phalaropus tricolor*) and one Killdeer (*Charadrius vociferus*). First AMAV eggs were laid at this site on 5/10, and the last young hatched on 7/25. BNST initiated nests five days later on 5/15 and the last young hatched on 7/25. The median date of clutch initiation was 6/13 for AMAV and 6/8 for BNST. A total of 296 AMAV eggs were laid with an average clutch size of 3.77 eggs/nest (range 2-5 eggs; modal clutch size= 4; Table 1). BNST laid a total of 137 eggs with an average clutch size of 3.84 eggs/nest (range 2-5 eggs; modal clutch size= 4; Table 1). The site produced a total of 137 AMAV young with an average of 3.34 young produced per successful nest (Table 1) and 70 BNST young with an average of 3.33 young/successful nest. Hatchability data are presented in Table 1.

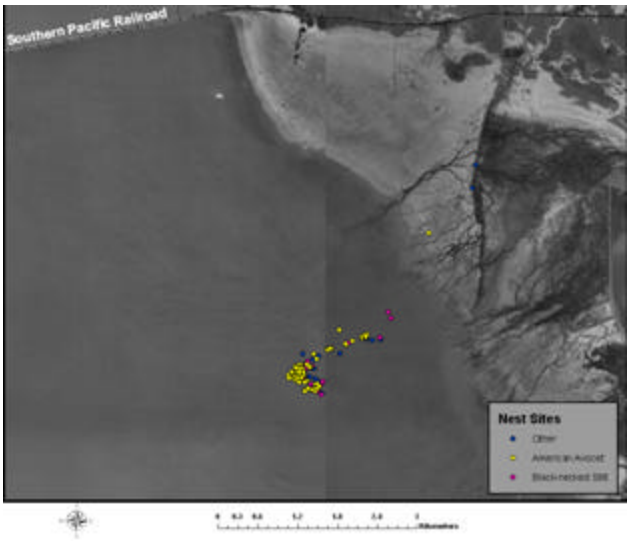

Figure 18. Nest site locations at Ogden Bay.

The most common source of nest failure at this site for both species was flooding, followed by nest predation (Figure 17). Because nests were located at the terminal end of the Weber River and along the shoreline of the Great Salt Lake, they were very susceptible to abrupt changes in water level. The flooding event that was responsible for the flooding nest losses occurred between 6/9 and 6/10 when 2.18 cm of rain fell and flooded 17 AMAV and 6 BNST nests.

The daily survival rate of AMAV nests at the Ogden Bay site was 0.979 ± 0.02. This corresponds to a Mayfield nesting success estimate of 0.56. The daily survival rate of BNST nests was 0.98 ± 0.006 and a Mayfield nesting success estimate of 0.61.

Saltair – A total of 13 AMAV nests were located and monitored at this site (Figure 1 and 19). This site did not produce any successful nests but the last date a nest was observed active at the site was on 6/10. A total of 32 eggs were laid but no young were produced. One of the major sources of nest failure at this site was a flooding event (Figure 17) that occurred between 5/28 and 5/30 which destroyed five nests. A total of 0.9 cm of rain was received at the Salt Lake International Airport on 5/27 and 5/28. Like the nesting aggregations at Ogden Bay, all the AMAV nests were along the shoreline of the Great Salt Lake and within the outflow of the Kennecott wastewater discharge. Consequently they were vulnerable to increased outflows.

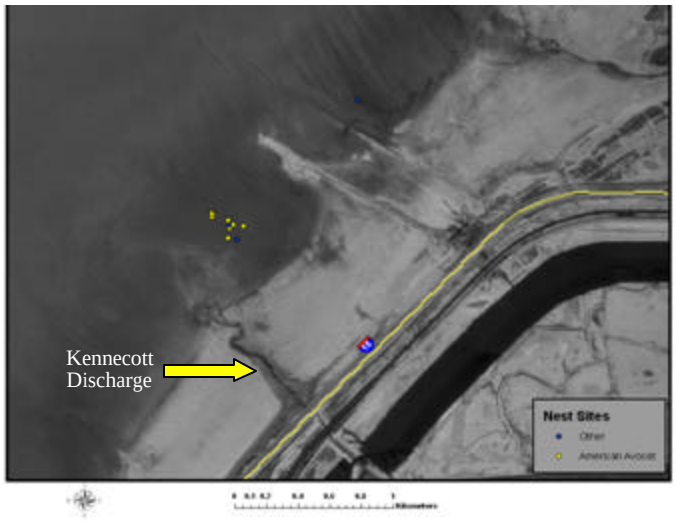

Figure 19. Nest site locations at Saltair.

Because so few birds were nesting at this site and because we were concerned that predation or additional flooding could jeopardize the collection of useable data, we collected a single egg from each of four newly initiated nests. These collections resulted in the abandonment of the nest due to our disturbance.

West Carrington – On 5/24 a few pairs of AMAV were observed on a small island in West Carrington Bay (Figure 1 and 20). A single nest was discovered on the island and an egg was collected. On 5/27 we only monitored the colony from a distance because of an approaching storm. At this visit we noted that an additional four birds were attending nests on the island. Three days latter on 5/30 we reached the island to discover that the entire colony had been abandoned with no signs of eggs or egg fragments. A Common Raven (*Corvus corax*) nest was located within 100m of the colony and may have contributed to the colony's abandonment. This species has been known to take both eggs and adult AMAV (Robinson et al. 1997). The site was revisited on several occasions but renesting never occurred. Two Snowy Plover nests were also located at this site.

Figure 20. Nest site location at West Carrington.

There were no significant differences between Antelope Island and Ogden Bay in AMAV hatchability (U = 1611.5, df = 1, P = 0.352) or DSR (X^2 = 0.048, df = 1, P = 0.83).

Egg collections/dissections

A total of 70 eggs (53 AMAV, 17 BNST) were collected, dissected and analyzed for total Se content (Table 2, Appendix 5). Nest visit data are included for nests in which eggs were collected (see Appendix 6). There were no malformations identified in the dissected embryos. Four eggs were classified as infertile. Two of the four were dropped AMAV eggs (one each from Ogden Bay and Saltair) and the other two infertile eggs were collected from AMAV nests at Ogden Bay where the remainder of the eggs successfully hatched. One AMAV egg collected from Antelope Island (AML-03-06, 17 + days old) had a possible Type I malposition. No other malpositions were observed. The fates of nests from which the eggs were collected are presented in Table 2.

In order to determine if the Se concentrations of eggs affected the fate of nests, comparisons were made within each sampling site. When only a single nest fate was represented within a sample, it was not included in the analysis. The Se concentration of AMAV eggs collected from nests that were ultimately successful at Antelope Island were significantly lower (mean ± se = 2.15 ± 0.08; n = 15) relative to eggs collected from nests that later were depredated (2.85 ± 0.05; n = 2) and those nests which later failed for unknown causes (2.7 ± 0.1; n = 2; $F_{2,18} = 6.670$, $P = 0.008$). Eggs collected from nests ultimately deserted at Saltair had significantly lower Se concentrations (3.78 ± 0.56; n = 4) relative to eggs whose nests later flooded (7.1 ± 1.1; n = 3; $t = -2.87$, $df = 5$, $P = 0.035$). No differences were found with nest fate for either AMAV or BNST at Ogden Bay (AMAV - $t = 0.309$, $df = 18$, $P = 0.761$; BNST - $F_{2,14} = 0.843$, $P = 0.454$).

To examine if AMAV eggs collected from nests with low hatchability had higher Se concentration, nests were classified as either complete (hatchability = 1.0), or low (hatchability < 1.0) and then Se concentrations compared with a t-test. There was no significant effect of Se concentration on the hatchability of AMAV eggs ($t = 0.12$, $df = 25$, $P = 0.905$).

The mass of eggs collected did not differ significantly among sites ($F_{2,48} = 0.251$, $P = 0.779$). However, sites differed significantly in the median Se concentration of eggs ($H = 19.07$, $df = 2$, $P = 0.001$). Eggs collected at Saltair were significantly higher in median Se concentration (5.4 µg/g *dw*) relative to both Antelope Island (2.2 µg/g *dw*) and Ogden Bay (2.0 µg/g *dw*, Figure 21).

Table 2. Ultimate fate of nests from which eggs were collected for Se analysis.

Fate of nest	**Site**				
	Antelope Island	Ogden Bay		Saltair	West Carrington
	AMAV	AMAV	BNST	AMAV	AMAV
Success	15	13	9		
Depredated	2	1	3		1
Flooded	1	1	1	3	
Abandonment	1			4	
Failure unknown	2	1	1		
Dropped eggs (no nest)		7	3	1	
Total	**21**	**23**	**17**	**8**	**1**

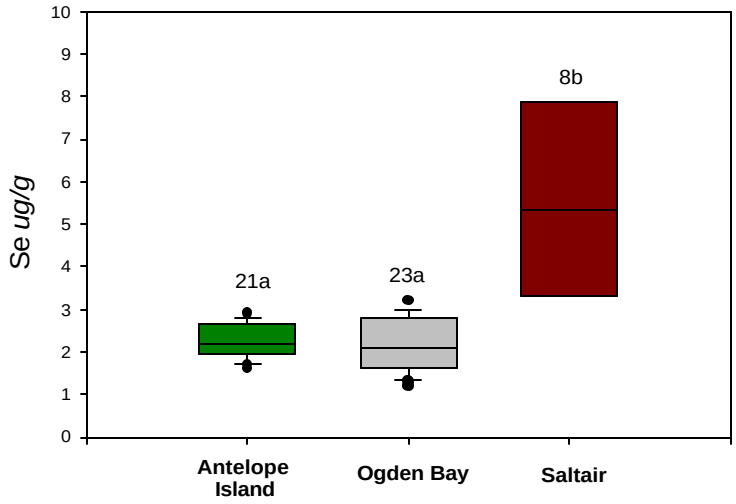

Figure 21. Median concentration of Se (µg/g *dw*, upper and lower quartiles) in eggs collected from each site ($H = 19.07$, $df = 2$, $P = 0.001$). Boxes with the same letter are not significantly different. Dots represent upper and lower extreme values. Sample sizes are located above each box plot.

DISCUSSION

The Se concentrations found within water samples collected at both Antelope Island and Ogden Bay were within reported average background levels (USDI 1998). However, the dissolved Se concentrations within water samples taken at Saltair (median = 33.7 μg/L) were much higher than reported background levels. Saltair water samples were also significantly higher relative to either Ogden Bay (median = 0.22 μg/L) or Antelope Island (median = 0.29 μg/L) samples. The Saltair site receives freshwater inflows from the Kennecott wastewater discharge. This discharge site drains the Kennecott Utah Copper Mine's tailings impoundment and thus high levels of Se entering the GSL at this site are not surprising. The dissolved Se concentrations within water samples at Saltair were high enough to warrant concern. At Kesterson National Wildlife Refuge, where Se toxicity produced high egg mortality and deformities within shorebirds and waterfowl, Se levels ranged from 15 – 350 μg/L (Ohlendorf et al. 1986, Ohlendorf et al. 1988).

The most important food items consumed by AMAV were chironomids (0-66% of total volume) and brine flies (20-100% of total volume). At Antelope Island, AMAV consumed exclusively brine flies but at Ogden Bay, where a significant freshwater inflow from the Weber River exists, AMAV consumed a more diverse diet of chironomids, brine flies, coleopteran larvae, and corixids. These results are consistent with data collected at other wetland sites within the GSL ecosystem (Cavitt 2006).

At Ogden Bay where AMAV and BNST co-occur, differences in diet were evident. BNST consumed more corixids (30% of total volume) and coleopteran larvae (50% of total volume) whereas AMAV diet consisted of a greater proportion of chironomids (66% of total volume). Data from this and other studies at GSL suggest that AMAV select food items in proportion to their availability within foraging sites, whereas BNST are more selective in their diet (Cavitt 2006).

Because of their importance in the diet of AMAV, brine fly larvae may represent a food chain link for the transfer of Se. The concentration of Se within brine fly larvae ranged from 0.8 to 3.8 μg/g *dw*. Brine fly larvae collected at Saltair tended to have a higher concentration of Se relative to the other sites. Unfortunately, only a single sample of chironomid larvae could be collected; the Se concentration of this sample collected at Ogden Bay was 2.0 μg/g *dw*. Maier and Knight (1994) reported a range of ambient selenium concentrations of 0.5 to 2.0 μg/g *dw* in invertebrates. Seven of the 16 brine fly samples were above the Maier and Knight (1994) upper background concentrations. Four of the five Saltair brine fly samples from FISAs were above 2.0 μg/g *dw* and one Saltair FISA sample had the highest Se concentration (3.8 μg/g *dw*) found within all macro-invertebrates collected. Although brine shrimp were not a major food item consumed by either AMAV or BNST collected for this study, their Se concentration were also high (range 2.5 – 3.2 μg/g *dw*). Lemly (1996a, 1996b) reported that Se concentrations in bird diets that are greater than 3 μg/g *dw* are above the toxicity threshold for sensitive species.

The Se concentrations found within the blood and livers of both AMAV (*mean* ± *se* – blood = 26.4 ± 3.2 µg/g *dw*; liver = 17.6 ± 2.0 µg/g *dw*) and BNST (blood = 37.6 ± 8.5 µg/g *dw*; liver = 24.2 ± 5.0 µg/g *dw*) were higher than expected based on concentrations found within invertebrate food sources. Furthermore, these concentrations are much higher than average background levels reported for these tissues (USDI 1998). Selenium concentrations in whole blood above 2 *ppm* are of concern and 5 *ppm* is a suggested threshold of toxicity (USDI 1998, Santolo and Yamamoto 1999). Background Se concentrations in liver tissue has been reported as less than 10 *ppm* (6.0 – 9.9 in recurvirostids; USDI 1998). However in this study AMAV had liver Se concentrations ranging from 8.3 – 38 *ppm* and BNST ranging from 11 – 40 *ppm*. Concentrations of Se in whole blood of predatory birds from a contaminated site in California ranged from 1.5 *ppm* to 38 *ppm*.

One possible explanation for the high Se concentrations found at GSL may be an interaction with elevated mercury (Hg) concentrations (Santolo and Ohlendorf 2006). Both Hg and Se seem to act antagonistically forming a stable complex. This complex may act to increase both the retention and buildup of Hg and Se in tissues. Studies have been initiated to examine this potential relationship.

The significant negative relationship found between AMAV liver Se concentrations and body mass suggest that these elevated levels may affect adult body condition. Previous studies have also reported reduced body mass (e.g., Ohlendorf et al. 1988, Smith et al. 1988, Ohlendorf et al. 1990, Heinz and Fitzgerald 1993) or lean mass (Yamamoto and Santolo 2000) in birds exposed to elevated levels of Se. This relationship may have important survival consequences for migratory shorebirds like the AMAV, as they must obtain sufficient reserves following reproduction to prepare for the prebasic molt and fall migration. However, mass loss is a complex physiological process in birds and has been demonstrated in some species to be adaptive (e.g. Cavitt and Thompson 1997). Consequently more studies are needed to understand the relationship between Se concentration and adult body conditions in shorebirds.

Despite the elevated levels of Se found within adult tissues, egg Se concentrations were relatively low. It is widely accepted that elevated Se levels can reduce the reproductive success of birds (Ohlendorf et al. 1988, 1989, Heinz et al. 1989, Adams et al. 2003); however, the threshold level at which negative effects occur is unclear. The suggested threshold of egg Se concentrations range from 6 µg/g to 16 µg/g (USDI 1998, Fairbrother et al. 1999, 2000, Adams et al. 2003, and Ohlendorf 2003). None of the BNST eggs collected were above 6 µg/g *dw* and 5.5% of AMAV eggs analyzed were above this level (range 1.2 – 9.2 µg/g *dw*). However, all AMAV eggs above this lower threshold were collected at Saltair. Although I did not observe any developmental abnormalities of embryos, the median Se concentrations of eggs (5.4 µg/g *dw*) was significantly higher at Saltair relative to the other sites.

The results of this study also indicate that on a population level, AMAV and BNST productivity at Antelope Island and Ogden Bay are not impacted by existing levels of Se in eggs. Due to nest depredation and flooding events I was unable to determine hatchability data for birds nesting at either Saltair or West Carrington. However, hatchability at Antelope Island and Ogden Bay ranged from 0.94 to 1.0. Hatchability of BNST eggs at Bear River

Migratory Bird Refuge, located in the north arm of the GSL, was found to be 0.95 for 24 nests during the 1980's (Sordahl 1996). In central Oregon, AMAV hatchability was only 0.9 for 59 nests monitored (Gibson 1971). In contrast, Ohlendorf et al. (1989) reported hatchability rates of 0.876 for BNST breeding at Kesterson Reservoir. On average the hatchability for uncontaminated populations of aquatic birds seems to be above ~ 0.91 (Ohlendorf 1989). Recent estimates of hatchability for AMAV and BNST at other sites within the GSL are also consistent with the rates found in this study. For example, at Farmington Bay Waterfowl Management Area, hatchability rates estimated from 2005 and 2006 are as follows: AMAV = 0.93, 0.96; BNST = 0.96, 0.97 (Cavitt 2006). Furthermore, Mayfield estimates of AMAV nesting success at Antelope Island (0.472) and Ogden Bay (0.56) are comparable to recent estimates at other sites within the GSL (Farmington Bay – 0.56; Bear River – 0.45 - 0.56; Cavitt 2006).

A single field season of data may be insufficient to adequately describe background levels of Se within the GSL and its potential impacts on AMAV and BNST. However, the data collected during the 2006 breeding season suggest that the concentration of Se found in water samples, food chain invertebrates and eggs at Antelope Island and Ogden Bay were low and within typical background levels reported elsewhere. Data collected at Saltair however, are elevated relative to the other sites. Since Saltair receives freshwater inflows from the Kennecott wastewater discharge, a shallow emergent wetland attractive to breeding shorebirds has developed.

The concentrations of Se found within adult tissues (blood and liver) were elevated and warrant additional study. Santolo and Ohlendorf (2006) suggest an interaction with Hg as an explanation. Additional studies were initiated during the 2007 breeding season to match Se and Hg concentrations of blood, liver and eggs from female AMAV.

SUMMARY

Selenium concentrations in blood from nesting birds on the Great Salt Lake were higher than expected given the concentrations found in livers, eggs and diets. In selenium feeding studies of mallards (Anas platyrhynchos; Heinz and Fitzgerald 1993) and American kestrels (Falco sparverius; Yamamoto et al. 1998), blood selenium concentrations did not significantly exceed dietary concentrations and were similar to diet concentrations after four to eight weeks. Concentrations of selenium in predatory terrestrial birds (kestrel, red-tailed hawk [Buteo jamaicensis], northern harrier [Circus cyaneus], barn owl [Tyto alba], and loggerhead shrike [Lanius ludovicianus]) from a contaminated grassland in California ranged from 1.5 to 38 µg/g dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 µg/g dry weight are considered to exceed normal background, and 5 µg/g dry weight is considered a provisional threshold indicating that further study is warranted (UDSI 1998). However, toxicity studies of marine species were not reviewed for the development of those guidelines, and the ecotoxicology of selenium to marine birds may differ from that for other species. For example, female spectacled eiders (Somateria fischeri) nesting on the Yukon-Kuskokwim Delta, Alaska, in 1996 had mean selenium concentrations in their blood (64 µg/g dry weight; Wilson et al 2004) that were higher than found in birds from the Great Salt Lake, but estimated mean concentration in their eggs (about 3.84 µg Se/g dry weight, converted from wet weight) that was only slightly higher than typical background for freshwater birds, and there was no significant effect of selenium on nest success or egg viability (Grand et al. 2002).

Studies are being conducted to determine the cause of the apparent anomaly in Great Salt Lake birds. Inter-laboratory comparisons are being conducted to validate the laboratory results for selenium, and blood and livers from additional Great Salt Lake birds are being analyzed. The new samples will be analyzed for mercury in addition to selenium, because of possible interactions that might increase bioaccumulation and retention of selenium in blood by the birds. We expect these studies, along with information obtained from the literature, to help us understand the high concentrations of selenium in blood.

ACKNOWLEDGEMENTS

Many thanks to the staff and managers of Antelope Island State Park, Kennecott Utah Copper, Ogden Bay Waterfowl Management Area, and US Magnesium for their support and access to study sites. Harry Ohlendorf and Gary Santolo, CH2M Hill, provided guidance on all aspects of this project and have greatly improved drafts of this manuscript with their comments and suggestions. Thanks also to Theron Miller and Bill Moellmer, Utah Division of Water Quality, for many stimulating conversations and assistance in identifying study sites. A debt of gratitude is owed to the many field assistants who endured the rigors of field research at Great Salt Lake including, Lindsay Anderson, Chris Bryan, Sunee Buck, Jen Cary, Nate Cooney, Jannette Dickinson, Christian Edwards, Kate Ennenga, Matt Fisher, Amber Freeland, Mike Gamble, Karla Krause, Aaron Layton, Andy McFadden, Trina Nixon, Brian Oney, Trey Parker, Shane Pearson, Josh Shepard, Nicole Snow, and Kyle Stone. Special thanks to Jen Cary, Christian Edwards, Kyle Stone, Rich Emerson, and Karla Krause for assistance with data entry and analyses.

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APPENDIX 1. Volume (cm^3) of food items recovered (mouth, esophagus, and proventriculus) and corresponding concentration of Se ($\mu g/g\ dw$) of tissues and adult body mass (wet weight) from adults collected at each study site (ANTI – Antelope Island, OGBA – Ogden Bay, SALT – Saltair).

Bird #	Species	Sex	Location	Blood Se	Liver Se	Mass (g)	Corixidae	Carabidae	Coleoptera parts	Chironomidae	Ephydridae	Muscidae	Dolichopodidae	Ceratopogonidae	Braconidae	Plant Material	Other
6106-1-AML	AMAV	F	ANTI	22.9	14	288.5	-	-	-	-	0.01	-	-	-	-	-	-
6106-2-AML	AMAV	M	ANTI	23	16	320.4	-	-	-	-	0.01	-	-	-	-	-	-
6106-3-AML	AMAV	M	ANTI	17	8.3	326.8	-	-	-	-	-	-	-	-	-	-	-
6106-4-AML	AMAV	F	ANTI	-	10	320.8	-	-	-	-	-	-	-	-	-	-	-
6106-5-AML	AMAV	M	ANTI	16	13	306.6	-	-	-	-	-	-	-	-	-	-	-
6606-1-JFC	AMAV	M	OGBA	60.4	28	317.9	-	-	-	0.01	-	-	-	-	-	0.01	-
6606-2-JFC	AMAV	M	OGBA	33	17	279.2	-	-	-	0.01	-	-	-	-	-	-	-
6606-3-JFC	AMAV	M	OGBA	34	15	276.9	0.3	-	-	1.38	0.01	0.03	-	0.01	-	-	-
6606-4-JFC	AMAV	F	OGBA	21	14	292.9	-	-	-	-	0.05	-	-	-	-	-	-
6606-5-JFC	AMAV	F	OGBA	24	11	355.7	-	-	-	0.03	-	-	-	-	-	-	-
61306-1-AML	BNST	M	OGBA	23	16	156.7	-	-	0.02	-	-	-	-	-	-	-	-
61306-2-AML	BNST	F	OGBA	20	11	183.1	-	-	0.02	-	-	-	-	-	-	-	0.01
61306-3-AML	BNST	M	OGBA	40	29	161	-	-	-	-	0.01	-	-	-	-	-	-
6706-1-JFC	BNST	M	OGBA	68	40	137.2	0.01	-	-	-	-	-	-	-	-	-	-
6706-2-JFC	BNST	M	OGBA	37	25	147.5	0.01	-	0.01	-	-	-	-	-	-	-	-
6606-10-AML	AMAV	M	SALT	28	19	277.1	-	-	0.01	-	0.01	-	-	-	-	-	-
6606-6-AML	AMAV	M	SALT	18	15	309.1	-	-	-	1.2	0.22	-	0.06	-	0.26	-	-
6606-7-AML	AMAV	M	SALT	34.7	24	277.7	0.08	-	-	0.98	0.78	-	0.04	-	0.09	-	-
6606-8-AML	AMAV	M	SALT	12	22	281.9	-	-	0.01	0.02	0.02	-	-	-	-	-	-
6606-9-AML	AMAV	M	SALT	25	38	267.3	-	-	-	-	-	-	-	-	-	-	-

APPENDIX 2. Volume (cm^3) of food items recovered from the entire digestive tract (mouth, esophagus, and proventriculus, ventriculus), corresponding concentration of Se ($\mu g / g$ *dw*) of tissues, and adult body mass (wet weight) from adults collected at each study site (ANTI – Antelope Island, OGBA – Ogden Bay, SALT – Saltair).

Bird #	Species	Sex	Location	Blood Se	Liver Se	Mass (g)	Cordulegadae	Zygoptera	Macrovelidae	Corixidae	Carabidae	Hydrophilidae	Coleoptera parts	Chironomidae	Ephydridae	Muscidae	Dolichopodidae	Ceratopogonidae	Braconidae	Plant Material	Other
6106-1-AML	AMAV	F	ANTI	22.9	14	288.5	-	-	-	-	-	-	-	-	0.07	-	-	-	-	0.05	-
6106-2-AML	AMAV	M	ANTI	23	16	320.4	-	-	-	-	-	-	-	-	0.22	-	-	-	-	0.02	-
6106-3-AML	AMAV	M	ANTI	17	8.3	326.8	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-
6106-4-AML	AMAV	F	ANTI	-	10	320.8	-	-	-	-	-	-	-	-	0.10	-	-	-	-	0.03	-
6106-5-AML	AMAV	M	ANTI	16	13	306.6	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-
6606-1-JFC	AMAV	M	OGBA	60.4	28	317.9	-	-	-	0.02	0.01	-	-	0.24	-	-	-	0.01	-	0.01	-
6606-2-JFC	AMAV	M	OGBA	33	17	279.2	-	-	-	0.01	0.01	-	-	0.04	0.08	0.02	-	-	-	0.01	-
6606-3-JFC	AMAV	M	OGBA	34	15	276.9	-	-	-	0.6	-	-	-	1.78	0.02	0.05	-	0.01	-	0.03	-
6606-4-JFC	AMAV	F	OGBA	21	14	292.9	-	-	-	0.03	-	-	-	0.14	0.14	0.01	-	-	-	-	-
6606-5-JFC	AMAV	F	OGBA	24	11	355.7	-	-	-	0.08	-	-	-	0.12	-	0.01	-	-	-	0.02	-
61306-1-AML	BNST	M	OGBA	23	16	156.7	-	0.02	-	-	-	-	0.04	-	-	0.01	-	-	-	-	-
61306-2-AML	BNST	F	OGBA	20	11	183.1	-	-	-	0.02	-	-	0.02	-	-	-	-	-	-	-	0.01
61306-3-AML	BNST	M	OGBA	40	29	161	-	-	-	-	-	-	-	-	0.04	0.05	-	-	-	-	-
6706-1-JFC	BNST	M	OGBA	68	40	137.2	0.03	-	-	0.03	-	0.01	0.12	-	0.02	-	-	-	-	-	-
6706-2-JFC	BNST	M	OGBA	37	25	147.5	-	-	0.03	0.04	-	-	0.01	0.01	-	-	-	-	-	-	-
6606-10-AML	AMAV	M	SALT	28	19	277.1	-	-	-	-	-	-	0.04	-	0.05	-	-	-	-	-	0.05[1]
6606-6-AML	AMAV	M	SALT	18	15	309.1	-	-	-	-	-	-	0.01	1.65	0.30	-	0.08	-	0.36	0.01	-
6606-7-AML	AMAV	M	SALT	34.7	24	277.7	-	-	-	0.10	-	-	0.11	3.8	0.97	-	0.07	-	0.09	-	-
6606-8-AML	AMAV	M	SALT	12	22	281.9	-	-	-	0.02	-	-	0.01	0.05	0.11	0.03	-	-	0.04	-	-
6606-9-AML	AMAV	M	SALT	25	38	267.3	-	-	-	0.01	-	-	0.01	0.01	0.03	-	-	-	0.02	-	-

[1] Unidentifiable Hemiptera parts

APPENDIX 3. Se concentration ($\mu g/g\ dw$)of invertebrates collected at each site. Means and standard deviations are presented for replicated samples.

Site	Taxa	Life Stage	Se $\mu g/g\ dw$	Date Collected	Mean	Stdev
Antelope Island	Brine Fly	Adult	2.2	16-June-06		
			2.0	16-June-06		
			2.3	16-June-06	2.17	0.15
		Larvae	1.5	16-June-06		
			0.9	16-June-06	1.20	0.42
		Pupae	1.4	16-June-06		
			1.4	16-June-06		
			0.8	16-June-06	1.20	0.35
	Brine Shrimp		3.2	16-June-06		
			2.5	16-June-06		
			3.2	16-June-06	2.97	0.40
	Corixid		2.5	16-June-06		
Ogden Bay	Brine Fly	Adult	0.97	23-June-06		
		Pupae	3	23-June-06		
			1	23-June-06	2.0	1.41
	Carabidae		1	23-June-06		
	Chironomid	Larvae	2	23-June-06		
	Corixid		2	23-June-06		
			3	23-June-06	2.5	0.71
	Muscidae		1	23-June-06		
	Snail		0.3	23-June-06		
Saltair	Brine Fly	Adult	2.2	21-June-06		
			3.8	21-June-06		
			2.1	21-June-06	2.7	0.95
		Larvae	3.4	21-June-06		
		Pupae	1.9	21-June-06		
	Corixid		2.1	21-June-06		

APPENDIX 4. Selenium concentrations from sediment ($\mu g/g\ dw$) and water samples ($\mu g/l$).

Site	Replicate	Number of samples	Sample	Date	Se Content
Antelope Island	1	5	Sediment	16-Jun-06	0.4
Antelope Island	2	5	Sediment	03-Jul-06	0.4
Antelope Island	3	5	Sediment	03-Jul-06	0.4
Ogden Bay	1	5	Sediment	25-Jul-06	0.4
Ogden Bay	2	5	Sediment	25-Jul-06	0.4
Ogden Bay	3	5	Sediment	25-Jul-06	0.4
Saltair	1	5	Sediment	28-Jun-06	1.3
Saltair	2	5	Sediment	28-Jun-06	2.5
Saltair	3	5	Sediment	28-Jun-06	1.3
Antelope Island	1	5	Water	16-Jun-06	0.293
Antelope Island	2	5	Water	16-Jun-06	0.294
Antelope Island	3	1	Water	16-Jun-06	0.297
Ogden Bay	1	5	Water	23-Jun-06	0.22
Ogden Bay	2	5	Water	23-Jun-06	0.246
Ogden Bay	3	5	Water	23-Jun-06	0.179
Saltair	1	5	Water	14-Jun-06	33.4
Saltair	2	5	Water	14-Jun-06	33.7
Saltair	3	5	Water	14-Jun-06	34.4

APPENDIX 5. Se concentration of collected eggs (µg/g dw), adjusted hatchability (# young hatched / # eggs incubated - # eggs removed for Se analysis), and ultimate fate of remaining eggs[1]

Site	Egg Identification	Spp.	Se Content µg/g dw	Embryo Age Estimate[2]	Adjusted Hatchability[3]	Fate of remaining eggs in nest
Antelope Island						
	AML-01-06	AMAV	2.4	36	1	SUCCESS
	AML-02-06	AMAV	1.8	30-31	1	SUCCESS
	AML-03-06	AMAV	2.8	39-40		DEPREDATED
	JAC-03-06	AMAV	2.9	14		DEPREDATED
	JAC-04-06	AMAV	2.2	19-23+	1	SUCCESS
	JAC-05-06	AMAV	1.7	13-17	0.67	SUCCESS
	JAC-06-06	AMAV	1.6	33-34	1	SUCCESS
	JAC-07-06	AMAV	2.7	6	0.67	SUCCESS
	JAC-08-06	AMAV	2.4	23- 28	0.67	SUCCESS
	JAC-09-06	AMAV	2.2	3-19	1	SUCCESS
	JAC-20-06	AMAV	1.8	37		FLOODED
	JAC-21-06	AMAV	2	23-28	1	SUCCESS
	JAC-22-06	AMAV	2.7	23-28	1	SUCCESS
	JAC-30-06	AMAV	1.9	29-30	1	SUCCESS
	JAC-31-06	AMAV	2.3	23-28		ABANDON
	JAC-32-06	AMAV	2.1	23+	1	SUCCESS
	JAC-33-06	AMAV	2.2	30	1	SUCCESS
	JAC-34-06	AMAV	2.3	23-28	1	SUCCESS
	JAC-60-06	AMAV	2.8	6-19		FAIL UNKNOWN
	JAC-61-06	AMAV	2.6	19		FAIL UNKNOWN
	JAC-62-06	AMAV	2	23+	1	SUCCESS
Ogden Bay						
	BJO-07-06	AMAV	2.8	Infertile	1	SUCCESS
	BJO-08-06	AMAV	2.6	0-19		FAIL UNKNOWN
	BJO-100-06	AMAV	3.2	3		DROPPED
	BJO-05-06	AMAV	2.1	19	1	SUCCESS
	CNE-502-06	AMAV	2.6	19-23+	1	SUCCESS
	JAC-15-06	AMAV	2	Infertile		SUCCESS
	JAC-50-06	AMAV	1.4	2	1	SUCCESS
	JAC-51-06	AMAV	2.1	No data collected		DROPPED
	JFC-32-06	AMAV	1.4	3-6	1	SUCCESS
	JFC-33-06	AMAV	1.4	3		DROPPED
	JFC-34-06	AMAV	1.6	2		DROPPED

[1] Abandon = nest with eggs left unattended
Depredated = eggs taken by nest predator
Dropped = eggs laid on ground with no nest scrape present
Fail Unknown = insufficient evidence to assign nest fate
Flooded = flooding event destroyed nest
Success = nest with at least 1 egg hatching

[2] Age of embryo estimated from Hamburger and Hamilton 1951.

[3] In the case marked as (?), the hatchability of the nest could not be determined due to uncertainty in original number of eggs incubated.

	JFC-35-06	AMAV	1.3	2	1	SUCCESS
	JFC-36-06	AMAV	1.2	3		DROPPED
	JFC-37-06	AMAV	2.6	3-5		FLOODED
	KT-1-06	AMAV	2.8	Infertile		DROPPED
	LJA-152-06	AMAV	2.5	7-9	1	SUCCESS
	LJA-212-06	AMAV	3	3		DROPPED
	LJA-213-06	AMAV	3	No data collected	1	SUCCESS
	MEF-74-06	AMAV	3	1-6	1	SUCCESS
	NS-08-06	AMAV	2.1	19-23+		DEPREDATED
	SAP-19-06	AMAV	1.6	45+-46	1	SUCCESS
	SAP-22-06	AMAV	1.8	37	0.67	SUCCESS
	SAP-25-06	AMAV	1.6	37	1	SUCCESS
	BJO-67-06	BNST	2.7	1-6	1	SUCCESS
	BJO-68-06	BNST	2.8	25-29	1	SUCCESS
	CNE-500-06	BNST	2.4	3-5		DROPPED
	CNE-501-06	BNST	1.7	No data collected		DEPREDATED
	KEE-02-06	BNST	2.5	9-23+	1	SUCCESS
	KEE-05-06	BNST	2.1	6		FAIL UNKNOWN
	KEE-169-06	BNST	3.4	0		DROPPED
	KEE-171-06	BNST	2.7	30	1	SUCCESS
	KEE-175-06	BNST	2.5	18-38+	1	SUCCESS
	LJA-151-06	BNST	1.3	23-28	1	SUCCESS
	LJA-160-06	BNST	3.6	3		DEPREDATED
	LJA-211-06	BNST	2.8	3-5		DEPREDATED
	NS-06-06	BNST	2.1	3-19	1	SUCCESS
	NS-100-06	BNST	3	7-9		DROPPED
	NS-10-06	BNST	3	43-44	1	SUCCESS
	NS-09-06	BNST	2.3	40-43	?	SUCCESS
	SAP-18-06	BNST	1.3	44+		FLOODED
Saltair						
	AML-131-06	AMAV	3.2	1		ABANDON
	JFC-09-06	AMAV	9.2	3		FLOODED
	JFC-12-06	AMAV	6.8	28		FLOODED
	JFC-6-06	AMAV	5.3	13		FLOODED
	SAP-1-06	AMAV	2.9	2-3		ABANDON
	SAP-2-06	AMAV	8.2	Infertile		DROPPED
	SAP-4-06	AMAV	3.6	1		ABANDON
	SAP-5-06	AMAV	5.4	2		ABANDON
West Carrington						
	JAC-01-06	AMAV	2.5	39		DEPREDATED

APPENDIX 6. Nest visit information for nests of collected eggs. Column definitions are as follows:

Nest ID – Identification code of nest
Egg ID – Identification code of egg analyzed for SE content
Spp Code – Species
Site – Code for each site monitored (ANTI – Antelope Island State Park, OGBA – Ogden Bay Waterfowl Management Area, SALT – Saltair, WCAR – West Carrington Bay).
SE Content – Se content reported for collected egg (*µg/g dw*).
Sample Date – Date (Julian) egg collected
Date 1…10 – Date (Julian) nest visited
Contents 1…10 – Number of eggs (or young = y) recorded on preceding date
H/F – Nest hatch (H) or Failure (F) code
Nest Fate – Fate code for nests

Nest ID	EggID	Spp Code	Site	SE Content	Sample Date	Date 1	Contents 1	Date 2	Contents 2	Date 3	Contents 3	Date 4	Contents 4	Date 5	Contents 5	Date 6	Contents 6	Date 7	Contents 7	Date 8	Contents 8	Date 9	Contents 9	Date 10	Contents 10	H/F	Nest Fate
KK-20-06	AML-03-06	AMAV	ANTI	2.8	163	163	4	167	3	171	2	173														F	DEPREDATED
MEF-30-06	JAC-03-06	AMAV	ANTI	2.9	149	149	4	152	3	156	2	159	2	167	2	171	4	173	4	184	0					F	DEPREDATED
AML-69-06	JAC-20-06	AMAV	ANTI	1.8	152	152	4	156	3	159	3	163	0													F	FLOODED
JAC-130-06	JAC-31-06	AMAV	ANTI	2.3	156	149	4	152	4	156	3	159	2	163	2	167		171	2	173	3	184	3	187	0	F	ABANDON
AML-125-06	JAC-60-06	AMAV	ANTI	2.8	166	163	2	166	4	167	3	171	3	173	3	180	0									F	FAIL UNKNOWN
KK-02-06	JAC-61-06	AMAV	ANTI	2.6	166	163	4	166	4	167	3	171	3	173	3	180	0									F	FAIL UNKNOWN
AML-99-06	AML-01-06	AMAV	ANTI	2.4	159	159	4	163	0																	H	SUCCESS
MEF-32-06	AML-02-06	AMAV	ANTI	1.8	159	149	2	152	4	156	4	159	4	163	3	167	3	171	1	187		191	0			H	SUCCESS
MEF-41-06	JAC-04-06	AMAV	ANTI	2.2	149	149	4	152	3	156	3	159	3	163	3	167		171								H	SUCCESS
JAC-131-06	JAC-05-06	AMAV	ANTI	1.7	149	149	4	152	3	156	3	159	3	163	3	167	3	171	2	173	1	180	0			H	SUCCESS
MEF-42-06	JAC-06-06	AMAV	ANTI	1.6	149	149	4	152	3	156	3	159	3	163	0											H	SUCCESS
MEF-43-06	JAC-07-06	AMAV	ANTI	2.7	149	149	4	152	3	156	3	159	3	163	3	167	3	171	1	173	1					H	SUCCESS
MEF-46-06	JAC-09-06	AMAV	ANTI	2.2	149	149	3	152	2	156	2	159	2	163	2	167	2	171	2	173	2	180	0			H	SUCCESS
AML-70-06	JAC-21-06	AMAV	ANTI	2	152	152	2	156	1	159	3	163	4	167	4	171	4	173	4	180	0					H	SUCCESS

MEF-40-06	JAC-22-06	AMAV	ANTI	2.7	152	149	**2**	152	**4**	156	**3**	159	**3**	163	**3**	167	**3**	171	**3**	172	**3**	180	**0**			H	SUCCESS
AML-73-06	JAC-30-06	AMAV	ANTI	1.9	156	152	**4**	156	**4**		**3**		**3**	167	**3**	171	**1**	173	**0**							H	SUCCESS
MEF-31-06	JAC-32-06	AMAV	ANTI	2.1	156	149	**3**	156	**3**	169	**2**	163	**2**	167	**2**	171	**0**									H	SUCCESS
AML-79-06	JAC-33-06	AMAV	ANTI	2.2	156	152	**4**	156	**4**	159	**3**	163	**3**	167	**3**	171	**3**	173	**0**							H	SUCCESS
JCB-19-06	JAC-34-06	AMAV	ANTI	2.3	156	156	**4**	159	**3**	163	**3**	167	**3**	171	**3**	173	**3**	177	**1**	180	**0**					H	SUCCESS
AML-98-06	JAC-62-06	AMAV	ANTI	2	166	159	**3**	163	**4**	166	**4**	167	**3**	171	**3**	173	**3**	180	**3**	184	**3**	187	**0**			H	SUCCESS
MEF-44-06	JAC-08-06	AMAV	ANTI	2.4	149	149	**4**	152	**3**	156	**3**	169	**3**	163	**3**	167	**2E1Y**	171	**1**							H	SUCCESS
BJO-70-06	BJO-08-06	AMAV	OGBA	2.6	174	174	**4**	178	**3**	182	**3**	188	**0**													F	FAIL UNKNOWN
NS-44-06	NS-08-06	AMAV	OGBA	2.1	174	158	**1**	171	**4**	174	**4**	178	**1**	182	**0**											F	DEPREDATED
JFC-37-06	JFC-37-06	AMAV	OGBA	2.6	165	165	**3**	171	**0**																	F	FLOODED
MEF-79-06	BJO-05-06	AMAV	OGBA	2.1	174	158	**2**	171	**4**	174	**3**	178	**3**	182	**3**	188	**0**									H	SUCCESS
JFC-20-06	JAC-15-06	AMAV	OGBA	2	151	151	**6**	157	**0**																	H	SUCCESS
JAC-250-06	JAC-50-06	AMAV	OGBA	1.4	165	165	**2**	171	**3**	174	**3**	178	**3**	182	**3**	188	**3**	192	**0**							H	SUCCESS
JFC-32-06	JFC-32-06	AMAV	OGBA	1.4	165	165	**2**	171	**3**	174	**3**	178	**3**	182	**3**	188	**3**	192	**0**							H	SUCCESS
JFC-35-06	JFC-35-06	AMAV	OGBA	1.3	165	165	**1**	171	**2**	174	**4**	178	**4**	182	**4**	188	**4**	192	**4**	195	**0**					H	SUCCESS
LJA-152-06	LJA-152-06	AMAV	OGBA	2.5	165	157	**4**	165	**4**	171	**3**	174	**3**	178	**3**	182	**3**	188	**0**							H	SUCCESS
LJA-213-06	LJA-213-06	AMAV	OGBA	3	165	165	**3**	171	**2**	174	**2**	178	**2**	182	**2**	188	**0**									H	SUCCESS
MEF-74-06	MEF-74-06	AMAV	OGBA	3	174	158	**1**	171	**4**	174	**5**	178	**4**	182	**4**	188	**4**	192	**4**	195	**0**					H	SUCCESS
SAP-22-06	SAP-22-06	AMAV	OGBA	1.8	165	151	**2**	157	**4**	165	**4**	171	**3**	174	**3**	178	**1**	182	**1**	188	**0**					H	SUCCESS
SAP-25-06	SAP-25-06	AMAV	OGBA	1.6	165	151	**1**	157	**4**	165	**4**	171	**3**	174	**3**	178	**0**									H	SUCCESS
BJO-69-06	BJO-07-06	AMAV	OGBA	2.8	174	174	**4**	178	**3**	182	**3**	188	**3**	192	**1E1Y**	195	**0**									H	SUCCESS
CNE-502-06	CNE-502-06	AMAV	OGBA	2.6	165	165	**1**	171	**2**	174	**3**	178	**3**	182	**3**	188	**3**	192	**2**	195	**0E1Y**					H	SUCCESS

SAP-19-06	SAP-19-06	AMAV	OGBA	1.6	156	151	**4**	156	**1**																H	SUCCESS
KEE-172-06	KEE-05-06	BNST	OGBA	2.1	174	171	**4**	174	**4**	178	**3**	182	**4**	188	**4**	192	**1**								F	FAIL UNKNOWN
LJA-160-06	LJA-160-06	BNST	OGBA	3.6	165	157	**3**	165	**1**	171	**1**	174	**0**												F	DEPREDATED
LJA-211-06	LJA-211-06	BNST	OGBA	2.8	165	165	**3**	171	**0**																F	DEPREDATED
CNE-501-06	CNE-501-06	BNST	OGBA	1.7	165	165	**3**	171	**2**	174	**2**	178	**1**	182	**0**										F	DEPREDATED
SAP-18-06	SAP-18-06	BNST	OGBA	1.3	156	151	**3**	156	**3**	165	**0**														F	FLOODED
BJO-67-06	BJO-67-06	BNST	OGBA	2.7	174	174	**4**	178	**3**	182	**3**	188	**0**												H	SUCCESS
BJO-68-06	BJO-68-06	BNST	OGBA	2.8	174	174	**4**	178	**3**	182	**3**	188	**0**												H	SUCCESS
KEE-171-06	KEE-171-06	BNST	OGBA	2.7	174	171	**4**	174	**4**	178	**3**	182	**3**	188	**3**	192	**0**								H	SUCCESS
LJA-151-06	LJA-151-06	BNST	OGBA	1.3	165	157	**4**	165	**4**	171	**3**	174	**3**	178	**0**										H	SUCCESS
NS-33-06	NS-06-06	BNST	OGBA	2.1	174	158	**4**	171	**4**	174	**3**	178	**3**	182	**3**	188	**0**								H	SUCCESS
NS-112-06	NS-09-06	BNST	OGBA	2.3	174	174	**4**	178	**1**	182	**0**														H	SUCCESS
KEE-164-06	KEE-02-06	BNST	OGBA	2.5	174	171	**4**	174	**4**	178	**3**	182	**3**	188	**3**	192	**3**	195	**3**	199	**2**	202	**2**	206	**1Y**	H	SUCCESS
KEE-175-06	KEE-175-06	BNST	OGBA	2.5	174	171	**4**	174	**4**	178	**3**	182	**3**	188	**3**	192	**3**	195	**3Y**							H	SUCCESS
NS-42-06	NS-10-06	BNST	OGBA	3	174	158	**4**	171	**4**	174	**4**	178	**1Y**													H	SUCCESS
JFC-10-06	JFC-06-06	AMAV	SALT	5.3	146	147	**4**	147	**3**	150	**0**														F	FLOODED
JFC-12-06	JFC-12-06	AMAV	SALT	6.8	146	146	**4**	147	**2**	150	**0**														F	FLOODED
JFC-09-06	JFC-09-06	AMAV	SALT	9.2	146	146	**3**	147	**3**	150	**0**														F	FLOODED
AML-131-06	AML-131-06	AMAV	SALT	3.2	165	165	**1**	172	**0**																F	ABANDON
AML-130-06	SAP-01-06	AMAV	SALT	2.9	165	165	**1**	172	**0**																F	ABANDON
AML-132-06	SAP-04-06	AMAV	SALT	3.6	165	165	**1**	172	**0**																F	ABANDON
AML-133-06	SAP-05-06	AMAV	SALT	5.4	165	165	**1**	172	**0**																F	ABANDON
JAC-120-06	JAC-01-06	AMAV	WCAR	2.5	144	144	**3**	150	**0**																F	DEPREDATED

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November 26, 2007

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INTRODUCTION

The Great Salt Lake (GSL) is well known as one of North America's most important inland shorebird sites. At least 22 species of shorebirds utilize the GSL during migration and another eight species nest in habitats associated with the lake. The breeding populations of American Avocets (*Recurvirostra americana;* AMAV) and Black-necked Stilts (*Himantopus mexicanus*; BNST) are among the highest in North America (Aldrich and Paul 2002). Consequently, the GSL is recognized as a site of hemispheric importance within the Western Hemisphere Shorebird Reserve Network (Andres et al. 2006). Because of the lake's importance to shorebirds, as well as other waterbirds, aquatic wildlife habitat is listed as a beneficial use of the GSL.

A recent proposal by the Southwest Jordan Valley Groundwater Project to dispose of reverse osmosis concentrate within the south arm of the GSL has led to public concern over potential selenium contamination. Selenium (Se) is a toxic trace element that may disrupt avian development, and increase mortality (Ohlendorf et al. 1988, 1989). This concern has brought a renewed focus on the need for numeric water quality standards.

Recent studies designed to examine the current concentration of Se in nesting shorebirds on the GSL (Cavitt 2007) documented higher concentrations within blood than would be expected given the concentrations found in egg and dietary samples. These results prompted the current study, which collected additional samples at GSL, and analyzed them for both total mercury (Hg) and total Se. Hg and Se may act antagonistically forming a stable complex. That may then increase both the retention and bioaccumulation of Se in tissues.

The objectives for this project were to:

- Determine ambient Se concentrations in brine fly larvae.
- Determine Se and Hg concentrations in American Avocet eggs.
- Determine stomach contents of nesting birds.
- Determine Se and Hg concentrations of American Avocet blood and liver.

METHODS

Data were collected for this study from late April until mid-July 2007.

Study Sites

A preliminary study conducted in 2006 found Ogden Bay (OGBA) to have high levels of Se within both blood and liver of AMAV (Cavitt 2007). Consequently, all AMAV collections during the 2007 breeding season occurred at this site. This study site is located at the Ogden Bay Waterfowl Management Area along the eastern shore of the GSL (Figure 1). Freshwater from the Weber River flows into the bay at this location and attracts large numbers of shorebirds and waterfowl. The study site is located at 41°12.038' N 112°14.597'W.

Figure 1. Ogden Bay Waterfowl Management Area.

In addition, invertebrates were sampled from Saltair, which is located along the south shore of the GSL. The site receives freshwater inflows from the Kennecott wastewater discharge. The study site is located at 40°46.116' N 112°10.466'W.

Adult collections for tissue and dietary analyses

Ogden Bay was searched for AMAV nests during late April – June 2007. Nests were marked during laying when 1 – 3 eggs were present. A spring-loaded nest trap was placed on the targeted nests to catch the laying female (Figure 2). Following capture, the female was euthanized by cervical dislocation (USFWS Permit #MB043593-0; UT Division of Wildlife Resources COR# 1COLL7037; WSU ACUC Approval 4/17/07). Any males captured were banded and then released. Collected birds were then dissected in the field.

Figure 2. Spring-loaded trap used to capture adults (photo courtesy of G. Santolo).

Blood was collected from a ventricle of the heart using a sterile syringe and then placed within a 1.8-mL Nalgene® cryogenic vial. A blood sample was also collected from the jugular vein of one individual for comparison to the ventricular blood sample. Each vial was labeled, and placed on ice until returned to the laboratory. The liver was removed, weighed, labeled and placed in a Whirl-pak® bag and stored on ice until returned to the laboratory. The entire oviduct (*infundibulum – junction with cloaca*) was then removed. Any developing, shelled-egg (oviduct eggs) within the oviduct was removed. The oviduct, and oviduct egg were placed in separate Whirl-pak® bags, labeled, and stored on ice until return to the laboratory.

Following collection, esophagus, and proventricular contents were removed, separated, and contents were examined for identification of food items. However, because birds were not collected while foraging, the esophagus and proventriulus were empty in all birds.

All liver and blood samples were frozen upon return to the laboratory and until shipment for analysis of total Se and total Hg. All blood samples were analyzed as whole blood.

Egg collections/dissections

Any eggs present within the nest were collected, prepared for Se and Hg analysis. The nest identification number, GPS coordinates of the nest, number of eggs in the nest and estimated stage of the eggs (determined by egg floatation) were also recorded. All eggs were refrigerated upon arrival at the laboratory. The eggs were then opened within 7 days and contents frozen until shipped for Se and Hg analysis.

Invertebrate samples

Brine fly larvae were collected from AMAV foraging areas at Ogden Bay and Saltair. Brine fly larvae were collected from the mudflat, benthos, and water column. Sufficient biomass for analysis (target 2 grams) was collected using sweep nets (Figure 3). Samples were sorted by taxon and life stage (i.e., larvae, pupae and adult), weighed, placed in Whirl-pak® bags and frozen for Se and Hg analysis.

Figure 3. Collecting brine flies.

RESULTS

The Ogden Bay breeding colony initiated 231 nests throughout the 2007 breeding season. The first nest was initiated on 25 April but median nest initiation was a month later (on 24 May). Of this total, only 19 nests successfully produced young at Ogden Bay. Most nest losses occurred during two flooding events (20 May and then 5 June) and a diversion of water away from the study site (20 June). This diversion resulted in adults abandoning nests and no further renesting attempts were made.

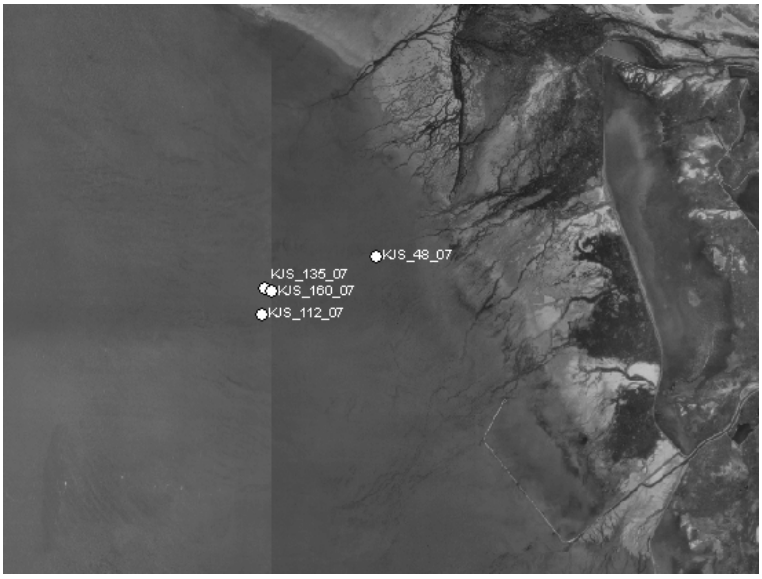

Figure 4. Nest site locations for female AMAV collections.

Because free-living birds vary in tissue moisture (e.g. Tieleman and Williams 2002, Tieleman et al. 2003) and moisture content can vary as a result of sample handing, all tissue results reported below are on a dry-weight basis.

Adult collections for tissue and dietary analyses

The large number of failed nests coupled with infrequent visits of adults to laying nests resulted in only four female AMAV collected (Figure 4, Table 1).

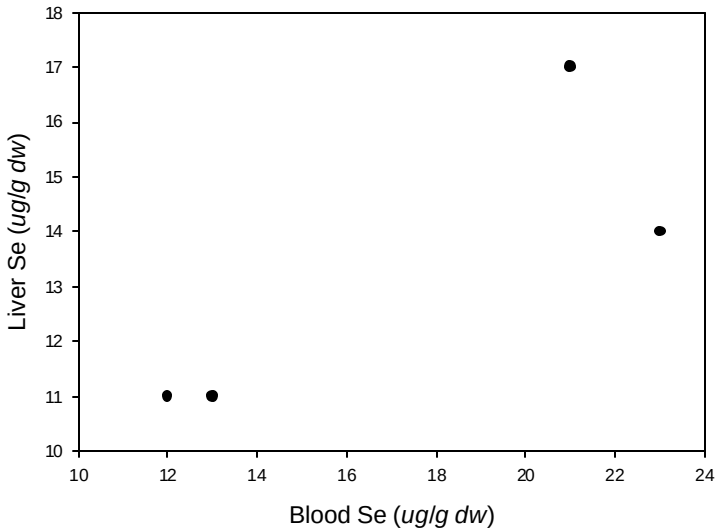

Figure 5. Relationship between blood Se and liver Se (µg/g dw).

AMAV females had blood Se concentrations (Figure 5), ranging from 12 - 23 µg/g dw and liver Se concentrations (Figure 5), ranging from 11 - 17 µg/g dw. There was no significant relationship between the log-transformed concentrations of Se in the blood and liver ($F_{1,3}$= 6.5, r^2 = 0.763, P = 0.126; Figure 5).

Blood Se concentrations at Ogden Bay tended to be higher in AMAV during the 2006 breeding season (⁋ = 34.5 µg/g dw ± se = 6.95) relative to those captured at the same location in 2007 (⁋ = 17.2 µg/g dw ± se = 2.71) although not significantly different (t = -2.089, df = 7, P = 0.075). There also was no significant difference in AMAV liver Se concentration at Ogden Bay between 2006 (⁋ = 17.0 µg/g dw ± se = 2.71) and 2007 (⁋ = 13.2 µg/g dw ± se = 2.71; t = -1.06, df = 7, P = 0.324).

Hg concentrations in AMAV blood ranged from 0.70 – 1.0 $\mu g/g$ *dw* and 1.7 – 2.7 $\mu g/g$ *dw* in the liver. There was no significant relationship between the concentration of Hg in blood and liver ($F_{1,3}$= 0.636, r^2 = 0.49, *P* = 0.51).

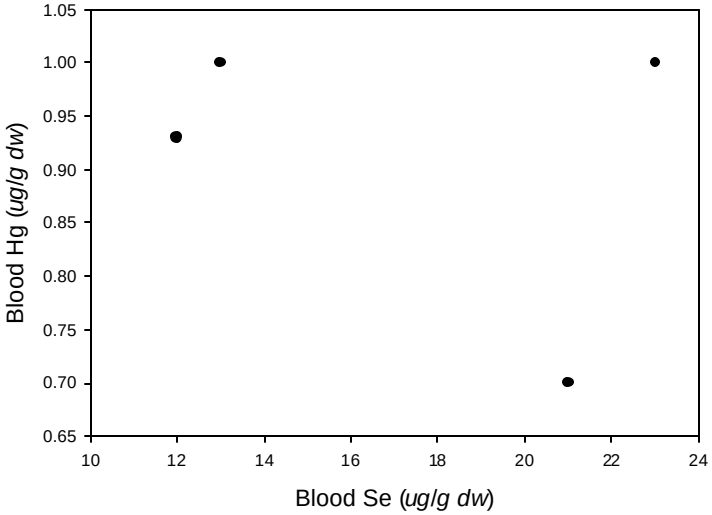

Figure 6. Relationship between blood Se and blood Hg (*µg/g dw*).

There also was no significant relationship between the concentration of Se and Hg in AMAV blood ($F_{1,3}$= 0.227, r^2 = 0.102, *P* = 0.681; Figure 6) or liver ($F_{1,3}$= 0.032, r^2 = 0.016, *P* = 0.875; Figure 7). Nor was there a significant relationship between blood Se concentration relative to the concentration of Hg found within the liver ($F_{1,3}$= 1.52, r^2 = 0.432, *P* = 0.343).

There were no significant relationships between liver Se concentration and body mass ($F_{1,3}$= 0.189, r^2 = 0.86, *P* = 0.71), or between blood Se concentration and body mass ($F_{1,3}$= 0.89, r^2 = 0.307, *P* = 0.446).

Egg collections/dissections

A total of 11 eggs were collected from four nests where females were trapped (Tables 1, 2). Two of the four females collected also had an egg present in their oviduct. These oviduct eggs were also analyzed for Se and Hg content.

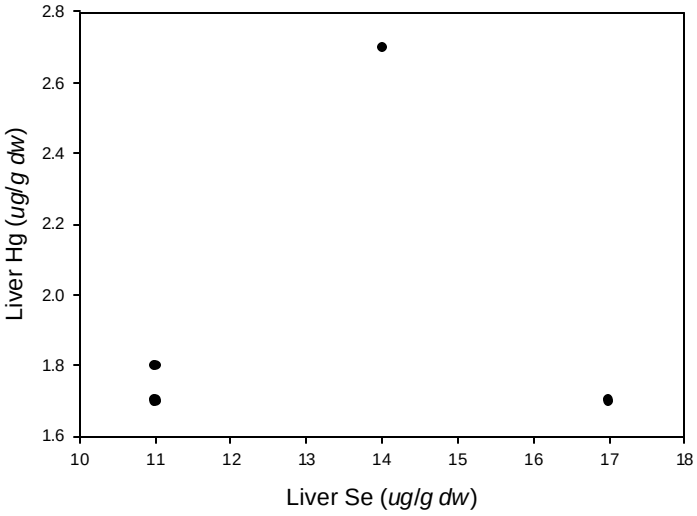

Figure 7. Relationship between liver Se and liver Hg (*µg/g dw*).

To examine if female blood Se concentration was positively associated with the concentration of Se deposited in her eggs, I calculated the mean Se concentration for eggs collected from each nest and regressed this mean on the attending female's blood Se. This resulted in a trend toward a positive relationship ($F_{1,3}$= 12.30, r^2 = 0.86, *P* = 0.073; Figure 8). The mean concentration of Se in eggs was not related to the female's liver Se concentration ($F_{1,3}$= 1.14, r^2 = 0.363, *P* = 0.398). In addition, there was no significant relationship between mean egg Hg and female blood Hg ($F_{1,3}$= 0.27, r^2 = 0.118, *P* = 0.657) or between mean egg Hg and female liver Hg ($F_{1,3}$= 0.34, r^2 = 0.145, *P* = 0.619).

There was no significant relationship between the concentration of Se and Hg within eggs collected ($F_{1,12}$= 2.73, r^2 = 0.2, *P* = 0.13). The concentration of Se in oviduct eggs was consistent with the concentration found in eggs collected at the nest (Table 2).

Invertebrate samples

Brine fly larvae and adults collected at Ogden Bay had Se concentrations of 1.6 and 1.2 *µg/g dw* respectively. The concentration of Se in brine fly larvae collected at Saltair was 1.4 *µg/g dw*. The concentration of Hg in brine fly adults at Ogden Bay was 0.1 *µg/g dw* and below detectable levels within the larvae samples collected. Hg was not tested for samples collected at Saltair (Table 3).

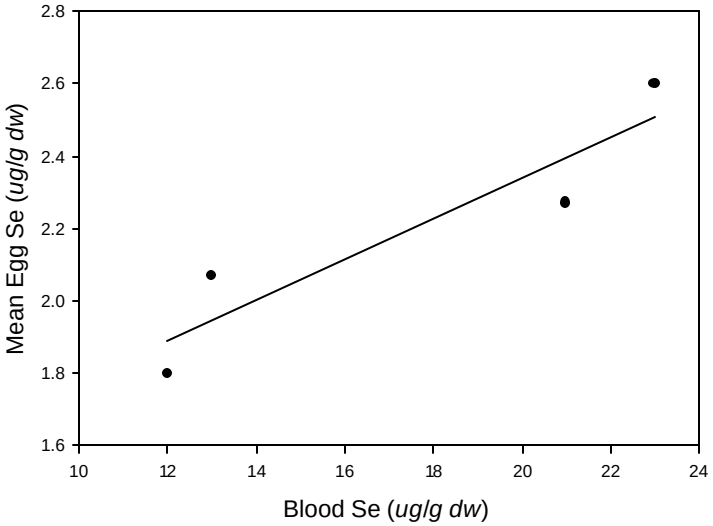

Figure 8. Relationship between blood Se and mean egg Se (*µg/g dw*).

Table 1. Se and Hg (*µg/g dw*) concentrations of females collected at Ogden Bay.

Date	Nest ID / Female ID	Status	Female Mass[1] (g)	Liver Mass (g)	# Eggs collected from Nest	Oviduct Eggs	Blood Se (µg/g dw)	Liver Se (µg/g dw)	Blood Hg (µg/g dw)	Liver Hg (µg/g dw)
5/19/07	KJS-48-07 KJS-1-07	Laying	263.9	8.6	3	1	23	14	1	2.7
6/2/07	KJS-112-07 KJS-2-07	Laying	366.7	7	2[2]	1	12	11	0.93	1.7
6/8/07	KJS-135-07 KJS-3-07	Laying	274.6	7.4	3	-	13	11	1	1.8
6/18/07	KJS-160-07 KJS-4-07	Laying/ Incubation	297.4	8.5	3	-	21	17	0.7	1.7

[1] Female mass determined after the removal of any oviduct eggs
[2] One of three eggs was crushed during trapping, thus only 2 eggs were collected

Table 2. Se and Hg (*µg/g dw*) concentrations of eggs collected from each nest at Ogden Bay with the corresponding attending female blood and liver Se concentrations.

Date	Nest ID	Egg	Egg Se (*µg/g dw*)	Egg Hg (*µg/g dw*)	Egg Mass (g)	Egg Length (mm)	Egg Width (mm)	Stage of development[1]	Female Blood Se (*µg/g dw*)	Female Liver Se (*µg/g dw*)
5/19/07	KJS-48-07	a	2.9	0.4	29.80	49.3	35.3	1-2	23	14
		b	2.3	0.42	27.40	46.0	34.5	1-2		
		c	2.8	0.41	28.60	46.8	35.3	3		
		Oviduct	2.4	0.32	8.1	-	-			
6/2/07	KJS-112-07	a	1.8	0.27	24.80	49.5	33.8	1-2	12	11
		b	1.8	0.29	28.10	49.0	33.4	3		
		Oviduct	1.8	0.1	13.4	-	-			
6/8/07	KJS-135-07	a	2.2	0.54	26.8	47.2	33.9	13	13	11
		b	2	0.42	30.7	51.5	34.9	13+		
		c	2	0.37	26.7	48.0	33.4	13		
6/18/07	KJS-160-07	a	2.1	0.32	28.1	49.1	34.3	29+	21	17
		b	2.3	0.39	28.7	50.4	34.3	29+		
		c	2.4	0.27	27.9	49.9	34.4	29+		

[1] Stage of development corresponds to Hamburger and Hamilton 1951. Stage of 1-3 ~ 6-13 hrs after laying; Stage 13 ~ 48-52 hrs after laying; Stage 29+ > 6 days after laying.

Table 3. Se and Hg (*µg/g dw*) concentrations of invertebrates collected from Ogden Bay and Saltair.

Date	Sample	Site	Se (*µg/g dw*)	Hg (*µg/g dw*)
6/22/07	Brine fly adults	Ogden Bay	1.2	0.1
6/22/07	Brine fly larvae	Ogden Bay	1.6	0.05[1]
7/19/07	Brine fly larvae	Saltair	1.4	-

[1] Analyte below detection limit

DISCUSSION

Unfortunately we were only able to capture four females for this project. The difficulty in catching females during the laying stage can be attributed to - 1) nest visitation by both adults during this stage is infrequent (Cavitt personal observation, Gibson 1978); 2) females typically spend less time at the nest than males during the early stages of breeding (Gibson 1978); 3) female home ranges are significantly larger during the laying stage than during either the incubation or brood rearing stages (Demers 2007); and 4) adults during the early stages of nesting are very leery of disturbance near their nests (L. Oring personal communication). This limited sample size reduced the power of statistical tests thus hindering the ability to detect differences.

The results of this study do confirm that the concentration of Se in blood and liver tissue at Ogden Bay are elevated above what is expected based on concentrations found within invertebrate food sources. The levels reported here were not significantly different from those reported for the 2006 breeding season (Cavitt 2007). Furthermore, the concentrations found within AMAV blood (12 – 23 *ppm*) are much higher than average background levels reported for these tissues (USDI 1998). Selenium concentrations in whole blood above 2 *ppm* are of concern and 5 *ppm* is a suggested threshold of toxicity (USDI 1998, Santolo and Yamamoto 1999). Background Se concentrations in liver tissue has been reported as less than 10 *ppm* (6.0 – 9.9 in recurvirostids; USDI 1998). However, in this study AMAV had liver Se concentrations ranging from 11 – 17 *ppm*.

Despite the elevated levels of Se found within AMAV tissues, their corresponding egg Se concentrations were relatively low (1.8 – 2.9 $\mu g/g$ *dw*). It is widely accepted that elevated Se levels can reduce the reproductive success of birds (Ohlendorf et al. 1988, 1989, Heinz et al. 1989, Adams et al. 2003); however, the threshold level at which negative effects occur is unclear. The suggested threshold of egg Se concentrations range from 6 $\mu g/g$ to 16 $\mu g/g$ (USDI 1998, Fairbrother et al. 1999, 2000, Adams et al. 2003, and Ohlendorf 2003). None of the eggs collected at Ogden Bay during the 2007 breeding season were above 6 $\mu g/g$ *dw*. The results also suggest that there may be a positive relationship between female blood Se and the corresponding Se concentrations found within the eggs she lays.

We were unable to find any significant relationship between the tissue concentrations of Se and Hg. In each regression we preformed the power of the test was below the desired power of 0.80. One complication in the results was that the female with the lowest blood Hg levels also had the highest blood Se. If this female (KJS-4-07) is considered an outlier and removed from the analysis, the liver Hg to blood Se regression becomes significant ($F_{1,2}$= 13467, r^2 = 1.0, P = 0.005) and the liver Hg to liver Se regression approaches significance ($F_{1,2}$= 120.3, r^2 = 0.99, P = 0.06). This should be interpreted cautiously since the removal of one individual reduces the sample to only three data points and the rationale for removing this female from the analysis is questionable.

ACKNOWLEDGEMENTS

Thanks to Val Bachman, manager of Ogden Bay Waterfowl Management Area for access to the study site and Lew Oring for the use of additional nest traps. Harry Ohlendorf and Gary Santolo, CH2M Hill, provided assistance on many aspects of this project. Many thanks to the numerous field technicians who endured the rigors of field research at GSL including, Jen Cary, Lindsay Cole, Christian Edwards, and Andy McFadden.

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Final Report: 2006 and 2007 Data

Concentration and Effects of Selenium in California Gulls Breeding on the Great Salt Lake

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Abstract

We examined selenium concentrations in California gulls (Larus californicus) nesting on the Great Salt Lake, Utah during 2006 and 2007. During 2006, the mean selenium concentration (± SE) in adult blood samples was 18.1 ± 1.5 µg/g (n = 35) on a dry weight basis, 8.1 ± 0.4 in adult liver samples (n = 36), and 3.0 ± 0.10 µg/g in eggs (n = 35). During 2007, selenium concentrations were 15.7 ± 1.5 µg/g in blood and 8.3 ± 0.4 µg/g in liver; mercury concentrations were 2.4 ± 0.3 µg/g in blood and 4.1 ± 0.5 in liver. Body mass was not correlated with selenium or mercury concentrations in the blood or liver for either adult males or females. Gulls collected from different Great Salt Lake colonies varied significantly in the concentration of selenium in their blood but not in livers or eggs. Selenium concentrations were higher in blood of gulls collected at the GSLM colony than in gulls collected from the Antelope Island colony or Hat Island colony. Gulls collected from a freshwater colony (Neponsett Reservoir) located in the headwaters of the Bear River had similar levels of selenium in the blood and liver as gulls collected on the Great Salt Lake but lower mercury levels. Of 72 eggs collected at random from Great Salt Lake colonies, only one showed no embryo development, and none of the embryos exhibited signs of malposition or deformities. We examined 100 newly hatched chicks from Great Salt Lake colonies for teratogenesis; all chicks appeared normal. Hence, the high selenium concentrations in blood of adult gulls do not seem to be impairing the gulls' health or reproductive ability.

Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. High concentrations of selenium have been shown, both in captive and free-ranging birds, to cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al.1989, Ohlendorf 2003). For example, birds foraging in California's Kesterson Reservoir, which was the disposal site for subsurface agricultural drainage from portions of the western San Joaquin Valley, accumulated high concentrations of selenium in their tissues (Ohlendorf 2002, 2003). Selenium concentrations in eggs of all aquatic birds collected from Kesterson Reservoir were higher than background levels (3 µg/g), and eared grebes (*Podiceps nigricollis*) had the highest concentrations, with a mean of 70 µg/g (all weights are reported on a dry-weight basis unless otherwise noted). Elevated concentrations of selenium impaired the reproductive ability of several avian species nesting at Kesterson Reservoir and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

Birds accumulate selenium from their food, and if they consume a diet too rich in selenium during the pre-laying period, they transfer selenium to their eggs, causing harmful effects. In laboratory studies, dietary concentrations of about 4.9 µg Se/g of food reduced the reproductive success of mallards (*Anas platyrhynchos*; Ohlendorf 2003). Mallard ducklings maintained on a diet containing 40 µg/g or greater selenium concentrations exhibited high mortality rates within 6 weeks of starting the diet. At Kesterson Reservoir, where many avian species that exhibited reproductive problems, some aquatic insects had mean selenium concentrations greater than 100 µg/g (Hothem and Ohlendorf 1989, Schuler et al. 1990).

Higher selenium concentrations also can impair the health of adult birds. Mallards maintained on a diet enriched with 20 µg Se/g of food had lesions in their liver and integument. Mallards on a diet of 40 µg/g lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998).

The Great Salt Lake (GSL) in Utah is an important habitat for many avian species. For instance, about half of the world's eared grebes spend the fall there eating brine shrimp and accumulating enough nutrients to fly to their wintering grounds in Mexico and California. During the breeding season, the lake also provides foraging and nesting habitat for California gulls (*Larus californicus*) and shorebirds. Hence, there is a need to ensure that selenium concentrations in the GSL do not reach concentrations that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium concentrations in adult California gulls breeding in three different parts of the GSL and in their eggs. We sampled their food during the pre-laying period and took water and sediment samples in their feeding grounds to assess them for selenium. We also checked California gull eggs for viability and embryos for deformities. This study was designed to answer the following specific questions.

1. What is the diet of California gulls during the egg-laying period?
2. What are the ambient selenium concentrations in the water, sediment, and diet items at the foraging sites of nesting California gulls in the GSL?
3. Are selenium and mercury levels in gulls nesting in the saline environment of the GSL similar to gulls nesting on a freshwater reservoir?
4. What is the relationship between selenium and mercury concentrations in the liver and blood of adult gulls and eggs?
5. What are the associated selenium concentrations in nesting California gulls (blood and liver), a random sample of gull eggs, and gull eggs that failed to hatch?

Methods

Collection of adult gulls. During 2006, we collected gulls from nesting colonies located on the Great Salt Lake at Hat Island, the Great Salt Lake Mineral (GSLM) facility, Egg Island, and White Rock Island. Egg Island and White Rock Island are small rocky islands within a few kilometers of each other. Both are within 1 km of the much larger Antelope Island. The gulls nesting in these 2 colonies use the same foraging areas (Conover, personal observation). Hence, we considered Egg Island and White Rock Island as a single colony and referred to them as the Antelope Island colony (Figure 1). During 2007, we re-sampled gulls from Hat Island and GSLM colonies and also collected California gulls from a Neponsett Reservoir colony, which is located in the headwaters of the Bear River in Rich County, Utah.

During the period when the gulls were laying eggs, we used a shotgun to collect 12 gulls from three GSL colonies (Hat Island, GSLM, and Antelope Island). To do this, we positioned ourselves 0.5-1.0 km from a colony and shot gulls that were flying back to the colony in a straight line. We assumed that these gulls were more likely to have food in their esophagus than gulls leaving the colony or gulls that were flying slowly in a circular pattern and appeared to be searching for food. All gulls from a single colony were shot on the same day. We immediately used a syringe to collect at least 1 ml of blood from the thoracic cavity. The blood was kept in the syringe and frozen. Within 12 hours of when the birds were shot, we collected all food from the bird's esophagus and obtained a liver sample. The liver sample was placed in a Whirl-Pak® bag and frozen. Esophagus samples were weighed (wet weight) and were stored in 95% alcohol. We weighed and measured the birds, determined their age by examining their plumage, and their sex by examining the gonads. Food in the esophagus was weighed and sorted by content or species. We determined the proportion of a food sample that could be attributed to different types of food or species.

Before we started collecting gulls, we observed where the gulls were foraging. We then went to those foraging sites and collected food samples by dragging a 1-m^2 circular seining net with a 5-mm mesh size behind the boat at a speed that just kept the top of the net at the top of the water. Hence, all food samples were obtained from the upper 1 m of the water column. Five seine samples were collected at each colony. Each of these was placed in a separate Whirl-Pak® bag and frozen.

We also collected 5 water samples from the upper 1 m of the water column and used a core to obtain 5 sediment samples from the top 0.1 m of the bottom sediment. The water and sediment samples were collected at the same places where the food samples were collected. These were placed in polypropylene vials and maintained at room temperature. Equal volumes of water from each of five water samples collected at the foraging grounds near each colony were combined to create a single composite water sample per colony. Likewise, the five sediment samples were combined in equal volume and homogenized to create a composite sediment sample for each colony

Selenium Analysis. Blood and liver samples from 11 or 12 gulls at each colony were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium analysis. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Quality control of selenium analyses was conducted using one or more method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006). The seine nets collected almost pure samples of brine shrimp, and the five brine shrimp samples from each colony were also sent to LET for selenium analysis. The water samples were sent to Frontier Geoscience, Seattle, Washington, and sediment samples were sent to LET for selenium analysis.

Collection of California gull eggs. We collected a single egg from each of 24 nests in each GSL colony (72 eggs total) when approximately 10% of the nests contained a chick or pipped egg. (This assured that the eggs we collected were likely to have late-stage embryos; therefore all [or almost all] eggs contained embryos assessable for developmental abnormalities.) All eggs were collected from three-egg clutches where no eggs had hatched. These nests were selected by placing a conceptual gird over the colony containing a series of numbered points, selecting points from a random numbers tables and sampling the nest located closest to that point that met the criteria. Which of the three eggs in that nest was collected was determined by numbering each egg in the clutch and selecting which number to sample based on a random numbers tables. All eggs were collected during 2006 except for the Neponsett Reservoir colony eggs, which were collected during 2007.

Eggs were stored in a refrigerator, and embryos were examined within four days of collection when samples were being prepared for selenium analysis. Each embryo was checked for stage of

embryonic development (embryo age) by comparing to existing aging criteria and atlases (Hamburger and Hamilton 1951; Hamilton 1952; Pisenti et al. 2001) and developmental abnormalities, including a determination of the embryo's pre-hatch position in the egg (i.e., for malposition) based on Romanoff and Romanoff (1972). An egg was considered viable if it contained a developing late incubation stage embryo. The contents of each egg (including the embryo) were placed in a marked chemically-cleaned container and preserved frozen for later chemical analysis. Eleven or 12 eggs from each colony were analyzed for total selenium by LET, and the others were stored for possible later analysis.

Examination of newly hatched chicks of California gulls and salvaged eggs for deformities. Immediately after the chicks hatched, we revisited the GSLM, Hat, and Antelope colonies to check 100 chicks that had hatched within the last 12 hours for deformities. Forty-eight salvaged eggs also were collected from the Hat Island and GSLM colonies (24 from each colony). A salvaged egg was defined as an egg remaining in a nest after the other eggs in the nest had hatched and that was no longer being incubated (i.e., egg was at ambient temperature). Salvaged eggs were checked to determine fertility and the presence of dead embryos. All embryos (including all contents of those eggs) were placed in chemically-cleaned containers and preserved frozen for later analysis.

Statistical analyses. Data on selenium concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test. Hence, parametric statistics were used. Correlations were conducted to compare selenium concentration in an individual gull's blood and liver. The same analyses were used to compare these to the gulls' mass and mercury concentrations in their blood and liver. Unpaired Students *t*–tests or *F*-tests were used to test for differences in mass and selenium concentrations. *F*-tests were used to test if selenium concentrations differed among colonies. In all tests, results were considered significant if $P < 0.05$.

Results

Food analyses for adults.–Thirty of the 35 adult gulls collected during 2006 had food in their esophagus (Appendix 1). Only one gull had more than a single kind of food item in its esophagus. That one contained 60% brine shrimp, 35% corixids, and 5% adult midges. For the 29 gulls that contained a single food item, 21 (75%) contained brine shrimp, 2 (7%) corixids, 2 (7%) brine fly larvae, 1 (4%) hot dogs, 1 (4%) earthworms, and 1 (4%) rotten carp (*Cyprinus carpio*) flesh. At all colonies, most gulls contained only brine shrimp. Corixids and midges were detected only at the GSLM colony. The earthworm and carp samples came from Antelope Island colony; hot hogs came from Hat Island colony.

Thirty two of the 36 adult gulls collected during 2007 had food in their esophagus (Appendix 2). Three gulls had more than a single kind of food item in its esophagus and those three had a combination of food from terrestrial sources (i.e., garbage and insects). Six gulls from GLSM colony contained brine shrimp, 4 had midge larvae, and 2 contained garbage. Ten of 12 gulls from Hat Island had eaten brine shrimp exclusively, and the other two contained either garbage or terrestrial insects in their esophagus. The eight gulls from Neponsett Reservoir that had food in their esophagus had fed on garbage and terrestrial insects.

Selenium analyses of adults collected during 2006.–Among individual gulls, selenium concentrations in blood and liver were highly correlated ($r^2 = 0.78$, $F = 117.22$; $d.f. = 1, 32$; $P = 0.0001$ [Figure 2]). There was no significant difference ($t = 1.56$, $d.f. = 27$, $P = 0.13$) between the selenium concentrations (mean $\pm$ SE) in the livers of adult males (7.4 $\pm$ 0.5 µg/g) and adult females (8.7 $\pm$ 0.8 µg/g). Likewise, there was no significant difference ($t = 1.75$, $d.f. = 27$, $P = 0.09$) between selenium concentrations (mean $\pm$ SE) in the blood of adult males (15.2 $\pm$ 1.6 µg/g) and adult females

(20.6 ± 3.0 µg/g). Hence, data from the two sexes were combined for further analyses. For all adults combined, selenium concentrations in blood samples were 18.1 ± 1.5 µg/g (n = 35); they were 8.1 ± 0.4 in liver samples (n = 36; Appendix 2).

There was no significant difference in blood selenium concentrations (F = 0.34; $d.f.$ = 1, 27; P = 0.56) between the 22 gulls that had mainly brine shrimp in their esophagus (16.9 ± 1.8 µg/g) and the 7 gulls that had other types of food in their esophagus (19.2 ± 4.0 µg/g). Likewise there was no significant difference (F = 0.12; $d.f.$ = 1, 27; P = 0.73) between selenium levels in the liver of gulls that fed on brine shrimp (8.4 ± 1.1 µg/g) and those that fed on some other type of food (8.0 ± 0.5 µg/g).

Among gulls collected from different colonies, there was a significant difference in the concentration of selenium in blood (F = 6.27; $d.f.$ = 2, 32; P = 0.005) but not in livers (F = 1.85; $d.f.$ = 2, 32; P = 0.17) (Table 1). Selenium concentrations were highest in blood of gulls collected at the GSLM colony, which is close to where water from the Bear River flows into GSL, and lowest in gulls from Antelope Island colony. Gulls from Hat Island colony had intermediate concentrations of selenium. This pattern of the highest selenium concentrations being recorded at the GSLM colony was true for selenium concentrations in blood, liver, eggs, and sediment although differences among colonies were significant only for blood

Not surprisingly, there was a significant difference (F = 10.31; $d.f.$ = 1, 26; P = 0.004) in the body mass of males (727 ± 16.4 g) and females (628 ± 23.2 g). Hence, the effects of selenium on body mass were analyzed separately for each sex. For males, body mass was not correlated with selenium concentrations in blood (r^2 = 0.01, F = 0.15; $d.f.$ = 1, 15; P = 0.71) or liver (r^2 = 0.002, F = 0.00; $d.f.$ = 1, 15; P = 0.96 [Figure 3]). Likewise for females, body mass was not correlated with selenium concentrations in blood (r^2 = 0.01, F = 0.78; $d.f.$ = 1, 9; P = 0.40) or liver (r^2 = 0.03, F = 0.23; $d.f.$ = 1, 15; P = 0.64 [Figure 4]).

Selenium and mercury analyses of adults during 2007.– For all adults collected during 2007 (n = 36), selenium concentrations were 15.7 ± 1.5 µg/g in blood and 8.3 ± 0.4 in liver (Appendix 2). For these same birds, mercury concentrations were 2.4 ± 0.3 µg/g in blood and 4.1 ± 0.5 in liver.

Among individual gulls, selenium concentrations in blood and liver were highly correlated (r^2 = 0.70, F = 80.79; $d.f.$ = 1, 34; P = 0.001) as was mercury concentrations in blood and liver (r^2 = 0.74, F = 95.03; $d.f.$ = 1, 34; P = 0.001). Blood selenium concentrations were correlated with mercury levels in blood (r^2 = 0.14, F = 5.75; $d.f.$ = 1, 34; P = 0.02) but not mercury levels in liver (r^2 = 0.05, F = 1.85; $d.f.$ = 1, 34; P = 0.18). Selenium concentrations in liver were not correlated with either mercury levels in the blood (r^2 = 0.07, F = 2.52; $d.f.$ = 1, 34; P = 0.12) or liver (r^2 = 0.03, F = 1.22; $d.f.$ = 1, 34; P = 0.28).

Among gulls collected during 2007, the highest selenium concentrations were once again found in adult gulls and eggs collected from GSLM colony (Table 2). In fact, selenium levels in GSLM gulls were significantly higher than those gulls from Hat Island but not from Neponsett gulls, which had intermediate levels of selenium (Table 2). Neponsett gulls had intermediate levels of selenium. When gulls collected at GSLM colony during 2007 were compared to those collected during 2006 (Tables 1 and 2), blood selenium concentrations were similar (F = 0.78; $d.f.$ = 1, 21; P = 0.39) as were liver selenium levels (F = 0.00; $d.f.$ = 1, 21; P = 0.95). For gulls collected at GSLM colony, those collected during 2006 had higher selenium levels in their blood than those collected during 2007 (F = 4.57; $d.f.$ = 1, 22; P = 0.04) but selenium levels in their livers were similar (F = 0.59; $d.f.$ = 1, 22; P = 0.59).

Mercury concentrations in blood and liver were similar in gulls collected from Hat Island and GSLM colonies (Table 2). However gulls from the freshwater colony (Neponsett Reservoir) had significantly lower mercury concentrations in blood and liver than gulls from Hat Island and GLSM colonies (Table 2).

Effects of selenium and mercury on body mass were analyzed separately for each sex. For males, body mass was not correlated with selenium concentrations in blood ($r^2 = 0.01$, $F = 0.15$; $d.f. = 1, 15$; $P = 0.71$), selenium concentrations in liver ($r^2 = 0.002$, $F = 0.00$; $d.f. = 1, 15$; $P = 0.96$), mercury concentrations in blood ($r^2 = 0.01$, $F = 0.15$; $d.f. = 1, 15$; $P = 0.71$), or mercury concentrations in liver ($r^2 = 0.002$, $F = 0.00$; $d.f. = 1, 15$; $P = 0.96$). Likewise for females, body mass was not correlated with selenium concentrations in blood ($r^2 = 0.01$, $F = 0.78$; $d.f. = 1, 9$; $P = 0.40$), selenium concentrations in liver ($r^2 = 0.03$, $F = 0.23$; $d.f. = 1, 15$; $P = 0.64$), mercury concentrations in blood ($r^2 = 0.01$, $F = 0.15$; $d.f. = 1, 15$; $P = 0.71$), or mercury concentrations in liver ($r^2 = 0.002$, $F = 0.00$; $d.f. = 1, 15$; $P = 0.96$).

Selenium and mercury analyses of food.–During 2006, selenium concentrations in water and brine shrimp were highest at the Hat Island colony (Table 1). For the water and sediment samples, only a single sample was analyzed from each colony, and statistics could not be used to test these variables.

During 2007, selenium concentrations in brine shrimp at Hat Island were once again higher than at GSLM colony, but mercury levels were similar (Table 2). Mercury concentrations in brine shrimp from the two colonies were similar. Brine shrimp collected at Hat Island during 2006 contained higher selenium concentrations than samples collected from the same colony during 2007 ($F = 27.09$; $d.f. = 1, 8$; $P = 0.001$). Likewise, brine shrimp collected from GSLM colony during 2006 had higher selenium levels than those collected during 2007 ($F = 13.83$; $d.f. = 1, 8$; $P = 0.006$). Food samples from Neponsett Reservoir colony were not analyzed because most gulls were foraging on bread and garbage and there seemed little need to determine the selenium or mercury concentration of bread.

Selenium and mercury analyses of eggs.–Selenium concentrations in eggs collected randomly during 2006 were 3.0 ± 0.10 µg/g ($n = 35$). Selenium concentrations did not differ ($F = 1.76$; $d.f. = 2, 32$; $P = 0.19$) among eggs collected from the different GSL colonies (Table 1 and Appendix 3).

Eggs collected randomly from Neponsett Reservoir during 2007 had selenium concentrations of 2.8 ± 0.10 µg/g and mercury concentrations of 0.26 ± 0.05 µg/g ($n = 12$). Selenium concentrations for eggs collected at Neponsett Reservoir differed from those collected at the GSLM colony ($F = 8.31$; $d.f. = 1, 21$; $P = 0.009$) but not from eggs collected at Hat Island ($F = 0.03$; $d.f. = 1, 21$; $P = 0.87$) or Antelope Island ($F = 0.01$; $d.f. = 1, 21$; $P = 0.92$). For eggs collected at Neponsett Reservoir, selenium concentrations were not correlated with mercury concentrations ($r^2 = 0.03$; $F = 0.30$; $d.f. = 1, 10$; $P = 0.60$).

Analyses of eggs and chicks for viability and deformities.–Among the sample of 24 eggs randomly sampled from 3-egg clutches during the late incubation period from GSL colonies (72 eggs total), all contained developing late incubation stage embryos except a single egg that came from the GSLM colony (Appendix 3). None of the embryos exhibited signs of malposition or deformities. We examined 100 newly hatched chicks from GSL colonies for teratogenesis; all chicks appeared normal. Out of 48 salvaged eggs from GSL colonies, 38 contained dead embryos; all embryos were normal in appearance and position.

During 2007, 1 of 12 eggs collected at Neponsett Reservoir colony was rotten, and one had no embryo (Appendix 3). Ten eggs contained late incubation stage embryos, and none of the embryos exhibited signs of malposition or deformities.

Discussion

In California gulls, we found that selenium concentrations ranged from 4 to 15 µg/g in livers. Mean background selenium concentrations have been reported to be <10 µg/g in livers (USDI 1998, Ohlendorf 2003). We detected selenium concentrations in California gull eggs ranging from 2.0 to 4.3 µg/g in eggs. Mean background selenium concentrations for individual eggs are considered to be < 5 µg/g (USDI 1998, Ohlendorf 2003) or < 3 µg/g for population means (Skorupa and Ohlendorf 1991). Hence, selenium concentrations in our egg and liver samples were generally consistent with background concentrations.

Surprisingly, selenium concentrations in blood of gulls nesting on GSL ranged from 5 to 46 µg/g. These concentrations were higher than we expected given the concentrations found in livers, eggs, and diets. In selenium feeding studies of mallards (*Anas platyrhynchos*; Heinz and Fitzgerald 1993) and American kestrels (*Falco sparverius*; Yamamoto et al. 1998), blood selenium concentrations did not significantly exceed dietary concentrations and were similar to diet concentrations after four to eight weeks. We found that mean selenium concentrations in the blood of gulls from different GSL colonies were 2.4 to 5.5 times higher than selenium concentrations in the brine shrimp upon which they were foraging.

Selenium concentrations in the blood of predatory terrestrial birds (kestrel, red-tailed hawk [*Buteo jamaicensis*], northern harrier [*Circus cyaneus*], barn owl [*Tyto alba*], and loggerhead shrike [*Lanius ludovicianus*]) from a contaminated grassland in California ranged from 1.5 to 38 µg/g dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 µg/g dry weight are considered to exceed normal background, and 5 µg/g dry weight is considered a provisional threshold indicating that further study is warranted (USDI 1998). However, toxicity studies of gulls were not reviewed for the development of those guidelines, and the ecotoxicology of selenium to gulls may differ from that for other species. Interestingly, we found that California gulls collected at a freshwater colony (Neponsett Reservoir) had selenium levels in their blood similar to those of GSL gulls but lower mercury concentrations. These results suggest that high selenium concentrations in blood may be a species trait rather than a characteristic of a saline environment.

Reasons for the anomalously high selenium concentrations in blood, but much lower concentrations in liver and eggs are not known. A possible explanation for the elevated concentrations of selenium in our blood samples may be relatively high mercury concentrations found in the Great Salt Lake ecosystem. Selenium and mercury may interact to form a stable, nontoxic complex so that selenium may provide adult birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from faster selenium elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver or kidney tissues (Goede and Wolterbeek 1994).

Although the few studies of selenium-mercury interaction in birds used various forms of Se and Hg (some not using environmentally relevant forms), they do provide approximations of potential effects. In a study by Heinz and Hoffman (1998) using mercury as methylmercury chloride

and seleno-DL-methionine, captive female mallards fed a diet containing both 10 µg Se/g of feed and 10 µg Hg/g had a selenium concentration in the liver 1.5 times higher than females fed a diet containing just selenium (10 µg Se/g). In the same experiment, male mallards fed the selenium and mercury combination diet had almost 12 times the selenium concentration of male mallards fed the selenium-only diet. Similar results were found with Japanese quail fed diets containing methylmercury and selenite (El-Begearmi et al. 1977, 1982). However, our results suggest that a selenium-mercury interaction may not be responsible for the high selenium levels in California gulls. Among individual gulls, we found a statistically significant but weak correlation ($r^2 = 0.14$) between the concentrations of selenium and mercury in blood but no correlation between selenium levels in blood and mercury levels in liver. Also, gulls from Neponsett Reservoir had similar selenium concentrations in their blood as GSL gulls, but they had much lower mercury concentrations.

Among free-ranging birds, sensitivity to selenium varies among species. In black-necked stilts (*Himantopus mexicanus*), the threshold for teratogenesis (EC_{10}) was 37 µg/g in eggs (Skorupa 1998, Ohlendorf 2003). However, the EC_{10} was 23 µg/g for mallards and 74 µg/g for American avocets (*Recurvirostra americana*). Even lower concentrations of selenium can cause a decrease in egg viability. Selenium concentrations in eggs as low as 6–7 µg/g resulted in reduced viability of eggs in black-necked stilts. Heinz (1996) suggested that 10 µg/g be considered the threshold where selenium concentrations start to have an effect on the hatchability of bird eggs, while Fairbrother et al. (1999) recommended a threshold concentration of 16 µg/g.

We found selenium concentrations in 30 California gull eggs collected from GSL colonies ranged from 2.0 to 4.3 µg/g. These concentrations were similar to California gulls eggs collected from Neponsett Reservoir colony located in the upper watershed of the Bear River and are below the concentrations shown in other avian species to cause teratogenesis or a significant decrease in egg viability. We detected no evidence that these concentrations of selenium were causing an adverse effect on California gulls nesting on GSL.

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Table 1. Selenium concentrations in µg/g dry weight (mean ± standard error) in adult California gulls, their eggs, food, water, and sediment collected at Antelope Island, Hat Island, and Great Salt Lake Mineral (GSLM) colonies located on the Great Salt Lake, 2006.

	Antelope Island	Hat Island	GSLM colony	*d. f.*	*F*-value	*P*
Male mass (*n* = 19)	728 ± 21 A	769 ± 20 A	629 ± 13 B	2, 16	12.24	0.0006
Female mass (*n* = 14)	640 ± 32	635 ± 58	619 ± 29	2,11	0.13	0.88
Se in adult liver (*n* = 35)	7.3 ± 0.7	7.8 ± 0.6	9.2 ± 0.9	2, 32	1.85	0.17
Se in adult blood[1] (*n* = 35)	13.8 ± 1.8 A	16.0 ± 2.0 A	25.1 ± 7.9 B	2, 32	6.27	0.005
Se in eggs (*n* = 35)	2.8 ± 0.2	3.1 ± 0.3	3.4 ± 0.1	2, 32	1.76	0.19
Se in brine shrimp (*n* = 15)	3.4 ± 0.1 A	5.5 ± 0.1 B	4.6 ± 0.1 C	2, 12	181.65	0.0001
Se in water (*n* = 3)	0.5	0.6	0.3	--	--	--
Se in sediment (*n* = 3)	0.4	0.4	0.5	--	--	--

[1] Means in rows not sharing the same uppercase letter are significantly different ($P \leq 0.05$). based on the Duncan's Multiple Range Test.

Table 2. Selenium concentrations in µg/g dry weight (mean ± standard error) in adult California gulls, their eggs, food, water, and sediment collected at Neponsett Reservoir, Hat Island, and Great Salt Lake Mineral (GSLM) colonies located on the Great Salt Lake, 2007.

	Neponsett Reservoir	Hat Island	GSLM colony	*d. f.*	*F*-value	*P*
Male mass (*n* = 20)	673 ± 27	760 ± 15	636 ± 86	2, 17	1.15	0.34
Female mass (*n* = 16)	555 ± 12	601 ± 29	591 ± 24	2, 13	1.49	0.26
Se in adult blood (*n* = 36)	15.5 ± 2.3 AB[1]	10.7 ± 1.4 A	20.9 ± 3.4 B	2, 30	3.79	0.03
Se in adult liver (*n* = 35)	8.3 ± 0.7	7.2 ± 0.4	9.3 ± 1.0	2, 30	2.20	0.13
Hg in adult blood (*n* = 36)	1.3 ± 0.3 A	3.0 ± 0.3 B	3.0 ± 0.6 B	2, 30	7.38	0.003
Hg in adult liver (*n* = 36)	2.4 ± 0.6 A	5.6 ± 0.7 B	4.2 ± 0.9 AB	2, 30	5.52	0.01
Se in brine shrimp (*n* = 10)	No data	4.5 ± 0.2 A	3.9 ± 0.2 B	1, 8	5.47	0.05
Hg in bring shrimp (*n* = 10)	No data	0.6 ± 0.1	0.4 ± 0.02	1,8	2.87	0.13

[1] Means in rows not sharing the same uppercase letter are significantly different ($P \leq 0.05$). based on the Duncan's Multiple Range Test.

Appendix 1. California gulls collected on 5/2/06 at the Great Salt Lake Mineral Colony (F= female, M = male, AL = active layer or female that has a large developing egg inside her, g = grams, mm = millimeters, L = length, H = height, and ww = wet weight, µg/g = micrograms of selenium per gram of tissue).

Sample	Sex	Mass (g)	Wing (mm)	Body (mm)	Head length	Bill L × H		Food in esophagus g (ww) Contents	Se (µg/g) dry weight Blood	Liver
Cg-01	F-AL*	666	380	496	100	18×16	4.9	100% brine fly larvae	17	6.7
Cg-02	M	656	397	499	111	22×11	8.9	100% brine fly larvae	28	12
Cg-03	F	544	371	500	99	18×15	0.1	2 cori×ids	32	9.9
Cg-04	F-AL	697	384	490	98	18×15	9.1	100% cori×ids	37	13
Cg-05	M	633	370	450	99	18×14	0.0	--	13	6.1
Cg-06	M	635	395	527	109	21×17	0.0	--	18	7.5
Cg-07	M	644	379	495	111	23×16	5.7	100% brine shrimp	5	3.9
Cg-08	F-AL	579	399	495	99	18×14	5.9	100% brine shrimp	33	11
Cg-09	F-AL	542	385	475	98	17×15	1.0	100% brine shrimp	31	11
Cg-10	F-AL	687	375	495	101	17×16	6.4	(60% brine shrimp, 35% cori×ids, 5% midges)	25	8.6
CG-11	M	579	395	500	107	19×17	0.0	--	37	12

Appendix 1 (continued). California gulls collected on 5/4/06 at the Antelope Island colony (F= female, M = male, AL = active layer or female that has a large developing egg inside her, g = grams, mm = millimeters, L = length, H = height, W = width, ww = wet weight, µg/g = micrograms of selenium per gram of tissue).

Sample	Sex	Mass (g)	Ling (mm)	Body (mm)	Head length	Bill L×H	Food in esophagus g (ww)	Food in esophagus Contents	Se (µg/g) dry weight Blood	Se (µg/g) dry weight Liver
A1	M	674	416	674	115	21×18	0.0	--	7.7	5.3
A2	M-subadult	787	380	510	108	20 ×14	0.0	--	20	6.9
A3	M	663	400	520	111	21×16	3.3	100% brine shrimp	19	9.5
A4	F-AL	665	385	490	100	19×14	13.9	100% brine shrimp	22	13
A5	M	731	404	500	107	23×16	157.0	100% carp carcass	14	6.1
A6	M	761	400	518	112	22×17	3.0	100% brine shrimp	25	9.9
A7	F	755	406	505	102	19×15	15.9	100% brine shrimp	13	6.0
A8	F	526	380	478	98	18×15	3.0	100% brine shrimp	13	6.7
A9	F	640	405	498	98	20×16	7.9	100% brine shrimp	7.7	4.0
A10	F-subadult	590	388	483	103	21×15	1.5	100% brine shrimp	8.8	6.5
A11	M	688	395	506	113	23×17	16.3	100% earthworms	10	6.9
A12	F-AL	669	386	490	96	18×10	1.2	100% brine shrimp	6.4	6.8

Appendix 1 (continued.). California gulls collected on 5/9/06 at the Hat Island Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, µg/g = micrograms of selenium per gram of tissue).

Sample	Sex	Mass (g)	Wing (mm)	Body (mm)	Head length	Bill L×H	Food in esophagus g (ww)	Food in esophagus contents	Se (µg/g) dry weight Blood	Se (µg/g) dry weight Liver
H1	M	806	395	478	112	22×18	16.1	100% brine shrimp	12	6.3
H2	?	767	395	496	109	22×17	27.1	100% brine shrimp	29	13
H3	F	693	382	480	105	20×15	6.4	100% brine shrimp	8.5	5.9
H4	M	767	400	520	109	20×16	33.7	100% brine shrimp	15	6.8
H5	M	854	394	520	107	21×17	24.3	100% brine shrimp	15	6.1
H6	M	657	410	515	109	20×17	5.3	100% brine shrimp	17	8.4
H7	M	813	395	533	109	21×16	13.5	100% brine shrimp	16	9.3
H8	F	578	360	505	99	18×15	0.3	100% brine fly larva	22	8.6
H9	M	784	402	521	109	21×16	14.2	100% brine shrimp	18	8.6
H10	M	709	377	536	110	20×17	7.1	100% brine shrimp	25	9.3
H11	M	737	397	519	109	20×17	41.4	100% brine shrimp	8.1	5.7
H12	M	794	386	526	115	23×19	30.8	100% hot dogs	6.3	5.6

Appendix 2. California gulls collected on 5/7/07 at the Great Salt Lake Mineral Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, µg/g = micrograms of selenium per gram of tissue).

Sample	Sex	Body Mass g (ww)	Liver Mass g (ww)	Food in crop Mass	Food in crop Contents	Se (ug/g) dry weight) Blood	Se (ug/g) dry weight) Liver	Hg (ug/g) dry weight) Blood	Hg (ug/g) dry weight) Liver
GSLM -01	F-AL	662	26	9	100% brine shrimp	9.9	7.3	3.4	6.31
GSLM -02	F	562	14	4	100% brine shrimp	13	6.8	6.02	9.94
GSLM -03	M	746	26	25	100% midge larva	28.3	14	2.3	3.1
GSLM -04	M	761	24	21	garbage (bread)	11	6.2	0.63	0.6
GSLM -05	M	741	20	46	garbage (bread)	21.8	7.4	1.0	1.0
GSLM -06	M	740	24	15	100% midge larva	28.9	9	3.2	5.03
GSLM -07	M	680	17	24	100% midge larva	13	7.2	0.72	0.92
GSLM -08	F	563	19	18	100% midge larva	17	11	1.1	1.3
GSLM -09	F	578	18	0.5	100% brine shrimp	45.7	15	7.61	9.59
GSLM -10	M	736	23	15	100% brine shrimp	38	14	3.7	6.3
GSLM -11	M	745	27	21	100% brine shrimp	8.7	7	3.1	3.6
GSLM -12	M	645	26	14	100% brine shrimp	16	6.5	3.5	3.3

Appendix 2 (continued). California gulls collected on 5/9/07 at the Hat Island Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, µg/g = micrograms of selenium per gram of tissue).

Sample	Sex	Body mass g (ww)	Liver mass g (ww)	Food in crop		Se (ug/g) dry weight)		Hg (ug/g) dw)	
				Mass	Contents	Blood	Liver	Blood	Liver
HAT -01	M	716	27	37	100% brine shrimp	23	9.7	3.4	6.57
HAT -02	M	722	20	28	100% brine shrimp	7.1	7.7	3.3	8.92
HAT -03	M	822	32	28	100% brine shrimp	13	8.8	3.4	4.6
HAT -04	M	789	17	85	garbage (bread)	13	5.9	4.3	5.27
HAT -05	F	635	16	45	100% brine shrimp	12	6.5	3.5	5.95
HAT -06	M	745	16	9	100% brine shrimp	4.8	4.7	0.56	0.77
HAT -07	F	612	20	27	90% garbage, 10% beetles	9	6.1	2.8	5.95
HAT -08	M	738	16	17	100% brine shrimp	7	6.7	2.6	3.8
HAT -09	F	673	16	16	100% brine shrimp	5.3	6.6	2.3	5.26
HAT -10	F	582	18	13	100% brine shrimp	12	8.3	3.5	6.3
HAT -11	M	788	21	57	100% brine shrimp	14	7.4	2.6	3.6
HAT -12	F	501	13	3	100% brine shrimp	8.7	8.3	3.3	9.8

Appendix 2 (continued). California gulls collected on 5/11//0 at the Neponset Reservoir Colony , Rich County, Utah Colony (F= female, M = male, g = grams, mm = millimeters, L = length, H = height, W = width,, ww = wet weight, µg/g = micrograms of selenium per gram of tissue).

Sample	Sex	Body mass g (ww)	Liver mass g (ww)	Food in crop		Se (ug/g) dry weight)		Hg (ug/g, dw)	
				Mass	Contents	Blood	Liver	Blood	Liver
NET -01	F	556	16	2	100% damsel fly larva	21	9.8	0.2	0.3
NET -02	F	553	18	19	100% garbage (bread)	13	6.1	2.2	3.0
NET -03	F	550	18	27	100% garbage (bread)	10	8.1	0.2	0.36
NET -04	M	650	16	0	nothing	22.3	13	1.5	2.0
NET -05	F	560	16	43	90% caterpillars,10% beetles	10	7.9	1.4	3.6
NET -06	M	612	16	0	nothing	5	5.6	0.75	0.93
NET -07	F	580	22	34	95% caterpillars, 5% beetles	24.8	8.2	1.4	5.93
NET -08	M	637	20	1	??	32.2	12	2.7	4.6
NET -09	F	492	17	0	nothing	8.2	6.8	0.21	0.32
NET -10	F	596	20	8	??	12	7.2	0.35	1.1
NET -11	M	764	17	7	2 bird leg bones	13	5.6	3.2	4.9
NET -12	M	700	17	0	nothing	15	8.7	1.0	2.3

Appendix 3. Selenium concentrations (µg/g dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Great Salt Lake Mineral colony on May 15, 2006.

Sample	Se (µg/g)	Mass (g)		Length (mm)	Width (mm)	Volume (ml)	H-H	Viable embryo?	Defects?
		Whole egg	Without shell						
M-1	3.6	69.5	62.9	66.1	46.8	65.0	37	YES	NO
M-2	3.0	70.1	63.9	69.7	45.0	63.9	37	YES	NO
M-3	2.6	59.3	53.9	65.6	44.0	60.0	44	YES	NO
M-4	3.2	70.3	62.8	68.1	48.1	76.5	44+	YES	NO
M-5	4.1	64.0	58.2	64.5	46.4	-	45+	YES	NO
M-6	3.7	69.7	62.9	68.9	43.6	70.8	44+	YES	NO
M-7	2.7	63.6	52.1	67.9	46.0	63.7	42	YES	NO
M-8	3.2	65.8	55.0	63.7	47.6	65.2	40	YES	NO
M-9	-	67.2	61.0	67.2	47.0	68.6	39	YES	NO
M-10	3.5	62.3	53.8	61.7	47.2	59.4	38	YES	NO
M-11	4.3	70.6	64.1	63.5	47.4	66.6	44+	YES	NO
M-12	3.3	62.6	54.3	65.2	47.0	-	45	YES	NO
M-13		60.5	54.0	66.7	45.6	-	45	YES	NO
M-14		65.8	56.5	64.0	46.8	61.4	38	YES	NO
M-15		67.2	60.7	65.3	45.1	58.0	36+	YES	NO
M-16		58.7	53.2	61.6	46.3	-	45	YES	NO
M-17		65.9	57.5	68.7	45.9	56.8	-	NO	?
M-18		66.4	59.8	64.4	46.1	54.8	39	YES	NO
M-19		73.1	66.6	68.1	48.8	71.8	43	YES	NO
M-20		66.3	59.7	64.1	46.9	-	44	YES	NO
M-21		67.4	56.8	63.1	48.4	81.3	45	YES	NO
M-22		68.0	59.9	66.0	46.1	78.0	37	YES	NO
M-23		68.1	61.4	66.2	47.3	61.8	39	YES	NO
M-24		54.8	47.0	58.3	47.7	-	44+	YES	NO

Appendix 3 (continued). Se concentrations (µg/g, dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Hat colony on May 25, 2006.

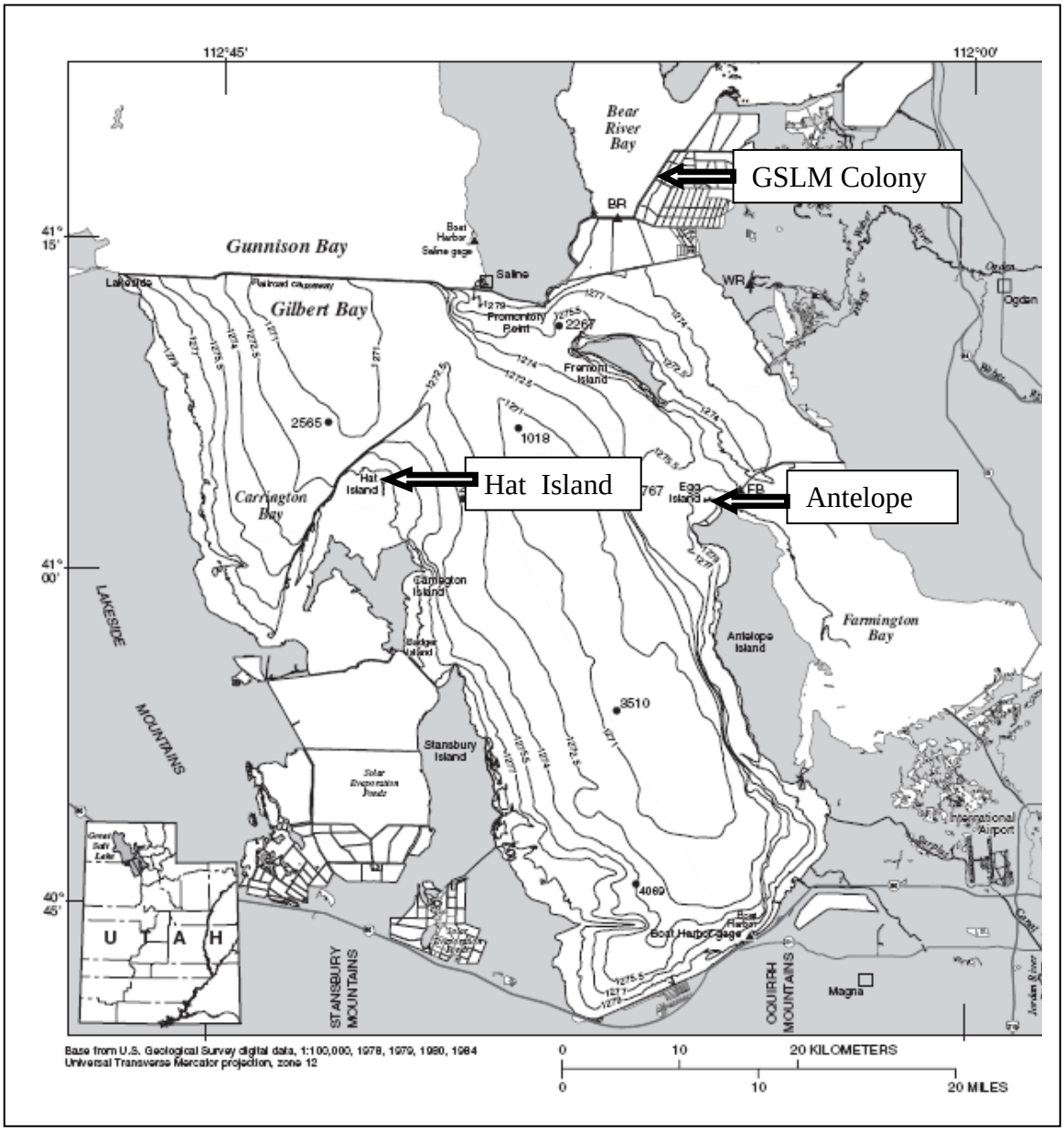
Sample	Se (µg/g)	Mass (g)		Length (mm)	Width (mm)	Volume (mL)	H-H embryo?	Viable	Defects?
		Whole egg	Without shell						
H-1	-	68.5	61.6	64.2	45.0	56.4	8	YES	NO
H-2	3.4	65.5	55.4	65.6	45.6	65.5	40	YES	NO
H-3	2.1	66.5	55.0	69.1	46.3	-	45+	YES	NO
H-4	3.4	66.0	57.8	63.5	46.1	64.4	41-42	YES	NO
H-5	3.3	66.5	59.2	67.0	44.7	62.1	37	YES	NO
H-6	2.8	63.6	56.6	63.6	46.2	62.2	43-44	YES	NO
H-7	2.3	63.1	53.2	62.5	46.3	64.0	43-44	YES	NO
H-8	-	75.3	64.3	64.7	48.2	74.5	42-43	YES	NO
H-9	3.1	72.1	65.1	65.3	47.3	71.3	36+	YES	NO
H-10	2.8	64.9	58.2	63.2	46.5	62.9	43-44	YES	NO
H-11	3.2	63.2	56.5	64.3	44.7	63.8	38+	YES	NO
H-12	2.5	57.7	52.3	62.7	44.7	60.2	45	YES	NO
H-13	2.0	67.4	58.1	67.0	45.5	66.0	42-43	YES	NO
H-14		69.5	63.0	67.3	47.1	72.1	44+	YES	NO
H-15		70.1	61.7	64.2	46.2	67.2	33	YES	NO
H-16		60.0	54.7	63.8	45.9	64.0	38+	YES	NO
H-17		67.7	61.0	68.0	44.9	68.6	41-42	YES	NO
H-18		58.4	51.6	64.3	43.4	57.5	43-44	YES	NO
H-19		72.4	63.8	67.8	46.0	71.7	37	YES	NO
H-20		63.9	55.5	66.9	44.5	64.5	42-43	YES	NO
H-21		63.2	53.3	64.4	44.7	62.9	44+	YES	NO
H-22		60.8	51.2	63.2	45.2	59.9	45	YES	NO
H-23		76.6	65.3	69.8	47.9	77.3	45	YES	NO
H-24		66.6	59.1	67.1	44.5	66.7	42-43	YES	NO

Appendix 3 (continued). Se concentrations (µg/g, dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Antelope Island colony on May 23, 2006.

Sample	Se (µg/g)	Mass (g)		Length (mm)	Width (mm)	Volume (mL)	H-H embryo?	Viable	Defects?
		Whole egg	Without shell						
A-1	3.2	62.6	53.4	64.0	45.4	62.9	42-43	YES	NO
A-2	3.0	63.4	55.0	62.2	46.9	66.0	44+	YES	NO
A-3	2.7	61.0	52.8	65.5	44.0	59.7	44+	YES	NO
A-4	4.1	57.8	52.6	62.4	44.3	-	45+	YES	NO
A-5	2.4	68.6	59.4	67.7	46.4	71.2	44+	YES	NO
A-6	-	61.5	54.2	60.6	47.2	-	45	YES	NO
A-7	2.1	58.1	51.4	62.1	45.4	62.5	38	YES	NO
A-8	2.6	61.3	53.5	66.5	44.6	61.5	41-42	YES	NO
A-9	2.6	78.4	69.5	68.1	47.2	73.2	29	YES	NO
A-10	2.4	82.0	71.8	67.1	48.3	-	23+	YES	NO
A-11	2.4	68.9	62.6	69.2	45.3	65.7	41-42	YES	NO
A-12	2.8	64.7	58.3	65.5	46.6	-	45+	YES	NO
A-13		75.7	67.0	66.6	47.1	70.1	18	YES	NO
A-14		72.1	62.6	64.2	47.2	68.8	39	YES	NO
A-15		63.7	55.2	62.0	45.8	62.6	42-43	YES	NO
A-16		69.4	60.2	64.3	47.3	71.0	42-43	YES	NO
A-17		63.9	54.5	65.6	45.5	-	45+	YES	NO
A-18		69.2	62.6	65.7	46.4	66.9	37	YES	NO
A-19		64.7	55.1	62.2	47.4	65.4	42-43	YES	NO
A-20		67.0	55.4	63.0	47.2	66.8	45	YES	NO
A-21		63.6	53.7	63.6	46.4	65.0	45	YES	NO
A-22		65.8	59.6	66.4	46.5	69.8	44+	YES	NO
A-23		71.6	64.5	66.8	45.6	68.6	35	YES	NO
A-24		66.9	59.7	63.0	47.4	67.5	41-42	YES	NO

Appendix 3 (continued). Se and Hg concentrations (µg/g, dry weights), mass, size, developmental stage (H-H), presence of a viable embryo, and presence of an embryo with a visible defect. Eggs were collected at random from 3-egg clutches at the Neponsett Reservoir colony on June 9, 2007.

Sample	Hg (µg/g)	Se (µg/g)	Mass (g) Whole	Mass (g) Without shell	Length (mm)	Width (mm)	Volume (ml)	H-H	Viable embryo?	Defects?
P-1	0.19	2.5	61.0	56.2	62.3	44.5	51	38	YES	NO
P-2	0.16	2.5	68.5	63.2	64.3	46.1	61	33	YES	NO
P-3	0.07	2.2	56.9	52.9	60.6	44.6	51	41-42	YES	NO
P-4	0.37	2.7	68.4	63.0	62.6	47.1	62	33	YES	NO
P-5	0.16	2.6	61.1	56.3	62.5	44.4	56	39	YES	NO
P-6	0.24	2.4	58.5	54.2	66.0	43.1	53	34	YES	NO
P-7	0.45	3.0	59.1	53.5	63.7	44.2	63	--	NO (rotten)	NO
P-8	0.39	3.1	65.7	61.2	70.1	44.0	52	44+	YES	NO
P-9	0.1	3.3	52.2	48.3	59.5	43.2	49	40	YES	NO
P-10	0.7	3.0	66.5	60.7	65.9	45.2	56	34	YES	NO
P-11	0.16	2.2	72.4	67.4	65.6	46.5	60	--	NO (infertile)	NO
P-12	0.1	3.8	54.2	50.7	60.0	41.7	--	--	YES	NO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Hat Island
Antelope
112°45'
112°00'
41° 15'
41° 00'
40° 45'
Bear River Bay
Gunnison Bay
Gilbert Bay
Carrington Bay
Farmington Bay
Saline
Promontory Point
Fremont Island
Hat Island
Egg Island
Carrington Island
Badger Island
Antelope Island
Stansbury Island
Solar Evaporation Ponds
LAKESIDE MOUNTAINS
STANSBURY MOUNTAINS
OQUIRRH MOUNTAINS
Boat Harbor Saline gage
Boat Harbor gage
Ogden
Magna
International Airport
BR
WR
FB
2267
2565
1018
767
3510
4069
U A H
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0 10 20 MILES

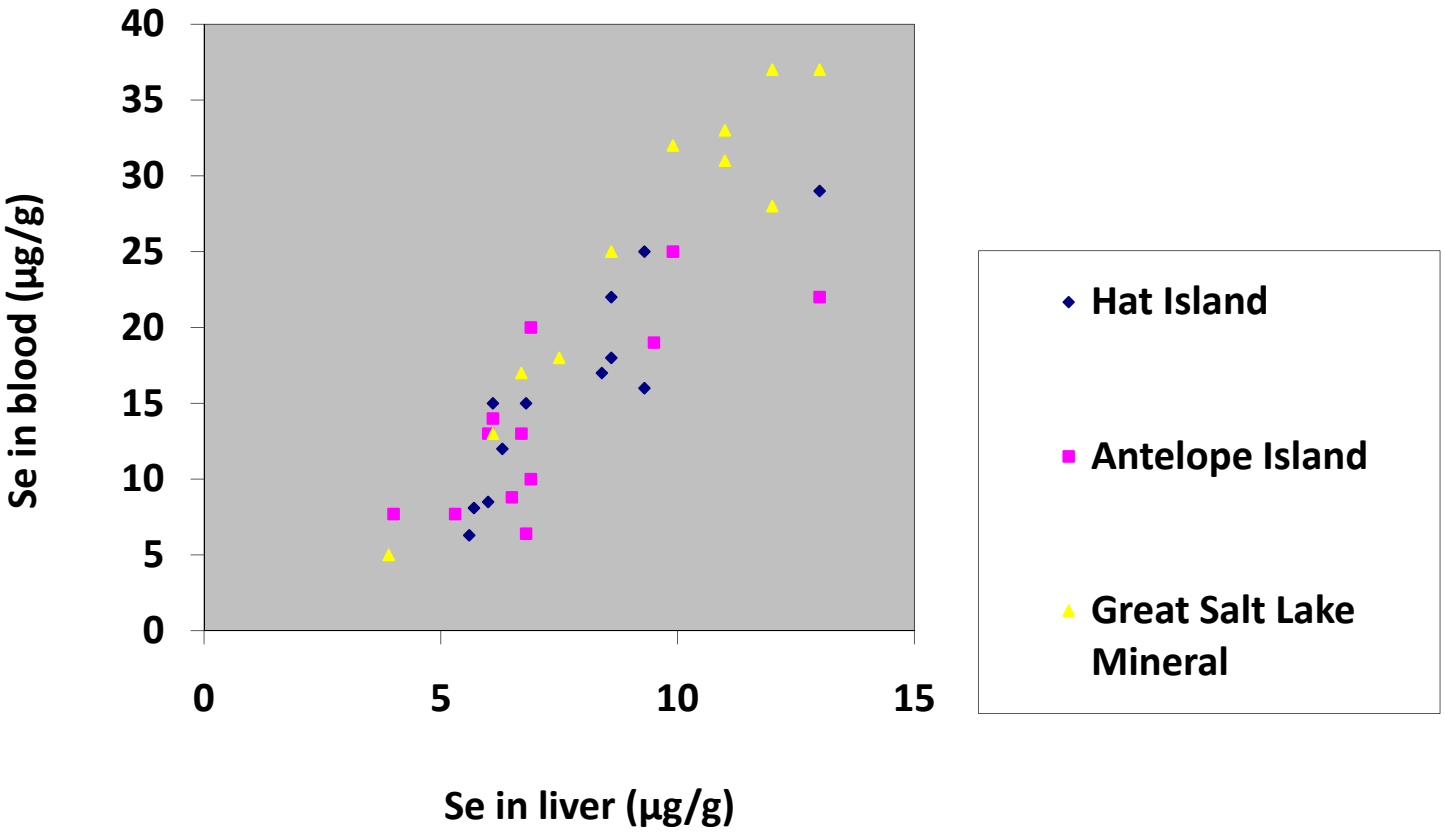

Figure 2. Relationship between a California gull's selenium concentration (µg/g, dry weight basis) in its blood and liver. Gulls collected from the three colonies are plotted separately.

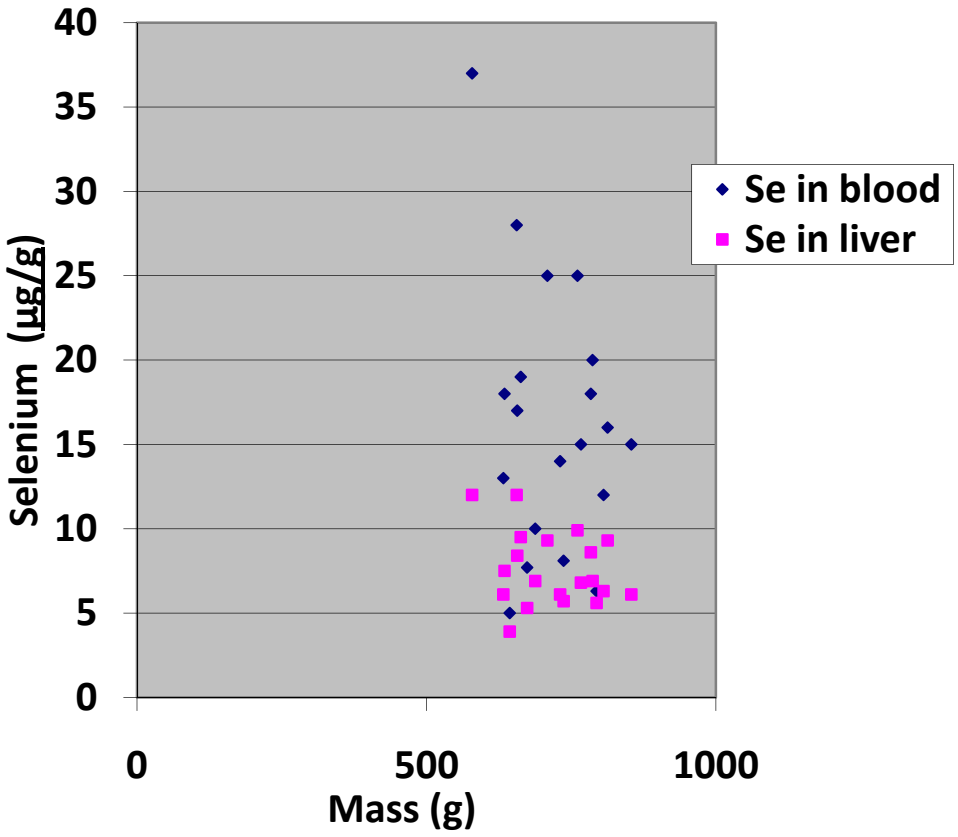

Figure 3. Relationship between the mass of male California gulls and the selenium concentration(µg/g, dry weight basis) in their blood and liver.

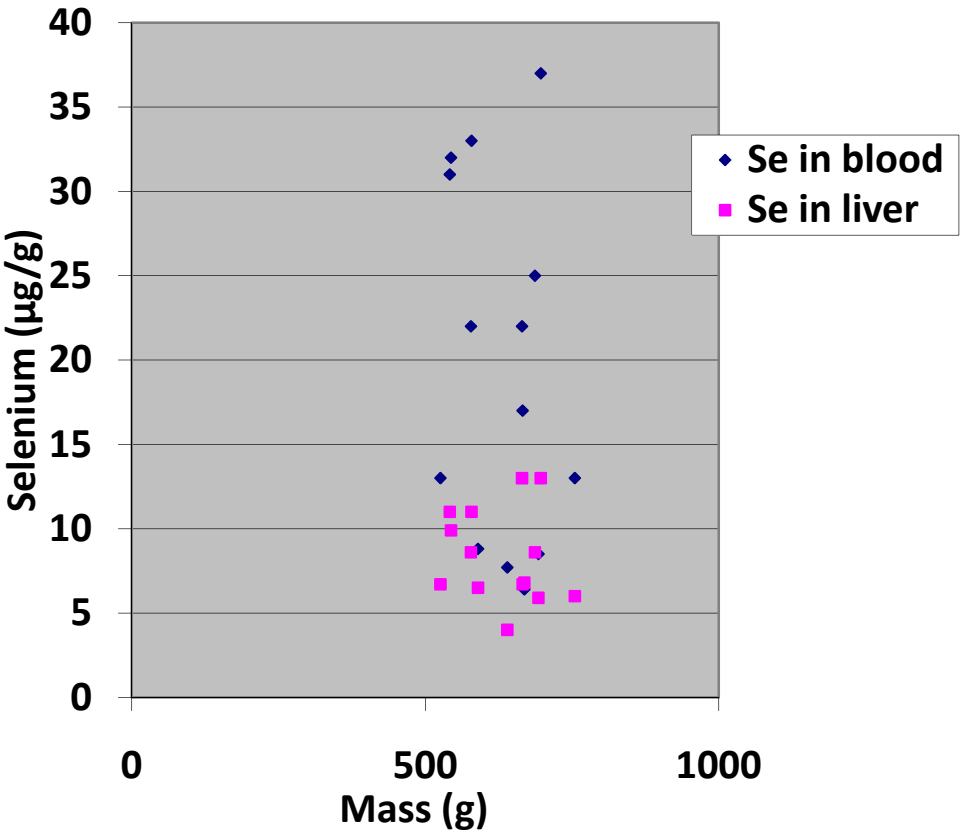

Figure 4. Relationship between mass of female California gulls and the selenium concentration (µg/g, dry weight basis) in their blood and liver.

Final Report:

Concentrations of Selenium in Eared Grebes from the Great Salt Lake, Utah

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Abstract

We examined selenium and mercury concentrations in eared grebes (*Podiceps nigricollis*) that spent the fall of 2006 on the Great Salt Lake, Utah. Food items in the birds' esophagus consisted primarily of brine shrimp. Selenium concentrations in livers varied based on when the grebes were collected (lower in September [mean ± SE = 9.4 ± 0.7 µg/g on a dry weight basis] than November [14.5 ± 1.4 µg/g]), where the birds were collected (Antelope Island = 8.6 ± 0.5 µg/g and Stansbury Island = 15.2 ± 1.4 µg/g), and the grebe's age (juveniles 8.5 ± 1.5 µg/g and adults = 15.8 ± 1.3 µg/g), but not by sex. In contrast, selenium concentrations in blood differed only by collection site (Antelope Island = 16.8 ± 2.3 and Stansbury Island = 25.4 ± 3.0 µg/g). Mercury concentration in the blood of grebes varied by when the grebes were collected (September = 5.6 ± 0.5 µg/g and November = 8.4 ± 1.2 µg/g), where the birds were collected (Antelope Island = 4.3 ± 0.5 and Stansbury Island = 10.1 ± 2.6 µg/g), and the grebe's age (juveniles = 5.5 ± 0.8 and adults 8.4 ± 1.0 µg/g), but not by sex. Selenium concentrations in blood were correlated with selenium concentrations in the liver and mercury concentrations in both blood and liver. Mercury levels in blood and liver were also correlated. Liver mass, pancreas mass, and spleen mass were not related to either selenium or mercury concentrations. Body mass of grebes increased dramatically from September (381 ± 14 g) to November (591 ± 11 g). Body mass was either not correlated with selenium or mercury concentrations, or the relationship was positive. These results suggest that high mercury and selenium levels were not preventing grebes for increasing or maintaining mass.

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Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. Elevated concentrations of selenium have been shown, both in captive and free-ranging birds, to cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al.1989, Ohlendorf 2003). For example, several avian species foraging in California's Kesterson Reservoir accumulated high concentrations of selenium in their tissues that impaired their reproductive ability and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

The Great Salt Lake (GSL) in Utah is an important habitat for many avian species. About half of North America's eared grebes (*Podiceps nigricollis*) spend the fall on the GSL eating brine shrimp and accumulating enough nutrients to fly to their wintering grounds in Mexico and California. Hence, there is a need to ensure that selenium concentrations in the GSL do not reach levels that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium concentrations in eared grebes in September (soon after they arrived on the GSL) and then again in late November before they migrate from the GSL. Because of the possible interactions between selenium and mercury that may affect bioaccumulation and effects, we also measured concentrations of mercury in grebe blood and livers.

This study was designed to answer the following specific questions.

1. What are selenium and mercury concentrations in blood and liver of eared grebes collected on the GSL?
2. Do eared grebes accumulate selenium and mercury while on the GSL?
3. Do selenium and mercury concentrations vary based on where the grebes were collected on the GSL or the age or sex of the birds?
4. Are selenium and mercury concentrations in blood and liver correlated?
5. Do selenium or mercury concentrations affect body condition of eared grebes on the GSL?

Methods

Collection of grebes. During September and November 2006, we collected eared grebes located in the GSL off Antelope Island and Stansbury Island (Figure 1). During these months, the grebes are flightless, and we used a shotgun and steel shot to collect them as they swam on the water surface. We collected 30 grebes during each month with an equal number (15) being collected at each site.

We immediately used a syringe to collect at least 1 mL of blood from the thoracic cavity. The blood was kept in the syringe and frozen. Within 12 hours of when the birds were collected, we collected all food from the bird's esophagus and obtained a liver sample. The liver sample was placed in a Whirl-Pak® bag and frozen. Esophagus samples were weighed (wet weight) and were stored in 95% alcohol. We determined the birds' body mass, aged them by eye color (Cullen et al. 1999), and determined their sex by gonadal inspection. We weighed each bird's liver, spleen, and pancreas. Food in the esophagus was sorted by species, and numbers of each species were counted because food items were too small and scarce to accurately weigh.

Selenium and mercury analysis. Blood and liver samples from some grebes were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium and mercury analysis. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry and mercury using cold vapor atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Selenium and mercury concentrations are reported on a dry-weight basis. Quality control of chemical analyses was conducted using one or more method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006).

Statistical analyses. To determine if the data were normally distributed, I examined data on the grebes collected during September separately from the grebes collected during November. For both

datasets, selenium and mercury concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test.

Analyses of Variance (ANOVAs) were used to determine the effect of collection date (September versus November), collection site (Antelope Island versus Stansbury Island), age of bird (juveniles versus adults), and sex on selenium concentrations in blood and liver. We did not determine the mercury concentrations in liver samples from juvenile birds. Because of this, there was an insufficient sample size to conduct an ANOVA on mercury concentrations in livers. We did, however, conduct an ANOVA to examine the effect of collection date, collection site, and sex on mercury concentrations in blood samples.

Regression tests were conducted to compare selenium and mercury concentration in an individual grebe's blood and liver. Selenium and mercury concentrations were also regressed with body mass, liver mass, spleen mass, and pancreas mass. Fat mass was not used because grebes fast before migrating from the GSL; therefore, it is not a reliable predictor of body condition of grebes. Because grebe mass varies by age and sex, we first conducted regression tests on all bird combined, and then separately analyzed juvenile males, adult males, juvenile females and adult females using only those birds collected in November. In all tests, results were considered significant if $P < 0.05$.

Results

Food analyses.–All grebes had a mass of feather fragments and brine shrimp (*Artemia* spp.) cysts in their gizzard; individual food items in the gizzard could not be identified. Hence, food analyses were limited to items in the birds' esophagus. Collected grebes had so few food items in their esophagus that food items were individually counted because weights were meaningless. During September, grebes were feeding primarily on adult brine shrimp and adult brine flies. During November, food items in the grebes contained almost entirely adult brine shrimp (Appendix 1).

Selenium and mercury analyses.– Selenium concentrations in livers varied based on when the grebes were collected (lower in September [mean $\pm$ SE = 9.4 $\pm$ 0.7 µg/g on a dry-weight basis] than November [14.5 $\pm$ 1.4 µg/g]), where the birds were collected (Antelope Island = 8.6 $\pm$ 0.5 and Stansbury Island = 15.2 $\pm$ 1.4 µg/g), and the grebe's age (juveniles = 8.5 $\pm$ 1.5 and adults = 15.8 $\pm$ 1.3 µg/g), but not by sex (Tables 1-3). In contrast, selenium concentrations in blood differed only by collection site (Antelope Island = 16.8 $\pm$ 2.3 and Stansbury Island = 25.4 $\pm$ 3.0 µg/g dry weight). Mercury concentration in the blood of grebes varied by when the grebes were collected (September = 5.6 $\pm$ 0.5 µg/g and November = 8.4 $\pm$ 1.2), where the birds were collected (Antelope Island = 4.3 $\pm$ 0.5 µg/g and Stansbury Island = 10.1 $\pm$ 2.6), and the grebe's age (juveniles = 5.5 $\pm$ 0.8 µg/g and adults = 8.4 $\pm$ 1.0), but not by sex (Tables 1-3).

When all birds were combined, selenium concentrations in blood and liver and mercury concentrations in blood and liver were all positively correlated with each other (Table 4). When juvenile males, adult males, juvenile females, and adult females collected in November were analyzed separately (Tables 5 and 6), selenium concentrations in blood were correlated with selenium concentrations in liver in all sex-age groups. In males, selenium concentrations in the liver and blood were correlated with mercury levels in blood but not mercury levels in livers (Table 5). In females, selenium concentrations were not correlated with mercury concentrations (Table 6), but sample sizes for females were so small that the probability of a Type II error was high. This was also true for comparisons involving mercury concentrations if the livers of males.

When all grebes were combined, there was a positive correlation between body mass and selenium concentrations in blood and liver and mercury concentrations in liver (Table 4). When only

grebes collected in November were considered and each age-sex group was analyzed separately, body mass was not correlated with selenium or mercury concentrations with two exception — mass of adult males was correlated with selenium concentrations in the liver (r^2 = 0.36) and mass of juvenile females was correlated with mercury concentrations in the blood (r^2 = 1.0). In both cases, the relationship was positive (Tables 5 and 6). Liver mass, pancreas mass, and spleen mass were not correlated with either selenium or mercury concentrations (Table 4).

Discussion

In eared grebes, we found that selenium concentrations in livers ranged from 5 to 28 µg/g. In California gulls (*Larus* californicus) that we collected from the GSL during the spring, selenium concentrations ranged from 4 to 14 µg/g (Conover et al. 2007). In other species, mean background levels of selenium have been reported to be less than 10 µg/g in livers (USDI 1998, Ohlendorf 2003). Our results indicate that selenium concentrations in liver samples were generally consistent with background concentrations for grebes collected in September. For eared grebes captured in November, however, all of those from Stansbury Island (range 17.4 to 28.4 µg/g) had selenium concentrations in livers that exceeded the 10 µg/g threshold that is considered to be the background level in liver tissue (Ohlendorf 2003). Grebes captured during November near Antelope Island had selenium concentrations (range 6.7 to 8.7 µg/g) consistent with background levels.

Among grebes collected during November, selenium concentrations in blood ranged from 1 to18 µg/g from birds collected near Antelope Island and 22 to 55 µg/g from birds collected near Stansbury Island. In California gulls that we collected during their breeding season on the GSL, selenium concentrations in blood ranged from 5 to 46 µg/g (Conover et al. 2007). These concentrations were higher than we expected given the concentrations found in livers. Selenium concentrations in the blood of predatory terrestrial birds (kestrel [*Falco sparverius*], red-tailed hawk [*Buteo jamaicensis*], northern harrier [*Circus cyaneus*], barn owl [*Tyto alba*], and loggerhead shrike [*Lanius ludovicianus*]) from a contaminated grassland in California ranged from 1 to 38 µg/g dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 µg/g dry weight are considered to exceed normal background, and 5 µg/g dry weight is considered a provisional threshold indicating that further study is warranted (USDI 1998).

We do not know why grebes collected around Stansbury Island during November had higher concentrations of selenium than those from around Antelope Island. However, during November, Stansbury Island grebes also had much higher mercury concentrations in their blood (range = 11.5 to 18 µg/g) than Antelope Island grebes (range = 2.5 to 4.7 µg/g). Selenium and mercury can interact to form a stable complex so that selenium can provide adult birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from faster selenium initial elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver or kidney tissues (Goede and Wolterbeek 1994). When we analyzed juvenile males, adult males, juvenile females, and adult females separately and used only those birds collected in November, selenium concentrations in both blood and liver were correlated with mercury concentrations in blood for males but not females. However, sample sizes were small for females and this increased the likelihood of a Type II error. Still, we discovered among female grebes a positive correlation between selenium concentrations and blood mercury levels.

Although the few studies of selenium-mercury interaction in birds used various forms of selenium and mercury (some not using environmentally relevant forms), they do provide approximations of potential effects. In a study by Heinz and Hoffman (1998) using mercury as methylmercury chloride and seleno-DL-methionine, captive female mallards (*Anas platyrhynchos*) fed a diet containing both 10 µg Se/g of feed and 10 µg Hg/g had a selenium concentration in the liver 1.5 times higher than females fed a diet containing just selenium (10 µg Se/g). In the same experiment, male mallards fed the selenium and mercury combination diet had almost 12 times the selenium concentration of male mallards fed the selenium-only diet. Similar results were found with Japanese quail fed diets containing methylmercury and selenite (El-Begearmi et al. 1977, 1982).

High selenium concentrations can affect the health of mature birds. At Kesterson Reservoir, chronic selenium toxicosis caused American coots (*Fulica americana*) to lose mass and feathers (Ohlendorf et al. 1990). American kestrels (*Falco sparverius*) fed a diet containing 12 µg Se/g of food had a lower ratio of fat and a higher ratio of lean mass to total body mass (Yamamoto and Santolo 2000). Adult mallards maintained on a diet enriched with 20 µg Se/g of food had lesions in their liver and integument. Mallards on a diet of 40 µg/g lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998). We noted none of these abnormalities among the eared grebes we collected from the GSL, and their body mass was usually not related to either selenium or mercury concentrations. Furthermore, when there was a statistically significant correlation between body mass and selenium or mercury concentrations, the relationship was positive. Liver mass, pancreas mass, and spleen mass were not correlated with either mercury or selenium concentrations.

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Table 1. Effect of collection site, collection date, sex of bird, and its age on the mean (± SE) concentration of selenium (ug/g dry weight); concentration of mercury (ug/g dry weight); and mass of body, liver, pancreas, and spleen (g wet weight) of eared grebes collected during 2006 on the Great Salt Lake, Utah.

	Collection sites		Collection dates		Sex		Age	
	Antelope	Stansbury	September	November	Male	Female	Juvenile	Adult
Se – blood	16.8 ± 2.3	25.4 ± 3.0	18.5 ± 2.5	23.3 ± 2.9	21.8 ± 3.0	19.7 ± 2.4	16.1 ± 2.3	25.2 ± 2.8
Se—liver	8.6 ± 0.5	15.2 ± 1.4	9.4 ± 0.7	14.5 ± 1.4	12.0 ± 1.2	11.8 ± 1.2	8.5 ± 0.7	15.8 ± 1.3
Hg—blood	4.3 ± 0.5	10.1 ± 1.0	5.6 ± 0.5	8.4 ± 1.2	7.1 ± 1.0	6.8 ± 0.9	5.5 ± 0.8	8.4 ± 1.0
Hg—liver	--	12.9 ± 1.7	10.1 ± 2.6	15.6 ± 1.9	14.1 ± 2.4	10.6 ± 1.7	13.1 ± 3.6	12.7 ± 1.8
Mass—body	480 ± 21	491 ± 25	381 ± 14	591 ± 11	521 ± 23	440 ± 20	431 ± 24	549 ± 16
Mass—liver	17.9 ± 1.2	17.0 ± 0.9	14.1 ± 0.8	20.8 ± 0.8	18.7 ± 1.0	15.7 ± 0.9	15.5 ± 1.1	19.8 ± 0.7
Mass—pancreas	0.25 ± 0.05	0.22 ± 0.05	0.15 ± 0.03	0.36 ± 0.07	0.24 ± 0.03	0.24 ± 0.09	0.25 ± 0.06	0.22 ± 0.05
Mass—spleen	0.20 ± 0.02	0.19 ± 0.01	0.19 ± 0.01	0.21 ± 0.02	0.21 ± 0.02	0.18 ± 0.01	0.19 ± 0.02	0.22 ± 0.02

Table 2. Mean (± SE) concentration of selenium (ug/g dry weight), concentration of mercury, (ug/g dry weight), and body mass (g wet weight) of eared grebes collected during November 2006 on the Great Salt Lake, Utah.

	Juveniles		Adults	
	Males	Females	Males	Females
Se – blood	17.8 ± 3.5 (*n* = 5)	14.6 ± 5.1 (*n* = 4)	29.2 ± 6.6 (*n* = 7)	27.1 ± 4.7 (*n* = 5)
Se—liver	8.4 ± 1.2 (*n* = 9)	12.7 ± 5.8 (*n* = 3)	17.9 ± 2.4 (*n* = 12)	17.6 ± 2.4 (*n* = 6)
Hg—blood	6.2 ± 2.3 (*n* = 5)	4.0 ± 2.0 (*n* = 4)	10.4 ± 2.3 (*n* = 7)	11.6 ± 1.8 (*n* = 5)
Hg—liver	--	--	15.7 ± 3.1 (*n* = 6)	14.7 ± 1.6 (*n* = 3)
Mass—body	593 ± 20	(*n* = 9) 569 ± 61 (*n* = 3)	623 ± 13 (*n* = 12)	539 ± 17 (*n* = 6)

Table 3. ANOVA tables for the effect of collection site, collection time, sex of bird, and age of bird on selenium and mercury concentrations (number of birds used for a comparison is one more than the two different degrees of freedom).

Term	Selenium (blood)			Selenium (liver)			Mercury (blood)		
	F	df	*P*	*F*	df	*P*	*F*	df	*P*
Site	5.91	1,27	0.02	53.65	1,44	0.0001	63.16	1,27	0.0001
Date	1.98	1,27	0.17	23.21	1,44	0.0001	19.93	1,27	0.0001
Site X Date	8.67	1,27	0.007	83.26	1,44	0.0001	34.09	1,27	0.0001
Sex	0.75	1,27	0.39	0.97	1,44	0.33	1.76	1,27	0.20
Site X Sex	0.01	1,27	0.94	2.80	1,44	0.10	1.63	1,27	0.21
Date X Sex	0.35	1,27	0.55	0.09	1,44	0.77	3.50	1,27	0.07
Site X Date X Sex	0.67	1,27	0.42	0.28	1,44	0.60	1.70	1,27	0.20
Age	1.80	1,27	0.19	7.49	1,44	0.009	0.84	1,27	0.36
Site X Age	0.11	1,27	0.73	1.41	1,44	0.24	0.11	1,27	0.73
Date X Age	0.06	1,27	0.81	5.54	1,44	0.02	1.92	1,27	0.17
Site X Date X Age	1.35	1,27	0.26	1.58	1,44	0.22	0.64	1,27	0.42
Sex X Age	2.64	1,27	0.11	0.10	1,44	0.76	5.84	1,27	0.02
Site X Sex X Age	0.05	1,27	0.83	1.15	1,44	0.29	0.05	1,27	0.83
Date X Sex X Age	3.05	1,27	0.09	6.61	1,44	0.01	0.00	1,27	0.94
Site X Date X Sex X Age	0.36	1,27	0.55	15.02	1,44	0.0004	0.72	1,27	0.40

Table 4. Regression analyses among selenium and mercury concentrations in the blood and liver and mass of body, liver, pancreas, and spleen using all eared grebes (males and females, juveniles and adults) collected during 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

Variable 1	Variable 2	r^2	*F*	df	*P*	
Se (blood)	Body mass	0.09	4.03	1,40	0.05	
	Liver mass	0.002	0.07	1,40	0.80	
	Pancreas mass		0.003	0.06	1,18	0.82
	Spleen mass	0.06	1.82	1,27	0.19	
	Se (blood)	--	--	--	--	
	Se (liver)	0.49	37.98	1,40	<0.001	
	Hg (blood)	0.49	38.78	1,41	<0.001	
	Hg (liver)	0.47	12.46	1,14	0.003	
Se (liver)	Body mass	0.32	27.72	1,58	<0.001	
	Liver mass	0.06	3.41	1,58	0.07	
	Pancreas mass		0.10	2.63	1,23	0.12
	Spleen mass	0.02	0.75	1,38	0.39	
	Se (blood)	see above				
	Se (liver)	--	--	--	--	
	Hg (blood)	0.54	47.12	1,40	<0.001	
	Hg (liver)	0.22	5.12	1,18	0.04	
Hg (blood)	Body mass	0.20	10.06	1,40	0.003	
	Liver mass	0.04	1.64	1,40	0.21	
	Pancreas mass		0.08	1.49	1,18	0.24
	Spleen mass	0.003	0.08	1,27	0.78	
	Se (blood)	see above				

	Se (liver)	see above				
	Hg (blood)	--	--	--	--	
	Hg (liver)	0.59	20.14	1,14	<0.001	
Hg (liver)	Body mass	0.08	1.62	1,18	0.22	
	Liver mass	0.01	0.18	1,18	0.68	
	Pancreas mass		0.99	92.26	1,3	0.07
	Spleen mass	0.23	1.87	1,6	0.22	
	Se (blood)	see above				
	Se (liver)	see above				
	Hg (blood)	see above				
	Hg (liver)	__	__	__	__	

Table 5. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using male eared grebes collected during November 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

		Juvenile males				Adult males			
Variable 1	Variable 2	r^2	*F*	df	*P*	r^2	*F*	df	*P*
Se (blood)	Body mass	0.32	1.40	1,3	0.08	0.28	1.92	1,5	0.23
	Se (blood)	--	--	--	--	--	--	--	--
	Se (liver)	0.98	162.72	1,3	0.001	0.92	56.58	1,5	0.001
	Hg (blood)	0.96	78.27	1,3	0.003	0.65	9.58	1,5	0.03
	Hg (liver)	insufficient data				0.48	1.84	1,2	0.31
Se (liver)	Body mass	0.31	3.12	1,7	0.12	0.36	5.74	1,10	0.04
	Se (blood)	see above					see above		
	Se (liver)	--	--	--	--	--	--	--	--
	Hg (blood)	0.98	155.27	1,3	0.001	0.82	24.12	1,5	0.004
	Hg (liver)	insufficient data				0.53	4.55	1,4	0.10
Hg (blood)	Body mass	0.42	2.19	1,3	0.23	0.46	4.27	1,5	0.09
	Se (blood)	see above					see above		
	Se (liver)	see above					see above		
	Hg (blood)	--	--	--	--	--	--	--	--
	Hg (liver)	insufficient data				0.64	3.67	1,2	0.19
Hg (liver)	Body mass	insufficient data				0.36	2.21	1,4	0.21
	Se (blood)	insufficient data					see above		
	Se (liver)	insufficient data					see above		
	Hg (blood)	insufficient data					see above		
	Hg (liver)	--	--	--	--	--	--	--	--

Table 6. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using female eared grebes collected during November 2006 on the Great Salt Lake, Utah (number of birds used for a comparison is one more than the two different degrees of freedom).

		Juvenile females				Adult females			
Variable 1	Variable 2	r^2	*F*	df	*P*	r^2	*F*	df	*P*
Se (blood)	Body mass	0.96	25.42	1,1	0.12	0.15	0.54	1,3	0.51
	Se (blood)	--	--	--	--	--	--	--	--
	Se (liver)	1.0	7930.0	1,1	0.007	0.68	6.44	1,3	0.09
	Hg (blood)	0.86	12.72	1,2	0.07	0.41	2.06	1,3	0.25
	Hg (liver)	insufficient data				0.47	0.90	1,1	0.52
Se (liver)	Body mass	0.96	22.67	1,1	0.13	0.46	3.45	1,4	0.14
	Se (blood)	see above					see above		
	Se (liver)	--	--	--	--	--	--	--	--
	Hg (blood)	0.95	20.1	1,1	0.14	0.80	11.94	1,3	0.04
	Hg (liver)	insufficient data				0.00	0.00	1,1	0.99
Hg (blood)	Body mass	1.0	6521.0	1,1	0.008	0.22	0.87	1,3	0.42
	Se (blood)	see above				see above			
	Se (liver)	see above				see above			
	Hg (blood)	--	--	--	--	--	--	--	--
	Hg (liver)	insufficient data				0.91	10.7	1,1	0.19
Hg (liver)	Body mass	insufficient data				0.31	0.45	1,1	0.63
	Se (blood)	insufficient data					see above		
	Se (liver)	insufficient data					see above		
	Hg (blood)	insufficient data					see above		
	Hg (liver)	--	--	--	--	--	--	--	--

Appendix 1. Data on individual eared grebes collected during 2006 on the Great Salt Lake including food in their esophagus (bs = adult brine shrimp, bf = adult brine flies, bfl = brine fly larva, c = hundreds of cysts.

Sample	Location date	Sex Age	Mass					Selenium		Mercury		Food
			Body	Liver	Gizzard	Pancreas	Spleen					
		1= male 2= female 1= juvenile 2 = adult						Blood	Liver	Blood	Liver	
EG-A1	Antelope 9/11/06	1 1	293	4.4	--	--	0.098	7.1	5.9	0.55	-	
EG-A2	Antelope 9/11/06	2 1	342	12.5	--	0.096	0.200	12.8	8.4	6.6	-	
EG-A3	Antelope 9/11/06	2 2	455	18.9	30.5	0.135	--	31.5	11.2	4.8	-	
EG-A4	Antelope 9/11/06	2 2	478	23.0	31.4	--	0.227	20.1	10.7	5.81	-	
EG-A5	Antelope 9/11/06	1 1	357	13.8	24.0	0.116	0.140	16	9.8	4.9	-	12 bs, 11 bf, c
EG-A6	Antelope 9/11/06	2 2	504	18.8	28.3	--	0.187	32.8	16.8	6.35	-	
EG-A7	Antelope 9/11/06	1 2	424	14.1	28.4	0.264	0.307	36.3	15.2	3.7	-	
EG-A8	Antelope 9/11/06	1 1	285	9.5	18.0	--	0.122	45.9	5	8.6	-	
EG-A9	Antelope 9/11/06	1 2	582	18.0	29.1	0.127	0.368	6.8	16	3.2	-	104 bs, 6 bf, c
EG-A10	Antelope 9/11/06	2 2	444	19.1	27.7	0.032	0.183	21.3	11.4	8.19	-	19 bs, 1bf, c
EG-A11	Antelope 9/11/06	1 1	388	17.9	30.8	0.287	0.329	9.7	6.9	7.78	-	15 bs, 8 bf
EG-A12	Antelope 9/11/06	2 1	366	11.5	28.4	0.082	0.187	0.3	11.9	0.09	-	36 bs, 6 bf
EG-A13	Antelope 9/11/06	2 1	394	14.0	30.1	0.081	0.112	-	8.6	-	-	20 bf
EG-A14	Antelope 9/11/06	2 1	245	9.0	13.3	0.025	0.085	-	5.9	-	-	3 bs, 2 bf
EG-A15	Antelope 9/11/06	2 1	318	7.0	24.2	--	--	-	7.2	-	-	
EG-A51	Antelope 11/10/06	1 1	651	21.6	29.3	0.119	0.240	13	7.1	3.8	-	100% bs
EG-A52	Antelope 11/10/06	1 2	633	23.0	33.2	0.369	0.213	17.8	7	4.2	-	100% bs
EG-A53	Antelope 11/10/06	1 2	542	17.7	31.6	0.347	0.191	15.2	7.5	3.2	-	100% bs
EG-A54	Antelope 11/10/06	1 1	604	33.2	34.2	--	0.147	14.2	6.4	4.3		
EG-A55	Antelope 11/10/06	2 1	490	14.0	25.8	0.581	0.139	15.9	7.1	2.6	-	
EG-A56	Antelope 11/10/06	1 1	550	20.7	33.9	0.405	0.247	16.1	7.3	3.3	-	

EG-A57	Antelope 11/10/06	1	1	520	17.3	23.5	--	0.432	-	6.9	-	-	100% bs
EG-A58	Antelope 11/10/06	1	1	580	24.3	30.0	0.397	0.319	-	7.8	-	-	100% bs
EG-A-59	Antelope 11/10/06	1	1	565	27.2	37.6	0.085	0.168	-	7.2	-	-	100% bs
EG-A60	Antelope 11/10/06	1	2	607	26.6	33.7	0.358	0.200	10.3	8.7	4.4	-	
EG-A61	Antelope 11/10/06	2	2	500	18.6	27.6	--	0.189	12.8	7.1	4.7	-	100% bs
EG-A62	Antelope 11/10/06	1	1	673	20.4	31.4	--	--	-	8.2	-	-	
EG-A63	Antelope11/10/06	2	1	529	18.6	29.0	0.902	0.147	15.8	6.7	4	-	100% bs
EG-A64	Antelope 11/10/06	1	1	520	14.3	18.4	0.335	0.200	14.2	6.8	4	-	100% bs
EG-A65	Antelope 11/10/06	1	2	587	28.0	25.8	0.041	0.140	-	7	-	-	100% bs
EG-A66	Antelope 11/10/06	2	1	----	----	----	--	--	1.1	-	0.05	-	
EG-Hat1	Stansbury 9/13/06	2	1	342	13.1	26.5	0.211	0.267	6.8	5.5	7	7.06	65 bs, c
EG-Hat2	Stansbury 9/13/06	2	1	378	16.7	27.6	--	0.214	13.7	7.1	3.5	-	42 bs, c
EG-Hat3	Stansbury 9/1/3/06	1	1	384	15.3	32.7	0.078	0.110	32.7	12.7	8.13	10.2	
EG-Hat4	Stansbury 9/13/06	1	2	403	16.0	30.0	--	0.257	9.1	6.2	4.8	4.6	
EG-Hat5	Stansbury 9/13/06	2	2	397	10.3	18.4	--	--	25.2	9.7	5.83	7.45	1 bs
EG-Hat6	Stansbury 9/13/06	1	2	499	21.7	33.6	0.337	0.160	7.7	5.6	4.9	5	15 bs
EG-Hat7	Stansbury 9/13/06	2	1	401	18.1	34.7	0.235	0.260	10.4	7.2	8.62	-	16 bs, 1 bf
EG-Hat8	Stansbury 9/13/06	1	1	363	17.4	35.6	--	0.188	22.4	10.5	6.42	7.23	
EG-Hat-9	Stansbury 9/13/06	2	1	336	10.6	18.4	--	0.130	-	6	-	4.5	
EG-Hat10	Stansbury 9/13/06	1	1	308	9.8	14.6	--	--	13.5	8	6.35	12.3	
EG-Hat-11	Stansbury 9/13/06	1	1	336	11 1	23.8	--	0.170	-	8.9	-	-	26 bs, 1 bfl, c
EG-Hat-12	Stansbury 9/13/06	2	1	324	15.6	31.4	--	0.212	-	7.9	-	-	1 bfl
EG-Hat13	Stansbury 9/13/06	2	2	469	19.2	28.7	--	0.176	25.6	20.3	6.66	10.5	55 bs, 1 bf
EG-Hat14	Stansbury 9/13/06	2	1	316	8.2	19.5	0.312	0.192	-	6	-	-	6 bs, 1 bf
EG-Hat16	Stansbury 9/13/06	1	1	297	8.5	14.4	--	0.108	-	8.8	-	32.2	5 bs
EG-Hat71	Stansbury 11/22/06	1	2	622	18.6	24.8	--	--	55.3	28.4	14	17	100% bs
EG-Hat72	Stansbury 11/22/06	1	2	717	16.8	25.7	--	--	50	27.4	18	28	
EG-Hat73	Stansbury 11/22/06	1	1	675	21.8	32.6	--	--	31.7	17.8	15.4	17.9	
EG-Hat74	Stansbury 11/22/06	1	2	598	26.0	27.9	--	--	31.7	17.8	14.6	5.87	100% bs

EG-Hat75	Stansbury 11/22/06	2 2	562	20.6	22.8	--	--	26	17.2	11.5	13.1	100% bs
EG-Hat76	Stansbury 11/22/06	2 2	600	23.4	27.3	--	--	37.8	24.2	12.7	13.1	100% bs
EG-Hat77	Stansbury 11/22/06	2 2	559	19.6	21.2	--	--	22.2	20.6	15.5	18	100% bs
EG-Hat78	Stansbury 11/22/06	1 2	660	18.6	30.4	--	--	24	18.1	14.4	11.6	100% bs
EG-Hat79	Stansbury 11/22/06	1 2	655	20.2	30.5	--	--	-	24.9	-	12.7	100% bs
EG-Hat80	Stansbury 11/22/06	1 2	591	22.4	25.6	--	--	-	22.5	-	18.8	100% bs
EG-Hat81	Stansbury 11/22/06	2 2	500	12.4	24.0	--	--	36.9	19.3	13.5	-	100% bs
EG-Hat82	Stansbury 11/22/06	2 2	513	20.2	24.8	--	--	-	17.4	-	-	100% bs
EG-Hat83	Stansbury11/22/06	1 2	604	21.3	22.7	--	--	-	18.8	-	-	100% bs
EG-Hat84	Stansbury 11/22/06	1 2	660	20.6	26.2	--	--	-	26.3	-	-	100% bs
EG-Hat85	Stansbury 11/22/06	2 1	688	17.4	28.9	--	--	25.7	24.2	9.27	-	100% bs

Final Report:

Concentrations of Selenium and Mercury in Common Goldeneyes from the Great Salt Lake, Utah

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Abstract

We examined selenium and mercury concentrations in male common goldeneyes (*Bucephala clangula*) that spent the winter of 2005–2006 on the Great Salt Lake, Utah. Selenium concentrations in livers were 15.3 ± 1.2 µg/g (mean ± SE on a dry-weight basis) and 16.7 ± 1.2 µg/g in blood. Mercury concentrations were 38.8 ± 4.5 µg/g in livers and 14.3 ± 1.2 µg/g in blood. Selenium concentrations in liver, selenium concentrations in blood, mercury concentrations in liver, and mercury concentrations in blood were all highly correlated with each other. Body mass and liver mass were not correlated with the concentration of selenium or mercury concentration in either blood or liver. Fat mass was negatively correlated with liver concentrations of selenium and mercury and with blood concentrations of mercury, but not blood concentrations of selenium. Selenium and mercury concentrations increased across time in ducks collected around Fremont Island but not in ducks collected around Stansbury Island.

Introduction

Selenium is a naturally occurring trace element, and small quantities of it are essential for animal health. However, it becomes toxic at higher concentrations. Elevated concentrations of selenium can cause reduced egg hatchability, embryonic defects, and lower survival rates of chicks and adults (Ohlendorf et al.1989, Ohlendorf 2003). For example, birds foraging in California's Kesterson Reservoir, which was the disposal site for subsurface agricultural drainage from portions of the western San Joaquin Valley, accumulated high concentrations of selenium in their tissues (Ohlendorf 2002, 2003). The high concentrations of selenium impaired the reproductive ability of several avian species nesting at Kesterson Reservoir and caused mortality of adult birds (Ohlendorf et al. 1989; Ohlendorf 2002, 2003).

The Great Salt Lake (GSL) is the fourth-largest terminal lake in the world and is an important region for breeding and migratory waterbirds including common goldeneyes (*Bucephala clangula*) that overwinter on it (Aldrich and Paul 2002). Because GSL is a closed basin, contaminants (e.g., mercury and selenium) may accumulate in the GSL. Thus, GSL ducks are likely exposed to these contaminants, and elevated contaminant concentrations may adversely affect their survival and reproduction (reviewed in Takekawa et al. 2002). Indeed, mercury concentrations identified in a 2005 reconnaissance investigation on the GSL were the highest among published results for common goldeneye (Gerstenberger et al. 2004). Hence, there is a need to ensure that selenium concentrations in the GSL do not reach levels that would impair the health or reproduction of the birds that depend upon the GSL. For this reason, the Utah Division of Water Quality wants to establish a water standard for selenium in the GSL. To aid this effort, we measured selenium and mercury concentrations in common goldeneyes soon after they arrived on the GSL and then again in February and March before they migrate from the GSL. Although the continental population of common goldeneye is relatively stable compared to other North American sea duck populations (e.g., eiders and scoters), insight into mercury and selenium concentrations in common goldeneye wintering on GSL presents a potentially unique opportunity to understand relationships between selenium and mercury concentrations in ducks and how their concentrations affect the condition of wintering sea ducks.

This study was designed to answer the following specific questions.

1. What are selenium and mercury concentrations in the blood and liver of male common goldeneye that winter on the GSL?
2. Do goldeneyes accumulate selenium and mercury while on the GSL?
3. Do selenium and mercury concentrations vary based on the age of the birds?
4. Are selenium and mercury concentrations in blood and liver correlated?
5. Do selenium or mercury concentrations affect body condition of goldeneyes?

Methods

Collection of goldeneyes. From November 2005 through March 2006, we used a shotgun to collect 40 male goldeneyes located on the GSL (Appendix 1). We collected ducks from two parts of the Great Salt Lake. One part was around Fremont Island in the northeastern section of the Great Salt Lake (Fremont Island and Farmington Bay); these ducks will be referred to as Fremont Island ducks. The other collection area was around Stansbury Island, Gilbert Bay, and the southern side of Carrington Bay; these ducks will be called the Stansbury Island ducks.

We used a syringe to collect at least 1 mL of blood from the thoracic cavity. Liver and blood samples were placed in separate Whirl-Pak® bags and frozen. We weighed and measured the birds, and determined their age by plumage. We also removed and weighed abdominal and intestinal fat.

Selenium and mercury analysis. Blood and liver samples from all ducks were sent to Laboratory and Environmental Testing Incorporated (LET), Columbia, Missouri, for selenium and mercury analyses. LET analyzed the tissue for total selenium using hydride generation atomic absorption spectrometry and mercury using the cold vapor atomic absorption spectrometry, with a target reporting limit of 0.2 µg/g. Quality control of chemical analyses was conducted using one or more

method blanks, matrix spikes, matrix spike duplicates, and reference samples for each sample batch (CH2M HILL 2006).

Statistical analyses. Data on selenium and mercury concentrations were normally distributed based on the D'Agostino-Pearson Omnibus K^2 normality test. Hence, parametric statistics were used. Analyses of Variance (ANOVAs) were used to determine the effect of collection site (Fremont Island versus Stansbury Island), and age of birds (juveniles versus adults) on selenium and mercury concentrations in blood and liver. Correlation analyses were conducted to compare selenium and mercury concentration in an individual duck's blood and liver. Selenium and mercury concentrations also were tested for correlation with body mass, liver mass, and fat mass. In all tests, results were considered significant if $P < 0.05$.

To assess the effect of collection date, we changed all collection dates to an Ordinal day with day 1 being November 29, 2005: the first day that a duck was collected. March 16, 2006, which was the last day a duck was collected, was changed to day 114. We then conducted a regression analysis to compare the different dependent variables to the Ordinal day. Data for collection date and site were confounded because almost all Fremont Island ducks were collected prior to February 1, 2006 and Stansbury Island ducks were collected after that date. Hence, we analyzed Fremont Island and Stansbury Island ducks separately.

Results

Selenium and mercury analyses.– Mean ($\pm$ SE) selenium concentrations in livers were 15.3 $\pm$ 1.2 µg/g on a dry-weight basis and 16.7 $\pm$ 1.2 µg/g in blood. Mercury concentrations were 38.8 $\pm$ 4.5 µg/g in livers and 14.3 $\pm$ 1.2 µg/g in blood (Table 1). Selenium and mercury concentrations in both livers and blood did not vary by age but collection site (Fremont Island versus Stansbury Island) (or associated sampling date) affected selenium concentrations in liver and mercury concentrations in both liver and blood (Table 2).

Selenium concentrations in liver, selenium concentrations in blood, mercury concentrations in liver, and mercury concentrations in blood were all highly correlated with each other (Table 3). Body mass and liver mass were not correlated with concentrations of selenium or mercury in either blood or liver (Table 3). Fat mass was negatively correlated with selenium concentrations in liver, mercury concentrations in liver, and mercury concentrations in blood.

Among Fremont Island ducks, selenium and mercury concentrations in both liver and blood samples varied by collection day but this was not true for Stansbury Island ducks (Table 4, Figure 1-4). Body mass, liver mass, and fat mass did not vary by collection day for either Fremont Island or Stansbury Island ducks (Table 4).

Discussion

In male common goldeneyes, we found that selenium concentrations in livers ranged from 4 to 48 µg/g. In earlier studies on birds collected from GSL (Conover et al. 2007*a*, *b*), we found that selenium concentrations in livers ranged from 5 to 28 µg/g in eared grebes (*Podiceps nigricollis*) and 4 to 14 µg/g in California gulls (*Larus californicus*). Mean selenium concentration in livers was higher in goldeneyes (mean =15.3 µg/g) than in eared grebes (mean = 12.0 µg/g) or California gulls (mean = 8.1 µg/g). In other avian species collected elsewhere, mean background levels of selenium have been reported to be less than 10 µg/g in livers (USDI 1998, Ohlendorf 2003).

Mean selenium concentration in blood samples from our goldeneyes was 16.7 µg/g (range =1 to 34). In California gulls that we collected on the GSL, mean selenium concentration in blood was 18.1 µg/g (range = 5 to 46) and in eared grebes 20.9 µg/g (range= 1 to 55; Conover et al. 2007*a*,*b*). Selenium concentrations in the blood of American kestrels (*Falco sparverius*), red-tailed hawk (*Buteo jamaicensis*), northern harrier (*Circus cyaneus*), barn owl (*Tyto alba*), and loggerhead shrike (*Lanius ludovicianus*) from a contaminated grassland in California ranged from 1 to 38 µg/g dry weight (Santolo and Yamamoto 1999). Selenium concentrations in whole blood above 2 µg/g are considered to exceed normal background, and 5 µg/g is considered a provisional threshold indicating that further study is warranted (USDI 1998).

In GSL goldeneyes, we found that selenium levels in liver and blood samples were both highly correlated with mercury concentrations in liver and blood. Among California gulls, selenium concentrations in blood were correlated with mercury concentrations in blood but not in livers (Conover et al. 2007*a*). Among male eared grebes, selenium concentrations in both blood and liver tissues were correlated with mercury levels in blood but not in livers (Conover et al. 2007*b*). Among female eared grebes, selenium and mercury concentrations were not related (Conover et al. 2007*b*). In wading birds, selenium and mercury concentrations were positively correlated in the blood, but not in liver tissues (Goede and Wolterbeek 1994). In surf scoters (*Melanitta perspicillata*) collected from San Francisco Bay, California, selenium and mercury concentrations were not correlated (Ohlendorf et al. 1991).

One reason that selenium and mercury concentrations in birds are correlated is because selenium and mercury can interact to form a stable, complex so that selenium may provide birds some protection from mercury toxicity (Ohlendorf 2003, Wiener et al. 2003). This interaction between mercury and selenium may cause an enhanced accumulation and retention of both chemicals in birds (Furness and Rainbow 1990, Scheuhammer et al. 1998, Spalding et al. 2000, Henny et al. 2002). Differences in blood and liver concentrations of selenium may result from initial faster selenium elimination in liver than blood and to the binding of selenium to inorganic mercury creating an inert mercury-selenium protein (Wayland et al. 2001).

In eared grebes and California gulls collected from the GSL, we found that age, collection day, and collection site affected selenium concentrations in their blood and liver. In this study, we found that age did not affect selenium or mercury concentrations in male goldeneyes from the GSL but collection day affected selenium and mercury concentrations for Fremont Island ducks but not Stansbury Island ducks. We are unable to assess the impact of collection site on selenium and mercury concentrations because collection day was confounded by collection site (most Fremont Island ducks were collected prior to February 1 and most Stansbury Island ducks were collected after that date). However, it is likely that collection site did not have a significant effect on selenium concentrations in goldeneyes because these ducks were very mobile while on GSL and foraged over wide areas, including in freshwater marshes (J. Vest, unpublished). In contrast, eared grebes are not very mobile while on the GSL because they cannot fly. Likewise, California gulls on the GSL cannot venture far from the nest to forage during the breeding season.

High selenium concentrations can affect the health of mature birds. At Kesterson Reservoir, chronic selenium toxicosis caused American coots (*Fulica americana*) to lose mass and feathers (Ohlendorf et al. 1990). American kestrels (*Falco sparverius*) fed a diet containing 12 µg Se/g of food had a lower ratio of fat and a higher ratio of lean mass to total body mass (Yamamoto and Santolo 2000). Adult mallards (*Anas platyrhynchos*) maintained on a diet enriched with 20 µg Se/g

of food had lesions in their liver and integument. Mallards on a diet of 40 µg/g lost weight and exhibited abnormalities such as feather loss, loss of nails, and beak necrosis (Albers et al. 1996, O'Toole and Raisbeck 1998). We noted no abnormalities among the goldeneyes that we collected from the GSL. In our goldeneyes, body and liver mass were not correlated with either selenium or mercury concentrations. However, fat mass was negatively correlated with liver concentrations of both selenium and mercury and mercury concentrations in blood. These findings raise the possibility that high levels of these contaminants may reduce the ability of male goldeneyes that are over-wintering on GSL to accumulate or retain fat.

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Table 1. Effect of collection site, collection date, and duck age on the mean (± SE) concentration of selenium (ug/g dry weight), concentration of mercury (ug/g dry weight), and avian mass (g wet weight) of male goldeneyes collected from around Fremont Island and Stansbury Island on the Great Salt Lake, Utah from November 2005 through January 2006 (early season) and from February 2006 through March 2006 (late season).

	All birds	Collection sites		Collection dates		Age	
		Fremont	Stansbury	Early	Late	Juvenile	Adult
N =	40	20	20	21	19	17	23
Se – liver	15.3 ± 1.2	12.6 ± 1.5	18.0 ± 1.7	12.2 ± 1.4	18.7 ± 1.7	12.7 ± 1.6	17.2 ± 1.6
Se—blood	16.7± 1.2	16.3± 1.9	17.1 ± 1.7	15.9 ± 1.8	17.6 ± 1.7	14.8 ± 1.5	18.1± 1.8
Hg—liver	38.8 ± 4.5	23.5 ± 3.7	54.1 ± 6.7	22.3 ± 3.6	56.4 ± 6.6	31.3 ± 6.5	44.3 ± 6.0
Hg—blood	14.3 ± 1.2	10.5 ± 1.1	18.1 ± 1.8	10.4 ± 1.0	14.1 ± 2.4	13. 4 ± 1.8	15.0 ± 1.6
Mass—body	1086 ± 14	1114 ± 20	1057 ± 16	1117± 19	1050 ± 16	1048 ± 20	1113 ± 16
Mass—liver	32.1 ± 1.0	33.9 ± 1.6	30.4 ± 1.3	34 ± 1.5	30.1 ± 1.3	33.2 ± 1.5	31.3 ± 1.4
Mass—fat	10.5 ± 1.0	12.5 ± 1.3	8.6 ± 1.3	12.8 ± 1.3	8.0 ± 1.2	10.7 ± 1.6	10.4 ± 1.2

Table 2. Results of ANOVA tests examining the effect of collection site (around Fremont Island versus Stansbury Island) and age of bird (juveniles versus adults) on concentrations of selenium and mercury in male goldeneyes collected on the Great Salt Lake during the winter of 2005–2006 (d.f. = 1,32 for all tests).

Term	Selenium (liver)		Selenium (blood)		Mercury (liver)		Mercury (blood)	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Site	5.25	0.03	0.04	0.84	14.39	0.001	13.10	0.001
Age	1.61	0.21	1.38	0.25	0.37	0.55	0.06	0.81
Site X Age	2.67	0.11	1.16	0.29	0.94	0.34	1.09	0.30

Table 3. Regression analyses between selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using all male goldeneyes (juveniles and adults) collected from November 2005 through March 2006 on the Great Salt Lake, Utah (*d.f.* = 1,38 for all tests).

Variable 1	Variable 2	r^2	*F*	*P*
Se (liver)	**Body mass**	**0.01**	**0.27**	**0.61**
	Liver mass	**0.09**	**3.79**	**0.06**
	Fat mass	**0.12**	**5.23**	**0.03**
	Se (liver)	**--**	**--**	**-**
	Se (blood)	**0.57**	**51.04**	**<0.001**
	Hg (liver)	**0.81**	**162.43**	**<0.001**
	Hg (blood)	**0.59**	**55.48**	**<0.001**
Se (blood)	**Body mass**	**0.01**	**0.25**	**0.62**
	Liver mass	**0.01**	**0.35**	**0.56**
	Fat mass	**0.01**	**0.22**	**0.64**
	Se (liver)	**see above**		
	Se (blood)	**--**	**--**	**--**
	Hg (liver)	**0.28**	**15.08**	**<0.001**
	Hg (blood)	**0.33**	**19.15**	**<0.001**
Hg (liver)	**Body mass**	**0.04**	**1.67**	**0.20**
	Liver mass	**0.09**	**3.73**	**0.06**
	Fat mass	**0.15**	**6.85**	**0.01**
	Se (liver)	**see above**		
	Se (blood)	**see above**		
	Hg (liver)	**--**	**--**	**--**

	Hg (blood)	**0.74**	**108.74**	**<0.001**
Hg (blood)	**Body mass**	**0.04**	**1.68**	**0.20**
	Liver mass	**0.01**	**0.07**	**0.80**
	Fat mass	**0.17**	**7.59**	**0.01**
	Se (liver)	**see above**		
	Se (blood)	**see above**		
	Hg (liver)	**see above**		
	Hg (blood)	__	__	__

Table 4. Regression analyses between collection date (converted to an Ordinal day) and selenium concentrations in the blood and liver, mercury concentrations in the blood and avian mass using male goldeneyes collected around Fremont Island from December 7, 2005 through January 17, 2006 and around Stansbury Island from December 7, 2005 through March 22, 2006 on the Great Salt Lake, Utah (*d.f.* = 1,18 for all tests).

Location	Dependent variable	r^2	*F*	*P*
Fremont Island				
	Body mass	**0.00**	**0.00**	**0.95**
	Liver mass	**0.04**	**0.74**	**0.40**
	Fat mass	**0.05**	**1.00**	**0.33**
	Se (liver)	**0.53**	**20.58**	**<0.001**
	Se (blood)	**0.34**	**9.26**	**0.007**
	Hg (liver)	**0.65**	**33.58**	**<0.001**
	Hg (blood)	**0.66**	**34.34**	**<0.001**
Stansbury Island				
	Body mass	**0.06**	**1.27**	**0.28**
	Liver mass	**0.09**	**1.73**	**0.20**
	Fat mass	**0.12**	**2.49**	**0.13**
	Se (liver)	**0.09**	**1.81**	**0.20**
	Se (blood)	**0.01**	**0.11**	**0.75**
	Hg (liver)	**0.13**	**2.70**	**0.12**
	Hg (blood)	**0.08**	**1.49**	**0.23**

Figure 1. Effect of collection date (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on selenium concentrations (ug/g dry weight) in livers of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

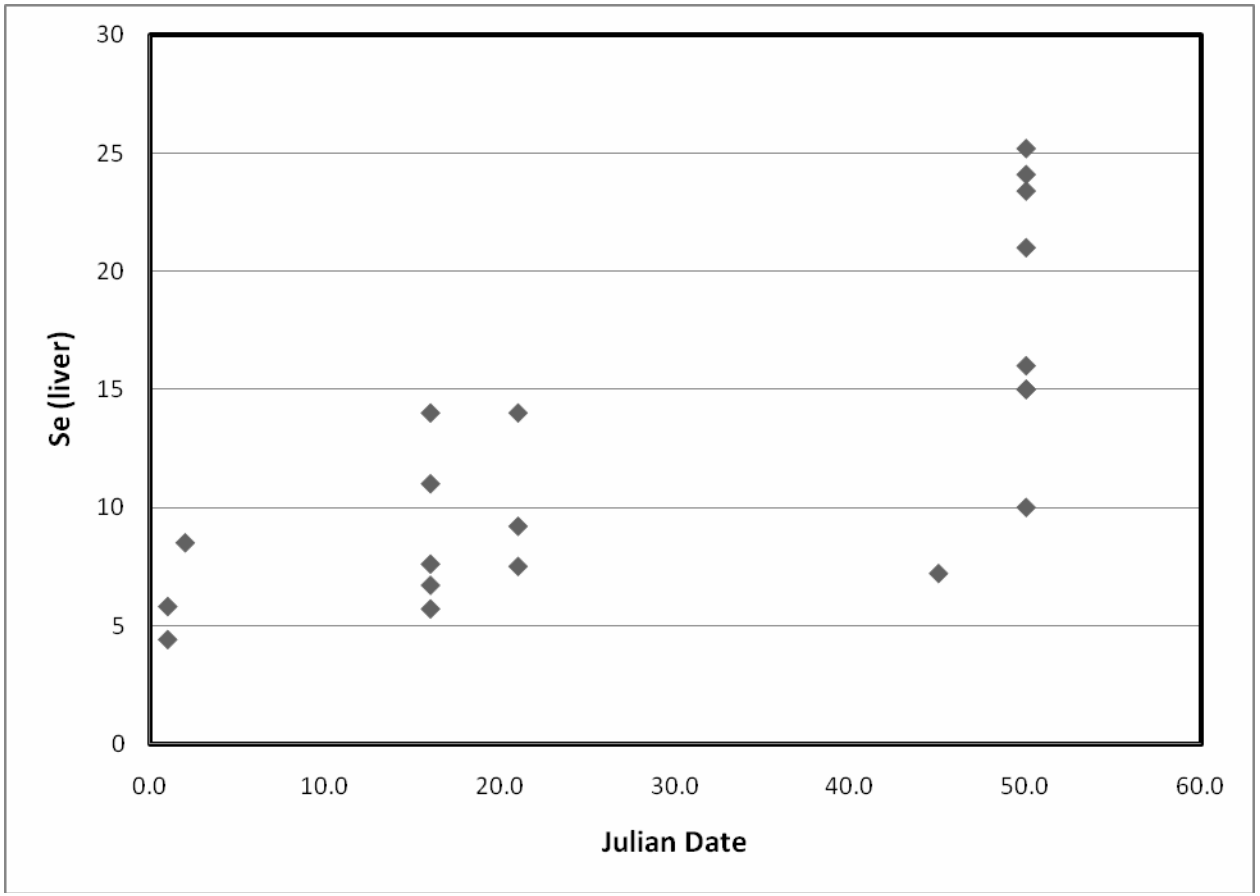


Figure 2. Effect of collection date (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on selenium concentrations (ug/g dry weight) in blood of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

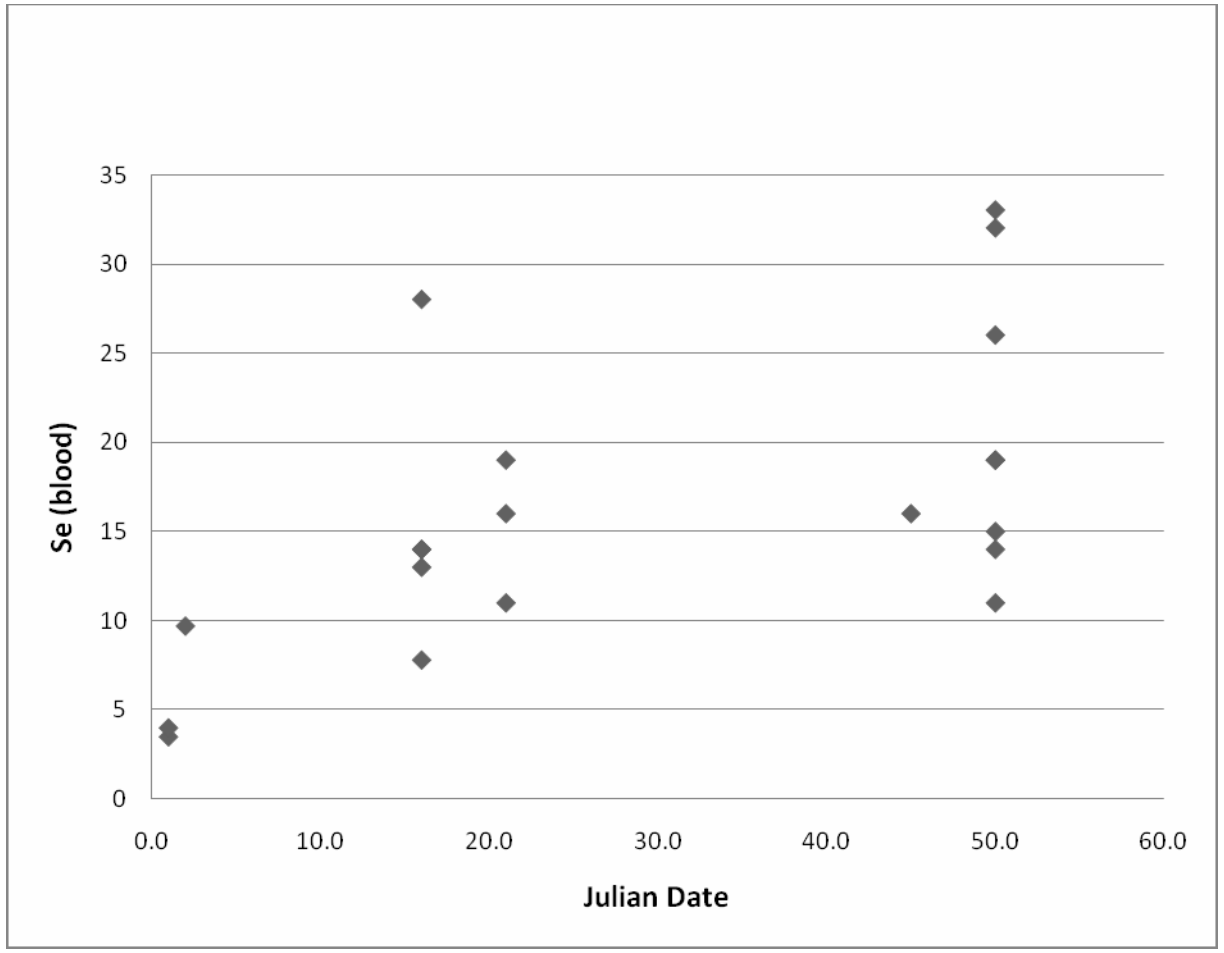


Figure 3. Effect of collection day (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on mercury concentrations (ug/g dry weight) in livers of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.

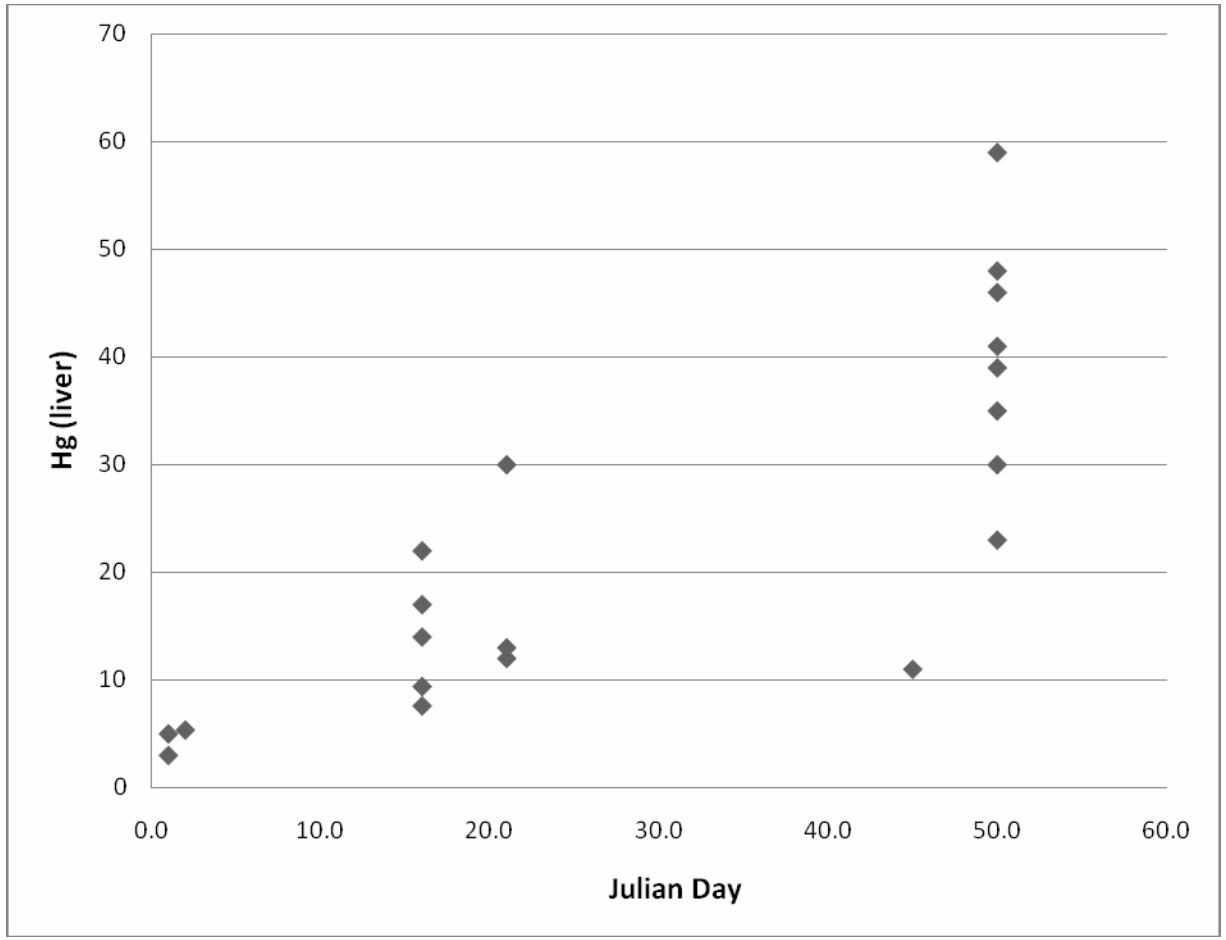
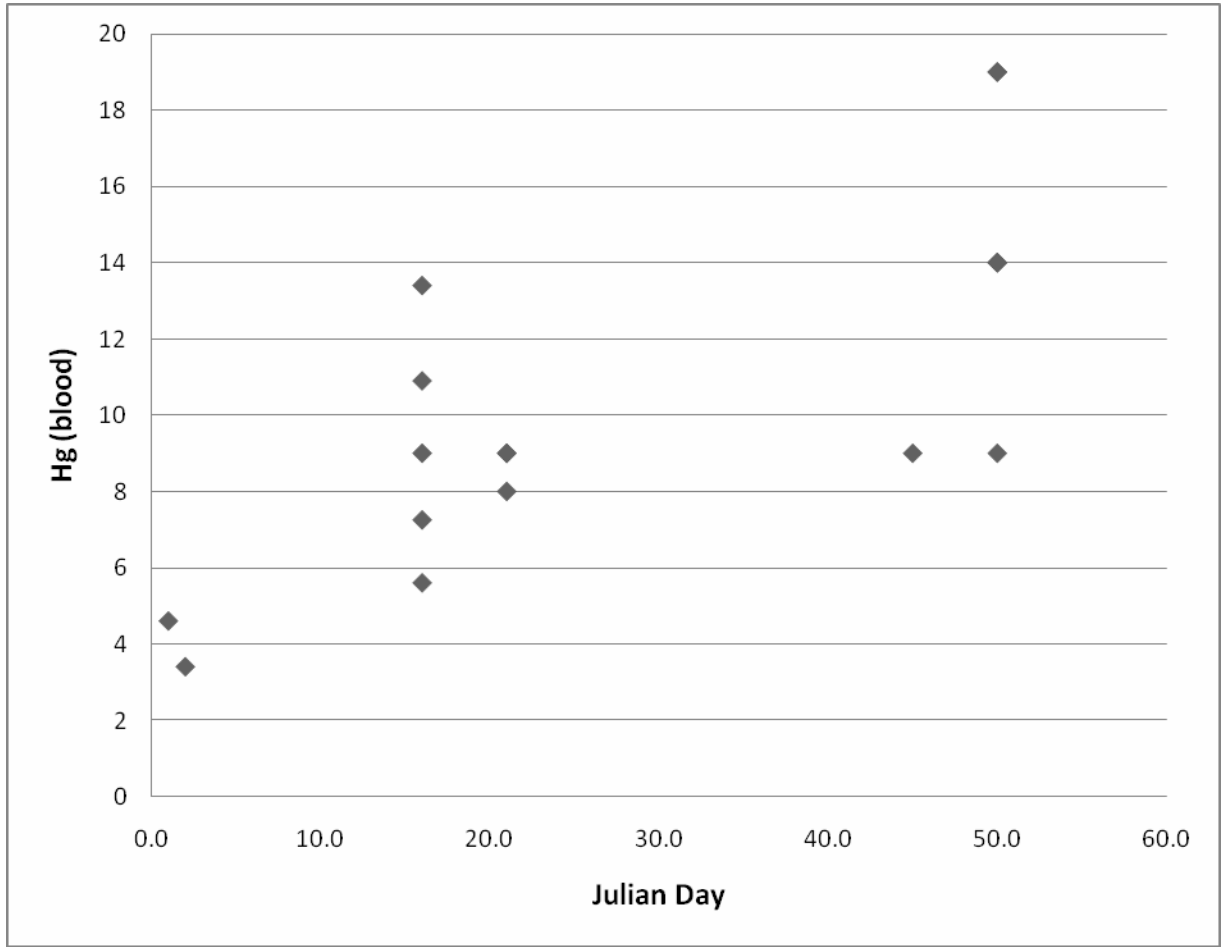


Figure 4. Effect of collection day (Ordinal day 1 is November 29, 2005 while day 50 is January 17, 2006) on mercury concentrations (ug/g dry weight) in the blood of male goldeneyes collected around Fremont Island, Great Salt Lake, Utah.



Appendix 1. Mass (wet weight) and concentrations of selenium and mercury (dry weight basis) of common goldeneyes collected during the winter of 2005-2006 on the Great Salt Lake, Utah.

ID No.	Age	Location	Date	Mass (g)			Se (µg/g)		Hg (µg/g)	
				Body	Liver	Fat	Liver	Blood	Liver	Blood
CG432	Adult	SW Gilbert Bay	3/6/2006	995	27	4.4	25	32	88.5	27.2
CG433	Adult	SW Gilbert Bay	3/6/2006	1074	23	21.1	3.6	1.1	1.6	0.57
CG437	Adult	SW Gilbert Bay	3/22/2006	1023	37	5.1	5.2	4	6.09	3.4
CG438	Adult	SW Gilbert Bay	3/22/2006	1045	36	11.3	25	25	80.7	23
CG439	Adult	SW Gilbert Bay	3/22/2006	1145	28	14.6	34	26	114	29
CG440	Adult	SW Gilbert Bay	3/22/2006	1155	35	5.6	18	12	62.7	27.1
CG445	Adult	SW Gilbert Bay	3/16/2006	1049	28	4.9	23	18	75.4	18.4
CG446	Adult	SW Gilbert Bay	3/16/2006	1122	33	3.8	17	13	50	14
CG450	Juv	SW Gilbert Bay	3/22/2006	992	37	3.7	27	16	94.2	25
CG456	Juv	Gilbert Bay	3/2/2006	921	34	4.0	18	17	57	30
CG469	Adult	SW Gilbert Bay	3/22/2006	1015	43	7.1	10	16	31	16
CG493	Juv	Fremont Island	12/14/2005	1203	32	28.4	6.7	14	9.39	7.25
CG494	Juv	Fremont Island	12/14/2005	1068	26	13.9	14	28	7.6	5.6

CG495	Juv	Fremont Island	12/14/2005	1194	48	16.7	7.6	14	17	13.4	
CG497	Juv	Farmington Bay	11/30/2005	1008	39	7.3	8.5	9.7	5.36	3.4	
CG513	Juv	Fremont Island	12/14/2005	1018	36	10.1	5.7	7.8	14	10.9	
CG514	Juv	Fremont Island	12/14/2005	962	28	5.4	11	13	22	8.95	
CG515	Adult	Fremont Island	12/19/2005	1246	39	10.7	7.5	11	11.9	8.14	
CG516	Adult	Fremont Island	12/19/2005	1221	37	24.8	9.2	19	12.7	9.24	
CG517	Adult	Fremont Island	12/19/2005	1164	32	10.4	14	16	30	9.31	
CG523	Juv	Farmington Bay	1/12/2006	1050	34	14.8	7.2	16	10.8	8.98	
CG545	Adult	Gilbert Bay	2/16/2006	1017	32	5.8	11	17	23	15	
CG555	Adult	Fremont Island	1/17/2006	1238	47	11.5	21	32.2	30	19	
CG565	Adult	Fremont Island	1/17/2006	1082	27	6.1	23.4	19	41	9.1	
CG566	Adult	Fremont Island	1/17/2006	1038	33	6.1	16	15	48	14	
CG587	Juv	Fremont Island	1/17/2006	1050	30	9.8	10	11	23	14	
CG594	Juv	Gilbert Bay	12/7/2005	1191	36	19.0	5.5	7.8	11.6	8.5	
CG596	Adult	Carrington Bay	2/9/2006	1089	24	9.1	18	22.9	51.4	16	
CG600	Adult	Carrington Bay	2/9/2006	1130	22	9.6	17	13	44	13.2	
CG601	Adult	Carrington Bay	2/9/2006	1058	26	5.3	20	19	52.1	22.8	
CG606	Juv	Fremont Island	11/29/2005	1094	42	9.5	4.4	3.5	5.07	4.6	
CG616	Juv	Carrington Bay	2/9/2006	960	28	4.9	20	23	63.9	23.2	

CG617	Adult	Carrington Bay	2/9/2006	1159	22	20.7	21.8	22	65	16
CG621	Juv	Carrington Bay	2/9/2006	954	29	5.1	22.1	24	39	15
CG622	Juv	Carrington Bay	2/9/2006	1052	27	6.2	19	14	71.2	19
CG626	Adult	Fremont Island	1/17/2006	1254	36	14.5	24.1	33	39	19
CG627	Adult	Fremont Island	1/17/2006	1142	26	10.3	25.2	26	59.1	14
CG642	Juv	Fremont Island	1/17/2006	1056	36	11.9	15	19	35	15
CG644	Juv	Fremont Island	1/17/2006	1043	23	10.5	15	14	46	15
CG665	Adult	Fremont Island	11/29/2005	1150	27	17.0	5.8	4.3	2.8	2.2

Final Report

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Preliminary Analyses of Selenium Bioaccumulation in Benthic Food Webs of the Great Salt Lake, Utah

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14 October 2007
(With 2007 Sediment Addendum)

Summary

Benthic organisms and substrates in the Great Salt Lake, Utah, were sampled during one week in June 2006 to test collection methodologies for biostromes and soft substrates and to get preliminary information on the selenium concentrations of benthic organisms. The sampling was focused on biostromes, as these solid reef-like structures cover 23% of the oxic benthic area of the lake and are the principal habitat for brine fly (*Ephydra cinerea*) larvae and pupae that are fed upon by some birds utilizing the lake. Samples were taken at depths of 1-5 m along two transects–one near Bridger Bay and another in the southern area of Gilbert Bay. The biostromes were sampled with a pumped-bucket device operated by a SCUBA diver whereas the soft sediments were sampled with a Ponar grab. Water samples and adult brine flies were also collected.

The pumped-bucket sampler effectively sampled brine flies on horizontal surfaces of the biostromes, but not on the sides of the mounded ones encountered in the southern part of Gilbert Bay. Brine fly larvae and pupae were far more abundant on the biostromes than on the soft substrates, with respective mean densities of 240/m^2, 530/m^2 and 9,140/m^2 on mud, sand and biostromes. In 2006 the mean selenium concentration in the combined organic matter-inorganic substrates in the biostromes was 1.7 ± 0.9 µg/g dry weight. Additional samples collected in 2007 yielded selenium concentrations of 0.3 ± 0.1. However, when the inorganic carbonates were removed, the remaining organic matter had selenium concentrations of 1.0 ± 0.1 µg/g dry weight. Mean Se concentrations in larvae, pupae and adult brine flies in 2006 were 1.3, 1.5 and 1.8 µg/g dry weight, respectively. A 2-way ANOVA indicated that selenium concentrations were significantly higher in Bridger Bay than in Gilbert South ($p < 0.000$), and in pupae than in larvae ($p = 0.046$), but the differences were not large. Although there was over a thousand-fold bioconcentration between Se dissolved in the water and in the periphyton of the

biostromes, the limited data suggested that there was no further bioconcentration between the periphyton and the brine flies.

Although biostromes cover only 18% of the area where phytoplankton can grow in Gilbert Bay, we estimated that the attached periphyton on them have approximately 68% of the chlorophyll contained in the lake's phytoplankton. Consequently, the biostromes represent a significant feature of primary production. The limited data from the June samplings suggests that the brine fly biomass in the lake is about 30% of that in *Artemia*. An analysis of the diets of birds collected for the selenium study, and that from the literature of saline lakes, suggests that brine fly produced on biostromes are an important diet component for American avocets (*Recurvirostra americana*), goldeneye ducks, and to a lesser extent, black-necked stilts (*Himantopus mexicanus*), California gulls (*Larus californicus*) and perhaps other species. Consequently the benthic food web may be important route for selenium uptake in these birds.

Given the importance of biostromes in the food web of the lake, more work is needed to improve sampling methodologies for the periphyton community on them and to assess how to effectively quantitatively sample brine flies from both vertical and horizontal surfaces of these unique structures. The seasonality of periphyton growth and brine fly production needs to be assessed, and the bioconcentration of other contaminants such as mercury needs to be studied.

Introduction

Brine flies are an important component of the food web in the Great Salt Lake and are important diet items of some nesting birds and consequently may serve as a vector for selenium uptake. However, only a single study has been done on the brine flies in the lake (Collins 1980). Two brine fly species have been described at the lake, *Ephydra cinerea*, and *E. hians*, with the former representing over 99% of the individuals. Adult brine flies lay their eggs on the lake surface, the eggs sink, and the 1st instar larvae hatch in benthic habitats. They proceed through three larval stages that feed on the bottom but frequently move into the water column, probably as a dispersal mechanism (Collins 1980). After growing 18-200 d the brine fly larvae attach to a solid substrate and pupate. Pupal duration varies from 37 d at 15 C, to 11 d at 25 C. The pupae release from the bottom, float to the surface and flies emerge as adults. High densities of adult flies are frequently present along the shoreline of the lake. Collins (1980) suggested that brine flies have 1–2 overlapping generations per year, although more detailed studies are needed to confirm this.

Collins (1980) found that fly larval and pupal densities were highest on the calcified biostromes (stromatolites or bioherms) in the lake that provide solid substrates. Mud substrates were secondarily important, and few flies were found on sand substrates. Based on a map by Eardley (1938), biostromes occupy 23% of Gilbert Bay's littoral zone and cover 261 km^2 (Fig. 1; Table 1). They occupy depths of ca. 1-4 m in the lake where there is sufficient light.

Parker (2005) studied the biostromes on the northern and NW sides of Antelope Island. He found that the cyanobacterium *Aphanothece* sp. represented over 99% of the cells in the biostromes, but some green algae were present. The small 1.4-µm diameter cells are embedded in a mucilaginous matrix that is partially calcified. The growing cyanobacteria change the pH of the water, causing carbonates to precipitate. Treatment with hydrochloric acid

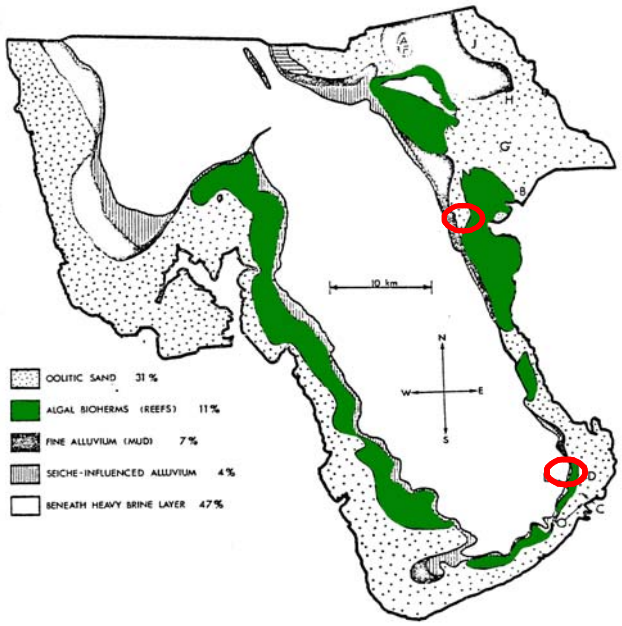


Figure 1. Map of Gilbert Bay showing the distribution of biostromes (bioherms) (green shading), oolitic sands (stippled) and mud substrates. Image taken from Collins (1980) who obtained data from Eardley (1938).

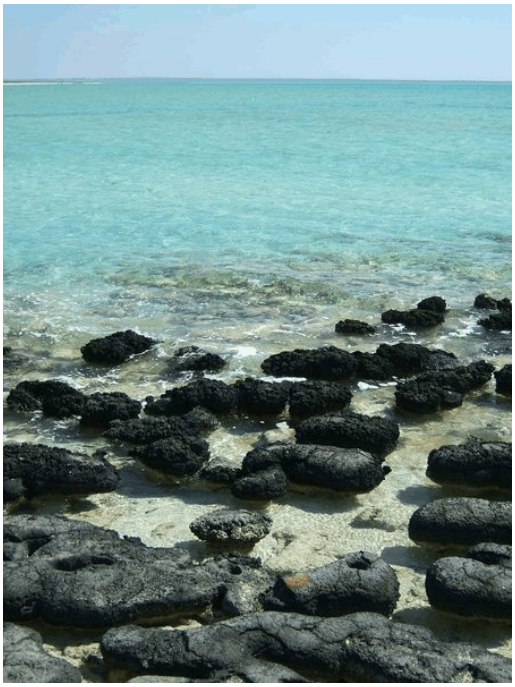
Table 1. Morphometric characteristics of Gilbert Bay of the Great Salt Lake at a lake elevation of 1280.2 m (4200 ft), which is near the mean historical elevation. The data exclude areas of the southern salt ponds and Farmington Bay. Data derived from Baskin (2005). The thickness of the mixed layer was estimated at 6.7 m (22 ft). The areas of biostromes, oolitic sand and mud were derived from the proportional areas shown in the map of Collins (1980), with an adjustment to a lake level of 1280.2 m. Hyposographic curves of the area and volume of Gilbert Bay at different lake elevations is shown in Appendix 1.

Section	Mean Depth (m)	Area of Sediments (km^2)	Volume ($m^3 \times 10^9$)
Gilbert Bay (total)	5.55	2,057	11.42
Deep-Brine Layer		912	1.73
Mixed Layer		1,145	9.69
Biostromes		261 (23%)	
Oolitic sand		712 (62%)	
Mud		172 (15%)	

dissolves the carbonates, leaving a solid, flexible mucilaginous plate ca. 1-cm thick. On the north end of Antelope Island and near Whiterock Bay in water ca. 0.8-m deep, Parker found that the circular-shaped biostromes covered a mean area of 0.70 m^2 each, and protruded 0.11 m above the sand bottom. In many places, the growing biostromes abutted each other, thus providing a completely calcified plate across the bottom. In the southern end of Gilbert Bay in 1-m of water we also have encountered the biostromes with flat-plate morphology similar to those in shallow water near Antelope Island. The plate-like structure of these biostromes is similar to the well-know growths in Shark Bay, Australia (Fig. 2a). During the sampling we found that biostromes in water about 3-m deep near the SE end of the lake had considerably different structure, with mounds that protruded ca. 0.8-1.5 m from the bottom, and that were ca. 0.5 m in diameter. These were in dense fields with limited space between mounds, although poor visibility precluded assessing them extensively. The biostromes in the 3-m-deep water were similar in morphology to those growing in the Bahamas (Fig. 2b). It is likely that stromatolites in these deeper zones have grown upward to more effectively utilize sunlight. Larval and pupal brine flies attach to the biostromes and the larvae feed on the dense cyanobacterial/algal growth (Fig. 2c, d).

The objectives of the study were two-fold. First, we needed to test methods for quantitatively sampling the periphyton and brine flies from the biostromes, mud and sand substrates. Most sampling of brine flies has relied on only semi-quantitative kick-net methods (Herbst 1988), or quantitative samples collected by wading in shallow water (Herbst 1990). Since biostromes and brine flies extend to at least 4 m of water depth (Collins 1980), methods were needed to sample effectively in the deeper water. Secondly, we sampled the periphyton and brine flies on the biostromes and sediments to provide preliminary information on whether bioaccumulation of selenium could be a problem for birds that use this prey resource.

A.



B.

C.

D.

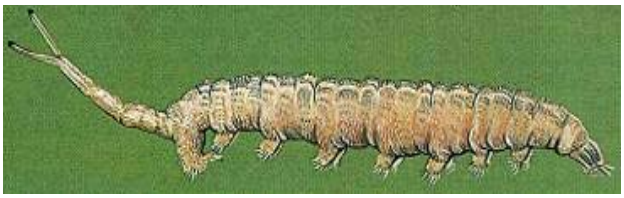


Figure 2. Biostrome structure and biota. A. Flat-plat biostromes (bioherms) similar to those observed near Bridger Bay on the NW end of Antelope Island. This photo was taken at Shark Bay, Australia. The biostromes near Bridger Bay were more closely packed and often adjoined each other. B. Dome-shaped biostromes similar to those observed at the Gilbert South site. This photo was taken in the Bahamas Islands (photo by David Liddell). C. A piece of biostrome broken from a flat-plate deposit near Bridger Bay. The dense cyanobacterial (algal) mat is obvious, as well as the brine fly pupae (light-brown protrusions). D. Drawing of a brine fly larvae (www.bioweb.lu/sapro/Ephydra.jpg).

Relevance to the Conceptual Model

Fig. 3 shows how the study of the benthic algal and brine fly populations fits in with the conceptual model developed for selenium fluxes in the Great Salt Lake. In this model dissolved selenium would be taken up by the biota in littoral sediments (including biostromes). Brine flies feed on the cyanobacteria attached to the biostromes, and they also likely feed on periphyton and perhaps detritus falling onto the loose sand and mud sediments. *Artemia fransciscana* (brine shrimp) also may feed on detrital matter in the benthic zone, as this behavior has been observed in laboratory colonies when food is limiting in the water column. The selenium accumulated in the benthic-feeding organisms could then be passed along to birds. Wading birds can feed on the attached brine flies on the biostromes and sediments. Diving birds such as goldeneye ducks (*Bucephala clangula*) can feed on the larval and pupal brine flies attached to biostromes as deep as 3-4 m (J. Vest, Utah State Univ, personal communication). Birds also have been observed feeding on the masses of brine flies that pause at the lake surface or those in flotsam slicks. Finally, birds such as gulls feed on the adult brine flies that amass along the lake's shoreline to reproduce.

In hypersaline ecosystems brine flies are often an important component of bird diets. Herbst (2006) studied bird (including black-necked stilts) use of prey in hypersaline ponds in California and concluded that nearly 90% of all feeding was on brine flies, with the remainder on *Artemia* and corixids. Brine flies (*E. hians*) also have been shown to be an important component of the diet of California gull chicks at Mono Lake, CA. In two years of study, Wrege et al. (2001) found that flies represented 15-40% of the meals given to chicks, whereas *Artemia* were 13-48% of the meals. Flies, however, have a higher nutrient value per individual prey item when compared to *Artemia* (Herbst 1986). At Mono Lake, fly larvae and pupae were the dominant forms given to chicks, with adult flies being relatively unimportant. Gull use of *Artemia*

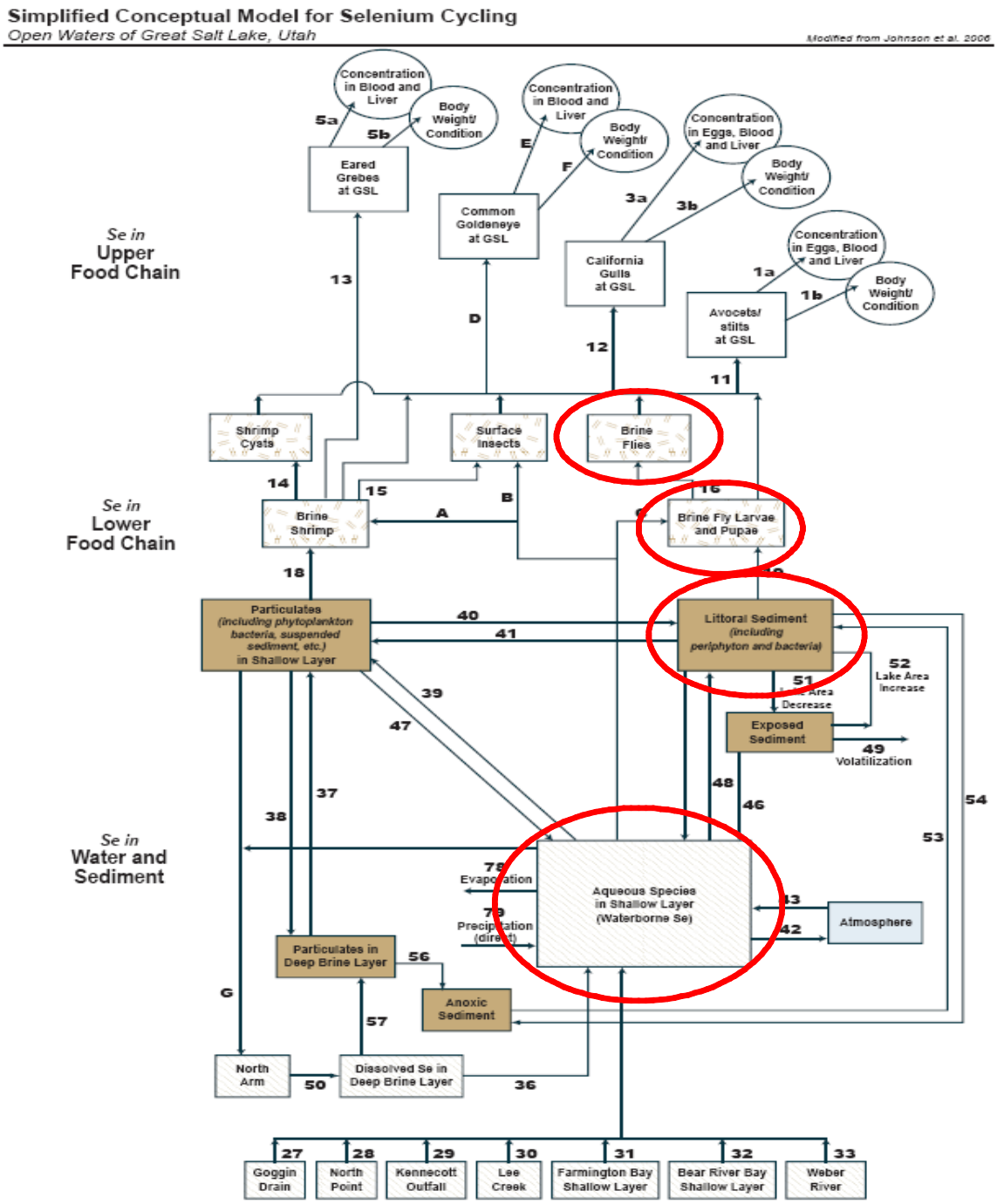


Figure 3. Conceptual model of selenium pools and transport in Gilbert Bay (Great Salt Lake) showing the pools studied in the benthic analysis (red circles). Note that "Littoral sediment" should also include the extensive calcified biostromes with cyanobacteria.

and brine flies was highly variable both within and between years, and likely reflects temporal variation of these two prey and other alternative prey. *Artemia* in the Great Salt Lake can be abundant in April and May (Wurtsbaugh and Gliwicz 2001) when bird nesting commences, but the timing is likely highly dependent on spring temperatures in the lake. The timing of brine fly abundance in the Great Salt Lake is not known. Collins (1980) studied the flies only from June through August, but based on the abundances of the larvae and pupae in June, he suggested that these forms were available in April and May. Cavitt (2007) and Conover (2007) found that brine flies were important components of the diets of wading birds, and to a lesser extent, gulls in the Great Salt Lake (see below)

The relative timing of *Artemia* and brine fly population development, as well as that of alternative terrestrial foods, could affect selenium uptake by birds, as brine fly prey may have different selenium concentrations than those present in *Artemia*. In a preliminary analysis of the Great Salt Lake, Adams (unpublished 2005) suggested that brine flies had only 36% of the selenium present in Artemia, and Herbst (2006) found that selenium was undetectable (<0.5 µg Se/g) in brine flies in saline ponds, whereas Artemia had concentrations ranging from 5-15 µg/g dry weight. For example, if brine flies are the dominant prey of birds in the early spring when egg development is occurring, reproductive impairment may be reduced as compared to a situation where the birds rely exclusively on Artemia.

Methods

Sampling Locations and dates

Brine fly pupae and larvae, periphyton, water, and sediment were sampled along two transects in Gilbert Bay of the Great Salt Lake (Fig. 4). The transect for Site 1 began at a water

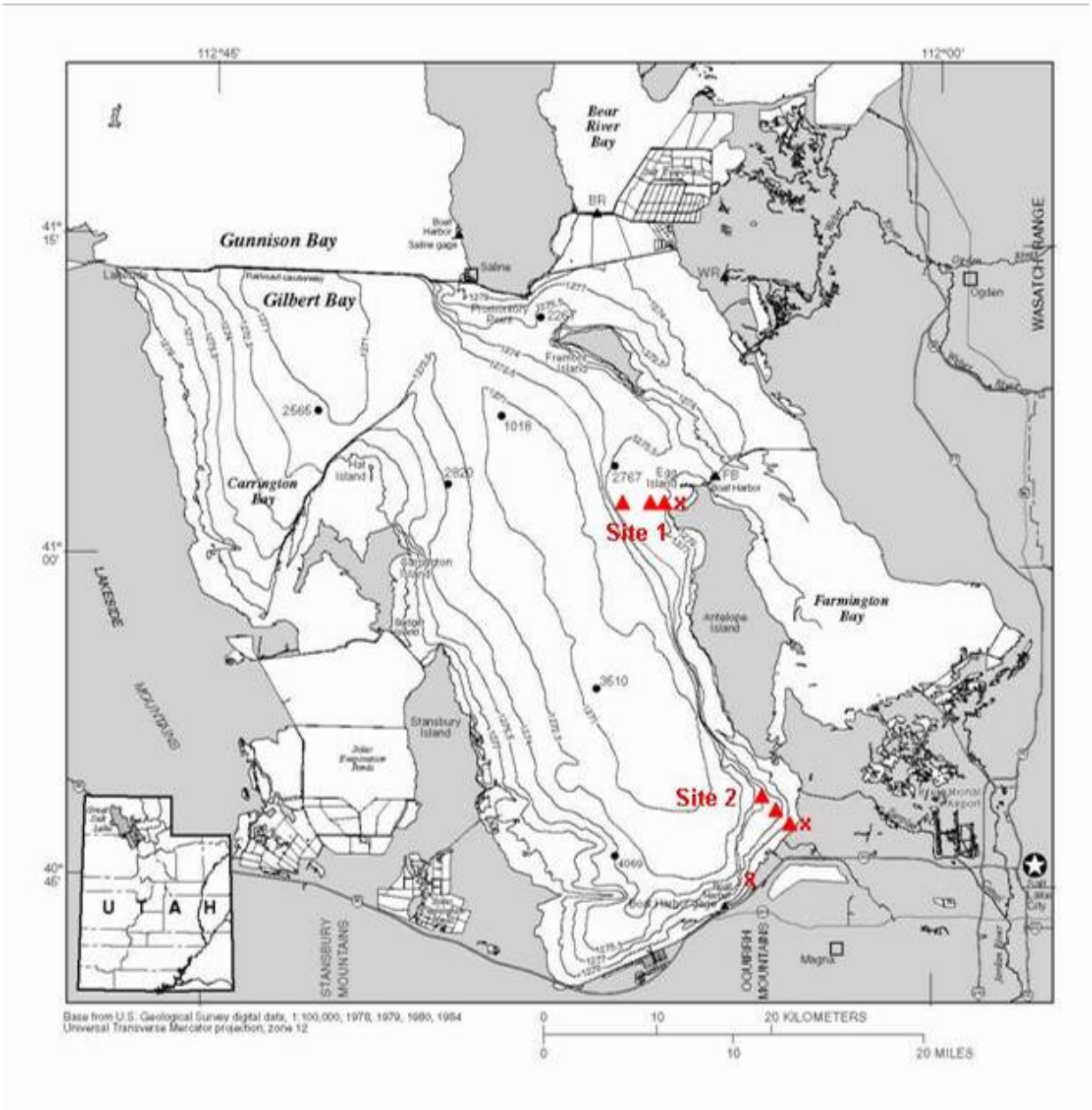


Figure 4. Map of Gilbert Bay showing benthic (▲) sampling sites for brine flies, sediments and biostromes. Sites where adult brine flies were collected on shore are shown with (**x**). Coordinates for sample sites are given in Table 2.

depth of 1 m at the SW corner of Bridger Bay on Antelope Island and proceeded westward. Site 2 (Gilbert South) was a N-S transect beginning in the SE end of Gilbert Bay. At each of these sites we sampled at nominal depths of 1, 3 and 5 m. The coordinates and actual depths sampled are shown in Table 2. We also collected adult brine flies at three shore locations: rock outcroppings at the SW corner of Bridger Bay, Saltair Beach, and at a beach just north of Kennecott mine tailings. Larval and pupal brine fly samples were collected at Site 1 on June 1, June 14 and June 16. Two additional samples were taken on September 28, 2006. Because relatively few sediment samples were collected in 2006, additional ones were collected on depths of 1-3 m on 28 April 2007, but the selenium and organic matter content of these is not yet available from the analytical laboratory. All samples at Site 2 were collected on June 15. Adult flies were collected on June 14, 15 and 16.

On June 14 Gilbert Bay's water elevation was 1279.58 m (4,198.1 ft) and it declined 0.5 m to 1279.06 m (4196.4 ft) by September 28th. At each site, salinity, oxygen and temperature profiles were measured with an InSitu sonde. Secchi disk measurements were made at each site.

Brine fly & sediment collection

Brine fly adults were captured with a fine-meshed butterfly net while running along the beach, or between rocks where brine flies were resting. Netted brine flies were placed in a cooler with dry ice to euthanize and transport them. They were kept frozen at -20°C after return to the laboratory, and then washed with de-ionized water to remove salts, counted, and weighed. A portion of the brine flies where ashed at 550°C for 2hrs, then reweighed to determine ash-free dry mass (AFDM).

Duplicate larval and pupal brine fly samples were collected at each depth. The larvae and pupae were sampled on the biostromes by SCUBA divers using a vacuum pump sampler

(Fig. 5) similar to that of Voshell et al. (1992). The sampler consists of an inverted plastic bucket with a port and glove attached to the side of the canister so that a diver can agitate the substrate. The apparatus sampled an area of 0.075 m^2. Four kilograms of dive weights were attached to the lower part of the bucket to increase stability and to keep the unit on the substrate. In order to function effectively, the sampler had to be placed on a relatively level and solid substrate. This precluded sampling on the sides of the dome-shaped biostromes in southern Gilbert Bay. Once the sampler was positioned, the diver jerked the attached pump tube so that the operators in the boat could begin bringing water to the surface with a hand-powered vacuum pump (Guzzler Model Vacuum Pump, U.S. Plastics Corp.). The diver then began scouring the substrate with a scrub brush. Pumping continued until three 20-L buckets were filled on the boat. This sample included 10.5 L of water that was in the pump tube. Samples were sieved through a 500-µm sieve and collected in an acid-washed 500-ml polyethylene bottle, and stored on ice for transport to the laboratory. To sample organic matter and chlorophyll, the diver broke off a portion of the calcified biostromes. Only edge pieces of flat biostromes, or exfoliating pieces of domed biostromes could be collected, and this could have introduced some bias. Sampled pieces were 100-300 cm^2, and usually about 3-cm thick.

On sand and mud substrates, brine flies were collected with a 0.050 m^2, 24-kg, Ponar grab (Wildco, Inc., Buffalo NY) lowered to the bottom with a rope. The Ponar dredge is weighted sufficiently to penetrate dense, sandy sediments. The samples were brought to the surface and discharged into a plastic tub, and then sieved through the 500-µm mesh. In all cases, insufficient brine flies were available from the soft sediment samples for selenium analyses because the analytical laboratory stated that they needed 1000 mg of dry weight and this required approximately 500 individual larvae or pupae. The average number of larvae recovered from the soft sediment Ponar samples was only 16 individuals.

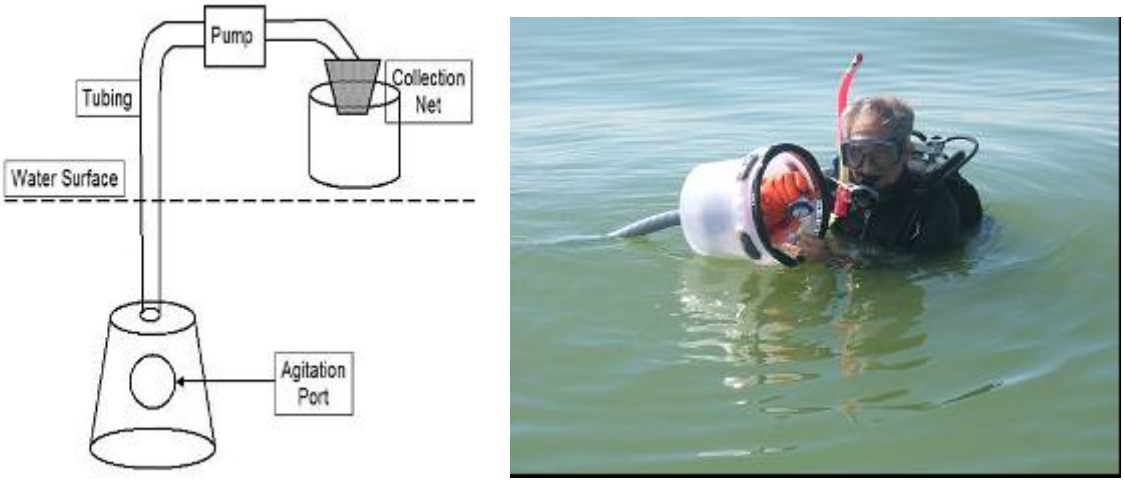


Figure 5. Left. Diagram of the bucket and pump assembly for quantitatively sampling brine fly larvae and pupae in the Great Salt Lake. Right. Photo showing the weighted bucked and the brush used to dislodge brine flies from the biostromes.

In the laboratory, larvae and pupae were counted, washed three times with de-ionized water, then weighed and frozen in polyethylene scintillation vials. Composite samples of larvae (mean, 236 individuals; range 47-500) and pupae (mean, 246 individuals; range 21-500) were analyzed for selenium. The brine fly samples were sent to LET Incorporated (Columbia, MO) for selenium analysis by hydride generation – atomic absorption spectrometry on acid-digested samples. The reporting limit for selenium was 0.1 µg Se/g. LET also measured percent solids by drying a subsample of the flies.

Pieces of biostromes of known area were frozen and subsequently placed in 95% ethanol and chlorophyll was extracted overnight at room temperature. The chlorophyll solution was then diluted with ethanol and concentrations measured in a Turner 10-AU fluorometer with

the non-acidification method (Welschmeyer 1994). Blanks and standard were analyzed at the beginning of each run. Biostrome and sediment subsamples were dried at 70°C, weighed and then ashed at 450°C for 6-8 h. Ashed samples were re-wetted using de-ionized water, dried overnight at 70ºC, and then weighed to obtain AFDM. A subsample of biostrome samples was treated with acid to remove carbonates. These samples were submerged in 1 N HCl until all CO_2 bubbling stopped. This required several hours and necessitated replacing the acid up to three times. By removing the carbonates, this procedure allowed us to determine the selenium concentration of the organic component of the stromatolites. To analyze organic matter in sediment samples, the top 3 and 3-50 mm of most grab samples was collected with a plastic spatula prior to the sample being sieved to remove brine flies. The depths and strata thicknesses are given in Table 2.

Water Samples

Water samples were taken first at all dive sites to avoid disturbed sediments. Collection of water samples occurred 2-5 cm above the sediment surface using 60-ml acid-washed syringes. Each syringe was rinsed three times with surface water, and once with water from above the sediments prior to collecting the actual sample. Water samples were taken ca. 5 m apart from each other. On the surface, water in the syringes was filtered through Whatman 47-mm GF/F filters (0.80 µm) and placed in 200-ml acid-washed polyethylene bottle. GF/F filters were used in lieu of 0.4 µm membrane filters because of the higher volume that they can filter, and because they are becoming a standard filter used in limnological and oceanographic research. The GF/F filters may allow slightly more colloids and picoplankton to pass and be considered as “dissolved” selenium. The first 40 ml of water was used to rinse the filters and bottles. Two ml of nitric acid were added to fix samples using an acid-rinsed disposable pipette.

Samples were sent to Frontier Geoscience, Seattle, WA for total dissolved selenium analysis by hydride generation and atomic fluorescence spectrometry (HG-AFS). Minimum detection limit for total Se was reported as 0.05 µg/L.

Results

Limnological Conditions

During the June 14-16 sampling, water temperatures ranged from 20.7°C at the surface to 20.4°C near the bottom and oxygen was at saturation. Surface salinities were 116 g/L (11.6%) at both sites, increasing to 126 g/L (12.6%) at 5 m. The Secchi depth (0.72 m) at Bridger Bay was influenced by the algal-laden Farmington Bay water reaching the site, as clearer water was observed farther offshore and in other areas of the lake. In the September sampling at Bridger Bay, water temperatures ranged from 20.0°C at the surface to 16.8°C at 1.8 m, and salinities ranged from 136 g/L (13.6%) at the surface to 146 g/L (14.6%) at 1.8 m, indicating an overflow of fresher water from Farmington Bay was influencing the site. The Secchi depth was 1.0 m at the Bridger Bay site. Much clearer water was observed in other parts of Gilbert Bay, but transparencies were not measured. Visibility limited our ability to assess the horizontal extent of the biostrome fields. However, at the Bridger Bay site the plate-shaped biostromes were largely continuous and interrupted by only small sand patches at perhaps 4-6 m intervals. Vertical structure was about 0.2-0.3 m. The biostromes extended from depths of <1 m to ca. 3.2 m. At 5 m, the bottom was covered in fine sand with occasional pieces of incipient biostrome material a couple of centimeters in diameter and 2-3 mm thick. At 1-m depth at the Gilbert South site there were some plate-like biostromes but these were overlain with 1-2 cm of loose, course sand, and hence did not provide solid attachment structure for brine flies. The 2.7-3.2 m sites were primarily biostrome mounds extending 0.7 to ca. 1.5 m above the bottom with some intervening patches of sand. In some cases the mounds were linked to each other. When our boat cruised over these sites the echo sounder failed to register depth because of the high depth variability. At a depth of 5 m along the transect, the bottom was all sand and mud. Diver

Table 2. Locations, substrate characteristics and brine fly abundances and selenium concentrations collected in Gilbert Bay of the Great Salt Lake during 2006.

Transect Location	Sample Date	Lat	Long	Depth (m) From Surface	Dominant Substrate	% Stromat-olite	%Sand	%Mud	Brine Fly Stage	Number m^{-2}	Wet mass (g m^{-2})	Percent Solids	Dry Mass (g m^{-2})	Se (ug/g dry wt)
Bridger Bay (1)	16-Jun-06	41.042	-112.276	**-1.0**	Air	-	-	-	Adult	-	-	-	-	1.9
Gilbert S. (2)	16-Jun-06	40.748	-112.193	**-1.0**	Air	-	-	-	Adult	-	-	-	-	1.8
Gilbert S. (2)	16-Jun-06	40.795	-112.150	**-1.0**	Air	-	-	-	Adult	-	-	-	-	1.8
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Larvae	198	0.6	14%	0.08	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Larvae	139	0.4	14%	0.06	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Pupae	0	0.0	9%	0.00	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**5.0**	Mud	2	0	98	Pupae	139	1.4	9%	0.12	
Bridger Bay (1)	16-Jun-06	41.036	-112.323	**3.9**	Sand	0	100	0	Larvae	1,012	3.0	14%	0.43	
Bridger Bay (1)	16-Jun-06	41.036	-112.323	**3.9**	Sand	0	100	0	Larvae	476	1.4	14%	0.20	
Bridger Bay (1)	16-Jun-06	41.036	-112.323	**3.9**	Sand	0	100	0	Pupae	0	0.0	9%	0.00	
Bridger Bay (1)	16-Jun-06	41.034	-112.325	**3.9**	Sand	0	100	0	Pupae	0	0.0	9%	0.00	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Larvae	8,930	26.6	14%	3.83	1.4
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Larvae	9,672	28.8	14%	4.15	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Pupae	3,670	36.3	9%	3.16	1.6
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**1.0**	Stromatolite	95	5	0	Pupae	6,625	65.6	9%	5.71	
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Larvae	2,491	7.4	14%	1.07	1.5
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Larvae	3,829	11.4	14%	1.64	1.5
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Pupae	543	5.4	9%	0.47	2.0
Bridger Bay (1)	9/28/2006	41.043	-112.277	**1.9**	Stromatolite	95	5	0	Pupae	278	2.8	9%	0.24	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Larvae	6,148	18.3	14%	2.64	1.5
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Larvae	11,288	33.6	14%	4.84	
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Pupae	3,008	29.8	9%	2.59	1.5
Bridger Bay (1)	14-Jun-06	41.043	-112.276	**3.0**	Stromatolite	95	5	0	Pupae	6,227	61.6	9%	5.36	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Larvae	80	0.2	14%	0.03	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Larvae	80	0.2	14%	0.03	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Pupae	320	3.2	9%	0.28	
Gilbert S. (2)	15-Jun-06	40.811	-112.184	**5.0**	Mud	2	48	50	Pupae	80	0.8	9%	0.07	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	15	85	0	Larvae	26	0.1	14%	0.01	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	15	85	0	Pupae	0	0.0	9%	0.00	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	25	75	0	Larvae	40	0.1	14%	0.02	
Gilbert S. (2)	15-Jun-06	40.799	-112.152	**1.2**	Sand	25	75	0	Pupae	0	0.0	9%	0.00	
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Sand	40	60	0	Pupae	450	4.5	9%	0.39	
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	75	25	0	Larvae	1,245	3.7	14%	0.53	
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	75	25	0	Pupae	2,045	20.2	9%	1.76	
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	100	0	0	Larvae	1,961	5.8	14%	0.84	1.0
Gilbert S. (2)	15-Jun-06	40.802	-112.163	**2.7**	Stromatolite	100	0	0	Pupae	4,982	49.3	9%	4.29	1.1
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Stromatolite	40	60	0	Larvae	623	1.9	14%	0.27	
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Stromatolite	90	10	0	Larvae	2,054	6.1	14%	0.88	0.9
Gilbert S. (2)	15-Jun-06	40.810	-112.183	**3.2**	Stromatolite	90	10	0	Pupae	14,071	139.3	9%	12.12	1.1

assessments of the approximate sediment composition are shown in Table 2. High densities of dense periphyton and larval and pupal brine flies were very visible underwater on the tops and sides of the biostromes. The sand and silt did not appear to be covered with any periphyton growths, nor were any brine flies noted on these substrates by the divers.

Brine fly densities, biomass, organic matter.

Brine fly larvae and pupae were very abundant on biostromes and scarce on sand and mud substrates (Figs. 6, 7). Total brine fly densities on biostromes averaged 9,140/m^2 and reached over 16,000/m^2 in three samples. In Bridger Bay, larvae were more abundant than pupae, but the reverse was true at the South Gilbert site. Larval brine flies were significantly more abundant in Bridger Bay than at the Gilbert South site ($p = 0.015$), but there was no significant difference for pupae ($p = 0.226$). Both larvae and pupae were significantly more abundant on biostromes than on the combined category of sand/mud ($p = 0.003$). Total brine fly biomass on biostromes averaged 5.9 g/m^2, but only 0.2 g/m^2 on sand/mud substrates (Table 2).

Our analyses suggested that organic matter content (AFDM) of the periphyton in the biostrome samples was very high, with a mean of 58% (Table 3), but these results are likely erroneous (see below). Strangely, treatment with acid to remove carbonates did not significantly influence organic matter content ($p = 0.577$). It is possible that the cyanobacteria and the mucilage matrix comprise the bulk of the upper portions of the biostromes, and the carbonates removed by acidification are insignificant. Organic matter content on the combined sand/mud substrates (6%) was significantly ($p < 0.000$) lower than on the biostromes. Chlorophyll *a* concentrations on the biostromes were very high, averaging 698 mg/m^2 ± 207. Chlorophyll was not measured on the sand/mud substrates. The AFDM and selenium content of the additional 15 samples taken in 2007 are not yet available.

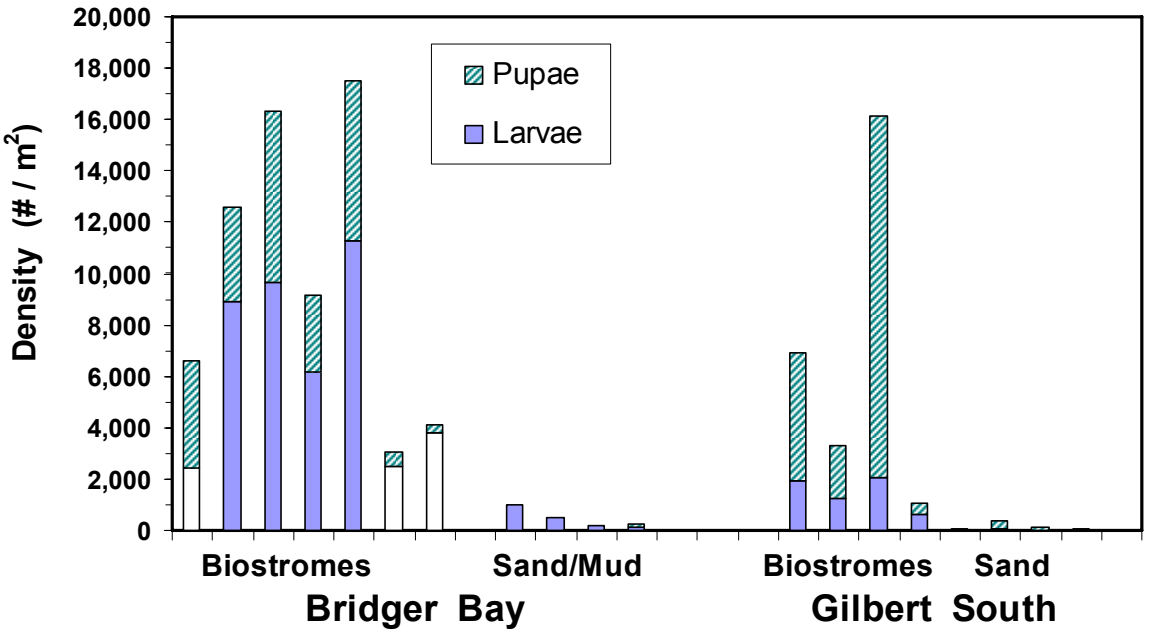


Figure 6. Cummulative abundances of brine fly (*Ephydra cinerea*) larvae and pupae on substrates that were predominantly biostromes, or on sand/mud, at either the Bridger Bay sampling site, or at the Gilbert South site of the Great Salt Lake. Most samples were collected from 14-16 June, 2006. The unfilled white bars for Bridger Bay indicate densities found on 1 June (left) or on 28 September (2 right bars). Brine fly larvae were significantly more abundant in Bridger Bay than at the Gilbert South site ($p = 0.015$), but there was no difference for pupae ($p = 0.226$). Both larvae and pupae were significantly more abundant on biostromes than on the combined category of sand/mud ($p = 0.003$).

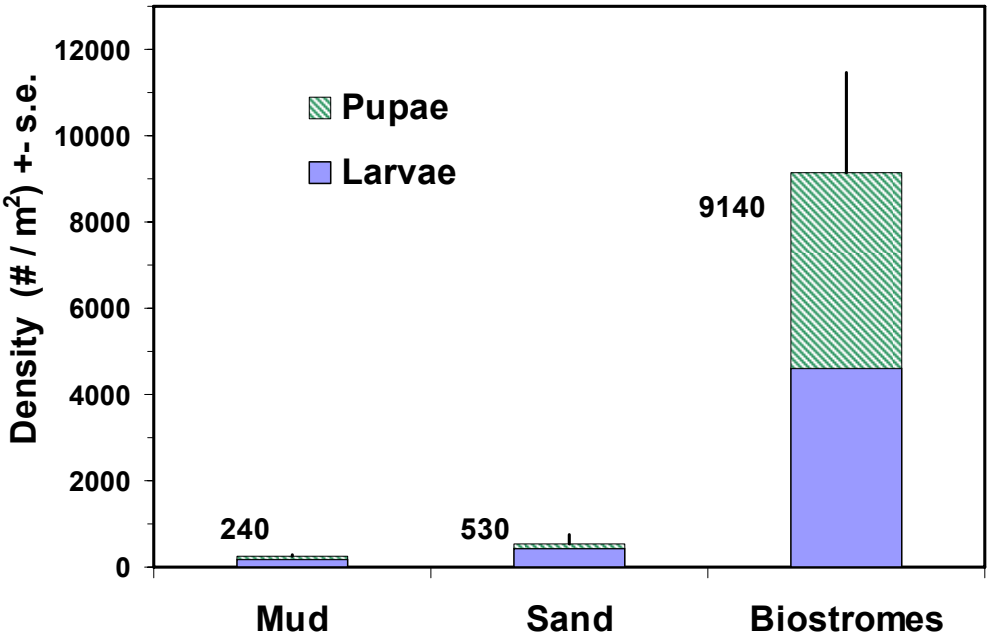


Figure 7. Summary of densities of larvae and pupae of brine flies (*Ephydra cinerea*) on three types of substrates in Gilbert Bay of the Great Salt Lake during June 2006. The Bridger Bay and Gilbert South sites were pooled.

Selenium Concentrations

Mean total dissolved selenium concentrations in the water were low (0.40 µg Se/L) and did not differ significantly between the Bridger Bay and the Gilbert South sites ($p = 0.117$). Variability in selenium concentrations in the water was very low with a range of 0.37-0.43 µg Se/L (Table 4). Mean selenium concentrations in the combined periphyton/sediment substrates (Table 4) was 1.7 µg Se/g (1.7 mg/kg; one outlier of 9.8 removed), and concentrations did not differ with respect to site ($p = 0.856$), substrate type ($p = 0.473$), or whether the samples were acidified ($p = 0.533$). However, sample sizes were small and variability was moderately high, limiting the possibility of finding differences among the different categories (Table 4). See addendum at end of report for additional measurements of sediments collected in 2007.

Selenium concentrations in the brine flies ranged from 0.9 to 2.0 µg Se/g (Table 2) and varied between groups and sites (Fig. 8). Concentrations increased from larvae (1.3 µg Se/g) to pupae (1.5 µg Se/g), and this difference was significant ($p = 0.046$). Concentrations were higher in adult flies (1.8 µg Se/g) than in pupae, but there were insufficient samples (3) to determine if this was significant or not. A two-way ANOVA indicated that the brine flies in Bridger Bay had significantly higher concentrations of selenium than did those in Gilbert South ($p < 0.000$) with a mean difference of 1.6 vs. 1.3 µg Se/g.

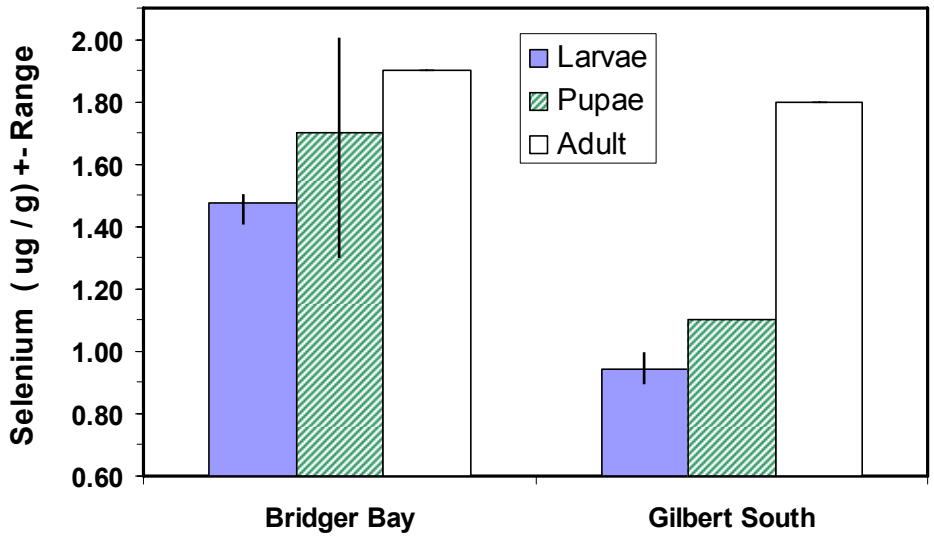


Figure 8. Concentrations of selenium in larvae, pupae and adult brine flies (Ephydra cinerea) collected near Bridger Bay, and at the south end of Gilbert Bay. A 2-way ANOVA indicated that selenium concentrations were significantly higher in Bridger Bay than in Gilbert South ($p = 0.000$), and in pupae than in larvae ($p = 0.046$). Only three samples of adult flies were measured for selenium and they were not included in the ANOVA. Note that although the results were statistically significant, the differences between stages was small.

Table 3. Samples collected for periphyton and ash free dry mass (AFDM) analyses in Gilbert Bay of the Great Salt Lake during 2006 and 2007. Most dredge samples included the upper 50 mm of material, but some samples were sectioned to determine if Se content varies with depth. Except for the acidified biostrome samples, the selenium concentrations represent that in the combined organic-inorganic matrix. The AFDM of the biostromes appears to be erroneously high. Ash-free dry weights and Se content of the samples collected in 2007 are not yet available.

Site	Sample Date	Latitude	Longit.	Depth (m)	Sediment strata (mm)	Substrate Type	% Stromatolite	% Sand	% Mud	Acidified?	AFDM %	ug Se/g dry wt
Bridger Bay (1)	14-Jun-06	41.043	112.276	1.0		Stromatolite	95	5	0	N		0.40
Bridger Bay (1)	14-Jun-06	41.043	112.276	1.0		Stromatolite	95	5	0	Y	56.0%	2.10
Bridger Bay (1)	14-Jun-06	41.043	112.276	1.0		Stromatolite	95	5	0	Y		0.90
Bridger Bay (1)	14-Jun-06	41.043	112.276	3.0		Stromatolite	95	5	0	N		0.60
Bridger Bay (1)	14-Jun-06	41.043	112.276	3.0		Stromatolite	95	5	0	Y	61.0%	2.20
Bridger Bay (1)	14-Jun-06	41.043	112.276	3.0		Stromatolite	95	5	0	Y		1.30
Bridger Bay (1)	16-Jun-06	41.036	12.323	3.9	0-50	Mud	2	98	0	Y	2.0%	*9.80*
Bridger Bay (1)	16-Jun-06	41.034	112.325	5.0	0-50	Mud	2	10	88	Y	6.0%	3.10
Bridger Bay (1)	16-Jun-06	41.034	112.325	5.0	0-3	Mud	2	10	88	Y	7.0%	3.30
Bridger Bay (1)	16-Jun-06	41.034	112.325	5.0	0-50	Mud	2	10	88	Y	10.0%	1.40
Gilbert South (2)	15-Jun-06	40.802	112.163	2.7		Stromatolite	100	0	0	N	58.0%	3.10
Gilbert South (2)	15-Jun-06	40.802	112.163	2.7		Stromatolite	90	10	0	N	59.0%	-
Gilbert South (2)	15-Jun-06	40.810	112.183	3.2		Stromatolite	90	10	0	N	52.0%	0.40
Gilbert South (2)	15-Jun-06	40.810	112.183	3.2		Stromatolite	40	60	0	Y	60.0%	1.30
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.5	3-40	Mud	0	0	100	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.5	0-3	Mud	0	5	95	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0	3-30	Mud	0	0	100	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0	0-3	Mud	0	0	100	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.271	1.0	30-50	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.274	1.0	3-50	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.274	1.0	0-3	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.271	1.0	0-3	Sand	0	100	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.275	1.0		Stromatolite	100	0	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.275	1.0		Stromatolite	100	0	0	Y	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.1		Stromatolite	100	0	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.041	112.279	2.1		Stromatolite	100	0	0	Y	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0		Stromatolite	100	0	0	N	Results Pending from LET	
Bridger Bay (1)	28-Apr-07	41.043	112.276	3.0		Stromatolite	100	0	0	Y	Results Pending from LET	

Table 4. Location of water samples collected of selenium analysis in Gilbert Bay of the Great Salt Lake during 2006. The water was collected by SCUBA divers utilizing 60-ml syringes. The water was taken ca. 2-5 cm above the substrate. Samples were filtered through 0.8 µm glass fiber filters.

Location	Sample Date	Lat	Long	Depth (m)	Substrate Type	Se (µg/L)	Comments
Bridger Bay	14-Jul-06	41.043	112.276	1.00	Water column	0.40	GF/F filtered
Bridger Bay	14-Jul-06	41.043	112.276	3.00	Water column	0.40	GF/F filtered
Bridger Bay	16-Jun-06	41.034	112.325	5.00	Water column	0.43	GF/F filtered
Gilbert South	15-Jun-06	40.799	112.152	1.20	Water column	0.41	GF/F filtered
Gilbert South	15-Jun-06	40.802	112.163	2.70	Water column	0.38	GF/F filtered
Gilbert South	15-Jun-06	40.810	112.183	3.20	Water column	0.38	GF/F filtered
Gilbert South	15-Jun-06	40.811	112.184	5.00	Water column	0.37	GF/F filtered

Discussion

Food web dynamics and selenium bioaccumulation

The data collected on the biostromes indicates that they are an important component of the food web in Gilbert Bay, and they may consequently have an important influence of the bioaccumulation of metals such as selenium and mercury. A relative comparison of periphyton on biostromes and the phytoplankton can be done as an approximation of how much production may come from these two sources. Primary production data are not available for the biostromes, so chlorophyll levels in the two can be compared. Biostromes are estimated to underlie an area of 261 km^2 in Gilbert Bay, which is only about 18% of the area where phytoplankton occur (Fig. 9A). However, chlorophyll concentrations are about 380% higher on the biostromes than in the integrated phytoplankton from the 6.75-m thick epilimnion (Fig. 9B). Multiplying the areal coverage of the two habitat types by the chlorophyll concentrations indicates the total amount of chlorophyll in the two habitats. This calculation suggests that the cyanobacteria and algae on the biostromes is about 70% of that in the water column (Fig. 9C). Note that this calculation does not include the contribution of chlorophyll on the muds and sands in the littoral zone of the lake. Although the cyanobacteria on (and in) the biostromes may not be as accessible to the brine flies as phytoplankton are to grazing *Artemia*, this preliminary analysis indicates that the abundant biostromes are an important component of the food web in the lake. This analysis is consistent with recent views on the importance of benthic areas for food web processes in lakes (Vadeboncoeur et al. 2002).

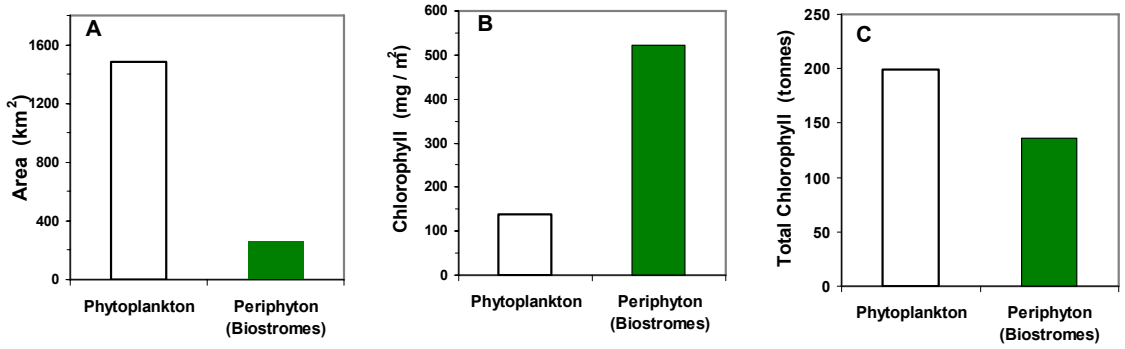


Figure 9. A. Comparison of the area covered by periphyton on biostromes (solid green) and that of the epilimnion of the Gilbert Bay where phytoplankton can grow (open). B. Concentrations of chlorophyll on biostromes (solid green) and that in phytoplankton in the water column (open). The latter was based on chlorophyll in Gilbert Bay calculated from data from 2002-2005 of W. Wurtsbaugh, and an estimated epilimnetic volume of 9.7 10^9 m^3. C: Total chlorophyll estimates (metric tones) for Gilbert Bay in periphyton attached to biostromes, and that in the phytoplankton.

The brine flies on the biostromes also represent a significant component of the invertebrates in the lake and contain a large amount of the bioavailable selenium for birds (Fig. 10). The biomass of brine flies we measured in June is about 30% of that in *Artemia* (Fig. 10A). The seasonality of brine flies is not well known, but Collins found comparable densities of pupae on biostromes from June through August. Selenium concentrations in brine flies were somewhat higher than in *Artemia* (1.5 vs. 1.2 µg/g; Fig. 10B), contrary to what others have found in the Great Salt Lake (Adams 2005 unpublished) or elsewhere (Herbst 2006) . The resulting estimate of total selenium in the benthic invertebrates suggests that brine flies contain about 38% of the total selenium that is contained in *Artemia.* These comparisons, although based on relatively few samples, indicate that brine flies could be a significant source of selenium for birds in the Great Salt Lake.

In contrast to the biostromes, the sand and mud substrates we sampled had relatively few brine flies associated with them. This is consistent with the findings of Collins (1980), although he did estimate that perhaps 18% of brine fly production could occur on mud and sand sediments. The soft sediments in much of the lake may produce little periphyton for the brine flies. It is likely that the sands in shallow waters shift so much that algae cannot become well-established. Conversely, in deeper water, periphyton may have insufficient light for photosynthesis. The photic zone at the time of our survey was estimated to be only about 2 meters deep (two Secchi depths), so photosynthesis would be negligible below this depth. Our survey sites, however, were located relatively close to discharges of nutrient-laden water (Farmington Bay and the Goggin Drain) from metropolitan Salt Lake City, and the resulting phytoplankton growth in these areas may shade-out periphyton. Sites on the western side of the lake might be expected to have periphyton growing in deeper water and more brine flies on

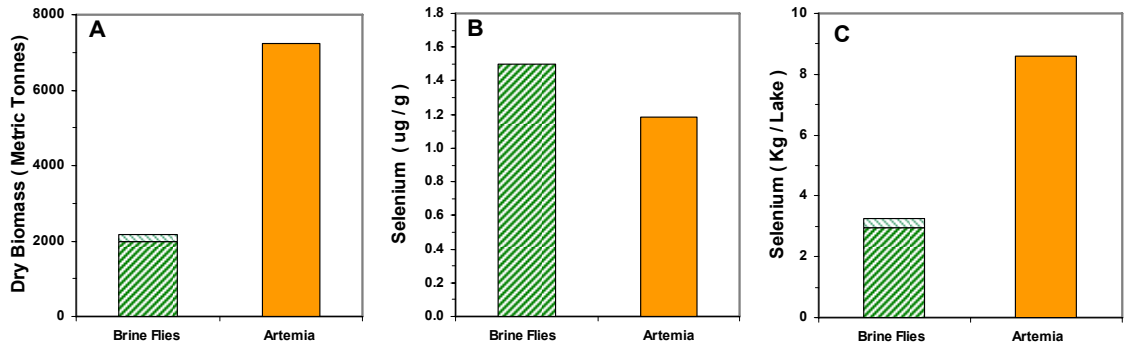


Figure 10. A. Comparison of the amount of biomass in brine flies and that in Artemia. The brine fly data are from June 2006, and represents the sum of larvae and pupae. The dark green diagonal shading shows brine flies on biostrome substrates. The light green shading represents brine flies on soft sediments. B. Mean selenium concentrations in brine fly larvae and pupae and that in adult Artemia (data of Brad Marden). Selenium concentrations were 2–4X lower in juvenile Artemia, but the data from adults was used because: (1) they are likely the main prey of birds; (2) under most circumstance they would dominate the biomass, and ; (3) with the information in the data base there was no way calculate a weighted average of selenium for the pooled plankton sample. C. Estimated total amount of selenium in brine fly larvae and pupae on biostromes (dark green shading), on soft sediments (light green shading), and in Artemia. The Artemia data are based on an April-December mean dry biomass of 0.75 mg/L (data of Brad Marden). Estimates of brine fly biomass and selenium concentrations are based on limited samples.

deep substrates. More thorough surveys of both the soft sediments and biostromes in different parts of the lake are needed to test this hypothesis.

The benthic food web is a likely route for selenium transport into birds, because more than 80% of the estimated 50 metric tones of selenium in the lake is in the bioactive benthic zone (Table 5). A comparison of data collected by Johnson et al. (2007) and that reported yields a rough estimate that 87% of the selenium is in the top 2-cm of the sediments and biostromes in the lake, 3% is in suspending particulate matter (seston) available for *Artemia* to graze on, and 10% is dissolved in the water (Table 5). Of the selenium in the benthic zone, 60% was estimated to be in the oxic sediments (46% soft sediments + 14% biostromes), and 28% in the anoxic zone. The lower amount in the anoxic sediments is due to the smaller area of this zone, and a mean selenium concentration of only 58% of that in the oxic sediments (but see addendum). It also is important to consider that the selenium in the organic material of the biostromes is potentially available to the invertebrates, whereas that beneath the deep brine layer will cycle only slowly to the oxic zone of the lake where invertebrates could take it up. The oxic sand and mud substrates, with an estimated selenium content of 1.7 µg/g and 6% organic material, could potentially be important for the transfer of selenium to invertebrates. However, the very low numbers of brine flies found on the sand and mud suggests that even the organic selenium in soft sediments would not be utilized to any significant degree. This comparison between the different lake zones is based on a small number of benthic samples from the oxic zone, and a high variability (0.4–9.8 µg Se/g) in the estimated selenium concentration, so it is clear that more work needs to be done in the oxic sediments in order to construct a true estimate of selenium in the different compartments.

Table 5. Estimates of selenium in different areas of the lake. That in the water column was based on the selenium concentrations reported by Johnson et al. (this report). Sediment estimates assume only a 2-cm thick bioactive layer, and a solids component of 76%. The solids estimate is derived from sediment core data of W. Johnson. Respective selenium concentrations in the anoxic and anoxic sediments are based on those reported by Johnson et al. (2007) and Wurtsbaugh (this report). Several of the values used to make the calculations are based on relatively few samples, so the values are only approximate.

	Se Concentration		Area/Volume	Se (Tones)	Percent
Water column (total)	0.56	ug/L	11.4 x 10^9 m^3	6.4	13%
Water column (dissolved)	0.42	ug/L	11.4 x 10^9 m^3	4.8	10%
Water column (particulate)	0.14	ug/L	11.4 x 10^9 m^3	1.6	3%
Sediments (total)			2057 km^2	43.4	87%
Sediments (anoxic)	1.0	ug/g	912 km^2	13.9	28%
Sediments (oxic sands & mud)	1.7	ug/g	884 km2	22.8	46%
Biostromes	1.7	ug/g	261 km2	6.7	14%
Total				49.8	

If the mean estimated selenium content in the biostrome periphyton/sediment material is correct (1.7 µg Se/g; range, 0.4-9.8 µg Se/g) there appears to be no biomagnification up the benthic food web (Fig. 11). The selenium content of organic material from biostromes measured in 2007 (Addendum) was lower (1.0 µg Se/g), but there still appears to be little, if any biomagnification. There was, however, nearly a 3,500-fold bioconcentration from the dissolved phase (0.4 ug Se/L = 0.4 ng Se/g of water) into the periphyton. However, the brine fly larvae do not increase concentrations further. This is similar to the results of Brix et al. (2004), who also did not find significant biomagnification of selenium by *Artemia*. The slight increase in selenium concentrations from larvae to pupae to adults that we found may be the result of modifications in fat content or other constituents, since feeding does not occur after the brine flies pupate. It is also possible that exoskeletons of pupae are low in selenium, so that molting into the adult stage would increase the selenium concentration in the flies.

With our limited sampling it is difficult to assess the spatial variations in selenium that may be present in the benthic zone of the lake. We did not anticipate finding higher selenium concentrations at the Bridger Bay site than at the Gilbert South site. The latter is near the discharge points of Kennecott Utah Copper Corporation and the Goggin drain where 55% of the selenium load enters the lake (Naftz et al. 2007). In contrast, the Farmington Bay discharge near the Bridger Bay site contributes only 13% of the selenium load, and concentrations of the effluent from Farmington Bay are only 56% of those from the Goggin drain (Naftz et al. 2007). The higher concentrations of selenium in the brine flies at Bridger Bay may be attributable to the very high organic content of the effluent from Farmington Bay, which is highly eutrophic (Wurtsbaugh and Marcarelli 2006). Rosetta and Knight (1995) found that brine flies bioaccumulated selenium much faster from a dissolved organic compound than they did from selenate or selenite. Indeed, most uptake of selenium by benthic invertebrates is thought to be via incorporation of organic selenium (Presser and Luoma 2006).

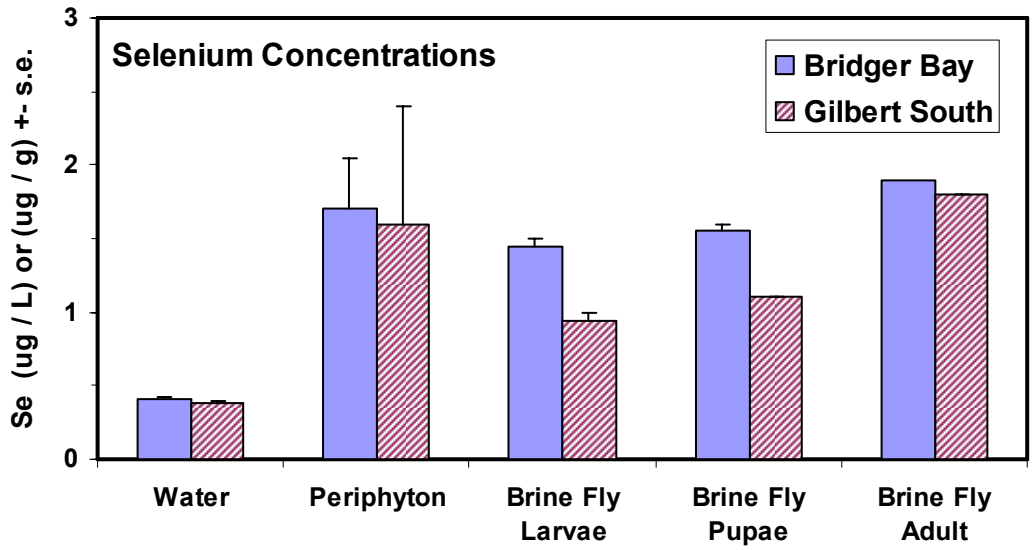


Figure. 11. Selenium concentrations in water (µg Se/L; dissolved), in periphyton (+sediment), and in brine fly larvae, pupae and adults (µg Se/g). Note that the relative scaling with these units indicates that selenium concentrations in the biota are >1000 times that dissolved in the water. Note that although this bioaccumulation is large, there is no further biomagnification from the periphyton to brine flies. Individual data are shown in Tables 2, 3, and 4. One periphyton sample concentration of 9.8 µg Se/g in a Bridger Bay mud sample was considered an outlier and was not included in the mean. Nevertheless, variability was still high in the periphyton/sediment samples. Concentrations of individual samples are shown in Tables 2-4.

The selenium content of brine flies is important because birds in the Great Salt Lake feed on them extensively. Cavitt (2007) found that brine fly larvae comprised 20-100% of the diet (by volume) of American avocets (*Recurvirostra americana*) sampled at different sites prior to or during nesting at the Great Salt Lake. The highest proportion of larvae in the diets occurred at Antelope Island where biostromes and dense brine fly populations occur close to shore. The lowest proportion of brine fly larvae in the avocet diets occurred in Ogden Bay where the mud flats are distant from biostromes and where fresher water allows other prey to be abundant. Black-necked stilts (*Himantopus mexicanus*) also ate 20% brine fly larvae at the Ogden Bay site during the nesting season. *Artemia* were absent from the diets of both of these birds. In contrast, Conover (2007) found that the diets of California gulls (*Larus californicus*) were composed of 45-83% *Artemia* at his three study sites, and brine flies represented a maximum of 25% of the diet. Curiously, at the Antelope Island sites where brine flies are very abundant, the gulls consumed no brine flies. Diet sample sizes were small for the birds, so these are only approximate proportions, and they represent only the short early or pre-nesting period when selenium in prey items can be passed to eggs.

Brine flies can be an important dietary component of other birds utilizing the Great Salt Lake (Figure 12). The diet of common goldeneye ducks is composed almost entirely of brine fly larvae and pupae (Joeseph Vest, USU, personal communication). Goldeneye have the highest concentrations of another contaminant of concern (mercury) of any birds sampled at the Great Salt Lake (J. Luft, Utah DWR, personal communication), so the potential for bioaccumulation of this toxicant through the benthic food web is likely. Mercury concentrates in lipids, and brine fly larvae have high fat levels (Herbst et al. 1984, Herbst 1986). Brine flies are also important component diets of eared grebes (*Podiceps nigricollis*) in saline lakes (Jehl 1988). Additionally,

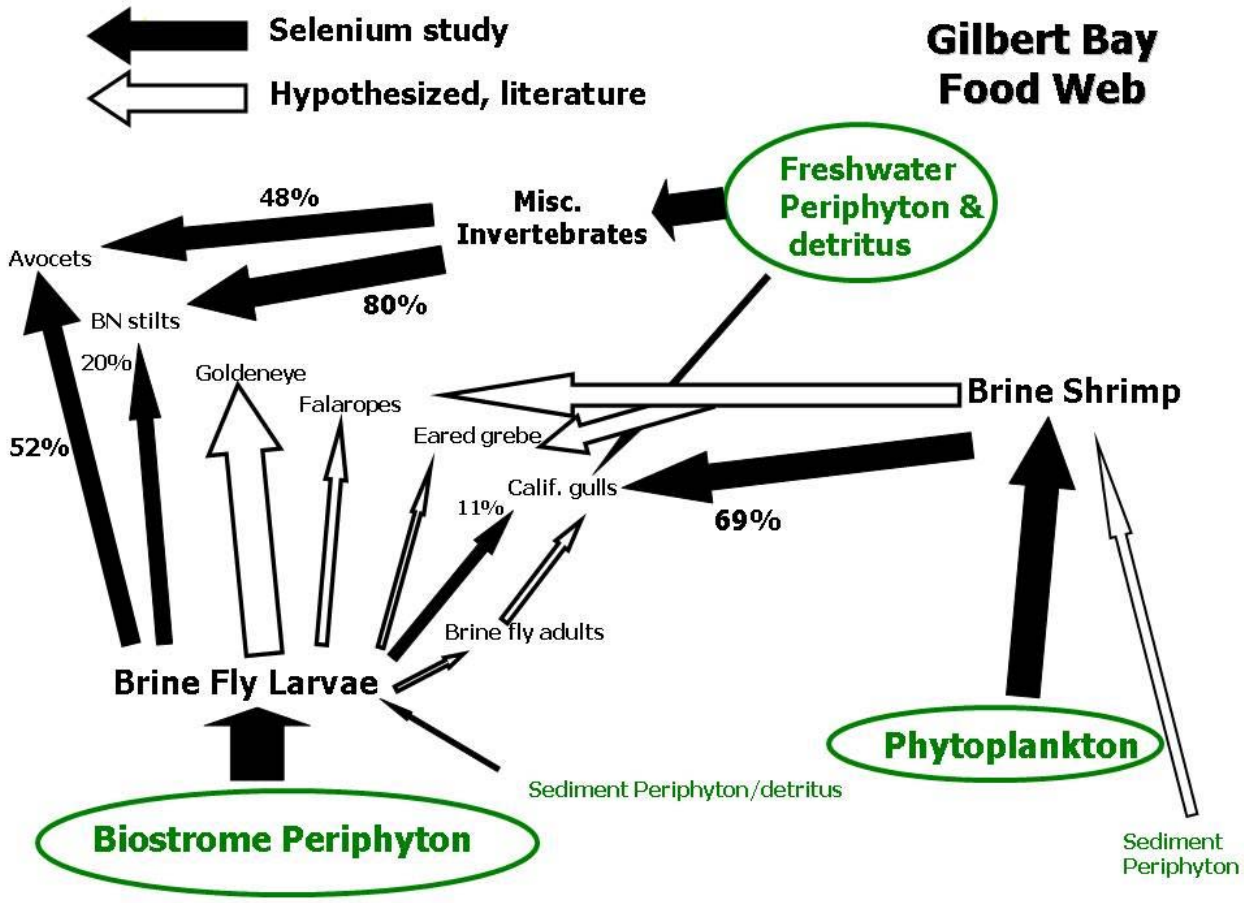


Figure 12. The food web in Gilbert Bay with an emphasis on pathways leading to birds that utilize the lake. The width of the arrows indicates the importance of a pathway. Solid arrows show data taken during the 2006 selenium study. Open arrows are hypothesized pathways based on studies in other saline lakes and ponds. The Freshwater Periphyton and Detritus pathway occurs on the mud flats of Gilbert and Farmington Bays.

red-necked phalaropes (*Phalaropus lobatus*) at Mono Lake feeding on brine flies maintained their weight, whereas those feeding only on *Artemia* lost weight (Rubega and Inouye 1994). The high fat levels and energy content of the Mono Lake brine flies makes them a good prey item for birds, but Caudell and Conover (2006) found that brine flies from the Great Salt Lake had lower caloric densities than did *Artemia*. The dominant brine fly in the Great Salt Lake (*E. cinerea*) is also considerably smaller than the *E. hians* at Mono Lake, so it is possible that the flies in the Great Salt Lake may not be utilized as extensively by birds as are the brine flies in Mono Lake.

Sampling methodology

The benthic habitat of lakes is far more difficult to sample than the open water pelagic areas, and consequently limnologists are just beginning to get good quantitative estimates of processes in this zone. The soft sand and mud sediments in Gilbert Bay were relatively easily sampled with the Ponar Grab. The only difficulty with this sampling device is that the softer sediments often mixed substantially when they were moved out of the dredge into a holding container. This made it difficult to section these types of sediments. A coring device would be better in this regard. Another drawback of the grab was that it sampled only a small area of sediments, and since brine flies were not abundant in this habitat, the variability between samples was high. Frequently, only 1–4 larvae or pupae were found in a dredge sample, so that stochastic errors become very large. The dredge also supplied insufficient numbers of brine flies for selenium analyses.

The bucket sampler was effective for quantifying the brine flies on most of the biostromes, and estimated sample sizes needed to evaluate the abundance of flies was not prohibitive. However, as presently configured, one could not effectively sample on the sides of the domed-shaped biostromes. For future work, it might be possible to attach a cam-strap to the bucket which would allow it to be cinched to the sides of biostromes. Another improvement

would be to attach the hose to the hollow hand brush so that dislodged larvae and pupae could be sucked immediately into the pump tube. This would limit their ability to float out of the bottom of the bucket when the seal is not tight. This loss, however, was not perceived to be significant. Another innovation would be to use a spherical dome instead of a bucket. This would decrease the accumulation of the pupae at the top inside of the flat bucket where they were difficult to move into the pump tube. The pupae are positively buoyant, and when their attachment to the substrate was broken, they floated upward to the top of the bucket, but not necessarily directly into the pump tube.

The periphyton/biofilm community on the biostromes proved to be the most difficult to sample. We were only able to sample by breaking off edge pieces of the biostromes or twisting off protruding pieces from irregularly-shaped domed biostromes. This undoubtedly introduced some bias in our results, although there was no obvious difference in the structure of the periphyton at the edges and in the center of the biostromes. Attempts to core a known area of the calcified material with a hole saw failed because the material crumbled after being “sawed”. Further innovation will be needed to effectively measure the biomass of periphyton and other properties of the biostromes. Additional work also is needed to verify the very high organic matter content we found during this sampling. The biostromes appear to be heavily calcified, yet nearly 60% of the material we measured was organic. Acid dissolution did not change the proportion of organic material we found. After dissolution, a thick plate of rubbery tissue is present that must compose a significant part of the total weight. However, Elser et al. (2005) found that only about 5% of the material scraped from the surface of Mexican biostromes was organic and Eardley (1938) reported that biostromes from the Great Salt Lake were only 2% organic matter, so it is likely that our high estimates are erroneous.

Predicting Sample Sizes Needed for Future Analyses

The benthic sampling in 2006 provides measures of sampling variability that allow us to conduct a power analysis to calculate the number of samples (n) required to determine mean levels at a given confidence level. Assuming normally-distributed variables, the following equation can be used to make these predictions (Prepas 1984):

$$n = \frac{t^2 s^2}{L^2}$$

Where:

n = necessary sample size

t = is the value of the Students' t-distribution for the degrees of freedom associated with the estimate of variance from the pilot survey

s^2 = variance estimate from the pilot survey

L = Allowable error in the sample mean

The power analysis of the 2006 survey data indicated that the number of samples necessary to adequately survey different parameters varied widely (Table 6). To provide a range of examples, the table includes allowable errors in the parameter estimates of 10-40%. For example, with the mean brine fly larval abundance of 5,240/m^2, and if we were able to accept an error of 30% (1570/m^2), and we wanted to be statistically confident at the 95% confidence interval, the analysis suggests that 36 replicate samples would be needed. Many more samples would be needed for Ponar samples of the sand/mud substrates, because the variability among replicates was high relative to the mean. The organic matter content on

Table 6. Input parameters for the power analysis and the estimated sample sizes needed to effectively sample Great Salt Lake biota and selenium concentrations.

					Sample Size Needed (n)			
					With Allowable Error (L) of:			
Parameter	**Mean**	**s**	**s^2**	**t_{95}**	**10%**	**20%**	**30%**	**40%**
Larval abundance - sand (#/m^2)	256	316	99811	2.37	852	213	95	53
Larval abundance - stromatolites (#/m^2)	5240	4013	16105080	2.37	328	82	36	21
Organic Matter Sand (%)	0.062	0.029	0.00082	3.18	216	54	24	13
Organic matter stromatolites (%)	0.580	0.030	0.00089	2.45	2	0.4	0.2	0.1
Chlorophyll on stromatolites (mg/m^2)	698	207	42849	2.45	53	13	6	3
Se Concentrations larvae (µg/g)	1.20	0.26	0.066	3.18	47	12	5	3
Se Concentrations pupae (µg/g)	1.33	0.23	0.052	3.18	30	7	3	2

biostromes varied little, and our data suggest that only 2 samples would be needed to estimate the mean within ± 10%. However, as mentioned previously, we are uncertain about the measurement of organic matter in these substrates, so additional work will be needed to estimate both the organic matter content and the samples sizes needed to adequately characterize this. Selenium concentrations in the brine flies were relatively uniform, so only 7-12 samples would be needed to characterize the Se with a 20% allowable error.

Note, however, that the 2006 survey included only two sites (albeit at several depths). If there is more spatial variability across the lake than that observed along our two transects, a higher number of samples would be needed. However, the two transects differed markedly with respect to biostrome morphometry and with respect to their orientation to inflows, so we may have captured a considerable amount of the actual variability in Gilbert Bay. When additional sampling is done, new power analyses should be conducted with the larger data set to compute the needed sample sizes.

Conclusions and Recommendations

Biostromes and their associated brine fly grazers are an important component of the food web in the Great Salt Lake. In contrast, the open mud and sand substrates appear to produce few brine flies, but more work in different parts of the lake is needed to confirm this. The brine flies produced on the biostromes are an important component of the diet of some birds that may be impacted by selenium, and for a number of other species that utilize the lake.

The preliminary data indicate that selenium concentrations in the organic material of the biostromes and in the brine fly larvae are higher than that in the pelagic zone. Marden (2007) found selenium concentrations of phytoplankton and *Artemia* to be 0.14 µg Se/g and 1.2 µg Se/g, respectively, suggesting that there is approximately a 9-fold bioconcentration factor

between the two trophic levels. In contrast, the preliminary data suggests that benthic periphyton in biostromes contained 1.7 µg Se/g, and larval and pupal brine flies had 1.5 µg Se/g, with a bioconcentration factor near 1. Although the limited benthic data collected so far restricts our inferences, the higher overall concentration of selenium in the benthic periphyton does not appear to pose severe risks higher in the food web due to the absence of bioconcentration.

Additional research is needed to better characterize the seasonal and spatial variability in the benthic habitats in the Great Salt Lake. Funding for this initial work constituted less than four percent of the budget of the DWQ selenium study, so only a limited number of benthic samples were collected and processed. Whereas *Artemia* and their phytoplankton food resources have been studied extensively over the past decade in support of the brine shrimp industry, very little work has been done to understand the brine flies and their biostrome habitats. Increasing eutrophication of Gilbert Bay may alter light penetration and influence the relative contribution of benthic and pelagic algae to the food web. Specific projects that need to be considered include: (1) detailed mapping of the benthic characteristics in the lake, and in particular, the distribution of different types of biostromes in the lake; (2) analysis of the spatial and temporal distribution of brine flies over at least two seasons; (3) increased effort to develop methods for sampling the periphyton and brine flies of the biostromes; (4) additional analyses of linkages between the periphyton, brine flies and the birds that feed on them; (5) studies to determine if *Artemia* utilize benthic food resources.

Acknowledgements

J. Kris Bell, Sonja Raub, Leyland del Re, and Joel Moore assisted in sampling and data processing. Ian Washbourn, Sanua Raub, and Justin Robison collected samples with SCUBA. David Naftz, William Johnson and Brad Marden shared unpublished data and provided constructive advice on the project. Harry Ohlendorf and Earl Byron provided advice on the study design and provided insightful reviews on an earlier draft. Teressa Presser and Anne Fairbrother also provided useful comments on the draft report. Jeffrey Denbleyker provided valuable administrative oversight. Funding for the study was provided by the Utah Division of Water Quality and the North Davis Sewer District.

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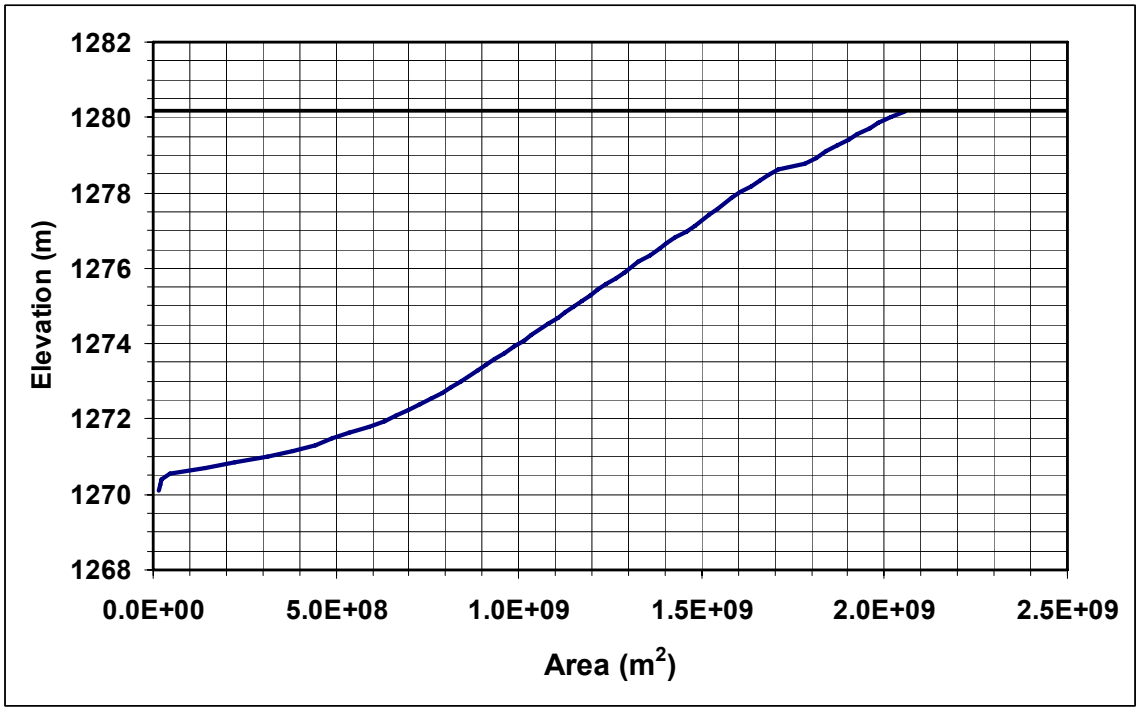
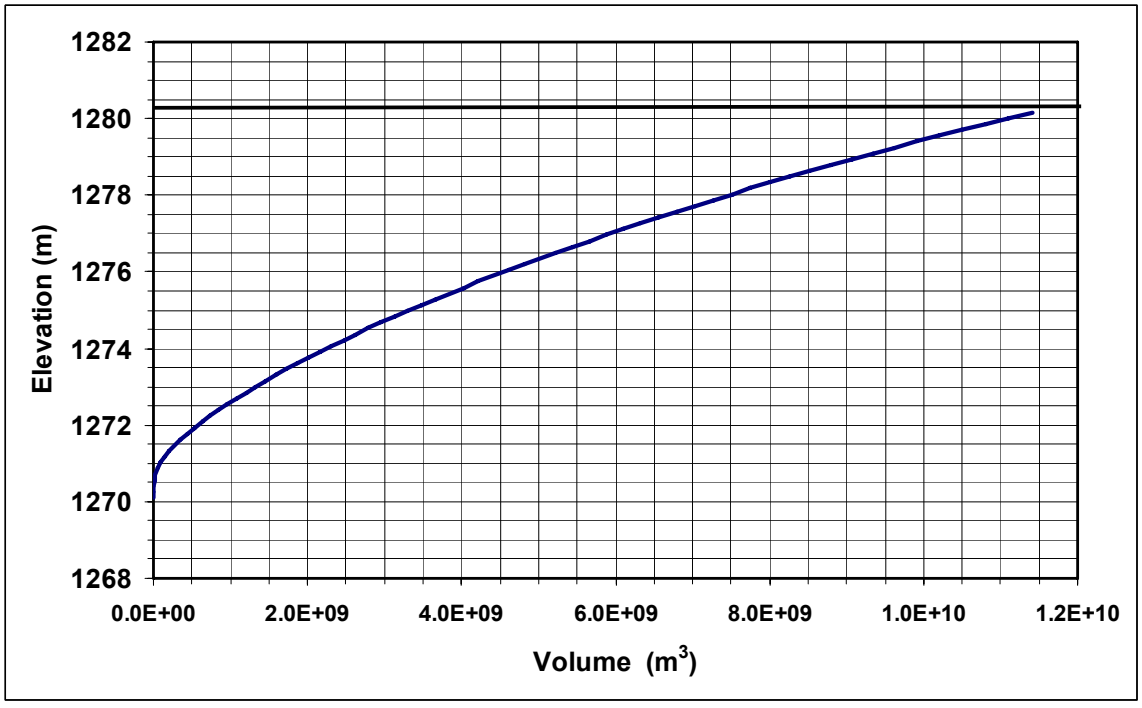
Appendix 1. Hypsographic curves showing the area and volume of Gilbert Bay (excluding Farmington Bay and salt ponds), derived from Baskin (2005). The maximum elevation plotted is 1280.2 m (4200 ft).





Addendum (2007 benthic sediment samples)

Because of the high variability in selenium concentrations found in the sediments in 2006, additional samples were collected on April 28, 2007, at the Bridger Bay site in Gilbert Bay. These were done after the funding for the benthic work had concluded, but they are presented here in the addendum. Mud and sand samples were collected with an Eckman dredge and strata of varying depths and thicknesses were scraped off for analysis. Biostrome (stromatolite) samples were broken off by a diver. Some were treated with 1-N HCl to dissolve the carbonates. Additional acid was added if necessary until all bubbling stopped (within 24 h). All samples were dried to constant weight at 70ºC and sent to LET for analysis of selenium content and organic material. Organic content was measured by combusting the samples at 450°C, adding water back, and then drying to constant weight at 70°C.

In contrast to the 2006 samples, there was a clear distinction in selenium concentrations between sediment types (Table 7; Figure 13). Both percent organic matter and selenium concentrations were significantly higher in acidified than in non-acidified biostromes (paired t-tests; p =0.004 and 0.055, respectively). Selenium concentrations in mud (0.7 ug Se/g) were significantly (ANOVA, p = 0.002) higher than in sand (0.3 ug/g) or non-acidified biostromes (0.3 ug/g). However, when the carbonates in the biostromes were removed by acidification, the remaining organic matter (cyanobacteria and its mucilage) had significantly higher concentrations than mud. The ANOVA identified one acidified stromatolite sample (0.6 ug/g) as an outlier (Durbin-Watson D Statistic 1.633). When this value was removed from the analysis, the acidified stromatolite samples had significantly (p = 0.002) higher selenium concentrations (mean = 1.2 ug Se/g) than any of the other substrates.

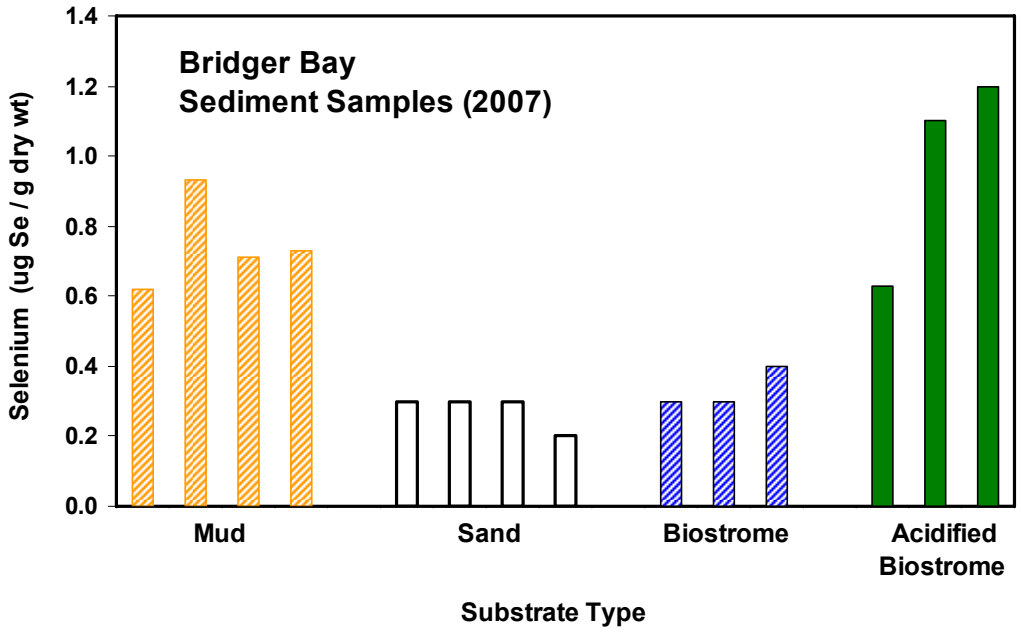


Figure 13. Selenium concentrations in sediments collected in Gilbert Bay (Bridger Bay) in 2007. Each bar represents an individual sample. Acidified biostromes were treated with HCl to remove carbonates.

The organic matter content of all substrates differed significantly ($p \leq 0.001$), with non-acidified biostromes having 27-32% organic content (Table 7). Acidification of the biostromes removed substantial amounts of carbonates, and the remaining material was 69-74% organic matter. There was a suggestion of a correlation between organic matter content in the various substrates and their selenium content (Figure 14), but the correlation was not significant ($p = 0.20$).

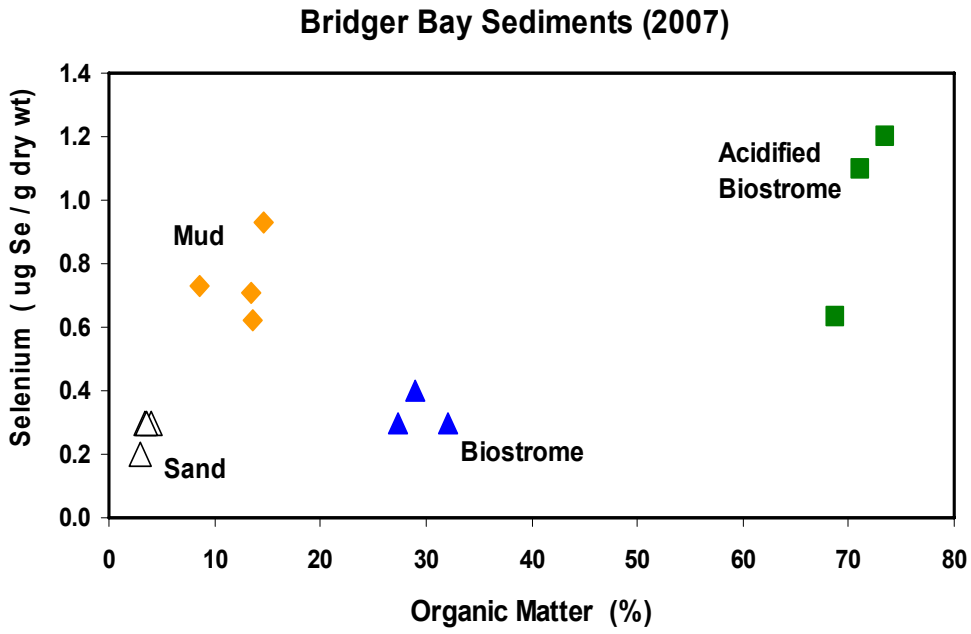
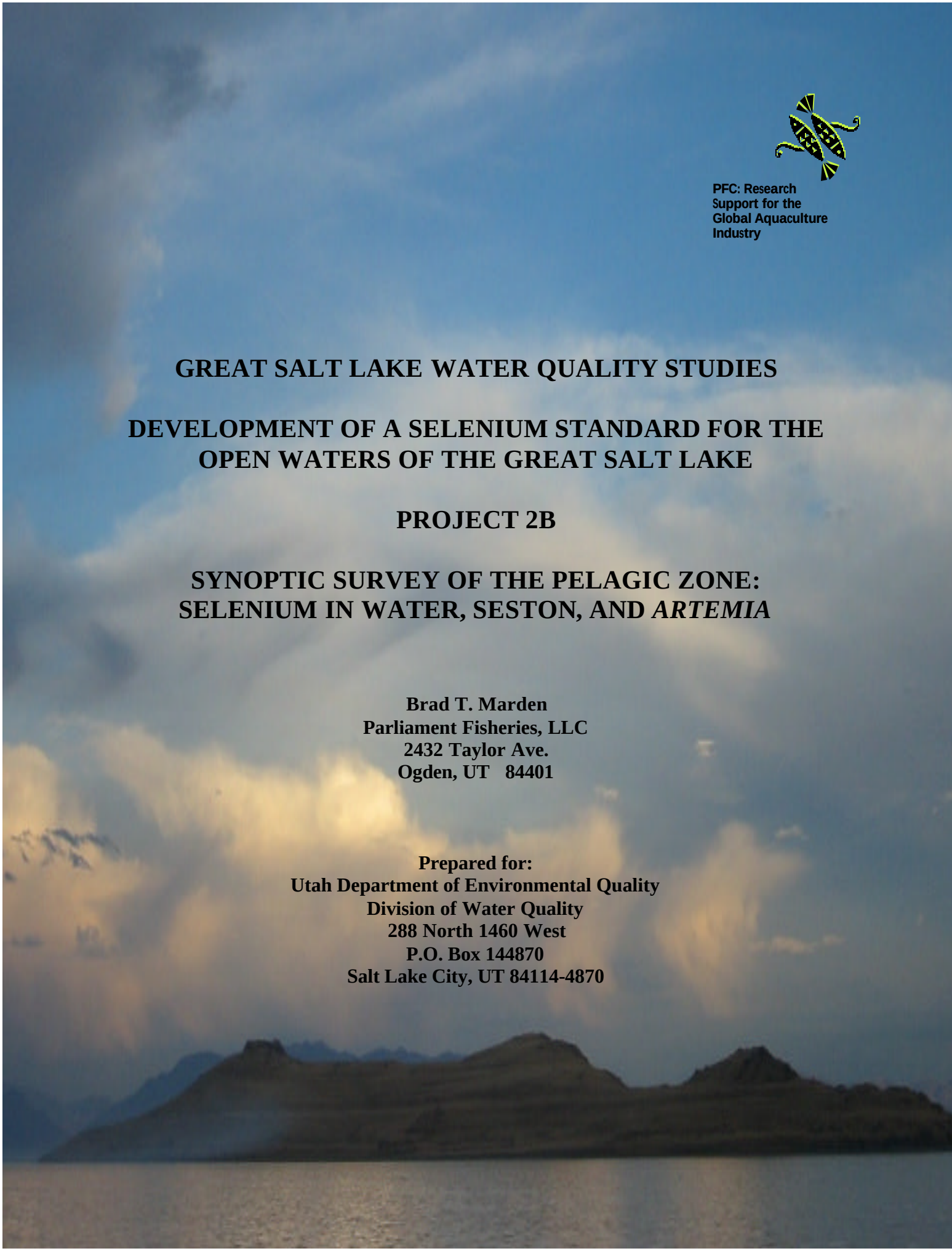


Figure 14. Relationship between the percent organic matter in the substrates from Bridger Bay in 2007 and their selenium concentration.

Table 7. Concentrations of selenium and percent organic matter (% lost on ignition) of sediment samples collected in Bridger Bay on April 28, 2007 (12:00-16:30). Mud and sand samples were collected with an Eckman dredge and strata of varying depths and thicknesses were scraped off for analysis. Biostrome (stromatolite) samples were broken off by a diver. Some were treated with 1-N HCl to dissolve the carbonates. All samples were dried to constant weight at 70ºC. Replicate concentrations of organic material content for one mud and one biostrome sample were measured, yielding very similar values.

Location	Latitude	Longitude	Depth (m)	Sediment strata (mm)	Substrate	Acidified?	% Lost to ignition	µg Se/g dry
Bridger Bay	41.0406	112.2792	2.5	0-3	Mud*	No	13.6	0.6
Bridger Bay	41.0406	112.2792	2.5	3-40	Mud	No	14.7	0.9
Bridger Bay	41.0431	112.2760	3.0	0-3	Mud	No	13.4/13.6	0.7
Bridger Bay	41.0431	112.2760	3.0	3-30	Mud	No	8.6	0.7
Bridger Bay	41.0429	112.2710	1.0	0-3	Sand	No	3.4	0.3
Bridger Bay	41.0429	112.2710	1.0	30-50	Sand	No	3.0	0.2
Bridger Bay	41.0427	112.2737	1.0	0-3	Sand	No	3.9	0.3
Bridger Bay	41.0427	112.2737	1.0	3-50	Sand	No	3.6	0.3
Bridger Bay	41.0426	112.2752	1.0		Biostrome	No	32.1/32.3	0.3
Bridger Bay	41.0426	112.2752	1.0		Biostrome	Yes	68.7	0.6
Bridger Bay	41.0407	112.2788	2.1		Biostrome	No	27.3	0.3
Bridger Bay	41.0407	112.2788	2.1		Biostrome	Yes	71.1	1.1
Bridger Bay	41.0431	112.2760	3.0		Biostrome	No	29.0	0.4
Bridger Bay	41.0431	112.2760	3.0		Biostrome	Yes	73.5	1.2

* Minute amount of sand



PFC: Research Support for the Global Aquaculture Industry

GREAT SALT LAKE WATER QUALITY STUDIES

DEVELOPMENT OF A SELENIUM STANDARD FOR THE OPEN WATERS OF THE GREAT SALT LAKE

PROJECT 2B

SYNOPTIC SURVEY OF THE PELAGIC ZONE: SELENIUM IN WATER, SESTON, AND *ARTEMIA*

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EXECUTIVE SUMMARY

A field study of the pelagic zone of the Great Salt Lake, Utah (GSL) was conducted from April 2006 through August 2007 to document selenium concentrations in GSL water, seston, and the dominant zooplankton—brine shrimp (*Artemia franciscana*). The transfer of selenium through trophic levels (i.e., water phase to seston, and then to brine shrimp) in the pelagic zone of the GSL was assessed. Population dynamics of brine shrimp and phytoplankton were also documented. Limnological conditions of the GSL were recorded with respect to those factors that play a key role in the growth and survival of zooplankton and phytoplankton.

The brine shrimp displayed characteristic cyclical patterns of population growth and decline throughout the summer months. Both modes of reproduction (e.g., ovoviviparous and oviparous) were documented from May until December, although oviparous reproduction dominated after September. The terminal population collapse occurred in late December when the water temperature dropped to less than 5 degrees Centigrade. The population structure and size was unremarkable with respect to earlier research on the GSL. Population parameters were well within the boundaries of previously reported population cycles on the GSL (Stephens, 1997, 1998, 1999; Belovsky and Larson, 2001). Mature adult abundance (1.21 adults/L & 0.68 adults/L), average productivity per location (6.97 cysts/L & 3.45 cysts/L), fecundity (89 cysts/brood & 74 cysts/brood), biomass (0.69 mg/L dw & 1.05 mg/L dw), cysts in the water column (21.63 cysts/L & 33.95 cysts/L) , and commercial harvest yield (16.6 million pounds & 14.9 million

pounds) for 2006 and 2007 respectively, indicate that this population is in a generally healthy condition (Appendices 2, 3, 4, & 5). As such, *Artemia* biomass, whether in the form of overwintering cysts or live brine shrimp, was prevalent throughout the year for foraging birds.

The phytoplankton population was initially composed of diverse taxa; in May 2006 there was a mixed population primarily consisting of green algae (Chlorophyceae), diatoms (Bacillariophyceae), blue-green algae (Cyanophyceae), and small numbers of dinoflagellates (Dinophyceae). Later in the summer the population was more homogenous. Chlorophytes progressively increased in relative dominance from 59% in May to 97% in August, 2006. *Dunaliella* was the most dominant genus represented in the GSL over the summer of 2006.

Chlorophyll-a measurements from water column samples showed declining values at the beginning of spring (7.0 ug Se/L in April to 3.2 ug Se/L in late May 2006) (Appendix 7.1). The concentration of chlorophyll-a over the 2006 summer was between 1.3 and 16.0 ug Se/L. Chlorophyll-a increased steadily, as the brine shrimp population declined in October 2006, from single digits to 20.8 ug Se/L. The highest chlorophyll-a concentration was measured in January 2007 (41.7 ug Se/L). Average chlorophyll-a in 2007 was 12.1 ug/L. From May 2007 to August 2007 the chlorophyll-a concentration was between 1.5 and 8.5 ug/L.

Total selenium concentration results for water were quite consistent spatially but not temporally. The geometric mean of selenium in water for all sample dates and locations was 0.61 ug Se/L (Appendix 8.5). The lowest and highest concentrations of selenium in water were 0.39 and 0.90 ug Se/L, respectively. 2007 had the most consistent results for selenium in water samples. From January 2007 to August 2007 there was a net increase of 0.11 ug Se/L is dissolved selenium. The average net change in total selenium for each sampling date was +0.026 ug Se/L.

Among seston selenium concentrations, the geometric mean was 1.32 ug Se/g and the arithmetic mean was 1.43 ug Se/g in 2006, and in 2007 the geometric mean was 0.86 ug Se/g and the arithmetic mean was 1.08 u Se/g (Appendix 8.3). The particulate fraction of selenium in water was determined from the seston selenium concentration reported on a per-liter basis (i.e., the number of liters filtered for each seston sample). The geometric mean of selenium in seston using a per-liter basis was 0.10 ug Se/L and the arithmetic mean was 0.11 ug Se/L for 2006. The 2007 geometric mean for seston in water was 0.13 ug Se/L and the arithmetic mean was 0.14 ug Se/L (Appendix 8.4). The arithmetic mean concentration of selenium in adult *Artemia* tissue in 2007 was 4.32 ug Se/g and the geometric mean was 4.30 ug Se/g (Appendix 8.1). The nauplii/cysts fraction in 2007 showed a geometric mean value of 2.32 ug Se/g and an arithmetic mean value of 2.42 ug Se/g. The nauplii were a factor of 0.538 multiplied by the adult selenium tissue concentration. Average values for selenium in brine shrimp tissue were below the 5 ug Se/g level of concern for protection of most birds.

No significant differences in selenium concentration among water samples were found for location ($P = 0.437$, df: 2, 103) or water depth categories ($P = 0.099$, df: 2, 103). Results for water samples did show significant differences in selenium concentration across sample dates ($P < 0.01$, df: 16, 89). 2007 results for selenium in brine shrimp tissue were significant for location ($P = 0.026$, df: 2, 42). They were also significantly different for depth categories ($P = 0.050$, df: 1, 43). There were statistically definable differences temporally in brine shrimp tissue selenium concentration ($P < 0.01$, df: 7, 37). Seston samples were uniform for site depth ($P = 0.794$, df: 2, 99) and geographic location ($P = 0.211$; df: 2, 99), yet differed substantially across sample dates ($P < 0.01$, df: 16, 99).

The data suggest that there are temporal events that influence selenium loading into specific trophic compartments. However, when results for each biological or physical compartment are examined collectively over the course of multiple months, and evaluated spatially, they do not differ in statistical measures of central tendency. Although some putative factors that may affect the temporal pattern of selenium in biological tissues have been inferred (e.g., interaction between *Artemia* and phytoplankton population fluctuations) it is not clear from the present study which factors are most important, or mechanistically, how such factors, or biochemical processes, may function within the GSL biota.

The selenium load in brine shrimp biomass is an inconsequential factor in the overall mass balance of selenium in the GSL; the maximal load for 2007 in *Artemia* biomass was 87.0 kg and the average load was 45.1 kg. The estimated amount of selenium removed

from the GSL via commercial harvesting of brine shrimp cysts is similarly trivial—2.21 kg to 10.75 kg per year. In 2006 the industry removed 4.2 kg and in 2007 3.74 kg of selenium.

There is little evidence of biomagnification in the selenium results—as has been corroborated in the scientific literature and by other authors in the GSL Selenium Study Group (Wurtsbaugh, 2007).

The most essential outcome of this study was to provide resource managers with quantitative information on the trophic transfer of selenium from water to seston and then to brine shrimp tissue. In this study the 2006 brine shrimp results were determined to be biased below actual values. Some procedural improvements were made and the resulting data collected from 2007 were quite reliable. Analyzing the 2007 data using least squares regression provided a tropic transfer factor for selenium from seston to brine shrimp of 2.57. The partition coefficient (Kd) for dissolved selenium in water to seston (dry weight) is 1841. The overall bioconcentration factor for total selenium in unfiltered water to adult brine shrimp tissue is 6494, and for dissolved selenium in filtered water to brine shrimp tissue the BCF is 7634. Laboratory studies on the progression of selenium through each trophic level in an artificial food web are currently underway (Grosell, 2007). The data derived from such controlled studies can be used in conjunction with field-generated transfer factors to more effectively model the trophic transfer of selenium through the GSL food web.

INTRODUCTION

The study was undertaken to support the State of Utah Department of Environmental Quality, Division of Water Quality in their effort to establish a site-specific water quality standard for selenium in the Great Salt Lake. This process involves an in-depth, multi-disciplinary approach for evaluating and modeling the transfer of selenium through identifiable trophic compartments of the GSL food web. The goal of this and related studies is to understand the transport, loading, loss, biogeochemical cycling, bioavailability, fate, and impact of selenium on biota within the GSL ecosystem. This information will be used to model changes that may occur as a result of increased selenium loading into the waters of the GSL. One of the simple, but very challenging, questions we are trying to address is: What impacts can be expected in the critical biota (i.e., brine shrimp, brine flies, and avifauna) found within the GSL, and its surrounding environs, if the selenium load into the GSL were increased? This is one of many questions being addressed by the GSL selenium study group, but it is the preeminent question that forms the conceptual basis for this current study on selenium in water, seston and brine shrimp (*Artemia franciscana*) in the pelagic zone of the GSL.

This preliminary report provides a summary of a detailed investigation into the trophic transfer of selenium from the water phase to seston (suspended particulate fraction) and then to brine shrimp. Also included is an in-depth examination of the population dynamics of brine shrimp and the phytoplankton population that comprises the dietary foundation for the brine shrimp. Brine shrimp population dynamics are considered from three perspectives: 1) comparative population dynamics as a measure of population

integrity, 2) reproductive capacity, cyst production, and biomass for foraging birds, and 3) as a biological conduit through which selenium is modified and transferred to higher trophic level consumers. Phytoplankton population dynamics were studied somewhat less rigorously, but are evaluated in sufficient detail to ascertain the dominant algal taxa and general spatial and temporal patterns. Limnological conditions are examined with respect to key abiotic factors that exert a pronounced influence on the GSL biota.

Selenium in each trophic compartment was evaluated, and transfer factors are described. The data are ultimately intended to be incorporated into the framework of the conceptual model of selenium in the GSL as developed by Johnson (2006) and further refined by CH2M HILL.

It should also be acknowledged that the data presented herein are from a rather extensive field investigation. Inherent in any large-scale field study there is an unavoidable element of surprise, such as irksome delays, equipment malfunctions, unanticipated logistical obstacles, weather-related complications, and other challenges. During this field study there was a need for periodic refinements, improvements, and modifications in the sampling and analytical procedures. In particular, improvements were made in the sample preparation of brine shrimp tissue that remedied problems in the 2006 samples. The outcome of this process is, hopefully, a better understanding of the GSL ecosystem as well as the development of improved experimental methods that can help the DEQ/DWQ during future scientific inquiries into the fate and effects of contaminants within the GSL ecosystem.

METHODS

Geographic Regions of the Great Salt Lake

This study was conducted exclusively in the South Arm (Gilbert Bay and Carrington Bay) of the Great Salt Lake. Any reference to the Great Salt Lake (GSL) hereafter refers only to the South Arm and excludes the region of the GSL north of the railroad causeway, unless otherwise specified. For the purposes of this study three regions of the GSL were defined, and clusters of sample sites were located in each region (Figure 1). The regions were based on primary sources of inflow. Ogden Bay and the northeast region of GSL receive water from Farmington Bay and Ogden, Weber, and Bear River drainage basins. In the southeast region of the GSL, drainages from Tooele Valley, the Oquirrh Mountains, and overflow canals from the Jordan River provide the predominant inflow volume into the lake. This region of the GSL is also nearest to the drainage zone for Kennecott's outflow. The central region of GSL (north of Hat Island) is isolated from any specific surface inflow source and is primarily a mixing zone of currents from Gilbert and Carrington bays. Deep brines from Gunnison Bay (North Arm) of the GSL are channeled along a subsurface fault ridge (Allen Ridge) in this area of the lake. Due to the known differences in lake current characteristics and tributary influences among these three regions, site selection was stratified to include representative sample sites from each of these areas.

Sample Site Locations and Characteristics.

Within each region, further stratification of sample site designation was based on depth and substrate (Table 1). Previous studies suggested that depth and substrate may have an influence on phytoplankton and *Artemia* population growth and abundance (Marden, unpublished). Deep sites of the GSL with an associated deep brine layer may be subjected to profoundly different geochemical cycling mechanisms than those associated with shallow or medium-depth sites (Naftz, pers. com.). Light penetration and temperature factors also differ markedly between these sites and likely play an important role in biogeochemical dynamics. Depth categories included shallow (1-3 meters in depth), medium (5-6 meters in depth), and deep sites (7-8 meters in depth). The respective elevation contours were roughly 4190-, 4180-, and 4170-foot contours.

The substrate differed among the depth categories. Shallow site substrate is predominantly characterized by the presence of calcified biostromes and oolitic sand. Biostromes, also referred to as bioherms or stromatolites, are calciferous formations that markedly increase the substrate surface area and may provide a unique micro-habitat that supports microalgae and benthic invertebrates (Wurtsbaugh, 2007). Medium-depth site substrate is generally mixed sands and mud. The deep site substrate is a gelatinous mud (described as "ooze" by Johnson, 2007) composed of decomposing organic matter intermixed with inorganic components. The substrate at each deep site is below the chemocline, or deep brine layer, which is formed by a dense North Arm brine layer (with a salinity typically in the range of 170 to 200 parts per thousand [ppt]) and characterized

by an anoxic and strongly reducing hydrochemical profile (Naftz, 2007). Sample site locations, depth characteristics, and substrate composition are detailed in Table 1.

Table 1. Sample site characteristics and geographic coordinates.

SITE ID	Max. Depth	Depth Category	Region	Substrate	Latitude	Longitude
1	2	Shallow	Northeast	Stromatolite/Mud	41.07.767	112.17.631
2	6.5	Medium	Northeast	Sand/Mud	41.05.097	112.21.145
3	8.5	Deep	Northeast	Gelatinous Mud	41.05.207	112.24.372
4	2	Shallow	Central	Stromatolite	41.05.137	112.35.437
5	6	Medium	Central	Sand/Mud	41.07.066	112.33.514
6	9	Deep	Central	Gelatinous Mud	41.06.440	112.38.260
7	1.5	Shallow	Southeast	Stromatolite	40.52.685	112.13.838
8	6	Medium	Southeast	Sand/Mud	40.49.524	112.11.431
9	8.5	Deep	Southeast	Gelatinous Mud	40.50.786	112.16.711

Sample site locations are portrayed in Figure 1. It is evident from the map that sample sites were clustered regionally. Bathymetric contours, along with field validation of substrate characteristics, were used to define site location according to depth category designations. A strictly randomized approach for sample site designation, along with a greater number of sample locations, was simply not feasible given the scope and financial resources for this project. A stratified-random approach was determined to be a manageable and sound approach for the experimental design.

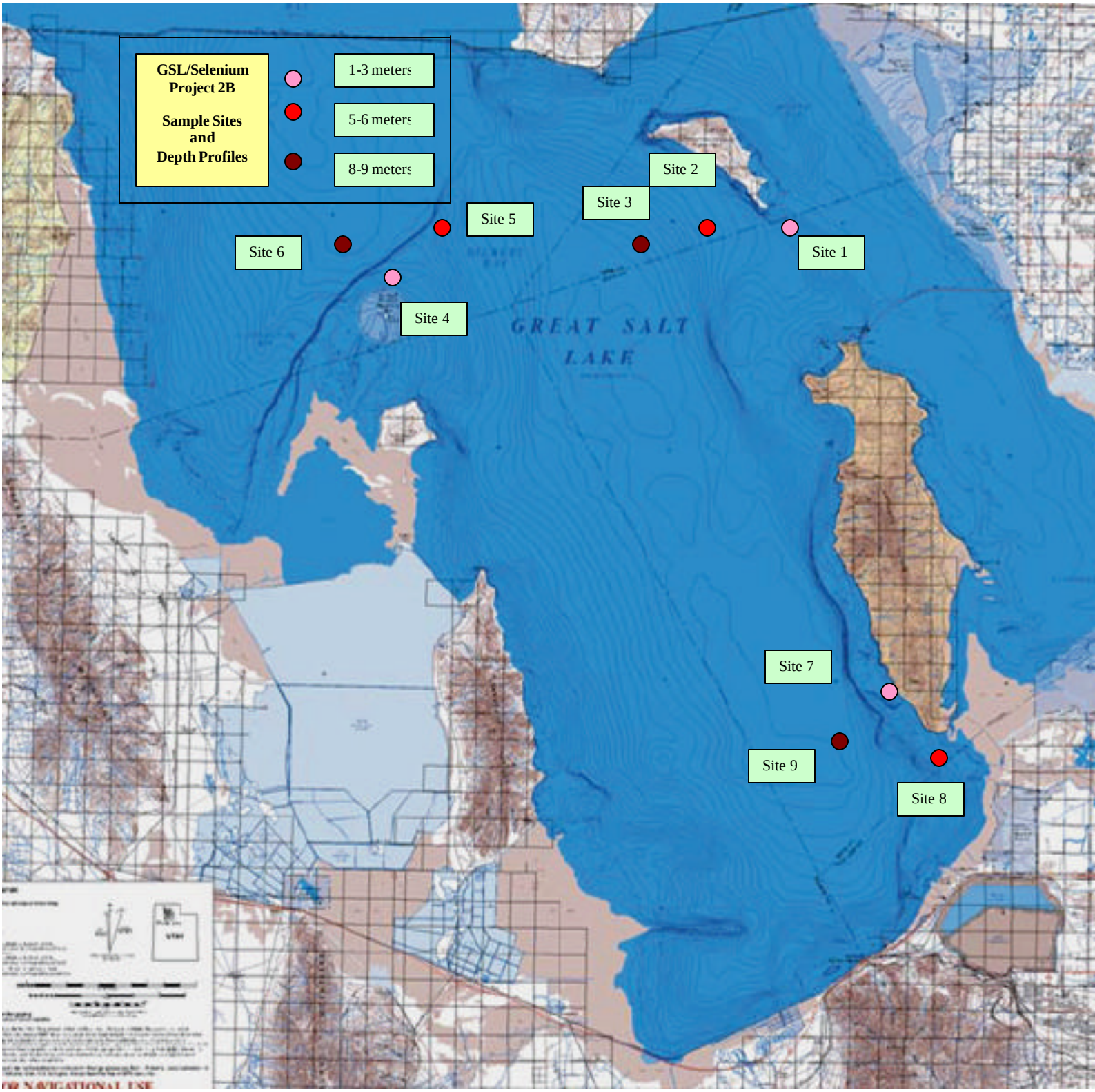


Figure 1: Great Salt Lake sample site locations. Sample locations were based on a stratified random design. Substrate composition, water depth and three geographic regions of the South Arm were used to select sample site locations.

Sampling Schedule

Sampling of the GSL began in April 2006 and has continued through August 2007. A total of 21 sampling programs were completed.

Nine sample sites were visited from April 2006 through June 2006. From July 2006 through August 2007 six sample sites were used for sample collection. This reduction in sample sizes was foreseen at the onset of the project and was implemented as a means of reducing time and analytical costs. Weather was an important consideration during the sampling programs and was a determining factor in the ability of the sampling crew to complete all sites within a sample program time period. Figure 2 depicts one of the many weather-related complications encountered on the GSL. The maximum allowable time period for a sampling program was set at 7 days. The primary objective of sampling was to complete all sampling on one sample day, or as short a period as allowable by weather, equipment function, and conditions on the GSL.

Figure 2. Extensive ice formations were encountered on the GSL during January 2007. Ice extended from Promontory Point to beyond Hat Island (sample site # 6). Diverse conditions on the GSL, such as high winds or ice sheets, rendered successful sampling at predetermined times quite challenging.

Sample collection, transport, and storage.

A summary of the samples collected is shown in Table 2. Biological and water samples were collected at each sample location. All samples were promptly stored on wet ice for transport to the laboratory. Abiotic factors were measured at each site and included temperature, dissolved oxygen, and salinity measurements at discrete intervals within the water column.

Table 2. The sampling program schedule and number of samples collected are shown. Not all samples collected have been analyzed, nor were they all intended to be analyzed. Some extra samples were collected opportunistically to expand the potential research scope of the project. Occasionally sample sizes were insufficient for analyses, or samples were not used for analysis due to budget constraints. Remaining samples are preserved by freezing (biomass), acidification and refrigeration (water samples), or with formaldehyde/Lugols iodine and refrigeration (algae samples).

Sampling Program	Sampling Dates	*Artemia* Biomass Samples	Water Samples	Seston Samples	Algae Samples	Chl-A Samples	Isotope Samples	*Artemia* Population Samples
Program 1	4/30/06	18	0	0	6	6	6	7
Program 2	5/4-12/06	42	0	0	8	8	14	14
Program 3	5/24-25/06	27	18	9	9	9	9	9
Program 4	6/12-13/06	18	0	0	6	6	6	6
Program 5	6/22-29/06	27	27	9	9	9	9	9
Program 6	7/10-13/06	18	18	6	6	6	6	6
Program 7	7/26-27/06	18	18	6	6	6	6	6
Program 8	8/18-23/06	18	18	6	6	6	6	6
Program 9	8/25-28/06	18	18	6	6	6	6	6
Program 10	9/18-24/06	18	18	6	6	6	6	6
Program 11	10/14/06	18	18	6	6	6	6	6
Program 12	11/20/06	18	18	6	6	6	6	6
Program 13	12/2/06	18	18	6	6	6	6	6
Program 14	1/26/07	18	18	6	6	6	6	6
Program 15 (Selenium Species)	3/15/07	0	0	3	3	3	0	0
Program 16	5/4-7/07	18	18	6	6	6	6	6
Program 17	5/22-23/07	18	18	6	6	6	6	6
Program 18	6/9/07	18	18	6	6	6	6	6
Program 19	6/27/07	18	18	6	6	6	6	6
Program 20	7/27/07	18	18	6	6	6	6	6
Program 21	8/21/07	12	12	4	4	4	4	4
Comparative Methods Exp.	5/8/07 & 8/31/07	18 16	0 0	0 0	0 0	0 0	0 0	0 0
Seston Filter Exp.	9/24/06	0	0	18	0	0	0	0
GSL Water Storage Exp.	7/27/06	0	8	0	0	0	0	0
SAMPLE TOTALS		**430**	**317**	**127**	**129**	**129**	**132**	**133**
GRAND TOTAL	**1,397**							

Table 3 lists the types of samples collected at each sample location, filtration (if included), replicates, preservative used, and storage conditions. Each sampling procedure is described in greater detail in Table 3.

Table 3. Sample type or matrix, analytical procedure, filtration steps, inclusion of replicate sample, preservative, and storage conditions for biological and water samples collected.

Sample Matrix/Type	Analysis	Pre-Filtration	Collection Filter	Post-Filtration	Replicate or Pooled Sample	Preservative	Storage
GSL Water	Total Selenium	Yes 125 micron	No	No	Rep.	Nitric Acid	Refrigeration[1]
GSL Water	Dissolved Selenium	Yes 0.45 micron	No	No	No	Nitric Acid	Refrigeration[1]
Seston	Total Selenium	Yes 125 micron	Yes 0.45 micron		No	None	Freezing -25 to -30° C
Artemia Biomass / Adult	Total Selenium	No	Yes 850 micron	No (2006) Yes (2007)	Pooled	None	Freezing -25 to -30° C
Artemia Biomass / Juvenile	Total Selenium	No	Yes 500 micron	No (2006) Yes (2007)	Pooled	None	Freezing -25 to -30° C
Artemia Biomass / Nauplii-Cyst	Total Selenium	No	Yes 125 micron	No (2006) Yes (2007)	Pooled	None	Freezing -25 to -30° C
Artemia Biomass	*Artemia* Population	No	Yes Plankton Net	No	Pooled	None	Refrigeration (less than 24 h)
GSL Water	Phytoplankton Population	Yes 125 micron	No	No	No	Lugol's/ Formalin	Refrigeration
GSL Water	Chlorophyll[2]	Yes 125 micron	Yes 0.45 micron	No	No	None	Freezing -25 to -30° C
GSL Water	Chlorophyll	Yes 125 micron	No	No	No	$MgCO_3$	Refrigeration

1. Water samples from May 25, 2006 to July 13, 2006 were initially stored at +5°C, but were stored at -25° C for a period of approximately 1 month.
2. Chlorophyll samples from May 4, 2006 to Oct 18, 2006 were filtered through 0.45 micron cellulose acetate filters and then stored in freezer until analyzed. Subsequent water samples were preserved with $MgCO_3$ and then promptly sent to Aquatic Research Inc. laboratory for chlorophyll analysis.

Depth intervals for sample collection and abiotic measurements.

Both biological samples and abiotic measurements were taken at specific depth intervals. Water samples were comprised of pooled samples collected at discrete depth intervals. *Artemia* samples were collected via pooled vertical, or horizontal (for the 1 meter sites only), plankton net hauls. Abiotic measurements included temperature, dissolved oxygen, and salinity. These measurements were taken at discrete intervals within the water column. The depth intervals of each abiotic measurement and biological sample collection are listed in Table 4.

Table 4. Sampling depth profile for abiotic measurements and biological sample collection.

Sample Site Depth Category	Dissolved Oxygen (discrete intervals)	Salinity (discrete intervals)	Temperature (discrete intervals)	*Artemia* for Selenium Analysis (depth from surface)	*Artemia* for Population Assessment (depth from surface)	Seston for Selenium Analysis (pooled discrete intervals)	Water Samples for Selenium, ChlA & Algae (pooled discrete intervals)
Shallow	1 m	1 m	1 m	1 m	1 m to S	1 m	1 m
Medium	1,3,5,6 m	1,3,5,6 m	1,3,5,6 m	5 m	5 m to S	1,3,5 m	1,3,5 m
Deep	1,3,5,6,7,8 m	1,3,5,6,7,8 m	1,3,5,6,7,8 m	5 m	7 m to S	1,3,5 m	1,3,5 m

Water Samples for Selenium Analysis.

Water samples were collected by means of a GeoPump™ peristaltic pump, supplied with Teflon™ lined tubing, and Masterflex® tubing. Samples were filtered through a 125-micron stainless steel sieve and collected in a 3-liter HDPE cylinder. Equivalent volumes were collected from 1, 3, and 5 meters for medium and deep sites and only from 1-meter depth from the shallow sites. Pooled volumes of GSL water were mixed thoroughly and then 250-ml samples were collected in certified and pre-cleaned HDPE or glass bottles. Water samples for dissolved selenium analysis were pre-filtered through a 0.45 micron, high-capacity cartridge filter. All tubing, bottles, and sample containers were pre-cleaned in the laboratory with DI water and a 2% solution of nitric acid. Field and method blanks were included in each sample program. Bottles were stored on ice for transport and then 2 ml of nitric acid were added to preserve solutions (pH < 2.0). Nitric acid was added within 12 hours of sample collection. Samples were then stored at 5º C until shipment for selenium analysis. Early samples (May 25 to July 13th) were initially stored at 5º C, but with delays in funding and the uncertainty of the analytical schedule were stored at -25º C. All subsequent water samples were stabilized with nitric acid and stored at 5º C until analysis.

Water Samples for Phytoplankton and Chlorophyll Analysis

Water samples used for chlorophyll analysis or for the identification and enumeration of phytoplankton were collected at discrete intervals using a 2.2-liter horizontal alpha bottle. Water samples were collected at 1, 3, and 5 meters for medium and deep sites and at 1-meter depth for the shallow sites. The water samples were filtered through a 125-micron sieve to remove zooplankton and large suspended particulates. Equivalent volumes were

collected at each depth interval providing a final volume of 1 liter each for phytoplankton and chlorophyll determination. Prior to preservation, all water samples were contained in amber Nalgene® bottles, stored on ice, and then transported to the laboratory. Water samples to be used for phytoplankton analysis were treated with Lugol's solution (0.5%) following which formaldehyde was added (1% formaldehyde). Water samples for chlorophyll analysis collected from May 4, 2006, to October 18, 2006, were vacuum-filtered through a 0.45-micron cellulose acetate filter, wrapped in foil, placed in Whirl-pak® bags and stored at -25C until being analyzed. Water samples collected after October 2006 and used for chlorophyll analysis were preserved with 1 ml per 1000 ml from a 1% stock solution of $MgCO_3$ and then refrigerated prior to shipment for analysis (usually shipped within 24-48h). Analysis of these water samples for chlorophyll was generally completed within one to two weeks of sampling.

***Artemia* Biomass for Population Assessment.**

Figure 3. Collecting brine shrimp with a plankton net.

Brine shrimp samples were collected by means of replicate vertical net hauls using a 50-cm-diameter, 165 micron mesh size, plankton net with removable collection cup (125 micron mesh size) (Figure 3). Duplicate net hauls were obtained from 1m, 5m, and 7m to the surface for shallow, medium, and deep sample sites respectively. The net haul contents were stored in 1-L Nalgene® bottles on ice and then transported to the laboratory. In the laboratory, samples were prepared by filtering the entire contents through 850-, 500-, and 125-micron sieves, resuspending in a known volume, and then replicate (n= 6 to 12) samples were obtained and counted. The volume of subsamples counted was typically 4% to 12% of the total volume. Brine shrimp were grouped according to specific age-classes: the age-classes defined for the purpose of this study included nauplii, meta-nauplii, juveniles, and adults. Cysts and empty shells were also identified and counted. Gender determination of adults was recorded as were the brood contents and brood sizes of gravid females. The dry-weight biomass for each sample was assessed. Gravid females were randomly selected, isolated, and used for brood size and characteristics determination. Ovisacs were dissected and all brood contents were identified and counted. If possible, 10 females from each site and

representing each brood type were dissected. The maximum possible number of dissections was 270 per sampling program, but fewer were often counted due to lack of adequate numbers of gravid females for each brood type. Population enumeration was completed within 24 to 36 hours of sample collection. In one exception, the biomass was stored in formaldehyde and counted later.

Artemia Biomass for Selenium Analysis.

Brine shrimp were collected via horizontal or vertical plankton net hauls. Multiple vertical net hauls were used for medium and deep sites (5-meter net hauls) whereas vertical or horizontal net hauls were employed for the 1-meter sites. The net haul contents were filtered through a sequence of three stainless steel sieves: 850-, 500-, and 125-micron opening size. Each fraction was rinsed with pre-filtered GSL water, collected in Whirl-pak® bags, and then stored on ice for transport. The samples were only rinsed with pre-filtered GSL water and never with any other source of water. In the laboratory the brine shrimp samples were poured into pre-cleaned Petri dishes where brine shrimp were carefully separated from other zooplankton or debris, water was removed via pipette, and then samples were frozen at -25º C. Samples collected during 2007 were vacuum-filtered as an additional measure to remove

Figure 4. Brine shrimp separated on the sampling vessel into three age-classes (adult, juvenile, and nauplii-cyst).

excess GSL water. All biomass samples were stored in a freezer at -25 º C until being shipped for analysis.

Figure 5. Seston filtration using Geotech polycarbonate housing and 0.45-um, 142-mm, flatstock filters.

Seston Samples.

Seston samples were extracted from GSL water collected in the manner outlined above for water samples. Pooled water samples from discrete intervals in the water column were collected via peristaltic pump and filtered to remove particulates and zooplankton greater than 125 microns. The pre-filtered GSL water was then pumped through a 0.45-micron, flatstock, cellulose acetate filter housed in a 142-mm polycarbonate in-line filter holder (Geotech) (Figure 5). The volume of water filtered generally ranged from one to five liters. The 0.45-micron filter was then removed from the filter housing, folded, placed in a Whirl-pak® bag, and stored on ice for transport. The filters were immediately placed in a freezer (-25º C) upon return to the laboratory and remained frozen until analysis. Dry filter weights were predetermined and were deducted from freeze-dried weights of the seston samples to allow for selenium determination on a dry-weight basis. Volumes filtered were used for calculations of selenium concentration in seston on a per-volume basis. Dry weights were corrected for residual salt mass on filters.

Abiotic Measurements.

Select limnological conditions, including water transparency, dissolved oxygen, temperature, and salinity, were evaluated at each sample location. Dissolved oxygen was determined using a YSI™ 550A meter calibrated to a salinity of 70 ppt (maximum possible for instrument). Dissolved oxygen was recorded at each site at depth intervals of 1 m (shallow sites), 1m, 3m, 5m, and 6m (medium depth sites), and 1m, 3m, 5m, 6m, 7m, & 8m for the "deep" sites. Dissolved oxygen is reported as both a percentage and in mg/L, Temperature and salinity were also determined and recorded at these same intervals in the water column (Figure 6.0). Salinity was assessed by means of a refractometer and temperature was obtained from a temperature probe on YSI™ 550A meter. Water transparency was recorded through observations of the final visible depth of a submerged 20-cm black-and-white Secchi disk.

Figure 6. Abiotic measurements.

Selenium Analysis in Water Samples.

All water samples were sent to Frontier GeoSciences Inc., Seattle, WA for determination of dissolved and total selenium. Total selenium included the dissolved and particulate fraction in water samples. Analytical procedures included hydride generation--atomic fluorescence (HG-AF).

Selenium Analysis of *Artemia* and Seston.

All brine shrimp samples and seston samples were sent to LET Inc. laboratory in Columbia, MO for analysis. Total selenium analysis of the biological samples was

carried out using acid digestion procedures and then hydride generation coupled with atomic absorption spectrometry. The selenium instrument detection limit was 0.01 ug and the tissue detection limit was 0.1 ug Se/g tissue. Prior to acid digestion, LET Inc. freeze-dried the samples and provided dry-weight values for each sample.

Chlorophyll Analysis.

All frozen, filtered samples used for determination of chlorophyll-a and phaeophytin concentration in phytoplankton were sent to Aquatic Research Inc. in Seattle, WA. Chlorophyll-a was determined using fluorometric methods with a detection limit of 0.1 ug Se/L.

Phytoplankton Identification and Enumeration.

Preserved phytoplankton samples were sent to the Laboratory of Ichthyology and Hydrobiology, Uzbekistan Academy of Sciences (LIH-UAS), Tashkent, Uzbekistan. Microalgae were identified to the level of family, genus, and species if possible. Results were reported in abundance per unit volume as well as the biovolume of representative algal species per volume of GSL water sampled. Identification was based on morphological features alone. Molecular markers were not used for confirmation of algal species identification. This laboratory was chosen because they have previously provided algae identification for saline lake research projects funded by NATO, in cooperation with the *Artemia* Reference Center, Ghent University, Gent, Belgium, and due to the greatly reduced analytical costs relative to laboratories in the U.S.

Samples preserved with Lugol's and formaldehyde were shipped to LIH-UAS where they were further processed and prepared for algal cell identification. Samples were vacuum-filtered through Millipore® glass fiber filters with a pore size of 0.45 microns and a 47-mm diameter. Filtered algal cells and the filter disk were placed in 47-mm Petri dishes and the cells were re-suspended by means of washing with 3 ml of distilled water. A minimum of 15 minutes of mixing was allowed for the cells to be washed from the filters. A 100-microliter aliquot was then introduced into a Palmer counting cell. Algal cells were examined at 400X to 1000X power using a Zeiss or Canon microscope with bright-field and phase-contrast optics. A 10-mm reticle was used for the enumeration and size measurements of algal cells. Identification and characterization of algal cells were taken to the species level if possible. Cell counts and biovolume measurements were conducted according to the methods of Wetzel and Likens (2000) and Hillebrand et al. (1999).

Additional supporting experiments.

Comparative study of *Artemia* sampling methods and their influence on apparent selenium concentration.

Brine shrimp were sampled concurrently using two different methods of sample collection and subsequent processing or cleaning before analysis. One method involved collecting brine shrimp, and any other debris or zooplankton, from the upper 1 meter of the GSL by hand-held plankton net. The sample was then placed in a Ziploc® bag, stored on wet ice, transported to the laboratory, frozen, and later shipped in a frozen condition to LET Inc. for analysis of dry weight and selenium content. No subsequent processing was included. The alternative method included the procedures defined

previously for sampling and processing *Artemia* for selenium analysis. Specifically, samples were collected from the water column by plankton net, filtered through tiered stainless steel sieves (850-, 500-, and 125-micron), placed in Whirl-pak® bags, stored on ice, and transported to the laboratory. The samples were then separated from any incidental debris or other zooplankton. The cleaned samples were then split into two fractions: those placed directly into Whirl-pak® bags and frozen, versus those that were subsequently vacuum-filtered to remove excess GSL water before freezing. The resulting biomass samples were stored at -25º C until analyzed by LET Inc. for total selenium and dry weight.

Influence of storage conditions on selenium determination in water samples.

Replicate water samples were collected, acidified, and then stored either in a refrigerator (+5º C) or in a freezer (-25º C). The purpose of this small study was to determine if storage conditions exerted any influence on selenium determination in GSL water samples.

Comparative study of three different flatstock filters for the collection of seston and subsequent determination of total selenium.

Suggestions for trying alternative filter types for the collection of seston arose during the course of this study. Other researchers have tried a variety of flatstock filter types and pore sizes for the purpose of collecting seston from water samples. Three different filters were used for the study: 0.45- and 0.8-micron cellulose acetate filters and 0.45-micron polycarbonate filters. All filters were 142-mm filters and were housed in a GeoTech

polycarbonate filter housing. On the day of the test, raw GSL water from the selected depth was pumped through each filter until the filter was clogged. Filters were removed, placed in pre-cleaned petri dishes then Ziploc® bags, and stored on wet ice for transport. The filters were promptly frozen at -25º C and remained frozen until being analyzed for total selenium by LET Inc.

RESULTS and DISCUSSION

Sampling Schedule

The final sampling schedule was a result of defining sampling dates and then making every effort possible to complete a sampling program within 7 days of the target date. Although occasional equipment malfunctions caused some delays, these seldom resulted in a delay of more than 1 day, and were usually attributable to the complications of working in a hypersaline environment. Weather was the main factor influencing the duration of a sampling program and in the ability to complete a full sampling program on, or near, the proposed date. There were notable occasions in which the winds increased dramatically, and all sampling efforts had to be abandoned for the day. The most memorable of those occurred in July 2006, when the wind speed near Hat Island increased from 10 - 15 mph to 77 mph in about 35 minutes. During the January 2007 sampling program, extensive sheets of ice (sufficiently thick to support the weight of a rapidly scurrying human) were present from Promontory Point to our sampling sites north of Hat Island (Figure 2). Needless to say, sampling under these conditions was less than optimal.

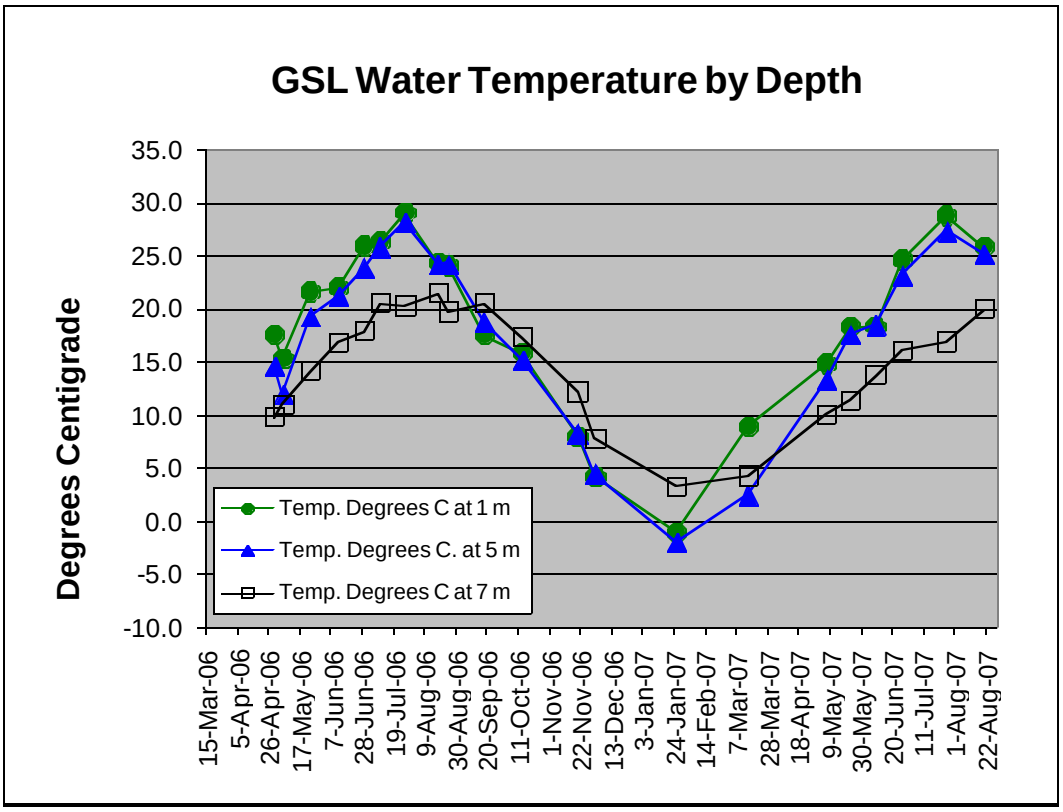
Limnological Conditions.

Water Temperature.

Water temperature was monitored at discrete intervals in the water column throughout this study (Figure 7). During the earliest sampling program in April 2006 the water temperature at 1 meter was already in excess of 15°C. This is about 8°C to 10°C above the typical threshold for the onset of *Artemia* hatching in spring. The temperature of the GSL at 1-m depth increased throughout the summer of 2006 reaching a maximum of 29.0°C on July 27, 2006. The temperature then declined throughout the fall and into winter reaching a minimum temperature of -1.1°C on January 26, 2007. During the winter of 2007, there were extensive sections of ice on the surface of the GSL ranging from 3 to 7 cm thick. The surface temperature again warmed to over 9°C on March 14, 2007 and the most recent temperature on June 9, 2007 was 18.3°C. The deep brine layer typically responds more slowly to warming and cooling than is exhibited in the upper "mixed zone" of the GSL. The deep brine layer remained cooler than the upper mixed layers throughout the spring and summer until September 18, 2006. On this date the upper layer had cooled to 18.7°C whereas the deep brine layer remained almost two degrees warmer (20.5°C). The deep brine layer reached a minimum temperature of 3.3°C during January 2007 and continued to be warmer than the upper layer until March 2007 when the upper mixed zone had warmed to 8.9°C and the deep brine layer was still only 4.3°C.

The results seen in Figure 7 demonstrate the significant interannual variability in water temperature patterns for the GSL.

Figure 7. Water temperature of the GSL from April 2006 through August 2007. Temperature was recorded at three different depth intervals (1 m, 3 m, and 7 m).

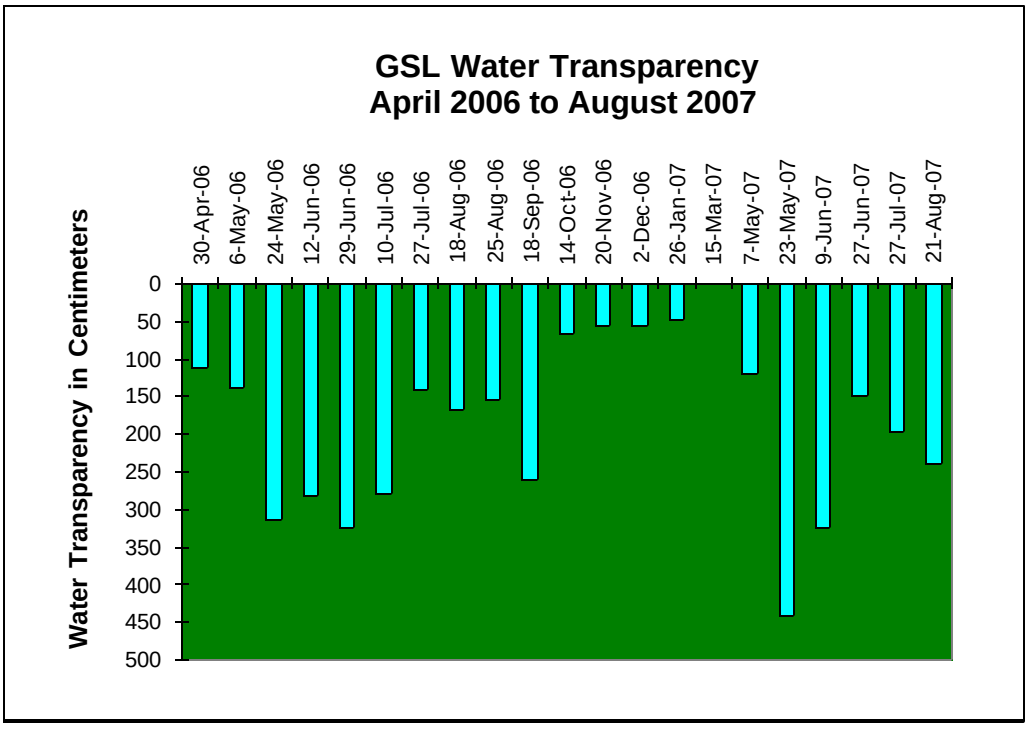


Water Transparency.

Water transparency during spring and summer 2006 varied from an average low in April 2006 of 112 cm to a maximum average depth of 324 cm in June 2006 (Figure 8). During the summer and fall of 2006 the GSL exhibited a characteristic pattern of cyclical changes in water transparency, largely attributable to the grazing pressure exerted on the algal population by the brine shrimp. Wind events and suspended particulate matter also influenced water transparency measurements. Following the brine shrimp population collapse in the winter of 2006-2007 the algal population once again flourished, obscuring visibility and resulting in a minimal water transparency of 47 cm during January 2007.

As the brine shrimp population expanded in the spring of 2007 grazing pressure on the algal population again increased dramatically and resulted in quite clear conditions with average water transparency values exceeding 440 cm in May 2007.

Figure 8. Water transparency of the GSL in centimeters. Measurements correspond to average transparency as measured by the final visible depth of a 20-cm diameter Secchi disk.

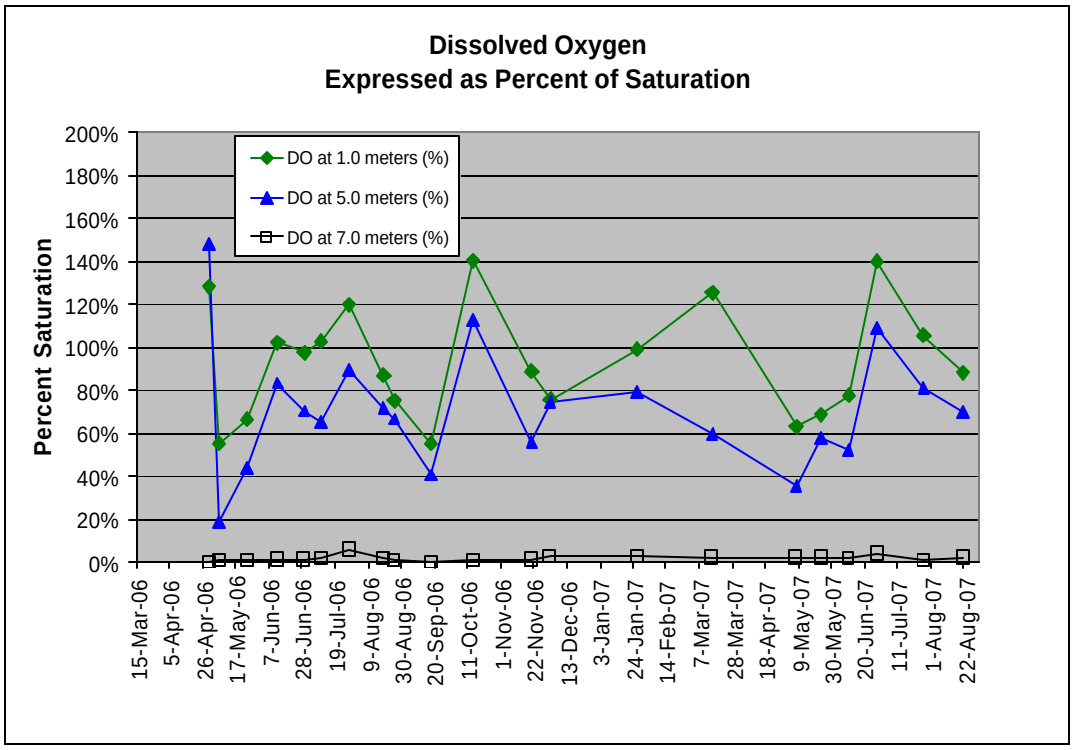


Dissolved Oxygen

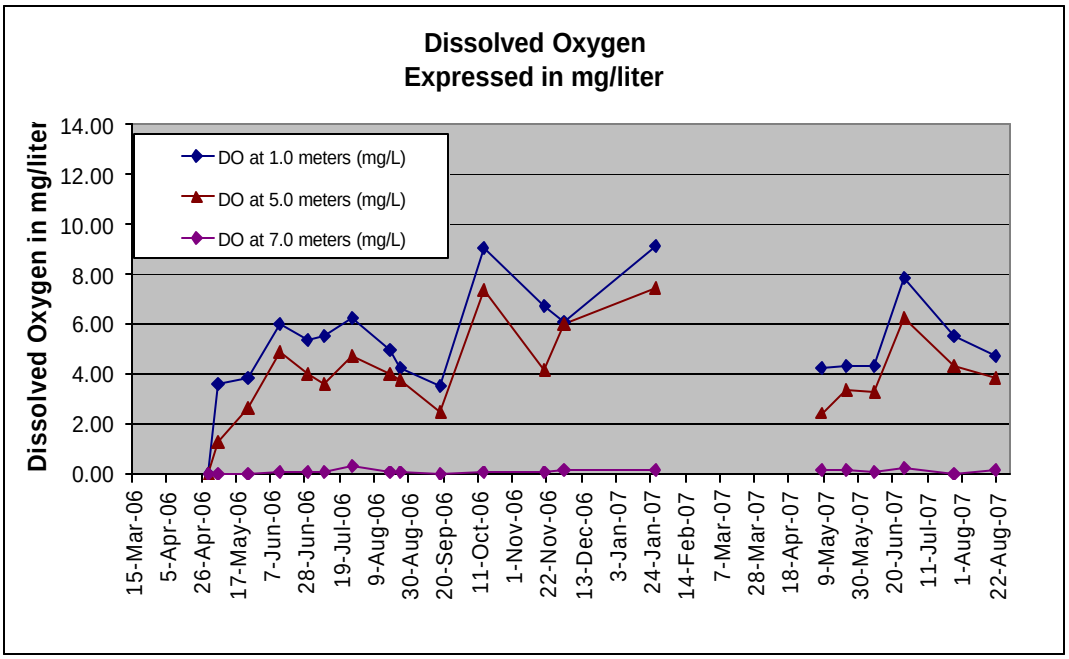
Dissolved oxygen followed a roughly inverse relationship to water transparency--at low Secchi disk measurements, and relatively high algal abundance, oxygen values were elevated. When the *Artemia* population expanded, algae were effectively depleted, transparency increased and dissolved oxygen was reduced. Dissolved oxygen in the upper mixed zone ranged from a high of 120% to 140% of saturation (Figure 9). Low

values typically observed at mid-depth during April and May were in the range of 20% to 40% of saturation. Characteristic fluctuations at shallow and mid-depth during the summer and fall months were generally between lows of 40% to highs of 80% saturation. Site-specific differences were present, the most notable of which was sample site #4 (Hat Island), which typically exhibited the highest average dissolved oxygen levels (range 55% to 216%). The deep brine layer remained anoxic throughout the study, as anticipated given the chemical composition of this layer. The transition from the upper mixed zone into the deep brine layer was quite abrupt, occurring between 6 and 6.5 m in depth. The average dissolved oxygen at 6 m was 61.2% whereas the average at 7 m was only 1.8% (Appendix 1.1). Dissolved oxygen values are also shown in mg/L (Figure 10). However, there are instrument limitations when the salinity is greater than 70 ppt that reduce the reliability of the conversion to mg/L oxygen.

Figure 9. Dissolved oxygen in the GSL at three different depths reported as percent saturation



. Figure 10. Dissolved oxygen in the GSL at three different depths reported as mg/L

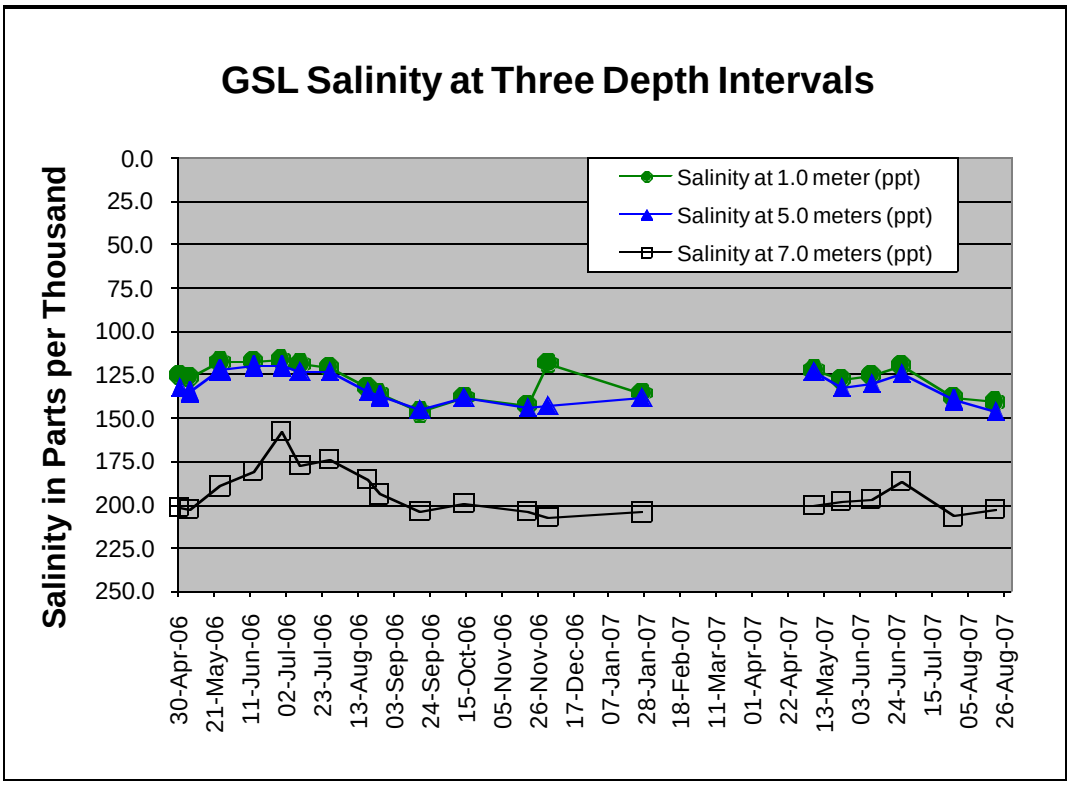


Salinity

Salinity was recorded at 6 different intervals (1 m, 3 m, 5 m, 6 m, 7 m, and 8 m) in the water column throughout this study. The upper 5 m (surface to 5 m depth) was quite uniform spatially across the GSL within each sampling program (Figure 11 and Appendix 1.1). The data indicate seasonal patterns of stratification and mixing of the upper zone of the GSL (the mixolimnion) combined with the presence of meromictic conditions (chemical barrier to deep mixing) in areas of the lake with an established deep brine layer (the monimolimnion). Evidence of exchange of the deep brine monimolimnion layer with the upper "mixing zone" begins to be apparent below 6 m depth. The salinity for the upper 5 m of the water column ranged from a minimum of 110 to a high of 150, whereas at 7 m in depth the range was 120.2 to 225.0 ppt. This was a similar pattern as observed

for dissolved oxygen in which the meromictic transition zone was usually evident below 6 m in depth (Appendix 1.1).

Figure 11. Salinity of GSL water samples as measured by refractometer. Three of six sampling depths are represented. The influence of inflow of saturated brine from the North Arm of the GSL is evident in the dramatic increase in the water column salinity at 7 m (not shown) and 8 m depths.



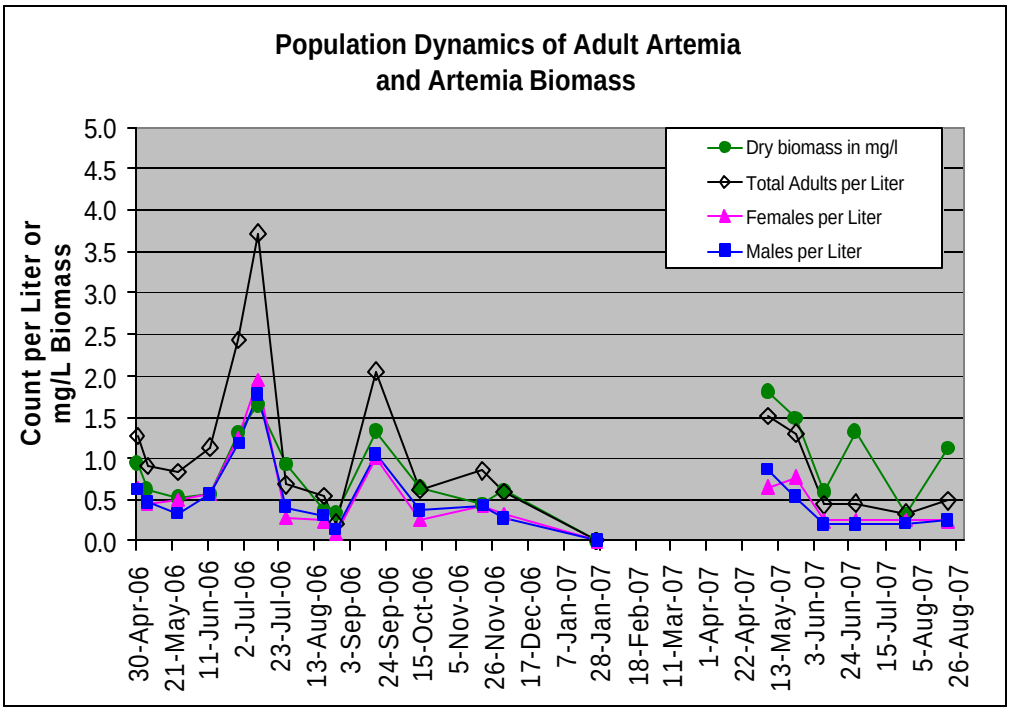
Brine Shrimp Population Dynamics.

Detailed brine shrimp population dynamics were assessed during this study because of the importance of brine shrimp as a critical component in the food web of the GSL and their role in the trophic transfer of selenium from the water to wildlife. Brine shrimp used for population assessments were collected from the water column extending from the surface to 7 m in depth. Although few brine shrimp are found below 6 m in depth

relative to those in the first 5 m of the water column, the upper layers of the monimolimnion were included in the brine shrimp population assessment because previous studies have shown that cyst abundance at the chemocline between the upper mixing zone and the deep brine layer can be quite substantial (Stephens, 1997). Brine shrimp were separated by size filtration and then counted in the laboratory to determine age-specific abundance (developmental instar stages) and reproductive status (brood contents and sizes). Although filtration provided reasonably adequate separation of age-classes, all samples were carefully counted under a binocular microscope to assure that age-class determination was based on morphological features and not defined solely by size distribution.

In the GSL, overwintering brine shrimp typically hatch during March and April, producing the first generation of nauplii for the reproductive season. During this study the frequency and timing of sampling resulted in our inability to specifically identify the onset of hatching and the full reproductive dynamics of the first generation. Samples collected during the first sampling program for the spring of 2006 (April 30) and 2007 (May 7) revealed that the first generation of brine shrimp were already established across all age-classes and the production of a second generation was well underway (Figure 12). Adult abundance was 0.2 to 2.0 adults per liter in April, and average adult abundance was usually between 0.2 and2.0 individuals per liter for the remainder of the reproductive season (Appendices 2, 3, & 4).

Figure 12. Adult *Artemia* population dynamics for the GSL during April 2006 to June 2007. Dry biomass expressed as mg/L is also shown and includes all age-classes of *Artemia*.



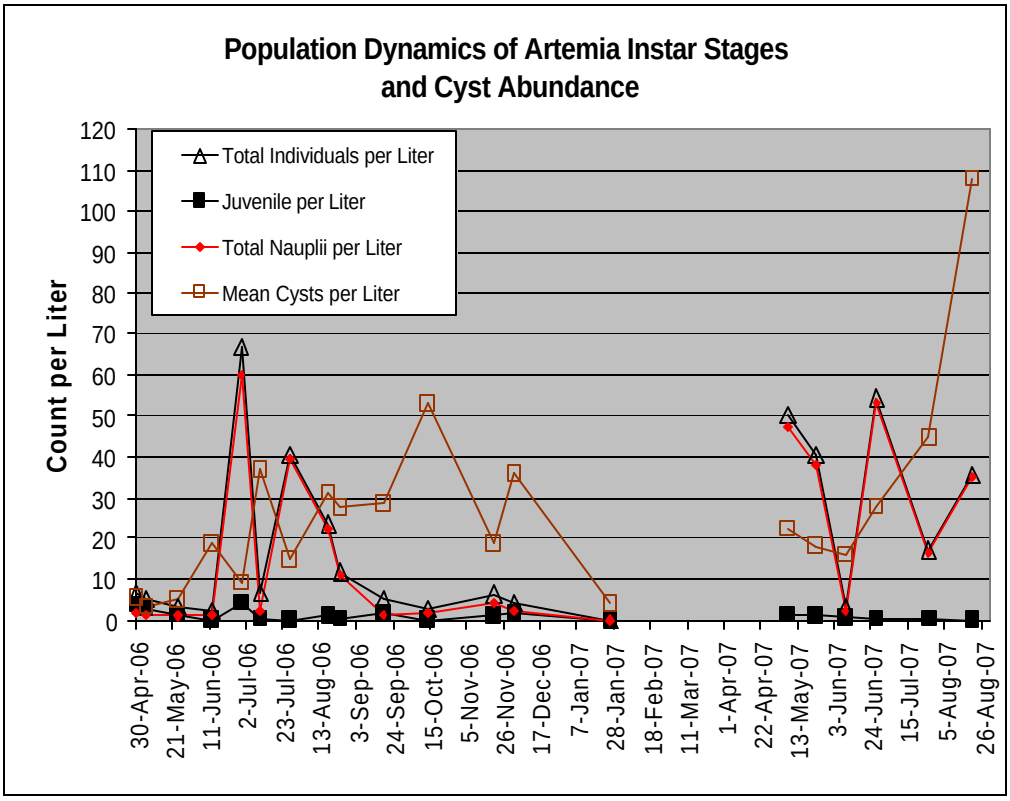
The sex ratio of adult *Artemia franciscana* varies within specific time periods, but over the course of the reproductive season the average remains close to a 1:1 ratio—the ratio of males:females over the course of this study was 1.19:1.00. Sex ratio is an important consideration for the GSL as there have been some concerns about the introduction of foreign *Artemia* (e.g., parthenogenetic species) into the GSL. A change in the sex ratio could be an important indicator of a shift in the genetic composition of the GSL *Artemia* population. The results of this study are consistent with a bisexual *Artemia* population.

There are typically between 3 and 5 identifiable generations in the brine shrimp population during the reproductive season, and in our study this pattern was also observed. Peak abundance of combined nauplii (nauplii and meta-nauplii) occurred in April, June, July, and August (Figure 13). There may have been one earlier F1 nauplii abundance spike in

April that was not recorded---the onset of our sampling schedule was likely too late to have recorded the initial synchronous hatching of cysts and production of F1 nauplii. The highest count of combined nauplii that we observed occurred on June 29th with a count of 60.1/L. Peak abundance of combined nauplii in May and June corresponds to the maximal reproductive output of the first generation. There was a slight increase in the number of combined nauplii per liter in November (4.36/L). This is somewhat unusual as the abundance of the younger age-classes of *Artemia* generally falls below 1/L in October due to the predominant shift from ovoviviparity to oviparous reproduction and rapidly decreasing water temperature. Juvenile brine shrimp exhibited a similar pattern as the combined nauplii in terms of the cycles of abundance, albeit on a much lower scale, and with an altered temporal component. Peak juvenile abundance was observed during the first two sampling programs (April 30 and May 6, 2006), then on June 29, September 18, and again at the end of November and early December. On December 2, 2006, 1.8 juveniles/L were counted. It is quite surprising to document an abundance of >1.0 juvenile/L at this time of year because juvenile brine shrimp are the least tolerant of environmental stressors (Belovsky, 2006). Adults can remain viable on the GSL well into December, and in the current study adult brine shrimp were still present on

December 2, 2006. By January 26, 2006, no live brine shrimp were observed at any of the sample locations.

Figure 13. Juvenile, combined nauplii, and cyst abundance for the GSL from April 2006 to June 2007. Cyclical patterns of production, survival, and collapse are evident. Predominant cyst production is initiated in July and continues into early winter. Cyst depletion from October to January is largely attributable to industry harvesting pressure.



Cyst abundance in the GSL during 2006 ranged from a low of 3.3/L on May 6 to a high of 53.0/L on October 14 (Figure 13). The April 30 count was slightly higher (5.3/L) than the May 6 count, and this coincides with an increase in the number of nauplii per liter from April 30 to May 6, suggesting that overwintering cysts were still viable and continued to hatch during early May. Cyst abundance increased sharply in July as the

shift from ovoviviparous reproduction to oviparity began. Brood counts were initiated only after the shift to oviparity was observed. This was done as a means of tracking cyst production from July through the onset of winter.

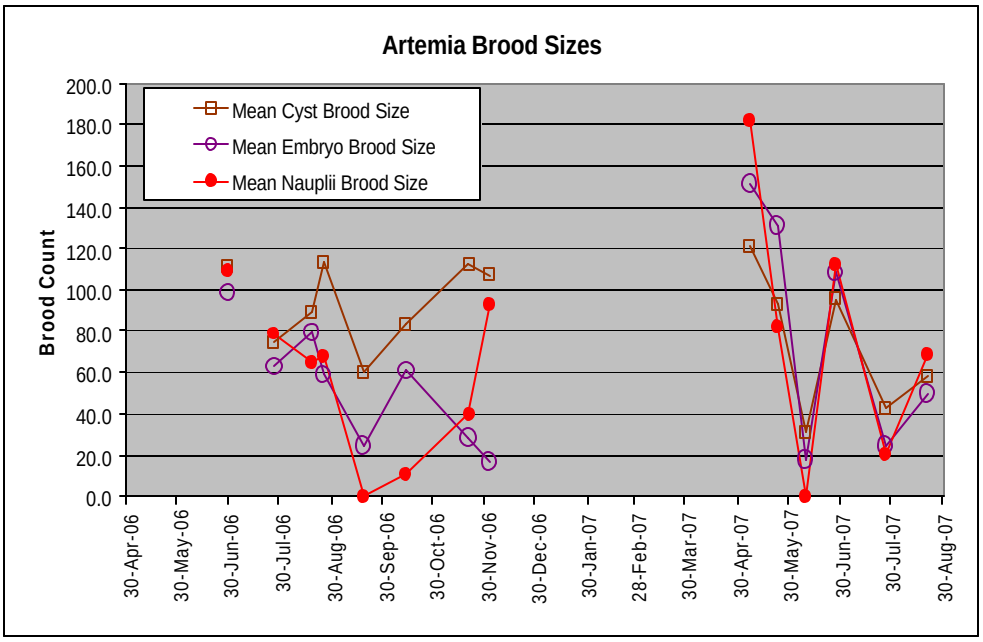
Brine Shrimp Fecundity and Cyst Production.

Fecundity (e.g., cyst production) during the summer and fall is an important measure of individual fitness—the ability to produce viable offspring and propagate one's genetic information. It is also one of the dominant factors influencing population dynamics in the subsequent reproductive season. Intact brood contents (Figure 14) were evaluated for brood size and brood characteristics (i.e., embryo, cyst, or nauplii production).

Figure 14. Female *Artemia* with intact broods. Brood contents can be observed under a dissecting microscope. In the image below, ovisacs are visible with cysts (brown spheres) and live young (pale-yellow). Individual females are randomly selected, the ovisac is dissected, brood contents are identified and counted. Brood contents are characterized as embryos, cysts, or nauplii. Undifferentiated embryos were also noted and recorded. Any brood abnormalities were documented. Retrieved July 2006 from http://www.wildlife.utah.gov/gsl/brineshrimp/

Cyst brood sizes in 2006 ranged from 60 (September) to 114 (August) and 112 (November) (Figure 15). Females reproducing ovoviviparously exhibited a range of brood sizes between 109 (June) to 11 (September) nauplii per brood. Oviparous reproduction predominated from July until winter, with very low numbers (<0.01/L) of ovoviviparous females observed from September through December. Peak brood sizes in 2007 occurred in May, with maximum average size of 121 cysts per ovisac on May 7. Ovoviviparous reproduction also showed very high per capita reproductive potential on May 7—the average nauplii brood size was 182 nauplii per ovisac. Brood sizes diminished substantially in June 2007 for both ovoviviparous and oviparous females; brood sizes were less than 50 offspring per female. Brood sizes among ovoviviparous females showed a similar pattern as oviparous females, albeit usually smaller average sizes (80%) than cyst broods. There was one exception on May 7 in which nauplii brood sizes were 50% larger than corresponding cyst brood sizes.

Figure 15. *Artemia* brood sizes from June 2006 to August 2007. Broods were characterized as containing embryos, nauplii, or cysts. Brood contents were counted from a subset of females from each sample location



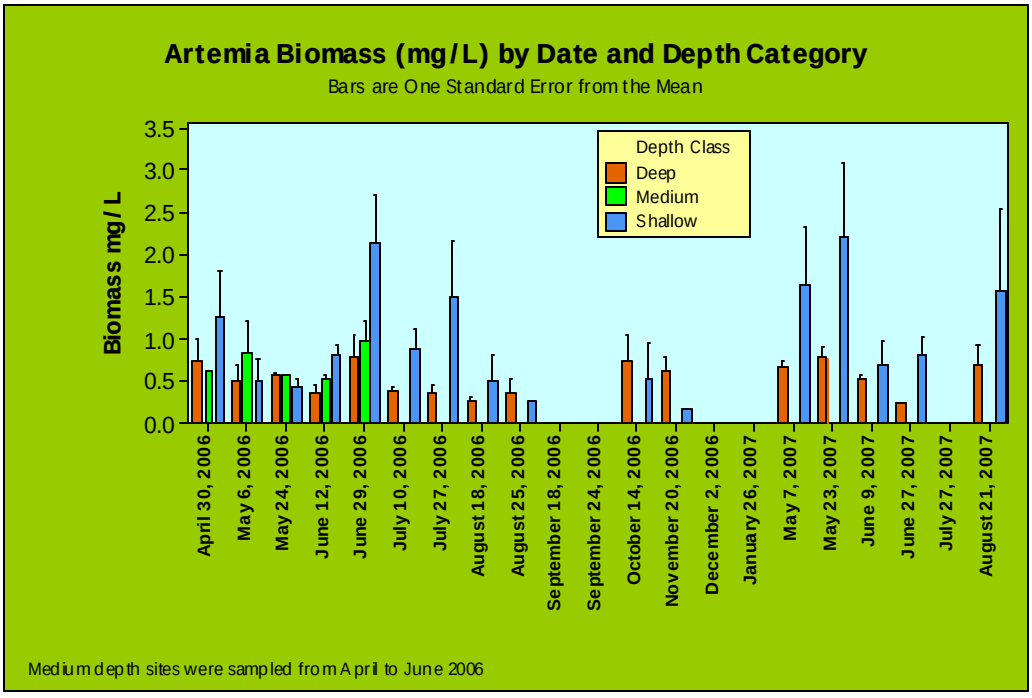
Productivity, defined as cysts per ovisac multiplied by the number of oviparous females per cubic meter, is a useful measure of the reproductive potential of the population at a given time and location on the GSL. Productivity in 2006 peaked on June 29, July 27, and then again on October 14. The maximal productivity measured in this study occurred on July 27 at 14,270 additional cysts per cubic meter. Sustained productivity was observed throughout the late fall and onset of winter. On December 2, 2006, the *Artemia* population still had a productivity count of 3,119 additional cysts per cubic meter. By January the productivity index for the population was zero. During the spring of 2007 both ovoviviparous and oviparous females were present. Productivity on May 23, 2007, was 2,643 additional cysts per cubic meter. No measure of productivity for May 7, 2007,

was available, although oviparous females were present and the average cysts brood size was 121 cysts per ovisac. The sharp decline in brood sizes during late May and June 2007 corresponds to low chlorophyll concentrations in the water column (chlorophyll-a < 2.0 ug Se/L).

Brine Shrimp Biomass.

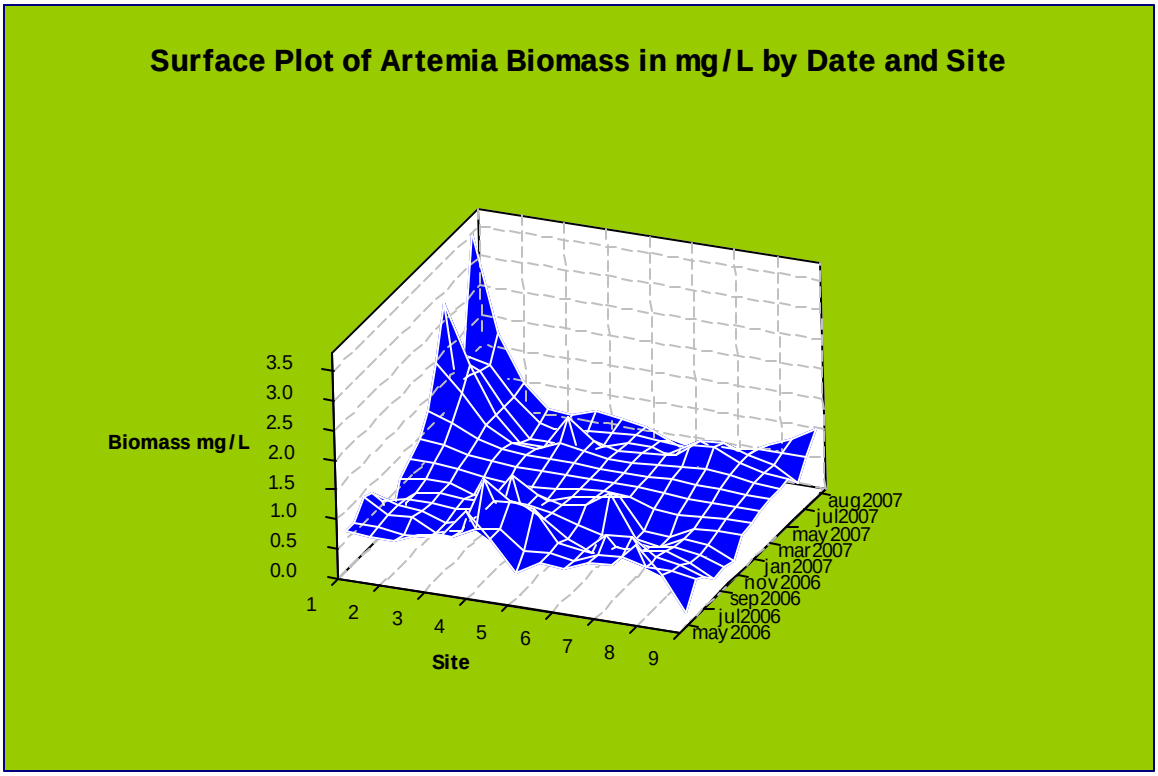
Artemia biomass, and its availability to foraging birds, is perhaps the most relevant statistic to consider in terms of the application of *Artemia* population statistics to an inquiry of selenium impacts on GSL biota, and the transfer of selenium through the food web.,. *Artemia* biomass in 2006 ranged from a low of 0.33 mg/L on August 25 to a high of 1.65 mg/L on July 10. During the spring of 2007 a peak of 1.80 mg/L was recorded on May 7. Biomass decreased to 1.48 mg/L on May 23 and continued decreasing to 0.60 mg/L by June 9 (Figure 16). This decrease corresponded with increasing water transparency and grazing of phytoplankton. Over this same time period in 2007 chlorophyll decreased from an average of 7.5 ug Se/L (maximum of 15.0 ug Se/L) to 1.6 ug Se/L (maximum of 2.1 ug Se/L).

Figure 16. The temporal pattern of brine shrimp biomass is shown from April 2006 to August 2007. Biomass was determined empirically by drying and weighing a subsample of *Artemia* biomass from every sample location and sampling program. Biomass was not estimated using literature values of average *Artemia* dry weights and then extrapolating using population statistics. Biomass values represent the average distribution in the water column, but may be well below values found in patchy accumulations of floating shrimp or cysts.



A three-dimensional plot of biomass by sample site and date is shown in Figure 17. The shallow sites #1 (Fremont Island site) and #4 (Hat Island) were the highest in biomass production per cubic meter of the sites sampled in this study. Dense accumulations of floating shrimp (?)biomass and cysts were observed throughout this study, but were not included in the determination of biomass. All samples for biomass determination were taken from water column samples and computed on a volumetric density basis. Birds were commonly seen foraging on surface accumulations of shrimp (?) or cysts, especially in the area close to Hat Island.

Figure 17. Three-dimensional relationship of *Artemia* biomass, sample site, and date of sampling program. Shallow sites were generally more productive than deep or medium depth locations.



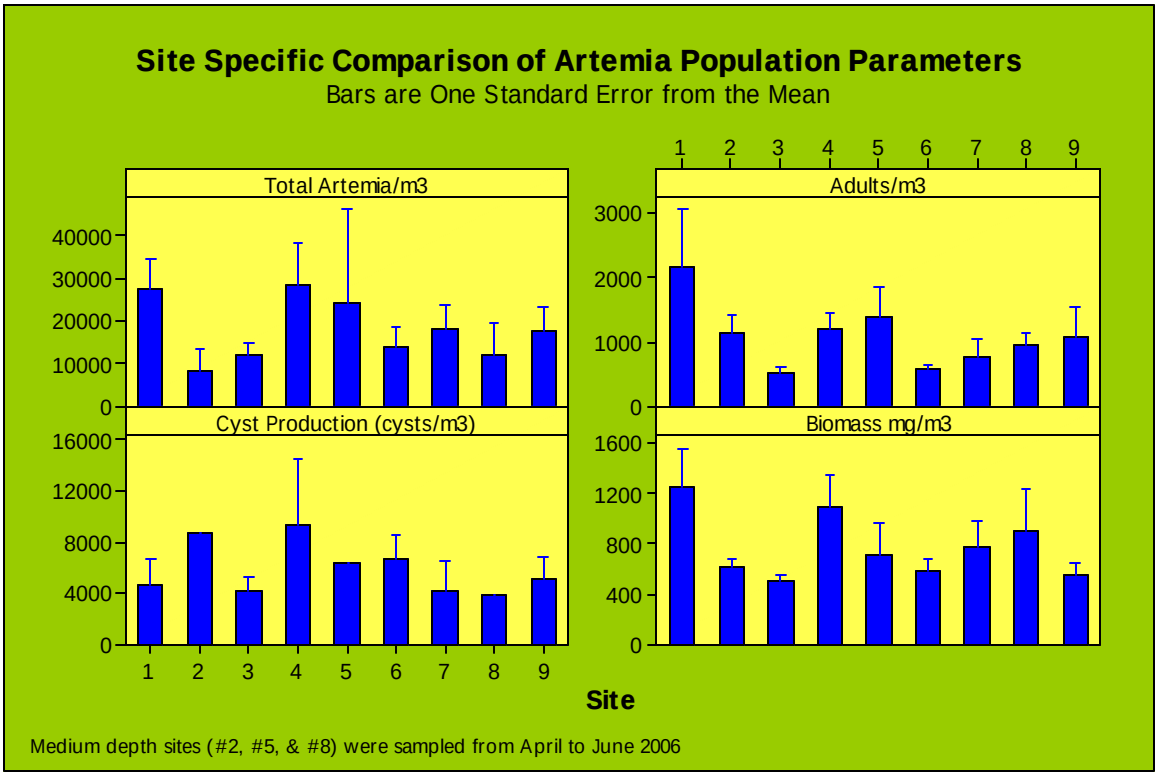
Although it is well documented that there are pronounced temporal changes in zooplankton and phytoplankton abundance on the GSL, it is not established whether there is a spatial component influencing population dynamics. From a conceptual standpoint,there should be differences spatially—the lake has distinct localized input sources, hydrochemical characteristics, currents, depths, and other physical and chemical features that should exert an influence on phytoplankton and zooplankton growth, survival, and reproduction. However, brine shrimp are mobile organisms and can propel themselves throughout the water column (although they do use their locomotion primarily for foraging). Brine shrimp are also certainly subjected to the movements of

the many pronounced currents, mixing zones, thermal and density cycling events, and wind-related disturbances that are commonplace at the GSL.

The many aspects of movement by the brine shrimp throughout the GSL add important elements of uncertainty when evaluating population and selenium results within a spatial context—the collection of brine shrimp that may be found in a given location on a particular sampling date may be transported to a distant location on subsequent days. The uncertain movement of brine shrimp needs to be considered as confounding any interpretation of spatial results.

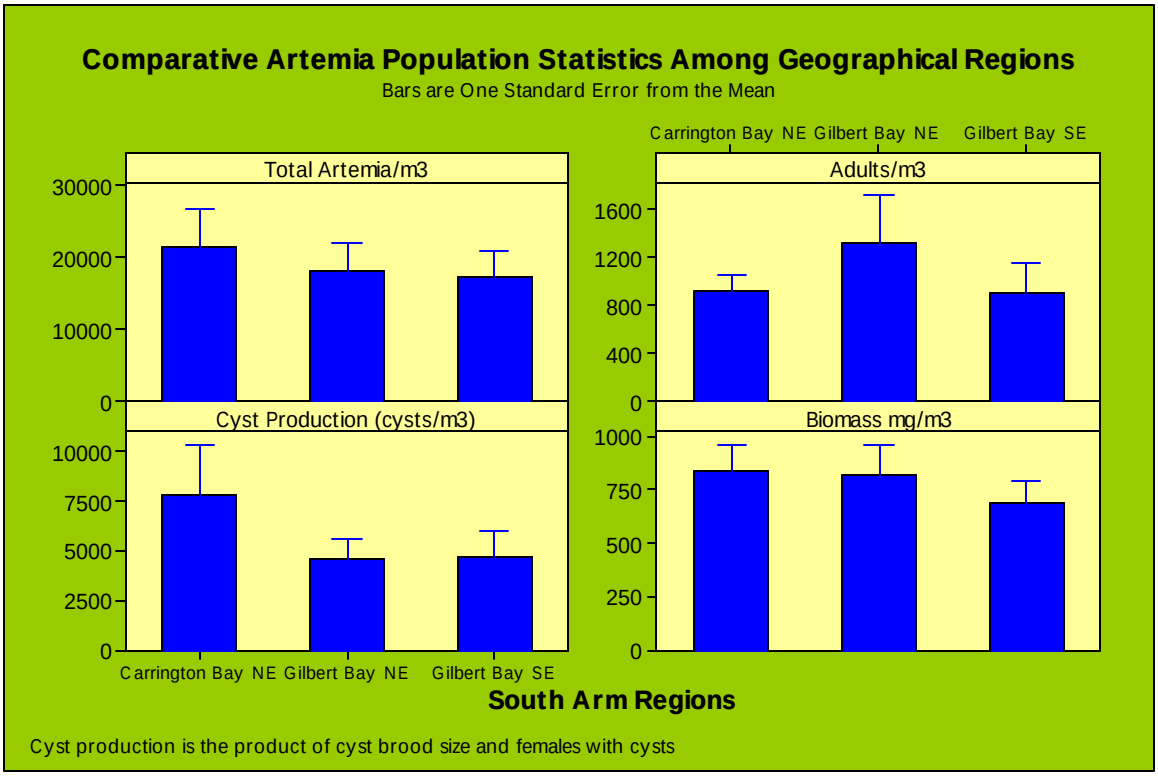
Parameters of *Artemia* population size, composition, and reproductive output were compared on a site-specific basis and across geographic locations. The results are detailed in Appendix 6.1 for each sample site surveyed and are shown in Figure 18.

Figure 18. Site-specific statistics for measures of *Artemia* population structure, biomass, and reproductive output. There are apparent differences among specific sample sites in terms of the brine shrimp population size and productivity.



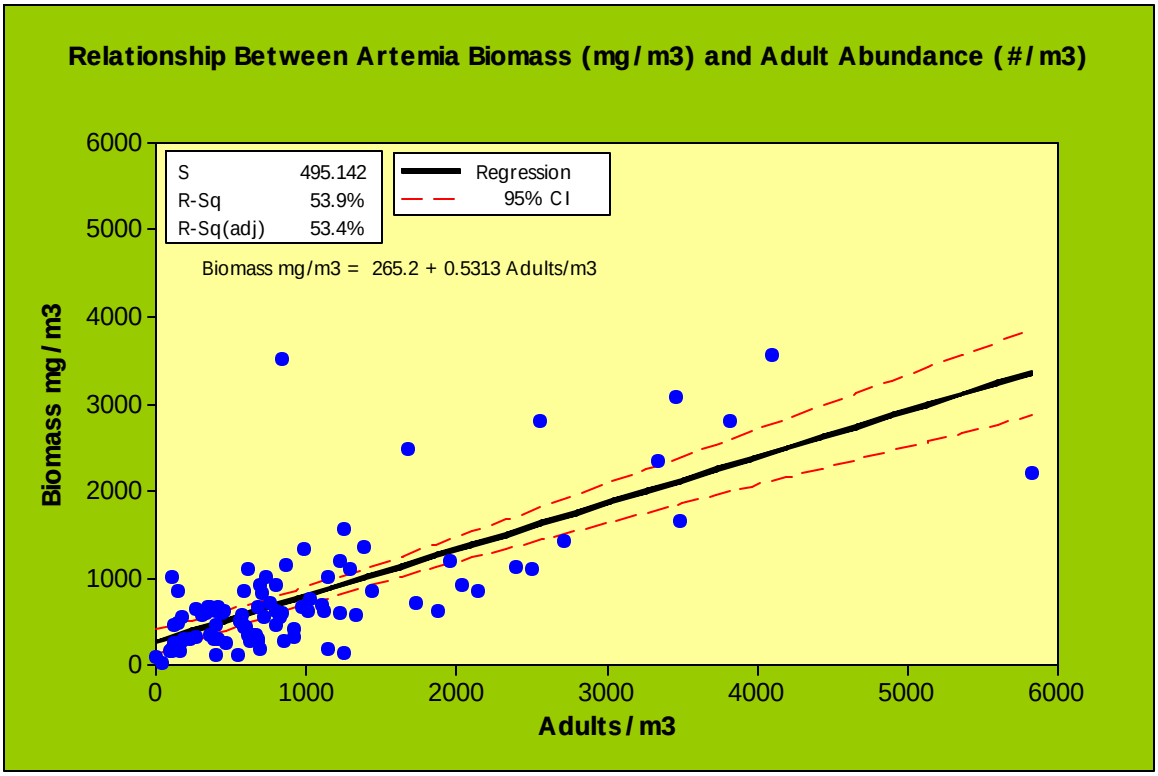
Statistical analyses were grouped across geographic regions. There were no statistically significant differences across these spatial categories (Northeast, Central, Southeast) for cysts per brood (P=0.784; df: 2, 65), biomass (P=0.457; df: 2, 90), productivity (P=0.624; df: 2, 61), or adults/m^3 (P=0.874; df: 2, 113). Descriptive statistics for these regions are shown graphically in Figure 19.

Figure 19. *Artemia* population statistics presented in terms of spatially distinct regions of the GSL. Average results for various measures of *Artemia* biology were examined over the summer and fall months of 2006. Population and reproductive data grouped according to these spatial categories were not statistically separable.



Although all age-classes were used for the biomass calculation, adult abundance was the best predictor of biomass--there is a positive linear correlation ($R^2 = 0.66$) between adult abundance (adults/L) and biomass (mg/L) (Figure 20). Individual adult weights were estimated by deducting nauplii and juvenile biomass from total biomass and then calculating the biomass per adult. The results of this estimate showed average adult biomass of 0.864 mg/adult ($\pm$ 0.636). The average weight of all individuals was 0.138 mg/individual brine shrimp.

Figure 20. Counts of adult brine shrimp per cubic meter allow for predictions of biomass in the GSL. Although the total count of all age-classes of brine shrimp is also correlated with biomass weight, the counts for adults provide a more reliable relationship and predictive equation.



Water depth influences nutrient cycling, temperature regulation, light penetration, zooplankton and phytoplankton growth and productivity. Because of this, *Artemia* reproductive and biomass statistics are compared across depth categories (Figure 21). Average values for biomass and productivity suggest that shallow sites are more productive for *Artemia* than deep sites (Tables 5, 6, and 7). However, a T-test comparing means between deep and shallow sites does not show statistically significant differences for cyst brood size ($P = 0.252$, df: 1, 65), productivity ($P = 0.674$, df: 1, 49), or biomass ($P = 0.394$, df: 1, 64). There was, however, a significant difference between deep and

shallow sites in the average number of adults per cubic meter (P=0.052; df: 1, 91): shallow sites had a greater number of adults/m3. It is possible that stromatolites and their resident population of benthic algae offer an alternative food supply for *Artemia* during times of over-grazing of the phytoplankton in the upper water column. This would provide an advantage for *Artemia* exploiting shallow sites rather than deep sites.

In comparison to all other sites, sample site #4 (shallow site near Hat Island) was uniquely an area of high phytoplankton and *Artemia* productivity. This site was typically 20% to 50% higher than other sites in measures of reproductive output, population size, and biomass. The Hat Island shallow site had the highest overall productivity per cubic meter (11,205 additional cysts per cubic meter), the highest average number of *Artemia* per cubic meter (27,001 brine shrimp/m3), the most biomass (1.158 mg/L), and consistently had the highest average (113.7%), minimum (55.5%), and maximum (214.0%) dissolved oxygen percentages. This site has been observed in past GSL research projects to be among the most productive of locations surveyed on the GSL. This location is near the gull colony on Hat Island and is therefore of interest when considering availability of *Artemia* for the diets of gulls and other avian species utilizing Hat Island.

Figure 21. Cyst brood size, productivity, and biomass results for Great Salt Lake *Artemia* population during May 2006 to June 2007. Statistics are presented in terms of depth category (shallow, medium, deep). Shallow and deep sites were included throughout the study. Medium depth sites were included only from April until June 2006.

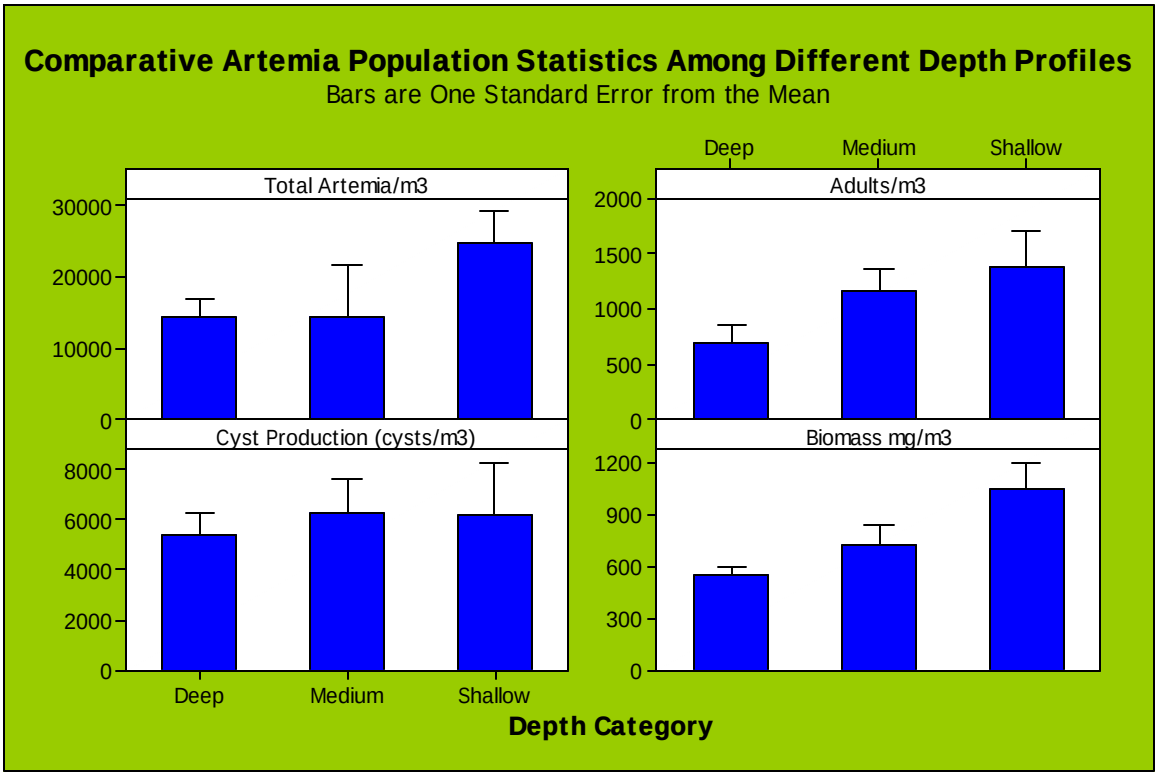


Table 5. Great Salt Lake *Artemia* biomass in mg dry weight per liter.

Artemia Biomass in mg/L by Depth Category						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	0.642	0.689	107.30	0.17	4.50	52
Medium	0.727	0.380	52.26	0.34	1.56	12
Shallow	1.181	1.355	114.70	0.02	7.03	52

Table 6. Average cyst brood size among oviparous female *Artemia.*

Cyst Brood Size by Depth Category						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	91	34	38	27	157	35
Medium	104	10	9	93	112	3
Shallow	81	34	42	24	154	30

Table 7. Fecundity estimates of *Artemia* reported as cyst brood size x number of females carrying encysted eggs in their ovisac.

Productivity per Cubic Meter (cyst brood size x # females w/cysts) by Depth Category						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	4,580	5,672	124	27	23,871	35
Medium	6,324	2,371	37	3,950	8,692	3
Shallow	6,562	13,565	207	28	69,450	30

Cyst Abundance, Harvest Yield.

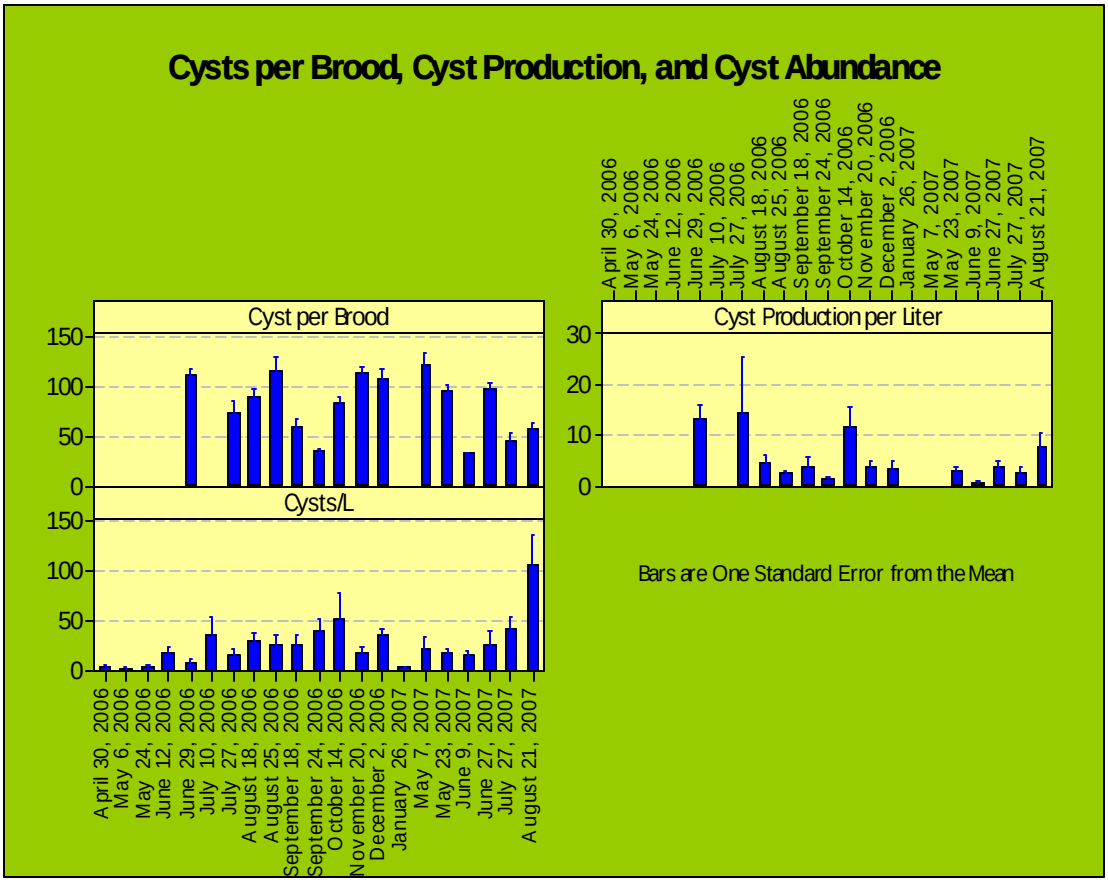
Average cyst abundance on the GSL is the critical parameter used to regulate the brine shrimp industry and to predict the annual harvest yield. It is also the most influential determinant of the amount of floating or shoreline brine shrimp cyst accumulations on the GSL during the winter months. These cyst accumulations are widely exploited as a food source by overwintering species of water birds, gulls, and shorebirds (Figure 22).

Figure 22. Brine shrimp cyst accumulation on the surface of the GSL. Accumulations can be a diffuse monolayer or can accumulate to a thickness exceeding 3 cm. Floating brine shrimp cyst and biomass accumulations are extensively utilized by foraging birds.

Peak cyst abundance during 2006 was observed on October 14 and showed a density of 52.9 cysts per liter (Figure 23 and Appendix 5.1). The lowest measure of cyst abundance during 2006 was on May 6, when 3.2 cysts/L were counted. The range of cysts per liter

during 2007 was from 4.0 (January 26) to 22.3 (May 7). Cyst abundance within the GSL can be patchy in distribution, rendering the arithmetic mean a less accurate measure of central tendency of cyst abundance. Median cyst abundance has been used by previous investigators as the most accurate representation of cyst abundance (Stephens, 1997). Median cyst abundance showed a generally lower value than the mean, especially in terms of peak values; the highest median value was 36.0 cysts/L on December 2, 2006. The highest median measure before the harvest season was 24.1 cysts/L in August. In the following sections the arithmetic mean will be considered because it is the statistic used by the State of Utah, Department of Natural Resources, Division of Wildlife Resources (DWR) to regulate the industry, thereby allowing for direct comparisons of the DWR results with our study.

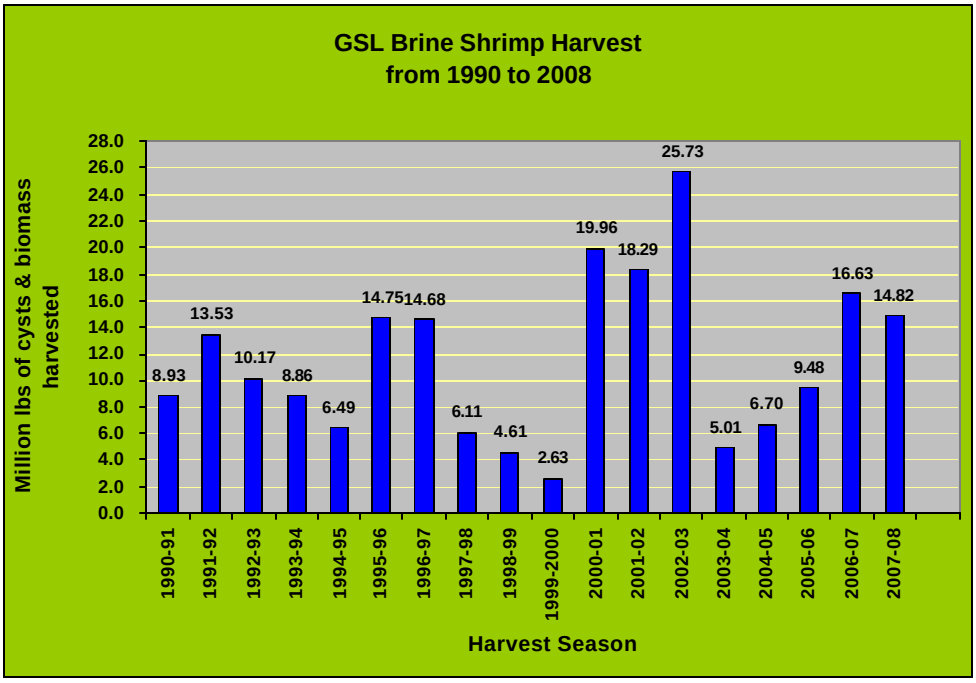
Figure 23. Cyst production by *Artemia* and cyst abundance within the GSL are shown. The dominant shift to oviparity occurred in June and exhibited a triphasic pattern. Cyst production resulted in a steady increase in cyst abundance from June until the onset of commercial harvesting in October 2006.



Because commercial harvesting had already begun on October 1, the estimate of maximal cyst production on the GSL is artificially low. Although cyst abundance was lower, by approximately three-fold, than some of the previous years on the GSL, the brine shrimp industry harvesting total was relatively high. During 2001 to 2005, peak cyst abundance on the GSL ranged from 87 to 158 cysts per liter just before the brine shrimp harvest season, and during that time period the industry harvested 5.0 to 25.7 million pounds per season. This season the brine shrimp industry harvested a total of 16.6 million pounds of

raw biomass from the GSL from October 1, 2006, to January 31, 2007 (Figure 24). By comparison, in 2003 the peak preseason average cyst abundance was 86 cysts/L (median = 72 cysts/L), but the industry harvested only 5 million pounds of raw biomass. The harvest yield for this season may be partially attributable to increased effort during the 2006-2007 harvesting season relative to previous years. Based on our measures of population dynamics, per-capita productivity, and harvest yield for the brine shrimp industry there is no indication that the *Artemia* population is substantially threatened by current conditions on the GSL, whether the concern is contaminants (e.g., mercury, zinc, copper, selenium, hydrocarbons), food availability, abiotic characteristics, predation, or other influential factors.

Figure 24. Raw *Artemia* biomass harvested from the Great Salt Lake from 1990 to 2008. Values are reported in million-pound increments.



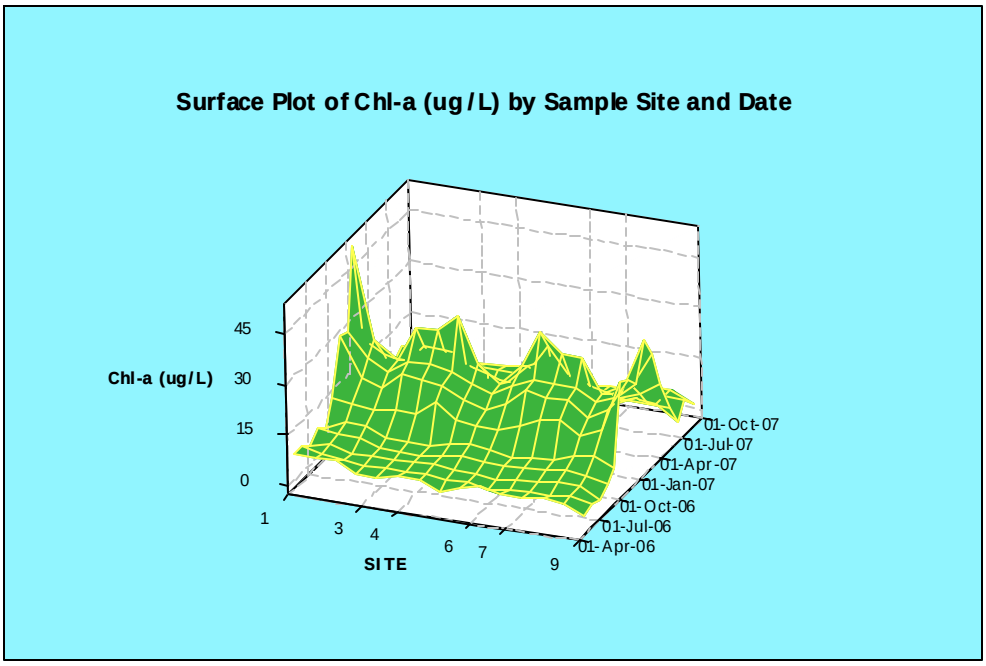
Phytoplankton, Chlorophyll, and Water Transparency.

Water samples were collected during each sampling program and were used to assess chlorophyll pigment concentrations as well as for algae identification and enumeration. Water samples were analyzed for chlorophyll-a and phaeophytin pigments. Average chlorophyll-a levels during 2006 were in the range of 1.9 ug Se/L (September 18) to 30.3 ug Se/L (December 2) (Appendix 7.1). Chlorophyll-a levels during the spring-summer season from April 30 to August 25 2006 did not exceed 7.2 ug Se/L. However, site-specific levels did show a range of 0.7 ug Se/L to16.0 ug Se/L over this same time period. It is likely that throughout the spring and summer the *Artemia* population exerted substantial grazing pressure on the algal food supply and kept chlorophyll levels low. For example, coinciding with decreased grazing pressure in the fall of 2006 (*Artemia* population size reduced to 1.7 individuals/L) the phytoplankton responded with rapid growth and concomitant increases in chlorophyll-a pigments (an average value of 20.8 ug Se/L and a high of 32.0 ug Se/L on October 14) and decreases in transparency—on October 14, 2006, the greatest visible depth was 100 cm with an average of 65.5 cm. This is in contrast to the maximum water transparency in September, which was 460 cm, with an average of 260 cm (Figure 8 and Appendix 7.4).

During the winter of 2007, when grazing pressure on the phytoplankton by *Artemia* was reduced to zero, the algal community responded with abundant growth. Mean chlorophyll-a concentration increased to 41.7 ug Se/L, and a high of 51.0 ug Se/L, in January. By March 15 the average concentration had decreased to 33.7 ug Se/L. Following the onset of hatching and the recolonization of *Artemia* in April, the

concentration of chlorophyll-a had decreased to7.5 ug Se/L. Subsequent sampling programs on May 23 and June 9 showed similar, albeit lower, chlorophyll-a levels to those observed during the spring and early summer of 2006. The concentrations were 1.8 ug Se/L on May 23 and 1.7 ug Se/L on June 9, 2007. Figure 25 portrays the chlorophyll-a concentration over the entire project period (May 2006 to August 2007) and by sample site.

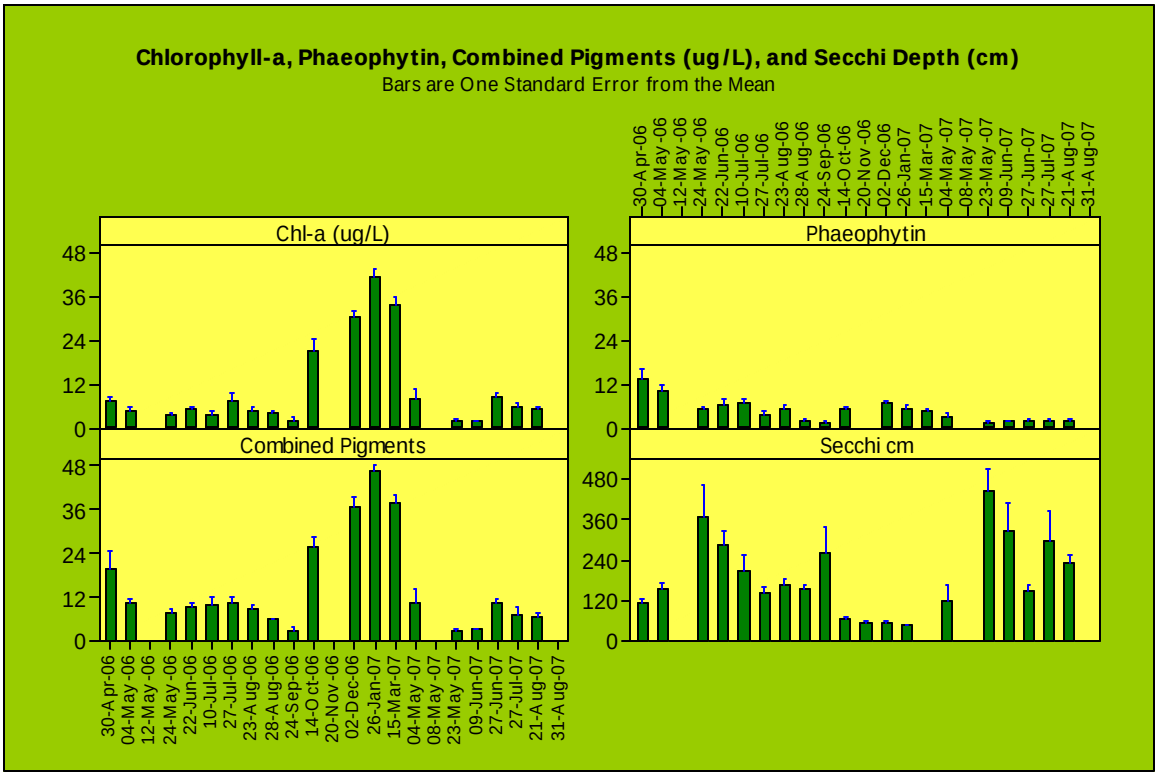
Figure 25. Surface plot of chlorophyll-a from May 2006 to August 2007. The temporal and spatial aspects of chloropyll-a can be observed. Grazing pressure from the brine shrimp population maintains the chlorophll-a production to below 10 ug Se/L throughout the Spring, Summer, and early Fall. Once the grazing pressure diminishes, algal population growth increases substantially and chlorophyll-a concentrations in the water correspondingly increase.



There were substantial differences in phaeophytin concentration between the spring of 2006 and 2007 (Appendix 7.2). In 2006 the phaeophytin concentration was highest on April 30 (13.1 ug Se/L) (Figure 26). The concentration decreased steadily thereafter and

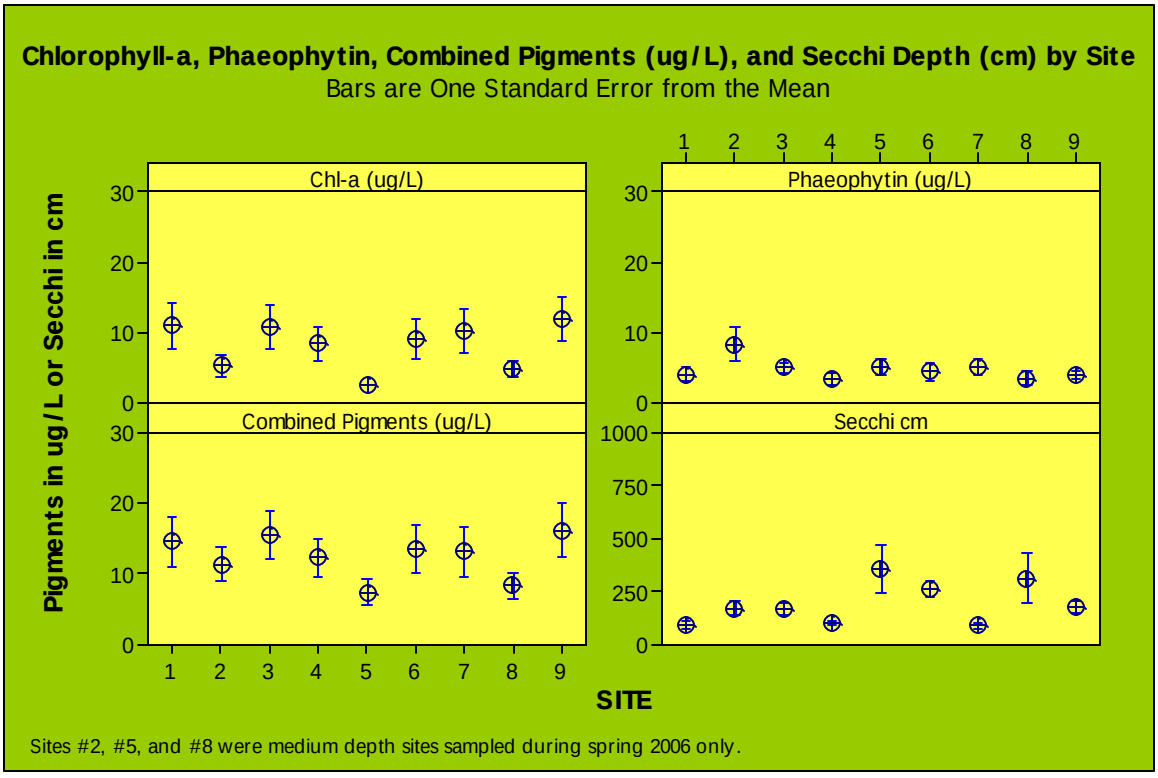
was in the range of 1.2 to 6.5 ug Se/L for the remainder of 2006. In contrast, phaeophytin levels during 2007 have not exceeded 6.5 ug Se/L and steadily decreased from this level in December to a low of 1.2 ug Se/L on May 23.

Figure 26. Interval plots in ug Se/L for chlorophyll-a, phaeophytin, and combined pigments (phaeophytin & chlorophyll-a) and Secchi depth (cm) for GSL water samples collected from April 2006 to June 2007.



A comparison of average chlorophyll concentration by site is a useful indirect measure of differences that may exist spatially in algal production. Figure 27 shows mean values and 95% confidence intervals for chlorophyll-a, phaeophytin, combined pigments and Secchi depth by sample location.

Figure 27. Site-specific interval plots in ug Se/L for chlorophyll-a, phaeophytin, and combined pigments (phaeophytin & chlorophyll-a) and Secchi depth (cm) for GSL water samples from April 2006 to June 2007.

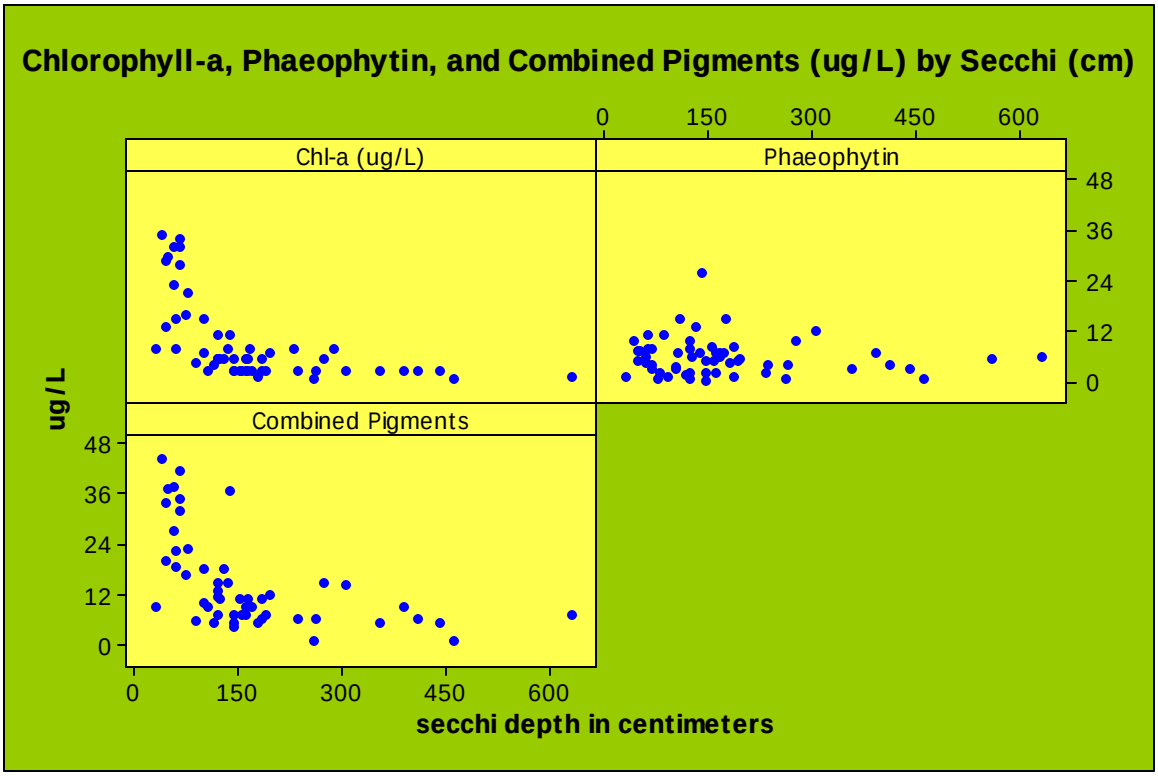


The results for sites 2, 5, and 8 (medium depth) are generally lower than the other sites. This is understandable in the context of the sampling schedule—medium-depth sites were included in the study only during the spring and early summer of 2006. During this time period grazing pressure on the algae remained high and did not allow for substantial algal growth. The maximum values of chlorophyll-a for all deep and shallow sites, except site #1 (Fremont Island), were quite similar and ranged from 37 to 43 ug Se/L. Site #1 did have a higher peak value of 51 ug Se/L, suggesting that this location may have greater primary productivity than the other locations. It is noteworthy that this location is near

fresh water inputs from the Bear River, Ogden Bay, and Farmington Bay. Medium depth sites had much larger 95% confidence intervals, which may be attributable to the limited number of samples taken from these sites relative to the deep and shallow sites.

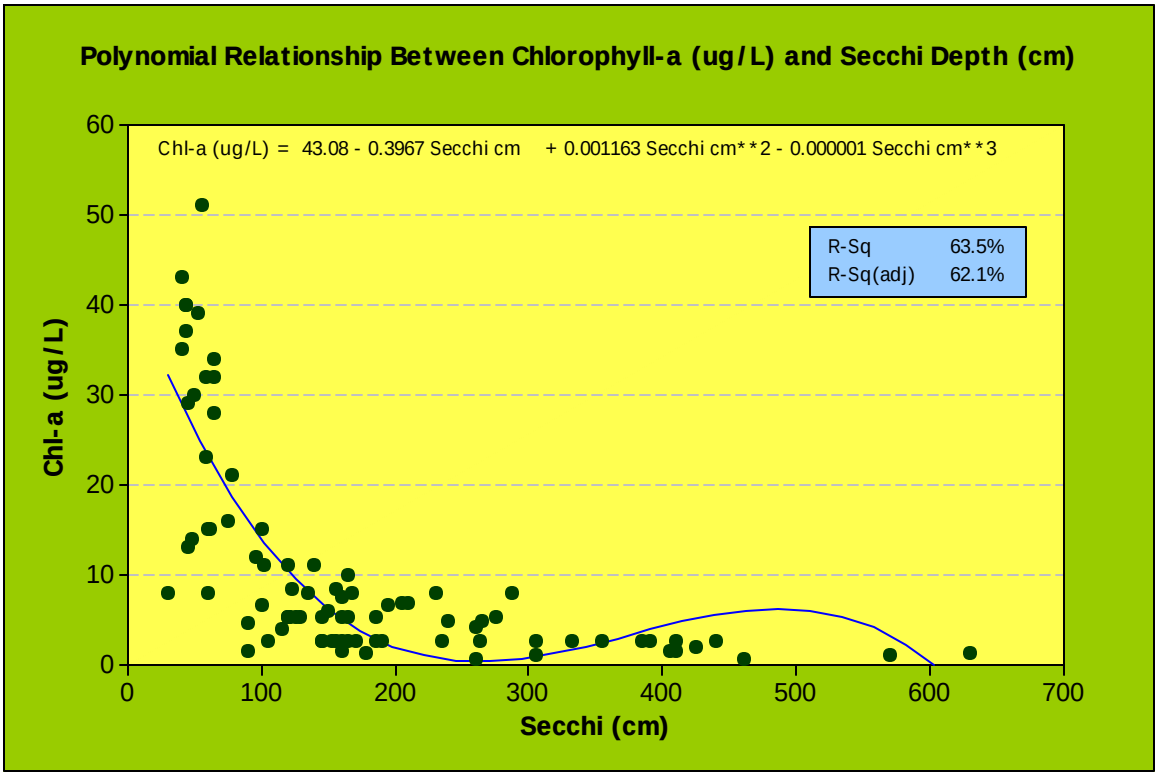
Water transparency measurements can be used as an indirect measure of primary productivity in lakes. The relationship between Secchi depths and chlorophyll-a concentrations is presented in Figure 28. We observed a pattern of exponentially increasing chlorophyll-a concentrations as Secchi depth decreased below 1.5 meters. Similar patterns demonstrating an exponential relationship between low Secchi depth and chlorophyll have been documented in other lake studies (Dodds, 2002). At Secchi depths of $\leq$1 meter chlorophyll-a concentrations were generally between 10 to 50 ug Se/L. Between one meter and three meters transparency the chlorophyll-a values were usually between 3 and 8 ug Se/L. At high levels of water clarity, at least with respect to the GSL, chlorophyll-a levels were very low, typically falling below 3 ug Se/L.

Figure 28. Scatter plot of Secchi depth and algal pigments for the GSL. Samples were collected from April 2006 to June 2007. Results show a characteristic exponential decline in chlorophyll-a as Secchi depth increases. Secchi depths of less than 1.5 meters correspond to levels of chlorophyll-a that are generally associated with robust growth and productivity of *Artemia*.



A best fit line was described for the relationship between chlorophyll-a and Secchi depth Figure 29). A polynomial equation was defined that can be used to estimate chlorophyll-a levels in the GSL when provided with Secchi depth measurements. It must be kept in mind that the accuracy of this equation will be influenced by the relative composition of the phytoplankton population due to differences in amounts of chlorophyll-a produced by the many species of algae found within the GSL. Turbidity, decomposing biomass, and other factors can affect Secchi depth measurements. However, in a chlorophyte-dominated algal population this equation should be a generally useful predictive tool.

Figure 29. The relationship between Secchi depth and chlorophyll-a for GSL water samples is shown and a best-fit line is provided. A reasonably good fit of a cubic polynomial equation (R^2 = 0.627) describes the relationship observed for the GSL during 2006 and 2007. The distribution of chlorophyll measurements may be decidedly different with changes in the relative abundance of phytoplankton taxa.



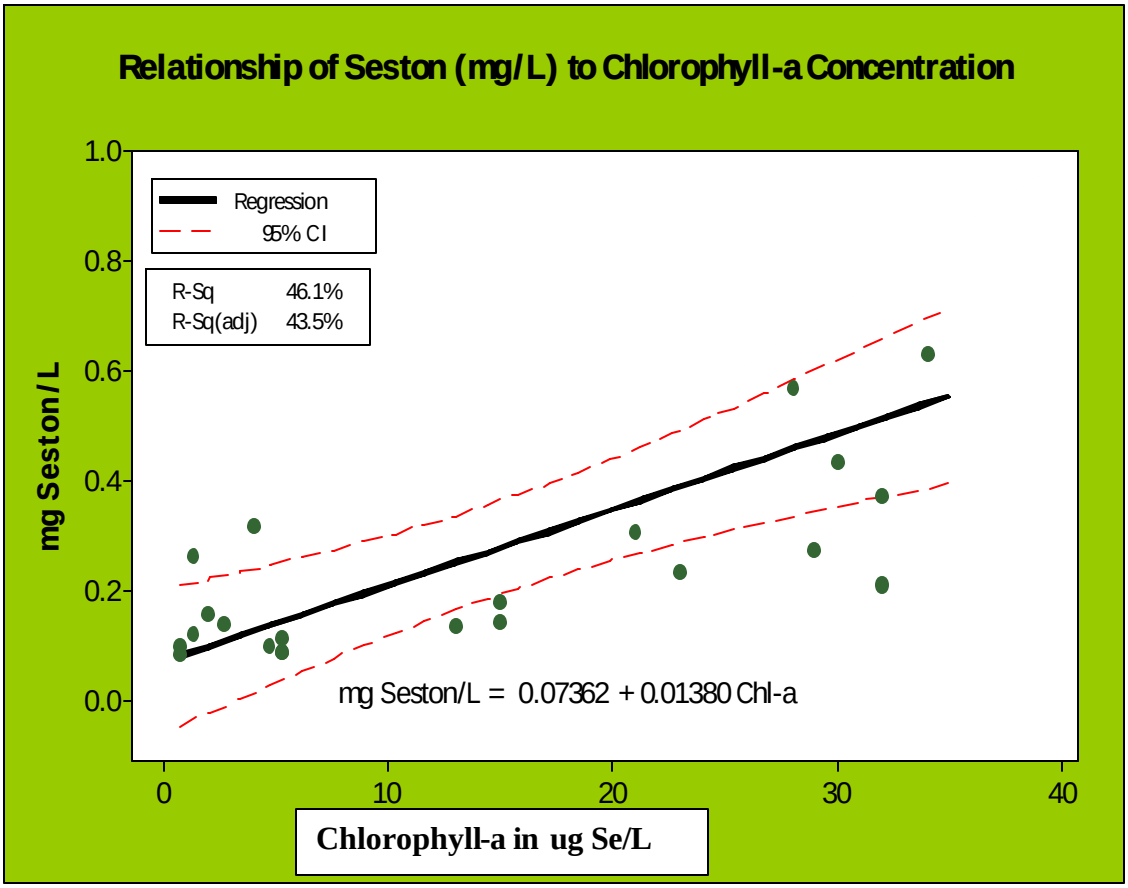
The mean and median chlorophyll-a concentration for all sites and sampling dates were 10.12 and 5.30 ug Se/L respectively. These statistics, and the maximum range over which chlorophyll-a is observed in the GSL, would characterize the GSL as a mesotrophic lake, fluctuating between robust algal growth and transient depletion of phytoplankton due to *Artemia* grazing pressure. As chlorophyll-a levels decline below 5 to 7 ug Se/L on the GSL, food-stress appears to induce a shift to oviparous reproduction. This shift to oviparity occurs at a similar concentration of chlorophyll as indicated in

laboratory studies (Gliwicz, et al., 1995). Other investigators have shown that survival declines dramatically as chlorophyll-a concentrations fall below 5.0 ug Se/L, and especially below 2.5 ug Se/L, (Belovsky and Mellison, 1997). In our study, average chlorophyll-a concentration was below 5.0 ug Se/L during 7 sample programs in 2006 and 2 programs in 2007, in which the ug Se/L. It was less than 2.5 ug Se/L during three sampling programs (Appendix 7.1). Improved accuracy in identifying the critical threshold of chlorophyll that is associated with changes in reproductive modes would require frequent sampling (i.e., weekly) from March to mid-June.

The relationship between chlorophyll concentration and seston yield per liter filtered was examined in the data. This relationship and that of Secchi depth to seston yield have practical applications for this and future studies. It is of value in the design of lake sampling protocols to anticipate seston yield from water filtration. The relationship between an easily measured endpoint (e.g., Secchi depth) or an alternative endpoint (e.g., chlorophyll) and seston yield can assist the investigator in anticipating the volume of filtered water required to provide adequate seston sample size for analytical purposes.

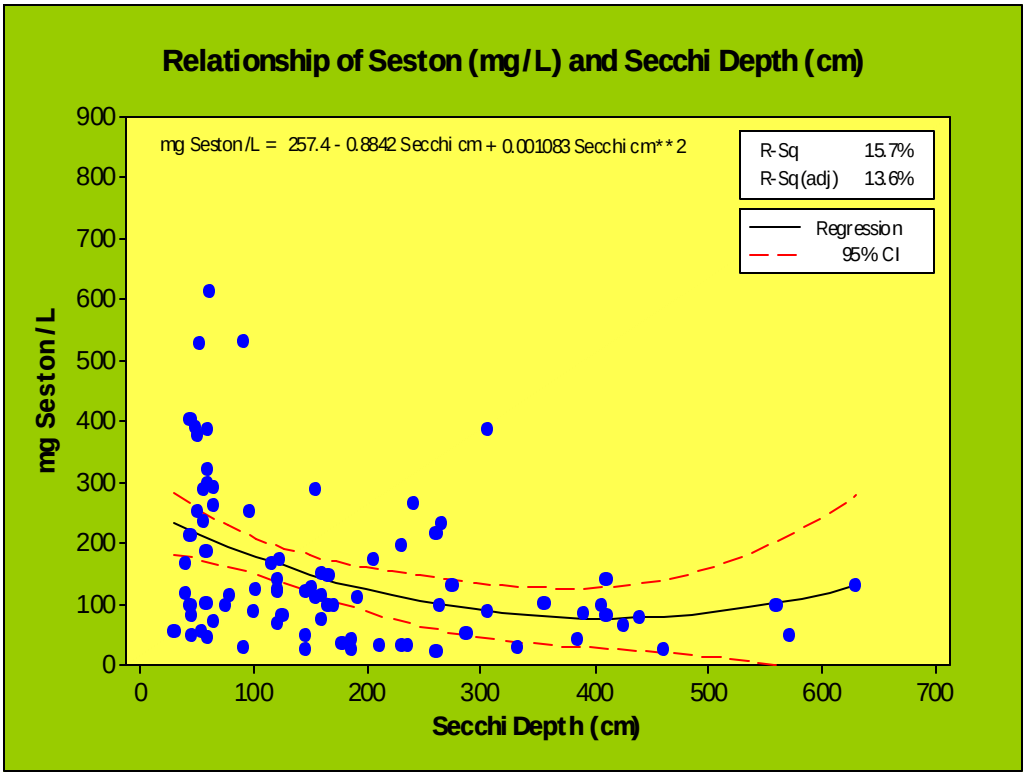
The relationship of chlorophyll and seston yield is shown in Figure 30. There is a moderate positive relationship ($R^2 = 0.461$) between chlorophyll-a and the yield of seston in mg/L.

Figure 30. Relationship of seston yields to chlorophyll-a concentration in GSL water from the same sample location and sampling program. A positive correlation between these two variables was observed.



The correlation between Secchi depth and seston yield was examined toward identifying a relatively easy endpoint to measure that can guide seston sampling protocols. There was a nonlinear negative relationship between seston yield and Secchi depth. A best-fit line relationship is shown in Figure 31. Although the equation provides a range of expected seston yield values, there are obvious limitations to the use of Secchi depth as a predictor of seston yield, especially at the extremes of Secchi depth.

Figure 31. A negative polynomial relationship between seston (mg/L) and Secchi depth can be described for GSL water samples. This relationship has practical applications for estimating the volume of filtered GSL water required for adequate seston sample size. The estimate of volume required can be based on a simple assessment of water transparency.



Seston samples were collected by filtering known volumes of GSL water through 0.45-micron, 142-mm, cellulose acetate filters (flatstock filters). Filtration was initially done (May to July 2006) on equivalent volumes (one liter) of GSL at each sample site. Due to concerns about low yield and limits of detection on seston samples, the volume filtered was increased—filtration was continued until the filters were clogged with particulate matter. The volume of GSL water filtered was then recorded. The cellulose acetate filters used in this study exhibited similar capacities at the point of clogging—the average

weight of material on the filters was 393 mg of seston. The mean quantity of seston per liter was 123.1 mg/L in 2006 and 185.8 mg/L in 2007.

Phytoplankton Composition and Abundance.

Although phytoplankton analysis was not included in the initial project budget, it was deemed important to examine, to the extent possible, the phytoplankton composition over the course of this study. Water samples were pooled according to geographic region (Northeast, Central, Southeast) and preserved in a combination of Lugol's solution (0.5%) and 1% formaldehyde solution. The samples were used for phytoplankton identification and enumeration. The results from May through August 2006 are shown in Figures 32 to 37. Results from subsequent sampling programs are awaiting finalization.

Figure 32. Relative abundance of GSL phytoplankton on May 25, 2006.

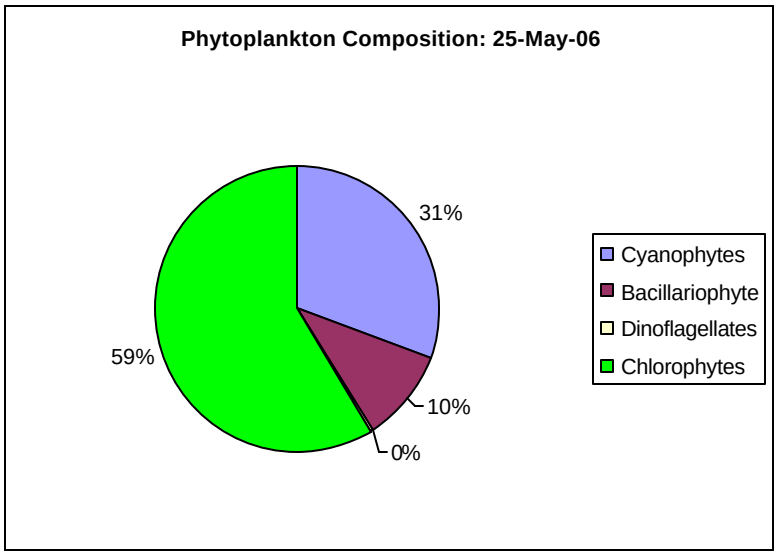


Figure 33. Relative abundance of GSL phytoplankton on June 29, 2006

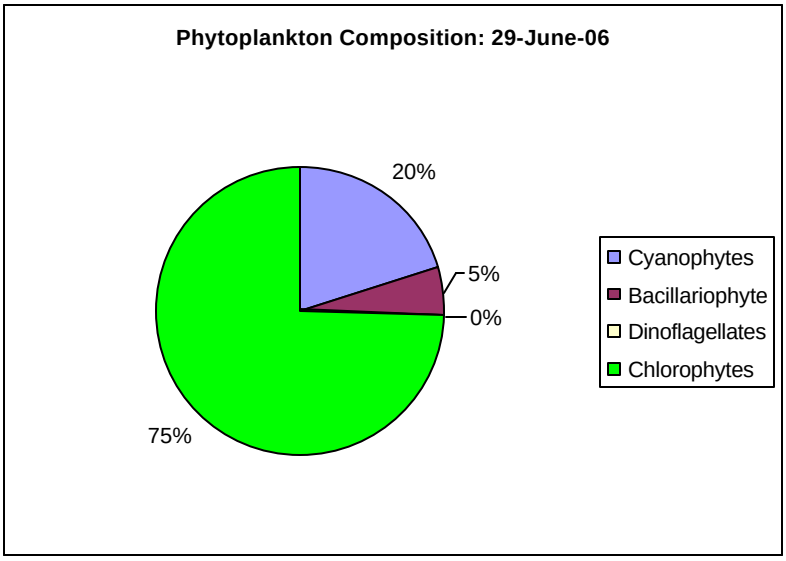


Figure 34. Relative abundance of GSL phytoplankton on July 10, 2006

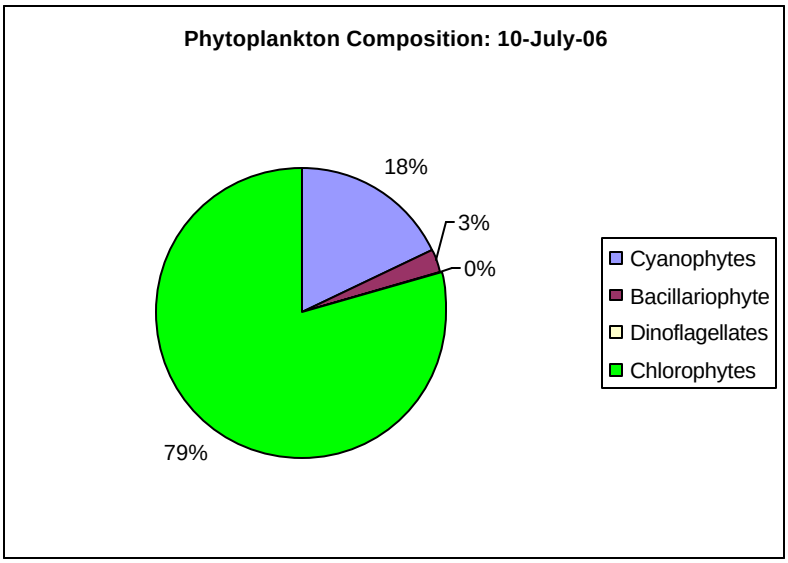


Figure 35. Relative abundance of GSL phytoplankton on July 27, 2006

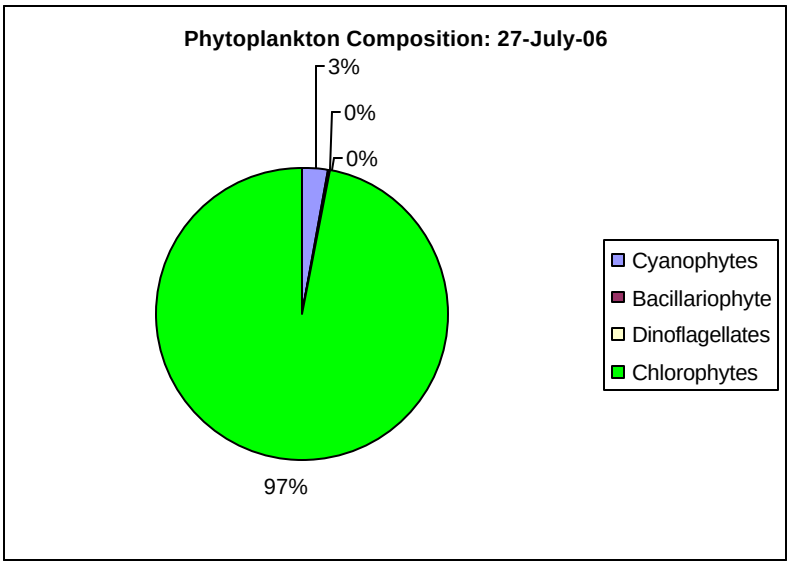


Figure 36. Relative abundance of GSL phytoplankton on August 18, 2006

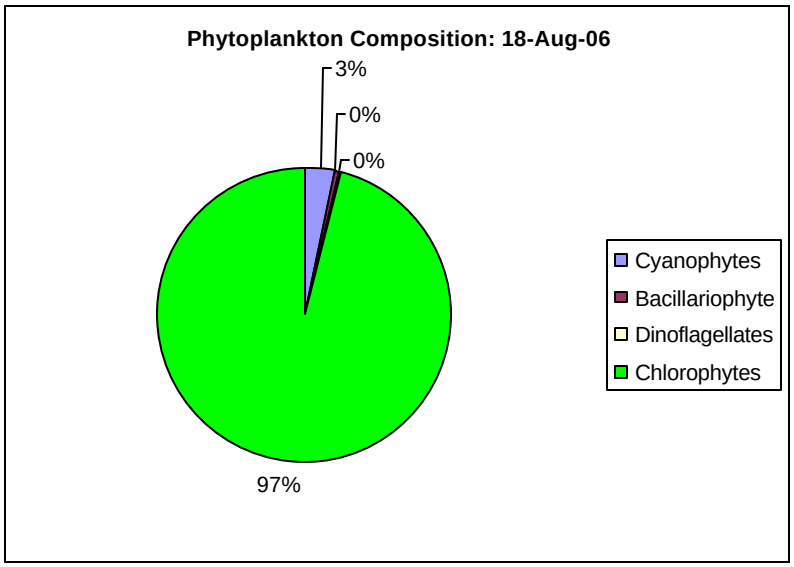
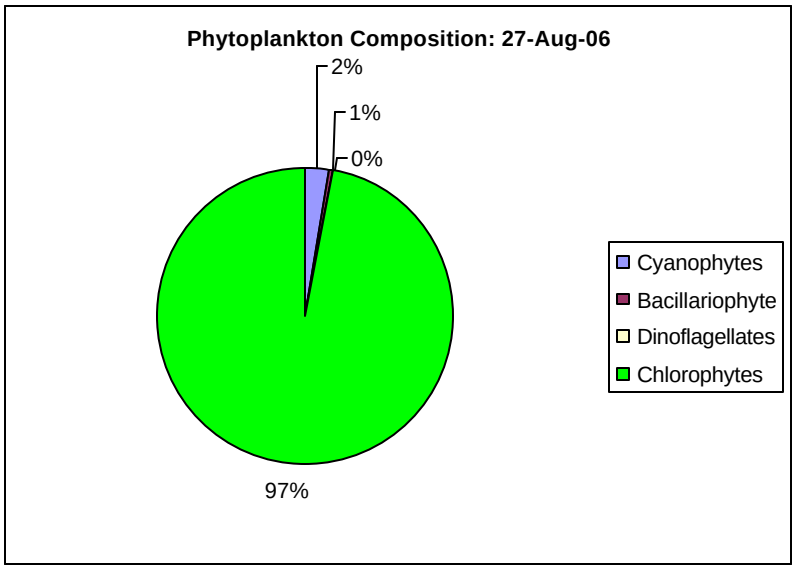


Figure 37. Relative abundance of GSL phytoplankton on August 27, 2006



There was a progressive shift in relative abundance from May to August 2006 in which the relative percentage of chlorophytes increased in dominance reaching a peak relative abundance of 97% in late July and sustaining this level throughout August. The composition of phytoplankton during earlier months exhibited a greater presence of other algae. In May, chlorophytes represented only 59% of the phytoplankton while cyanobacteria (31%) and bacillariophytes (10%) made up the remaining 41%. The combined percentage of cyanobacteria and bacillariophytes decreased to 25% in June and then to 13% in early July. The dominant genus of phytoplankton was *Dunaliella*.

Cell counts were determined in the phytoplankton samples and are shown in Table 8. Cell counts were lowest in June (47,672 cells per liter) and were the highest on July 27 (622,350 cells per liter). These results do not correlate well with chlorophyll measurements—a regression analysis of the relationship between algal cell count and chlorophyll results in a weak positive linear relationship (R^2 value = 0.239). Algal cells are quite fragile and can easily be damaged during prolonged storage or transport and by the filtration/resuspension method of counting used in this study (especially flagellated cells). Ideally, samples should be analyzed within days of collection (Stephens, 1997). It is possible that storage conditions and transport may have had an adverse effect on the algal cells and may have altered the accuracy of cell counts. Notwithstanding these concerns, our results for algal cell counts are similar in range to previous studies (Stephens 1997, 1998, 1999). It is also noteworthy that in these previous studies no clear relationship between chlorophyll, brine shrimp population structure, and algal cell counts was reported.

Table 8. Phytoplankton cell counts from GSL water samples taken from May 2006 to August 2006. Counts are expressed in cells per liter.

Date	Cyanophyceae	Bacillariophyceae	Dinophyceae	Chlorophyceae	Total
May 25, 2006	16,157.66	5,531.26	167.60	30,921.79	52,778.31
June 29, 2006	9,683.43	2,467.41	-	35,521.41	47,672.25
July 10, 2006	27,541.90	4,022.34	111.73	123,156.42	154,832.38
July 27, 2006	17,569.83	1,747.37	-	603,032.24	622,349.45
August 18, 2006	12,247.06	999.39	105.53	341,852.90	355,204.87
August 25, 2006	1,725.63	366.23	-	67,554.30	69,646.17

SELENIUM IN BRINE SHRIMP TISSUE

Selenium analysis results from brine shrimp tissue are presented for each year separately. This format is used for this report because changes were made in the brine shrimp tissue sample preparation methods in 2007 that had a substantial effect on the measured concentration of selenium in brine shrimp tissue. The methods used for the samples collected during 2006 introduced a downward bias in the calculation of selenium on a dry weight brine shrimp tissue basis—residual salt in the samples decreased the apparent concentration of selenium in brine shrimp tissue. Therefore, uncorrected values for all of the 2006 brine shrimp tissue in this report are below true selenium concentration values. Because of this known influence of sample preparation and analytical laboratory procedures on the selenium measurements for the 2006 samples the results are evaluated separately from the 2007 results and the 2006 results should not be used for management purposes.

The methods used to prepare and analyze samples from 2007 were improved and resulted in reliable values that are consistent with previous and concurrent research on selenium in GSL brine shrimp tissue. The results from 2007 therefore can be used for any management decisions and for the purpose of establishing a selenium standard for the GSL. The results from 2006 have been reevaluated using a correction factor that was derived by collecting and preparing co-located samples using the "2006" and "2007" methods. The corrected 2006 values can be used for general comparisons with other data, but are not sufficiently rigorous to be used for regulatory purposes.

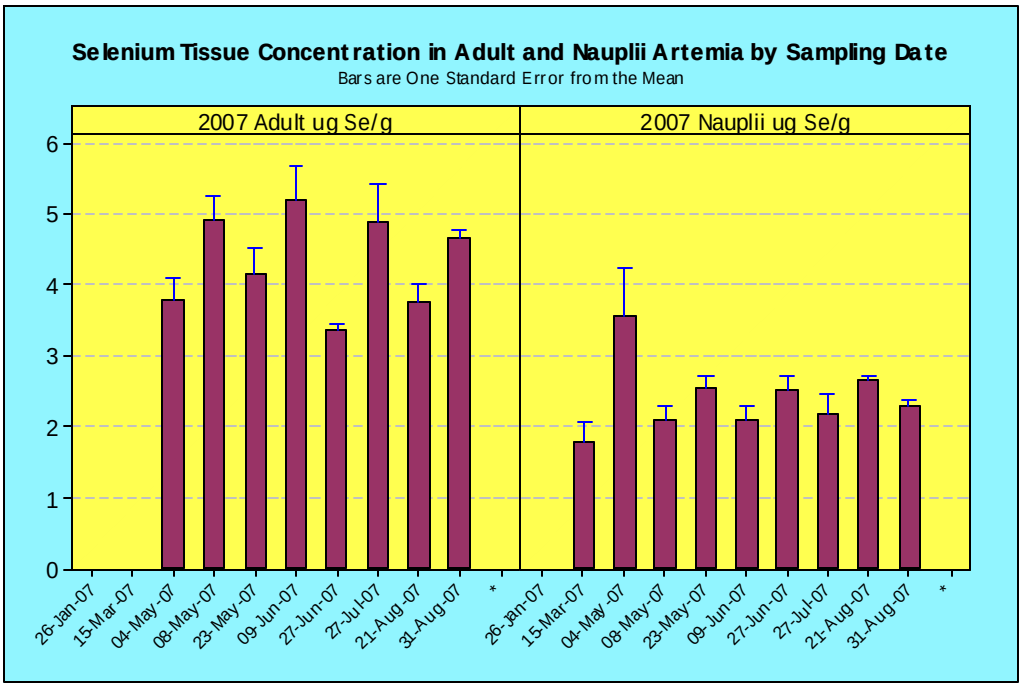
2007 Results: Selenium in Brine Shrimp Tissue

The main modifications made for the sample collection and preparation of brine shrimp tissue during 2007 included increasing the sample size and adding an additional filtration step after age-classes were separated. The final filtration step was used to remove any residual salt, but was done in a manner that maintained the osmolarity of brine shrimp tissues. The same three age-classes (nauplii/cysts, juveniles, and adults) that were collected in 2006 were also included in the 2007 season. All age-classes were submitted for selenium analysis for each sampling program. Although an effort was made to increase sample size during the 2007 season there were still many sampling programs in which the juvenile fraction was insufficient (i.e., < 0.10 g dw) to derive an accurate selenium determination. Because of this limitation the juvenile fraction results will not be presented nor discussed in this section, though the results are included in Appendix

8.2. In contrast, adults and nauplii were collected in sufficient quantities (i.e., > 0.50 g dw) for reliable selenium determination.

The average concentration of selenium in adult brine shrimp tissue during 2007 was 4.32 ug Se/g and the geometric mean for all of the 2007 sampling programs was 4.30 ug Se/g (Figure 38). The lowest average adult tissue value occurred on June 27, 2007 and was 3.37 ug Se/g. The highest average value was 5.21 ug Se/g and was observed on June 9, 2007. The sampling dates and the corresponding selenium tissue values for adult and brine shrimp are shown in Figure 38 and in more detail in Appendix 8.1.

Figure 38. Tissue selenium concentration in brine shrimp adults and nauplii/cysts from 2007. Selenium concentrations are expressed as arithmetic means for each date.



Nauplii and cysts were analyzed for selenium together as one age-class. However, on March 15, 2007 only cysts were collected and analyzed. The selenium tissue value (1.72 ug Se/g) on this date for the nauplii/cyst fraction represents the cyst selenium concentration only. The geometric mean selenium tissue value for the nauplii/cyst fraction for 2007 was 2.35 ug Se/g and the arithmetic mean value was 2.42 ug Se/g. The highest selenium concentration was measured on May 4, 2007 and showed 3.56 ug Se/g while the lowest value of 2.09 ug Se/g occurred on June 9, 2007. The other average daily values were quite consistent and were between 2.18 and 2.65 ug Se/g (Figure 38).

Spatial and temporal differences and trends were analyzed for selenium in brine shrimp tissue using one-way ANOVA. Significant differences among the adult brine shrimp results for the 2007 data set were observed for sampling date, depth characteristics, and geographical region. Although no definitive temporal trend was identified for selenium in adult brine shrimp tissue, comparisons over time showed alternating fluctuating patterns. Whereas the differences among sample dates were significant ($P < 0.000$; 16, 86 DF), these differences are not apparent if results are grouped by month rather than actual sample date ($P=0.640$; 3, 41 DF). The population structure of brine shrimp does vary temporally, and differences are observed on weekly or bi-weekly basis. It is possible that the discrete age structure differences (i.e., age of adults) of the population may have some influence on the apparent selenium tissue concentration for a given location and sample date. Although we analyzed broad groups of age-classes separately, there can be substantial differences among adults in terms of the duration that an adult has been living and foraging in the GSL. It is possible that the amount of time an adult has spent

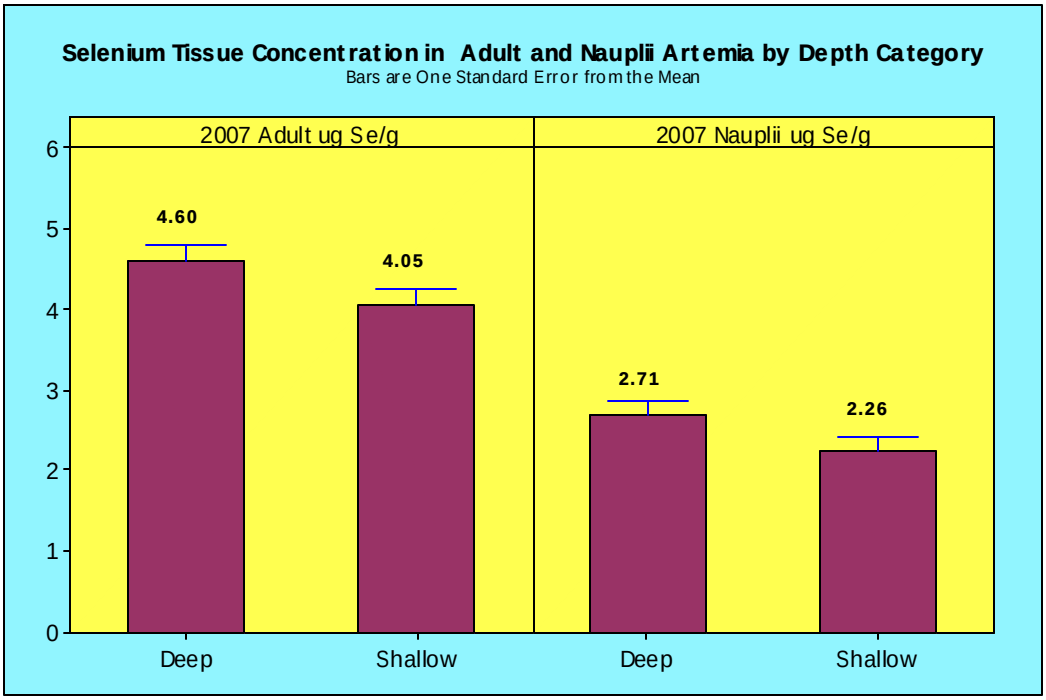
foraging on selenium contaminated algae could have an influence on the individual brine shrimp body burden of selenium. We have demonstrated that this pattern of accumulation exists between age-classes; adults have nearly a two-fold increase in selenium tissue concentration relative to the younger nauplius age-class.

The adult brine shrimp tissue concentration reported for 2007 brine shrimp tissue samples (4.32 ug Se/g) was in close agreement with the few other samples of brine shrimp collected and analyzed by concurrent GSL research teams or in the scientific literature. The average value of selenium in brine shrimp in Conover's (2007) database was 4.5 ug Se/g and of the few samples listed for Cavitt (2007) the values were 2.5 to 3.2 ug Se/g. Our concentration of 4.32 ug Se/g was also somewhat higher than that reported by Brix et al. (2003), who reported selenium tissue concentrations of 2 to 3 ug Se/g for samples collected from the open water of the GSL. Our values are also some higher than those presented by Brooks (2007); she cited studies from 1994 to 2004 that measured 0.3 to 4.5 ug Se/g selenium in brine shrimp. Consistent with studies comparing brine shrimp to brine flies, the selenium concentration in brine shrimp tissue in the current study was higher than concentrations reported by Cavitt (2007) for brine fly larvae (0.8 to 3.8 ug Se/g) and those reported for brine fly larvae (1.3 ug Se/g) and pupae (1.8 ug Se/g) by Wurtsbaugh (2007).

Selenium values in brine shrimp adult tissue were grouped according to spatial and depth categories. The average selenium tissue concentration for adult brine shrimp by depth category is shown in Figure 39. Adult brine shrimp collected at deep sites (>7m depth)

had significantly (P=0.050; 1, 43 DF) elevated selenium tissue concentration compared to samples collected from shallow (1-3m) sites. The mean concentration of selenium in adults from deep sites was 4.60 ug Se/g dw compared to 4.05 ug Se/g dw for shallow sites (Figure 39). Notwithstanding the problems associated with the 2006 brine shrimp tissue selenium values, there was a similar pattern of deep sites showing a slightly higher tissue concentration of selenium than that observed in brine shrimp from shallow sites.

Figure 39. Tissue selenium concentration in brine shrimp adults and nauplii/cysts from 2007. Selenium concentrations are expressed as arithmetic means for each site depth characteristic. Shallow sites showed consistently lower brine shrimp tissue concentrations than were observed at deeper sites.

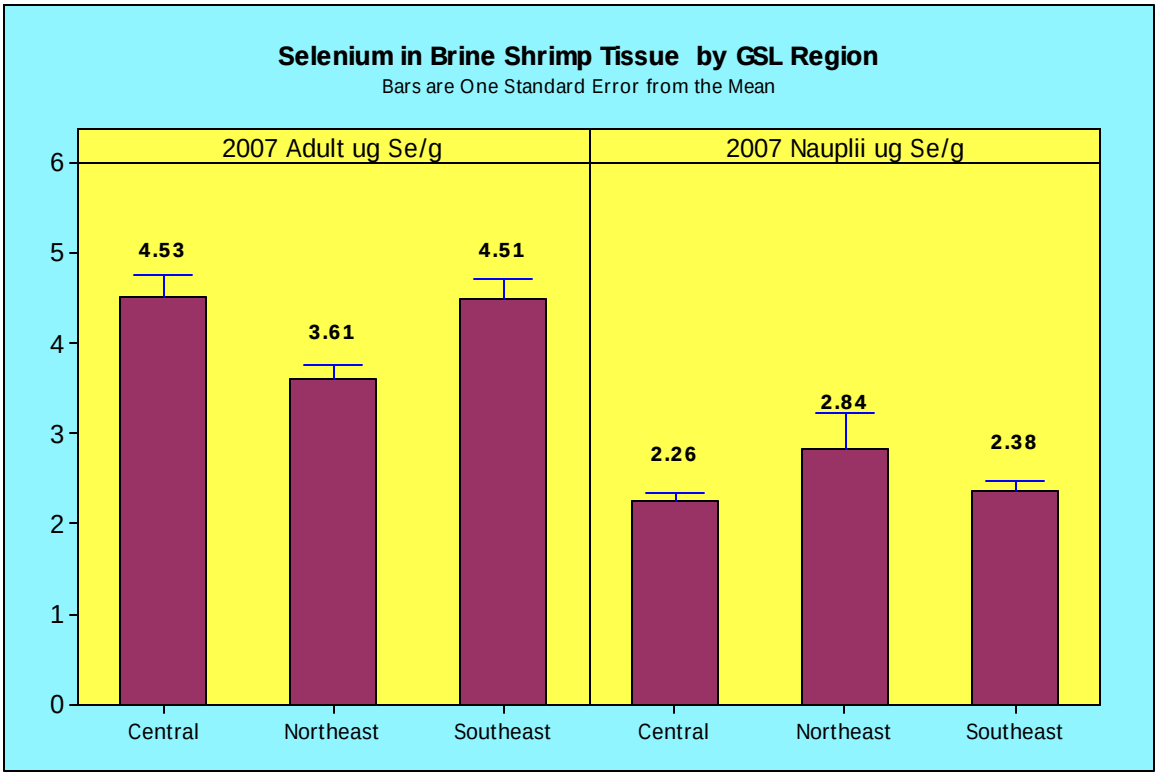


This outcome is of interest with respect to the age structure of the brine shrimp population in a given location and date. Our population results have demonstrated that shallow sites are more productive than deep sites. Shallow sites consistently have higher

dissolved oxygen content, brine shrimp biomass production, and brine shrimp abundance compared to deep sites. This continual production and support of the brine shrimp population could contribute to the observed selenium concentration in brine shrimp tissue indirectly through age structure differences. Laboratory studies of specific ages of brine shrimp and their respective uptake and body burdens would be necessary to confirm this hypothesis. The investigations by Grossell (2007) indicate accumulation of selenium in adults relative to dietary and water concentrations over time, but they don't specifically address the influence of age-structure on tissue selenium assessments.

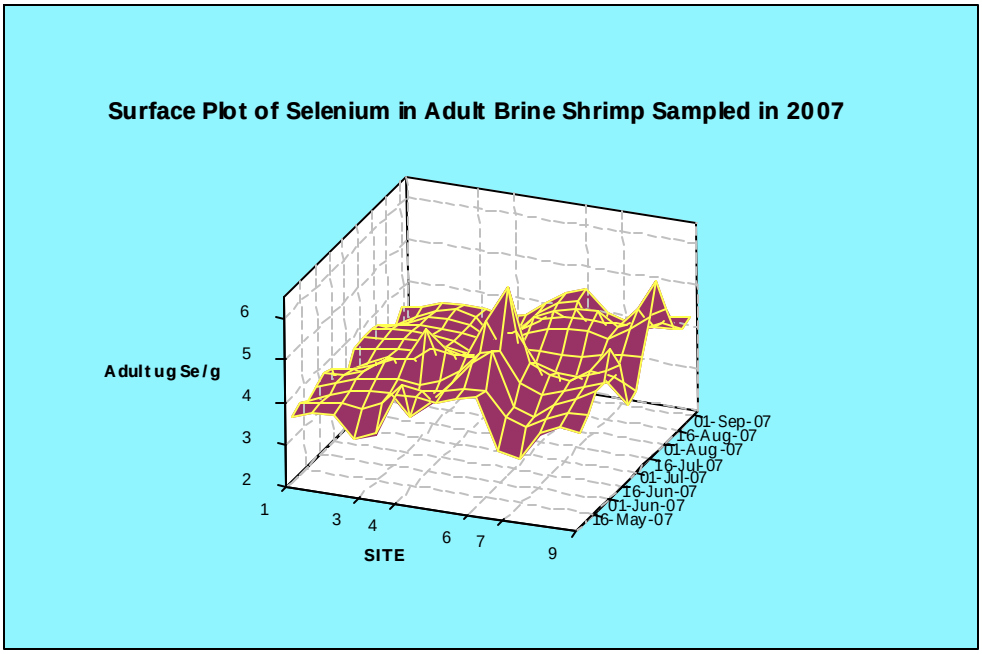
Selenium in brine shrimp tissue was also examined on the basis of geographic region of the GSL. The average values for selenium in brine shrimp tissue, according to region of the GSL, are shown in Figure 40. There were significant differences (P=0.026; 2, 42 DF) in selenium tissue concentration among the three regions of the GSL for adult brine shrimp, but no significant differences were observed for the nauplii/cyst fraction. The region designated "Northeast" includes samples sites that are influenced by input from Ogden Bay, Farmington Bay, and Willard Bay. The phytoplankton composition, water characteristics, and abiotic factors do differ in this region from other regions of the GSL that are further removed to the west and south. However, the results for brine shrimp tissue concentration do not correspond to differences in selenium from unfiltered water—there were no differences among regions in the concentration of selenium in unfiltered water samples (Figure 40). The differences in this region may simply be an artifact of inherent population differences, sampling frequency and sample size.

Figure 40. Tissue selenium concentration in brine shrimp adults and nauplii/cysts from 2007. Selenium concentrations are expressed as arithmetic means for region.



The combined spatial and temporal patterns of selenium in brine shrimp are displayed in Figures 41 and 42. Although these surface plots can be difficult to interpret, they do allow for an inspection of the pattern of selenium in brine shrimp tissue over time and sample site.

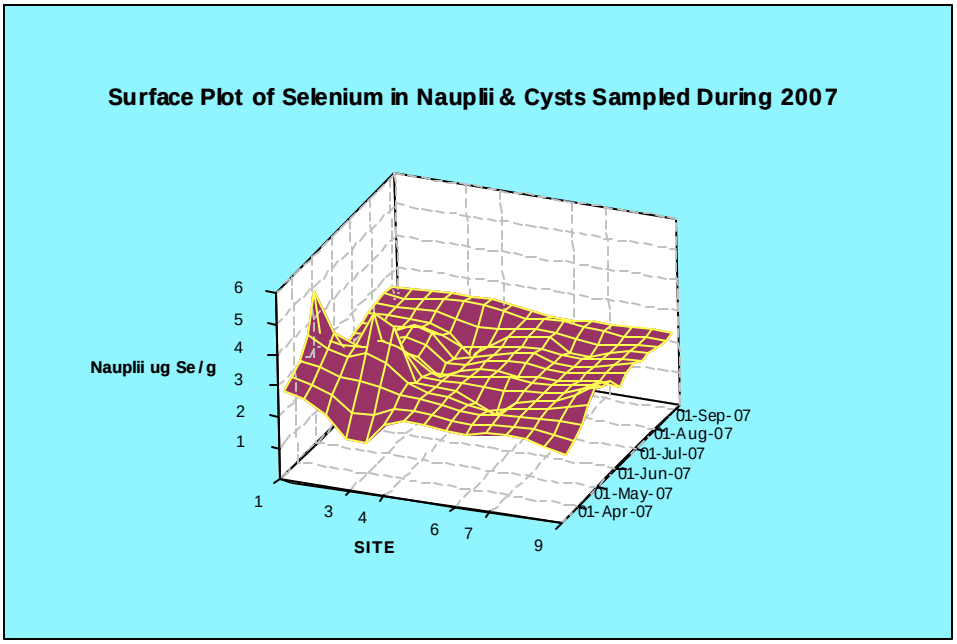
Figure 41. Surface plot of selenium concentration in adult brine shrimp tissue from May to August 2007. The temporal and spatial aspects of selenium in brine shrimp tissue can be observed.



Separately, the adults were nearly twice the selenium tissue concentration as the nauplii tissue concentration. Regression analysis of selenium brine shrimp tissue from 2007 samples shows a 0.538 coefficient factor for the nauplii tissue selenium concentration relative to the value for adults. The larval stages that were grouped in the nauplius age-class include some early instar stages in which the nauplius is primarily deriving energy from the metabolism of stored lipids. During older stages the stored lipids become depleted and meta-nauplii begin to actively forage for algae. The concentration of selenium in nauplii is slightly higher than the baseline value for selenium in the brine shrimp cysts (1.77 ug/g) observed during the late winter (March 15, 2007), suggesting some uptake of selenium by larval stages (Figure 38).

The results for the younger nauplii age-class are remarkably consistent over time and location, with some exceptions in May 2007-- higher values at sample sites 1 and 3 were observed. It is not clear why these locations exhibited average values well in excess of other locations or sample dates, though it may have been an artifact of sample size.

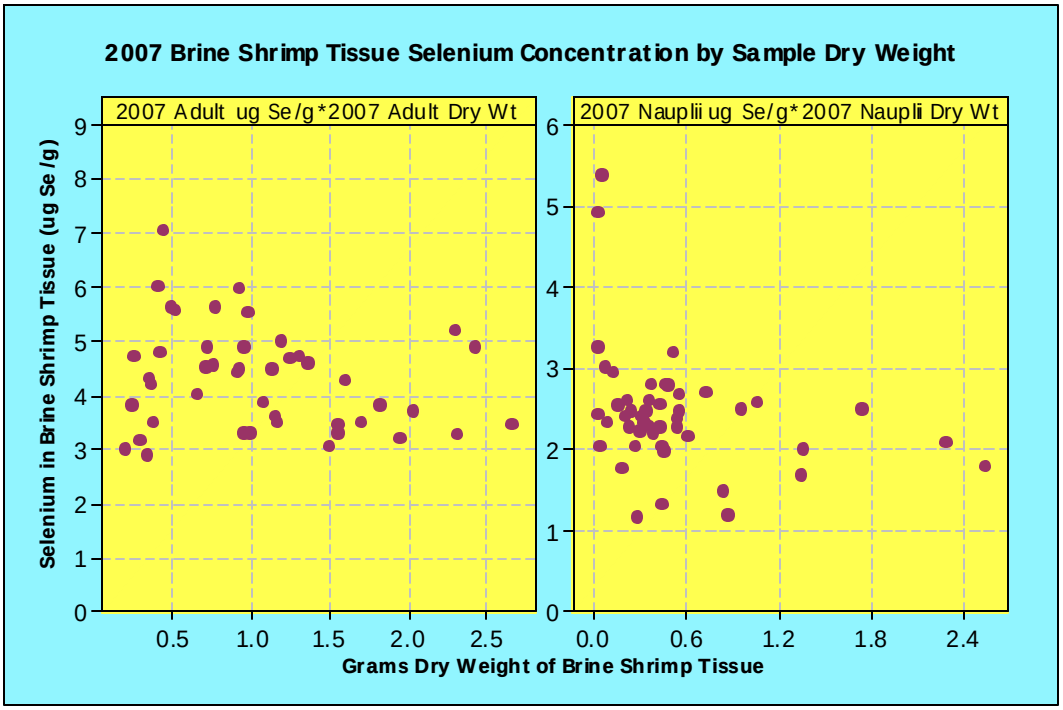
Figure 42. Surface plot of selenium concentration in nauplii/cyst tissue from May to August 2007. The temporal and spatial aspects of selenium in brine shrimp tissue can be observed.



The samples taken during May were some of the smallest yields for the nauplii/cyst fraction over the entire course of the 2007 sampling season—the May 4, 2007 samples had an average weight of 0.053 g dw whereas the average for all nauplii/cysts collected during the 2007 season was 0.573 g dw. The results from selenium analysis for all brine shrimp tissue suggest that limited tissue mass, especially for samples that were less than

0.50 g dw, increased variability in the calculated selenium tissue concentration (Figure 43).

Figure 43. Tissue selenium concentration in brine shrimp adults and nauplii as a function of sample dry weight.



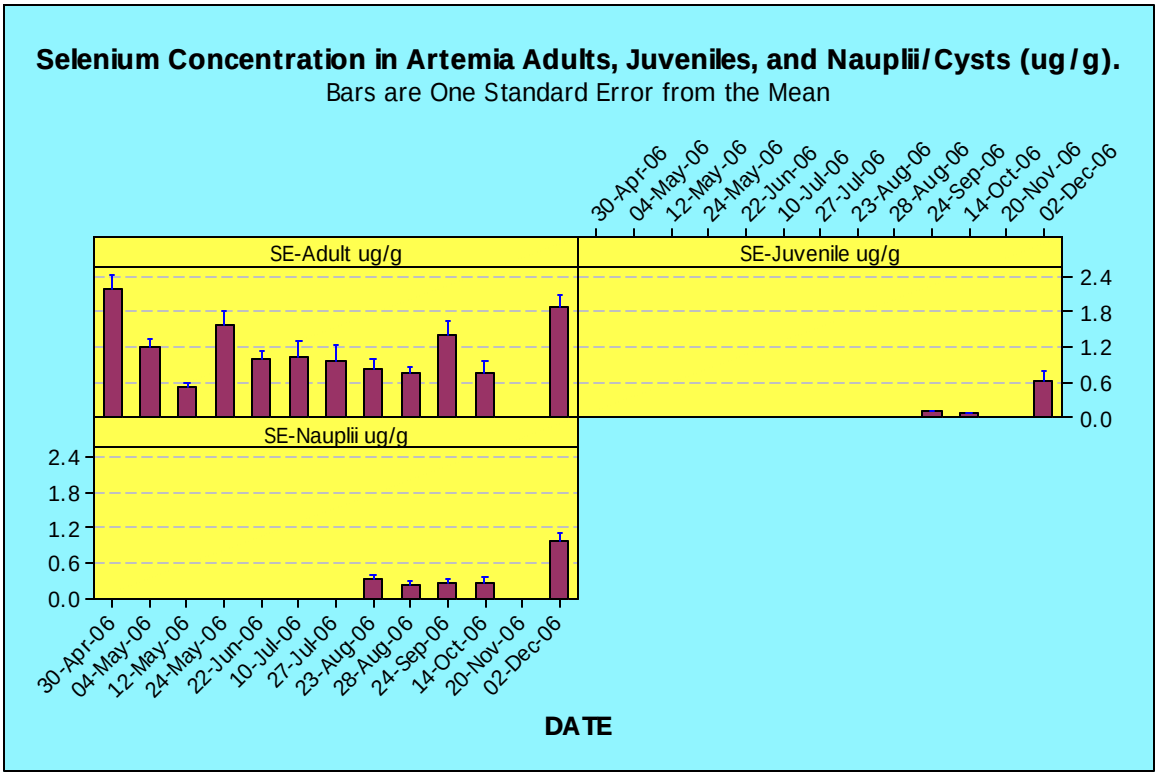
2006 Results: Selenium in Brine Shrimp Tissue

The results for selenium analysis in brine shrimp tissue collected and analyzed during 2006 are presented in this report, as they were in the 2006 draft report. Since the completion of that report the cause of artificially lower values for selenium in the brine shrimp tissue samples was identified. Because of the recognition of artificially low values in the 2006 data set most statistical tests and discussion points have been removed. A correction factor for the 2006 brine shrimp tissue was derived by concurrently sampling, preparing and analyzing brine shrimp tissue using the 2006 methods and

updated “2007” methods. The corrected data were used for some limited statistical analyses.

The results for each sample date are depicted in Figure 44 and are provided in greater detail in Appendices 8.1 to 8.5. The arithmetic mean concentration in adult brine shrimp from April 30, 2006 to December 2, 2006 was 1.185 ug Se/g and the geometric mean was 0.984 ug Se/g. The highest concentration in a single composite of adult brine shrimp was 3.30 ug Se/g. Average concentrations varied across sampling program dates. The highest average concentration of selenium in adult brine shrimp tissue was recorded on April 30, 2006 (2.19 ug Se/g). The lowest average concentration of 0.50 ug Se/g was observed on May 12, 2006. Tissue selenium concentrations in adult brine shrimp were transformed (Johnson transformation—essentially a natural log transformation) and then analyzed by sample date using one-way ANOVA. Selenium concentrations did vary significantly over time ($P < 0.01$, df: 11, 68).

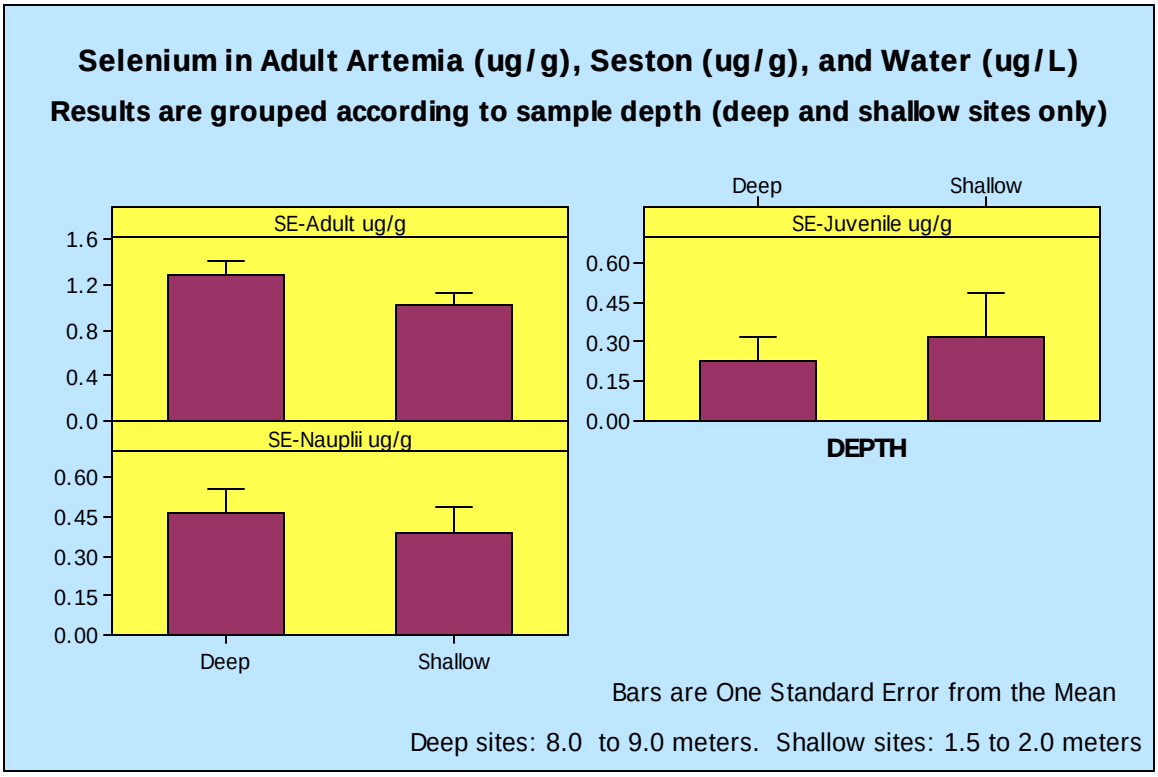
Figure 44. Tissue selenium concentration in brine shrimp adults, juveniles, and nauplii/cysts from 2006. Samples were collected for all age-classes on each sample date. A limited number of the younger age-classes have been analyzed. Selenium concentrations are expressed as arithmetic means for each sample location on a given date.



Tissue concentrations of selenium were quite similar when grouped by type of sample site (i.e., shallow or deep) across regions (Figure 45). Statistical analyses for geographic distribution were done according to regional sample locations (Northeast, Central, Southeast), rather than for site-specific results. No significant differences were found in selenium concentrations across sample locations ($P = 0.759$, df: 2, 77). Grouping brine shrimp tissue concentrations according to depth categories was of interest for this study because of the distinct differences in biogeochemical processes that occur among sites

with distinctly different maximum depths. Since medium depth sites were not sampled throughout the study period statistical tests by depth included only the shallow and deep sites. Although the average concentration of selenium in brine shrimp tissue collected at deep sites was slightly higher (+ 0.28 ug Se/g) than the average for shallow sites, the difference in mean values between these depth categories was not statistically different at the $P \leq 0.05$ level (P=0.085, df: 1, 66).

Figure 45. Selenium concentration in brine shrimp tissue (ug Se/g) grouped according to sample depth. The average concentration in adult brine shrimp tissue for the deep sites was greater than the selenium tissue concentration for the corresponding shallow site in each region of the GSL.

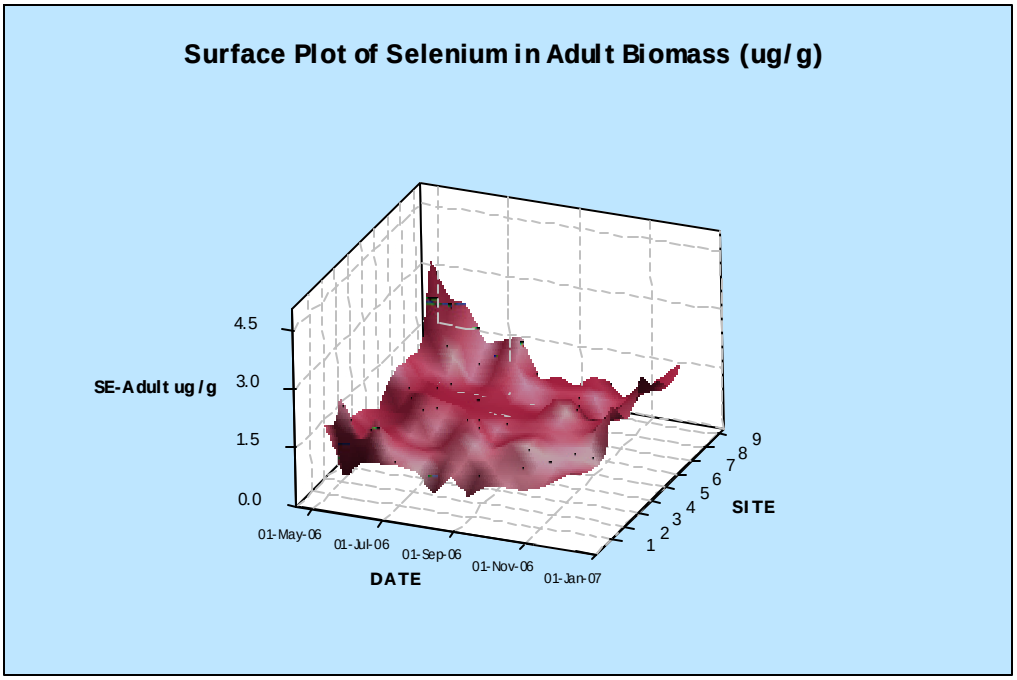


A plot of selenium in adult brine shrimp tissue depicted spatially and temporally is shown in Figure 46. This surface plot provides a constructive visual representation of the

pattern of selenium in brine shrimp tissue. Site #9 (deep site in Southeastern region of the lake) had the highest value observed (3.3 ug Se/g) and was ranked second in average selenium concentration (1.49 ug Se/g). Site #7 (shallow site near the southern end of Antelope Island) had the lowest mean value (0.885 ug Se/g). Temporally, April (2.11 ug Se/g) and December (1.80 ug Se/g) showed the highest mean concentrations of selenium in adult brine shrimp.

As mentioned previously, with regard to evaluating spatial differences in brine shrimp population dynamics and reproductive output, one must always consider that grouping and analyzing results spatially runs the risk of making the incorrect assumption that brine shrimp sampled at given location have been in that particular location sufficiently long to be influenced physiologically or biologically by local biotic and abiotic conditions. We cannot say with certainty that this is the case for the brine shrimp collected in each specific location—we can only examine the results in terms of consistent or meaningful spatial patterns.

Figure 46. Surface plot of selenium concentration in adult brine shrimp tissue from April to December 2006. The temporal and spatial aspects of selenium in brine shrimp tissue can be observed. Although significant differences did exist over time no such differences were found among the geographic locations.



Although juvenile and nauplii/cyst fractions were collected and stored for each sampling program, not all of the samples were analyzed. This was done because the primary focus of this study is in regard to avian dietary exposure to selenium via the food web, and adults comprise most of the *Artemia* biomass as well as the diets of birds foraging on brine shrimp. Therefore, it was determined that all adults would be analyzed and that younger age-class *Artemia* would be analyzed from a subset of the sampling programs (August 2006 through June 2007).

The results for the younger age-classes indicate that there is an age-related difference in the tissue concentration of selenium. Juveniles were 6% to 32% and the nauplii/cyst fraction was 18% to 54% of the selenium concentration in adults for the same sample site and date (Appendices 8.1 and 8.2). Average juvenile tissue selenium levels were quite low with values of 0.06 to 0.61 ug Se/g tissue dry weight and for the nauplii/cyst fraction the selenium concentration was 0.24 to 1.01 ug Se/g. The maximum tissue concentration observed for juveniles was 1.40 ug Se/g (December 2, 2006) and 1.30 ug Se/g for the nauplii/cyst fraction on the same date. Biomass sample sizes for the smaller age-classes were low compared to the adult fraction and this may have had some influence on the selenium concentration determination. Sample sizes for all age-classes were increased substantially during the 2007 sampling programs.

Comparative Study of 2006 and 2007 Methods for Brine Shrimp Tissue Preparation.

Since 2006 brine shrimp tissue samples were lower than anticipated a comparative study was done in May 2007 to determine the cause of the lower than expected values. It was inferred that the low selenium concentration values were a result of excess residual salt in the samples. Because of this concern, an additional filtration step was added to the sample preparation to remove the salt. Samples collected and filtered were compared to samples collected and prepared according to the same methods used during the 2006 study.

The additional filtration procedure involved vacuum filtering the brine shrimp samples in the laboratory after the samples were sorted according to age-classes. The filtration step

was the final step just prior to freezing. The selenium results for brine shrimp tissue from these two methods were also compared to methods previously employed for the collection and preparation of brine shrimp samples (Brix et. al., 2004; Adams, 2005). In this third method (the Adams method) all age-classes are pooled together, brine shrimp are collected from the upper 1-2 meters of the water column by repeated net hauls, sample sizes are larger (10 to 30 grams minimum mass wet weight) than the mass typically obtained for Project 2b 2006 sampling season, and the residual GSL water is passively drained from the sample. Comparative methodological studies were done both in May and in August—the beginning and end of the 2007 study.

The results from these method comparisons are shown in Table 9. The results from the comparative study indicate that the brine shrimp tissue selenium values from 2006 are indeed artificially low. The results from 2007 for filtered samples are in alignment with other investigators, especially when the weighted averages of adult and nauplius fractions are combined. The results from the comparative studies in both May and August show an average concentration of 4.10 and 4.01 ug/g dry weight for the combined adult and nauplius fractions. The weighted average concentration is in general agreement with the Adams method, thereby lending credibility to the simplified method that is used by Adams for collecting brine shrimp samples for selenium analysis. The advantage of the Adams method is that it does not involved the multiple steps of separating age-classes of brine shrimp and the subsequent filtration step to remove residual salt water. With each laborious step time is involved and there is an added element of variability that is introduced. The disadvantage of the Adams method is that differences between the age-

classes cannot be discerned. Our results do indicate that the differences between adult and nauplius age-classes is substantial, and if comparisons are to be made with laboratory studies of a particular age-class, then it is necessary to separate brine shrimp on the basis of developmental stage.

Table 9. Selenium concentration in tissue from brine shrimp adults and nauplii. Results for the three methods of sample collection and preparation are shown. A calculated weighted average result for selenium in the adults and nauplii samples, that were analyzed separately, is also indicated.

Artemia Age-class	Filtered (Yes or No)	Program ID Comparative Study (CS)	Sample Date	Mean Selenium in ug/g	SD	Mean Wet Weight gm	Mean Dry Weight gm	% Moisture Content	Number of Samples
Adult	Yes	CS-1	5/8/07	4.92	0.81	6.12	0.74	88	6
Adult	[1]No	CS-1	5/8/07	1.33	0.25	7.71	0.89	89	5
Nauplius	Yes	CS-1	5/8/07	2.11	0.48	1.12	0.24	80	6
All	[2]No	CS-1	5/8/07	3.91	0.17	18.43	2.19	88	5
Adult	Yes	CS-2	8/31/07	4.68	0.25	6.51	0.98	85	5
Nauplius	Yes	CS-2	8/31/07	2.30	0.18	1.33	0.40	70	5
All	[2]No	CS-2	8/31/07	3.96	0.09	8.66	1.21	86	5
Calculated Selenium in Filtered Adult+Naup	**Yes**	**CS-1**	**5/8/07**	**4.10**					**12**
Calculated Selenium in Filtered Adult+Naup	**Yes**	**CS-2**	**8/31/07**	**4.01**					**10**
	[1]2006 Method **[2]Adams Method**								

Results from the May comparative study were used to derive a correction factor for the 2006 data. The application of such a correction factor itself introduces variability and

uncertainty and involves many assumptions. Because of these concerns the correction factor is applied only for very general purposes of comparing 2006 to 2007, with full recognition of the potential errors involved. The original and corrected values for the 2006 results are shown in Table 10. The mean corrected concentration of selenium in brine shrimp tissue from 2006 samples is 3.79 ug Se/g dw. This overall mean value does elevate the measured selenium in brine shrimp tissue from the 2006 season into a range that is more consistent with other reported values.

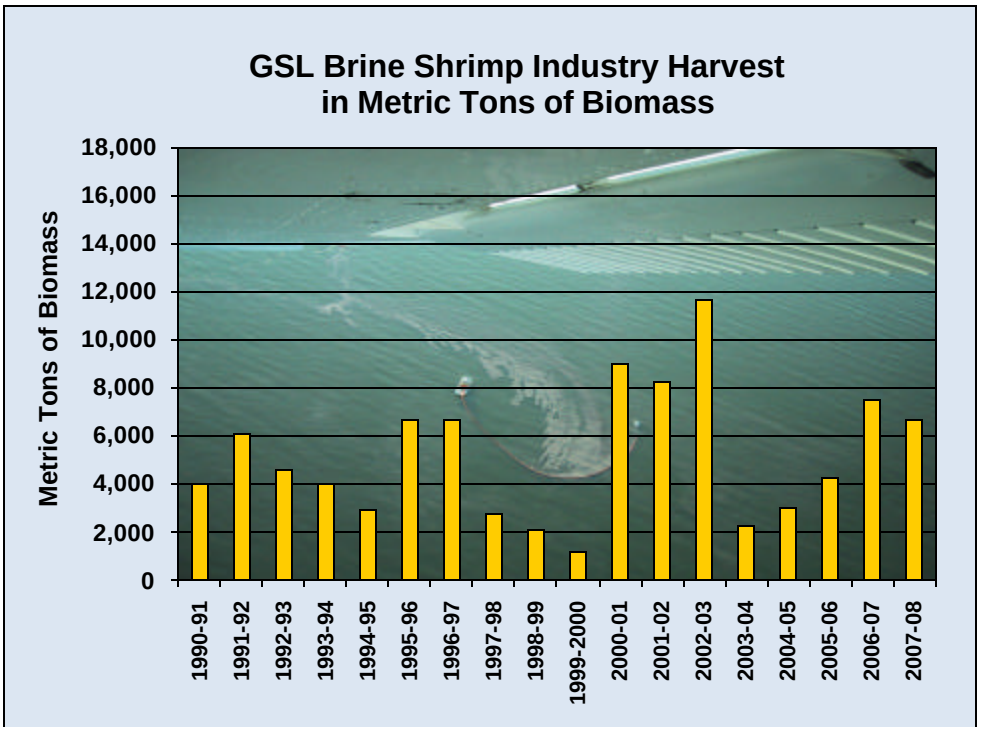
Table 10. Selenium in brine shrimp adult tissue for 2006 and 2007 samples. 2006 samples are shown as determined analytically and with a correction factor applied. The Correction factor was derived from comparative studies in which the influence of sample preparation on apparent tissue selenium concentration was determined.

DATE	Adult Selenium ug Se/g	Adult Selenium X CF ug Se/g	N
April 30, 2006	2.19	6.78	7.00
May 4, 2006	1.18	3.67	8.00
May 12, 2006	0.50	1.56	6.00
May 24, 2006	1.56	4.82	9.00
June 22, 2006	0.98	3.02	9.00
July 10, 2006	1.03	3.19	6.00
July 27, 2006	0.97	2.99	6.00
August 23, 2006	0.83	2.57	6.00
August 28, 2006	0.76	2.34	6.00
September 24, 2006	1.41	4.38	5.00
October 14, 2006	0.76	2.35	6.00
November 20, 2006	1.35	4.20	6.00
December 2, 2006	1.87	5.79	6.00
January 27, 2007			
March 15, 2007			
May 4, 2007	3.79	3.79	6.00
May 8, 2007	4.92	4.92	12.00
May 23, 2007	4.16	4.16	6.00
June 9, 2007	5.21	5.21	6.00
June 27, 2007	3.37	3.37	6.00
July 27, 2007	4.90	4.90	4.00
August 21, 2007	3.76	3.76	6.00
August 31, 2007	4.68	4.68	10.00
2006 Results	**1.20**	**3.79**	
2007 Results	**4.32**	**4.32**	

The Great Salt Lake Brine Shrimp Industry, Selenium Load in Brine Shrimp and Selenium Removal from GSL via Commercial Harvesting of Cysts.

A commercial brine shrimp harvesting industry has been involved in the removal of brine shrimp biomass and cysts since the 1950's. This industry has been a strong proponent and financial supporter of basic ecological research on the GSL. The royalty revenues and permit renewal fees from the brine shrimp industry have provided the financial basis for the highly successful Great Salt Lake Ecosystem Project (DWR). The brine shrimp industry was started by Mr. C.C. Sanders, of Sanders Brine Shrimp Co. in 1950 (Sturm, Sanders & Allen, 1980). From 1952 to 1988 there were generally only four brine shrimp harvesting companies working on the GSL. After 1988 the number of companies expanded in earnest—the number of companies increased until it reached a peak of 32 companies, and a total of 79 harvesting permits, in 1996. Although the number of companies has decreased since 1996, the number of permits remains the same. The brine shrimp industry has harvested from as little as 1.9 metric tons of brine shrimp cysts to a maximum of almost 12,000 metric tons during the 2000-2001 harvest season. The harvest results for the brine shrimp industry from 1990 to 2007 are shown in Figure 47.

Figure 47. Commercial brine shrimp cyst harvest results from 1990 to 2008. Values are reported in metric tons and are taken from harvest reports submitted to the State of Utah Division of Wildlife Resources. An aerial view of a harvesting operation underway is visible in the graph background.



Commercial harvesters of brine shrimp endeavor to selectively remove only the floating cysts and to avoid collecting any of the live brine shrimp. This is done by means of a harvesting vessel that tows floating containment barrier across the surface of the GSL consolidating the floating masses of cysts (Figure 48) and leaving behind the brine shrimp. The cysts are then pumped onto transport vessels by means of large filter sacks. The brine shrimp adults and other age-classes that are inadvertently collected are discarded back into the GSL to continue their lifecycle.

Figure 48. Brine shrimp harvesting vessel with consolidated cysts enclosed by floating containment barrier. The estimated haul from this collection of cysts is 12 to 14 tons wet weight.

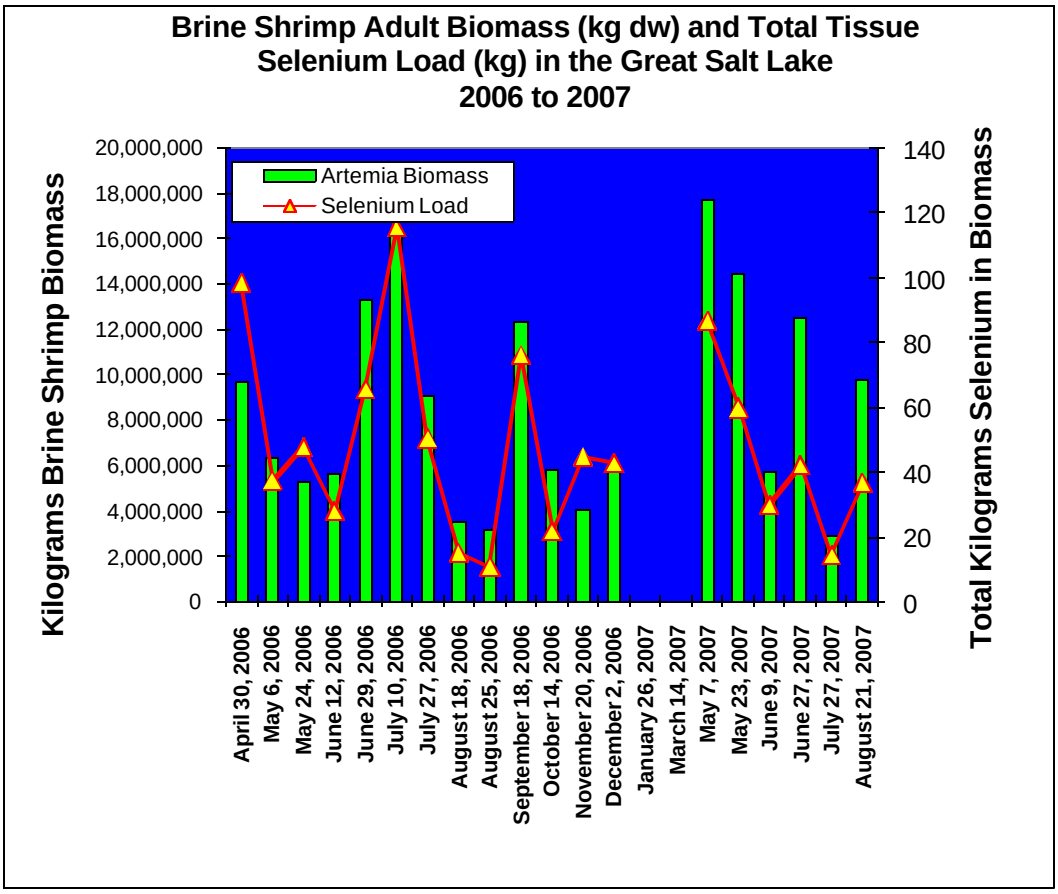
Because of the need to account for the mass balance of selenium in the GSL, it is necessary to calculate the removal quantity of selenium from the GSL via the brine shrimp harvest. The average 2007 selenium concentration in the nauplii/cyst fraction is 2.42 ug Se/g and can be used to determine the selenium removal from the GSL by the brine shrimp industry. This value represents the approximate concentration of selenium in the cysts and is more relevant than the brine shrimp adult selenium tissue value because the vast proportion of the brine shrimp biomass that is removed from the GSL by the brine shrimp industry is cyst biomass.

Although we don't have precise figures for industry dry yields, a recovery of 23% dry yield could be expected for an average harvest season. The brine shrimp industry removed 7,549 metric tons of cysts over the 2006-2007 season and 6,726 metric tons during the 2007-2008 harvest season (DWR, 2007). Using a nauplii/cyst selenium concentration of 2.42 ug Se/g dw, and a dry yield of 23%, the annual removal of selenium would be 4.20 kg for 2006 and 3.74 kg for 2007. According to Naftz et al. (2007) daily selenium loading into the GSL is between 0.6 kg Se/day to 9.8 kg Se/day. With regard to these loading values for selenium into the GSL, the removal of selenium by the brine shrimp industry is seemingly inconsequential for the mass balance of selenium in the GSL—it is the equivalent of selenium loading from a single day.

Mass Balance of Selenium in Brine Shrimp Tissue

The estimated GSL selenium load in the entire adult brine shrimp population, on any particular sampling date during the 2007 sampling season, was between 14.35 kg and 87.02 kg over the entire lake, with an average selenium load of 45.06 kg. These values are based on *Artemia* biomass statistics (mg dw/L), South Arm GSL elevation-to-volume relationships as determined by Baskin (2005), and adult tissue selenium concentration (ug Se/g dw). The values shown for the 2006 season are recalculated from the 2006 selenium values for adult brine shrimp using a correction factor for salt content. The 2006 values should only be used as a general estimate due to the use of the correction factor.

Figure 49. Brine shrimp biomass and the calculated selenium tissue load are shown for each sampling program. The total biomass of brine shrimp in the South Arm of the GSL is derived from the population counts and elevation/volume relationships determined by Baskin (2005) in his extensive bathymetric survey of the GSL.

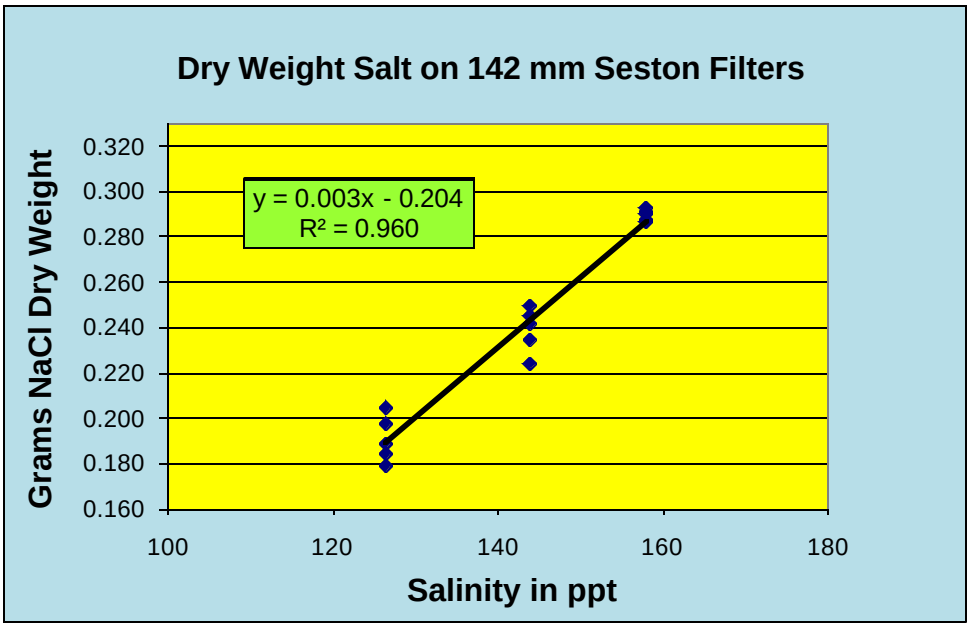


Selenium in Seston and Water during 2006 and 2007

Seston samples were collected by filtering between 1 and 5 liters of GSL water through a pre-weighed 0.45-micron (pore size), 142-mm, flatstock cellulose acetate filter. Filters and particulates, primarily algal cells, were freeze-dried and weighed. The entire filter and filtrate were then acid-digested and analyzed for selenium concentration. All sample weights were corrected for residual salt on filters based on the relationship between salinity and residual salt on filters shown in Figure 50. Blank filters were similarly

analyzed for selenium concentration to ensure that dry unused filters were below detection limits.

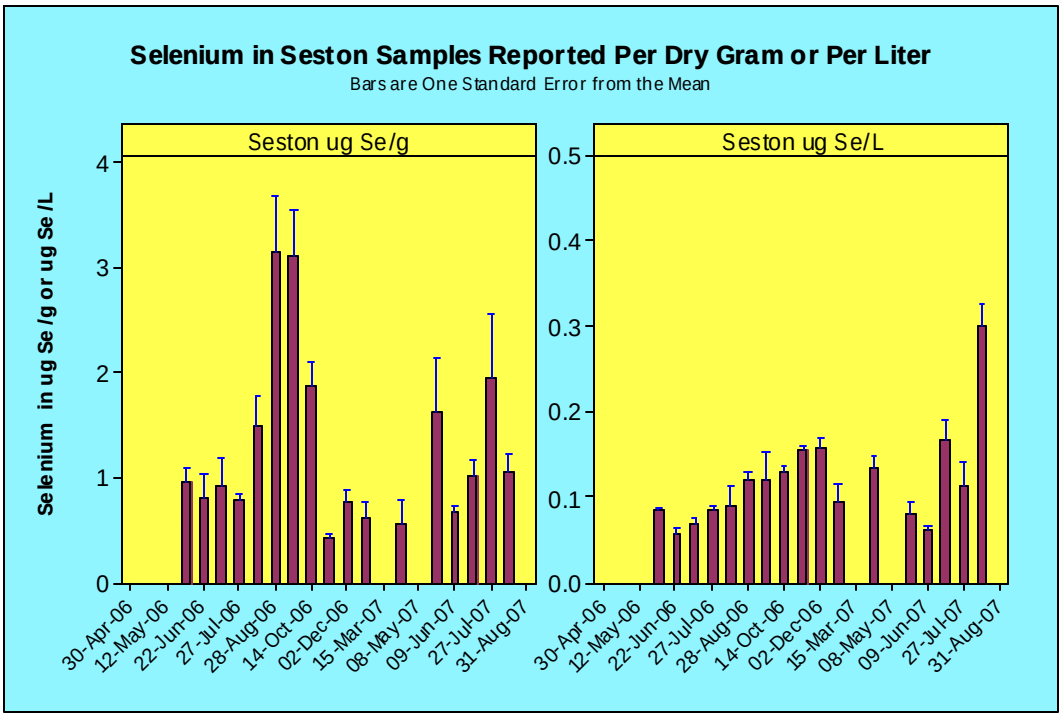
Figure 50. Correction curve for residual salt on 142 mm filters used to extract seston (particulates) from water samples. The curve was established using salt solutions that encompassed the range of salinity observed on the GSL over the 2006 and 2007 sample seasons. Residual salt was deducted from the final seston weight following which the selenium concentration in seston was recalculated on a dry weight basis.



The geometric mean for selenium in 2006 seston samples was 1.32 ug Se/g, and the arithmetic mean was 1.43 ug Se/g (Appendix 8.4). The geometric mean for selenium in 2007 seston samples was 0.86 ug Se/g, and the arithmetic mean was 1.08 ug Se/g. The highest selenium concentration in seston (3.16 ug Se/g) was on August 28, 2006, and the lowest concentration occurred on November 20, 2006 (0.44 ug Se/g) (Figure 51). The selenium concentration in seston on a volumetric basis was also calculated (the volume of GSL water filtered was recorded to the nearest 5 ml for all seston samples). The results show a geometric mean value for 2006 samples of 0.10 ug Se/L and an arithmetic

average of 0.11 ug Se/L. For the 2007 samples the geometric mean value was 0.13 ug Se/L and the mean concentration was 0.14 ug Se/L. The concentration of selenium in seston on a liquid volume basis is essentially the same as the calculated particulate fraction in water samples that are separately analyzed for total and dissolved selenium (total – dissolved = particulate). Our results for selenium in seston (ug Se/L) are very similar to the calculated particulate fraction for GSL water samples (0.14 ug Se/L) as reported by Johnson et al. (2007).

Figure 51. Selenium concentration in seston and water samples. Seston samples are expressed on a per-weight and per-volume basis. The concentration of selenium in seston (ug Se/L) shows an increasing temporal trend for both the 2006 and 2007 results. The 2006 trend corresponds to an increase in the phytoplankton population. This secondarily coincides with a decrease in grazing pressure following a reduction in the size of the *Artemia* population.



Spatial and temporal differences in seston selenium concentration were evaluated. There were no significant differences in terms of geographic region within each sample year for seston (Figures 52 and 53).

Figure 52. Selenium in seston samples collected in 2006 grouped according to geographic location.

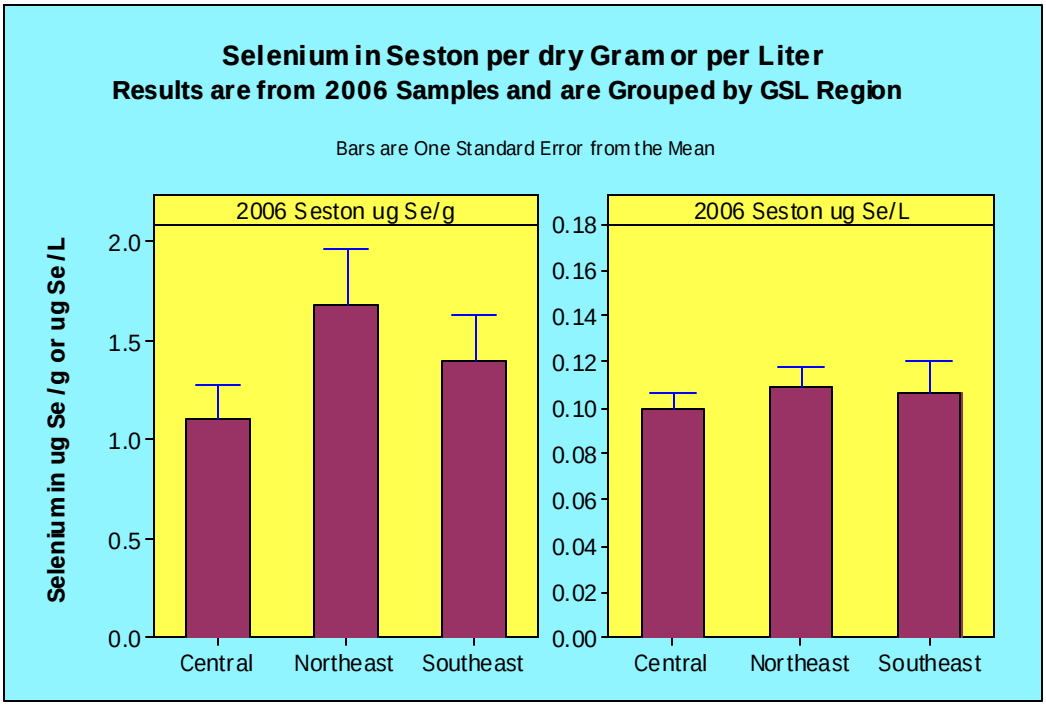
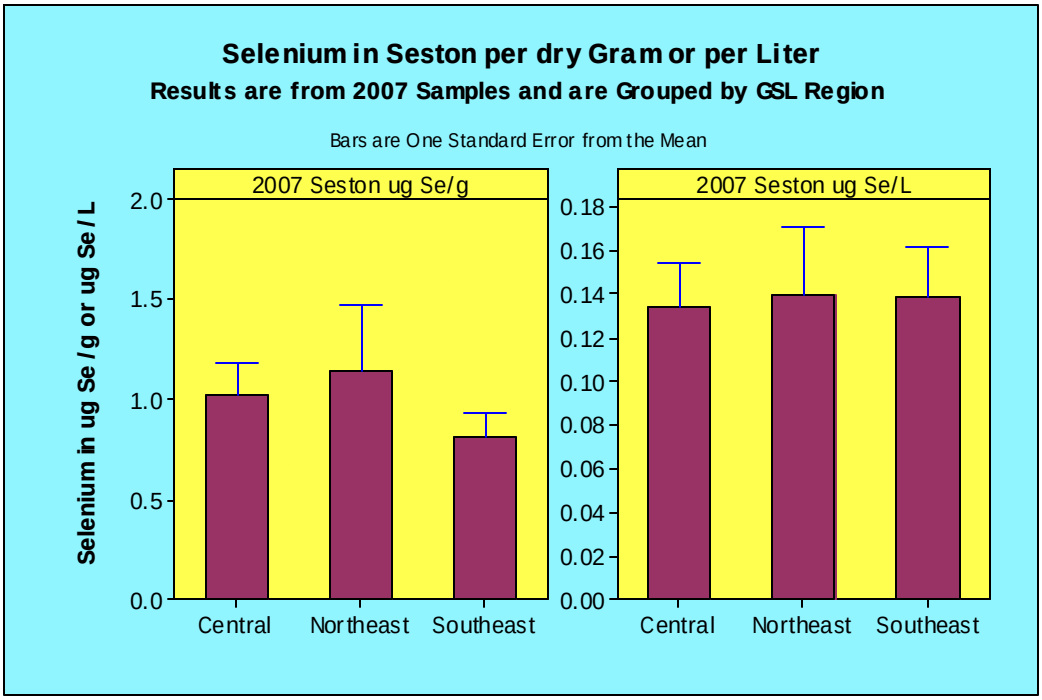


Figure 53. Selenium in seston samples collected in 2007 grouped according to geographic location.



Seston was evaluated according to the depth profile of the sample site (Figures 54 and 55). Grouping seston values according to depth profile did reveal a higher selenium concentration in the shallow sites from the 2006 samples. The average seston selenium concentration per liter for shallow sites in 2006 was 0.12 ug Se/L and it was significantly higher (P=0.048; 2, 60 DF) than the values for deep (0.10 ug Se/L) and medium depth sites (0.08 ug Se/L). There were no significant differences in seston values according to depth in 2007.

Figure 54. Selenium in seston samples collected in 2006 grouped according to depth profile.

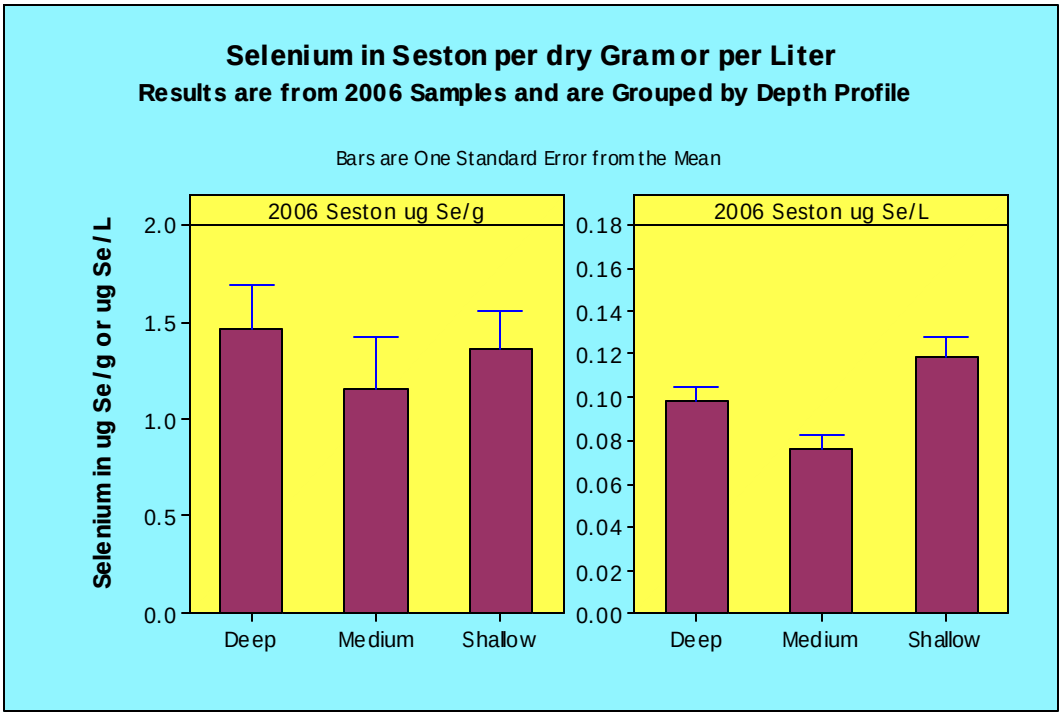
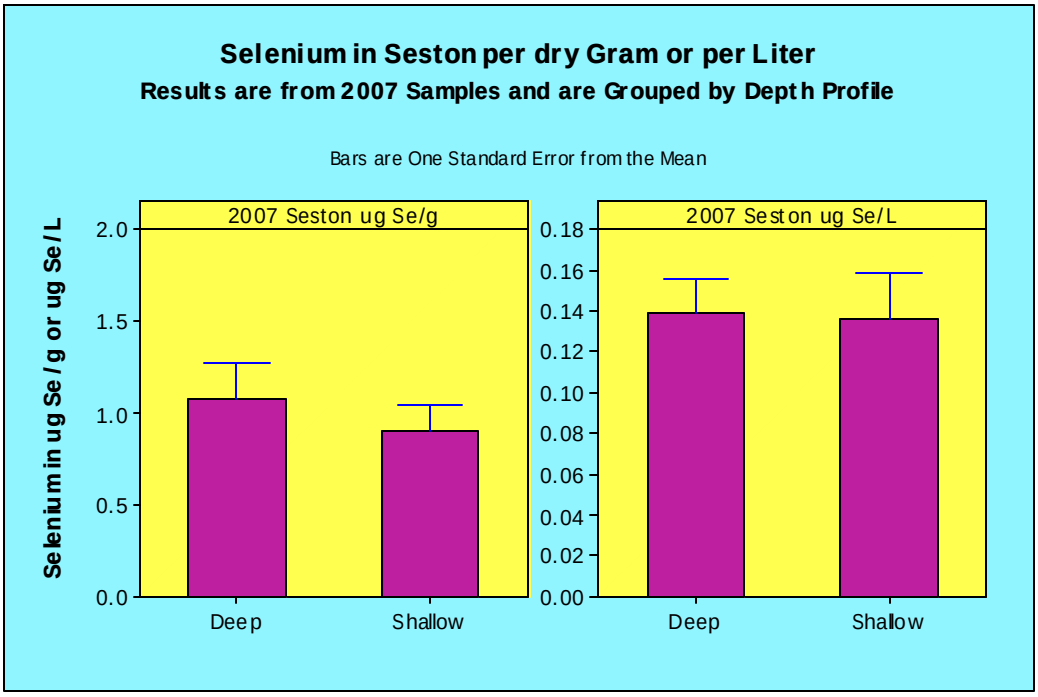
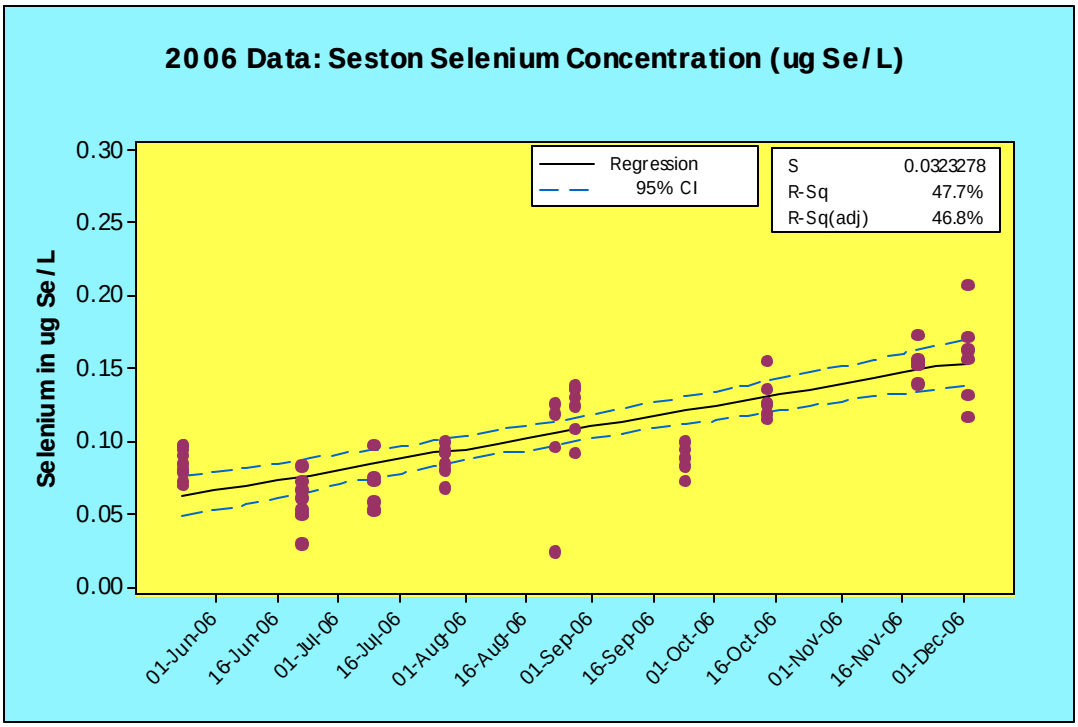


Figure 55. Selenium in seston samples collected in 2007 grouped according to depth profile.



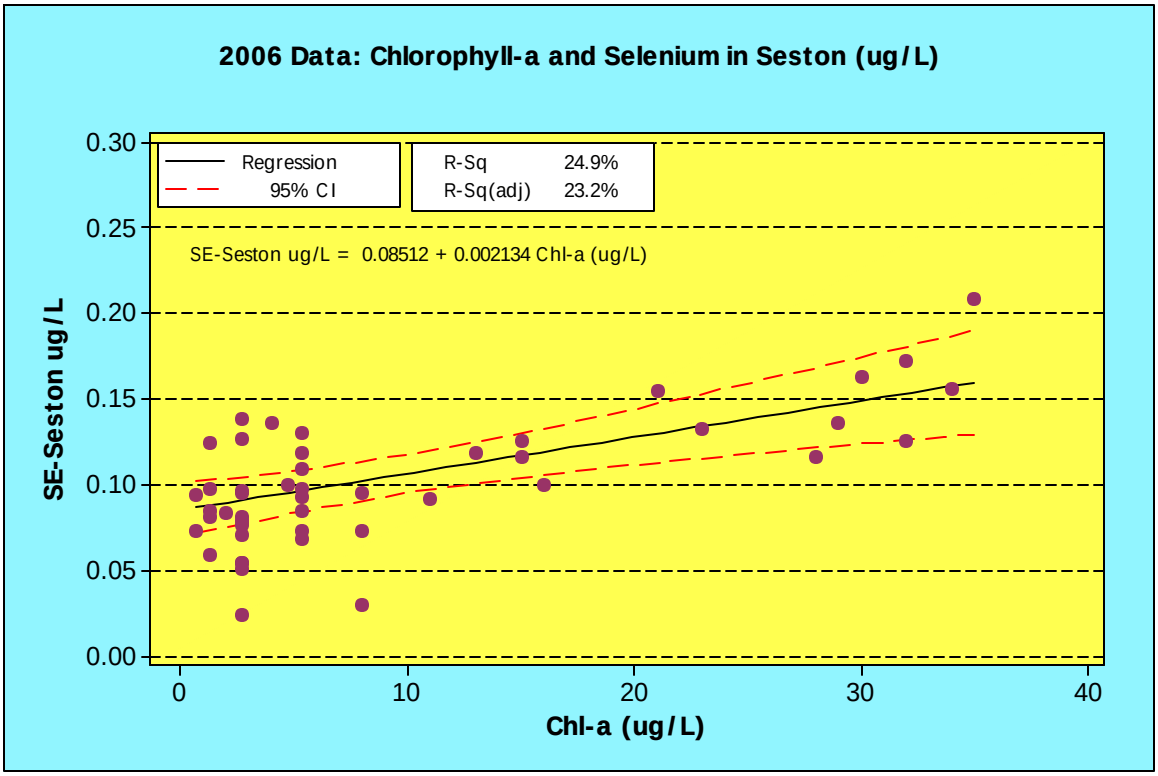
Temporally, the samples did substantially differ--there was a significant difference in the samples among the sampling dates (P=0.000; 16, 86 DF). Some interesting patterns in the seston data emerged. The concentration of selenium in the seston fraction on a dry weight basis increased sharply in August 2006 and then decreased substantially from October 2006 through March 2007. Alternatively, the seston concentration on a per volume basis showed a linear increasing trend from June 2006 to December 2006 (Figure 56). This increase generally followed the increase in algal growth over the same time period. This pattern of increasing particulate selenium was not as consistently observed from June to August 2007.

Figure 56. Selenium concentration in seston during 2006. From May to December 2006 there was a steady increase in the concentration of selenium in the particulate fraction of water.



This trend in 2006 can possibly be explained by the increase in algal growth, and therefore in the mass of algae per liter, attributable to decreased grazing pressure by the brine shrimp. To investigate this interpretation the seston results are plotted in terms of chlorophyll-a (Figure 57). There is a weak positive linear correlation ($R^2 = 0.24$) between increasing chlorophyll-a (i.e., increasing algal production) and the concentration of selenium in the particulate fraction of water. A linear relationship between chlorophyll-a and particulate selenium concentration in GSL water can be expected if chlorophyll-a is an accurate and linear measure of algal cell abundance, selenium uptake and loss in algal cells approaches equilibrium, and the pool of bioavailable selenium is not depleted by uptake into a rapidly growing algal population.

Figure 57. Relationship between chlorophyll-a concentration in GSL water and selenium concentration in suspended particulate matter. An increase in particulate selenium (ug Se/L) is expected to be correlated with algal population growth if there is no depletion in the selenium source and if uptake and loss approach equilibrium.



No such relationship was identified during 2007 for selenium in seston (ug Se/L) and chlorophyll-a.

Selenium in Water Samples

The results for selenium in unfiltered and filtered water varied temporally (Figure 58). Selenium in the water demonstrated a significantly increasing trend both within each year and across years. The temporal trend of selenium in water samples is more meaningfully evaluated within each year, rather than across years. There are annual or seasonal cycles in the GSL that may exert a profound influence on contaminant flux in the GSL. Some of

these cycles and seasonal events include spring run-off, phytoplankton production, brine shrimp population dynamics, evaporation cycles, hydrochemical cycling, thermal mixing, and weather events. The influence of these factors on the GSL hydrochemistry is both within and across years.

To discern some the trends in selenium in water samples the results for both total selenium and dissolved selenium in water samples were statistically evaluated for the entire 2-year study period and within each year. The results are shown in Figures 58 and 59 for total selenium in unfiltered GSL water and in Figures 60 and 61 for dissolved selenium in filtered GSL water.

Figure 58. Temporal trend of total selenium in unfiltered GSL water from May 2006 through August 2007.

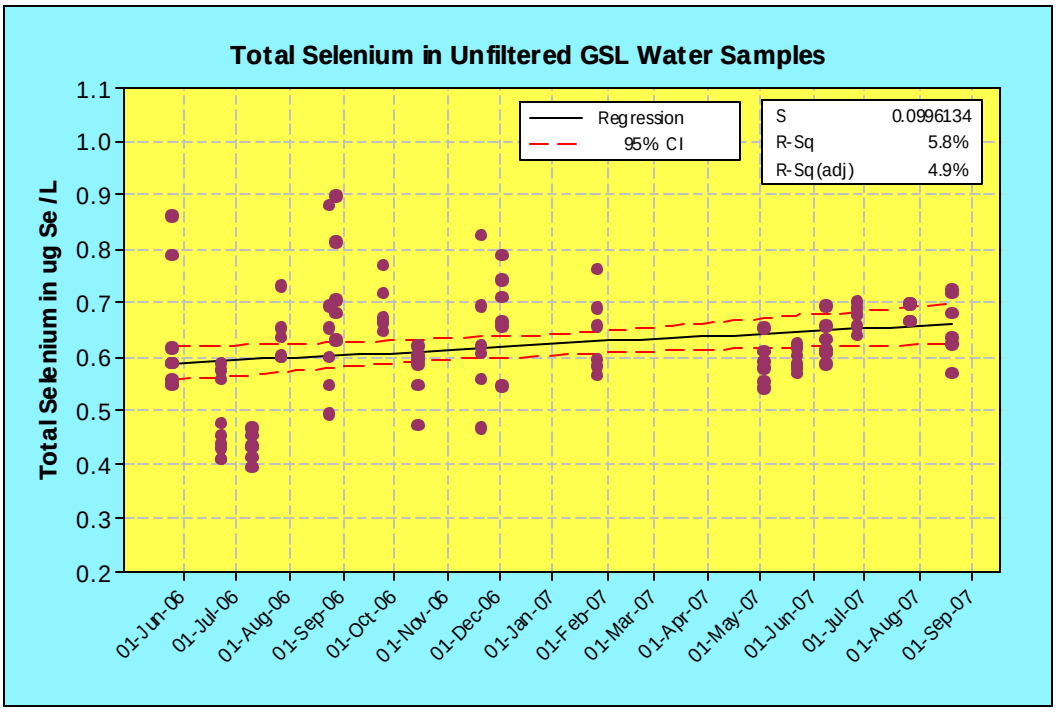
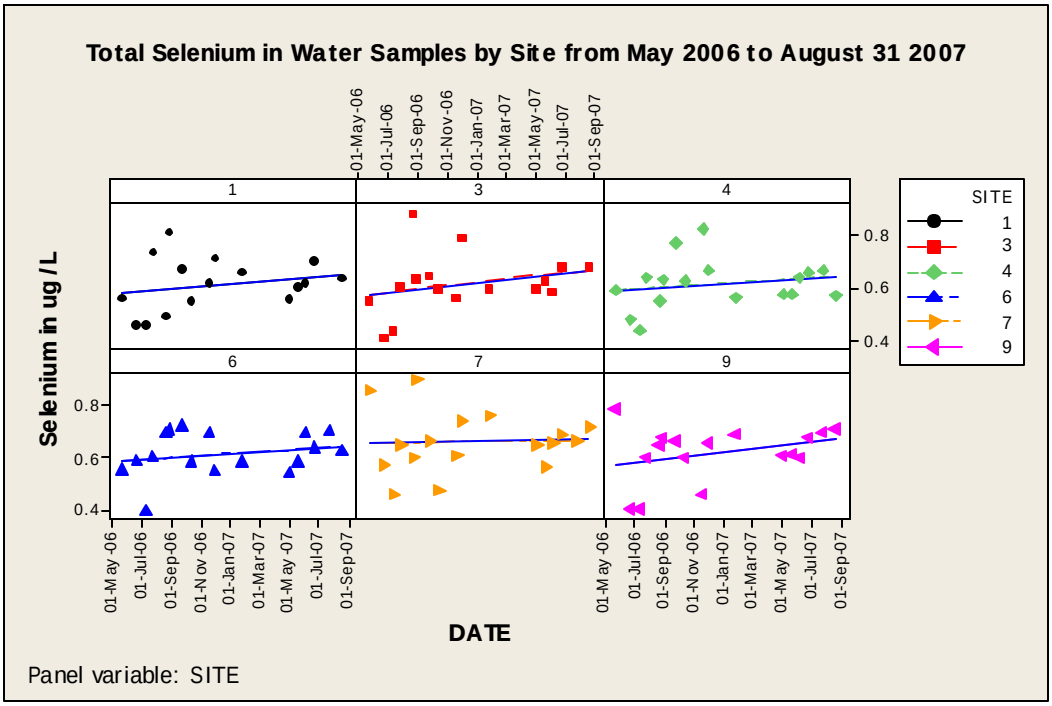


Figure 59. Temporal trend of total selenium in unfiltered GSL water from May 2006 through August 2007 for each sample site.

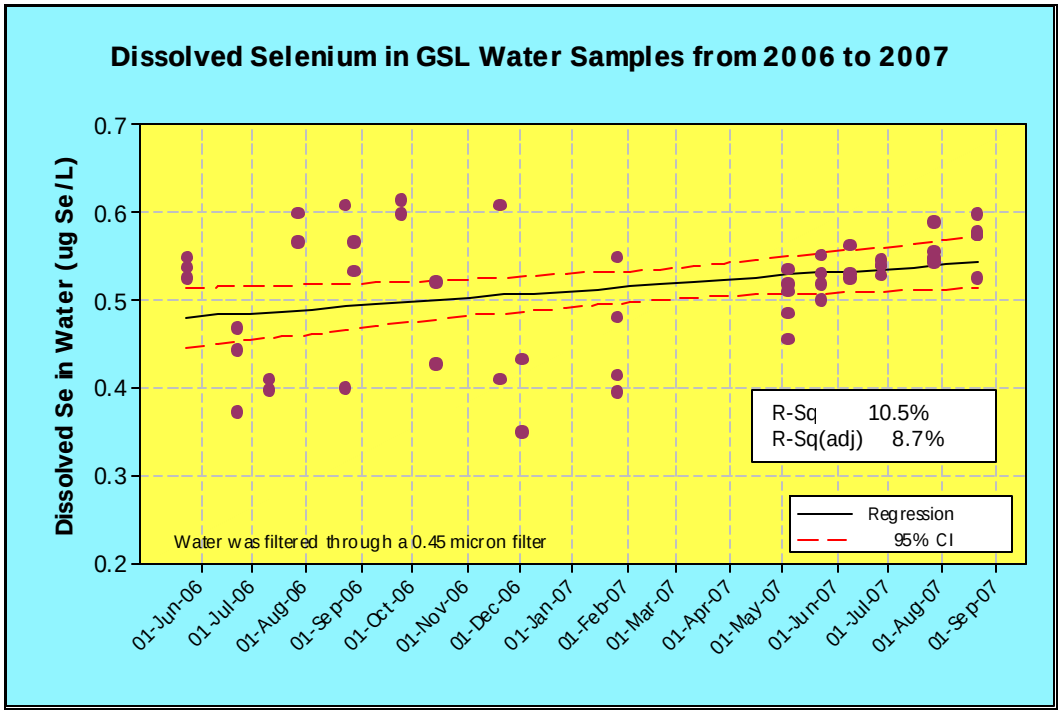


The temporal pattern for total selenium in water for the entire lake and for each sample site indicated a positive increase over time. However, there was considerable variability in the 2006 data that limited the ability to statistically identify a significant positive trend. Because total selenium in water samples includes the particulate fraction there can be overlapping events, such as phytoplankton population growth, that may obscure patterns of dissolved selenium flux in the water column.

Dissolved selenium values in GSL water samples from May 2006 to August 2007 are shown in Figure 60. The pattern for dissolved water showed a more definitive increasing trend in selenium concentration, especially when the 2007 results were evaluated

separately from the 2006 data. As was observed in the samples for total selenium, the 2006 values were considerably more variable than those in 2007. There were some issues of laboratory recoveries in 2006 that may have contributed to the outcome of the analyses. Sample collection, preparation, and handling procedures were essentially the same for both 2006 and 2007, though there were longer storage times and a lower storage temperature for some the early 2006 samples.

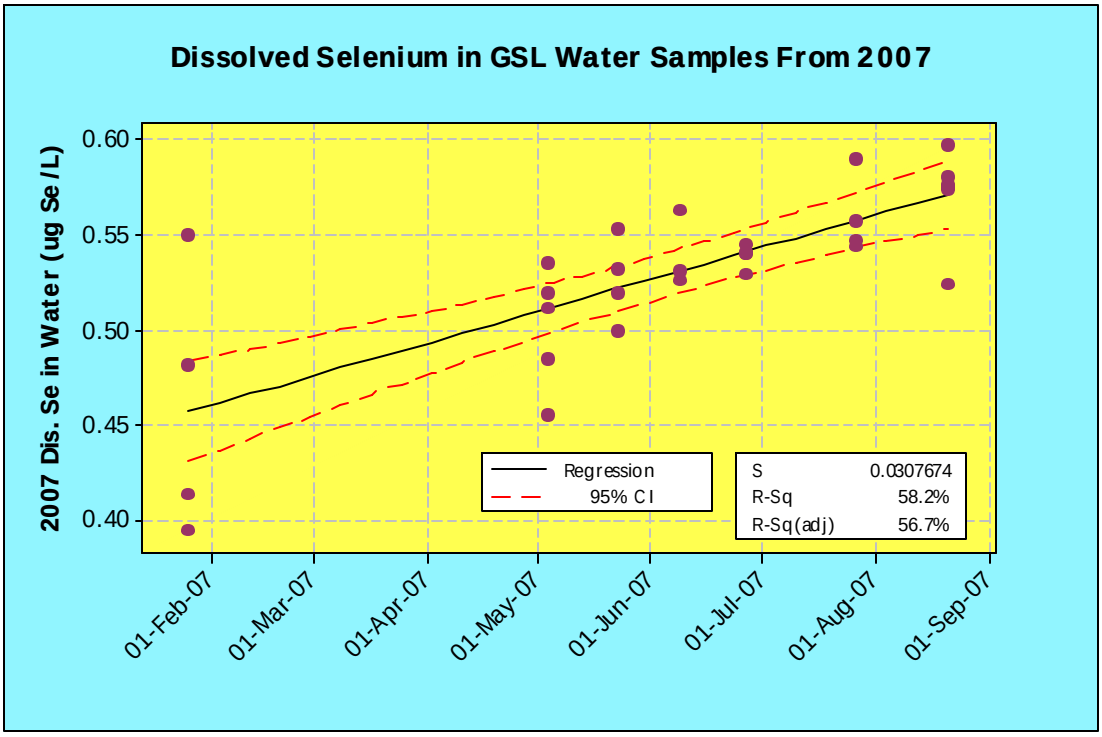
Figure 60. Dissolved selenium in filtered GSL water samples collected from May 2006 to August 2007.



The 2007 results for dissolved selenium in water samples did show a definitive increase in selenium concentration. There was a positive linear relationship between sample date and dissolved selenium in 2007 GSL water samples (Figure 61). The 2007 results for

dissolved selenium indicate an increase from an average of 0.46 ug Se/L in January to 0.57 ug Se/L in August 2007. According to Naftz et al. (2007) the expected increase over the 15 months from May 2006 to July 2007 for dissolved selenium in GSL water is 0.17 ug Se/L. The overall increase in dissolved selenium that we observed over the 8 month period from January to August 2007 of 0.11 ug Se/L does lend support to the estimate by Naftz et al. (2007).

Figure 61. Dissolved selenium in filtered GSL water samples collected from January 2007 to August 2007. A regression analysis of within year selenium concentration in water samples provides an improved interpretation and analysis of the trends.



The geometric mean of total selenium in unfiltered water for 2006 was 0.61 ug Se/L and the arithmetic mean was 0.60 ug Se/L (Appendix 8.5). The lowest and highest average

daily concentration of selenium in water from May 2006 to Aug 2007 was 0.43 ug Se/L (July 10, 2006) and 0.73 ug Se/L (August 28, 2006). An average net change from one sample period to the next for the entire study was 0.026 ug Se/L (Table 11).

Table 11. Net change in arithmetic mean selenium concentration (ug Se/L) in GSL water samples. Net change is determined on each subsequent sampling date for all sample locations. The result indicates a net increase of 0.026 ug Se/L.

Change in Average Water Selenium Concentration for All Sample Sites by Sampling Date.		
	ARITHMETIC	Net Change
DATE	MEAN	From Previous
		Date (ug/L)
April 30, 2006	No Data	No Data
May 4, 2006	No Data	No Data
May 12, 2006	No Data	No Data
May 24, 2006	0.634	xx
June 22, 2006	0.484	-0.150
July 10, 2006	0.418	-0.066
July 27, 2006	0.639	0.221
August 23, 2006	0.554	-0.085
August 28, 2006	0.718	0.164
September 24, 2006	0.691	-0.027
October 14, 2006	0.572	-0.119
November 20, 2006	0.630	0.058
December 2, 2006	0.668	0.037
January 27, 2007	0.644	-0.023
May 4, 2007	0.590	-0.055
May 23, 2007	0.597	0.008
June 9, 2007	0.633	0.036
June 27, 2007	0.676	0.043
July 27, 2007	0.684	0.008
August 21, 2007	0.660	-0.024
Avg Net Change		**0.026**

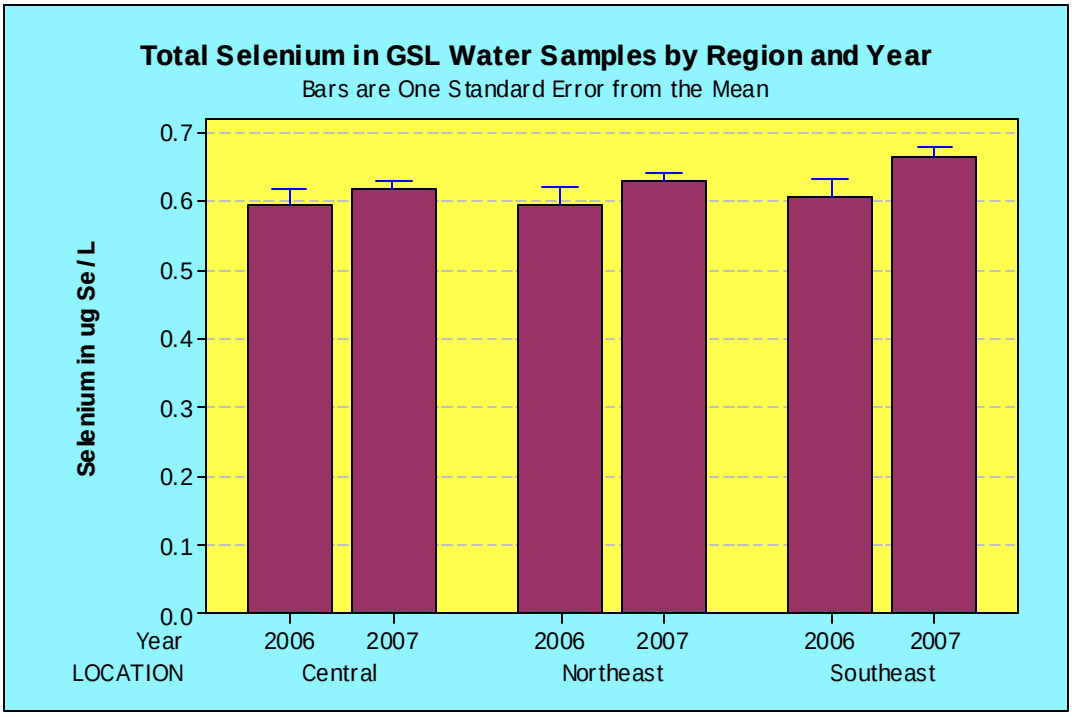
Mean Selenium Concentration in Unfiltered Water (ug Se/L)		
Year	Mean	Standard Deviation
2006	0.60	0.12
2007	0.64	0.05
2006 & 2007	0.61	0.10

The net change in total selenium in GSL water for each sequential sampling program varies considerably. In addition, the average net change in selenium concentration over time is substantially lower than the statistic comparing the overall change in selenium

from January 2007 to August 2007 for dissolved selenium in water (0.11 ug Se.L). Because of these differences in impression from dissolved and total selenium in water samples, on-going monitoring programs of selenium accumulation in the GSL should include both total and dissolved selenium assessments.

Spatial comparisons of total selenium in GSL water samples did not show any statistically significant difference across geographic regions (P = 0.736; df: 2, 63).

Figure 62. Selenium in unfiltered GSL water samples sorted by region and year.



The data suggest that there are temporal events that influence selenium loading into specific trophic compartments. The source of these temporal events is not entirely clear, but may be more apparent once the data from all research programs are integrated and interpreted collectively.

Trophic Transfer Relationships for Selenium in the GSL

For the purposes of understanding selenium dynamics in the GSL ecosystem it is essential to derive a quantifiable relationship between trophic levels. Selenium transfer between linked trophic components was evaluated using regression analysis. No

statistically significant polynomial regression relationship across all measurements of selenium in water, seston, and brine shrimp tissue was observed. The results for the 2006 and 2007 data are shown in Figures 63 and 64.

Figure 63. Scatter plot of selenium in brine shrimp tissue and seston or water for samples collected in 2007. There is no statistically significant polynomial regression relationship for selenium concentration between these trophic compartments. All P values were >0.100 and all R-squared values for the fitted lines were <0.10.

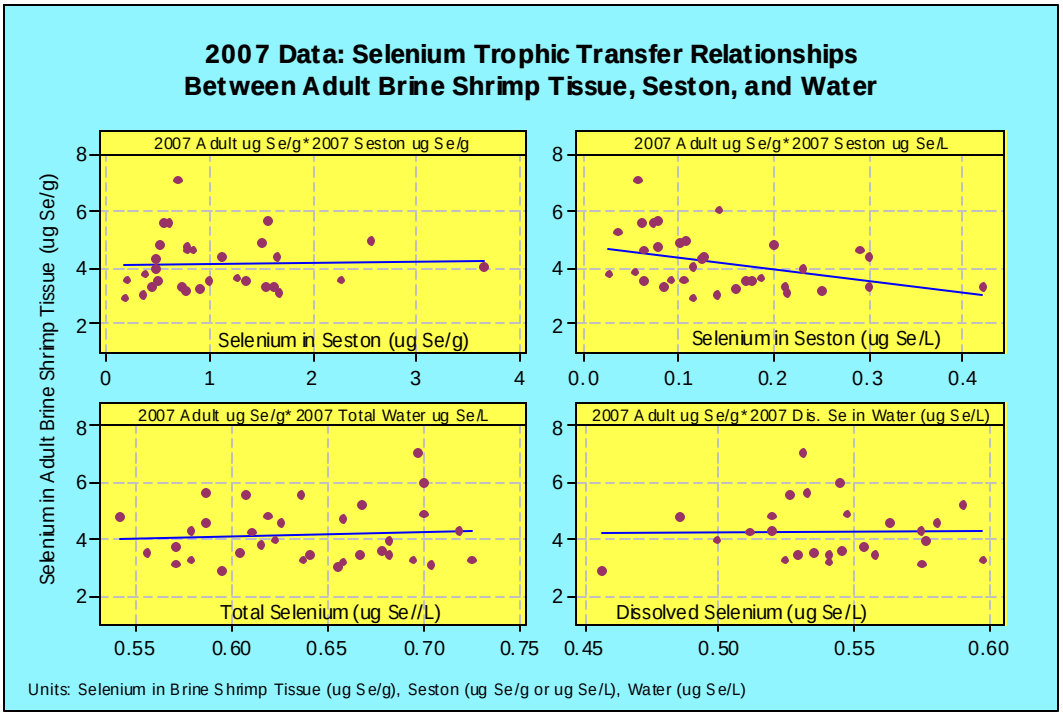
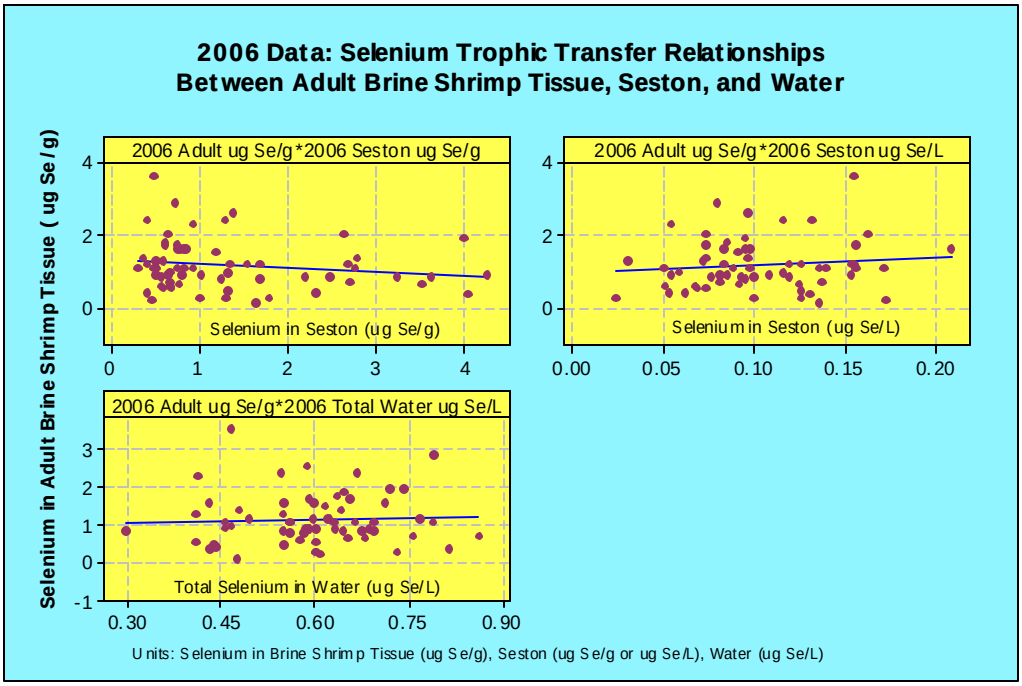


Figure 64. Scatter plot of selenium in brine shrimp tissue and seston or water for samples collected in 2006.



This outcome is not surprising given the small range of exposure concentrations encountered on the GSL. For example, the total range over which *Artemia* are exposed to dissolved selenium in the water is a mere 0.18 ug Se/L (0.39 to 0.57 ug Se/L) and the exposure range in the seston is 2.72 ug Se/g or 0.24 ug Se/L. It is indeed quite difficult to identify uptake patterns in selenium by invertebrates over such a small range of source concentrations.

Other investigators have previously reported a weak relationship between low concentrations of selenium in water and algae and brine shrimp tissue. In the presentation given to the science panel (November 2006), Dr. Marge Brooks indicated

that in the range of 1 to 11 ug Se/L selenium in water there is a poorly defined relationship with brine shrimp tissue selenium levels. Brooks further inferred that at these low environmental concentrations the brine shrimp are regulating their selenium levels in a manner largely independent of exposure concentration. The concentration of selenium in water for all sample dates and locations in our study was well below 11 ug Se/L. We concur with the observation of Brooks that there is a poorly defined relationship between brine shrimp tissue concentrations and exposure to selenium in water or algae at such low concentrations.

Because of the inability to derive a statistically meaningful polynomial regression relationship for selenium between trophic levels within the GSL, transfer factors are examined as an alternative means of interpreting the flow of selenium through the GSL food web. Transfer factors have been used by other authors to describe the relationship between selenium in soil and ephemeral pools (Byron et al., 2003). The partitioning values (Kds) from water (dissolved selenium) to seston were calculated for results from 2006 and 2007 (Table 12). Transfer factor relationships from seston and water to brine shrimp adults for co-located samples (by date and location) were determined for the 2007 results and are also reported in Table 12. The data from 2006 for selenium in adult brine shrimp was adjusted with a correction factor and then used to determine transfer factors for the combined 2006 and 2007 data. It should be reiterated that there is a increased uncertainty in the 2006 data as a result of the application of a correction factor. All statistics were calculated using least squares regression analysis.

The partition coefficients (Kd) for selenium transfer from dissolved water concentration to seston were quite similar for both 2006 and 2007 data. The 2007 Kd was 1841 and the 2006 Kd was 2254. Analyzing all seston values and all dissolved selenium values collectively gives a Kd of 1994. The transfer factor for selenium in seston (dry weight) to adult brine shrimp tissue was 2.57. As anticipated, the TF for the naupliar fraction was lower than for the adults and was 1.57. Combining all values for selenium in adult brine shrimp tissue, and after applying a correction factor to the 2006 data, the overall TF was 1.78. The trophic relationships between selenium in unfiltered and filtered water to adult brine shrimp tissue (BCF) are also listed. In 2007 the BCF values were 6494 for total selenium in water to brine shrimp tissue and 7634 for dissolved selenium to adult brine shrimp tissue. In naupllii these BCF values were 4014 for total selenium in water and 4818 for dissolved selenium. The combined 2006 and 2007 BCF values were 5964 for total selenium in water and 7613 for dissolved selenium. Residuals were analyzed for goodness of fit and for a normal distribution. Residual plots are shown in Figure 65 and 66 for the combined and corrected 2006 and 2007 adult selenium tissue data.

Table 12. Trophic transfer relationships for selenium in GSL water and biota. Statistics were calculated using least squares regression. P values for all statistics were P=0.000.

	TROPHIC TRANSFER RELATIONSHIPS Selenium in GSL Water and Biota		COEFFICIENT		
Data	**Response Source**	**Predictor Source**	**Kd**	**TF**	**BCF**
			Water (ppm Se) to Seston (ug Se/g)	Seston (ug Se/g) to BS (ug Se/g)	Water (ppm Se) to BS (ug Se/g)
2007	Adult Brine Shrimp	Seston (dry)		2.57	
2007	Adult Brine Shrimp	Unfiltered Water (Total Se)			6494
2007	Adult Brine Shrimp	Filtered Water (Dissolved Se)			7634
2007	Nauplii Brine Shrimp	Seston (dry)		1.57	
2007	Nauplii Brine Shrimp	Unfiltered Water (Total Se)			4014
2007	Nauplii Brine Shrimp	Filtered Water (Dissolved Se)			4818
2006 &2007	Adult Brine Shrimp (2006 data x CF)	Seston (dry)		1.78	
2006 &2007	Adult Brine Shrimp (2006 data x CF)	Unfiltered Water (Total Se)			5964
2006 &2007	Adult Brine Shrimp (2006 data x CF)	Filtered Water (Dissolved Se)			7613
2007	Seston (dry)	Filtered Water (Dissolved Se)	1841		
2006	Seston (dry)	Filtered Water (Dissolved Se)	2254		
2006 & 2007	Seston (dry)	Filtered Water (Dissolved Se)	1994		

LEGEND
CF: Correction Factor (used for 2006 adult brine shrimp Se concentration only)
BS: Brine Shrimp
SE: Selenium
TF: Transfer Factor
BCF: Bioconcentration Factor
Kd: Partition Coefficient

Figure 65. Normal probability plot for residuals from the regression analysis of selenium in adult brine shrimp tissue and seston selenium concentration.

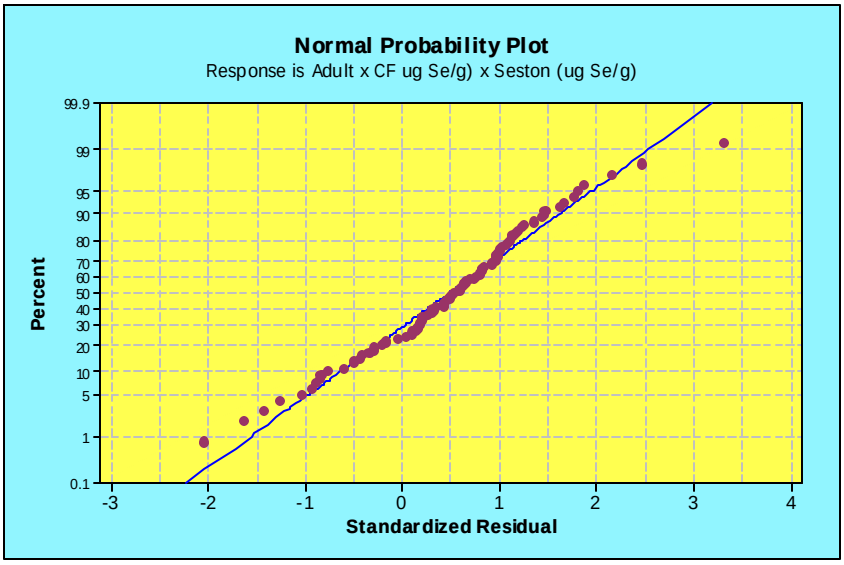
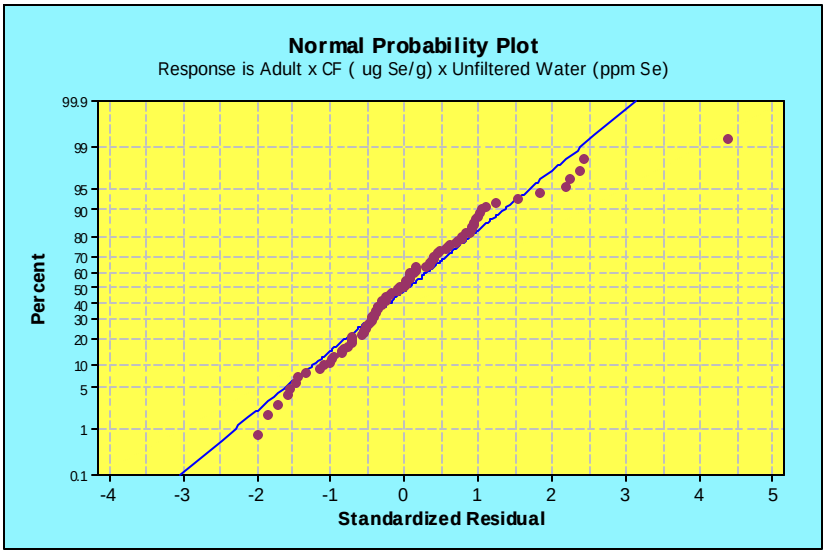


Figure 66. Normal probability plot for residuals from the regression analysis of selenium in adult brine shrimp tissue and total selenium concentration in unfiltered water.



CONCLUSION

This report contains summary findings from a pelagic study of the GSL investigating selenium in water, seston, and brine shrimp conducted from April 2006 to August 2007. In addition to a survey of selenium in water and biota, an extensive effort was made to document the population characteristics of resident brine shrimp and phytoplankton. Some aspects of the research were modified to improve the accuracy of results during the 2007 season.

The results of the brine shrimp population data show population cycles, reproductive output, biomass production, and cyst accumulation in the water column that are indicative of a 'healthy' brine shrimp population. All of the reproductive parameters investigated were within the range of values reported for the GSL over the past decade. There is no indication of any serious adverse effects on the brine shrimp population during 2006 and the spring of 2007. Brine shrimp biomass was available as a food source throughout the study period for aquatic and semi-aquatic birds.

The phytoplankton population was dominated by algae (e.g., Chlorophyceae) that are generally quite favorable and nutritious as a prey base for brine shrimp. The algal population demonstrated an ability to rapidly respond to release from *Artemia* grazing pressure and to effectively re-colonize the water column following the collapse of the brine shrimp population. Chlorophyll concentrations were lower than some previous years, but the winter concentration (41.7 ug Se/L) was sufficiently high to indicate an

abundant nutritional foundation for the emerging brine shrimp population in the spring of 2007.

The results from this two-year study indicate that selenium is found across all sample locations and sample dates in water, seston, and brine shrimp tissue. The mean concentration of selenium in water documented from May 2006 to December 2006 (0.60± 0.11 ug Se/L) corresponds well to the results of other concurrent studies (0.56 ± 0.18 ug Se/L) (Naftz et al., 2007; Johnson et al., 2007). The cumulative net change in total selenium in unfiltered water for all sample locations that were surveyed over this same time period in 2006 was an increase of 0.098 ug Se/L. The mean concentration of selenium in unfiltered GSL water from January 2007 to August 2007 was 0.64 ±0.05 ug Se/L, and the dissolved concentration of selenium in GSL water was 0.53 ±0.05 ug Se/L. The dissolved selenium concentration in filtered GSL water increased from January to August 2007 by 0.11 ug Se/L.

The average dry-weight selenium concentration in seston for 2006 was 1.43 ± 0.58 ug Se/g and for 2007 it was 1.08 ± 0.57 ug Se/g. Seston selenium values were alternatively used to determine the particulate fraction of selenium in the water phase. The average seston value per liter of GSL water filtered in 2006 was 0.11 ± 0.03 ug Se/L and for 2007 it was 0.14 ± 0.04 ug Se/L. This is in agreement with values reported by Johnson (2007) for the particulate fraction of GSL water (0.14 ug Se/L).

The measured concentration of selenium in adult brine shrimp tissue in 2006 (1.18 ug Se/g) was about 1.4 ug Se/g below previous studies on the GSL (Brix et al., 2004; Adams, 2005). Procedurally there were differences in the handling, cleaning, and sorting of brine shrimp in our study relative to others that may have had some effect on the selenium calculations. It was determined that residual salt in the 2006 adult brine shrimp samples resulted in artificially low values. A correction factor was applied to the 2006 data to allow for some comparisons to 2007 results. The mean corrected value for 2006 brine shrimp adults was 3.71 ug Se/g. Brine shrimp adults collected in 2007 showed a mean concentration of 4.32 $\pm$ 0.95 ug Se/g, while the value for nauplii was 2.42 $\pm$ 0.53 ug Se/g.

Younger age-classes of brine shrimp were analyzed for tissue selenium, and the results show substantially lower concentrations than those found for adults (53.8% of adults). The average selenium concentration in brine shrimp collected and analyzed were below the critical 5 mg/kg dietary level for protection of birds. However, there may be concerns among the brine shrimp industry members because the risk level for fish begins at 3.0 ug Se/g for diet items (Hamilton, 2003; Hamilton, 2004). The cyst level remains below this threshold at 1.77 ug Se/g, but the potential use of GSL brine shrimp biomass as a food source for finfish may already be compromised by the level of selenium.

Trophic transfer relationships were determined for selenium from water to seston and from seston to brine shrimp. The results from the 2007 study show a Kd of 1841 for dissolved selenium in water to seston. The transfer factor of selenium from seston to

adult brine shrimp is 2.57. The bioconcentration factor (BCF) for total selenium in GSL water to adult brine shrimp tissue is 6494 and the BCF for dissolved selenium is 7634. These values are our best current estimate of the trophic relationships for selenium in water, seston and adult brine shrimp.

The draft report submitted for this study in 2007 did not find the trophic transfer relationships to be sufficiently robust to use for management purposes. In contrast, the improved sample preparation methods in the 2007 study, consistency of the results with other concurrent research investigations on the GSL, and the results from inferential statistics all lend substantial credibility to the results from 2007. The trophic transfer relations can, and should, be used for management purposes and for advancing our understanding of the dynamics of selenium in the GSL ecosystem.

APPENDIX 1.1: DESCRIPTIVE STATISTICS FOR LIMNOLOGICAL CONDITIONS

Dissolved Oxygen Expressed as Percent Saturation

Dissolved Oxygen (% Saturation) by Sample Depth						
		April 2006 to June 2007				
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	90.7	32.1	35.4	27.0	211.0	135
2	99.2	40.7	41.0	42.7	214.0	45
3	77.7	28.4	36.6	12.0	144.9	90
5	66.7	30.2	45.3	0.2	148.4	90
6	61.2	26.3	43.1	0.7	107.3	90
7	1.8	2.2	120.8	0.1	8.9	45
8	0.7	0.2	28.6	0.5	0.9	45

Salinity in g/L

Salinity by Sample Depth						
		April 2006 to June 2007				
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	129.1	10.9	8.5	110.0	147.2	135
2	129.2	8.3	6.4	118.0	144.0	45
3	129.1	9.9	7.7	111.0	146.0	90
5	131.5	9.4	7.1	116.0	150.0	90
6	140.0	9.8	7.0	120.0	165.0	90
7	160.7	25.9	16.1	120.2	225.0	45
8	192.0	22.4	11.6	152.0	233.0	45

APPENDIX 1.2: DESCRIPTIVE STATISTICS FOR LIMNOLOGICAL CONDITIONS

Temperature in Degrees Centigrade

Water Temperature (degrees Centigrade) by Sample Depth						
		April 2006 to June 2007				
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	18.7	8.3	44.4	(2.0)	29.5	135
2	17.4	9.7	55.8	(1.9)	28.8	45
3	18.5	8.0	43.2	(2.1)	28.4	90
5	17.8	8.0	45.0	(2.0)	28.2	90
6	17.9	9.1	51.0	(2.0)	28.1	90
7	15.7	5.9	37.4	2.3	25.1	45
8	13.3	4.3	32.4	4.0	19.8	45

APPENDIX 2.1: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Adult *Artemia* Statistics

Artemia Adult (M+F) per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	1266	934	74	676	3341	7
May 6, 2006	913	318	35	411	1253	8
May 24, 2006	828	437	53	335	1879	9
June 12, 2006	1127	671	60	462	2040	6
June 29, 2006	2426	1515	62	921	5829	9
July 10, 2006	3722	7152	192	396	18307	6
July 27, 2006	674	939	139	93	2557	6
August 18, 2006	550	958	174	34	2498	6
August 25, 2006	205	126	61	102	411	6
September 18, 2006	2054	3725	181	185	9626	6
September 24, 2006	710	452	64	362	1468	5
October 14, 2006	619	492	79	0	1383	6
November 20, 2006	844	281	33	540	1222	6
December 2, 2006	582	463	80	159	1485	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	1516	1672	110	115	3819	6
May 23, 2007	1297	1461	113	170	4099	6
June 9, 2007	431	399	93	149	1218	6
Arithmetic Mean	**1,127**					
Standard Dev.	**2,039**					
Median	**620**					

APPENDIX 2.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Adult *Artemia* Statistics

Artemia Adult Male per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	626	619	99	258	2,015	7
May 6, 2006	465	215	46	191	772	8
May 24, 2006	327	242	74	140	958	9
June 12, 2006	563	326	58	213	922	6
June 29, 2006	1,178	812	69	492	3,082	9
July 10, 2006	1,767	3,334	189	189	8,565	6
July 27, 2006	404	534	132	62	1,468	6
August 18, 2006	306	483	158	21	1,283	6
August 25, 2006	131	81	61	67	286	6
September 18, 2006	1,045	1,899	182	132	4,904	6
September 24, 2006	345	173	50	222	645	5
October 14, 2006	363	320	88	0	887	6
November 20, 2006	426	157	37	244	669	6
December 2, 2006	266	233	88	83	726	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	862	936	109	76	2,357	6
May 23, 2007	524	541	103	127	1,553	6
June 9, 2007	190	173	91	79	535	6
Arithmetic Mean	**556**					
Standard Dev.	**988**					
Median	**284**					

APPENDIX 2.3: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Adult *Artemia* Statistics

Artemia Adult Female per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	640	323	50	348	1,326	7
May 6, 2006	448	142	32	220	642	8
May 24, 2006	501	227	45	195	921	9
June 12, 2006	564	356	63	249	1,133	6
June 29, 2006	1,248	736	59	387	2,747	9
July 10, 2006	1,955	3,818	195	207	9,742	6
July 27, 2006	270	405	150	29	1,089	6
August 18, 2006	244	476	195	13	1,215	6
August 25, 2006	73	57	78	34	165	6
September 18, 2006	1,008	1,827	181	44	4,722	6
September 24, 2006	365	282	77	141	823	5
October 14, 2006	256	176	69	0	496	6
November 20, 2006	418	131	31	295	611	6
December 2, 2006	316	235	74	76	760	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	654	819	125	38	2,122	6
May 23, 2007	773	921	119	42	2,546	6
June 9, 2007	241	228	95	70	683	6
Arithmetic Mean	**571**					
Standard Dev.	**1,064**					
Median	**331**					

APPENDIX 3.1: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Nauplii per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	684	595	87	159	1,697	7
May 6, 2006	935	1,559	167	0	4,444	8
May 24, 2006	341	232	68	0	723	9
June 12, 2006	694	640	92	127	1,697	6
June 29, 2006	21,737	15,521	71	8,381	52,980	9
July 10, 2006	326	558	171	0	1,414	6
July 27, 2006	3,847	3,730	97	931	10,183	6
August 18, 2006	2,890	285	10	2,418	3,235	6
August 25, 2006	1,273	635	50	358	1,949	6
September 18, 2006	251	226	90	1	643	6
September 24, 2006	194	222	115	30	557	5
October 14, 2006	966	1,433	148	0	3,819	6
November 20, 2006	1,584	1,306	82	91	3,501	6
December 2, 2006	1,033	1,599	155	0	4,243	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	36,417	30,339	83	2,864	70,873	6
May 23, 2007	34,948	29,553	85	7,081	73,988	6
June 9, 2007	737	830	113	68	1,856	6
Arithmetic Mean	**6,222**					
Standard Dev.	**15,114**					
Median	**733**					

APPENDIX 3.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Meta-Nauplii per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	1112	763	69	424	2387	7
May 6, 2006	443	533	120	0	1697	8
May 24, 2006	751	646	86	106	2015	9
June 12, 2006	657	777	118	71	2130	6
June 29, 2006	38312	43935	115	8465	147707	9
July 10, 2006	2146	1903	89	341	5445	6
July 27, 2006	35563	32367	91	2400	95470	6
August 18, 2006	19133	13423	70	6434	43803	6
August 25, 2006	9948	3173	32	7637	15276	6
September 18, 2006	1125	1034	92	318	3050	6
September 24, 2006	695	682	98	0	1667	5
October 14, 2006	835	513	61	182	1697	6
November 20, 2006	2792	3165	113	364	8910	6
December 2, 2006	1003	808	81	0	2122	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	10973	11650	106	110	33357	6
May 23, 2007	3052	5271	173	0	13366	6
June 9, 2007	1172	1537	131	3	4010	6
Arithmetic Mean	**7,731**					
Standard Dev.	**18,675**					
Median	**1,040**					

APPENDIX 3.3: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Juveniles per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	3,715	4,954	133	759	14,872	7
May 6, 2006	2,647	2,641	100	282	8,537	8
May 24, 2006	1,362	539	40	296	2,089	9
June 12, 2006	1	3	245	-	8	6
June 29, 2006	4,307	2,535	59	1,781	9,848	9
July 10, 2006	417	688	165	13	1,800	6
July 27, 2006	27	42	157	1	110	6
August 18, 2006	855	1,962	229	0	4,857	6
August 25, 2006	433	395	91	-	1,034	6
September 18, 2006	1,739	3,106	179	9	8,013	6
September 24, 2006	111	142	128	6	299	5
October 14, 2006	105	123	117	-	320	6
November 20, 2006	1,132	777	69	524	2,673	6
December 2, 2006	1,799	2,239	124	364	6,269	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	1,243	1,337	108	25	3,556	6
May 23, 2007	929	1,311	141	13	3,479	6
June 9, 2007	587	266	45	185	980	6
Arithmetic Mean	**1,331**					
Standard Dev.	**2,218**					
Median	**536**					

APPENDIX 4.1: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Total *Artemia* Abundance and Biomass

Total *Artemia* Abundance per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	6,778	5,754	85	2,375	19,327	7
May 6, 2006	4,938	3,539	72	931	11,481	8
May 24, 2006	3,282	1,406	43	1,528	6,309	9
June 12, 2006	2,479	1,756	71	887	5,150	6
June 29, 2006	66,781	52,356	78	26,491	193,081	9
July 10, 2006	6,611	9,344	141	1,432	25,553	6
July 27, 2006	40,111	31,956	80	3,740	98,404	6
August 18, 2006	23,428	13,004	56	9,077	47,310	6
August 25, 2006	11,858	3,198	27	8,569	17,098	6
September 18, 2006	5,169	7,255	140	679	19,518	6
September 24, 2006	1,709	1,101	64	520	2,970	5
October 14, 2006	2,525	2,365	94	796	7,220	6
November 20, 2006	6,353	3,781	60	2,492	12,211	6
December 2, 2006	4,416	3,841	87	851	9,778	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	50,149	42,003	84	3,114	109,826	6
May 23, 2007	40,226	34,761	86	8,100	92,509	6
June 9, 2007	2,926	2,329	80	775	6,956	6
Arithmetic Mean	**16,410**					
Standard Dev.	**28,444**					
Median	**4,381**					

APPENDIX 4.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Total *Artemia* Abundance and Biomass

Artemia Biomass in mg/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	0.936	0.684	73	0.191	2.342	7
May 6, 2006	0.619	0.472	76	0.143	1.555	8
May 24, 2006	0.516	0.122	24	0.283	0.623	9
June 12, 2006	0.554	0.236	43	0.252	0.922	6
June 29, 2006	1.300	0.852	66	0.331	3.075	9
July 10, 2006	1.649	2.650	161	0.271	7.026	6
July 27, 2006	0.920	0.966	105	0.167	2.800	6
August 18, 2006	0.368	0.377	102	0.018	1.104	6
August 25, 2006	0.333	0.221	66	0.169	0.658	6
September 18, 2006						
September 24, 2006						
October 14, 2006	0.628	0.581	93	0.094	1.357	6
November 20, 2006	0.432	0.335	78	0.108	0.927	6
December 2, 2006						
January 26, 2007						
May 7, 2007	1.795	1.595	89	0.455	4.499	6
May 23, 2007	1.482	1.260	85	0.499	3.574	6
June 9, 2007	0.596	0.343	58	0.165	1.206	6
Arithmetic Mean	**0.770**					
Standard Dev.	**0.695**					
Median	**0.592**					

APPENDIX 5.1: DESCRIPTIVESTATISTICS FOR *ARTEMIA* POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Cyst Abundance per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	5,343	3,519	66	1,432	9,653	7
May 6, 2006	3,228	1,707	53	926	6,172	8
May 24, 2006	5,088	2,689	53	2,459	10,502	9
June 12, 2006	18,865	17,659	94	1,768	49,644	6
June 29, 2006	9,148	12,007	131	891	39,381	9
July 10, 2006	36,794	45,876	125	11,138	128,988	6
July 27, 2006	14,868	20,678	139	3,000	56,857	6
August 18, 2006	31,015	21,832	70	13,820	72,255	6
August 25, 2006	27,384	21,711	79	10,986	70,187	6
September 18, 2006	28,353	20,225	71	9,229	61,736	6
September 24, 2006	41,742	24,357	58	15,578	81,906	5
October 14, 2006	52,966	68,931	130	5,864	187,118	6
November 20, 2006	18,697	13,708	73	1,955	35,748	6
December 2, 2006	35,990	16,235	45	16,730	52,773	6
January 26, 2007	3,976	3,044	77	1,641	9,759	6
May 7, 2007	22,311	29,013	130	273	62,054	6
May 23, 2007	18,067	13,175	73	7,425	43,643	6
June 9, 2007	16,195	12,654	78	6,205	37,915	6
Arithmetic Mean	**20,284**					
Standard Dev.	**26,188**					
Median	**10,744**					

APPENDIX 5.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Cyst Brood Size per Female w/Cysts

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006						
May 6, 2006						
May 24, 2006						
June 12, 2006						
June 29, 2006	111	18	16	93	151	9
July 10, 2006						
July 27, 2006	74	24	32	48	102	6
August 18, 2006	89	14	15	67	103	6
August 25, 2006	114	36	32	69	157	6
September 18, 2006	60	14	24	43	76	6
September 24, 2006	34	7	21	24	44	5
October 14, 2006	83	17	20	64	108	6
November 20, 2006	112	15	13	88	128	6
December 2, 2006	107	26	25	56	128	6
January 26, 2007						6
May 7, 2007	121	22	18	89	136	6
May 23, 2007	93	20	21	67	111	6
June 9, 2007	31	4	12	27	36	6
Arithmetic Mean	**87.34**					
Standard Dev.	**33.90**					
Median	**92.00**					

APPENDIX 5.3: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Productivity (Cyst Brood Size x # Females w/cysts) per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006						
May 6, 2006						
May 24, 2006						
June 12, 2006						
June 29, 2006	12,879	8,963	70	3,950	27,557	9
July 10, 2006						6
July 27, 2006	14,270	27,099	190	978	69,450	6
August 18, 2006	3,765	3,462	92	1,827	9,889	6
August 25, 2006	2,076	1,293	62	233	3,908	6
September 18, 2006	3,178	3,642	115	588	9,508	6
September 24, 2006	1,519	931	61	605	2,921	5
October 14, 2006	11,464	9,100	79	66	23,871	6
November 20, 2006	3,125	2,493	80	116	5,414	6
December 2, 2006	3,119	4,462	143	111	10,880	6
January 26, 2007						
May 7, 2007						
May 23, 2007	2,643	2,112	80	69	4,689	6
June 9, 2007	323	732	227	27	1,816	6
Arithmetic Mean	**5,533**					
Standard Dev.	**9,873**					
Median	**2,354**					

APPENDIX 6.1: COMPARATIVE STATISTICS FOR *ARTEMIA* POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Artemia Biomass in mg/L by Sample Site						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	1.082	1.063	98.2	0.117	3.574	18
2	0.625	0.146	23.3	0.428	0.839	5
3	0.510	0.245	48.0	0.186	1.158	18
4	1.158	1.028	88.7	0.165	3.075	18
5	0.723	0.484	67.0	0.339	1.432	4
6	0.616	0.322	52.2	0.244	1.334	18
7	0.817	0.793	97.0	0.018	2.491	16
8	0.903	0.572	63.3	0.491	1.555	3
9	0.503	0.321	63.7	0.167	1.189	16
Arithmetic Mean	**0.770**					
Standard Dev.	**0.695**					
Median	**0.592**					

APPENDIX 6.2: COMPARATIVE STATISTICS FOR *ARTEMIA* POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Cyst Brood Size by Sample Site						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	74	34	46	24	136	11
2	107			107	107	1
3	94	36	38	34	151	12
4	85	29	34	33	122	11
5	112			112	112	1
6	87	33	39	27	128	12
7	86	43	50	36	154	8
8	93			93	93	1
9	94	36	39	31	157	11

Arithmetic Mean	**87.34**
Standard Dev.	**33.90**
Median	**92.00**

APPENDIX 6.3: COMPARATIVE STATISTICS FOR *ARTEMIA* POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Productivity per Cubic Meter (cyst brood size x # females w/cysts) by Sample Site						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	5,188	7,702	148	28	25,188	10
2	8,692			8,692	8,692	1
3	4,282	4,292	100	34	14,954	11
4	11,205	21,075	188	69	69,450	10
5	6,331			6,331	6,331	1
6	5,459	6,685	122	27	23,871	11
7	4,938	9,291	188	66	27,557	8
8	3,950			3,950	3,950	1
9	5,248	6,463	123	31	20,490	11

Arithmetic Mean	5,533
Standard Dev.	9,873
Median	2,354

APPENDIX 7.1: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Chlorophyll –A in ug Se/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	7.00	3.14	44.82	2.70	11.00	6
May 6, 2006	4.56	2.59	56.76	2.70	8.00	8
May 24, 2006	3.16	2.36	74.65	1.30	8.00	9
June 12, 2006	4.25	2.44	57.32	2.70	8.00	6
June 29, 2006	6.31	1.40	22.14	5.30	8.00	9
July 10, 2006	3.46	1.77	51.28	1.30	5.30	6
July 27, 2006	7.17	5.28	73.73	2.70	16.00	6
August 18, 2006	4.45	2.16	48.44	2.70	8.00	6
August 25, 2006	3.98	1.68	42.08	1.30	5.30	6
September 18, 2006	1.88	1.66	88.56	0.70	4.70	6
October 14, 2006	20.83	8.01	38.45	13.00	32.00	6
November 20, 2006						
December 2, 2006	30.33	4.41	14.55	23.00	35.00	6
January 26, 2007	41.67	4.97	11.92	37.00	51.00	6
March 15, 2007	33.67	4.16	12.37	29.00	37.00	3
May 7, 2007	7.47	6.86	91.91	1.10	15.00	6
May 23, 2007	1.78	0.89	49.70	0.50	2.70	6
June 9, 2007	1.55	0.34	21.88	1.10	2.10	6
Arithmetic Mean	**10.12**					
Standard Dev.	**12.28**					
Median	**5.30**					

APPENDIX 7.2: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Phaeophytin in ug Se/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	13.1	7.1	54.4	6.7	26.0	6
May 6, 2006	9.9	4.2	42.4	5.5	16.0	8
May 24, 2006	4.8	1.9	39.0	1.3	7.7	9
June 12, 2006	5.1	3.8	75.5	1.3	12.0	6
June 29, 2006	5.2	4.5	87.4	1.3	15.0	9
July 10, 2006	6.5	2.6	40.2	3.9	9.6	6
July 27, 2006	3.5	2.7	77.3	0.5	6.7	6
August 18, 2006	5.2	2.3	44.2	2.1	8.5	6
August 25, 2006	1.8	1.4	77.2	0.3	4.3	6
September 18, 2006	1.2	0.7	54.8	0.7	2.3	6
October 14, 2006	4.7	2.3	49.6	2.0	7.7	6
November 20, 2006						
December 2, 2006	6.5	2.1	32.9	4.1	9.6	6
January 26, 2007	4.8	3.0	62.7	1.1	9.3	6
March 15, 2007	4.2	1.5	35.1	2.6	5.5	3
May 7, 2007	2.7	3.2	117.2	0.1	7.7	6
May 23, 2007	1.2	0.8	71.4	0.1	2.6	6
June 9, 2007	1.6	0.6	35.1	0.9	2.5	6
Arithmetic Mean	**4.92**					
Standard Dev.	**4.20**					
Median	**4.30**					

APPENDIX 7.3: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Combined Chl-a & Phaeophytin, and Water Transparency by Date

Combined Chl-a and Phaeophytin Pigments in ug Se/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	18.9	9.5	50.1	9.4	37.0	6
May 6, 2006	11.5	2.8	24.2	8.0	16.0	8
May 24, 2006	7.7	2.3	30.7	5.6	13.0	9
June 12, 2006	9.3	3.2	34.3	5.6	14.7	6
June 29, 2006	10.2	2.6	25.7	7.4	15.0	9
July 10, 2006	9.3	4.4	46.6	5.6	14.9	6
July 27, 2006	10.6	3.5	32.8	7.4	16.8	6
August 18, 2006	8.2	2.6	31.3	4.8	11.2	6
August 25, 2006	5.8	1.7	29.9	2.7	7.3	6
September 18, 2006	2.6	1.4	55.6	1.4	5.4	6
October 14, 2006	25.6	7.3	28.6	18.1	35.2	6
November 20, 2006						
December 2, 2006	36.9	6.3	17.1	27.3	44.6	6
January 26, 2007	46.5	4.2	9.0	41.1	53.5	6
March 15, 2007	37.9	3.8	9.9	33.6	40.5	3
May 7, 2007	10.2	9.8	96.3	1.2	22.7	6
May 23, 2007	2.9	1.4	46.6	1.8	5.3	6
June 9, 2007	3.1	0.6	18.9	2.3	4.1	6
Arithmetic Mean	**14.07**					
Standard Dev.	**12.98**					
Median	**9.30**					

APPENDIX 7.4: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Water Transparency (Secchi Disk in cm)

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	112.5	29.4	26.1	60.0	139.0	6
May 6, 2006	156.7	34.3	21.9	85.0	195.0	8
May 24, 2006	365.2	239.9	65.7	30.0	630.0	9
June 12, 2006	282.6	112.9	40.0	100.0	390.0	6
June 29, 2006	324.5	74.7	23.0	245.0	420.0	9
July 10, 2006	230.5	178.0	77.2	87.0	480.0	6
July 27, 2006	140.0	42.5	30.4	75.0	190.0	6
August 18, 2006	166.7	36.7	22.0	125.0	230.0	6
August 25, 2006	153.6	28.4	18.5	115.0	185.0	6
September 18, 2006	260.0	152.5	58.7	90.0	460.0	6
October 14, 2006	65.5	21.1	32.2	45.0	100.0	6
November 20, 2006	56.2	4.5	8.0	50.0	60.0	6
December 2, 2006	56.0	9.6	17.2	40.0	65.0	6
January 26, 2007	46.7	5.9	12.7	40.0	55.0	6
March 15, 2007						
May 7, 2007	119.8	105.4	88.0	48.0	305.0	6
May 23, 2007	442.3	119.9	27.1	332.0	570.0	6
June 9, 2007	325.0	142.9	44.0	160.0	410.0	6
Arithmetic Mean	**179.3**					
Standard Dev.	**142.2**					
Median	**137.0**					

APPENDIX 8.1: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER.

Selenium Concentration in *Artemia* Biomass: Adult *Artemia* (ug Se/g).

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	2.11	2.19	0.64	29.1	1.60	3.30	7.00
May 4, 2006	1.10	1.18	0.46	39.0	0.61	1.90	8.00
May 12, 2006	0.46	0.50	0.21	40.9	0.20	0.72	6.00
May 24, 2006	1.40	1.56	0.77	49.4	0.70	2.90	9.00
June 22, 2006	0.90	0.98	0.41	41.6	0.42	1.60	9.00
July 10, 2006	0.87	1.03	0.68	66.1	0.39	2.30	6.00
July 27, 2006	0.80	0.97	0.61	62.9	0.28	1.80	6.00
August 23, 2006	0.72	0.83	0.42	51.1	0.27	1.40	6.00
August 28, 2006	0.71	0.76	0.26	34.0	0.35	1.10	6.00
September 24, 2006	1.34	1.41	0.51	36.0	0.86	2.00	5.00
October 14, 2006	0.56	0.76	0.47	62.3	0.10	1.20	6.00
November 20, 2006	1.01	1.35	1.16	85.5	0.22	3.60	6.00
December 2, 2006	1.80	1.87	0.50	27.0	1.10	2.40	6.00
January 27, 2007							
March 15, 2007							
May 4, 2007	3.72	3.79	0.76	21.1	2.90	4.75	6.00
May 8, 2007	4.87	4.92	0.81	16.4	3.81	6.01	12.00
May 23, 2007	4.09	4.16	0.89	21.4	3.30	5.63	6.00
June 9, 2007	5.11	5.21	1.13	21.7	3.82	7.07	6.00
June 27, 2007	3.36	3.37	0.20	5.9	3.09	3.61	6.00
July 27, 2007	4.81	4.90	1.05	21.4	3.49	6.00	4.00
August 21, 2007	3.73	3.76	0.59	15.8	3.18	4.60	6.00
August 31, 2007	4.68	4.68	0.25	5.3	4.49	4.99	10.00
2006 Results	**1.06**	**1.20**	**0.72**				
2007 Results	**4.30**	**4.32**	**0.95**				

APPENDIX 8.2: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER Selenium Concentration in *Artemia* Biomass: Juvenile *Artemia* (ug Se/g)

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006							
June 22, 2006							
July 10, 2006							
July 27, 2006							
August 23, 2006							
August 28, 2006							
September 24, 2006	0.08	0.09	0.04	47.3	0.03	0.15	6
October 14, 2006	0.05	0.06	0.04	74.0	0.02	0.12	6
November 20, 2006							
December 2, 2006	0.51	0.61	0.42	69.2	0.26	1.40	6
January 27, 2007							
March 15, 2007							
May 4, 2007	5.68	5.76	1.00	17.5	4.71	7.41	6
May 8, 2007	10.29	10.52	2.53	24.1	8.25	15.00	12
May 23, 2007	6.93	7.44	2.89	38.8	3.49	11.20	6
June 9, 2007	13.26	15.08	8.52	56.5	7.37	25.64	6
June 27, 2007	4.09	4.18	0.72	22.0	3.16	5.53	6
July 27, 2007	2.65	3.08	2.17	70.5	1.81	5.59	4
August 21, 2007	2.78	2.89	0.88	30.5	1.89	3.96	6
August 31, 2007							
2006 Results	**0.26**	**0.25**	**0.17**				
2007 Results	**6.53**	**6.99**	**2.67**				

***Juvenile values were extremely variable and unreliable. The variability was attributable to the small sample size. Laboratory calculations for selenium on a dry weight basis was prone to error due to the minute final dry weight of the samples. The juvenile age-class is the least represented in terms of biomass among all age-classes. Juvenile selenium values were therefore not considered valid for management purposes nor as an accurate representation of selenium in brine shrimp.**

APPENDIX 8.3: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER.

Selenium Concentration in *Artemia* Biomass: Nauplii Biomass (ug Se/g)

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006							
June 22, 2006							
July 10, 2006							
July 27, 2006							
August 23, 2006	0.34	0.35	0.10	27.2	0.22	0.47	6
August 28, 2006	0.21	0.24	0.16	63.9	0.12	0.54	6
September 24, 2006	0.22	0.26	0.17	67.1	0.13	0.57	6
October 14, 2006	0.23	0.29	0.22	77.2	0.11	0.62	6
November 20, 2006							
December 2, 2006	0.97	1.01	0.25	25.3	0.56	1.30	6
January 27, 2007							6
March 15, 2007	1.72	1.77	0.49	27.7	1.20	2.10	3
May 4, 2007	3.27	3.56	1.57	44.0	1.77	5.39	6
May 8, 2007	2.05	2.20	0.48	22.7	1.18	2.49	12
May 23, 2007	2.53	2.55	0.40	15.8	2.05	3.03	6
June 9, 2007	2.05	2.09	0.44	21.0	1.34	2.48	6
June 27, 2007	2.45	2.50	0.52	20.9	1.70	3.20	6
July 27, 2007	2.12	2.18	0.55	25.5	1.48	2.63	4
August 21, 2007	2.65	2.65	0.14	5.4	2.50	2.82	6
August 31, 2007	2.30	2.30	0.18	7.7	2.04	2.47	10
2006 Results	**0.36**	**0.43**	**0.18**				
2007 Results	**2.35**	**2.42**	**0.53**				

APPENDIX 8.4: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER

Selenium Concentration in Seston in ug Se/g

DATE	GEO-MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.89	0.96	0.39	40.3	0.50	1.68	9
June 22, 2006	0.68	0.81	0.63	77.6	0.35	2.32	9
July 10, 2006	0.79	0.92	0.65	70.8	0.41	2.21	6
July 27, 2006	0.77	0.78	0.14	17.6	0.60	1.00	6
August 23, 2006	1.33	1.48	0.74	49.6	0.56	2.78	6
August 28, 2006	2.80	3.16	1.27	40.1	0.82	4.27	6
September 24, 2006	2.95	3.11	1.06	33.9	1.53	4.49	6
October 14, 2006	1.81	1.88	0.58	30.7	1.32	2.68	6
November 20, 2006	0.43	0.44	0.08	18.3	0.29	0.51	6
December 2, 2006	0.72	0.77	0.31	39.9	0.40	1.28	6
January 26, 2007	0.51	0.62	0.37	59.6	0.22	1.09	6
March 15, 2007							
May 4, 2007	0.42	0.57	0.55	97.5	0.19	1.66	6
May 8, 2007							
May 23, 2007	1.22	1.64	1.23	75.0	0.37	3.66	6
June 9, 2007	0.55	0.69	0.12	16.8	0.55	0.83	6
June 27, 2007	0.94	1.01	0.41	40.8	0.50	1.67	6
July 27, 2007	1.38	1.96	0.86	44.0	1.35	2.56	4
August 21, 2007	0.96	1.05	0.46	43.5	0.47	1.61	6
August 31, 2007							
2006 Results	**1.32**	**1.43**	**0.58**				
2007 Results	**0.86**	**1.08**	**0.57**				

APPENDIX 8.5: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER

Selenium Concentration in Seston in ug Se/L

DATE	GEO-MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.09	0.09	0.01	12.0	0.07	0.10	9
June 22, 2006	0.06	0.06	0.02	27.7	0.03	0.08	9
July 10, 2006	0.07	0.07	0.02	25.1	0.05	0.10	6
July 27, 2006	0.09	0.09	0.01	13.2	0.07	0.10	6
August 23, 2006	0.08	0.09	0.05	51.0	0.02	0.13	6
August 28, 2006	0.12	0.12	0.02	14.6	0.09	0.14	6
September 24, 2006	0.11	0.12	0.08	67.2	0.07	0.28	6
October 14, 2006	0.13	0.13	0.01	11.1	0.12	0.16	6
November 20, 2006	0.15	0.15	0.01	7.0	0.14	0.17	6
December 2, 2006	0.16	0.16	0.03	20.3	0.12	0.21	6
January 26, 2007	0.08	0.10	0.05	53.5	0.05	0.16	6
March 15, 2007							
May 4, 2007	0.13	0.13	0.03	25.5	0.10	0.20	6
May 8, 2007							
May 23, 2007	0.07	0.08	0.03	37.5	0.02	0.11	6
June 9, 2007	0.06	0.06	0.01	15.3	0.05	0.08	6
June 27, 2007	0.16	0.17	0.06	33.2	0.06	0.21	6
July 27, 2007	0.10	0.11	0.06	51.8	0.03	0.17	4
August 21, 2007	0.29	0.30	0.07	22.2	0.23	0.42	6
August 31, 2007							
2006 Results	**0.10**	**0.11**	**0.03**				
2007 Results	**0.13**	**0.14**	**0.04**				

APPENDIX 8.6: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER

Selenium Concentration in Unfiltered GSL Water in ug Se/L

DATE	GEO-MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.63	0.63	0.11	17.9	0.55	0.86	9
June 22, 2006	0.48	0.48	0.07	15.1	0.41	0.59	9
July 10, 2006	0.43	0.43	0.03	6.0	0.40	0.47	6
July 27, 2006	0.64	0.64	0.05	8.0	0.60	0.73	6
August 23, 2006	0.64	0.65	0.14	21.1	0.49	0.88	6
August 28, 2006	0.72	0.73	0.11	14.7	0.63	0.90	6
September 24, 2006	0.69	0.69	0.05	6.6	0.65	0.77	6
October 14, 2006	0.57	0.57	0.05	9.2	0.48	0.62	6
November 20, 2006	0.62	0.63	0.12	19.4	0.47	0.83	6
December 2, 2006	0.68	0.69	0.08	12.3	0.55	0.79	6
January 26, 2007	0.64	0.64	0.08	11.7	0.57	0.76	6
March 15, 2007							
May 4, 2007	0.59	0.59	0.04	6.9	0.54	0.66	6
May 8, 2007							
May 23, 2007	0.60	0.60	0.02	3.6	0.57	0.62	6
June 9, 2007	0.63	0.63	0.04	6.3	0.59	0.70	6
June 27, 2007	0.68	0.68	0.02	3.4	0.64	0.70	6
July 27, 2007	0.68	0.68	0.02	2.7	0.67	0.70	4
August 21, 2007	0.66	0.66	0.06	9.0	0.57	0.73	6
August 31, 2007							10
2006 Results	**0.61**	**0.60**	**0.11**				
2007 Results	**0.64**	**0.64**	**0.05**				

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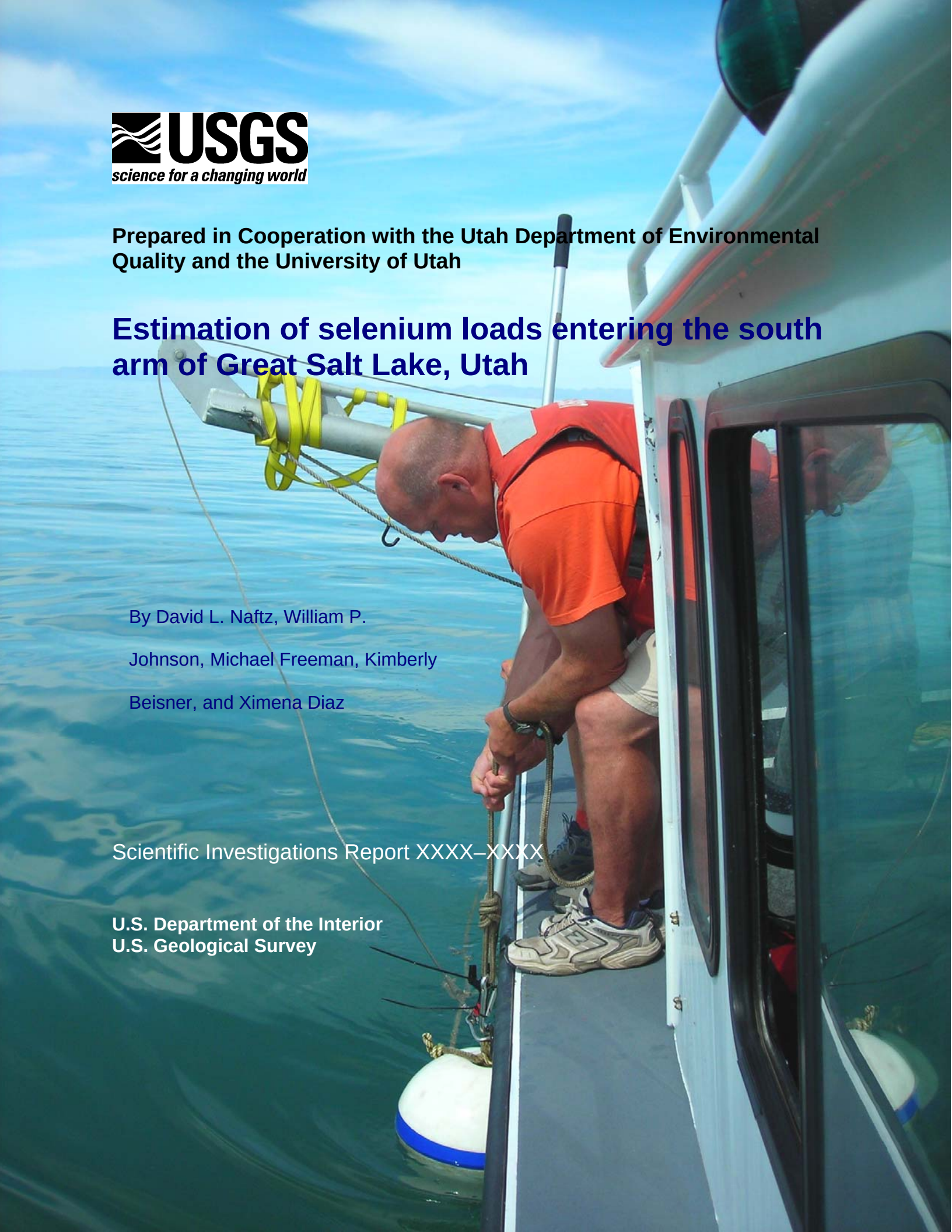

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Scientific Investigations Report XXXX–XXXX

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Suggested citation:
Naftz, D.L., and others, 2008, Estimation of selenium loads entering the south arm of Great Salt Lake, Utah: U.S. Geological Survey Scientific Investigations Report ___

Estimation of selenium loads entering the south arm of Great Salt Lake, Utah

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Abstract

Discharge and water-quality data from six gages were used in combination with the LOADEST software to provide an estimate of total (dissolved + particulate) selenium (Se) load to the south arm of Great Salt Lake (GSL) during the period of May 2006 through July 2007. Total estimated Se load to GSL during this time period was 1,540 kilograms (kg). The 12-month estimated Se load to GSL for the time period from May 1, 2006 to April 30, 2007 was 1,480 kg. The largest cumulative monthly Se load occurred during May 2006 (304 kg), and the smallest cumulative monthly load occurred during July 2007 (21 kg). During the 15-month monitoring period, inflows from the Kennecott Utah Copper Corporation (KUCC) Outfall and Goggin Drain contributed equally to the largest proportion of total Se load to GSL, accounting for 54 percent of the total Se load. Current (2006 and 2007) median Se loadings from Lee Creek (0.28 kg/day) have increased by more than an order of magnitude relative to historic Se loads (< 0.025 kg/day) calculated from data collected during 1972 through 1984. Historic Se loads during peak flow periods (1972-1984) for the Goggin Drain outflow site were about 50 percent lower than current (2006-2007) daily Se loads during peak runoff periods. Five instantaneous discharge measurements at three sites along the railroad causeway during the 15-month monitoring period

indicate a consistent net loss of Se mass from the south arm to the north arm of GSL (mean = 2.4 kg/day, n = 5). Application of the average daily loss rate equates to annual Se loss rate to the north arm of 880 kg (55 % of the annual Se input to the south arm); however, without continuous measurement of discharge the error associated with this annual loss estimate is high. The majority of Se in water entering GSL is in the dissolved (< 0.45 micron) state and ranges in concentration from 0.06 to 35.7 ug/L. Particulate Se concentration ranged from < 0.05 to 2.5 ug/L. Except for the KUCC gage site, dissolved (< 0.45 um) inflow samples were comprised of 21 % selenite (SeO_3^{2-}) during two sampling events (May 2006 and 2007).

Selenium concentrations in water samples collected from four monitoring sites within GSL during May 2006 through June 2007 were used to understand how the cumulative Se load was being processed by various biogeochemical processes within the lake. Based on the Mann-Kendall test, changes in dissolved Se concentration at the four monitoring sites indicate a statistically significant (90 % confidence interval) upward trend in Se concentration with time. Furthermore, the upward trend at two of the four GSL sites was also significant at the 95 % confidence interval. Regression models for each lake monitoring site indicated a net increase in Se concentration that ranged from 0.16 to 0.34 ug/L during the 15-month monitoring period. The net increase expected from measured riverine Se influx (without accounting for sedimentation and gas losses) over the same monitoring period was + 0.17 ug/L. The expected net increase in open-water Se concentration of 0.17 ug/L is approximately half of the net concentration change measured at 3 of the 4 lake monitoring sites. This comparison indicates an unmeasured source of Se contributing a minimum of an additional 1500 kg of Se load to the south arm. This value for the unmeasured Se contribution does not consider measured Se loss mechanisms that include: (1)

Se export to the north arm of GSL; (2) Se loss via permanent sedimentation; and (3) Se loss via gas flux to the atmosphere. Potential source(s) of this unmeasured Se load could include: (1) Se loads entering GSL from unmeasured surface inflows; (2) submarine groundwater discharge; (3) wind-blown dust that is deposited directly on the lake surface; (4) wet and dry atmospheric deposition falling directly on the lake surface; and (5) lake sediment pore water diffusion into the overlying water column. Processes and sources of additional Se loads and Se concentration from the unmeasured sources and processes identified during the study were further assessed with existing and recently available data: (1) Additional Se loads from the Weber River system are small and would only contribute an additional 46 kg of Se during the 15-month monitoring period; (2) resistivity surveys in the south part of GSL indicate areas of potential submarine groundwater discharge to the open water of GSL and previous work has found elevated (exceeding 10,000 ug/L) Se in groundwater within 1 mile of the south shore of GSL; and (3) comparison between salinity and dissolved (< 0.45 micron) Se concentrations at the four lake monitoring sites show a negative correlation, indicative that evaporative processes play a limited role in the statistically significant increase in open-water Se observed during the study period.

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1. Introduction

Great Salt Lake (GSL), in the western United States, is a terminal lake with a surface area that can exceed 5,100-km^2 (fig. 1). The GSL ecosystem receives industrial, urban, mining, and agricultural discharge from a 37,500-km^2 watershed that includes over 1.7 million people. The open water and adjacent wetlands of the GSL ecosystem support millions of migratory waterfowl and shorebirds from throughout the Western Hemisphere (Aldrich and Paul, 2002). In addition to supporting migratory waterbirds, the brine shrimp (*Artemia franciscana*) population residing in

GSL supports a shrimp industry with annual revenues as high as 60 million dollars (Isaacson et al., 2002). Other industries supported by GSL include mineral production (sodium chloride, potassium salts, magnesium metal, chlorine gas, magnesium chloride, and nutritional supplements) and recreation that includes waterfowl hunting (Anderson and Anders, 2002; Butts, 2002; Isaacson et al., 2002; and Tripp, 2002). Natural oil seeps and potential oil reserves also exist within and adjacent to the shoreline of GSL (Bortz, 2002; Hunt and Chidsey, 2002). Full production of these reserves has been limited by high production and refining costs; however, increasing trends in the market value of crude oil could strengthen the economic viability of these reserves. Despite the ecological and economic importance of GSL, little is known about the input and biogeochemical cycling of trace elements, including selenium (Se) in the lake. Information on the input and biogeochemical cycling of trace elements is needed to understand potential geochemical and biological affects from increased loadings.

Figure 1. Location of continuous and non-continuous stream gages, lake monitoring sites, and exposed sediment transects adjacent to and within Great Salt Lake, Utah.

Domagalski et al. (1990) evaluated the geochemical response of a suite of trace metals (Cd, Co, Cu, Fe, Mn, Mo, Pb, V, and Zn) to diagenetic processes in the bottom sediments of GSL. Results from their research found that most trace metals were associated with sulfide mineral phases in conjunction with decomposition of organic matter and production of hydrogen sulfide that occurred in the near-surface sediments. Enrichment of Co, Cu, Pb, and Zn in near-surface bottom sediments was attributed to anthropogenic sources in the GSL watershed. Most of the organic

matter at the sediment/anoxic water interface was mineralized to carbon dioxide due to excess sulfate in the system.

Work completed by Tayler et al. (1980) postulated that the GSL acts as a "natural disposal system" with respect to the immobilization of dissolved and suspended heavy metals and metalloids (Ag, As, Cd, Cu, Hg, Mn, Mo, Pb, Se, and Zn) in the water column. Concentration factors (concentration in lake/concentration in inflow) for selected heavy metals and mettalloids in the water column of GSL indicated accumulation (> 1.0) or depletion (< 1.0). The concentration factors calculated by Tayler et al. (1980) ranged from 0.1 for Cd to 2.5 for Se to 11.5 for As; however, industrial inflows were not considered during their calculations. In general, the highest enrichments of heavy metals and metalloids in GSL sediments were found in areas beneath an anoxic layer, likely due to the production of sulfide and subsequent precipitation of insoluble metal sulfides.

From 1998 to 2001, the U.S. Geological Survey (USGS) conducted a water quality and biological assessment within the GSL watershed (Waddell et al., 2004). Results from that study indicated that most streambed sediment, collected from areas affected by mine tailing and metal smelters, had elevated concentrations of selected trace elements that exceeded aquatic life guidelines for As, Cd, Cu, Pb, Hg, Ag, and Zn. Elevated P concentrations were found in 12 of the 27 streams in the GSL watershed that were sampled. Pesticides were found in about 95 % of the sampled streams, with the concentrations of carbaryl, diazinon, and malathion exceeding guidelines for the protection of aquatic life.

Sediment cores collected from the Farmington Bay area of GSL (Naftz et al., 2000) were used to reconstruct changes in the water quality entering GSL from the early 1700s to 1998. The 28-cm core indicated that deposition of contaminated sediments (elevated concentrations of Cd, Cu, Pb, Zn, N, organic C, and P) began to occur sometime in the early to mid-1900s and concentrations became progressively greater in recently deposited sediments. Selenium was not included in this analytical schedule. The most contaminated sediments were deposited from 1979-98. Prior to the early 1900s, uncontaminated sediments were deposited in Farmington Bay. The historical trends observed in the GSL core were attributed to the increase in anthropogenic activities in the Salt Lake Valley.

In response to increasing public concern regarding Se input to the GSL ecosystem, the Utah Department of Environmental Quality (UDEQ) initiated coordinated studies to quantify and evaluate the significance of current and future inputs of Se to GSL. Although a number of USGS stream gages existed on upstream reaches of inflow sources to GSL, additional gage sites were needed to allow the measurement of Se loads that are input directly to the lake after passing through the perimeter wetlands systems. The specific objectives of this project are to: (1) accurately measure water discharge and Se concentration at all major inflow sites to GSL; (2) utilize the data collected in objective one in combination with regression modeling techniques to simulate daily, monthly, and annual Se loads to Gilbert Bay of Great Salt Lake; (3) compare current and historic Se load data from selected inflow sites; and (4) model in-lake Se concentration expected from monitored loading rates and compare to observed water column Se concentration and temporal trends.

2. Methodology

2.1 Field methods

The FB and BR gages (fig. 1 and table 1) were already operating prior to the initiation of this study in May 2006. Four additional gages (GD, WR, LC, and KUCC) were reactivated during May and June 2006 (fig. 1 and table 1). Prior to the reactivation of the KUCC gage, discharge and Se data collected by KUCC were used. Stream discharge at the GD, WR, and LC gages was measured using standard USGS methods (Buchanan and Somers, 1968, 1969; Carter and Davidian, 1968) using a continuous record of water stage calibrated to periodic measurements of streamflow. Due to the low channel gradients and wind influence on inflow rates at the BR, FB, and KUCC gage sites, normal stage-to-discharge relationships did not exist. Instead, hydroacoustic equipment in combination with velocity index methods (Simpson, 2001) was used to accurately gage discharge at those sites. The period of operation for each gage is summarized in Table 1. Discharge data from each gage site can be accessed at: http://waterdata.usgs.gov/ut/nwis/sw.

Table 1. Streamflow-gaging stations with continuous records adjacent to Great Salt Lake, Utah, where stream discharge and water-quality samples were collected to simulate selenium loads.

Water samples (filtered and unfiltered) were collected from each gage site at monthly to bimonthly intervals (May 2006 through July 2007) for the analysis of dissolved and total Se. Water samples from each inflow site were composited using the equal discharge increment (EDI)

or equal width increment (EWI) methods (Wilde et al., 1999). Water samples were composited into a churn splitter and processed on site using standard USGS procedures (U.S. Geological Survey, variously dated). Automated samplers were installed at the GD, FB, and BR gage sites (fig. 1) to collect daily water-quality samples during the peak runoff period (unfiltered samples only). The stream hydrograph was used to select which samples collected by the autosamplers were submitted for chemical analyses. Filtered water samples (dissolved Se and selenite (SeO_3^{2-})) were passed through a 0.45-micron capsule filter and placed into acid- and field-rinsed polyethylene bottles and acidified to a pH of less than 2 with ultra-pure nitric acid. Unfiltered water samples (total Se) were placed directly into acid- and field-rinsed polyethylene bottles and acidified to a pH of less than 2 with ultra-pure nitric acid.

Daily water samples collected from the autosamplers were processed every two to three weeks in a similar manner as the composite water samples. Only unfiltered water samples were collected from the autosamplers. Sample bottles used in the autosamplers were cleaned with a 10% HCl solution and then triple rinsed with deionized water prior to redeployment. Specific conductance and pH were also measured on each water sample collected by the autosampler.

2.2 Laboratory methods

Dissolved and total (dissolved + particulate) Se, as well as SeO_3^{2-}, concentration was measured by hydride generation atomic fluoresence (HG-AF) at Frontier GeoSciences, Inc. in Seattle, Washington. The concentration of dissolved selenate (SeO_4^{2-}) was determined by difference (dissolved Se – SeO_3^{2-}).

2.3 Quality assurrance

Thirty-six process blanks were collected during the inflow site sampling from May 2006 through July 2007, and analyzed for Se. The Se concentration in the process blanks did not exceed the lower reporting limit (0.05 ug/L) in 34 of the 36 samples. The only two process blanks to exceed the lower reporting limit, contained a Se concentration of 0.05 ug/L. Based on the process blank results, there was no Se contamination above the lower reporting limit introduced during sample processing at the inflow sites.

Table 2. Results of field process blanks and sample replicates collected at inflow sites to Great Salt Lake from May 2006 through July 2007.

Twenty-one sample replicates were collected during the inflow site sampling from May 2006 through July 2007. The Se concentration for each sample replicate was compared to the Se concentration in the original sample collected from the churn splitter approximately 5 minutes prior to collection of the sample replicate. The absolute difference between the original and replicate samples ranged from 0.002 to 0.457 ug/L and the median difference was 0.023 ug/L (table 2).

2.4 Mass loading estimation method

The USGS loading software, LOADEST (Runkel et al., 2004), was used to estimate the mass loading of total Se at each gage site. The automated model selection in LOADEST was used to select the best regression model from the set of nine predefined models (table 3). Under the

automated selection option, adjusted maximum likelihood estimation (AMLE) (Cohn, 1988; Cohn et al., 1992), is used to determine model coefficients and estimates of log load. The predefined model with the lowest value of the Akaike Information Criterion (AIC) statistic was then used for final load estimation (Judge et al., 1988).

Table 3. Regression models considered during the automated selection option in LOADEST (Runkel et al., 2004).

2.5 Exposed sediment collection and processing

Sediment samples from mud flats surrounding the Great Salt Lake were collected at three transect sites (fig 1). Five samples were collected at each site along a transect perpendicular to the shoreline. Samples at each transect were seperated by variable distances: (transect 1) samples seperatred by 60-m intervals; (transect 2) samples seperatred by 120-m intervals; and (transect 3) samples seperatred by 180-m intervals. The samples closest to shoreline were numbered GSL #-1 sequentially up to GSL #-5 (sample farthest from shoreline).

Samples were processed according to methods in Hageman and Briggs, 2000. Each sample was dried at 60^{o}C for 7 days before processing. After drying, 50 grams of sediment was added to 1 liter of deionized water and mixed for one hour. After settling, the samples were processed as unfiltered acidified (RA) and filtered (< 0.45 micron) acidified (FA). Samples were acidified with ultrapure nitric acid to a pH < 2.0 units. Water samples were analyzed for Se at Frontier

GeoSciences, Inc. A split of the sediment taken before extraction with deionized water was sent to LET, Inc. for analysis of total available Se using a strong acid digestion.

3. Results and Discussion

3.1 Simulation of Se loadings from inflow sites

Lee Creek near Magna, Utah: The LOADEST model calibration file contained 14 observations for total (dissolved + particulate) Se during the time period of May 2006 through July 2007 (fig. 2). The LOADEST estimation file contained 440 measurements of mean daily discharge. Both the calibration and estimation file used in the LOADEST model can be found in Appendix A. Regression model 8 (table 3) was determined to best simulate daily total Se loads from Lee Creek to GSL with an R^2 value of 0.9289 (Appendix A).

Figure 2. Stream discharge and dates when selenium samples were collected at the Lee Creek gaging station.

Comparisons between the measured and simulated loads of total Se at the Lee Creek gage indicate reasonable agreement (fig. 3). For example, the measured total Se load on 03/06/2007 was 0.24 kg/day and the simulated load was 0.29 kg/day (fig. 3), resulting in an underestimation in daily Se loading of 50 g. The complete output of LOADEST model results can be found in Appendix A.

Figure 3. Measured and simulated loads of total Se at the Lee Creek streamflow-gaging station near Magna, Utah during May 2006 through July 2007.

Goggin Drain near Magna, Utah: The LOADEST model calibration file contained 41 observations for total (dissolved + particulate) Se during the time period of May 2006 through July 2007 (fig. 4). The LOADEST estimation file contained 455 measurements of mean daily discharge. Both the calibration and estimation file used in the LOADEST model can be found in Appendix A. Regression model 4 (table 3) was determined to best simulate daily total Se loads from the Goggin Drain to GSL with an R^2 value of 0.9946 (Appendix A).

Figure 4. Stream discharge and dates when selenium samples were collected at the Goggin Drain gaging station.

Comparisons between the measured and simulated loads of total Se at the Goggin Drain gage indicate reasonable agreement (fig. 5). For example, the measured total Se load on 03/06/2007 was 3.6 kg/day and the simulated load was 3.8 kg/day (fig. 5), resulting in an underestimation in Se loading of 200 g. The complete output of LOADEST model results can be found in Appendix A.

Figure 5. Measured and simulated loads of total Se at the Goggin Drain streamflow-gaging station near Magna, Utah during May 2006 through July 2007.

Weber River near West Warren, Utah: The LOADEST model calibration file contained 12 observations for total (dissolved + particulate) Se during the time period from May 2006 through July 2007 (fig. 6). The LOADEST estimation file contained 447 measurements of mean daily discharge. Both the calibration and estimation file used in the LOADEST model can be found in Appendix A. Regression model 2 (table 3) was determined to best simulate daily total Se loads from the Weber River with an R^2 value of 0.9332 (Appendix A).

Figure 6. Stream discharge and dates when selenium samples were collected at the Weber River gaging station.

Comparisons between the measured and simulated loads of total Se at the Weber River gage indicate reasonable agreement (fig. 7). For example, the measured total Se load on 05/17/2007 was 0.021 kg/day and the simulated load was 0.020 kg/day (fig. 7), resulting in an underestimation in Se loading of 1 g. The complete output of LOADEST model results can be found in Appendix A.

Figure 7. Measured and simulated loads of total Se at the Weber River streamflow-gaging station near West Warren, Utah during May 2006 through July 2007.

Kennecott Drain near Magna, Utah: Because of the large number of samples collected by KUCC at the Kennecott Drain gaging station from October 2005 through September 2006 (fig. 8), the LOADEST software was used to estimate total Se loads only during the time period from October 1, 2006 through July 31, 2007. The LOADEST model calibration file contained 134 observations for total (dissolved + particulate) Se during the time period from July 2006 through July 2007. The LOADEST estimation file contained 399 measurements of mean daily discharge measured by the USGS from June 2006 through July 2007. Both the calibration and estimation file used in the LOADEST model can be found in Appendix A. Regression model 9 (table 3) was determined to best simulate daily total Se loads from the Kennecott Drain to GSL with an R^2 value of 0.9774 (Appendix A).

Figure 8. Stream discharge and dates when selenium samples were collected at the KUCC gaging station. Discharge and selenium data prior to June 30, 2006 provided by KUCC (K. Payne, written commun., 2006 and 2007). Selenium data after June 30, 2006 provided by KUCC and USGS.

Comparisons between the measured and simulated loads of total Se at the Kennecott Drain gage indicate reasonable agreement (fig. 9) during water year 2007. For example, the measured total Se load on 04/27/2007 was 2.4 kg/day and the simulated Se load was 2.4 kg/day (fig. 9). The complete output of LOADEST model results can be found in Appendix A.

Figure 9. Measured and simulated loads of total Se at the Kennecott Drain streamflow-gaging station near Magna, Utah during October 2005 through July 2007.

Bear River Bay Outflow at GSL Minerals Corp. Bridge: The LOADEST model calibration file contained 42 observations for total (dissolved + particulate) Se during the time period from May 2006 through July 2007 (fig. 10). The LOADEST estimation file contained 498 measurements of mean daily discharge collected from March 2006 through July 2007. Because of equipment failure and gage removal in November 2006 due to ice conditions, daily discharge measurements from October 1, 2006 through April 15, 2007 were estimated from an upstream gage (Bear River near Corinne, Utah). Mean daily discharge for the missing time period was estimated from the linear relationship between measured discharge at both sites from March 21, 2006 through September 30, 2006 (fig. 11). The regression equation developed from this comparison explained 80 percent of the variance ($p < 0.0001$, $N = 194$).

Figure 10. Stream discharge and dates when selenium samples were collected at the Bear River Bay outflow gaging station. Negative mean daily discharge values (wind-driven flow into Bear River Bay) were assigned a discharge value of 0.0001 cubic feet per second. Discharge data between October 1, 2006 and April 15, 2007 were calculated using a simulated mean daily discharge based on an upstream USGS gage (10126000 Bear River near Corinne, Utah).

Figure 11. Stream discharge and dates when selenium samples were collected at the Bear River Bay outflow gaging station. Negative mean daily discharge values (wind-driven flow into Bear River Bay) were assigned a discharge value of 0.0001 cubic feet per second. Discharge data between October 1, 2006 and April 15, 2007 were calculated using a simulated mean daily discharge based on an upstream USGS gage (10126000 Bear River near Corinne, Utah).

Both the calibration and estimation file used in the LOADEST model can be found in Appendix A. Regression model 7 (table 3) was determined to best simulate daily total Se loads from the Bear River to GSL with an R^2 value of 0.9987 (Appendix A).

Comparisons between the measured and simulated loads of total Se at the Bear River Bay outflow gage during water year 2006 indicate reasonable agreement for most sample dates (fig.

12). For example, the measured total Se load on 05/28/2007 was 1.9 kg/day and the simulated load was 2.0 kg/day (fig. 12), resulting in an underestimation in selenium loading of 100 g. Comparisons between the measured and simulated loads of total Se from October 1, 2006 to April 15, 2007 indicate some slight differences, likely due to the estimated discharge during this time period. For example, the measured total Se load on 10/10/2006 was 2.1 kg/day and the simulated load was 2.0 kg/day (fig. 12), resulting in an underestimation in Se loading of 100 g. The complete output of LOADEST model results can be found in Appendix A.

Figure 12. Measured and simulated loads of total selenium at the Bear River Bay Outflow streamflow-gaging station. Load estimates between 10/1/2006 and 04/14/2007 were calculated using a simulated mean daily discharge based on an upstream USGS gage (10126000 Bear River near Corinne, Utah).

Farmington Bay Outflow at Causeway Bridge: The LOADEST model calibration file contained 47 observations for total (dissolved + particulate) Se during the time period from May 2006 through July 2007 (fig. 13). The LOADEST estimation file contained 455 measurements of mean daily discharge measured from May 2006 through July 2007. Because of intermittent equipment failures, selected mean daily discharge records were reconstructed from three existing USGS gages (fig. 14), using the formula:

$$Q_{FB} = (Q_{SC} + Q_{JR}) - Q_{GD} \quad (1)$$

where, Q_{FB} is the calculated discharge at Farmington Bay outflow, in cubic feet per second; Q_{SC} is the mean daily discharge measured at the Surplus Canal gage, in cubic feet per second; Q_{JR} is the mean daily discharge measured at the Jordan River gage, in cubic feet per second; and Q_{GD} is the mean daily discharge measured at the Goggin Drain gage, in cubic feet per second. This formula estimates the amount of water from the Jordan River system that is discharged into Farmington Bay and was used to estimate discharge when mean daily discharge records for FB were missing prior to 10/10/2006. After 10/10/2006 discharge data were missing only for short time periods, and the mean daily discharge was estimated by interpolating between last and next mean daily discharge value that was measured.

Figure 13. Stream discharge and dates when selenium samples were collected at the Farmington Bay Outflow gaging station. Negative mean daily discharge values (wind-driven flow into Farmington Bay) were assigned a discharge value of 0.0001 cubic feet per second.

Figure 14. Locations of gages used to estimate mean daily discharge at the Farmington Bay Outflow gage site during periods of missing record.

Both the calibration and estimation file used in the LOADEST model can be found in Appendix A. Regression model 4 (table 3) was determined to best simulate daily total Se loads from the Farmington Bay to GSL with an R^2 value of 0.9990 (Appendix A).

Comparisons between the measured and simulated loads of total Se at the Farmington Bay outflow gage during water year 2006 indicate reasonable agreement (fig. 15). For example, the measured total Se load on 03/05/2007 was 0.36 kg/day and the simulated load was 0.35 kg/day (fig. 15), resulting in a slight underestimation of Se loading of 10 g. The complete output of LOADEST model results can be found in Appendix A.

Figure 15. Measured and simulated loads of total selenium at the Farmington Bay outflow streamflow-gaging station. Because of intermittent periods of missing discharge record during 2006, selected selenium load estimates were based on calculated discharge estimates using the following formula: ($Q_{FB} = Q_{SC} + Q_{JR}$) – Q_{GD}; where Q is the mean daily discharge in cubic feet per second, FB is Farmington Bay Outflow; SC, is the Surplus Canal; JR, is the Jordan River at 1700 South; and GD, is the Goggin Drain. Locations of these additional gage sites are shown in Figure 14.

Wetting of Shoreline Sediments: Solubilization of Se into the water column due to lake level increase likely occurs on an annual cycle during the seasonal rise of lake level during spring runoff. Lake level increased from 4196.5 ft in November, 2006 to 4197.5 ft in April, 2007. The observed increase in lake level during this time period corresponds to a lake area increase of 14,976 acres and a lake volume increase of 463,415 acre-ft (Baskin 2005).

Average total Se concentration from sediment samples was 0.37±0.31 μg/g. Total Se concentrations in exposed sediment samples were identical from two transect sites (GSL 1 and GSL 3) 0.20±0 μg/g and was significantly higher at the other transect site (GSL 2) 0.70±0.37 μg/g. Average water soluble Se concentration in the raw acidified (RA) samples was 0.52±0.42 μg/L, whereas the average water soluble Se concentration in the filtered acidified (FA) samples was slightly lower at 0.45±0.32 μg/L.

The following equations were used to estimate the Se mass input contributed to GSL during the resaturation of near-shore sediments during the 1-foot lake level increase recorded from Novebmer 2006 to April 2007. Assuming a sediment bulk density (ρ_b) of 1.6 g/ cm^3 and an effective leaching depth of 1 cm:

$$\mathrm{kg_{Se}} = \frac{\mu g_{\text{solubilized}}}{\text{unit surface area } (\mathrm{cm^2})} (\text{area}_{\text{mud flat}}) \left(\frac{\mathrm{kg}}{10^9 \mu g} \right)$$

Where the unit surface area refers to the interaction (top) surface of a rectangular prism made up of the leached sediment mass (50 g).

$$\text{unit surface area } (\mathrm{cm^2}) = \frac{\text{leached sediment mass (g)}}{\rho_b \left(\mathrm{g/cm^3} \right)} \left(\frac{1}{\text{leaching depth (cm)}} \right)$$

$$\text{unit surface area } (\mathrm{cm^2}) = \frac{50 \text{ g}}{1.6 \text{ g/cm}^3} \left(\frac{1}{1 \text{ cm}} \right)$$

$$\text{unit surface area } (\mathrm{cm^2}) = 31.25 \, \mathrm{cm^2}$$

Using the average value obtained from the unfiltered water soluble Se tests (0.52 ug) over a mudflat area of 14,976 acres results in a calculated total Se mass contributed by the observed water-level increase.

$$kg_{Se} = \frac{0.52\,\mu g_{solubilized}}{31.25\,cm^2}(14{,}976\,acres)\left(\frac{4.05E7\,cm^2}{1\,acre}\right)\left(\frac{kg}{10^9\,\mu g}\right)$$

$$kg_{Se} = 10$$

The addition of 10 kg of Se from the flooding of near-shore sediments is not significant relative to the annual Se loads contributed by riverine inflow to GSL. Higher Se loads from near-shore sediments to GSL could be contributed by larger lake level increases that could occur in future years.

The amount of extractable Se present in each sample was small relative to the total available Se (strong acid leachable) in each lake-shore sample. The average percent of water soluble Se relative to the total Se in each lake-shore sample was 3.12±1.63 % (unfiltered sediment extracts) and 2.72±1.62 % (filtered sediment extracts). The small amount of water soluble Se relative to total Se (acid soluble) in lake-shore samples indicates that additional water soluble Se will likely be made available during future wet/dry cycles.

3.2 Cumulative Se loadings

The Se input models developed for each gage site were used to estimate the cumulative daily total (dissolved + particulate) Se load to GSL from May 2006 through July 2007 (fig. 16). Total estimated Se load to GSL during this 15-month time period was 1,540 kg. The estimated 12-

month Se load to GSL for the time period from May 1, 2006 to April 30, 2007 was 1,480 kg. This calculated annual loading is within the range of the initial projected annual Se load to GSL (990 to 1,490 kg/year) estimated from input load modeling from data collected from May to December, 2006.

The largest estimated cumulative monthly Se load occurred in May 2006 (304 kg), and the smallest estimated cumulative monthly load occurred in July 2007 (21 kg). The large Se loads during May 2006 can be attributed to the large river inflows resulting from snowmelt runoff combined with active discharge from the KUCC Outfall. In contrast, the low runoff conditions experienced during 2007 resulted in a May 2007 cumulative Se load of only 82 kg. As shown in Figure 16, the largest single-day Se load to GSL occurred on May 26, 2006 (14.4 kg).

Figure 16. Modeled total (dissolved + particulate) daily selenium loads from May through December, 2006, at the six major inflow sites to Great Salt Lake, Utah. Pie charts indicate relative load contributed by each inflow site.

The low runoff conditions during 2007 relative to 2006 are further exemplified by comparing the date when Bear River discharge dropped to zero during both years (fig. 10). During water year 2006, there was measurable discharge from Bear River to GSL until July 31. In contrast, during water year 2007 no measurable discharge to GSL was recorded after May 29.

During the monitoring period from May 2006 through July 2007, the KUCC Outfall and Goggin Drain contributed equally to the largest proportion of total Se load to GSL (fig. 17). The combined input to GSL from both the KUCC Outfall and Goggin Drain accounted for 54 percent of the total Se load during the 15-month monitoring period. The Se load from Bear River during this same time period contributed 26 percent of the total Se load to GSL. This overall trend in loading was not consistent on a month-by-month basis. For example, the Se load from the Goggin Drain was the major loading source during May and June, 2006, and the Bear River was the major loading source during July 2006 (fig. 16). The high proportion of Se loadings contributed by the Bear River from October 1, 2006 through April 15, 2007, is partly the result of the estimated streamflows from the upstream gage; however, equipment removal during winter "ice over" prevented site-specific measurements during this time period.

Figure 17. Distribution of total selenium loads contributed to Great Salt Lake from each inflow site from May 18, 2006 to July 31, 2007.

An additional Se-loading factor to the open water of GSL is the interaction of water with perimeter wetland systems. Prior to entering GSL, water in the Bear River, Goggin Drain, Lee Creek, Farmington Bay, and Weber River systems flow through wetland complexes on the perimeter of GSL. In contrast, water entering GSL from the KUCC Outfall is piped directly into GSL and has little or no opportunity to interact with Se removal processes in natural wetland systems (this is a function of lake elevation). By dividing the total Se load by the cumulative discharge from each inflow site (May 18 through December 31, 2006), the impact of Se removal

by wetland systems is evident (fig. 18). Outflow sites flowing through natural wetlands adjacent to GSL display a low amount of Se load relative to the cumulative discharge. In contrast, the KUCC outflow site that is piped directly to GSL, with no wetland interaction, displays a high amount of Se load relative to the cumulative discharge (fig. 18).

Figure 18. Comparison of cumulative selenium load (May thru December, 2006) divided by cumulative discharge (May 18 thru December 31, 2006) for the six major inflow sources to Great Salt Lake, Utah.

3.3 Trends in Se loads over time

Prior to the start of the current study, the USGS operated gages at Lee Creek, Goggin drain, and KUCC outfall sites. Dissolved (0.45 micron) Se concentration was determined from water samples collected on an intermittent basis from these gage sites from 1972 through 1984. Because of improvements in analytical sensitivity and sample collection procedures, historic trace-element data must be interpreted with caution; however, it is likely that the historic USGS data from these sites are representative of actual Se concentrations and associated loadings. Current (2006-07) loadings from Lee Creek have increased by more than an order of magnitude relative to historic Se loads (fig. 19). Most historic Se loads were less than 0.025 kg/day relative to the median Se load from May 2006 through July 2007 of 0.28 kg/day. Although the historic Se loading data did not measure particulate Se, this would not account for the order-of-magnitude increase that is observed in the 2006-2007 Se-load data.

Figure 19. Comparison of simulated daily total (dissolved + particulate) selenium loads (May 2006 through April 2007) with measured historic dissolved (0.45 micron) selenium loads (1972 through 1982) at the Lee Creek gage site.

The process(es) causing the increased Se loadings in Lee Creek are unknown. In the 1990s, KUCC stopped diverting water from their mine tailings impoundments into Lee Creek (Hillwalker, 2004). These diversions should have decreased the Se loading to Lee Creek instead of the observed increase in 2006 Se loads. It is likely that other processes may be causing the increased Se loadings to Lee Creek. These processes could include canal tailwater input from KUCC outfall to Lee Creek, increases in wastewater treatment plant effluent, and increased discharge of groundwater with elevated Se concentrations to selected stream reaches.

The historic Se load data from the Goggin Drain gage site during low-flow periods compares favorably with current (2006-2007) daily Se loads (fig. 20). In contrast, historic Se loads during peak flow periods appear to be about 50 percent lower than current (2006-2007) daily Se loads. This trend may be related to an increase in available Se within the contributing watershed to Goggin Drain resulting from increased development over the past 35 years.

Figure 20. Comparison of simulated daily total (dissolved + particulate) selenium loads (May 2006 through April 2007) with measured historic dissolved (0.45 micron) selenium loads (1972 through 1984) at the Goggin Drain gage site.

The median Se load from the KUCC outfall from 1972 through 1984 was 3.8 kg/day (fig. 21). Comparison of this median Se load value with measured and modeled Se loading data collected from 2005 to 2007 suggest an overall decrease in recent Se loads from the KUCC outfall (fig. 21).

Figure 21. Comparison of present day measured and simulated loads of total Se at the Kennecott Drain streamflow-gaging station to the median dissolved Se loads measured from 1972 to 1984.

3.4 Se concentration and loads from miscellaneous sites

The railroad causeway that separates GSL into a north and a south arm has two culverts (WC and EC) and a breach (CB) that allow water to flow between the two arms (fig. 1). Although permanent streamflow gages are not installed on these openings, instantaneous discharge measurements were measured five times from May 2006 through May 2007 (table 4). Because of the higher salinities present in the north arm of GSL, bidirectional flow in the causeway openings can occur. Unfiltered water samples collected during the discharge measurements were analyzed

for total Se (dissolved + particulate) concentration. The instantaneous discharge data were combined with the concentration of Se in the water to calculate the Se load (kg/day) moving into the north arm of GSL (south-to-north flow) and south arm of GSL (north-to-south flow).

Table 4. Instantaneous discharge and associated total (dissolved + particulate) selenium loads measured from May 2006 through May 2007, at measurement sites along the railroad causeway, Great Salt Lake, Utah.

During the five measurement periods, a net loss of total Se to the north arm was observed (table 4). The net Se losses were: > 4.1 kg/day on May 25, 2006; 1.9 kg/day on September 28, 2006; 2.2 kg/day on January 9, 2007; 2.4 kg/day on March 19, 2007: and 1.5 kg/day on May 30, 2007. These data provide a "snapshot" of Se exchange between the north and south arms; however, without a continuous discharge record at each site, an annual estimate of Se exchange cannot be determined. With this qualification, the average annual Se loss from the south to the north arm during the monitoring period would be about 2.4 kg/day. Applying the average daily Se loss to an annual cycle would equate to 880 kg of Se loss to the north arm. This would account for more than 55 % of the total Se input to the south arm of GSL during an annual loading cycle.

Samples for total Se were collected and analyzed at two additional miscellaneous sites, Morton Salt (MS) and the salt canal at Great Salt Lake Minerals (SC) (fig. 1). The sample collected at the MS site on November 3, 2006 contained a total Se concentration of 0.99 ug/L. Three samples were collected and analyzed for total Se from the SC site. The total Se concentrations in these

samples were 0.35 ug/L (May 25, 2006); 1.08 ug/L (September 7, 2006); and <0.25 ug/L (December 16, 2006).

The amount of Se load contributed from groundwater inflow as well as dry and wet deposition falling directly on the open waters of GSL was not measured during this study; hence, no selenium loads associated with these potential sources were determined.

3.5 Distribution of Se species and particulate fractions

Dissolved (0.45 micron) and total Se concentrations were determined from samples collected from inflow sites to GSL during the monitoring period from May 2006 through July 2007. Particulate Se was calculated by subtracting the dissolved Se concentration from the total Se concentration (fig. 22). If the dissolved Se concentration was greater than the total Se concentration, it was assumed that this was caused by analytical variability and the particulate Se concentration was set to 0.0. Most of Se in water entering GSL was in the dissolved (0.45 micron) state and ranged from 0.06 to 35.7 ug/L. Particulate Se concentration entering GSL ranged from 0 to 2.5 ug/L.

Figure 22. Distribution of dissolved and particulate selenium in water samples collected from inflow sites to Great Salt Lake during May 2006 through July 2007. Note the difference in scale for the KUCC Drain in comparison to other sites.

Filtered water samples collected during May 2006 and May 2007 were analyzed for selenite (SeO_3^{2-}). The concentration of selenate (SeO_4^{2-}) was then calculated by subtracting SeO_3^{2-} from the total dissolved (0.45 micron) Se. With the exception of the KUCC outflow, each inflow site contained a substantial proportion of SeO_3^{2-}, which averaged 21 percent of the total dissolved Se during the two monitoring periods. (fig. 23). Although the KUCC discharge contained > 35 ug/L total dissolved Se in May 2006 and > 20 ug/L in May 2007, less than 5.1 percent was present as SeO_3^{2-}.

Figure 23. Distribution of selenate and selenite, in ug/L and (percentage of total selenium) in filtered water samples collected from inflow sites to Great Salt Lake during May 2006 (A) and May 2007 (B).

3.6 Impacts of Se load to observed Se concentrations in Great Salt Lake

The loading data collected over a 15-month period indicate that about 1,540 kg of total (dissolved + particulate) Se entered the south arm of GSL. The Se concentration in water samples collected from GSL during the 14-month monitoring period from May 2006 through June 2007 were used to understand how the cumulative Se load was being processed by various biogeochemical processes within the lake. Changes in dissolved (0.45 micron) and total Se concentration at the four monitoring sites (2267, 2565, 2767, and 3510) from May 2006 through June 2007 indicate an increasing concentration with time (fig. 24). The correlation coefficient (R) for the linear regression line through the filtered (< 0.45 micron) water samples ranged from 0.33 ($p = 0.32219$, $n = 11$) at site 2565 to 0.82 ($p = 0.00191$, $n = 11$) at site 2767. The two

shallow monitoring sites of 2267 and 2767 (total water depth < 5 m) have the highest correlation coefficients indicating a statistically significant trend of increasing dissolved Se concentration concurrent with the measured riverine loads of Se.

Figure 24. Trends in dissolved (0.45 micron) selenium concentration (A) and total selenium concentration (B) from May 2006 through June 2007 at open water sites, Great Salt Lake, Utah.

The dissolved + particulate Se data exhibited similar trends as the filtered Se data (fig. 24). The correlation coefficient (R) for the linear regression line through the unfiltered (dissolved + particulate) water samples ranged from 0.46 ($p = 0.13082$, $n = 12$) at site 2767 to 0.62 ($p = 0.04072$, $n = 11$) at site 2565.

The Mann-Kendall statistical test (Helsel and Hirsch, 1992) was applied to the Se data from filtered (< 0.45 microns) water samples collected from the monitoring sites in GSL to determine if the occurrence of increasing concentrations over time was statistically significant. The Mann-Kendall test is a non-parametric test that is suitable for censored data sets. The test was performed at both the 95- and 90-percent confidence levels. The Z score calculated for each data set was compared to the expected Z score at both the 95- and 90-percent confidence levels. If the calculated Z score exceeded the expected Z score, the occurrence of an upward trend in Se concentration with time was indicated.

Results of the Mann-Kendall statistical analysis for the Se data collected from sites 2267, 2565, 2767, and 3510 are summarized in Table 5. Statistically significant upward trend in dissolved (< 0.45 micron) Se concentration was indicated at all four sites at the 90-percent confidence level (table 5). In addition, the upward trend in dissolved (< 0.45 micron) Se concentration over the 14-month monitoring period was statistically significant at the 95-percent confidence level for sites 2267 and 2767.

Table 5. Summary of Mann-Kendall statistical trend analysis conducted on water samples analyzed for dissolved selenium, Great Salt Lake, Utah.

A potential contributing source of variance in the observed increases in Se concentration over time could be associated with analytical error. To address the analytical error, a series of laboratory replicates of water samples collected from GSL were analyzed throughout the 14-month monitoring period. The Se concentration measured in 15 laboratory replicates was compared to the dissolved (< 0.45 micron) Se concentration in the corresponding routine water sample (fig. 25). Results of these comparisons indicated that the mean difference between the routine and replicate samples was $\pm$ 15 percent. Elimination of the clear outlier from this data set resulted in a mean difference of $\pm$ 12 percent. Based on similar Se concentration between the routine and replicate samples, it is clear that laboratory error could not explain the large observed dissolved (< 0.45 micron) Se concentration increases of over 0.3 ug/L during the 14-month monitoring period.

Figure 25. Comparison of dissolved (< 0.45 micron) selenium concentration in laboratory replicates with routine samples collected from near-surface depths at sites 2267, 2767, 2565, and 3510 from May 2006 through June 2007. The mean difference between routine and replicate samples is +/- 15 percent (n = 15). Elimination of the outlier results in a mean difference of +/- 12 percent (n = 14).

The observed net increase in dissolved + particulate Se observed from May 2006 through July 2007 at each lake monitoring site was compared to the Se concentration increase expected from the cumulative Se mass added during the same time period for both dissolved (< 0.45 micron) and total (dissolved + particulate) Se in water. For the purpose of the following calculations, the biogeochemical behavior of Se in GSL is assumed to be conservative, which is certainly not the case, but provides a useful "worst case" end point to evaluate the impacts of annual Se loads to the open-water of GSL. The non-conservative behavior of Se in GSL is evidenced from the sediment core records and the gaseous Se flux measured from the lake surface (Johnson et al., 2007).

Based on the regression models for each lake monitoring site, the net change in dissolved (< 0.45 micron) Se concentration ranged from 0.16 to 0.34 ug/L and the net change in total (dissolved + particulate) Se concentration ranged from 0.25 to 0.28 ug/L (table 6). Mixing the cumulative riverine Se input (dissolved + particulate) over the same 15-month monitoring period with the lake volume of the south arm of GSL measured on July 31, 2007 (Baskin 2005), the expected net

increase in Se concentration would be 0.17 ug/L. This expected net increase in open-water Se concentration is approximately equal to the net change of 0.16 ug/L observed at site 2565 (dissolved Se only), but approximately half of the observed net change for both the dissolved (0.45 micron) at 3 lake-monitoring sites and total (dissolved + particulate) Se data at all 4 lake-monitoring sites (table 6). This suggests an additional, unquantified source(s) of Se should be contributing an additional 1500 kg of Se load to the south arm of GSL over the 15-month monitoring period. If Se export to the north arm as well as sedimentation and gaseous flux removal processes are considered, the unquantified source contribution would be substantially higher than 1500 kg/year. Potential source(s) of this additional Se load could include: (1) Se loads entering GSL from unmeasured surface inflows; (2) submarine groundwater discharge; (3) wind-blown dust that is deposited directly on the lake surface; (4) wet and dry atmospheric deposition falling directly on the lake surface; and (5) lake sediment pore water diffusion into the overlying water column. Evaporative concentration of Se due to falling lake levels would not increase the mass loading of Se to GSL; however, evaporation could be causing some of the observed increasing trends in Se concentration in water column samples. Additional supporting information regarding additional Se loads and concentration from a few of the unmeasured sources and processes listed previously is presented in the subsequent material. This supporting information was limited to the unmeasured sources and processes where site-specific supporting data were available: (1) unmeasured surface inflows; (2) submarine groundwater discharge; and (3) evaporative concentration.

Table 6. Selenium concentration increases expected from riverine inputs compared to observed selenium concentration increase at four lake sites from May 15, 2006 through July 31, 2007, Great Salt Lake, Utah.

The cumulative Se load to GSL contributed by the Weber River inflow may not have been measured during this study. Due to multiple diversion structures, flow in the Weber River is extensively diverted downstream of USGS gage site 10141000 (Weber River near Plain City, Utah) (fig. 1). The total discharge from May 11, 2006 through July 31, 2007, measured at Weber River near Plain City (upstream) was about 6.8 times larger than the total discharge measured at Weber River near West Warren, Utah (downstream gage monitored for Se load to GSL) during the same time period. Assuming that all the water flow measured at the upstream gage discharged to the open water of GSL (worst case scenario) and that this additional surface-water discharge had a similar Se concentration to what was measured at the downstream gage, an additional Se load of 46 kg was calculated for the 15-month monitoring period. This additional Se load of 46 kg is inconsequential relative to the unmeasured Se of 1500 kg.

The potential for submarine groundwater discharge was assessed with a preliminary resistivity survey conducted by the USGS in September 2007 along the southerly shoreline of GSL. The resistivity survey was designed to utilize a 35-m string of electrodes that was towed behind a boat to view areas of high resistivity (non-saline) water in the near-surface sediments underlying the low resistivity (highly saline) water in the south and east sides of GSL (fig. 26). Although

additional follow-up work is needed for verification, high resistivity zones were detected that could indicate areas of non-saline, submarine groundwater discharge and corresponding unmeasured Se loads to the open water of GSL. For example, regions of high and low resistivity were found in the near-surface sediments on the south end of GSL (figs. 27 and 28). The high resistivity zones indicate potential areas of ground-water discharge that may justify the installation of nested piezometers to measure the shallow groundwater gradient and associated Se flux from these regions to the open water of GSL.

Figure 26. Location of continuous resistivity survey profiles collected during September 2007, Great Salt Lake, Utah.

Figure 27. Location of high resistivity zone along transect l1f1 (A) and cross section of resistivity values (B). White horizontal line on resistivity cross section denotes approximate position of surface water/sediment interface.

Figure 28. Location of low resistivity zone along transect l1f1 (A) and cross section of resistivity values (B). White horizontal line on resistivity cross section denotes approximate position of surface water/sediment interface.

Previous work (KUCC, 1999) has found elevated (exceeding 10,000 ug/L) Se in groundwater beneath KUCC smelter and refinery facilities within 1 mile of the south shore of GSL (fig. 29). Ground-water modeling of this contaminant plume has indicated minimal discharge to GSL (KUCC, 1999); however, no ground-water monitoring data have been collected beneath GSL to verify the ground-water modeling results. Based on KUCC estimates, total water volume in the contaminant plume may exceed 64,000 acre feet and contain a Se concentration ranging between 50 and 17,000 ug/L. Assuming that 30 percent of the contaminant plume eventually discharged to GSL and the plume contained an average Se concentration of 8,500 ug/L, this would represent a Se mass of 208,000 kg. This Se mass would represent over 138 years of cumulative annual Se loads measured during the current study. Without monitoring data beneath GSL, the Se load to the open water associated with potential groundwater source(s) cannot be assessed.

Figure 29. Predicted and observed extent of groundwater contaminant plume containing elevated concentrations of selenium located on the south margin of GSL (KUCC, 1999).

Evaporation of the water from GSL could also contribute to the observed increases in dissolved (< 0.45 micron) Se concentration during the monitoring period (table 6). In order to assess the impact of evaporation, comparison between salinity and dissolved (< 0.45 micron) Se were made at the four lake monitoring sites (fig. 30). The salinity data represents water samples collected from the Saltair gage site (January 2006 through May 2007) and individual lake monitoring sites (September 2006 through June 2007). For the period of record, comparison of the salinity and Se

data from the four lake-monitoring stations indicates a negative relationship (fig. 30). Additional salinity and Se data are needed to determine if this negative relationship continues through the summer and fall seasons of 2007.

Figure 30. Comparison between salinity and dissolved (< 0.45 micron) selenium concentration in water samples from lake monitoring stations, Great Salt Lake, Utah. Salinity data represents water samples from Saltair gage site (January 2006 through May 2007) and individual lake monitoring sites (September 2006 through June 2007).

4.0 Summary

Discharge and water-quality data from six gages were used in combination with the LOADEST software to provide an estimate of total (dissolved + particulate) selenium (Se) load to the south arm of Great Salt Lake (GSL) during the period of May 2006 through July 2007. The six USGS gages used for the Se loading calculations included: (1) Bear River Bay Outflow at GSL Minerals Corp Bridge (BR); (2) North Fork Weber River near West Warren, Utah (WR); (3) Goggin Drain near Magna, Utah (GD); (4) Lee Creek near Magna, Utah (LC); (5) Kennecott Drain near Magna, Utah (KUCC); and (6) GSL Farmington Bay Outflow at Causeway Bridge (FB). Due to the low channel gradients and wind influence on inflow rates, hydroacoustic equipment in combination with velocity index methods were used to accurately gage discharge at the KUCC, FB, and BR gage sites. Discharge data can be accessed at: http://waterdata.usgs.gov/ut/nwis/sw. Measured Se loads from the flooding of near-shore

sediments during annual water-level increases were small (10 kg) and not considered significant relative to the measured surface-water loadings.

Total estimated Se load to GSL during 15-month monitoring period was 1,540 kilograms (kg). The 12-month estimated Se load to GSL for the time period from May 1, 2006 to April 30, 2007 was 1,480 kg. The largest cumulative monthly Se load occurred during May 2006 (304 kg) and the smallest cumulative monthly load occurred during July 2007 (21 kg). During the 15-month monitoring period, inflows from the Kennecott Utah Copper Corporation (KUCC) Outfall, Goggin Drain, and Bear River contributed equally to the largest proportion of total Se load to GSL, accounting for 80 percent of the total Se load. Current (2006 and 2007) median Se loadings from Lee Creek (0.28 kg/day) have increased by more than an order of magnitude relative to historic Se loads (< 0.025 kg/day) calculated from data collected during 1972 through 1984. Historic Se loads during peak flow periods (1972-1984) for the Goggin Drain outflow site were about 50 percent lower than current (2006-2007) daily Se loads during peak runoff periods.

Five instantaneous discharge measurements at three sites along the railroad causeway during the 15-month monitoring period indicate a consistent net loss of Se mass from the south arm to the north arm of GSL (mean = 2.4 kg/day, n = 5). Application of the average daily loss rate equates to annual Se loss rate to the north arm of 880 kg (55 % of the annual Se input to the south arm); however, without continuous measurement of discharge the error associated with this annual loss estimate is high. The majority of Se in water entering GSL is in the dissolved (0.45 micron) state and ranges in concentration from 0.06 to 35.7 ug/L. Particulate Se concentration ranged from <

0.05 to 2.5 ug/L. Except for the KUCC gage site, dissolved (0.45 um) inflow samples were comprised of 21 % selenite (SeO_3^{2-}) during two sampling events (May 2006 and 2007).

Selenium concentration in water samples collected from four monitoring sites within GSL during from May 2006 through June 2007 were used to understand how the cumulative Se load was being processed by various biogeochemical processes within the lake. Based on the Mann-Kendall test, changes in dissolved Se concentration at the four monitoring sites indicate a statistically significant (90 % confidence interval) upward trend in Se concentration with time. Furthermore, the upward trend at two of the four GSL sites was also significant at the 95 % confidence interval. Regression models for each lake monitoring site indicated a net change in Se concentration that ranged from 0.16 to 0.34 ug/L during the 15-month monitoring period. Comparison of the observed net increase in Se concentration with the net increase expected from measured riverine Se influx over the same monitoring period was + 0.17 ug/L. The expected net increase in open-water Se concentration of 0.17 ug/L is approximately half of the net concentration change measured at 3 of the 4 lake monitoring sites.

An unmeasured source of Se contributing a minimum of an additional 1,500 kg of Se load to the south arm is indicated by the previous comparison. The value for the unmeasured Se contribution does not consider measured Se loss mechanisms that include: (1) Se export to the north arm of GSL; (2) Se loss via permanent sedimentation; and (3) Se loss via gas flux to the atmosphere. Potential source(s) of this unmeasured Se load could include: (1) Se loads entering GSL from unmeasured surface inflows; (2) submarine groundwater discharge; (3) wind-blown dust that is deposited directly on the lake surface; (4) wet and dry atmospheric deposition falling directly on

the lake surface; and (5) lake sediment pore water diffusion into the overlying water column. Evaporative concentration of Se due to falling lake levels would not increase the mass loading of Se to GSL; however, evaporation could be causing some of the observed increasing trends in Se concentration in water column samples.

Processes and sources of additional Se loads and Se concentration from the unmeasured sources and processes identified during the study were further assessed with existing and recently available data. The findings are listed below:

1. Additional Se loads from the Weber River system are small and would only contribute an additional 46 kg of Se during the 15-month monitoring period.
2. Resistivity surveys in the south part of GSL indicate high resistivity areas of potential submarine groundwater discharge to the open water of GSL. Previous work has found elevated (exceeding 10,000 ug/L) Se in groundwater beneath KUCC smelter and refinery facilities within 1 mile of the south shore of GSL. Total water volume in this contaminant plume may exceed 64,000 acre feet and contain a Se concentration ranging between 50 and 17,000 ug/L.
3. Comparison between salinity and dissolved (< 0.45 micron) Se concentrations at the four lake monitoring sites show a negative correlation, indicative that evaporative processes play a limited role in the statistically significant increase in open-water Se observed during the study period.

Acknowledgments. Use of brand names in this article is for identification purposes only and does not constitute endorsement by the USGS.

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Appendix A

LOADEST input and output files

Kennecott Drain near Magna, Utah

```
#############################################################################
#
#  LOADEST Calibration File
#
#  KUCC outfall (used to est. loads from 10/1/06 thru 07/31/07)
#
#  Total Se (dissolved + particulate)
#  Contract lab data added = 12/4/06; 1/3/07; 3/6/07; and 5/16/07
#
#############################################################################
#
#CDATE      CTIME     CFLOW      CCONC
#
#############################################################################
20060718     1200     0.18    3.06
20060720     1200     12      28
20060727     1200     27      26
20060728     1200     27      39
20060729     1200     12      33
20060803     1200     14      35
20060816     1200     20      30
20060819     1200     27      31
20060820     1200     27      28
20060821     1200     24      31
20060822     1200     26      29
20060823     1200     26      34
20060824     1200     17      31
20060825     1200     18      35
20060826     1200     32      31
20060827     1200     29      31
20060828     1200     16      30
20060829     1200     26      32
20060830     1200     25      34
20060902     1200     56      30
20060903     1200     49      29
20060904     1200     14      29
20060912     1200     13      27
20060913     1200     0.1     32
20060930     1200     0.26    33
20061011     1200     27      29
20061012     1200     28      29
20061013     1200     30      29
20061014     1200     33      21
20061015     1200     34      22
20061016     1200     3.7     21
20061031     1200     20      28
20061101     1200     0.28    28
20061108     1200     28      27
```

20061109	1200	29	28
20061110	1200	30	27
20061111	1200	34	27
20061112	1200	39	25
20061113	1200	17	26
20061202	1200	44	25
20061203	1200	45	26
20061204	0920	46	18.4
20061205	1200	47	23
20061206	1200	39	23
20061207	1200	44	22
20061208	1200	45	23
20061209	1200	45	22
20061210	1200	33	23
20061211	1200	34	22
20061212	1200	35	22
20061213	1200	25	25
20061214	1200	17	25
20061221	1200	38	24
20061222	1200	40	25
20061223	1200	65	26
20061224	1200	8.1	28
20061229	1200	43	25
20061230	1200	74	22
20061231	1200	74	23
20070101	1200	74	21
20070102	1200	74	23
20070103	1115	74	20.3
20070104	1200	74	21
20070105	1200	75	21
20070106	1200	74	21
20070107	1200	74	20
20070108	1200	69	20
20070109	1200	46	20
20070110	1200	0.52	20
20070208	1200	59	23
20070209	1200	78	23
20070210	1200	77	22
20070211	1200	76	23
20070212	1200	70	23
20070213	1200	79	22
20070214	1200	78	22
20070215	1200	65	21
20070216	1200	68	22
20070217	1200	78	20
20070218	1200	78	20
20070219	1200	9.4	20
20070303	1200	44	20
20070304	1200	43	19
20070305	1200	39	18
20070306	1235	35	19.4
20070307	1200	29	21
20070308	1200	25	22
20070309	1200	25	21
20070310	1200	26	21
20070311	1200	26	20

20070312	1200	15	21
20070314	1200	37	21
20070315	1200	18	21
20070324	1200	0.54	20
20070331	1200	25	21
20070401	1200	27	22
20070402	1200	28	21
20070403	1200	28	20
20070404	1200	26	20
20070405	1200	26	20
20070406	1200	14	21
20070413	1200	24	20
20070414	1200	14	20
20070417	1200	4.5	23
20070421	1200	26	19
20070422	1200	27	20
20070423	1200	35	20
20070424	1200	43	23
20070425	1200	39	22
20070426	1200	16	21
20070502	1200	36	21
20070503	1200	0.72	22
20070509	1200	36	23
20070510	1200	40	26
20070511	1200	24	22
20070516	1430	20	22.5
20070517	1200	30	24
20070518	1200	14	24
20070522	1200	24	23
20070523	1200	25	23
20070524	1200	23	23
20070525	1200	22	19
20070526	1200	21	20
20070527	1200	29	20
20070528	1200	33	21
20070529	1200	27	23
20070530	1200	27	24
20070531	1200	25	24
20070601	1200	23	22
20070602	1200	16	21
20070614	1200	30	22
20070615	1200	17	23
20070616	1200	24	23
20070617	1200	9.1	21

```
#############################################################################
#
#  LOADEST Estimation File
#
#  KUCC outfall (data prior to 6/28/06 is not USGS)
#
#  0 or negative discharges replaced with 0.0001
#
#
#############################################################################
#
#  Number of observations per day, NOBSPD (col. 1-5)
#
#############################################################################
1
#############################################################################
#
# EDATE     ETIME   EFLOW
#
#############################################################################
20060628     1200     0.0001
20060629     1200     0.0001
20060630     1200     0.29
20060701     1200     0.36
20060702     1200     0.29
20060703     1200     0.29
20060704     1200     0.25
20060705     1200     0.15
20060706     1200     0.18
20060707     1200     0.12
20060708     1200     0.16
20060709     1200     0.14
20060710     1200     0.13
20060711     1200     0.12
20060712     1200     0.18
20060713     1200     0.13
20060714     1200     0.19
20060715     1200     0.17
20060716     1200     0.18
20060717     1200     0.19
20060718     1200     0.18
20060719     1200     12
20060720     1200     12
20060721     1200     5.7
20060722     1200     0.19
20060723     1200     0.17
20060724     1200     0.22
20060725     1200     4.4
20060726     1200     17
20060727     1200     27
20060728     1200     27
20060729     1200     12
20060730     1200     0.14
20060731     1200     0.14
20060801     1200     6.8
20060802     1200     13
```

20060803	1200	14
20060804	1200	0.18
20060805	1200	0.11
20060806	1200	0.25
20060807	1200	0.0001
20060808	1200	0.35
20060809	1200	0.25
20060810	1200	0.05
20060811	1200	4.2
20060812	1200	0.16
20060813	1200	0.13
20060814	1200	0.02
20060815	1200	15
20060816	1200	0.22
20060817	1200	8.9
20060818	1200	15
20060819	1200	27
20060820	1200	27
20060821	1200	24
20060822	1200	26
20060823	1200	26
20060824	1200	17
20060825	1200	18
20060826	1200	32
20060827	1200	29
20060828	1200	16
20060829	1200	26
20060830	1200	25
20060831	1200	0.1
20060901	1200	23
20060902	1200	56
20060903	1200	49
20060904	1200	14
20060905	1200	0.13
20060906	1200	0.1
20060907	1200	7
20060908	1200	0.07
20060909	1200	0.11
20060910	1200	0.1
20060911	1200	16
20060912	1200	13
20060913	1200	0.1
20060914	1200	0.08
20060915	1200	0.3
20060916	1200	0.3
20060917	1200	0.3
20060918	1200	0.3
20060919	1200	0.4
20060920	1200	0.4
20060921	1200	0.41
20060922	1200	0.4
20060923	1200	0.4
20060924	1200	0.4
20060925	1200	0.3
20060926	1200	0.3
20060927	1200	0.3

20060928	1200	0.28
20060929	1200	3.6
20060930	1200	0.26
20061001	1200	0.35
20061002	1200	0.28
20061003	1200	0.29
20061004	1200	0.22
20061005	1200	0.31
20061006	1200	0.28
20061007	1200	0.41
20061008	1200	0.3
20061009	1200	0.26
20061010	1200	9.4
20061011	1200	27
20061012	1200	28
20061013	1200	30
20061014	1200	33
20061015	1200	34
20061016	1200	3.7
20061017	1200	0.33
20061018	1200	0.3
20061019	1200	0.28
20061020	1200	0.39
20061021	1200	0.21
20061022	1200	0.36
20061023	1200	0.22
20061024	1200	0.36
20061025	1200	0.32
20061026	1200	0.32
20061027	1200	0.28
20061028	1200	0.29
20061029	1200	0.39
20061030	1200	14
20061031	1200	20
20061101	1200	0.28
20061102	1200	0.32
20061103	1200	0.28
20061104	1200	0.32
20061105	1200	0.34
20061106	1200	0.87
20061107	1200	12
20061108	1200	28
20061109	1200	29
20061110	1200	30
20061111	1200	34
20061112	1200	39
20061113	1200	17
20061114	1200	0.41
20061115	1200	0.43
20061116	1200	0.33
20061117	1200	0.27
20061118	1200	0.38
20061119	1200	0.39
20061120	1200	0.39
20061121	1200	0.38
20061122	1200	0.46

20061123	1200	0.48
20061124	1200	0.37
20061125	1200	0.41
20061126	1200	0.4
20061127	1200	0.44
20061128	1200	0.47
20061129	1200	0.4
20061130	1200	0.38
20061201	1200	19
20061202	1200	44
20061203	1200	45
20061204	1200	46
20061205	1200	47
20061206	1200	39
20061207	1200	44
20061208	1200	45
20061209	1200	45
20061210	1200	33
20061211	1200	34
20061212	1200	35
20061213	1200	25
20061214	1200	17
20061215	1200	0.53
20061216	1200	0.41
20061217	1200	0.42
20061218	1200	0.49
20061219	1200	5.5
20061220	1200	14
20061221	1200	38
20061222	1200	40
20061223	1200	65
20061224	1200	8.1
20061225	1200	0.47
20061226	1200	0.38
20061227	1200	0.36
20061228	1200	49
20061229	1200	43
20061230	1200	74
20061231	1200	74
20070101	1200	74
20070102	1200	74
20070103	1200	74
20070104	1200	74
20070105	1200	75
20070106	1200	74
20070107	1200	74
20070108	1200	69
20070109	1200	46
20070110	1200	0.52
20070111	1200	0.35
20070112	1200	0.35
20070113	1200	0.39
20070114	1200	0.38
20070115	1200	0.26
20070116	1200	11
20070117	1200	0.37

20070118	1200	0.37
20070119	1200	0.33
20070120	1200	0.29
20070121	1200	0.33
20070122	1200	0.28
20070123	1200	0.3
20070124	1200	0.46
20070125	1200	0.43
20070126	1200	0.41
20070127	1200	0.4
20070128	1200	0.27
20070129	1200	8.6
20070130	1200	0.37
20070131	1200	0.28
20070201	1200	0.27
20070202	1200	0.34
20070203	1200	0.34
20070204	1200	0.28
20070205	1200	0.27
20070206	1200	3.6
20070207	1200	47
20070208	1200	59
20070209	1200	78
20070210	1200	77
20070211	1200	76
20070212	1200	70
20070213	1200	79
20070214	1200	78
20070215	1200	65
20070216	1200	68
20070217	1200	78
20070218	1200	78
20070219	1200	9.4
20070220	1200	0.72
20070221	1200	0.57
20070222	1200	0.62
20070223	1200	0.87
20070224	1200	0.86
20070225	1200	0.73
20070226	1200	0.95
20070227	1200	1.2
20070228	1200	8.7
20070301	1200	0.99
20070302	1200	22
20070303	1200	44
20070304	1200	43
20070305	1200	39
20070306	1200	35
20070307	1200	29
20070308	1200	25
20070309	1200	25
20070310	1200	26
20070311	1200	26
20070312	1200	15
20070313	1200	25
20070314	1200	37

20070315	1200	18
20070316	1200	0.53
20070317	1200	0.4
20070318	1200	0.33
20070319	1200	0.27
20070320	1200	0.24
20070321	1200	0.24
20070322	1200	0.22
20070323	1200	16
20070324	1200	0.54
20070325	1200	0.55
20070326	1200	0.34
20070327	1200	0.31
20070328	1200	0.29
20070329	1200	6.3
20070330	1200	18
20070331	1200	25
20070401	1200	27
20070402	1200	28
20070403	1200	28
20070404	1200	26
20070405	1200	26
20070406	1200	14
20070407	1200	0.54
20070408	1200	0.43
20070409	1200	0.39
20070410	1200	0.33
20070411	1200	4.8
20070412	1200	18
20070413	1200	24
20070414	1200	14
20070415	1200	0.38
20070416	1200	6.9
20070417	1200	4.5
20070418	1200	0.41
20070419	1200	0.31
20070420	1200	12
20070421	1200	26
20070422	1200	27
20070423	1200	35
20070424	1200	43
20070425	1200	39
20070426	1200	16
20070427	1200	0.39
20070428	1200	0.4
20070429	1200	0.26
20070430	1200	0.27
20070501	1200	31
20070502	1200	36
20070503	1200	0.72
20070504	1200	0.34
20070505	1200	0.21
20070506	1200	0.22
20070507	1200	5.7
20070508	1200	24
20070509	1200	36

20070510	1200	40
20070511	1200	24
20070512	1200	0.31
20070513	1200	0.35
20070514	1200	0.18
20070515	1200	0.15
20070516	1200	20
20070517	1200	30
20070518	1200	14
20070519	1200	0.27
20070520	1200	0.25
20070521	1200	15
20070522	1200	24
20070523	1200	25
20070524	1200	23
20070525	1200	22
20070526	1200	21
20070527	1200	29
20070528	1200	33
20070529	1200	27
20070530	1200	27
20070531	1200	25
20070601	1200	23
20070602	1200	16
20070603	1200	0.24
20070604	1200	0.16
20070605	1200	0.2
20070606	1200	0.26
20070607	1200	0.33
20070608	1200	0.17
20070609	1200	0.23
20070610	1200	0.13
20070611	1200	0.21
20070612	1200	3
20070613	1200	11
20070614	1200	30
20070615	1200	17
20070616	1200	24
20070617	1200	9.1
20070618	1200	0.19
20070619	1200	0.24
20070620	1200	0.18
20070621	1200	0.15
20070622	1200	0.2
20070623	1200	0.13
20070624	1200	0.1
20070625	1200	0.08
20070626	1200	0.08
20070627	1200	0.17
20070628	1200	0.1
20070629	1200	0.12
20070630	1200	0.09
20070701	1200	0.15
20070702	1200	0.02
20070703	1200	0.0001
20070704	1200	0.0001

20070705	1200	0.07
20070706	1200	0.0001
20070707	1200	0.0001
20070708	1200	0.0001
20070709	1200	0.02
20070710	1200	0.07
20070711	1200	0.0001
20070712	1200	0.0001
20070713	1200	0.0001
20070714	1200	0.15
20070715	1200	0.0001
20070716	1200	0.0001
20070717	1200	0.0001
20070718	1200	0.06
20070719	1200	0.17
20070720	1200	0.01
20070721	1200	0.03
20070722	1200	0.08
20070723	1200	0.07
20070724	1200	0.09
20070725	1200	0.0001
20070726	1200	0.34
20070727	1200	0.3
20070728	1200	0.0001
20070729	1200	0.0001
20070730	1200	0.0001
20070731	1200	0.04

LOADEST
A Program to Estimate Constituent Loads
U.S. Geological Survey, Version: MOD36 (Sep 2004)

KUCC Outfall

Constituent: selenium

Constituent Output File Part Ia: Calibration (Load Regression)

Number of Observations : 134
Number of Uncensored Observations: 134
"center" of Decimal Time : 2007.014
"center" of Ln(Q) : 1.5768
Period of record : 2006-2007

Model Evaluation Criteria Based on AMLE Results

Model #	AIC	SPPC
1	0.001	-2.984
2	-0.055	-0.667
3	-0.156	6.116
4	-0.303	14.508
5	-0.262	11.780
6	-0.349	16.140
7	-0.288	12.062
8	-0.334	13.677
9	-0.426	18.367

Model # 9 selected

Selected Model:

Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)
+ a5 dtime + a6 dtime^2

where:
Load = constituent load [kg/d]
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Model Coefficients

a0	a1	a2	a3	a4	a5	a6

AMLE	-0.9034	1.0523	-0.0186	-0.1739	-0.4856	-0.0343	-4.7003
MLE	-0.9034	1.0523	-0.0186	-0.1739	-0.4856	-0.0343	-4.7003
LAD	-1.1277	0.9995	0.0028	-0.1197	-0.2548	-0.1833	-1.5670

AMLE Regression Statistics

R-Squared [%] : 97.74
Prob. Plot Corr. Coeff. (PPCC) : 0.8063
Serial Correlation of Residuals: 0.2170

Coeff.	Std.Dev.	t-ratio	P Value
a0	0.1008	-8.96	5.310E-16
a1	0.0151	69.88	4.124-109
a2	0.0080	-2.31	1.877E-02
a3	0.0460	-3.78	1.567E-04
a4	0.1186	-4.09	4.582E-05
a5	0.1239	-0.28	7.763E-01
a6	1.2416	-3.79	1.535E-04

Correlation Between Explanatory Variables

Explanatory variable corresponding to:

	a1	a2	a3	a4	a5
a2	0.0000				
a3	0.1123	-0.0722			
a4	0.3024	0.4492	-0.0481		
a5	0.1266	-0.1139	0.8613	-0.0354	
a6	-0.2836	-0.4078	0.0135	-0.9769	0.0000

Additional Regression Statistics

	Residual Variance	Turnbull-Weiss Stat	DF	PL
AMLE	0.036	82.64	23	1.180E-08
MLE	0.036	82.64	23	1.180E-08

Constituent Output File Part Ib: Calibration (Concentration Regression)

AMLE Regression Statistics

Model # 9 was selected for the load regression (PART Ia) and is used here:

Ln(Conc) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)
+ a5 dtime + a6 dtime^2

where:
Conc = constituent concentration
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Concentration Regression Results

R-Squared [%] : 40.48
Residual Variance : 0.0363

Coeff.	Value	Std.Dev.	t-ratio	P Value
a0	3.5328	0.1008	35.05	5.690E-71
a1	0.0523	0.0151	3.47	4.856E-04
a2	-0.0186	0.0080	-2.31	1.877E-02
a3	-0.1739	0.0460	-3.78	1.567E-04
a4	-0.4856	0.1186	-4.09	4.582E-05
a5	-0.0343	0.1239	-0.28	7.763E-01
a6	-4.7003	1.2416	-3.79	1.535E-04

Constituent Output File Part IIa: Estimation (test for extrapolation)

Load Estimates for 20060628-20070731

Streamflow Summary Statistics [cfs]

Data	Mean	Minimum	10th Pct	25th Pct	Median	75th Pct	90th Pct	Maximum
Cal.	34.	0.	12.	21.	28.	43.	74.	79.
Est.	13.	0.	0.	0.	0.	24.	40.	79.

The maximum estimation data set steamflow does not exceed the maximum calibration data set streamflow. No extrapolation is required.

Constituent Output File Part IIb: Estimation (Load Estimates)

Load Estimates for 20060628-20070731

Load Estimates [KG/DAY]

AMLE Load Estimates

95% Conf.Intervals

	N	Mean Load	Lower	Upper	Std Error Prediction	Standard Error
Est. Period	399	0.74	0.71	0.78	0.02	0.01

MLE Load Estimates

	N	Mean Load	Standard Error
Est. Period	399	0.74	0.01

LAD Load Estimates

	N	Mean Load	Standard Error
Est. Period	399	0.73	0.01

Summary Statistics - Estimated Loads [KG/DAY]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.000	0.010	0.021	1.348	2.378	3.614	3.955	4.259
MLE	0.000	0.010	0.021	1.348	2.378	3.614	3.955	4.259
LAD	0.000	0.014	0.026	1.287	2.292	3.548	3.950	4.262

Summary Statistics - Estimated Concentrations [UG/L]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.56	15.77	20.65	22.98	26.74	30.66	31.87	32.47
MLE	0.56	15.77	20.65	22.98	26.74	30.66	31.87	32.47
LAD	20.	21.	23.	29.	31.	31.	33.	41.

Individual Load Estimates for KUCC outfall in kg/day

			Loads Estimated by:		
Date	Time	Flow	AMLE	MLE	LAD
20060628	1200	1.000E-04	1.6453E-07	1.6454E-07	8.3776E-06
20060629	1200	1.000E-04	1.6744E-07	1.6745E-07	8.4337E-06
20060630	1200	2.900E-01	8.2662E-03	8.2662E-03	1.8076E-02
20060701	1200	3.600E-01	1.0798E-02	1.0798E-02	2.2508E-02
20060702	1200	2.900E-01	8.5618E-03	8.5618E-03	1.8310E-02
20060703	1200	2.900E-01	8.7105E-03	8.7105E-03	1.8426E-02
20060704	1200	2.500E-01	7.4571E-03	7.4571E-03	1.6023E-02
20060705	1200	1.500E-01	4.1620E-03	4.1620E-03	9.7652E-03
20060706	1200	1.800E-01	5.2480E-03	5.2480E-03	1.1747E-02
20060707	1200	1.200E-01	3.2982E-03	3.2982E-03	7.9423E-03
20060708	1200	1.600E-01	4.7172E-03	4.7172E-03	1.0589E-02
20060709	1200	1.400E-01	4.0910E-03	4.0910E-03	9.3433E-03
20060710	1200	1.300E-01	3.8047E-03	3.8047E-03	8.7381E-03
20060711	1200	1.200E-01	3.5118E-03	3.5118E-03	8.1242E-03
20060712	1200	1.800E-01	5.7664E-03	5.7664E-03	1.2153E-02
20060713	1200	1.300E-01	3.9811E-03	3.9811E-03	8.8810E-03
20060714	1200	1.900E-01	6.3294E-03	6.3294E-03	1.2950E-02
20060715	1200	1.700E-01	5.6330E-03	5.6330E-03	1.1671E-02
20060716	1200	1.800E-01	6.1117E-03	6.1117E-03	1.2406E-02
20060717	1200	1.900E-01	6.6046E-03	6.6046E-03	1.3146E-02
20060718	1200	1.800E-01	6.2831E-03	6.2831E-03	1.2526E-02
20060719	1200	1.200E+01	6.3869E-01	6.3869E-01	8.1390E-01
20060720	1200	1.200E+01	6.4722E-01	6.4722E-01	8.1763E-01
20060721	1200	5.700E+00	3.0394E-01	3.0394E-01	3.8940E-01
20060722	1200	1.900E-01	7.0570E-03	7.0570E-03	1.3450E-02
20060723	1200	1.700E-01	6.2687E-03	6.2687E-03	1.2111E-02
20060724	1200	2.200E-01	8.5918E-03	8.5918E-03	1.5663E-02
20060725	1200	4.400E+00	2.4335E-01	2.4335E-01	3.0572E-01
20060726	1200	1.700E+01	9.9237E-01	9.9237E-01	1.1903E+00
20060727	1200	2.700E+01	1.5925E+00	1.5925E+00	1.9046E+00
20060728	1200	2.700E+01	1.6108E+00	1.6108E+00	1.9117E+00
20060729	1200	1.200E+01	7.2173E-01	7.2173E-01	8.4800E-01
20060730	1200	1.400E-01	5.4030E-03	5.4030E-03	1.0285E-02
20060731	1200	1.400E-01	5.4611E-03	5.4611E-03	1.0321E-02
20060801	1200	6.800E+00	4.1531E-01	4.1531E-01	4.8466E-01
20060802	1200	1.300E+01	8.1687E-01	8.1687E-01	9.3146E-01
20060803	1200	1.400E+01	8.8953E-01	8.8953E-01	1.0066E+00
20060804	1200	1.800E-01	7.6558E-03	7.6558E-03	1.3371E-02
20060805	1200	1.100E-01	4.3054E-03	4.3054E-03	8.2775E-03
20060806	1200	2.500E-01	1.1463E-02	1.1463E-02	1.8565E-02
20060807	1200	1.000E-04	2.7882E-07	2.7884E-07	1.0116E-05
20060808	1200	3.500E-01	1.7233E-02	1.7233E-02	2.5985E-02
20060809	1200	2.500E-01	1.1773E-02	1.1773E-02	1.8708E-02
20060810	1200	5.000E-02	1.7262E-03	1.7262E-03	3.8838E-03
20060811	1200	4.200E+00	2.7476E-01	2.7476E-01	3.0760E-01
20060812	1200	1.600E-01	7.1456E-03	7.1456E-03	1.2154E-02
20060813	1200	1.300E-01	5.6279E-03	5.6279E-03	9.9366E-03
20060814	1200	2.000E-02	5.6480E-04	5.6481E-04	1.6084E-03
20060815	1200	1.500E+01	1.0569E+00	1.0569E+00	1.1105E+00
20060816	1200	2.200E-01	1.0707E-02	1.0707E-02	1.6736E-02
20060817	1200	8.900E+00	6.2925E-01	6.2925E-01	6.5956E-01
20060818	1200	1.500E+01	1.0790E+00	1.0790E+00	1.1158E+00
20060819	1200	2.700E+01	1.9541E+00	1.9541E+00	2.0202E+00
20060820	1200	2.700E+01	1.9663E+00	1.9663E+00	2.0228E+00

20060821	1200	2.400E+01	1.7604E+00	1.7604E+00	1.7983E+00
20060822	1200	2.600E+01	1.9169E+00	1.9169E+00	1.9517E+00
20060823	1200	2.600E+01	1.9277E+00	1.9277E+00	1.9536E+00
20060824	1200	1.700E+01	1.2684E+00	1.2684E+00	1.2743E+00
20060825	1200	1.800E+01	1.3504E+00	1.3504E+00	1.3508E+00
20060826	1200	3.200E+01	2.4026E+00	2.4026E+00	2.4149E+00
20060827	1200	2.900E+01	2.1913E+00	2.1913E+00	2.1877E+00
20060828	1200	1.600E+01	1.2169E+00	1.2169E+00	1.2020E+00
20060829	1200	2.600E+01	1.9850E+00	1.9850E+00	1.9611E+00
20060830	1200	2.500E+01	1.9174E+00	1.9174E+00	1.8856E+00
20060831	1200	1.000E-01	4.5569E-03	4.5569E-03	7.8334E-03
20060901	1200	2.300E+01	1.7788E+00	1.7788E+00	1.7340E+00
20060902	1200	5.600E+01	4.2591E+00	4.2591E+00	4.2625E+00
20060903	1200	4.900E+01	3.7582E+00	3.7582E+00	3.7229E+00
20060904	1200	1.400E+01	1.0918E+00	1.0918E+00	1.0516E+00
20060905	1200	1.300E-01	6.3450E-03	6.3450E-03	1.0121E-02
20060906	1200	1.000E-01	4.6478E-03	4.6478E-03	7.8270E-03
20060907	1200	7.000E+00	5.4067E-01	5.4067E-01	5.2397E-01
20060908	1200	7.000E-02	3.0337E-03	3.0337E-03	5.5191E-03
20060909	1200	1.100E-01	5.2496E-03	5.2496E-03	8.5773E-03
20060910	1200	1.000E-01	4.6917E-03	4.6917E-03	7.8083E-03
20060911	1200	1.600E+01	1.2711E+00	1.2711E+00	1.1982E+00
20060912	1200	1.300E+01	1.0320E+00	1.0320E+00	9.7149E-01
20060913	1200	1.000E-01	4.7160E-03	4.7160E-03	7.7870E-03
20060914	1200	8.000E-02	3.6072E-03	3.6072E-03	6.2548E-03
20060915	1200	3.000E-01	1.7285E-02	1.7285E-02	2.2821E-02
20060916	1200	3.000E-01	1.7303E-02	1.7303E-02	2.2792E-02
20060917	1200	3.000E-01	1.7317E-02	1.7317E-02	2.2762E-02
20060918	1200	3.000E-01	1.7330E-02	1.7330E-02	2.2730E-02
20060919	1200	4.000E-01	2.4152E-02	2.4152E-02	3.0128E-02
20060920	1200	4.000E-01	2.4161E-02	2.4161E-02	3.0080E-02
20060921	1200	4.100E-01	2.4859E-02	2.4859E-02	3.0770E-02
20060922	1200	4.000E-01	2.4167E-02	2.4167E-02	2.9979E-02
20060923	1200	4.000E-01	2.4164E-02	2.4164E-02	2.9924E-02
20060924	1200	4.000E-01	2.4158E-02	2.4158E-02	2.9868E-02
20060925	1200	3.000E-01	1.7336E-02	1.7336E-02	2.2456E-02
20060926	1200	3.000E-01	1.7327E-02	1.7327E-02	2.2411E-02
20060927	1200	3.000E-01	1.7314E-02	1.7314E-02	2.2364E-02
20060928	1200	2.800E-01	1.5970E-02	1.5970E-02	2.0851E-02
20060929	1200	3.600E+00	2.7262E-01	2.7262E-01	2.6116E-01
20060930	1200	2.600E-01	1.4622E-02	1.4622E-02	1.9298E-02
20061001	1200	3.500E-01	2.0600E-02	2.0600E-02	2.5792E-02
20061002	1200	2.800E-01	1.5894E-02	1.5894E-02	2.0657E-02
20061003	1200	2.900E-01	1.6529E-02	1.6529E-02	2.1328E-02
20061004	1200	2.200E-01	1.1962E-02	1.1962E-02	1.6215E-02
20061005	1200	3.100E-01	1.7794E-02	1.7794E-02	2.2657E-02
20061006	1200	2.800E-01	1.5785E-02	1.5785E-02	2.0443E-02
20061007	1200	4.100E-01	2.4451E-02	2.4451E-02	2.9676E-02
20061008	1200	3.000E-01	1.7027E-02	1.7027E-02	2.1757E-02
20061009	1200	2.600E-01	1.4389E-02	1.4389E-02	1.8847E-02
20061010	1200	9.400E+00	7.2945E-01	7.2945E-01	6.6281E-01
20061011	1200	2.700E+01	2.1086E+00	2.1086E+00	1.9105E+00
20061012	1200	2.800E+01	2.1800E+00	2.1800E+00	1.9760E+00
20061013	1200	3.000E+01	2.3271E+00	2.3271E+00	2.1120E+00
20061014	1200	3.300E+01	2.5484E+00	2.5484E+00	2.3181E+00
20061015	1200	3.400E+01	2.6164E+00	2.6164E+00	2.3815E+00
20061016	1200	3.700E+00	2.7068E-01	2.7068E-01	2.5594E-01
20061017	1200	3.300E-01	1.8552E-02	1.8552E-02	2.3244E-02
20061018	1200	3.000E-01	1.6564E-02	1.6564E-02	2.1093E-02
20061019	1200	2.800E-01	1.5240E-02	1.5240E-02	1.9643E-02
20061020	1200	3.900E-01	2.2261E-02	2.2261E-02	2.7126E-02
20061021	1200	2.100E-01	1.0823E-02	1.0823E-02	1.4705E-02
20061022	1200	3.600E-01	2.0162E-02	2.0162E-02	2.4896E-02
20061023	1200	2.200E-01	1.1346E-02	1.1346E-02	1.5285E-02

20061024	1200	3.600E-01	2.0014E-02	2.0014E-02	2.4720E-02
20061025	1200	3.200E-01	1.7407E-02	1.7407E-02	2.1935E-02
20061026	1200	3.200E-01	1.7339E-02	1.7339E-02	2.1855E-02
20061027	1200	2.800E-01	1.4797E-02	1.4797E-02	1.9095E-02
20061028	1200	2.900E-01	1.5350E-02	1.5350E-02	1.9693E-02
20061029	1200	3.900E-01	2.1511E-02	2.1511E-02	2.6264E-02
20061030	1200	1.400E+01	1.0233E+00	1.0233E+00	9.2385E-01
20061031	1200	2.000E+01	1.4592E+00	1.4592E+00	1.3178E+00
20061101	1200	2.800E-01	1.4493E-02	1.4493E-02	1.8741E-02
20061102	1200	3.200E-01	1.6842E-02	1.6842E-02	2.1291E-02
20061103	1200	2.800E-01	1.4367E-02	1.4367E-02	1.8598E-02
20061104	1200	3.200E-01	1.6695E-02	1.6695E-02	2.1127E-02
20061105	1200	3.400E-01	1.7824E-02	1.7824E-02	2.2340E-02
20061106	1200	8.700E-01	5.1506E-02	5.1506E-02	5.6260E-02
20061107	1200	1.200E+01	8.4463E-01	8.4463E-01	7.6729E-01
20061108	1200	2.800E+01	1.9674E+00	1.9674E+00	1.7939E+00
20061109	1200	2.900E+01	2.0272E+00	2.0272E+00	1.8512E+00
20061110	1200	3.000E+01	2.0863E+00	2.0863E+00	1.9081E+00
20061111	1200	3.400E+01	2.3482E+00	2.3482E+00	2.1567E+00
20061112	1200	3.900E+01	2.6725E+00	2.6725E+00	2.4677E+00
20061113	1200	1.700E+01	1.1685E+00	1.1685E+00	1.0636E+00
20061114	1200	4.100E-01	2.1189E-02	2.1189E-02	2.5926E-02
20061115	1200	4.300E-01	2.2268E-02	2.2268E-02	2.7064E-02
20061116	1200	3.300E-01	1.6352E-02	1.6352E-02	2.0769E-02
20061117	1200	2.700E-01	1.2900E-02	1.2900E-02	1.6980E-02
20061118	1200	3.800E-01	1.9048E-02	1.9048E-02	2.3675E-02
20061119	1200	3.900E-01	1.9529E-02	1.9529E-02	2.4192E-02
20061120	1200	3.900E-01	1.9433E-02	1.9433E-02	2.4095E-02
20061121	1200	3.800E-01	1.8770E-02	1.8770E-02	2.3393E-02
20061122	1200	4.600E-01	2.3242E-02	2.3242E-02	2.8128E-02
20061123	1200	4.800E-01	2.4278E-02	2.4278E-02	2.9218E-02
20061124	1200	3.700E-01	1.7938E-02	1.7938E-02	2.2516E-02
20061125	1200	4.100E-01	2.0080E-02	2.0080E-02	2.4814E-02
20061126	1200	4.000E-01	1.9425E-02	1.9425E-02	2.4122E-02
20061127	1200	4.400E-01	2.1557E-02	2.1557E-02	2.6394E-02
20061128	1200	4.700E-01	2.3128E-02	2.3128E-02	2.8058E-02
20061129	1200	4.000E-01	1.9142E-02	1.9142E-02	2.3840E-02
20061130	1200	3.800E-01	1.7960E-02	1.7960E-02	2.2577E-02
20061201	1200	1.900E+01	1.1967E+00	1.1967E+00	1.1077E+00
20061202	1200	4.400E+01	2.7266E+00	2.7266E+00	2.5757E+00
20061203	1200	4.500E+01	2.7733E+00	2.7733E+00	2.6249E+00
20061204	1200	4.600E+01	2.8195E+00	2.8195E+00	2.6737E+00
20061205	1200	4.700E+01	2.8651E+00	2.8651E+00	2.7221E+00
20061206	1200	3.900E+01	2.3789E+00	2.3789E+00	2.2454E+00
20061207	1200	4.400E+01	2.6625E+00	2.6625E+00	2.5272E+00
20061208	1200	4.500E+01	2.7084E+00	2.7084E+00	2.5757E+00
20061209	1200	4.500E+01	2.6959E+00	2.6959E+00	2.5662E+00
20061210	1200	3.300E+01	1.9829E+00	1.9829E+00	1.8685E+00
20061211	1200	3.400E+01	2.0325E+00	2.0325E+00	1.9187E+00
20061212	1200	3.500E+01	2.0816E+00	2.0816E+00	1.9686E+00
20061213	1200	2.500E+01	1.4873E+00	1.4873E+00	1.3966E+00
20061214	1200	1.700E+01	1.0071E+00	1.0071E+00	9.4354E-01
20061215	1200	5.300E-01	2.4480E-02	2.4480E-02	2.9642E-02
20061216	1200	4.100E-01	1.8189E-02	1.8189E-02	2.2931E-02
20061217	1200	4.200E-01	1.8617E-02	1.8617E-02	2.3401E-02
20061218	1200	4.900E-01	2.2102E-02	2.2102E-02	2.7151E-02
20061219	1200	5.500E+00	3.0913E-01	3.0913E-01	2.9890E-01
20061220	1200	1.400E+01	8.0666E-01	8.0666E-01	7.6030E-01
20061221	1200	3.800E+01	2.1698E+00	2.1698E+00	2.0738E+00
20061222	1200	4.000E+01	2.2718E+00	2.2718E+00	2.1771E+00
20061223	1200	6.500E+01	3.6144E+00	3.6144E+00	3.5483E+00
20061224	1200	8.100E+00	4.5324E-01	4.5324E-01	4.3329E-01
20061225	1200	4.700E-01	2.0485E-02	2.0485E-02	2.5469E-02
20061226	1200	3.800E-01	1.6003E-02	1.6003E-02	2.0590E-02

20061227	1200	3.600E-01	1.4982E-02	1.4982E-02	1.9463E-02
20061228	1200	4.900E+01	2.7028E+00	2.7028E+00	2.6239E+00
20061229	1200	4.300E+01	2.3728E+00	2.3728E+00	2.2922E+00
20061230	1200	7.400E+01	3.9831E+00	3.9831E+00	3.9616E+00
20061231	1200	7.400E+01	3.9691E+00	3.9691E+00	3.9503E+00
20070101	1200	7.400E+01	3.9555E+00	3.9555E+00	3.9392E+00
20070102	1200	7.400E+01	3.9421E+00	3.9421E+00	3.9283E+00
20070103	1200	7.400E+01	3.9291E+00	3.9291E+00	3.9176E+00
20070104	1200	7.400E+01	3.9164E+00	3.9164E+00	3.9072E+00
20070105	1200	7.500E+01	3.9541E+00	3.9541E+00	3.9504E+00
20070106	1200	7.400E+01	3.8920E+00	3.8920E+00	3.8870E+00
20070107	1200	7.400E+01	3.8803E+00	3.8803E+00	3.8772E+00
20070108	1200	6.900E+01	3.6197E+00	3.6197E+00	3.6027E+00
20070109	1200	4.600E+01	2.4447E+00	2.4447E+00	2.3832E+00
20070110	1200	5.200E-01	2.1787E-02	2.1787E-02	2.6934E-02
20070111	1200	3.500E-01	1.3818E-02	1.3818E-02	1.8189E-02
20070112	1200	3.500E-01	1.3782E-02	1.3782E-02	1.8148E-02
20070113	1200	3.900E-01	1.5566E-02	1.5566E-02	2.0146E-02
20070114	1200	3.800E-01	1.5072E-02	1.5072E-02	1.9595E-02
20070115	1200	2.600E-01	9.6993E-03	9.6993E-03	1.3460E-02
20070116	1200	1.100E+01	5.7752E-01	5.7752E-01	5.5476E-01
20070117	1200	3.700E-01	1.4516E-02	1.4516E-02	1.8971E-02
20070118	1200	3.700E-01	1.4484E-02	1.4484E-02	1.8935E-02
20070119	1200	3.300E-01	1.2671E-02	1.2671E-02	1.6887E-02
20070120	1200	2.900E-01	1.0891E-02	1.0891E-02	1.4844E-02
20070121	1200	3.300E-01	1.2621E-02	1.2621E-02	1.6827E-02
20070122	1200	2.800E-01	1.0418E-02	1.0418E-02	1.4291E-02
20070123	1200	3.000E-01	1.1265E-02	1.1265E-02	1.5270E-02
20070124	1200	4.600E-01	1.8375E-02	1.8375E-02	2.3229E-02
20070125	1200	4.300E-01	1.6987E-02	1.6987E-02	2.1702E-02
20070126	1200	4.100E-01	1.6062E-02	1.6062E-02	2.0677E-02
20070127	1200	4.000E-01	1.5592E-02	1.5592E-02	2.0152E-02
20070128	1200	2.700E-01	9.8953E-03	9.8953E-03	1.3669E-02
20070129	1200	8.600E+00	4.3841E-01	4.3841E-01	4.2437E-01
20070130	1200	3.700E-01	1.4204E-02	1.4204E-02	1.8592E-02
20070131	1200	2.800E-01	1.0285E-02	1.0285E-02	1.4116E-02
20070201	1200	2.700E-01	9.8505E-03	9.8505E-03	1.3605E-02
20070202	1200	3.400E-01	1.2848E-02	1.2848E-02	1.7051E-02
20070203	1200	3.400E-01	1.2837E-02	1.2837E-02	1.7035E-02
20070204	1200	2.800E-01	1.0249E-02	1.0249E-02	1.4060E-02
20070205	1200	2.700E-01	9.8186E-03	9.8186E-03	1.3555E-02
20070206	1200	3.600E+00	1.7480E-01	1.7480E-01	1.7621E-01
20070207	1200	4.700E+01	2.3783E+00	2.3783E+00	2.3287E+00
20070208	1200	5.900E+01	2.9594E+00	2.9594E+00	2.9299E+00
20070209	1200	7.800E+01	3.8604E+00	3.8604E+00	3.8865E+00
20070210	1200	7.700E+01	3.8123E+00	3.8123E+00	3.8339E+00
20070211	1200	7.600E+01	3.7645E+00	3.7645E+00	3.7815E+00
20070212	1200	7.000E+01	3.4809E+00	3.4809E+00	3.4773E+00
20070213	1200	7.900E+01	3.9044E+00	3.9044E+00	3.9300E+00
20070214	1200	7.800E+01	3.8575E+00	3.8575E+00	3.8783E+00
20070215	1200	6.500E+01	3.2434E+00	3.2434E+00	3.2225E+00
20070216	1200	6.800E+01	3.3866E+00	3.3866E+00	3.3728E+00
20070217	1200	7.800E+01	3.8592E+00	3.8592E+00	3.8760E+00
20070218	1200	7.800E+01	3.8603E+00	3.8603E+00	3.8757E+00
20070219	1200	9.400E+00	4.7668E-01	4.7668E-01	4.5812E-01
20070220	1200	7.200E-01	3.0069E-02	3.0069E-02	3.5456E-02
20070221	1200	5.700E-01	2.3116E-02	2.3116E-02	2.8150E-02
20070222	1200	6.200E-01	2.5436E-02	2.5436E-02	3.0592E-02
20070223	1200	8.700E-01	3.7231E-02	3.7231E-02	4.2774E-02
20070224	1200	8.600E-01	3.6780E-02	3.6780E-02	4.2297E-02
20070225	1200	7.300E-01	3.0636E-02	3.0636E-02	3.5978E-02
20070226	1200	9.500E-01	4.1162E-02	4.1162E-02	4.6708E-02
20070227	1200	1.200E+00	5.3378E-02	5.3378E-02	5.8899E-02
20070228	1200	8.700E+00	4.4297E-01	4.4297E-01	4.2485E-01

20070301	1200	9.900E-01	4.3217E-02	4.3217E-02	4.8722E-02
20070302	1200	2.200E+01	1.1372E+00	1.1372E+00	1.0808E+00
20070303	1200	4.400E+01	2.2510E+00	2.2510E+00	2.1779E+00
20070304	1200	4.300E+01	2.2039E+00	2.2039E+00	2.1292E+00
20070305	1200	3.900E+01	2.0066E+00	2.0066E+00	1.9303E+00
20070306	1200	3.500E+01	1.8076E+00	1.8076E+00	1.7316E+00
20070307	1200	2.900E+01	1.5046E+00	1.5046E+00	1.4332E+00
20070308	1200	2.500E+01	1.3010E+00	1.3010E+00	1.2349E+00
20070309	1200	2.500E+01	1.3028E+00	1.3028E+00	1.2360E+00
20070310	1200	2.600E+01	1.3564E+00	1.3564E+00	1.2870E+00
20070311	1200	2.600E+01	1.3585E+00	1.3585E+00	1.2883E+00
20070312	1200	1.500E+01	7.8464E-01	7.8464E-01	7.4099E-01
20070313	1200	2.500E+01	1.3107E+00	1.3107E+00	1.2409E+00
20070314	1200	3.700E+01	1.9310E+00	1.9310E+00	1.8456E+00
20070315	1200	1.800E+01	9.4742E-01	9.4742E-01	8.9314E-01
20070316	1200	5.300E-01	2.1875E-02	2.1875E-02	2.6614E-02
20070317	1200	4.000E-01	1.5896E-02	1.5896E-02	2.0189E-02
20070318	1200	3.300E-01	1.2763E-02	1.2763E-02	1.6725E-02
20070319	1200	2.700E-01	1.0135E-02	1.0135E-02	1.3746E-02
20070320	1200	2.400E-01	8.8527E-03	8.8527E-03	1.2259E-02
20070321	1200	2.400E-01	8.8687E-03	8.8687E-03	1.2276E-02
20070322	1200	2.200E-01	8.0262E-03	8.0262E-03	1.1286E-02
20070323	1200	1.600E+01	8.5350E-01	8.5350E-01	8.0154E-01
20070324	1200	5.400E-01	2.2666E-02	2.2666E-02	2.7399E-02
20070325	1200	5.500E-01	2.3186E-02	2.3186E-02	2.7941E-02
20070326	1200	3.400E-01	1.3405E-02	1.3405E-02	1.7416E-02
20070327	1200	3.100E-01	1.2072E-02	1.2072E-02	1.5927E-02
20070328	1200	2.900E-01	1.1196E-02	1.1196E-02	1.4938E-02
20070329	1200	6.300E+00	3.3181E-01	3.3181E-01	3.1742E-01
20070330	1200	1.800E+01	9.7367E-01	9.7367E-01	9.1207E-01
20070331	1200	2.500E+01	1.3539E+00	1.3539E+00	1.2721E+00
20070401	1200	2.700E+01	1.4639E+00	1.4639E+00	1.3770E+00
20070402	1200	2.800E+01	1.5203E+00	1.5203E+00	1.4309E+00
20070403	1200	2.800E+01	1.5232E+00	1.5232E+00	1.4333E+00
20070404	1200	2.600E+01	1.4182E+00	1.4182E+00	1.3322E+00
20070405	1200	2.600E+01	1.4209E+00	1.4209E+00	1.3345E+00
20070406	1200	1.400E+01	7.6568E-01	7.6568E-01	7.1663E-01
20070407	1200	5.400E-01	2.3273E-02	2.3273E-02	2.8026E-02
20070408	1200	4.300E-01	1.7987E-02	1.7987E-02	2.2425E-02
20070409	1200	3.900E-01	1.6112E-02	1.6112E-02	2.0403E-02
20070410	1200	3.300E-01	1.3318E-02	1.3318E-02	1.7339E-02
20070411	1200	4.800E+00	2.5563E-01	2.5563E-01	2.4722E-01
20070412	1200	1.800E+01	9.9718E-01	9.9718E-01	9.3259E-01
20070413	1200	2.400E+01	1.3312E+00	1.3312E+00	1.2484E+00
20070414	1200	1.400E+01	7.7650E-01	7.7650E-01	7.2682E-01
20070415	1200	3.800E-01	1.5799E-02	1.5799E-02	2.0101E-02
20070416	1200	6.900E+00	3.7679E-01	3.7679E-01	3.5863E-01
20070417	1200	4.500E+00	2.4116E-01	2.4116E-01	2.3428E-01
20070418	1200	4.100E-01	1.7317E-02	1.7317E-02	2.1781E-02
20070419	1200	3.100E-01	1.2570E-02	1.2570E-02	1.6568E-02
20070420	1200	1.200E+01	6.6993E-01	6.6993E-01	6.2922E-01
20070421	1200	2.600E+01	1.4585E+00	1.4585E+00	1.3729E+00
20070422	1200	2.700E+01	1.5159E+00	1.5159E+00	1.4287E+00
20070423	1200	3.500E+01	1.9590E+00	1.9590E+00	1.8600E+00
20070424	1200	4.300E+01	2.3969E+00	2.3969E+00	2.2944E+00
20070425	1200	3.900E+01	2.1822E+00	2.1822E+00	2.0823E+00
20070426	1200	1.600E+01	9.0317E-01	9.0317E-01	8.4914E-01
20070427	1200	3.900E-01	1.6531E-02	1.6531E-02	2.1063E-02
20070428	1200	4.000E-01	1.7033E-02	1.7033E-02	2.1632E-02
20070429	1200	2.600E-01	1.0365E-02	1.0365E-02	1.4180E-02
20070430	1200	2.700E-01	1.0838E-02	1.0838E-02	1.4741E-02
20070501	1200	3.100E+01	1.7520E+00	1.7520E+00	1.6679E+00
20070502	1200	3.600E+01	2.0297E+00	2.0297E+00	1.9430E+00
20070503	1200	7.200E-01	3.3304E-02	3.3304E-02	3.8961E-02

20070504	1200	3.400E-01	1.4182E-02	1.4182E-02	1.8613E-02
20070505	1200	2.100E-01	8.1025E-03	8.1025E-03	1.1608E-02
20070506	1200	2.200E-01	8.5581E-03	8.5581E-03	1.2168E-02
20070507	1200	5.700E+00	3.1473E-01	3.1473E-01	3.0687E-01
20070508	1200	2.400E+01	1.3636E+00	1.3636E+00	1.3022E+00
20070509	1200	3.600E+01	2.0328E+00	2.0328E+00	1.9637E+00
20070510	1200	4.000E+01	2.2523E+00	2.2523E+00	2.1875E+00
20070511	1200	2.400E+01	1.3628E+00	1.3628E+00	1.3076E+00
20070512	1200	3.100E-01	1.2745E-02	1.2745E-02	1.7192E-02
20070513	1200	3.500E-01	1.4654E-02	1.4654E-02	1.9398E-02
20070514	1200	1.800E-01	6.7485E-03	6.7485E-03	1.0103E-02
20070515	1200	1.500E-01	5.4360E-03	5.4360E-03	8.4596E-03
20070516	1200	2.000E+01	1.1330E+00	1.1330E+00	1.0949E+00
20070517	1200	3.000E+01	1.6923E+00	1.6923E+00	1.6499E+00
20070518	1200	1.400E+01	7.8967E-01	7.8967E-01	7.6637E-01
20070519	1200	2.700E-01	1.0794E-02	1.0794E-02	1.5130E-02
20070520	1200	2.500E-01	9.8559E-03	9.8559E-03	1.4041E-02
20070521	1200	1.500E+01	8.4336E-01	8.4336E-01	8.2385E-01
20070522	1200	2.400E+01	1.3482E+00	1.3482E+00	1.3238E+00
20070523	1200	2.500E+01	1.4015E+00	1.4015E+00	1.3806E+00
20070524	1200	2.300E+01	1.2877E+00	1.2877E+00	1.2702E+00
20070525	1200	2.200E+01	1.2295E+00	1.2295E+00	1.2154E+00
20070526	1200	2.100E+01	1.1712E+00	1.1712E+00	1.1605E+00
20070527	1200	2.900E+01	1.6093E+00	1.6093E+00	1.6081E+00
20070528	1200	3.300E+01	1.8227E+00	1.8227E+00	1.8333E+00
20070529	1200	2.700E+01	1.4921E+00	1.4921E+00	1.4978E+00
20070530	1200	2.700E+01	1.4880E+00	1.4880E+00	1.4984E+00
20070531	1200	2.500E+01	1.3748E+00	1.3748E+00	1.3870E+00
20070601	1200	2.300E+01	1.2617E+00	1.2617E+00	1.2755E+00
20070602	1200	1.600E+01	8.7444E-01	8.7444E-01	8.8524E-01
20070603	1200	2.400E-01	9.0847E-03	9.0847E-03	1.3598E-02
20070604	1200	1.600E-01	5.6212E-03	5.6212E-03	9.1349E-03
20070605	1200	2.000E-01	7.2850E-03	7.2850E-03	1.1371E-02
20070606	1200	2.600E-01	9.8610E-03	9.8610E-03	1.4713E-02
20070607	1200	3.300E-01	1.2946E-02	1.2946E-02	1.8600E-02
20070608	1200	1.700E-01	5.9426E-03	5.9426E-03	9.6921E-03
20070609	1200	2.300E-01	8.4383E-03	8.4383E-03	1.3037E-02
20070610	1200	1.300E-01	4.2836E-03	4.2836E-03	7.4476E-03
20070611	1200	2.100E-01	7.5146E-03	7.5146E-03	1.1914E-02
20070612	1200	3.000E+00	1.4719E-01	1.4719E-01	1.6535E-01
20070613	1200	1.100E+01	5.7022E-01	5.7022E-01	6.0630E-01
20070614	1200	3.000E+01	1.5520E+00	1.5520E+00	1.6640E+00
20070615	1200	1.700E+01	8.7701E-01	8.7701E-01	9.3795E-01
20070616	1200	2.400E+01	1.2307E+00	1.2307E+00	1.3266E+00
20070617	1200	9.100E+00	4.5891E-01	4.5891E-01	4.9977E-01
20070618	1200	1.900E-01	6.4258E-03	6.4258E-03	1.0747E-02
20070619	1200	2.400E-01	8.3952E-03	8.3952E-03	1.3504E-02
20070620	1200	1.800E-01	5.9522E-03	5.9522E-03	1.0170E-02
20070621	1200	1.500E-01	4.7658E-03	4.7658E-03	8.4949E-03
20070622	1200	2.000E-01	6.6458E-03	6.6458E-03	1.1250E-02
20070623	1200	1.300E-01	3.9639E-03	3.9639E-03	7.3643E-03
20070624	1200	1.000E-01	2.8741E-03	2.8741E-03	5.6888E-03
20070625	1200	8.000E-02	2.1786E-03	2.1786E-03	4.5673E-03
20070626	1200	8.000E-02	2.1617E-03	2.1617E-03	4.5599E-03
20070627	1200	1.700E-01	5.2840E-03	5.2840E-03	9.5177E-03
20070628	1200	1.000E-01	2.7847E-03	2.7847E-03	5.6506E-03
20070629	1200	1.200E-01	3.4359E-03	3.4359E-03	6.7409E-03
20070630	1200	9.000E-02	2.4111E-03	2.4111E-03	5.0778E-03
20070701	1200	1.500E-01	4.4033E-03	4.4033E-03	8.3530E-03
20070702	1200	2.000E-02	3.6657E-04	3.6657E-04	1.1704E-03
20070703	1200	1.000E-04	1.8963E-07	1.8965E-07	7.4605E-06
20070704	1200	1.000E-04	1.8789E-07	1.8790E-07	7.4427E-06
20070705	1200	7.000E-02	1.6968E-03	1.6968E-03	3.9277E-03
20070706	1200	1.000E-04	1.8433E-07	1.8434E-07	7.4051E-06

20070707	1200	1.000E-04	1.8251E-07	1.8252E-07	7.3853E-06
20070708	1200	1.000E-04	1.8067E-07	1.8068E-07	7.3648E-06
20070709	1200	2.000E-02	3.4187E-04	3.4187E-04	1.1494E-03
20070710	1200	7.000E-02	1.6104E-03	1.6104E-03	3.8735E-03
20070711	1200	1.000E-04	1.7503E-07	1.7504E-07	7.2993E-06
20070712	1200	1.000E-04	1.7311E-07	1.7312E-07	7.2761E-06
20070713	1200	1.000E-04	1.7117E-07	1.7119E-07	7.2523E-06
20070714	1200	1.500E-01	3.8422E-03	3.8422E-03	8.0563E-03
20070715	1200	1.000E-04	1.6725E-07	1.6726E-07	7.2027E-06
20070716	1200	1.000E-04	1.6526E-07	1.6527E-07	7.1769E-06
20070717	1200	1.000E-04	1.6326E-07	1.6327E-07	7.1504E-06
20070718	1200	6.000E-02	1.2120E-03	1.2120E-03	3.2425E-03
20070719	1200	1.700E-01	4.1828E-03	4.1828E-03	8.9414E-03
20070720	1200	1.000E-02	1.2232E-04	1.2232E-04	5.6601E-04
20070721	1200	3.000E-02	4.9320E-04	4.9320E-04	1.6323E-03
20070722	1200	8.000E-02	1.6304E-03	1.6304E-03	4.2239E-03
20070723	1200	7.000E-02	1.3670E-03	1.3670E-03	3.6918E-03
20070724	1200	9.000E-02	1.8273E-03	1.8273E-03	4.6977E-03
20070725	1200	1.000E-04	1.4684E-07	1.4685E-07	6.9161E-06
20070726	1200	3.400E-01	8.5044E-03	8.5044E-03	1.7142E-02
20070727	1200	3.000E-01	7.2494E-03	7.2494E-03	1.5083E-02
20070728	1200	1.000E-04	1.4057E-07	1.4058E-07	6.8183E-06
20070729	1200	1.000E-04	1.3847E-07	1.3848E-07	6.7846E-06
20070730	1200	1.000E-04	1.3636E-07	1.3637E-07	6.7503E-06
20070731	1200	4.000E-02	6.0842E-04	6.0842E-04	2.0598E-03

Bear River Bay Outflow at GSL Minerals Corp Bridge

```
#############################################################################
#
#  LOADEST Calibration File
#
#  Bear River going into GSL
#
#  Total Se (dissolved + particulate)
#  2007 autosampler data added
#  Zero or negative discharge = 0.0001 cfs
#
#############################################################################
#
#CDATE      CTIME       CFLOW       CCONC
#
#############################################################################
20060503     1425        5300        0.366
20060504     1400        3940        0.321
20060506     1400        3460        0.35
20060510     1400        4760        0.318
20060516     1400        2670        0.506
20060519     1400         369       0.363
20060523     1400        2810        0.435
20060525     1007        2380        0.423
20060526     1007        3500        0.419
20060528     1007          77       0.468
20060603     1007        2800        0.313
20060607     1005          57       0.512
20060611     1005        2430        0.734
20060619     1005        1550        0.614
20060621     1005        1490        0.39
20061010     1515        1790        0.479
20061120     1200        2950        0.326
20061220     1100        1592        0.541
20070202     1030        1033        0.409
20070302     1050         938       0.405
20070416     1130          11       0.381
20070417     1215       0.001        0.422
20070418     1130        1480        0.506
20070419     1130        1270        0.506
20070420     1130        1920        0.456
20070421     1130        1300        0.401
20070422     1130        1360        0.378
20070423     1130        3040        0.355
20070425     1130        1340        0.354
20070509     1315         471        0.42
20070511     1315        1140        0.463
20070513     1315        1410        0.42
20070515     1315         176       0.365
20070517     1230       0.001        0.548
20070525     1040         284       0.654
20070526     1040         219        0.53
20070528     1040        1490        0.512
20070529     1040      0.0001        0.505
```

20070603	1040	178	0.662
20070613	1040	0.0001	0.777
20070619	1045	0.0001	0.72
20070716	1100	0.0001	1.39

```
#############################################################################
#
#  LOADEST Estimation File
#
#  Bear River at GSL Minerals Bridge
#  Discharge estimated from Corrinne gage from 10/1/2006 to 4/15/2007
#  All negative or no flow data (from GSL) asigned a 0.0001 value
#  Missing days from Corrinne gage were interpolated
#
#############################################################################
#
#  Number of observations per day, NOBSPD (col. 1-5)
#
#############################################################################
1
#############################################################################
#
# EDATE       ETIME      EFLOW
#
#############################################################################
20060321       1200       2990
20060322       1200       3570
20060323       1200       2760
20060324       1200       2820
20060325       1200       1760
20060326       1200       3870
20060327       1200       3700
20060328       1200       1420
20060329       1200       3890
20060330       1200       4450
20060331       1200       4070
20060401       1200       2790
20060402       1200       4570
20060403       1200       3790
20060404       1200       1300
20060405       1200       734
20060406       1200       5980
20060407       1200       8390
20060408       1200       7490
20060409       1200       7350
20060410       1200       5540
20060411       1200       4890
20060412       1200       5700
20060413       1200       5100
20060414       1200       7480
20060415       1200       3750
20060416       1200       2670
20060417       1200       11000
20060418       1200       7060
20060419       1200       6360
20060420       1200       6450
20060421       1200       6820
20060422       1200       6980
20060423       1200       6170
20060424       1200       5350
20060425       1200       6400
```

20060426	1200	7020
20060427	1200	7910
20060428	1200	6630
20060429	1200	3600
20060430	1200	5440
20060501	1200	4470
20060502	1200	6740
20060503	1200	5300
20060504	1200	3940
20060505	1200	4650
20060506	1200	3460
20060507	1200	6460
20060508	1200	5230
20060509	1200	6020
20060510	1200	4760
20060511	1200	4440
20060512	1200	4650
20060513	1200	4980
20060514	1200	3530
20060515	1200	3020
20060516	1200	2670
20060517	1200	1950
20060518	1200	1970
20060519	1200	369
20060520	1200	861
20060521	1200	1440
20060522	1200	174
20060523	1200	2810
20060524	1200	2670
20060525	1200	2380
20060526	1200	3500
20060527	1200	2730
20060528	1200	77
20060529	1200	3350
20060530	1200	3460
20060531	1200	3240
20060601	1200	2850
20060602	1200	2500
20060603	1200	2800
20060604	1200	1810
20060605	1200	2010
20060606	1200	1140
20060607	1200	57
20060608	1200	568
20060609	1200	1350
20060610	1200	3120
20060611	1200	2430
20060612	1200	1350
20060613	1200	923
20060614	1200	1990
20060615	1200	1890
20060616	1200	88
20060617	1200	1680
20060618	1200	2430
20060619	1200	1550
20060620	1200	205

20060621	1200	1490
20060622	1200	370
20060623	1200	519
20060624	1200	793
20060625	1200	871
20060626	1200	1080
20060627	1200	113
20060628	1200	20
20060629	1200	79
20060630	1200	1780
20060701	1200	432
20060702	1200	200
20060703	1200	189
20060704	1200	1200
20060705	1200	1100
20060706	1200	515
20060707	1200	596
20060708	1200	928
20060709	1200	596
20060710	1200	225
20060711	1200	1380
20060712	1200	385
20060713	1200	669
20060714	1200	58
20060715	1200	322
20060716	1200	33
20060717	1200	622
20060718	1200	1260
20060719	1200	292
20060720	1200	807
20060721	1200	462
20060722	1200	444
20060723	1200	452
20060724	1200	135
20060725	1200	524
20060726	1200	122
20060727	1200	202
20060728	1200	40
20060729	1200	485
20060730	1200	68
20060731	1200	149
20060801	1200	120
20060802	1200	27
20060803	1200	42
20060804	1200	63
20060805	1200	91
20060806	1200	108
20060807	1200	665
20060808	1200	166
20060809	1200	131
20060810	1200	174
20060811	1200	31
20060812	1200	24
20060813	1200	253
20060814	1200	20
20060815	1200	123

20060816	1200	142
20060817	1200	184
20060818	1200	166
20060819	1200	33
20060820	1200	52
20060821	1200	8.8
20060822	1200	19
20060823	1200	18
20060824	1200	80
20060825	1200	7
20060826	1200	26
20060827	1200	12
20060828	1200	68
20060829	1200	161
20060830	1200	5.9
20060831	1200	86
20060901	1200	65
20060902	1200	60
20060903	1200	201
20060904	1200	43
20060905	1200	1.3
20060906	1200	3.9
20060907	1200	1.4
20060908	1200	76
20060909	1200	100
20060910	1200	17
20060911	1200	109
20060912	1200	151
20060913	1200	120
20060914	1200	3.5
20060915	1200	49
20060916	1200	230
20060917	1200	57
20060918	1200	79
20060919	1200	101
20060920	1200	124
20060921	1200	53
20060922	1200	47
20060923	1200	109
20060924	1200	79
20060925	1200	93
20060926	1200	4.7
20060927	1200	18
20060928	1200	20
20060929	1200	20
20060930	1200	20
20061001	1200	395
20061002	1200	670
20061003	1200	652
20061004	1200	671
20061005	1200	703
20061006	1200	994
20061007	1200	904
20061008	1200	870
20061009	1200	847
20061010	1200	1344

20061011	1200	1107
20061012	1200	859
20061013	1200	881
20061014	1200	949
20061015	1200	792
20061016	1200	647
20061017	1200	1129
20061018	1200	1220
20061019	1200	1186
20061020	1200	926
20061021	1200	870
20061022	1200	825
20061023	1200	994
20061024	1200	1242
20061025	1200	983
20061026	1200	788
20061027	1200	983
20061028	1200	1005
20061029	1200	698
20061030	1200	1220
20061031	1200	1378
20061101	1200	1118
20061102	1200	1039
20061103	1200	926
20061104	1200	915
20061105	1200	926
20061106	1200	825
20061107	1200	1208
20061108	1200	938
20061109	1200	971
20061110	1200	1062
20061111	1200	892
20061112	1200	1039
20061113	1200	1186
20061114	1200	1513
20061115	1200	1332
20061116	1200	1231
20061117	1200	1299
20061118	1200	1615
20061119	1200	915
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20061122	1200	1197
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20061124	1200	994
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20061126	1200	1062
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20061128	1200	1378
20061129	1200	781
20061130	1200	1084
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20061202	1200	1163
20061203	1200	1017
20061204	1200	1017
20061205	1200	1045

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20061207	1200	1101
20061208	1200	1129
20061209	1200	1304
20061210	1200	1479
20061211	1200	859
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20061216	1200	1468
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20061218	1200	904
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20061220	1200	1592
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20061227	1200	1332
20061228	1200	1705
20061229	1200	1434
20061230	1200	1411
20061231	1200	1152
20070101	1200	1163
20070102	1200	983
20070103	1200	1457
20070104	1200	1287
20070105	1200	1096
20070106	1200	1028
20070107	1200	529
20070108	1200	533
20070109	1200	1400
20070110	1200	1671
20070111	1200	1276
20070112	1200	1332
20070113	1200	1524
20070114	1200	1062
20070115	1200	1400
20070116	1200	1141
20070117	1200	971
20070118	1200	739
20070119	1200	994
20070120	1200	1096
20070121	1200	1118
20070122	1200	1084
20070123	1200	1065
20070124	1200	1046
20070125	1200	1028
20070126	1200	1005
20070127	1200	1009
20070128	1200	1013
20070129	1200	1017
20070130	1200	1021

20070131	1200	1025
20070201	1200	1029
20070202	1200	1033
20070203	1200	1037
20070204	1200	1041
20070205	1200	1044
20070206	1200	1048
20070207	1200	1052
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20070213	1200	1479
20070214	1200	1615
20070215	1200	1705
20070216	1200	1397
20070217	1200	1089
20070218	1200	781
20070219	1200	938
20070220	1200	1615
20070221	1200	1310
20070222	1200	1411
20070223	1200	1310
20070224	1200	1265
20070225	1200	758
20070226	1200	1310
20070227	1200	1400
20070228	1200	1434
20070301	1200	762
20070302	1200	938
20070303	1200	1084
20070304	1200	760
20070305	1200	1637
20070306	1200	1485
20070307	1200	1332
20070308	1200	1180
20070309	1200	1028
20070310	1200	1637
20070311	1200	1976
20070312	1200	2551
20070313	1200	1998
20070314	1200	2246
20070315	1200	1660
20070316	1200	1930
20070317	1200	1750
20070318	1200	1660
20070319	1200	1727
20070320	1200	2122
20070321	1200	1885
20070322	1200	2246
20070323	1200	1953
20070324	1200	2066
20070325	1200	2258
20070326	1200	2111
20070327	1200	1942

20070328	1200	2077
20070329	1200	1930
20070330	1200	2032
20070331	1200	2009
20070401	1200	2009
20070402	1200	1321
20070403	1200	1976
20070404	1200	1581
20070405	1200	1400
20070406	1200	1637
20070407	1200	1355
20070408	1200	1197
20070409	1200	1152
20070410	1200	1626
20070411	1200	1332
20070412	1200	1761
20070413	1200	2449
20070414	1200	1930
20070415	1200	1727
20070416	1200	11
20070417	1200	0.0001
20070418	1200	1480
20070419	1200	1270
20070420	1200	1920
20070421	1200	1300
20070422	1200	1360
20070423	1200	3040
20070424	1200	1100
20070425	1200	1340
20070426	1200	1770
20070427	1200	464
20070428	1200	542
20070429	1200	452
20070430	1200	515
20070501	1200	336
20070502	1200	0.0001
20070503	1200	2150
20070504	1200	2180
20070505	1200	1650
20070506	1200	0.0001
20070507	1200	0.0001
20070508	1200	540
20070509	1200	471
20070510	1200	346
20070511	1200	1140
20070512	1200	0.0001
20070513	1200	1410
20070514	1200	604
20070515	1200	176
20070516	1200	0.0001
20070517	1200	0.0001
20070518	1200	379
20070519	1200	394
20070520	1200	558
20070521	1200	1350
20070522	1200	0.0001

20070523	1200	0.0001
20070524	1200	0.0001
20070525	1200	284
20070526	1200	219
20070527	1200	0.0001
20070528	1200	1490
20070529	1200	0.0001
20070530	1200	0.0001
20070531	1200	0.0001
20070601	1200	0.0001
20070602	1200	42
20070603	1200	178
20070604	1200	0.0001
20070605	1200	63
20070606	1200	403
20070607	1200	0.0001
20070608	1200	0.0001
20070609	1200	25
20070610	1200	286
20070611	1200	410
20070612	1200	0.0001
20070613	1200	0.0001
20070614	1200	72
20070615	1200	25
20070616	1200	21
20070617	1200	103
20070618	1200	0.0001
20070619	1200	0.0001
20070620	1200	0.0001
20070621	1200	33
20070622	1200	0.0001
20070623	1200	0.0001
20070624	1200	25
20070625	1200	54
20070626	1200	40
20070627	1200	15
20070628	1200	1
20070629	1200	23
20070630	1200	0.0001
20070701	1200	0.0001
20070702	1200	0.0001
20070703	1200	0.0001
20070704	1200	53
20070705	1200	120
20070706	1200	187
20070707	1200	564
20070708	1200	0.0001
20070709	1200	0.0001
20070710	1200	0.0001
20070711	1200	0.0001
20070712	1200	0.0001
20070713	1200	0.0001
20070714	1200	0.0001
20070715	1200	0.0001
20070716	1200	0.0001
20070717	1200	0.0001

20070718	1200	0.0001
20070719	1200	0.0001
20070720	1200	0.0001
20070721	1200	0.0001
20070722	1200	0.0001
20070723	1200	0.0001
20070724	1200	0.0001
20070725	1200	0.0001
20070726	1200	0.0001
20070727	1200	0.0001
20070728	1200	0.0001
20070729	1200	0.0001
20070730	1200	0.0001
20070731	1200	0.0001

LOADEST

A Program to Estimate Constituent Loads
U.S. Geological Survey, Version: MOD36 (Sep 2004)

Bear River at GSL Minerals Bridge

Constituent: selenium

Constituent Output File Part Ia: Calibration (Load Regression)

Number of Observations : 42
Number of Uncensored Observations: 42
"center" of Decimal Time : 2006.886
"center" of Ln(Q) : -0.4316
Period of record : 2006-2007

Model Evaluation Criteria Based on AMLE Results

Model #	AIC	SPPC
1	0.055	-2.887
2	0.103	-4.773
3	0.087	-4.439
4	-0.095	-1.490
5	0.133	-6.276
6	-0.048	-3.338
7	-0.200	-0.138
8	-0.150	-2.072
9	-0.157	-2.781

Model # 7 selected

Selected Model:

Ln(Load) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime) + a4 dtime

where:
Load = constituent load [kg/d]
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Model Coefficients

	a0	a1	a2	a3	a4
AMLE	-7.1100	0.9870	-0.3795	0.0268	0.2175
MLE	-7.1100	0.9870	-0.3795	0.0268	0.2175
LAD	-6.9599	0.9893	-0.4168	0.2043	0.1621

AMLE Regression Statistics

R-Squared [%] : 99.87
Prob. Plot Corr. Coeff. (PPCC) : 0.9918
Serial Correlation of Residuals: 0.1058

Coeff.	Std.Dev.	t-ratio	P Value
a0	0.0731	-97.31	1.292E-52
a1	0.0074	134.16	1.763E-58
a2	0.0908	-4.18	5.549E-05
a3	0.0634	0.42	6.525E-01
a4	0.0870	2.50	1.042E-02

Correlation Between Explanatory Variables

Explanatory variable corresponding to:

	a1	a2	a3
a2	0.3142		
a3	0.1156	0.1142	
a4	-0.4645	0.1888	0.0290

Additional Regression Statistics

	Residual Variance	Turnbull-Weiss Stat	DF	PL
AMLE	0.043	5.27	5	3.835E-01
MLE	0.043	5.27	5	3.835E-01

Constituent Output File Part Ib: Calibration (Concentration Regression)

AMLE Regression Statistics

Model # 7 was selected for the load regression (PART Ia) and is used here:

Ln(Conc) = a0 + a1 LnQ + a2 Sin(pi dtime) + a3 Cos(2 pi dtime) + a4 dtime

where:
Conc = constituent concentration
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Concentration Regression Results

R-Squared [%] : 54.90
Residual Variance : 0.0425

Coeff.	Value	Std.Dev.	t-ratio	P Value

a0	-0.6654	0.0731	-9.11	2.102E-12
a1	-0.0130	0.0074	-1.77	6.509E-02
a2	-0.3795	0.0908	-4.18	5.549E-05
a3	0.0268	0.0634	0.42	6.525E-01
a4	0.2175	0.0870	2.50	1.042E-02

Constituent Output File Part IIa: Estimation (test for extrapolation)

Load Estimates for 20060321-20070731

Streamflow Summary Statistics [cfs]

Data	Mean	Minimum	10th Pct	25th Pct	Median	75th Pct	90th Pct	Maximum
Cal.	1500.	0.	0.	178.	1350.	2490.	3488.	5300.
Est.	1316.	0.	0.	118.	1019.	1530.	3251.	11000.

WARNING: The maximum estimation data set steamflow exceeds the maximum calibration data set streamflow. Load estimates require extrapolation.

Maximum Estimation Streamflow : 1.1000E+04
Maximum Calibration Streamflow: 5.3000E+03

Constituent Output File Part IIb: Estimation (Load Estimates)

Load Estimates for 20060321-20070731

Load Estimates [KG/DAY]

AMLE Load Estimates

	N	Mean Load	95% Conf.Intervals Lower	95% Conf.Intervals Upper	Std Error Prediction	Standard Error
Est. Period	498	1.26	1.14	1.39	0.06	0.06

MLE Load Estimates

	N	Mean Load	Standard Error

	N	Mean Load	Standard Error
Est. Period	498	1.26	0.06

LAD Load Estimates

	N	Mean Load	Standard Error
Est. Period	498	1.40	0.33

Summary Statistics - Estimated Loads [KG/DAY]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.000	0.181	1.065	1.625	2.952	4.389	5.852	8.637
MLE	0.000	0.181	1.065	1.625	2.952	4.389	5.852	8.637
LAD	0.000	0.214	1.231	1.903	2.995	4.477	5.918	8.826

Summary Statistics - Estimated Concentrations [UG/L]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.29	0.37	0.48	0.64	0.70	0.85	0.95	0.96
MLE	0.29	0.37	0.48	0.64	0.70	0.85	0.95	0.96
LAD	0.31	0.40	0.55	0.75	0.87	0.89	0.99	1.01

Individual Load Estimates for Bear River Bay Outflow (kg/day)

			Loads Estimated by:		
Date	Time	Flow	AMLE	MLE	LAD
20060321	1200	2.990E+03	2.0995E+00	2.0995E+00	2.2603E+00
20060322	1200	3.570E+03	2.5100E+00	2.5100E+00	2.6963E+00
20060323	1200	2.760E+03	1.9540E+00	1.9540E+00	2.0926E+00
20060324	1200	2.820E+03	2.0035E+00	2.0035E+00	2.1403E+00
20060325	1200	1.760E+03	1.2627E+00	1.2627E+00	1.3444E+00
20060326	1200	3.870E+03	2.7599E+00	2.7599E+00	2.9359E+00
20060327	1200	3.700E+03	2.6509E+00	2.6509E+00	2.8130E+00
20060328	1200	1.420E+03	1.0341E+00	1.0341E+00	1.0926E+00
20060329	1200	3.890E+03	2.8088E+00	2.8088E+00	2.9669E+00
20060330	1200	4.450E+03	3.2216E+00	3.2216E+00	3.3962E+00
20060331	1200	4.070E+03	2.9630E+00	2.9630E+00	3.1161E+00
20060401	1200	2.790E+03	2.0502E+00	2.0502E+00	2.1497E+00
20060402	1200	4.570E+03	3.3526E+00	3.3526E+00	3.5114E+00
20060403	1200	3.790E+03	2.8001E+00	2.8001E+00	2.9256E+00
20060404	1200	1.300E+03	9.7829E-01	9.7829E-01	1.0178E+00
20060405	1200	7.340E+02	5.5910E-01	5.5910E-01	5.7985E-01
20060406	1200	5.980E+03	4.4573E+00	4.4573E+00	4.6334E+00
20060407	1200	8.390E+03	6.2581E+00	6.2581E+00	6.4976E+00
20060408	1200	7.490E+03	5.6237E+00	5.6237E+00	5.8266E+00
20060409	1200	7.350E+03	5.5487E+00	5.5487E+00	5.7383E+00
20060410	1200	5.540E+03	4.2197E+00	4.2197E+00	4.3535E+00
20060411	1200	4.890E+03	3.7507E+00	3.7507E+00	3.8619E+00
20060412	1200	5.700E+03	4.3872E+00	4.3872E+00	4.5112E+00
20060413	1200	5.100E+03	3.9527E+00	3.9527E+00	4.0569E+00
20060414	1200	7.480E+03	5.8013E+00	5.8014E+00	5.9497E+00
20060415	1200	3.750E+03	2.9509E+00	2.9510E+00	3.0174E+00
20060416	1200	2.670E+03	2.1224E+00	2.1224E+00	2.1654E+00
20060417	1200	1.100E+04	8.6366E+00	8.6366E+00	8.8258E+00
20060418	1200	7.060E+03	5.6076E+00	5.6076E+00	5.7171E+00
20060419	1200	6.360E+03	5.0886E+00	5.0886E+00	5.1799E+00
20060420	1200	6.450E+03	5.1907E+00	5.1907E+00	5.2773E+00
20060421	1200	6.820E+03	5.5179E+00	5.5180E+00	5.6039E+00
20060422	1200	6.980E+03	5.6804E+00	5.6804E+00	5.7625E+00
20060423	1200	6.170E+03	5.0604E+00	5.0605E+00	5.1264E+00
20060424	1200	5.350E+03	4.4235E+00	4.4235E+00	4.4751E+00
20060425	1200	6.400E+03	5.3129E+00	5.3129E+00	5.3715E+00
20060426	1200	7.020E+03	5.8578E+00	5.8578E+00	5.9180E+00
20060427	1200	7.910E+03	6.6327E+00	6.6327E+00	6.6966E+00
20060428	1200	6.630E+03	5.6082E+00	5.6082E+00	5.6553E+00
20060429	1200	3.600E+03	3.0893E+00	3.0893E+00	3.1086E+00
20060430	1200	5.440E+03	4.6740E+00	4.6740E+00	4.7041E+00
20060501	1200	4.470E+03	3.8759E+00	3.8759E+00	3.8964E+00
20060502	1200	6.740E+03	5.8521E+00	5.8521E+00	5.8848E+00
20060503	1200	5.300E+03	4.6471E+00	4.6471E+00	4.6679E+00
20060504	1200	3.940E+03	3.4913E+00	3.4913E+00	3.5028E+00
20060505	1200	4.650E+03	4.1396E+00	4.1396E+00	4.1529E+00
20060506	1200	3.460E+03	3.1131E+00	3.1131E+00	3.1198E+00
20060507	1200	6.460E+03	5.8052E+00	5.8052E+00	5.8239E+00
20060508	1200	5.230E+03	4.7453E+00	4.7453E+00	4.7569E+00
20060509	1200	6.020E+03	5.4899E+00	5.4899E+00	5.5038E+00
20060510	1200	4.760E+03	4.3844E+00	4.3844E+00	4.3923E+00
20060511	1200	4.440E+03	4.1219E+00	4.1219E+00	4.1283E+00
20060512	1200	4.650E+03	4.3446E+00	4.3446E+00	4.3514E+00
20060513	1200	4.980E+03	4.6815E+00	4.6815E+00	4.6895E+00

20060514	1200	3.530E+03	3.3568E+00	3.3568E+00	3.3600E+00
20060515	1200	3.020E+03	2.8980E+00	2.8980E+00	2.9001E+00
20060516	1200	2.670E+03	2.5845E+00	2.5845E+00	2.5860E+00
20060517	1200	1.950E+03	1.9087E+00	1.9087E+00	1.9089E+00
20060518	1200	1.970E+03	1.9418E+00	1.9418E+00	1.9425E+00
20060519	1200	3.690E+02	3.7433E-01	3.7433E-01	3.7318E-01
20060520	1200	8.610E+02	8.7013E-01	8.7013E-01	8.6942E-01
20060521	1200	1.440E+03	1.4560E+00	1.4560E+00	1.4571E+00
20060522	1200	1.740E+02	1.8209E-01	1.8209E-01	1.8146E-01
20060523	1200	2.810E+03	2.8571E+00	2.8571E+00	2.8667E+00
20060524	1200	2.670E+03	2.7361E+00	2.7361E+00	2.7466E+00
20060525	1200	2.380E+03	2.4601E+00	2.4601E+00	2.4704E+00
20060526	1200	3.500E+03	3.6254E+00	3.6254E+00	3.6466E+00
20060527	1200	2.730E+03	2.8573E+00	2.8574E+00	2.8745E+00
20060528	1200	7.700E+01	8.5006E-02	8.5006E-02	8.4898E-02
20060529	1200	3.350E+03	3.5472E+00	3.5472E+00	3.5762E+00
20060530	1200	3.460E+03	3.6882E+00	3.6883E+00	3.7222E+00
20060531	1200	3.240E+03	3.4814E+00	3.4814E+00	3.5163E+00
20060601	1200	2.850E+03	3.0893E+00	3.0893E+00	3.1225E+00
20060602	1200	2.500E+03	2.7338E+00	2.7338E+00	2.7654E+00
20060603	1200	2.800E+03	3.0790E+00	3.0790E+00	3.1189E+00
20060604	1200	1.810E+03	2.0159E+00	2.0159E+00	2.0423E+00
20060605	1200	2.010E+03	2.2513E+00	2.2514E+00	2.2842E+00
20060606	1200	1.140E+03	1.2954E+00	1.2954E+00	1.3142E+00
20060607	1200	5.700E+01	6.7809E-02	6.7809E-02	6.8414E-02
20060608	1200	5.680E+02	6.6047E-01	6.6047E-01	6.7077E-01
20060609	1200	1.350E+03	1.5629E+00	1.5629E+00	1.5928E+00
20060610	1200	3.120E+03	3.5974E+00	3.5974E+00	3.6791E+00
20060611	1200	2.430E+03	2.8304E+00	2.8304E+00	2.8973E+00
20060612	1200	1.350E+03	1.5954E+00	1.5954E+00	1.6334E+00
20060613	1200	9.230E+02	1.1037E+00	1.1037E+00	1.1308E+00
20060614	1200	1.990E+03	2.3718E+00	2.3718E+00	2.4385E+00
20060615	1200	1.890E+03	2.2693E+00	2.2693E+00	2.3369E+00
20060616	1200	8.800E+01	1.1071E-01	1.1071E-01	1.1338E-01
20060617	1200	1.680E+03	2.0473E+00	2.0473E+00	2.1152E+00
20060618	1200	2.430E+03	2.9664E+00	2.9664E+00	3.0733E+00
20060619	1200	1.550E+03	1.9159E+00	1.9159E+00	1.9864E+00
20060620	1200	2.050E+02	2.6188E-01	2.6188E-01	2.7073E-01
20060621	1200	1.490E+03	1.8667E+00	1.8667E+00	1.9428E+00
20060622	1200	3.700E+02	4.7510E-01	4.7510E-01	4.9380E-01
20060623	1200	5.190E+02	6.6770E-01	6.6770E-01	6.9598E-01
20060624	1200	7.930E+02	1.0210E+00	1.0210E+00	1.0675E+00
20060625	1200	8.710E+02	1.1270E+00	1.1270E+00	1.1812E+00
20060626	1200	1.080E+03	1.4021E+00	1.4021E+00	1.4735E+00
20060627	1200	1.130E+02	1.5203E-01	1.5203E-01	1.5925E-01
20060628	1200	2.000E+01	2.7687E-02	2.7687E-02	2.8952E-02
20060629	1200	7.900E+01	1.0808E-01	1.0808E-01	1.1363E-01
20060630	1200	1.780E+03	2.3516E+00	2.3516E+00	2.4970E+00
20060701	1200	4.320E+02	5.8487E-01	5.8487E-01	6.2032E-01
20060702	1200	2.000E+02	2.7511E-01	2.7511E-01	2.9193E-01
20060703	1200	1.890E+02	2.6166E-01	2.6166E-01	2.7830E-01
20060704	1200	1.200E+03	1.6307E+00	1.6307E+00	1.7466E+00
20060705	1200	1.100E+03	1.5049E+00	1.5049E+00	1.6155E+00
20060706	1200	5.150E+02	7.1555E-01	7.1555E-01	7.6864E-01
20060707	1200	5.960E+02	8.3100E-01	8.3101E-01	8.9526E-01
20060708	1200	9.280E+02	1.2933E+00	1.2933E+00	1.3984E+00
20060709	1200	5.960E+02	8.3988E-01	8.3988E-01	9.0953E-01
20060710	1200	2.250E+02	3.2283E-01	3.2283E-01	3.4968E-01
20060711	1200	1.380E+03	1.9432E+00	1.9432E+00	2.1200E+00
20060712	1200	3.850E+02	5.5411E-01	5.5411E-01	6.0421E-01
20060713	1200	6.690E+02	9.6061E-01	9.6061E-01	1.0518E+00
20060714	1200	5.800E+01	8.6419E-02	8.6419E-02	9.4312E-02
20060715	1200	3.220E+02	4.7136E-01	4.7136E-01	5.1799E-01
20060716	1200	3.300E+01	5.0005E-02	5.0005E-02	5.4802E-02

20060717	1200	6.220E+02	9.1107E-01	9.1107E-01	1.0085E+00
20060718	1200	1.260E+03	1.8367E+00	1.8367E+00	2.0425E+00
20060719	1200	2.920E+02	4.3587E-01	4.3587E-01	4.8430E-01
20060720	1200	8.070E+02	1.1937E+00	1.1937E+00	1.3336E+00
20060721	1200	4.620E+02	6.9138E-01	6.9138E-01	7.7352E-01
20060722	1200	4.440E+02	6.6755E-01	6.6755E-01	7.4896E-01
20060723	1200	4.520E+02	6.8218E-01	6.8218E-01	7.6764E-01
20060724	1200	1.350E+02	2.0784E-01	2.0784E-01	2.3386E-01
20060725	1200	5.240E+02	7.9550E-01	7.9550E-01	9.0078E-01
20060726	1200	1.220E+02	1.8952E-01	1.8952E-01	2.1445E-01
20060727	1200	2.020E+02	3.1286E-01	3.1286E-01	3.5552E-01
20060728	1200	4.000E+01	6.3511E-02	6.3511E-02	7.2099E-02
20060729	1200	4.850E+02	7.4779E-01	7.4779E-01	8.5673E-01
20060730	1200	6.800E+01	1.0796E-01	1.0796E-01	1.2345E-01
20060731	1200	1.490E+02	2.3489E-01	2.3489E-01	2.6993E-01
20060801	1200	1.200E+02	1.9032E-01	1.9032E-01	2.1925E-01
20060802	1200	2.700E+01	4.3801E-02	4.3801E-02	5.0429E-02
20060803	1200	4.200E+01	6.7943E-02	6.7943E-02	7.8545E-02
20060804	1200	6.300E+01	1.0166E-01	1.0166E-01	1.1800E-01
20060805	1200	9.100E+01	1.4654E-01	1.4654E-01	1.7076E-01
20060806	1200	1.080E+02	1.7399E-01	1.7399E-01	2.0345E-01
20060807	1200	6.650E+02	1.0486E+00	1.0486E+00	1.2355E+00
20060808	1200	1.660E+02	2.6724E-01	2.6724E-01	3.1473E-01
20060809	1200	1.310E+02	2.1204E-01	2.1204E-01	2.5034E-01
20060810	1200	1.740E+02	2.8122E-01	2.8122E-01	3.3326E-01
20060811	1200	3.100E+01	5.1359E-02	5.1359E-02	6.0789E-02
20060812	1200	2.400E+01	3.9975E-02	3.9975E-02	4.7430E-02
20060813	1200	2.530E+02	4.0933E-01	4.0933E-01	4.8997E-01
20060814	1200	2.000E+01	3.3515E-02	3.3515E-02	3.9989E-02
20060815	1200	1.230E+02	2.0160E-01	2.0160E-01	2.4234E-01
20060816	1200	1.420E+02	2.3266E-01	2.3266E-01	2.8063E-01
20060817	1200	1.840E+02	3.0088E-01	3.0088E-01	3.6424E-01
20060818	1200	1.660E+02	2.7218E-01	2.7218E-01	3.3040E-01
20060819	1200	3.300E+01	5.5338E-02	5.5338E-02	6.7108E-02
20060820	1200	5.200E+01	8.6777E-02	8.6777E-02	1.0566E-01
20060821	1200	8.800E+00	1.5046E-02	1.5046E-02	1.8297E-02
20060822	1200	1.900E+01	3.2189E-02	3.2189E-02	3.9332E-02
20060823	1200	1.800E+01	3.0541E-02	3.0541E-02	3.7422E-02
20060824	1200	8.000E+01	1.3320E-01	1.3320E-01	1.6428E-01
20060825	1200	7.000E+00	1.2039E-02	1.2039E-02	1.4805E-02
20060826	1200	2.600E+01	4.3976E-02	4.3976E-02	5.4406E-02
20060827	1200	1.200E+01	2.0510E-02	2.0510E-02	2.5400E-02
20060828	1200	6.800E+01	1.1364E-01	1.1364E-01	1.4173E-01
20060829	1200	1.610E+02	2.6605E-01	2.6605E-01	3.3347E-01
20060830	1200	5.900E+00	1.0181E-02	1.0181E-02	1.2695E-02
20060831	1200	8.600E+01	1.4328E-01	1.4328E-01	1.8031E-01
20060901	1200	6.500E+01	1.0867E-01	1.0867E-01	1.3704E-01
20060902	1200	6.000E+01	1.0038E-01	1.0038E-01	1.2692E-01
20060903	1200	2.010E+02	3.3082E-01	3.3082E-01	4.2068E-01
20060904	1200	4.300E+01	7.2182E-02	7.2182E-02	9.1688E-02
20060905	1200	1.300E+00	2.2824E-03	2.2824E-03	2.8833E-03
20060906	1200	3.900E+00	6.7453E-03	6.7453E-03	8.5652E-03
20060907	1200	1.400E+00	2.4516E-03	2.4516E-03	3.1140E-03
20060908	1200	7.600E+01	1.2621E-01	1.2621E-01	1.6225E-01
20060909	1200	1.000E+02	1.6529E-01	1.6529E-01	2.1317E-01
20060910	1200	1.700E+01	2.8725E-02	2.8725E-02	3.6981E-02
20060911	1200	1.090E+02	1.7951E-01	1.7951E-01	2.3274E-01
20060912	1200	1.510E+02	2.4727E-01	2.4727E-01	3.2164E-01
20060913	1200	1.200E+02	1.9680E-01	1.9680E-01	2.5648E-01
20060914	1200	3.500E+00	6.0013E-03	6.0014E-03	7.7745E-03
20060915	1200	4.900E+01	8.1038E-02	8.1038E-02	1.0589E-01
20060916	1200	2.300E+02	3.7205E-01	3.7205E-01	4.8914E-01
20060917	1200	5.700E+01	9.3728E-02	9.3728E-02	1.2309E-01
20060918	1200	7.900E+01	1.2909E-01	1.2909E-01	1.7004E-01

20060919	1200	1.010E+02	1.6415E-01	1.6415E-01	2.1685E-01
20060920	1200	1.240E+02	2.0054E-01	2.0054E-01	2.6564E-01
20060921	1200	5.300E+01	8.6473E-02	8.6473E-02	1.1456E-01
20060922	1200	4.700E+01	7.6617E-02	7.6617E-02	1.0169E-01
20060923	1200	1.090E+02	1.7529E-01	1.7529E-01	2.3362E-01
20060924	1200	7.900E+01	1.2725E-01	1.2725E-01	1.6980E-01
20060925	1200	9.300E+01	1.4907E-01	1.4907E-01	1.9940E-01
20060926	1200	4.700E+00	7.8104E-03	7.8104E-03	1.0395E-02
20060927	1200	1.800E+01	2.9309E-02	2.9309E-02	3.9205E-02
20060928	1200	2.000E+01	3.2423E-02	3.2423E-02	4.3464E-02
20060929	1200	2.000E+01	3.2323E-02	3.2323E-02	4.3409E-02
20060930	1200	2.000E+01	3.2219E-02	3.2219E-02	4.3349E-02
20061001	1200	3.950E+02	6.0995E-01	6.0995E-01	8.2803E-01
20061002	1200	6.700E+02	1.0239E+00	1.0239E+00	1.3943E+00
20061003	1200	6.520E+02	9.9336E-01	9.9336E-01	1.3548E+00
20061004	1200	6.710E+02	1.0183E+00	1.0183E+00	1.3912E+00
20061005	1200	7.030E+02	1.0623E+00	1.0623E+00	1.4538E+00
20061006	1200	9.940E+02	1.4897E+00	1.4897E+00	2.0436E+00
20061007	1200	9.040E+02	1.3514E+00	1.3514E+00	1.8561E+00
20061008	1200	8.700E+02	1.2962E+00	1.2962E+00	1.7827E+00
20061009	1200	8.470E+02	1.2574E+00	1.2574E+00	1.7316E+00
20061010	1200	1.344E+03	1.9750E+00	1.9750E+00	2.7268E+00
20061011	1200	1.107E+03	1.6242E+00	1.6242E+00	2.2443E+00
20061012	1200	8.590E+02	1.2593E+00	1.2593E+00	1.7411E+00
20061013	1200	8.810E+02	1.2856E+00	1.2856E+00	1.7797E+00
20061014	1200	9.490E+02	1.3775E+00	1.3775E+00	1.9095E+00
20061015	1200	7.920E+02	1.1473E+00	1.1473E+00	1.5914E+00
20061016	1200	6.470E+02	9.3552E-01	9.3552E-01	1.2984E+00
20061017	1200	1.129E+03	1.6132E+00	1.6132E+00	2.2442E+00
20061018	1200	1.220E+03	1.7334E+00	1.7334E+00	2.4142E+00
20061019	1200	1.186E+03	1.6778E+00	1.6778E+00	2.3387E+00
20061020	1200	9.260E+02	1.3081E+00	1.3081E+00	1.8237E+00
20061021	1200	8.700E+02	1.2241E+00	1.2241E+00	1.7077E+00
20061022	1200	8.250E+02	1.1559E+00	1.1559E+00	1.6136E+00
20061023	1200	9.940E+02	1.3824E+00	1.3824E+00	1.9321E+00
20061024	1200	1.242E+03	1.7137E+00	1.7137E+00	2.3979E+00
20061025	1200	9.830E+02	1.3537E+00	1.3537E+00	1.8941E+00
20061026	1200	7.880E+02	1.0828E+00	1.0828E+00	1.5150E+00
20061027	1200	9.830E+02	1.3399E+00	1.3399E+00	1.8767E+00
20061028	1200	1.005E+03	1.3623E+00	1.3623E+00	1.9091E+00
20061029	1200	6.980E+02	9.4572E-01	9.4572E-01	1.3246E+00
20061030	1200	1.220E+03	1.6322E+00	1.6322E+00	2.2899E+00
20061031	1200	1.378E+03	1.8308E+00	1.8308E+00	2.5700E+00
20061101	1200	1.118E+03	1.4815E+00	1.4815E+00	2.0790E+00
20061102	1200	1.039E+03	1.3706E+00	1.3706E+00	1.9234E+00
20061103	1200	9.260E+02	1.2167E+00	1.2167E+00	1.7071E+00
20061104	1200	9.150E+02	1.1958E+00	1.1958E+00	1.6778E+00
20061105	1200	9.260E+02	1.2033E+00	1.2033E+00	1.6884E+00
20061106	1200	8.250E+02	1.0677E+00	1.0677E+00	1.4976E+00
20061107	1200	1.208E+03	1.5468E+00	1.5468E+00	2.1714E+00
20061108	1200	9.380E+02	1.1983E+00	1.1983E+00	1.6808E+00
20061109	1200	9.710E+02	1.2328E+00	1.2328E+00	1.7290E+00
20061110	1200	1.062E+03	1.3391E+00	1.3391E+00	1.8780E+00
20061111	1200	8.920E+02	1.1208E+00	1.1208E+00	1.5707E+00
20061112	1200	1.039E+03	1.2954E+00	1.2954E+00	1.8154E+00
20061113	1200	1.186E+03	1.4676E+00	1.4676E+00	2.0565E+00
20061114	1200	1.513E+03	1.8555E+00	1.8555E+00	2.6002E+00
20061115	1200	1.332E+03	1.6267E+00	1.6267E+00	2.2777E+00
20061116	1200	1.231E+03	1.4962E+00	1.4962E+00	2.0932E+00
20061117	1200	1.299E+03	1.5685E+00	1.5685E+00	2.1932E+00
20061118	1200	1.615E+03	1.9331E+00	1.9331E+00	2.7026E+00
20061119	1200	9.150E+02	1.0969E+00	1.0969E+00	1.5303E+00
20061120	1200	1.175E+03	1.3957E+00	1.3957E+00	1.9468E+00
20061121	1200	1.389E+03	1.6366E+00	1.6366E+00	2.2817E+00

20061122	1200	1.197E+03	1.4048E+00	1.4048E+00	1.9561E+00
20061123	1200	1.220E+03	1.4230E+00	1.4230E+00	1.9796E+00
20061124	1200	9.940E+02	1.1556E+00	1.1556E+00	1.6052E+00
20061125	1200	1.366E+03	1.5722E+00	1.5722E+00	2.1832E+00
20061126	1200	1.062E+03	1.2191E+00	1.2191E+00	1.6899E+00
20061127	1200	1.445E+03	1.6423E+00	1.6423E+00	2.2757E+00
20061128	1200	1.378E+03	1.5579E+00	1.5579E+00	2.1558E+00
20061129	1200	7.810E+02	8.8426E-01	8.8426E-01	1.2205E+00
20061130	1200	1.084E+03	1.2149E+00	1.2149E+00	1.6759E+00
20061201	1200	1.231E+03	1.3693E+00	1.3693E+00	1.8869E+00
20061202	1200	1.163E+03	1.2871E+00	1.2871E+00	1.7708E+00
20061203	1200	1.017E+03	1.1209E+00	1.1209E+00	1.5394E+00
20061204	1200	1.017E+03	1.1143E+00	1.1143E+00	1.5281E+00
20061205	1200	1.045E+03	1.1380E+00	1.1380E+00	1.5582E+00
20061206	1200	1.073E+03	1.1613E+00	1.1613E+00	1.5877E+00
20061207	1200	1.101E+03	1.1844E+00	1.1844E+00	1.6166E+00
20061208	1200	1.129E+03	1.2071E+00	1.2071E+00	1.6450E+00
20061209	1200	1.304E+03	1.3837E+00	1.3837E+00	1.8829E+00
20061210	1200	1.479E+03	1.5579E+00	1.5579E+00	2.1168E+00
20061211	1200	8.590E+02	9.0608E-01	9.0608E-01	1.2273E+00
20061212	1200	1.513E+03	1.5754E+00	1.5754E+00	2.1327E+00
20061213	1200	1.220E+03	1.2667E+00	1.2667E+00	1.7107E+00
20061214	1200	1.287E+03	1.3280E+00	1.3280E+00	1.7901E+00
20061215	1200	1.310E+03	1.3440E+00	1.3440E+00	1.8080E+00
20061216	1200	1.468E+03	1.4956E+00	1.4956E+00	2.0084E+00
20061217	1200	1.411E+03	1.4305E+00	1.4305E+00	1.9167E+00
20061218	1200	9.040E+02	9.1680E-01	9.1681E-01	1.2246E+00
20061219	1200	1.547E+03	1.5497E+00	1.5497E+00	2.0680E+00
20061220	1200	1.592E+03	1.5858E+00	1.5858E+00	2.1115E+00
20061221	1200	1.411E+03	1.4003E+00	1.4003E+00	1.8598E+00
20061222	1200	1.569E+03	1.5469E+00	1.5469E+00	2.0503E+00
20061223	1200	1.513E+03	1.4847E+00	1.4847E+00	1.9631E+00
20061224	1200	1.445E+03	1.4116E+00	1.4116E+00	1.8618E+00
20061225	1200	1.107E+03	1.0797E+00	1.0797E+00	1.4197E+00
20061226	1200	1.028E+03	9.9862E-01	9.9862E-01	1.3097E+00
20061227	1200	1.332E+03	1.2833E+00	1.2833E+00	1.6797E+00
20061228	1200	1.705E+03	1.6295E+00	1.6295E+00	2.1287E+00
20061229	1200	1.434E+03	1.3669E+00	1.3669E+00	1.7805E+00
20061230	1200	1.411E+03	1.3389E+00	1.3389E+00	1.7394E+00
20061231	1200	1.152E+03	1.0909E+00	1.0909E+00	1.4128E+00
20070101	1200	1.163E+03	1.0961E+00	1.0961E+00	1.4158E+00
20070102	1200	9.830E+02	9.2429E-01	9.2430E-01	1.1902E+00
20070103	1200	1.457E+03	1.3570E+00	1.3570E+00	1.7441E+00
20070104	1200	1.287E+03	1.1953E+00	1.1953E+00	1.5317E+00
20070105	1200	1.096E+03	1.0156E+00	1.0156E+00	1.2973E+00
20070106	1200	1.028E+03	9.4936E-01	9.4936E-01	1.2091E+00
20070107	1200	5.290E+02	4.9067E-01	4.9067E-01	6.2224E-01
20070108	1200	5.330E+02	4.9231E-01	4.9231E-01	6.2254E-01
20070109	1200	1.400E+03	1.2721E+00	1.2721E+00	1.6073E+00
20070110	1200	1.671E+03	1.5089E+00	1.5089E+00	1.9017E+00
20070111	1200	1.276E+03	1.1518E+00	1.1518E+00	1.4465E+00
20070112	1200	1.332E+03	1.1971E+00	1.1971E+00	1.4991E+00
20070113	1200	1.524E+03	1.3623E+00	1.3623E+00	1.7013E+00
20070114	1200	1.062E+03	9.5031E-01	9.5031E-01	1.1823E+00
20070115	1200	1.400E+03	1.2439E+00	1.2439E+00	1.5438E+00
20070116	1200	1.141E+03	1.0130E+00	1.0130E+00	1.2528E+00
20070117	1200	9.710E+02	8.6100E-01	8.6100E-01	1.0611E+00
20070118	1200	7.390E+02	6.5546E-01	6.5546E-01	8.0484E-01
20070119	1200	9.940E+02	8.7552E-01	8.7552E-01	1.0724E+00
20070120	1200	1.096E+03	9.6121E-01	9.6121E-01	1.1739E+00
20070121	1200	1.118E+03	9.7735E-01	9.7735E-01	1.1899E+00
20070122	1200	1.084E+03	9.4529E-01	9.4529E-01	1.1471E+00
20070123	1200	1.065E+03	9.2637E-01	9.2637E-01	1.1205E+00
20070124	1200	1.046E+03	9.0762E-01	9.0762E-01	1.0943E+00

20070125	1200	1.028E+03	8.8991E-01	8.8991E-01	1.0695E+00
20070126	1200	1.005E+03	8.6810E-01	8.6810E-01	1.0398E+00
20070127	1200	1.009E+03	8.6944E-01	8.6944E-01	1.0381E+00
20070128	1200	1.013E+03	8.7086E-01	8.7087E-01	1.0364E+00
20070129	1200	1.017E+03	8.7236E-01	8.7236E-01	1.0348E+00
20070130	1200	1.021E+03	8.7394E-01	8.7394E-01	1.0333E+00
20070131	1200	1.025E+03	8.7560E-01	8.7560E-01	1.0319E+00
20070201	1200	1.029E+03	8.7734E-01	8.7734E-01	1.0305E+00
20070202	1200	1.033E+03	8.7916E-01	8.7916E-01	1.0293E+00
20070203	1200	1.037E+03	8.8107E-01	8.8107E-01	1.0281E+00
20070204	1200	1.041E+03	8.8306E-01	8.8306E-01	1.0271E+00
20070205	1200	1.044E+03	8.8430E-01	8.8430E-01	1.0251E+00
20070206	1200	1.048E+03	8.8647E-01	8.8647E-01	1.0242E+00
20070207	1200	1.052E+03	8.8873E-01	8.8873E-01	1.0235E+00
20070208	1200	1.056E+03	8.9107E-01	8.9107E-01	1.0228E+00
20070209	1200	1.062E+03	8.9518E-01	8.9518E-01	1.0241E+00
20070210	1200	1.107E+03	9.3178E-01	9.3178E-01	1.0625E+00
20070211	1200	1.230E+03	1.0331E+00	1.0331E+00	1.1745E+00
20070212	1200	1.355E+03	1.1359E+00	1.1359E+00	1.2874E+00
20070213	1200	1.479E+03	1.2378E+00	1.2378E+00	1.3984E+00
20070214	1200	1.615E+03	1.3495E+00	1.3495E+00	1.5199E+00
20070215	1200	1.705E+03	1.4232E+00	1.4232E+00	1.5979E+00
20070216	1200	1.397E+03	1.1688E+00	1.1688E+00	1.3074E+00
20070217	1200	1.089E+03	9.1397E-01	9.1397E-01	1.0184E+00
20070218	1200	7.810E+02	6.5828E-01	6.5828E-01	7.3059E-01
20070219	1200	9.380E+02	7.8885E-01	7.8885E-01	8.7299E-01
20070220	1200	1.615E+03	1.3490E+00	1.3490E+00	1.4899E+00
20070221	1200	1.310E+03	1.0976E+00	1.0976E+00	1.2077E+00
20070222	1200	1.411E+03	1.1816E+00	1.1816E+00	1.2962E+00
20070223	1200	1.310E+03	1.0987E+00	1.0987E+00	1.2012E+00
20070224	1200	1.265E+03	1.0622E+00	1.0622E+00	1.1574E+00
20070225	1200	7.580E+02	6.4119E-01	6.4119E-01	6.9569E-01
20070226	1200	1.310E+03	1.1013E+00	1.1013E+00	1.1926E+00
20070227	1200	1.400E+03	1.1772E+00	1.1772E+00	1.2709E+00
20070228	1200	1.434E+03	1.2068E+00	1.2068E+00	1.2989E+00
20070301	1200	7.620E+02	6.4731E-01	6.4732E-01	6.9357E-01
20070302	1200	9.380E+02	7.9578E-01	7.9578E-01	8.5040E-01
20070303	1200	1.084E+03	9.1928E-01	9.1928E-01	9.7967E-01
20070304	1200	7.600E+02	6.4850E-01	6.4850E-01	6.8845E-01
20070305	1200	1.637E+03	1.3854E+00	1.3854E+00	1.4688E+00
20070306	1200	1.485E+03	1.2606E+00	1.2606E+00	1.3322E+00
20070307	1200	1.332E+03	1.1345E+00	1.1345E+00	1.1951E+00
20070308	1200	1.180E+03	1.0087E+00	1.0087E+00	1.0591E+00
20070309	1200	1.028E+03	8.8218E-01	8.8218E-01	9.2329E-01
20070310	1200	1.637E+03	1.3995E+00	1.3995E+00	1.4620E+00
20070311	1200	1.976E+03	1.6892E+00	1.6892E+00	1.7603E+00
20070312	1200	2.551E+03	2.1789E+00	2.1789E+00	2.2655E+00
20070313	1200	1.998E+03	1.7164E+00	1.7164E+00	1.7785E+00
20070314	1200	2.246E+03	1.9317E+00	1.9317E+00	1.9966E+00
20070315	1200	1.660E+03	1.4373E+00	1.4373E+00	1.4805E+00
20070316	1200	1.930E+03	1.6726E+00	1.6726E+00	1.7188E+00
20070317	1200	1.750E+03	1.5231E+00	1.5231E+00	1.5606E+00
20070318	1200	1.660E+03	1.4503E+00	1.4503E+00	1.4818E+00
20070319	1200	1.727E+03	1.5129E+00	1.5129E+00	1.5418E+00
20070320	1200	2.122E+03	1.8601E+00	1.8601E+00	1.8917E+00
20070321	1200	1.885E+03	1.6605E+00	1.6605E+00	1.6840E+00
20070322	1200	2.246E+03	1.9810E+00	1.9810E+00	2.0047E+00
20070323	1200	1.953E+03	1.7319E+00	1.7319E+00	1.7477E+00
20070324	1200	2.066E+03	1.8376E+00	1.8376E+00	1.8501E+00
20070325	1200	2.258E+03	2.0137E+00	2.0137E+00	2.0229E+00
20070326	1200	2.111E+03	1.8916E+00	1.8916E+00	1.8955E+00
20070327	1200	1.942E+03	1.7491E+00	1.7491E+00	1.7482E+00
20070328	1200	2.077E+03	1.8767E+00	1.8767E+00	1.8718E+00
20070329	1200	1.930E+03	1.7529E+00	1.7529E+00	1.7440E+00

20070330	1200	2.032E+03	1.8522E+00	1.8522E+00	1.8390E+00
20070331	1200	2.009E+03	1.8395E+00	1.8395E+00	1.8224E+00
20070401	1200	2.009E+03	1.8478E+00	1.8478E+00	1.8267E+00
20070402	1200	1.321E+03	1.2272E+00	1.2272E+00	1.2095E+00
20070403	1200	1.976E+03	1.8346E+00	1.8346E+00	1.8062E+00
20070404	1200	1.581E+03	1.4792E+00	1.4792E+00	1.4526E+00
20070405	1200	1.400E+03	1.3182E+00	1.3182E+00	1.2916E+00
20070406	1200	1.637E+03	1.5458E+00	1.5458E+00	1.5123E+00
20070407	1200	1.355E+03	1.2891E+00	1.2891E+00	1.2583E+00
20070408	1200	1.197E+03	1.1464E+00	1.1464E+00	1.1167E+00
20070409	1200	1.152E+03	1.1096E+00	1.1096E+00	1.0788E+00
20070410	1200	1.626E+03	1.5673E+00	1.5673E+00	1.5224E+00
20070411	1200	1.332E+03	1.2941E+00	1.2941E+00	1.2543E+00
20070412	1200	1.761E+03	1.7139E+00	1.7139E+00	1.6596E+00
20070413	1200	2.449E+03	2.3862E+00	2.3862E+00	2.3089E+00
20070414	1200	1.930E+03	1.8968E+00	1.8968E+00	1.8316E+00
20070415	1200	1.727E+03	1.7094E+00	1.7094E+00	1.6477E+00
20070416	1200	1.100E+01	1.1693E-02	1.1693E-02	1.1124E-02
20070417	1200	1.000E-04	1.2366E-07	1.2366E-07	1.1498E-07
20070418	1200	1.480E+03	1.4934E+00	1.4934E+00	1.4331E+00
20070419	1200	1.270E+03	1.2916E+00	1.2916E+00	1.2375E+00
20070420	1200	1.920E+03	1.9537E+00	1.9537E+00	1.8714E+00
20070421	1200	1.300E+03	1.3376E+00	1.3376E+00	1.2786E+00
20070422	1200	1.360E+03	1.4071E+00	1.4071E+00	1.3436E+00
20070423	1200	3.040E+03	3.1312E+00	3.1312E+00	2.9928E+00
20070424	1200	1.100E+03	1.1554E+00	1.1554E+00	1.1004E+00
20070425	1200	1.340E+03	1.4126E+00	1.4126E+00	1.3448E+00
20070426	1200	1.770E+03	1.8708E+00	1.8708E+00	1.7807E+00
20070427	1200	4.640E+02	5.0232E-01	5.0232E-01	4.7614E-01
20070428	1200	5.420E+02	5.8933E-01	5.8933E-01	5.5839E-01
20070429	1200	4.520E+02	4.9584E-01	4.9584E-01	4.6925E-01
20070430	1200	5.150E+02	5.6766E-01	5.6766E-01	5.3703E-01
20070501	1200	3.360E+02	3.7489E-01	3.7489E-01	3.5407E-01
20070502	1200	1.000E-04	1.3597E-07	1.3597E-07	1.2447E-07
20070503	1200	2.150E+03	2.3720E+00	2.3720E+00	2.2483E+00
20070504	1200	2.180E+03	2.4208E+00	2.4208E+00	2.2936E+00
20070505	1200	1.650E+03	1.8514E+00	1.8514E+00	1.7522E+00
20070506	1200	1.000E-04	1.3971E-07	1.3971E-07	1.2763E-07
20070507	1200	1.000E-04	1.4068E-07	1.4068E-07	1.2846E-07
20070508	1200	5.400E+02	6.2754E-01	6.2754E-01	5.9174E-01
20070509	1200	4.710E+02	5.5211E-01	5.5211E-01	5.2034E-01
20070510	1200	3.460E+02	4.1005E-01	4.1005E-01	3.8611E-01
20070511	1200	1.140E+03	1.3391E+00	1.3391E+00	1.2647E+00
20070512	1200	1.000E-04	1.4567E-07	1.4567E-07	1.3288E-07
20070513	1200	1.410E+03	1.6747E+00	1.6747E+00	1.5826E+00
20070514	1200	6.040E+02	7.3056E-01	7.3056E-01	6.8894E-01
20070515	1200	1.760E+02	2.1789E-01	2.1789E-01	2.0487E-01
20070516	1200	1.000E-04	1.4985E-07	1.4985E-07	1.3671E-07
20070517	1200	1.000E-04	1.5092E-07	1.5092E-07	1.3772E-07
20070518	1200	3.790E+02	4.7439E-01	4.7439E-01	4.4727E-01
20070519	1200	3.940E+02	4.9640E-01	4.9640E-01	4.6825E-01
20070520	1200	5.580E+02	7.0474E-01	7.0475E-01	6.6567E-01
20070521	1200	1.350E+03	1.6971E+00	1.6971E+00	1.6075E+00
20070522	1200	1.000E-04	1.5642E-07	1.5642E-07	1.4298E-07
20070523	1200	1.000E-04	1.5755E-07	1.5755E-07	1.4408E-07
20070524	1200	1.000E-04	1.5868E-07	1.5868E-07	1.4520E-07
20070525	1200	2.840E+02	3.7496E-01	3.7496E-01	3.5462E-01
20070526	1200	2.190E+02	2.9220E-01	2.9220E-01	2.7638E-01
20070527	1200	1.000E-04	1.6214E-07	1.6214E-07	1.4866E-07
20070528	1200	1.490E+03	1.9656E+00	1.9656E+00	1.8717E+00
20070529	1200	1.000E-04	1.6448E-07	1.6448E-07	1.5105E-07
20070530	1200	1.000E-04	1.6566E-07	1.6566E-07	1.5227E-07
20070531	1200	1.000E-04	1.6684E-07	1.6685E-07	1.5351E-07
20070601	1200	1.000E-04	1.6804E-07	1.6804E-07	1.5476E-07

20070602	1200	4.200E+01	6.0180E-02	6.0180E-02	5.7069E-02
20070603	1200	1.780E+02	2.5197E-01	2.5197E-01	2.4012E-01
20070604	1200	1.000E-04	1.7165E-07	1.7165E-07	1.5861E-07
20070605	1200	6.300E+01	9.1691E-02	9.1691E-02	8.7363E-02
20070606	1200	4.030E+02	5.7622E-01	5.7622E-01	5.5244E-01
20070607	1200	1.000E-04	1.7531E-07	1.7531E-07	1.6260E-07
20070608	1200	1.000E-04	1.7654E-07	1.7654E-07	1.6396E-07
20070609	1200	2.500E+01	3.7866E-02	3.7866E-02	3.6196E-02
20070610	1200	2.860E+02	4.2226E-01	4.2226E-01	4.0684E-01
20070611	1200	4.100E+02	6.0654E-01	6.0654E-01	5.8588E-01
20070612	1200	1.000E-04	1.8148E-07	1.8148E-07	1.6955E-07
20070613	1200	1.000E-04	1.8272E-07	1.8272E-07	1.7098E-07
20070614	1200	7.200E+01	1.1124E-01	1.1124E-01	1.0749E-01
20070615	1200	2.500E+01	3.9434E-02	3.9434E-02	3.8068E-02
20070616	1200	2.100E+01	3.3422E-02	3.3422E-02	3.2308E-02
20070617	1200	1.030E+02	1.6156E-01	1.6156E-01	1.5711E-01
20070618	1200	1.000E-04	1.8894E-07	1.8894E-07	1.7834E-07
20070619	1200	1.000E-04	1.9018E-07	1.9018E-07	1.7985E-07
20070620	1200	1.000E-04	1.9142E-07	1.9142E-07	1.8137E-07
20070621	1200	3.300E+01	5.3929E-02	5.3929E-02	5.2700E-02
20070622	1200	1.000E-04	1.9390E-07	1.9390E-07	1.8445E-07
20070623	1200	1.000E-04	1.9514E-07	1.9514E-07	1.8601E-07
20070624	1200	2.500E+01	4.1788E-02	4.1788E-02	4.1064E-02
20070625	1200	5.400E+01	8.9894E-02	8.9894E-02	8.8711E-02
20070626	1200	4.000E+01	6.7266E-02	6.7266E-02	6.6475E-02
20070627	1200	1.500E+01	2.5712E-02	2.5712E-02	2.5401E-02
20070628	1200	1.000E+00	1.7873E-03	1.7873E-03	1.7576E-03
20070629	1200	2.300E+01	3.9672E-02	3.9672E-02	3.9419E-02
20070630	1200	1.000E-04	2.0368E-07	2.0368E-07	1.9716E-07
20070701	1200	1.000E-04	2.0488E-07	2.0488E-07	1.9879E-07
20070702	1200	1.000E-04	2.0607E-07	2.0607E-07	2.0042E-07
20070703	1200	1.000E-04	2.0726E-07	2.0726E-07	2.0206E-07
20070704	1200	5.300E+01	9.3038E-02	9.3038E-02	9.3786E-02
20070705	1200	1.200E+02	2.0951E-01	2.0951E-01	2.1220E-01
20070706	1200	1.870E+02	3.2632E-01	3.2632E-01	3.3177E-01
20070707	1200	5.640E+02	9.7488E-01	9.7488E-01	9.9684E-01
20070708	1200	1.000E-04	2.1304E-07	2.1304E-07	2.1033E-07
20070709	1200	1.000E-04	2.1417E-07	2.1417E-07	2.1199E-07
20070710	1200	1.000E-04	2.1529E-07	2.1529E-07	2.1366E-07
20070711	1200	1.000E-04	2.1639E-07	2.1640E-07	2.1532E-07
20070712	1200	1.000E-04	2.1749E-07	2.1749E-07	2.1699E-07
20070713	1200	1.000E-04	2.1857E-07	2.1857E-07	2.1866E-07
20070714	1200	1.000E-04	2.1964E-07	2.1964E-07	2.2033E-07
20070715	1200	1.000E-04	2.2069E-07	2.2069E-07	2.2200E-07
20070716	1200	1.000E-04	2.2173E-07	2.2173E-07	2.2367E-07
20070717	1200	1.000E-04	2.2275E-07	2.2275E-07	2.2533E-07
20070718	1200	1.000E-04	2.2376E-07	2.2376E-07	2.2699E-07
20070719	1200	1.000E-04	2.2475E-07	2.2475E-07	2.2865E-07
20070720	1200	1.000E-04	2.2573E-07	2.2573E-07	2.3030E-07
20070721	1200	1.000E-04	2.2669E-07	2.2669E-07	2.3195E-07
20070722	1200	1.000E-04	2.2763E-07	2.2763E-07	2.3359E-07
20070723	1200	1.000E-04	2.2856E-07	2.2856E-07	2.3522E-07
20070724	1200	1.000E-04	2.2947E-07	2.2947E-07	2.3685E-07
20070725	1200	1.000E-04	2.3035E-07	2.3035E-07	2.3847E-07
20070726	1200	1.000E-04	2.3122E-07	2.3122E-07	2.4008E-07
20070727	1200	1.000E-04	2.3207E-07	2.3207E-07	2.4168E-07
20070728	1200	1.000E-04	2.3290E-07	2.3290E-07	2.4327E-07
20070729	1200	1.000E-04	2.3371E-07	2.3371E-07	2.4484E-07
20070730	1200	1.000E-04	2.3450E-07	2.3450E-07	2.4641E-07
20070731	1200	1.000E-04	2.3526E-07	2.3526E-07	2.4796E-07

Lee Creek near Magna, Utah

```
#############################################################################
#
#  LOADEST Calibration File
#
#  Lee Creek (2007 data thru 6/2007)
#
#
#  Total Se (dissolved + particulate)
#
#############################################################################
#
#CDATE      CTIME    CFLOW     CCONC
#
#############################################################################
20060512     1015     32.40     1.28
20060606     1445     69.00     1.46
20060712     1330     52.00     1.66
20060810     0900     52.00     1.64
20060905     0930     79.00     1.51
20060915     1245     68.00     1.64
20061012     1350    120.00      1.42
20061115     1030     87.00     1.61
20061221     1215     53.00     2.30
20070201     0920      52       2.47
20070306     1510      60       1.62
20070418     1210      55       1.89
20070516     1230      82       1.72
20070618     1315      63       1.96
```

```
################################################################################
#
#  LOADEST Estimation File
#
#  Lee Creek
#
#
#
################################################################################
#
#  Number of observations per day, NOBSPD (col. 1-5)
#
################################################################################
1
################################################################################
#
# EDATE    ETIME   EFLOW
#
################################################################################
20060518    1200    67
20060519    1200    66
20060520    1200    79
20060521    1200    71
20060522    1200    74
20060523    1200    58
20060524    1200    59
20060525    1200    52
20060526    1200    65
20060527    1200    80
20060528    1200    83
20060529    1200    97
20060530    1200    84
20060531    1200    78
20060601    1200    64
20060602    1200    73
20060603    1200    68
20060604    1200    59
20060605    1200    70
20060606    1200    69
20060607    1200    78
20060608    1200    87
20060609    1200    96
20060610    1200    82
20060611    1200    88
20060612    1200    64
20060613    1200    58
20060614    1200    51
20060615    1200    45
20060616    1200    66
20060617    1200    69
20060618    1200    59
20060619    1200    56
20060620    1200    52
20060621    1200    48
20060622    1200    43
20060623    1200    51
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20060624	1200	44
20060625	1200	42
20060626	1200	44
20060627	1200	41
20060628	1200	46
20060629	1200	45
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20060701	1200	49
20060702	1200	46
20060703	1200	55
20060704	1200	46
20060705	1200	61
20060706	1200	49
20060707	1200	39
20060708	1200	38
20060709	1200	52
20060710	1200	47
20060711	1200	49
20060712	1200	52
20060713	1200	51
20060714	1200	56
20060715	1200	51
20060716	1200	54
20060717	1200	46
20060718	1200	44
20060719	1200	43
20060720	1200	36
20060721	1200	36
20060722	1200	38
20060723	1200	41
20060724	1200	44
20060725	1200	47
20060726	1200	50
20060727	1200	53
20060728	1200	56
20060729	1200	59
20060730	1200	62
20060731	1200	65
20060801	1200	68
20060802	1200	71
20060803	1200	74
20060804	1200	73
20060805	1200	70
20060806	1200	68
20060807	1200	62
20060808	1200	52
20060809	1200	42
20060810	1200	52
20060811	1200	60
20060812	1200	60
20060813	1200	56
20060814	1200	61
20060815	1200	50
20060816	1200	51
20060817	1200	48
20060818	1200	61

20060819	1200	60
20060820	1200	66
20060821	1200	68
20060822	1200	66
20060823	1200	66
20060824	1200	70
20060825	1200	77
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20060827	1200	64
20060828	1200	65
20060829	1200	58
20060830	1200	60
20060831	1200	61
20060901	1200	78
20060902	1200	92
20060903	1200	94
20060904	1200	80
20060905	1200	79
20060906	1200	62
20060907	1200	63
20060908	1200	83
20060909	1200	76
20060910	1200	72
20060911	1200	75
20060912	1200	66
20060913	1200	70
20060914	1200	55
20060915	1200	68
20060916	1200	82
20060917	1200	95
20060918	1200	95
20060919	1200	83
20060920	1200	83
20060921	1200	83
20060922	1200	61
20060923	1200	80
20060924	1200	78
20060925	1200	92
20060926	1200	105
20060927	1200	96
20060928	1200	86
20060929	1200	83
20060930	1200	117
20061001	1200	98
20061002	1200	70
20061003	1200	79
20061004	1200	92
20061005	1200	78
20061006	1200	74
20061007	1200	99
20061008	1200	90
20061009	1200	101
20061010	1200	120
20061011	1200	103
20061012	1200	120
20061013	1200	124

20061014	1200	112
20061015	1200	81
20061016	1200	69
20061017	1200	57
20061018	1200	48
20061019	1200	47
20061020	1200	51
20061021	1200	57
20061022	1200	73
20061023	1200	73
20061024	1200	55
20061025	1200	42
20061026	1200	28
20061027	1200	36
20061028	1200	63
20061029	1200	54
20061030	1200	56
20061031	1200	51
20061101	1200	47
20061102	1200	49
20061103	1200	50
20061104	1200	51
20061105	1200	48
20061106	1200	49
20061107	1200	52
20061108	1200	52
20061109	1200	58
20061110	1200	60
20061111	1200	56
20061112	1200	62
20061113	1200	63
20061114	1200	75
20061115	1200	87
20061116	1200	61
20061117	1200	59
20061118	1200	58
20061119	1200	58
20061120	1200	55
20061121	1200	53
20061122	1200	50
20061123	1200	51
20061124	1200	52
20061125	1200	55
20061126	1200	56
20061127	1200	58
20061128	1200	61
20061129	1200	56
20061130	1200	62
20061201	1200	52
20061202	1200	63
20061203	1200	52
20061204	1200	46
20061205	1200	46
20061206	1200	46
20061207	1200	46
20061208	1200	47

20061209	1200	49
20061210	1200	50
20061211	1200	60
20061212	1200	54
20061213	1200	53
20061214	1200	58
20061215	1200	50
20061216	1200	60
20061217	1200	58
20061218	1200	60
20061219	1200	55
20061220	1200	53
20061221	1200	53
20061222	1200	51
20061223	1200	53
20061224	1200	54
20061225	1200	52
20061226	1200	52
20061227	1200	55
20061228	1200	59
20061229	1200	59
20061230	1200	57
20061231	1200	53
20070101	1200	56
20070102	1200	56
20070103	1200	55
20070104	1200	57
20070105	1200	58
20070106	1200	57
20070107	1200	57
20070108	1200	57
20070109	1200	56
20070110	1200	55
20070111	1200	57
20070112	1200	58
20070113	1200	58
20070114	1200	58
20070115	1200	56
20070116	1200	54
20070117	1200	52
20070118	1200	52
20070119	1200	53
20070120	1200	54
20070121	1200	56
20070122	1200	55
20070123	1200	54
20070124	1200	50
20070125	1200	51
20070126	1200	50
20070127	1200	50
20070128	1200	51
20070129	1200	51
20070130	1200	52
20070131	1200	54
20070201	1200	52
20070202	1200	50

20070203	1200	49
20070204	1200	54
20070205	1200	55
20070206	1200	55
20070207	1200	56
20070208	1200	58
20070209	1200	58
20070210	1200	65
20070211	1200	61
20070212	1200	56
20070213	1200	60
20070214	1200	60
20070215	1200	58
20070216	1200	57
20070217	1200	57
20070218	1200	56
20070219	1200	65
20070220	1200	66
20070221	1200	58
20070222	1200	53
20070223	1200	57
20070224	1200	74
20070225	1200	62
20070226	1200	64
20070227	1200	67
20070228	1200	64
20070301	1200	56
20070302	1200	57
20070303	1200	60
20070304	1200	60
20070305	1200	59
20070306	1200	60
20070307	1200	60
20070308	1200	60
20070309	1200	59
20070310	1200	57
20070311	1200	55
20070312	1200	55
20070313	1200	54
20070314	1200	53
20070315	1200	52
20070316	1200	50
20070317	1200	51
20070318	1200	52
20070319	1200	51
20070320	1200	52
20070321	1200	61
20070322	1200	63
20070323	1200	57
20070324	1200	61
20070325	1200	65
20070326	1200	66
20070327	1200	63
20070328	1200	93
20070329	1200	116
20070330	1200	81

20070331	1200	69
20070401	1200	60
20070402	1200	57
20070403	1200	55
20070404	1200	55
20070405	1200	50
20070406	1200	44
20070407	1200	43
20070408	1200	45
20070409	1200	44
20070410	1200	35
20070411	1200	41
20070412	1200	36
20070413	1200	37
20070414	1200	34
20070415	1200	33
20070416	1200	37
20070417	1200	41
20070418	1200	55
20070419	1200	62
20070420	1200	53
20070421	1200	55
20070422	1200	61
20070423	1200	58
20070424	1200	78
20070425	1200	60
20070426	1200	70
20070427	1200	64
20070428	1200	67
20070429	1200	66
20070430	1200	71
20070501	1200	67
20070502	1200	52
20070503	1200	70
20070504	1200	66
20070505	1200	74
20070506	1200	64
20070507	1200	73
20070508	1200	72
20070509	1200	84
20070510	1200	78
20070511	1200	85
20070512	1200	82
20070513	1200	72
20070514	1200	77
20070515	1200	70
20070516	1200	82
20070517	1200	77
20070518	1200	78
20070519	1200	78
20070520	1200	68
20070521	1200	68
20070522	1200	69
20070523	1200	82
20070524	1200	75
20070525	1200	75

20070526	1200	76
20070527	1200	71
20070528	1200	64
20070529	1200	61
20070530	1200	54
20070531	1200	57
20070601	1200	61
20070602	1200	63
20070603	1200	67
20070604	1200	63
20070605	1200	62
20070606	1200	62
20070607	1200	74
20070608	1200	74
20070609	1200	71
20070610	1200	71
20070611	1200	66
20070612	1200	62
20070613	1200	64
20070614	1200	61
20070615	1200	60
20070616	1200	60
20070617	1200	60
20070618	1200	63
20070619	1200	55
20070620	1200	60
20070621	1200	52
20070622	1200	55
20070623	1200	54
20070624	1200	62
20070625	1200	64
20070626	1200	59
20070627	1200	62
20070628	1200	56
20070629	1200	54
20070630	1200	50
20070701	1200	57
20070702	1200	59
20070703	1200	56
20070704	1200	59
20070705	1200	53
20070706	1200	57
20070707	1200	55
20070708	1200	56
20070709	1200	57
20070710	1200	56
20070711	1200	54
20070712	1200	51
20070713	1200	58
20070714	1200	57
20070715	1200	55
20070716	1200	58
20070717	1200	56
20070718	1200	65
20070719	1200	60
20070720	1200	63

20070721	1200	59
20070722	1200	61
20070723	1200	62
20070724	1200	57
20070725	1200	58
20070726	1200	54
20070727	1200	66
20070728	1200	64
20070729	1200	68
20070730	1200	66
20070731	1200	60

LOADEST
A Program to Estimate Constituent Loads
U.S. Geological Survey, Version: MOD36 (Sep 2004)

Lee Creek

Constituent: selenium

Constituent Output File Part Ia: Calibration (Load Regression)

Number of Observations : 14
Number of Uncensored Observations: 14
"center" of Decimal Time : 2006.914
"center" of Ln(Q) : 4.1459
Period of record : 2006-2007

Model Evaluation Criteria Based on AMLE Results

Model #	AIC	SPPC
1	-0.392	2.105
2	-0.611	3.318
3	-0.809	4.705
4	-0.396	1.492
5	-0.854	4.700
6	-0.789	3.924
7	-0.906	4.743
8	-1.079	5.637
9	-0.883	3.944

Model # 8 selected

Selected Model:

Ln(Load) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)
+ a5 dtime

where:
Load = constituent load [kg/d]
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Model Coefficients

	a0	a1	a2	a3	a4	a5
AMLE	-1.2665	0.7324	-0.4506	-0.0047	0.1184	0.2907

MLE	-1.2665	0.7324	-0.4506	-0.0047	0.1184	0.2907
LAD	-1.3029	0.8064	-0.5929	-0.0079	0.0444	0.2489

AMLE Regression Statistics

R-Squared [%] : 92.89
Prob. Plot Corr. Coeff. (PPCC) : 0.9730
Serial Correlation of Residuals: -.2987

Coeff.	Std.Dev.	t-ratio	P Value
a0	0.0382	-33.13	9.829E-17
a1	0.1409	5.20	5.443E-06
a2	0.2410	-1.87	2.427E-02
a3	0.0653	-0.07	9.241E-01
a4	0.0471	2.51	4.306E-03
a5	0.1310	2.22	9.565E-03

Correlation Between Explanatory Variables

Explanatory variable corresponding to:

	a1	a2	a3	a4
a2	0.0000			
a3	-0.3846	-0.0712		
a4	0.3787	0.0642	-0.0790	
a5	0.2100	-0.3832	0.4811	-0.0030

Additional Regression Statistics

	Residual Variance	Turnbull-Weiss Stat	DF	PL
AMLE	0.013	5.29	1	2.144E-02
MLE	0.013	5.29	1	2.144E-02

Constituent Output File Part Ib: Calibration (Concentration Regression)

AMLE Regression Statistics

Model # 8 was selected for the load regression (PART Ia) and is used here:

Ln(Conc) = a0 + a1 LnQ + a2 LnQ^2 + a3 Sin(2 pi dtime) + a4 Cos(2 pi dtime)

+ a5 dtime

where:
Conc = constituent concentration
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Concentration Regression Results

R-Squared [%] : 75.37
Residual Variance : 0.0130

Coeff.	Value	Std.Dev.	t-ratio	P Value
a0	0.6007	0.0382	15.71	3.365E-12
a1	-0.2676	0.1409	-1.90	2.243E-02
a2	-0.4506	0.2410	-1.87	2.427E-02
a3	-0.0047	0.0653	-0.07	9.241E-01
a4	0.1184	0.0471	2.51	4.306E-03
a5	0.2907	0.1310	2.22	9.565E-03

Constituent Output File Part IIa: Estimation (test for extrapolation)

Load Estimates for 20060518-20070731

Streamflow Summary Statistics [cfs]

Data	Mean	Minimum	10th Pct	25th Pct	Median	75th Pct	90th Pct	Maximum
Cal.	66.	32.	42.	52.	62.	80.	104.	120.
Est.	61.	28.	47.	53.	58.	67.	80.	124.

WARNING: The maximum estimation data set steamflow exceeds the maximum calibration data set streamflow. Load estimates require extrapolation.

Maximum Estimation Streamflow : 1.2400E+02
Maximum Calibration Streamflow: 1.2000E+02

Constituent Output File Part IIb: Estimation (Load Estimates)

Load Estimates for 20060518-20070731

Load Estimates [KG/DAY]

AMLE Load Estimates

N	Mean Load	95% Conf.Intervals Lower	95% Conf.Intervals Upper	Std Error Prediction	Standard Error

Est. Period	440	0.27	0.25	0.29	0.01	0.01

MLE Load Estimates

	N	Mean Load	Standard Error
Est. Period	440	0.27	0.01

LAD Load Estimates

	N	Mean Load	Standard Error
Est. Period	440	0.27	0.02

Summary Statistics - Estimated Loads [KG/DAY]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.12	0.25	0.28	0.30	0.33	0.34	0.39	0.39
MLE	0.12	0.25	0.28	0.30	0.33	0.34	0.39	0.39
LAD	0.10	0.25	0.27	0.30	0.34	0.35	0.37	0.39

Summary Statistics - Estimated Concentrations [UG/L]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	1.	2.	2.	2.	2.	2.	2.	2.
MLE	1.	2.	2.	2.	2.	2.	2.	2.
LAD	1.	2.	2.	2.	2.	2.	2.	2.

Lee Creek gage

Loads Estimated by:

Date	Time	Flow	AMLE	MLE	LAD
20060518	1200	6.700E+01	2.2369E-01	2.2369E-01	2.4755E-01
20060519	1200	6.600E+01	2.2154E-01	2.2154E-01	2.4495E-01
20060520	1200	7.900E+01	2.4707E-01	2.4707E-01	2.7539E-01
20060521	1200	7.100E+01	2.3261E-01	2.3261E-01	2.5835E-01
20060522	1200	7.400E+01	2.3861E-01	2.3861E-01	2.6550E-01
20060523	1200	5.800E+01	2.0179E-01	2.0179E-01	2.2061E-01
20060524	1200	5.900E+01	2.0468E-01	2.0468E-01	2.2418E-01
20060525	1200	5.200E+01	1.8416E-01	1.8416E-01	1.9867E-01
20060526	1200	6.500E+01	2.2025E-01	2.2025E-01	2.4329E-01
20060527	1200	8.000E+01	2.4994E-01	2.4994E-01	2.7863E-01
20060528	1200	8.300E+01	2.5476E-01	2.5476E-01	2.8407E-01
20060529	1200	9.700E+01	2.7167E-01	2.7167E-01	3.0212E-01
20060530	1200	8.400E+01	2.5667E-01	2.5667E-01	2.8614E-01
20060531	1200	7.800E+01	2.4755E-01	2.4755E-01	2.7570E-01
20060601	1200	6.400E+01	2.1902E-01	2.1902E-01	2.4150E-01
20060602	1200	7.300E+01	2.3894E-01	2.3894E-01	2.6547E-01
20060603	1200	6.800E+01	2.2878E-01	2.2878E-01	2.5323E-01
20060604	1200	5.900E+01	2.0670E-01	2.0670E-01	2.2613E-01
20060605	1200	7.000E+01	2.3362E-01	2.3362E-01	2.5888E-01
20060606	1200	6.900E+01	2.3175E-01	2.3175E-01	2.5654E-01
20060607	1200	7.800E+01	2.4945E-01	2.4945E-01	2.7735E-01
20060608	1200	8.700E+01	2.6337E-01	2.6337E-01	2.9291E-01
20060609	1200	9.600E+01	2.7403E-01	2.7403E-01	3.0401E-01
20060610	1200	8.200E+01	2.5691E-01	2.5691E-01	2.8554E-01
20060611	1200	8.800E+01	2.6571E-01	2.6571E-01	2.9515E-01
20060612	1200	6.400E+01	2.2186E-01	2.2186E-01	2.4388E-01
20060613	1200	5.800E+01	2.0618E-01	2.0618E-01	2.2454E-01
20060614	1200	5.100E+01	1.8481E-01	1.8481E-01	1.9804E-01
20060615	1200	4.500E+01	1.6372E-01	1.6372E-01	1.7200E-01
20060616	1200	6.600E+01	2.2799E-01	2.2799E-01	2.5074E-01
20060617	1200	6.900E+01	2.3521E-01	2.3521E-01	2.5925E-01
20060618	1200	5.900E+01	2.1053E-01	2.1053E-01	2.2916E-01
20060619	1200	5.600E+01	2.0211E-01	2.0211E-01	2.1867E-01
20060620	1200	5.200E+01	1.8979E-01	1.8979E-01	2.0336E-01
20060621	1200	4.800E+01	1.7630E-01	1.7630E-01	1.8665E-01
20060622	1200	4.300E+01	1.5766E-01	1.5766E-01	1.6380E-01
20060623	1200	5.100E+01	1.8737E-01	1.8737E-01	1.9991E-01
20060624	1200	4.400E+01	1.6212E-01	1.6212E-01	1.6894E-01
20060625	1200	4.200E+01	1.5441E-01	1.5441E-01	1.5948E-01
20060626	1200	4.400E+01	1.6268E-01	1.6268E-01	1.6932E-01
20060627	1200	4.100E+01	1.5082E-01	1.5082E-01	1.5489E-01
20060628	1200	4.600E+01	1.7098E-01	1.7098E-01	1.7907E-01
20060629	1200	4.500E+01	1.6746E-01	1.6746E-01	1.7463E-01
20060630	1200	4.700E+01	1.7538E-01	1.7538E-01	1.8406E-01
20060701	1200	4.900E+01	1.8303E-01	1.8303E-01	1.9318E-01
20060702	1200	4.600E+01	1.7226E-01	1.7226E-01	1.7991E-01
20060703	1200	5.500E+01	2.0405E-01	2.0405E-01	2.1834E-01
20060704	1200	4.600E+01	1.7293E-01	1.7293E-01	1.8034E-01
20060705	1200	6.100E+01	2.2273E-01	2.2273E-01	2.4047E-01
20060706	1200	4.900E+01	1.8484E-01	1.8484E-01	1.9435E-01
20060707	1200	3.900E+01	1.4505E-01	1.4505E-01	1.4652E-01
20060708	1200	3.800E+01	1.4090E-01	1.4090E-01	1.4149E-01
20060709	1200	5.200E+01	1.9661E-01	1.9661E-01	2.0791E-01
20060710	1200	4.700E+01	1.7891E-01	1.7891E-01	1.8632E-01
20060711	1200	4.900E+01	1.8679E-01	1.8679E-01	1.9557E-01
20060712	1200	5.200E+01	1.9789E-01	1.9789E-01	2.0871E-01
20060713	1200	5.100E+01	1.9483E-01	1.9483E-01	2.0476E-01

20060714	1200	5.600E+01	2.1207E-01	2.1207E-01	2.2523E-01
20060715	1200	5.100E+01	1.9570E-01	1.9570E-01	2.0530E-01
20060716	1200	5.400E+01	2.0650E-01	2.0650E-01	2.1799E-01
20060717	1200	4.600E+01	1.7779E-01	1.7779E-01	1.8335E-01
20060718	1200	4.400E+01	1.7011E-01	1.7011E-01	1.7399E-01
20060719	1200	4.300E+01	1.6633E-01	1.6634E-01	1.6929E-01
20060720	1200	3.600E+01	1.3526E-01	1.3526E-01	1.3294E-01
20060721	1200	3.600E+01	1.3557E-01	1.3557E-01	1.3312E-01
20060722	1200	3.800E+01	1.4531E-01	1.4531E-01	1.4410E-01
20060723	1200	4.100E+01	1.5925E-01	1.5925E-01	1.6006E-01
20060724	1200	4.400E+01	1.7255E-01	1.7255E-01	1.7541E-01
20060725	1200	4.700E+01	1.8520E-01	1.8520E-01	1.9007E-01
20060726	1200	5.000E+01	1.9720E-01	1.9720E-01	2.0399E-01
20060727	1200	5.300E+01	2.0857E-01	2.0857E-01	2.1715E-01
20060728	1200	5.600E+01	2.1932E-01	2.1932E-01	2.2953E-01
20060729	1200	5.900E+01	2.2947E-01	2.2947E-01	2.4114E-01
20060730	1200	6.200E+01	2.3904E-01	2.3904E-01	2.5197E-01
20060731	1200	6.500E+01	2.4804E-01	2.4804E-01	2.6206E-01
20060801	1200	6.800E+01	2.5651E-01	2.5651E-01	2.7141E-01
20060802	1200	7.100E+01	2.6446E-01	2.6446E-01	2.8005E-01
20060803	1200	7.400E+01	2.7191E-01	2.7191E-01	2.8802E-01
20060804	1200	7.300E+01	2.7044E-01	2.7044E-01	2.8598E-01
20060805	1200	7.000E+01	2.6420E-01	2.6420E-01	2.7857E-01
20060806	1200	6.800E+01	2.5994E-01	2.5994E-01	2.7335E-01
20060807	1200	6.200E+01	2.4414E-01	2.4414E-01	2.5486E-01
20060808	1200	5.200E+01	2.1153E-01	2.1153E-01	2.1660E-01
20060809	1200	4.200E+01	1.7086E-01	1.7086E-01	1.6918E-01
20060810	1200	5.200E+01	2.1268E-01	2.1268E-01	2.1723E-01
20060811	1200	6.000E+01	2.4070E-01	2.4070E-01	2.4930E-01
20060812	1200	6.000E+01	2.4136E-01	2.4136E-01	2.4967E-01
20060813	1200	5.600E+01	2.2884E-01	2.2884E-01	2.3484E-01
20060814	1200	6.100E+01	2.4581E-01	2.4581E-01	2.5397E-01
20060815	1200	5.000E+01	2.0788E-01	2.0788E-01	2.0990E-01
20060816	1200	5.100E+01	2.1237E-01	2.1237E-01	2.1471E-01
20060817	1200	4.800E+01	2.0092E-01	2.0092E-01	2.0120E-01
20060818	1200	6.100E+01	2.4856E-01	2.4856E-01	2.5545E-01
20060819	1200	6.000E+01	2.4609E-01	2.4609E-01	2.5222E-01
20060820	1200	6.600E+01	2.6475E-01	2.6475E-01	2.7289E-01
20060821	1200	6.800E+01	2.7095E-01	2.7095E-01	2.7936E-01
20060822	1200	6.600E+01	2.6625E-01	2.6625E-01	2.7369E-01
20060823	1200	6.600E+01	2.6700E-01	2.6700E-01	2.7409E-01
20060824	1200	7.000E+01	2.7849E-01	2.7849E-01	2.8636E-01
20060825	1200	7.700E+01	2.9565E-01	2.9565E-01	3.0447E-01
20060826	1200	6.500E+01	2.6640E-01	2.6640E-01	2.7210E-01
20060827	1200	6.400E+01	2.6421E-01	2.6421E-01	2.6921E-01
20060828	1200	6.500E+01	2.6791E-01	2.6791E-01	2.7289E-01
20060829	1200	5.800E+01	2.4636E-01	2.4636E-01	2.4834E-01
20060830	1200	6.000E+01	2.5382E-01	2.5382E-01	2.5629E-01
20060831	1200	6.100E+01	2.5782E-01	2.5782E-01	2.6033E-01
20060901	1200	7.800E+01	3.0372E-01	3.0372E-01	3.0982E-01
20060902	1200	9.200E+01	3.2896E-01	3.2896E-01	3.3466E-01
20060903	1200	9.400E+01	3.3259E-01	3.3260E-01	3.3766E-01
20060904	1200	8.000E+01	3.1046E-01	3.1046E-01	3.1546E-01
20060905	1200	7.900E+01	3.0928E-01	3.0928E-01	3.1380E-01
20060906	1200	6.200E+01	2.6547E-01	2.6547E-01	2.6619E-01
20060907	1200	6.300E+01	2.6940E-01	2.6940E-01	2.7009E-01
20060908	1200	8.300E+01	3.1984E-01	3.1984E-01	3.2321E-01
20060909	1200	7.600E+01	3.0620E-01	3.0620E-01	3.0877E-01
20060910	1200	7.200E+01	2.9738E-01	2.9738E-01	2.9903E-01
20060911	1200	7.500E+01	3.0558E-01	3.0558E-01	3.0721E-01
20060912	1200	6.600E+01	2.8244E-01	2.8244E-01	2.8208E-01
20060913	1200	7.000E+01	2.9459E-01	2.9459E-01	2.9469E-01
20060914	1200	5.500E+01	2.4638E-01	2.4638E-01	2.4171E-01
20060915	1200	6.800E+01	2.9064E-01	2.9064E-01	2.8956E-01

20060916	1200	8.200E+01	3.2507E-01	3.2507E-01	3.2492E-01
20060917	1200	9.500E+01	3.4718E-01	3.4718E-01	3.4559E-01
20060918	1200	9.500E+01	3.4812E-01	3.4812E-01	3.4607E-01
20060919	1200	8.300E+01	3.2968E-01	3.2968E-01	3.2820E-01
20060920	1200	8.300E+01	3.3057E-01	3.3057E-01	3.2865E-01
20060921	1200	8.300E+01	3.3146E-01	3.3146E-01	3.2909E-01
20060922	1200	6.100E+01	2.7393E-01	2.7393E-01	2.6849E-01
20060923	1200	8.000E+01	3.2710E-01	3.2710E-01	3.2391E-01
20060924	1200	7.800E+01	3.2358E-01	3.2358E-01	3.1992E-01
20060925	1200	9.200E+01	3.5044E-01	3.5044E-01	3.4553E-01
20060926	1200	1.050E+02	3.6685E-01	3.6685E-01	3.5914E-01
20060927	1200	9.600E+01	3.5785E-01	3.5785E-01	3.5142E-01
20060928	1200	8.600E+01	3.4326E-01	3.4326E-01	3.3764E-01
20060929	1200	8.300E+01	3.3844E-01	3.3844E-01	3.3258E-01
20060930	1200	1.170E+02	3.7910E-01	3.7910E-01	3.6650E-01
20061001	1200	9.800E+01	3.6404E-01	3.6404E-01	3.5541E-01
20061002	1200	7.000E+01	3.0972E-01	3.0972E-01	3.0226E-01
20061003	1200	7.900E+01	3.3335E-01	3.3335E-01	3.2593E-01
20061004	1200	9.200E+01	3.5851E-01	3.5851E-01	3.4954E-01
20061005	1200	7.800E+01	3.3270E-01	3.3270E-01	3.2447E-01
20061006	1200	7.400E+01	3.2367E-01	3.2367E-01	3.1497E-01
20061007	1200	9.900E+01	3.7064E-01	3.7064E-01	3.5909E-01
20061008	1200	9.000E+01	3.5880E-01	3.5880E-01	3.4838E-01
20061009	1200	1.010E+02	3.7471E-01	3.7471E-01	3.6184E-01
20061010	1200	1.200E+02	3.8978E-01	3.8978E-01	3.7162E-01
20061011	1200	1.030E+02	3.7860E-01	3.7860E-01	3.6440E-01
20061012	1200	1.200E+02	3.9157E-01	3.9157E-01	3.7249E-01
20061013	1200	1.240E+02	3.9389E-01	3.9389E-01	3.7324E-01
20061014	1200	1.120E+02	3.8891E-01	3.8891E-01	3.7113E-01
20061015	1200	8.100E+01	3.4730E-01	3.4730E-01	3.3501E-01
20061016	1200	6.900E+01	3.1700E-01	3.1700E-01	3.0430E-01
20061017	1200	5.700E+01	2.7562E-01	2.7563E-01	2.6071E-01
20061018	1200	4.800E+01	2.3621E-01	2.3621E-01	2.1865E-01
20061019	1200	4.700E+01	2.3177E-01	2.3177E-01	2.1368E-01
20061020	1200	5.100E+01	2.5144E-01	2.5144E-01	2.3419E-01
20061021	1200	5.700E+01	2.7793E-01	2.7793E-01	2.6185E-01
20061022	1200	7.300E+01	3.3259E-01	3.3259E-01	3.1805E-01
20061023	1200	7.300E+01	3.3325E-01	3.3325E-01	3.1838E-01
20061024	1200	5.500E+01	2.7126E-01	2.7126E-01	2.5392E-01
20061025	1200	4.200E+01	2.0809E-01	2.0809E-01	1.8738E-01
20061026	1200	2.800E+01	1.2154E-01	1.2154E-01	1.0083E-01
20061027	1200	3.600E+01	1.7367E-01	1.7367E-01	1.5174E-01
20061028	1200	6.300E+01	3.0473E-01	3.0473E-01	2.8769E-01
20061029	1200	5.400E+01	2.6947E-01	2.6947E-01	2.5063E-01
20061030	1200	5.600E+01	2.7856E-01	2.7856E-01	2.5989E-01
20061031	1200	5.100E+01	2.5676E-01	2.5676E-01	2.3680E-01
20061101	1200	4.700E+01	2.3758E-01	2.3758E-01	2.1651E-01
20061102	1200	4.900E+01	2.4801E-01	2.4801E-01	2.2718E-01
20061103	1200	5.000E+01	2.5330E-01	2.5330E-01	2.3247E-01
20061104	1200	5.100E+01	2.5849E-01	2.5850E-01	2.3767E-01
20061105	1200	4.800E+01	2.4424E-01	2.4424E-01	2.2259E-01
20061106	1200	4.900E+01	2.4962E-01	2.4962E-01	2.2799E-01
20061107	1200	5.200E+01	2.6442E-01	2.6442E-01	2.4320E-01
20061108	1200	5.200E+01	2.6481E-01	2.6481E-01	2.4340E-01
20061109	1200	5.800E+01	2.9146E-01	2.9146E-01	2.7090E-01
20061110	1200	6.000E+01	2.9988E-01	2.9988E-01	2.7940E-01
20061111	1200	5.600E+01	2.8389E-01	2.8389E-01	2.6264E-01
20061112	1200	6.200E+01	3.0838E-01	3.0838E-01	2.8774E-01
20061113	1200	6.300E+01	3.1249E-01	3.1249E-01	2.9177E-01
20061114	1200	7.500E+01	3.5098E-01	3.5098E-01	3.3025E-01
20061115	1200	8.700E+01	3.7910E-01	3.7910E-01	3.5674E-01
20061116	1200	6.100E+01	3.0615E-01	3.0615E-01	2.8471E-01
20061117	1200	5.900E+01	2.9862E-01	2.9862E-01	2.7680E-01
20061118	1200	5.800E+01	2.9488E-01	2.9488E-01	2.7278E-01

20061119	1200	5.800E+01	2.9521E-01	2.9521E-01	2.7297E-01
20061120	1200	5.500E+01	2.8267E-01	2.8267E-01	2.5986E-01
20061121	1200	5.300E+01	2.7390E-01	2.7390E-01	2.5065E-01
20061122	1200	5.000E+01	2.5982E-01	2.5982E-01	2.3594E-01
20061123	1200	5.100E+01	2.6497E-01	2.6497E-01	2.4116E-01
20061124	1200	5.200E+01	2.7002E-01	2.7002E-01	2.4628E-01
20061125	1200	5.500E+01	2.8407E-01	2.8407E-01	2.6071E-01
20061126	1200	5.600E+01	2.8873E-01	2.8873E-01	2.6542E-01
20061127	1200	5.800E+01	2.9751E-01	2.9751E-01	2.7437E-01
20061128	1200	6.100E+01	3.0985E-01	3.0985E-01	2.8695E-01
20061129	1200	5.600E+01	2.8944E-01	2.8944E-01	2.6588E-01
20061130	1200	6.200E+01	3.1417E-01	3.1417E-01	2.9122E-01
20061201	1200	5.200E+01	2.7158E-01	2.7158E-01	2.4728E-01
20061202	1200	6.300E+01	3.1837E-01	3.1837E-01	2.9537E-01
20061203	1200	5.200E+01	2.7194E-01	2.7194E-01	2.4754E-01
20061204	1200	4.600E+01	2.4157E-01	2.4157E-01	2.1616E-01
20061205	1200	4.600E+01	2.4171E-01	2.4171E-01	2.1626E-01
20061206	1200	4.600E+01	2.4184E-01	2.4184E-01	2.1636E-01
20061207	1200	4.600E+01	2.4197E-01	2.4197E-01	2.1646E-01
20061208	1200	4.700E+01	2.4744E-01	2.4744E-01	2.2208E-01
20061209	1200	4.900E+01	2.5796E-01	2.5796E-01	2.3291E-01
20061210	1200	5.000E+01	2.6311E-01	2.6312E-01	2.3823E-01
20061211	1200	6.000E+01	3.0816E-01	3.0816E-01	2.8472E-01
20061212	1200	5.400E+01	2.8248E-01	2.8248E-01	2.5825E-01
20061213	1200	5.300E+01	2.7792E-01	2.7792E-01	2.5355E-01
20061214	1200	5.800E+01	3.0021E-01	3.0021E-01	2.7660E-01
20061215	1200	5.000E+01	2.6351E-01	2.6351E-01	2.3869E-01
20061216	1200	6.000E+01	3.0855E-01	3.0855E-01	2.8525E-01
20061217	1200	5.800E+01	3.0038E-01	3.0038E-01	2.7689E-01
20061218	1200	6.000E+01	3.0864E-01	3.0864E-01	2.8544E-01
20061219	1200	5.500E+01	2.8740E-01	2.8740E-01	2.6359E-01
20061220	1200	5.300E+01	2.7823E-01	2.7823E-01	2.5415E-01
20061221	1200	5.300E+01	2.7824E-01	2.7824E-01	2.5422E-01
20061222	1200	5.100E+01	2.6865E-01	2.6865E-01	2.4435E-01
20061223	1200	5.300E+01	2.7823E-01	2.7823E-01	2.5436E-01
20061224	1200	5.400E+01	2.8286E-01	2.8286E-01	2.5924E-01
20061225	1200	5.200E+01	2.7344E-01	2.7344E-01	2.4956E-01
20061226	1200	5.200E+01	2.7341E-01	2.7341E-01	2.4962E-01
20061227	1200	5.500E+01	2.8728E-01	2.8728E-01	2.6414E-01
20061228	1200	5.900E+01	3.0440E-01	3.0440E-01	2.8200E-01
20061229	1200	5.900E+01	3.0433E-01	3.0433E-01	2.8206E-01
20061230	1200	5.700E+01	2.9586E-01	2.9586E-01	2.7342E-01
20061231	1200	5.300E+01	2.7784E-01	2.7784E-01	2.5481E-01
20070101	1200	5.600E+01	2.9135E-01	2.9135E-01	2.6901E-01
20070102	1200	5.600E+01	2.9125E-01	2.9125E-01	2.6905E-01
20070103	1200	5.500E+01	2.8671E-01	2.8671E-01	2.6448E-01
20070104	1200	5.700E+01	2.9535E-01	2.9535E-01	2.7364E-01
20070105	1200	5.800E+01	2.9945E-01	2.9945E-01	2.7808E-01
20070106	1200	5.700E+01	2.9509E-01	2.9509E-01	2.7371E-01
20070107	1200	5.700E+01	2.9494E-01	2.9494E-01	2.7374E-01
20070108	1200	5.700E+01	2.9479E-01	2.9479E-01	2.7377E-01
20070109	1200	5.600E+01	2.9032E-01	2.9032E-01	2.6928E-01
20070110	1200	5.500E+01	2.8574E-01	2.8574E-01	2.6469E-01
20070111	1200	5.700E+01	2.9429E-01	2.9429E-01	2.7384E-01
20070112	1200	5.800E+01	2.9832E-01	2.9832E-01	2.7827E-01
20070113	1200	5.800E+01	2.9813E-01	2.9813E-01	2.7829E-01
20070114	1200	5.800E+01	2.9793E-01	2.9793E-01	2.7830E-01
20070115	1200	5.600E+01	2.8922E-01	2.8922E-01	2.6939E-01
20070116	1200	5.400E+01	2.8014E-01	2.8014E-01	2.6006E-01
20070117	1200	5.200E+01	2.7066E-01	2.7066E-01	2.5029E-01
20070118	1200	5.200E+01	2.7046E-01	2.7046E-01	2.5030E-01
20070119	1200	5.300E+01	2.7492E-01	2.7492E-01	2.5524E-01
20070120	1200	5.400E+01	2.7928E-01	2.7928E-01	2.6008E-01
20070121	1200	5.600E+01	2.8789E-01	2.8789E-01	2.6943E-01

20070122	1200	5.500E+01	2.8328E-01	2.8328E-01	2.6481E-01
20070123	1200	5.400E+01	2.7857E-01	2.7857E-01	2.6008E-01
20070124	1200	5.000E+01	2.5950E-01	2.5950E-01	2.4010E-01
20070125	1200	5.100E+01	2.6412E-01	2.6412E-01	2.4525E-01
20070126	1200	5.000E+01	2.5903E-01	2.5903E-01	2.4009E-01
20070127	1200	5.000E+01	2.5878E-01	2.5879E-01	2.4009E-01
20070128	1200	5.100E+01	2.6338E-01	2.6338E-01	2.4523E-01
20070129	1200	5.100E+01	2.6312E-01	2.6312E-01	2.4522E-01
20070130	1200	5.200E+01	2.6759E-01	2.6759E-01	2.5025E-01
20070131	1200	5.400E+01	2.7646E-01	2.7646E-01	2.6001E-01
20070201	1200	5.200E+01	2.6704E-01	2.6704E-01	2.5022E-01
20070202	1200	5.000E+01	2.5724E-01	2.5724E-01	2.4002E-01
20070203	1200	4.900E+01	2.5206E-01	2.5206E-01	2.3475E-01
20070204	1200	5.400E+01	2.7530E-01	2.7530E-01	2.5994E-01
20070205	1200	5.500E+01	2.7941E-01	2.7941E-01	2.6465E-01
20070206	1200	5.500E+01	2.7910E-01	2.7910E-01	2.6463E-01
20070207	1200	5.600E+01	2.8308E-01	2.8308E-01	2.6923E-01
20070208	1200	5.800E+01	2.9106E-01	2.9106E-01	2.7812E-01
20070209	1200	5.800E+01	2.9073E-01	2.9073E-01	2.7810E-01
20070210	1200	6.500E+01	3.1651E-01	3.1651E-01	3.0601E-01
20070211	1200	6.100E+01	3.0177E-01	3.0177E-01	2.9063E-01
20070212	1200	5.600E+01	2.8147E-01	2.8147E-01	2.6911E-01
20070213	1200	6.000E+01	2.9726E-01	2.9726E-01	2.8649E-01
20070214	1200	6.000E+01	2.9691E-01	2.9691E-01	2.8647E-01
20070215	1200	5.800E+01	2.8870E-01	2.8870E-01	2.7795E-01
20070216	1200	5.700E+01	2.8430E-01	2.8430E-01	2.7352E-01
20070217	1200	5.700E+01	2.8395E-01	2.8395E-01	2.7349E-01
20070218	1200	5.600E+01	2.7947E-01	2.7947E-01	2.6896E-01
20070219	1200	6.500E+01	3.1313E-01	3.1313E-01	3.0575E-01
20070220	1200	6.600E+01	3.1609E-01	3.1609E-01	3.0931E-01
20070221	1200	5.800E+01	2.8661E-01	2.8661E-01	2.7779E-01
20070222	1200	5.300E+01	2.6518E-01	2.6518E-01	2.5471E-01
20070223	1200	5.700E+01	2.8189E-01	2.8189E-01	2.7334E-01
20070224	1200	7.400E+01	3.3833E-01	3.3833E-01	3.3446E-01
20070225	1200	6.200E+01	3.0037E-01	3.0037E-01	2.9424E-01
20070226	1200	6.400E+01	3.0705E-01	3.0705E-01	3.0187E-01
20070227	1200	6.700E+01	3.1661E-01	3.1661E-01	3.1260E-01
20070228	1200	6.400E+01	3.0629E-01	3.0629E-01	3.0182E-01
20070301	1200	5.600E+01	2.7572E-01	2.7572E-01	2.6869E-01
20070302	1200	5.700E+01	2.7946E-01	2.7947E-01	2.7317E-01
20070303	1200	6.000E+01	2.9081E-01	2.9081E-01	2.8602E-01
20070304	1200	6.000E+01	2.9045E-01	2.9045E-01	2.8600E-01
20070305	1200	5.900E+01	2.8630E-01	2.8630E-01	2.8179E-01
20070306	1200	6.000E+01	2.8974E-01	2.8974E-01	2.8596E-01
20070307	1200	6.000E+01	2.8939E-01	2.8939E-01	2.8594E-01
20070308	1200	6.000E+01	2.8904E-01	2.8904E-01	2.8592E-01
20070309	1200	5.900E+01	2.8491E-01	2.8491E-01	2.8172E-01
20070310	1200	5.700E+01	2.7676E-01	2.7676E-01	2.7302E-01
20070311	1200	5.500E+01	2.6827E-01	2.6827E-01	2.6390E-01
20070312	1200	5.500E+01	2.6795E-01	2.6795E-01	2.6389E-01
20070313	1200	5.400E+01	2.6342E-01	2.6342E-01	2.5917E-01
20070314	1200	5.300E+01	2.5881E-01	2.5881E-01	2.5434E-01
20070315	1200	5.200E+01	2.5412E-01	2.5412E-01	2.4941E-01
20070316	1200	5.000E+01	2.4477E-01	2.4477E-01	2.3924E-01
20070317	1200	5.100E+01	2.4907E-01	2.4907E-01	2.4437E-01
20070318	1200	5.200E+01	2.5325E-01	2.5325E-01	2.4940E-01
20070319	1200	5.100E+01	2.4850E-01	2.4851E-01	2.4437E-01
20070320	1200	5.200E+01	2.5269E-01	2.5269E-01	2.4939E-01
20070321	1200	6.100E+01	2.8837E-01	2.8837E-01	2.8988E-01
20070322	1200	6.300E+01	2.9508E-01	2.9508E-01	2.9774E-01
20070323	1200	5.700E+01	2.7270E-01	2.7270E-01	2.7295E-01
20070324	1200	6.100E+01	2.8745E-01	2.8745E-01	2.8990E-01
20070325	1200	6.500E+01	3.0081E-01	3.0081E-01	3.0521E-01
20070326	1200	6.600E+01	3.0372E-01	3.0372E-01	3.0880E-01

20070327	1200	6.300E+01	2.9355E-01	2.9355E-01	2.9779E-01
20070328	1200	9.300E+01	3.6375E-01	3.6375E-01	3.7308E-01
20070329	1200	1.160E+02	3.8530E-01	3.8530E-01	3.9141E-01
20070330	1200	8.100E+01	3.4177E-01	3.4177E-01	3.5163E-01
20070331	1200	6.900E+01	3.1137E-01	3.1137E-01	3.1906E-01
20070401	1200	6.000E+01	2.8160E-01	2.8160E-01	2.8595E-01
20070402	1200	5.700E+01	2.7003E-01	2.7003E-01	2.7310E-01
20070403	1200	5.500E+01	2.6182E-01	2.6182E-01	2.6402E-01
20070404	1200	5.500E+01	2.6159E-01	2.6159E-01	2.6405E-01
20070405	1200	5.000E+01	2.3986E-01	2.3986E-01	2.3945E-01
20070406	1200	4.400E+01	2.1072E-01	2.1072E-01	2.0649E-01
20070407	1200	4.300E+01	2.0538E-01	2.0538E-01	2.0068E-01
20070408	1200	4.500E+01	2.1543E-01	2.1543E-01	2.1231E-01
20070409	1200	4.400E+01	2.1021E-01	2.1021E-01	2.0659E-01
20070410	1200	3.500E+01	1.6023E-01	1.6023E-01	1.5098E-01
20070411	1200	4.100E+01	1.9416E-01	1.9416E-01	1.8884E-01
20070412	1200	3.600E+01	1.6589E-01	1.6589E-01	1.5751E-01
20070413	1200	3.700E+01	1.7158E-01	1.7158E-01	1.6396E-01
20070414	1200	3.400E+01	1.5378E-01	1.5378E-01	1.4457E-01
20070415	1200	3.300E+01	1.4761E-01	1.4761E-01	1.3803E-01
20070416	1200	3.700E+01	1.7123E-01	1.7123E-01	1.6407E-01
20070417	1200	4.100E+01	1.9338E-01	1.9338E-01	1.8908E-01
20070418	1200	5.500E+01	2.5902E-01	2.5902E-01	2.6474E-01
20070419	1200	6.200E+01	2.8500E-01	2.8500E-01	2.9494E-01
20070420	1200	5.300E+01	2.5050E-01	2.5050E-01	2.5532E-01
20070421	1200	5.500E+01	2.5863E-01	2.5863E-01	2.6496E-01
20070422	1200	6.100E+01	2.8113E-01	2.8113E-01	2.9120E-01
20070423	1200	5.800E+01	2.7010E-01	2.7010E-01	2.7868E-01
20070424	1200	7.800E+01	3.2957E-01	3.2957E-01	3.4628E-01
20070425	1200	6.000E+01	2.7726E-01	2.7726E-01	2.8738E-01
20070426	1200	7.000E+01	3.0909E-01	3.0909E-01	3.2401E-01
20070427	1200	6.400E+01	2.9079E-01	2.9079E-01	3.0339E-01
20070428	1200	6.700E+01	3.0016E-01	3.0016E-01	3.1431E-01
20070429	1200	6.600E+01	2.9702E-01	2.9702E-01	3.1093E-01
20070430	1200	7.100E+01	3.1156E-01	3.1156E-01	3.2763E-01
20070501	1200	6.700E+01	2.9998E-01	2.9998E-01	3.1469E-01
20070502	1200	5.200E+01	2.4527E-01	2.4527E-01	2.5144E-01
20070503	1200	7.000E+01	3.0866E-01	3.0866E-01	3.2491E-01
20070504	1200	6.600E+01	2.9681E-01	2.9681E-01	3.1158E-01
20070505	1200	7.400E+01	3.1929E-01	3.1929E-01	3.3720E-01
20070506	1200	6.400E+01	2.9041E-01	2.9041E-01	3.0455E-01
20070507	1200	7.300E+01	3.1672E-01	3.1672E-01	3.3466E-01
20070508	1200	7.200E+01	3.1411E-01	3.1411E-01	3.3187E-01
20070509	1200	8.400E+01	3.4141E-01	3.4141E-01	3.6197E-01
20070510	1200	7.800E+01	3.2895E-01	3.2895E-01	3.4866E-01
20070511	1200	8.500E+01	3.4338E-01	3.4338E-01	3.6433E-01
20070512	1200	8.200E+01	3.3764E-01	3.3764E-01	3.5836E-01
20070513	1200	7.200E+01	3.1433E-01	3.1433E-01	3.3276E-01
20070514	1200	7.700E+01	3.2691E-01	3.2691E-01	3.4690E-01
20070515	1200	7.000E+01	3.0900E-01	3.0900E-01	3.2694E-01
20070516	1200	8.200E+01	3.3800E-01	3.3800E-01	3.5919E-01
20070517	1200	7.700E+01	3.2722E-01	3.2722E-01	3.4753E-01
20070518	1200	7.800E+01	3.2965E-01	3.2965E-01	3.5029E-01
20070519	1200	7.800E+01	3.2978E-01	3.2978E-01	3.5052E-01
20070520	1200	6.800E+01	3.0378E-01	3.0378E-01	3.2136E-01
20070521	1200	6.800E+01	3.0392E-01	3.0392E-01	3.2158E-01
20070522	1200	6.900E+01	3.0701E-01	3.0701E-01	3.2515E-01
20070523	1200	8.200E+01	3.3906E-01	3.3906E-01	3.6085E-01
20070524	1200	7.500E+01	3.2348E-01	3.2348E-01	3.4381E-01
20070525	1200	7.500E+01	3.2368E-01	3.2368E-01	3.4406E-01
20070526	1200	7.600E+01	3.2634E-01	3.2634E-01	3.4704E-01
20070527	1200	7.100E+01	3.1361E-01	3.1361E-01	3.3278E-01
20070528	1200	6.400E+01	2.9263E-01	2.9263E-01	3.0875E-01
20070529	1200	6.100E+01	2.8257E-01	2.8257E-01	2.9707E-01

20070530	1200	5.400E+01	2.5579E-01	2.5579E-01	2.6576E-01
20070531	1200	5.700E+01	2.6809E-01	2.6809E-01	2.8015E-01
20070601	1200	6.100E+01	2.8324E-01	2.8324E-01	2.9779E-01
20070602	1200	6.300E+01	2.9044E-01	2.9044E-01	3.0611E-01
20070603	1200	6.700E+01	3.0366E-01	3.0366E-01	3.2130E-01
20070604	1200	6.300E+01	2.9097E-01	2.9097E-01	3.0663E-01
20070605	1200	6.200E+01	2.8780E-01	2.8780E-01	3.0290E-01
20070606	1200	6.200E+01	2.8808E-01	2.8808E-01	3.0317E-01
20070607	1200	7.400E+01	3.2471E-01	3.2471E-01	3.4489E-01
20070608	1200	7.400E+01	3.2506E-01	3.2506E-01	3.4520E-01
20070609	1200	7.100E+01	3.1733E-01	3.1733E-01	3.3644E-01
20070610	1200	7.100E+01	3.1769E-01	3.1769E-01	3.3676E-01
20070611	1200	6.600E+01	3.0307E-01	3.0307E-01	3.2002E-01
20070612	1200	6.200E+01	2.9000E-01	2.9000E-01	3.0486E-01
20070613	1200	6.400E+01	2.9725E-01	2.9725E-01	3.1310E-01
20070614	1200	6.100E+01	2.8715E-01	2.8715E-01	3.0132E-01
20070615	1200	6.000E+01	2.8385E-01	2.8385E-01	2.9738E-01
20070616	1200	6.000E+01	2.8423E-01	2.8423E-01	2.9767E-01
20070617	1200	6.000E+01	2.8461E-01	2.8461E-01	2.9798E-01
20070618	1200	6.300E+01	2.9579E-01	2.9579E-01	3.1074E-01
20070619	1200	5.500E+01	2.6563E-01	2.6563E-01	2.7565E-01
20070620	1200	6.000E+01	2.8582E-01	2.8582E-01	2.9891E-01
20070621	1200	5.200E+01	2.5339E-01	2.5339E-01	2.6111E-01
20070622	1200	5.500E+01	2.6680E-01	2.6680E-01	2.7653E-01
20070623	1200	5.400E+01	2.6295E-01	2.6295E-01	2.7189E-01
20070624	1200	6.200E+01	2.9491E-01	2.9491E-01	3.0868E-01
20070625	1200	6.400E+01	3.0241E-01	3.0241E-01	3.1707E-01
20070626	1200	5.900E+01	2.8467E-01	2.8467E-01	2.9648E-01
20070627	1200	6.200E+01	2.9636E-01	2.9636E-01	3.0972E-01
20070628	1200	5.600E+01	2.7357E-01	2.7357E-01	2.8325E-01
20070629	1200	5.400E+01	2.6553E-01	2.6553E-01	2.7374E-01
20070630	1200	5.000E+01	2.4778E-01	2.4778E-01	2.5302E-01
20070701	1200	5.700E+01	2.7913E-01	2.7913E-01	2.8901E-01
20070702	1200	5.900E+01	2.8764E-01	2.8764E-01	2.9855E-01
20070703	1200	5.600E+01	2.7600E-01	2.7600E-01	2.8492E-01
20070704	1200	5.900E+01	2.8870E-01	2.8870E-01	2.9927E-01
20070705	1200	5.300E+01	2.6396E-01	2.6396E-01	2.7058E-01
20070706	1200	5.700E+01	2.8173E-01	2.8173E-01	2.9075E-01
20070707	1200	5.500E+01	2.7381E-01	2.7381E-01	2.8141E-01
20070708	1200	5.600E+01	2.7864E-01	2.7864E-01	2.8667E-01
20070709	1200	5.700E+01	2.8339E-01	2.8339E-01	2.9184E-01
20070710	1200	5.600E+01	2.7975E-01	2.7975E-01	2.8740E-01
20070711	1200	5.400E+01	2.7160E-01	2.7160E-01	2.7778E-01
20070712	1200	5.100E+01	2.5830E-01	2.5830E-01	2.6229E-01
20070713	1200	5.800E+01	2.8987E-01	2.8987E-01	2.9806E-01
20070714	1200	5.700E+01	2.8633E-01	2.8633E-01	2.9372E-01
20070715	1200	5.500E+01	2.7833E-01	2.7833E-01	2.8429E-01
20070716	1200	5.800E+01	2.9174E-01	2.9174E-01	2.9923E-01
20070717	1200	5.600E+01	2.8392E-01	2.8392E-01	2.9002E-01
20070718	1200	6.500E+01	3.1979E-01	3.1979E-01	3.3016E-01
20070719	1200	6.000E+01	3.0180E-01	3.0180E-01	3.0960E-01
20070720	1200	6.300E+01	3.1400E-01	3.1400E-01	3.2296E-01
20070721	1200	5.900E+01	2.9914E-01	2.9914E-01	3.0589E-01
20070722	1200	6.100E+01	3.0783E-01	3.0783E-01	3.1529E-01
20070723	1200	6.200E+01	3.1241E-01	3.1241E-01	3.2006E-01
20070724	1200	5.700E+01	2.9282E-01	2.9282E-01	2.9767E-01
20070725	1200	5.800E+01	2.9778E-01	2.9778E-01	3.0288E-01
20070726	1200	5.400E+01	2.8079E-01	2.8079E-01	2.8339E-01
20070727	1200	6.600E+01	3.3012E-01	3.3012E-01	3.3815E-01
20070728	1200	6.400E+01	3.2373E-01	3.2373E-01	3.3067E-01
20070729	1200	6.800E+01	3.3861E-01	3.3861E-01	3.4664E-01
20070730	1200	6.600E+01	3.3256E-01	3.3256E-01	3.3957E-01
20070731	1200	6.000E+01	3.1052E-01	3.1052E-01	3.1476E-01

Goggin Drain near Magna, Utah

```
#############################################################################
#
#  LOADEST Calibration File
#
#  Goggin Drain
#
#  Total Se (dissolved + particulate)
#  Autosampler data from 2007 added
#
#############################################################################
#
#CDATE     CTIME     CFLOW    CCONC
#
#############################################################################
20060512     1500     1340     1.17
20060515     1500     1480     1.12
20060517     1045     1580     0.837
20060521     1500     1800     0.927
20060524     1311     1760     1.01
20060529     1311     1660     1.08
20060601     1311     1340     1.24
20060604     1311     1440     1
20060606     1330     1580     0.753
20060607     1400     1620     1.13
20060611     1400     1800     1.05
20060615     1400     1430     1.02
20060728     1420       15     1.16
20060810     1130       19     1.27
20060905     0820       33     1.17
20061012     1220       18     1.08
20061109     1300       41     1.38
20061219     0940       27     1.48
20070131     1435      178     1.68
20070306     1405     1240     1.17
20070413     1530      466     1.27
20070415     1500      372     1.14
20070420     1500      196     1.29
20070421     1500      154     1.4
20070422     1500       91     1.35
20070424     1500      159     1.4
20070508     1130      115     1.32
20070509     1130       63     1.33
20070513     1130       49     1.39
20070514     1130      131     1.17
20070516     1000      202     0.991
20070517     1130      178     1.13
20070519     1130      190     1.09
20070522     1130      253     0.984
20070524     1130      187     1.05
20070527     1130       84     1.37
20070530     1130      232     1.38
20070531     1130      149     1.35
20070601     1130       48     1.34
20070618     1130       19     1.22
```

20070629 1130 21 1.37

```
#################################################################################
#
#  LOADEST Estimation File
#
#  Goggin Drain
#
#
#
#################################################################################
#
#  Number of observations per day, NOBSPD (col. 1-5)
#
#################################################################################
1
#################################################################################
#
# EDATE      ETIME     EFLOW
#
#################################################################################
20060503      1200      1290
20060504      1200      1290
20060505      1200      1500
20060506      1200      1460
20060507      1200      1420
20060508      1200      1420
20060509      1200      1430
20060510      1200      1410
20060511      1200      1360
20060512      1200      1340
20060513      1200      1360
20060514      1200      1390
20060515      1200      1480
20060516      1200      1550
20060517      1200      1580
20060518      1200      1620
20060519      1200      1670
20060520      1200      1760
20060521      1200      1800
20060522      1200      1820
20060523      1200      1810
20060524      1200      1760
20060525      1200      1710
20060526      1200      1710
20060527      1200      1720
20060528      1200      1740
20060529      1200      1660
20060530      1200      1550
20060531      1200      1410
20060601      1200      1340
20060602      1200      1330
20060603      1200      1380
20060604      1200      1440
20060605      1200      1530
20060606      1200      1580
20060607      1200      1620
20060608      1200      1660
```

20060609	1200	1730
20060610	1200	1830
20060611	1200	1800
20060612	1200	1720
20060613	1200	1580
20060614	1200	1500
20060615	1200	1430
20060616	1200	1280
20060617	1200	1170
20060618	1200	1160
20060619	1200	1170
20060620	1200	1140
20060621	1200	1090
20060622	1200	1060
20060623	1200	972
20060624	1200	926
20060625	1200	894
20060626	1200	867
20060627	1200	846
20060628	1200	765
20060629	1200	666
20060630	1200	623
20060701	1200	523
20060702	1200	403
20060703	1200	332
20060704	1200	309
20060705	1200	283
20060706	1200	319
20060707	1200	285
20060708	1200	227
20060709	1200	198
20060710	1200	147
20060711	1200	85
20060712	1200	60
20060713	1200	40
20060714	1200	20
20060715	1200	16
20060716	1200	26
20060717	1200	14
20060718	1200	12
20060719	1200	14
20060720	1200	21
20060721	1200	17
20060722	1200	16
20060723	1200	18
20060724	1200	17
20060725	1200	22
20060726	1200	28
20060727	1200	18
20060728	1200	15
20060729	1200	13
20060730	1200	14
20060731	1200	11
20060801	1200	179
20060802	1200	335
20060803	1200	181

20060804	1200	114
20060805	1200	35
20060806	1200	19
20060807	1200	20
20060808	1200	26
20060809	1200	22
20060810	1200	19
20060811	1200	17
20060812	1200	22
20060813	1200	123
20060814	1200	42
20060815	1200	42
20060816	1200	33
20060817	1200	25
20060818	1200	21
20060819	1200	23
20060820	1200	24
20060821	1200	20
20060822	1200	24
20060823	1200	30
20060824	1200	12
20060825	1200	22
20060826	1200	29
20060827	1200	29
20060828	1200	26
20060829	1200	45
20060830	1200	44
20060831	1200	34
20060901	1200	28
20060902	1200	25
20060903	1200	27
20060904	1200	38
20060905	1200	33
20060906	1200	29
20060907	1200	26
20060908	1200	33
20060909	1200	46
20060910	1200	38
20060911	1200	33
20060912	1200	29
20060913	1200	25
20060914	1200	18
20060915	1200	298
20060916	1200	548
20060917	1200	263
20060918	1200	115
20060919	1200	108
20060920	1200	211
20060921	1200	283
20060922	1200	271
20060923	1200	298
20060924	1200	224
20060925	1200	182
20060926	1200	153
20060927	1200	88
20060928	1200	84

20060929	1200	81
20060930	1200	80
20061001	1200	77
20061002	1200	64
20061003	1200	32
20061004	1200	27
20061005	1200	43
20061006	1200	258
20061007	1200	425
20061008	1200	279
20061009	1200	154
20061010	1200	106
20061011	1200	68
20061012	1200	18
20061013	1200	13
20061014	1200	13
20061015	1200	13
20061016	1200	31
20061017	1200	163
20061018	1200	51
20061019	1200	15
20061020	1200	17
20061021	1200	20
20061022	1200	20
20061023	1200	21
20061024	1200	31
20061025	1200	25
20061026	1200	25
20061027	1200	28
20061028	1200	44
20061029	1200	40
20061030	1200	37
20061031	1200	35
20061101	1200	34
20061102	1200	34
20061103	1200	34
20061104	1200	35
20061105	1200	37
20061106	1200	38
20061107	1200	38
20061108	1200	39
20061109	1200	41
20061110	1200	43
20061111	1200	42
20061112	1200	42
20061113	1200	43
20061114	1200	100
20061115	1200	127
20061116	1200	46
20061117	1200	43
20061118	1200	42
20061119	1200	41
20061120	1200	40
20061121	1200	40
20061122	1200	40
20061123	1200	41

20061124	1200	41
20061125	1200	41
20061126	1200	41
20061127	1200	42
20061128	1200	43
20061129	1200	43
20061130	1200	41
20061201	1200	41
20061202	1200	41
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20061206	1200	39
20061207	1200	39
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20061214	1200	28
20061215	1200	28
20061216	1200	28
20061217	1200	28
20061218	1200	28
20061219	1200	27
20061220	1200	25
20061221	1200	25
20061222	1200	24
20061223	1200	24
20061224	1200	24
20061225	1200	24
20061226	1200	25
20061227	1200	27
20061228	1200	29
20061229	1200	28
20061230	1200	27
20061231	1200	26
20070101	1200	27
20070102	1200	26
20070103	1200	26
20070104	1200	28
20070105	1200	29
20070106	1200	30
20070107	1200	30
20070108	1200	30
20070109	1200	31
20070110	1200	31
20070111	1200	32
20070112	1200	32
20070113	1200	32
20070114	1200	32
20070115	1200	32
20070116	1200	32
20070117	1200	32
20070118	1200	32

20070119	1200	32
20070120	1200	32
20070121	1200	32
20070122	1200	32
20070123	1200	32
20070124	1200	32
20070125	1200	32
20070126	1200	32
20070127	1200	32
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20070129	1200	32
20070130	1200	32
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20070205	1200	300
20070206	1200	310
20070207	1200	349
20070208	1200	359
20070209	1200	381
20070210	1200	362
20070211	1200	399
20070212	1200	523
20070213	1200	652
20070214	1200	745
20070215	1200	820
20070216	1200	871
20070217	1200	829
20070218	1200	835
20070219	1200	885
20070220	1200	925
20070221	1200	883
20070222	1200	882
20070223	1200	912
20070224	1200	947
20070225	1200	911
20070226	1200	922
20070227	1200	940
20070228	1200	960
20070301	1200	936
20070302	1200	1010
20070303	1200	1140
20070304	1200	1200
20070305	1200	1230
20070306	1200	1240
20070307	1200	1260
20070308	1200	1270
20070309	1200	1310
20070310	1200	1280
20070311	1200	1270
20070312	1200	1270
20070313	1200	1270
20070314	1200	1270
20070315	1200	1240

20070316	1200	1220
20070317	1200	1210
20070318	1200	1210
20070319	1200	1190
20070320	1200	1190
20070321	1200	1210
20070322	1200	1230
20070323	1200	1210
20070324	1200	1180
20070325	1200	1180
20070326	1200	1180
20070327	1200	1180
20070328	1200	1260
20070329	1200	1370
20070330	1200	1270
20070331	1200	1190
20070401	1200	1100
20070402	1200	1060
20070403	1200	979
20070404	1200	966
20070405	1200	970
20070406	1200	966
20070407	1200	786
20070408	1200	634
20070409	1200	585
20070410	1200	528
20070411	1200	480
20070412	1200	478
20070413	1200	466
20070414	1200	343
20070415	1200	372
20070416	1200	289
20070417	1200	144
20070418	1200	186
20070419	1200	218
20070420	1200	196
20070421	1200	154
20070422	1200	91
20070423	1200	151
20070424	1200	159
20070425	1200	139
20070426	1200	111
20070427	1200	61
20070428	1200	65
20070429	1200	66
20070430	1200	63
20070501	1200	113
20070502	1200	151
20070503	1200	223
20070504	1200	356
20070505	1200	332
20070506	1200	284
20070507	1200	218
20070508	1200	115
20070509	1200	63
20070510	1200	18

20070511	1200	13
20070512	1200	17
20070513	1200	49
20070514	1200	131
20070515	1200	197
20070516	1200	202
20070517	1200	178
20070518	1200	191
20070519	1200	190
20070520	1200	208
20070521	1200	224
20070522	1200	253
20070523	1200	228
20070524	1200	187
20070525	1200	154
20070526	1200	133
20070527	1200	84
20070528	1200	15
20070529	1200	118
20070530	1200	232
20070531	1200	149
20070601	1200	48
20070602	1200	17
20070603	1200	18
20070604	1200	20
20070605	1200	34
20070606	1200	257
20070607	1200	482
20070608	1200	314
20070609	1200	223
20070610	1200	177
20070611	1200	123
20070612	1200	85
20070613	1200	90
20070614	1200	92
20070615	1200	91
20070616	1200	88
20070617	1200	78
20070618	1200	19
20070619	1200	18
20070620	1200	17
20070621	1200	14
20070622	1200	14
20070623	1200	14
20070624	1200	18
20070625	1200	17
20070626	1200	18
20070627	1200	17
20070628	1200	16
20070629	1200	21
20070630	1200	22
20070701	1200	22
20070702	1200	14
20070703	1200	19
20070704	1200	17
20070705	1200	29

20070706	1200	20
20070707	1200	18
20070708	1200	17
20070709	1200	18
20070710	1200	22
20070711	1200	24
20070712	1200	17
20070713	1200	13
20070714	1200	11
20070715	1200	14
20070716	1200	11
20070717	1200	13
20070718	1200	29
20070719	1200	23
20070720	1200	19
20070721	1200	18
20070722	1200	27
20070723	1200	30
20070724	1200	21
20070725	1200	19
20070726	1200	41
20070727	1200	284
20070728	1200	292
20070729	1200	207
20070730	1200	118
20070731	1200	104

LOADEST

A Program to Estimate Constituent Loads
U.S. Geological Survey, Version: MOD36 (Sep 2004)

Goggin Drain

Constituent: selenium

Constituent Output File Part Ia: Calibration (Load Regression)

Number of Observations : 41
Number of Uncensored Observations: 41
"center" of Decimal Time : 2006.905
"center" of Ln(Q) : 5.3403
Period of record : 2006-2007

Model Evaluation Criteria Based on AMLE Results

Model #	AIC	SPPC
1	-1.123	21.318
2	-1.231	22.655
3	-1.171	21.443
4	-1.390	25.078
5	-1.180	20.759
6	-1.344	23.267
7	-1.342	23.218
8	-1.307	21.646
9	-1.274	20.123

Model # 4 selected

Selected Model:

Ln(Load) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime)

where:
Load = constituent load [kg/d]
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Model Coefficients

	a0	a1	a2	a3
AMLE	-0.4935	0.9318	0.1653	0.0302
MLE	-0.4935	0.9318	0.1653	0.0302
LAD	-0.4750	0.9449	0.1481	0.0283

AMLE Regression Statistics

R-Squared [%] : 99.46
Prob. Plot Corr. Coeff. (PPCC) : 0.9880
Serial Correlation of Residuals: 0.1511

Coeff.	Std.Dev.	t-ratio	P Value
a0	0.0318	-15.53	9.389E-20
a1	0.0136	68.71	3.250E-45
a2	0.0419	3.94	1.487E-04
a3	0.0372	0.81	3.944E-01

Correlation Between Explanatory Variables

Explanatory variable corresponding to:

	a1	a2
a2	0.3437	
a3	-0.4511	-0.1232

Additional Regression Statistics

	Residual Variance	Turnbull-Weiss Stat	DF	PL
AMLE	0.013	3.20	5	6.692E-01
MLE	0.013	3.20	5	6.692E-01

Constituent Output File Part Ib: Calibration (Concentration Regression)

AMLE Regression Statistics

Model # 4 was selected for the load regression (PART Ia) and is used here:

Ln(Conc) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime)

where:
Conc = constituent concentration
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Concentration Regression Results

R-Squared [%] : 52.42
Residual Variance : 0.0132

Coeff.	Value	Std.Dev.	t-ratio	P Value
a0	0.1793	0.0318	5.65	4.484E-07

a1	-0.0682	0.0136	-5.03	3.782E-06
a2	0.1653	0.0419	3.94	1.487E-04
a3	0.0302	0.0372	0.81	3.944E-01

Constituent Output File Part IIa: Estimation (test for extrapolation)

Load Estimates for 20060503-20070731

Streamflow Summary Statistics [cfs]

Data	Mean	Minimum	10th Pct	25th Pct	Median	75th Pct	90th Pct	Maximum
Cal.	580.	15.	19.	56.	187.	1385.	1652.	1800.
Est.	385.	11.	18.	28.	77.	623.	1290.	1830.

WARNING: The maximum estimation data set steamflow exceeds the maximum calibration data set streamflow. Load estimates require extrapolation.

Maximum Estimation Streamflow : 1.8300E+03
Maximum Calibration Streamflow: 1.8000E+03

Constituent Output File Part IIb: Estimation (Load Estimates)

Load Estimates for 20060503-20070731

Load Estimates [KG/DAY]

AMLE Load Estimates

	N	Mean Load	95% Conf.Intervals Lower	95% Conf.Intervals Upper	Std Error Prediction	Standard Error
Est. Period	455	1.07	1.01	1.13	0.03	0.03

MLE Load Estimates

	N	Mean Load	Standard Error
Est. Period	455	1.07	0.03

LAD Load Estimates

	N	Mean Load	Standard Error
Est. Period	455	1.08	0.07

Summary Statistics - Estimated Loads [KG/DAY]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.034	0.095	0.222	1.709	3.706	3.928	4.423	4.566
MLE	0.034	0.095	0.222	1.709	3.706	3.928	4.423	4.566
LAD	0.033	0.094	0.217	1.701	3.737	4.014	4.546	4.695

Summary Statistics - Estimated Concentrations [UG/L]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.97	1.14	1.24	1.32	1.50	1.57	1.60	1.61
MLE	0.97	1.14	1.24	1.32	1.50	1.57	1.60	1.61
LAD	1.	1.	1.	1.	1.	2.	2.	2.

Individual Load Estimates for Goggin Drain in kg/day

			Loads Estimated by:		
Date	Time	Flow	AMLE	MLE	LAD
20060503	1200	1.290E+03	3.4994E+00	3.4994E+00	3.5614E+00
20060504	1200	1.290E+03	3.4896E+00	3.4896E+00	3.5524E+00
20060505	1200	1.500E+03	4.0047E+00	4.0047E+00	4.0862E+00
20060506	1200	1.460E+03	3.8941E+00	3.8941E+00	3.9730E+00
20060507	1200	1.420E+03	3.7839E+00	3.7839E+00	3.8602E+00
20060508	1200	1.420E+03	3.7732E+00	3.7732E+00	3.8504E+00
20060509	1200	1.430E+03	3.7871E+00	3.7871E+00	3.8660E+00
20060510	1200	1.410E+03	3.7271E+00	3.7271E+00	3.8051E+00
20060511	1200	1.360E+03	3.5935E+00	3.5935E+00	3.6681E+00
20060512	1200	1.340E+03	3.5340E+00	3.5340E+00	3.6077E+00
20060513	1200	1.360E+03	3.5728E+00	3.5728E+00	3.6491E+00
20060514	1200	1.390E+03	3.6357E+00	3.6357E+00	3.7155E+00
20060515	1200	1.480E+03	3.8434E+00	3.8434E+00	3.9322E+00
20060516	1200	1.550E+03	4.0009E+00	4.0009E+00	4.0971E+00
20060517	1200	1.580E+03	4.0612E+00	4.0612E+00	4.1611E+00
20060518	1200	1.620E+03	4.1449E+00	4.1449E+00	4.2496E+00
20060519	1200	1.670E+03	4.2516E+00	4.2516E+00	4.3621E+00
20060520	1200	1.760E+03	4.4517E+00	4.4517E+00	4.5720E+00
20060521	1200	1.800E+03	4.5327E+00	4.5327E+00	4.6580E+00
20060522	1200	1.820E+03	4.5664E+00	4.5664E+00	4.6947E+00
20060523	1200	1.810E+03	4.5299E+00	4.5299E+00	4.6583E+00
20060524	1200	1.760E+03	4.4006E+00	4.4006E+00	4.5249E+00
20060525	1200	1.710E+03	4.2717E+00	4.2717E+00	4.3920E+00
20060526	1200	1.710E+03	4.2594E+00	4.2594E+00	4.3808E+00
20060527	1200	1.720E+03	4.2704E+00	4.2704E+00	4.3937E+00
20060528	1200	1.740E+03	4.3043E+00	4.3043E+00	4.4306E+00
20060529	1200	1.660E+03	4.1079E+00	4.1079E+00	4.2271E+00
20060530	1200	1.550E+03	3.8429E+00	3.8429E+00	3.9519E+00
20060531	1200	1.410E+03	3.5086E+00	3.5086E+00	3.6047E+00
20060601	1200	1.340E+03	3.3366E+00	3.3366E+00	3.4267E+00
20060602	1200	1.330E+03	3.3041E+00	3.3041E+00	3.3940E+00
20060603	1200	1.380E+03	3.4101E+00	3.4101E+00	3.5057E+00
20060604	1200	1.440E+03	3.5382E+00	3.5382E+00	3.6405E+00
20060605	1200	1.530E+03	3.7334E+00	3.7334E+00	3.8456E+00
20060606	1200	1.580E+03	3.8363E+00	3.8363E+00	3.9545E+00
20060607	1200	1.620E+03	3.9159E+00	3.9159E+00	4.0392E+00
20060608	1200	1.660E+03	3.9950E+00	3.9950E+00	4.1234E+00
20060609	1200	1.730E+03	4.1405E+00	4.1405E+00	4.2772E+00
20060610	1200	1.830E+03	4.3513E+00	4.3513E+00	4.4996E+00
20060611	1200	1.800E+03	4.2734E+00	4.2734E+00	4.4194E+00
20060612	1200	1.720E+03	4.0854E+00	4.0854E+00	4.2236E+00
20060613	1200	1.580E+03	3.7649E+00	3.7649E+00	3.8890E+00
20060614	1200	1.500E+03	3.5777E+00	3.5777E+00	3.6941E+00
20060615	1200	1.430E+03	3.4131E+00	3.4131E+00	3.5229E+00
20060616	1200	1.280E+03	3.0705E+00	3.0705E+00	3.1655E+00
20060617	1200	1.170E+03	2.8168E+00	2.8168E+00	2.9013E+00
20060618	1200	1.160E+03	2.7874E+00	2.7874E+00	2.8714E+00
20060619	1200	1.170E+03	2.8028E+00	2.8028E+00	2.8885E+00
20060620	1200	1.140E+03	2.7291E+00	2.7291E+00	2.8123E+00
20060621	1200	1.090E+03	2.6110E+00	2.6110E+00	2.6898E+00
20060622	1200	1.060E+03	2.5379E+00	2.5379E+00	2.6142E+00
20060623	1200	9.720E+02	2.3355E+00	2.3355E+00	2.4036E+00
20060624	1200	9.260E+02	2.2272E+00	2.2272E+00	2.2912E+00
20060625	1200	8.940E+02	2.1504E+00	2.1504E+00	2.2118E+00

20060626	1200	8.670E+02	2.0851E+00	2.0851E+00	2.1443E+00
20060627	1200	8.460E+02	2.0334E+00	2.0334E+00	2.0910E+00
20060628	1200	7.650E+02	1.8473E+00	1.8473E+00	1.8976E+00
20060629	1200	6.660E+02	1.6200E+00	1.6200E+00	1.6614E+00
20060630	1200	6.230E+02	1.5191E+00	1.5191E+00	1.5569E+00
20060701	1200	5.230E+02	1.2879E+00	1.2879E+00	1.3172E+00
20060702	1200	4.030E+02	1.0082E+00	1.0082E+00	1.0278E+00
20060703	1200	3.320E+02	8.3989E-01	8.3989E-01	8.5426E-01
20060704	1200	3.090E+02	7.8397E-01	7.8397E-01	7.9681E-01
20060705	1200	2.830E+02	7.2091E-01	7.2091E-01	7.3203E-01
20060706	1200	3.190E+02	8.0441E-01	8.0441E-01	8.1831E-01
20060707	1200	2.850E+02	7.2286E-01	7.2286E-01	7.3441E-01
20060708	1200	2.270E+02	5.8368E-01	5.8368E-01	5.9136E-01
20060709	1200	1.980E+02	5.1295E-01	5.1295E-01	5.1888E-01
20060710	1200	1.470E+02	3.8796E-01	3.8796E-01	3.9099E-01
20060711	1200	8.500E+01	2.3247E-01	2.3247E-01	2.3266E-01
20060712	1200	6.000E+01	1.6775E-01	1.6775E-01	1.6716E-01
20060713	1200	4.000E+01	1.1477E-01	1.1477E-01	1.1379E-01
20060714	1200	2.000E+01	6.0059E-02	6.0059E-02	5.9029E-02
20060715	1200	1.600E+01	4.8704E-02	4.8704E-02	4.7741E-02
20060716	1200	2.600E+01	7.6458E-02	7.6458E-02	7.5427E-02
20060717	1200	1.400E+01	4.2874E-02	4.2874E-02	4.1970E-02
20060718	1200	1.200E+01	3.7082E-02	3.7082E-02	3.6235E-02
20060719	1200	1.400E+01	4.2752E-02	4.2752E-02	4.1864E-02
20060720	1200	2.100E+01	6.2300E-02	6.2300E-02	6.1334E-02
20060721	1200	1.700E+01	5.1095E-02	5.1095E-02	5.0175E-02
20060722	1200	1.600E+01	4.8226E-02	4.8226E-02	4.7328E-02
20060723	1200	1.800E+01	5.3756E-02	5.3756E-02	5.2842E-02
20060724	1200	1.700E+01	5.0907E-02	5.0907E-02	5.0012E-02
20060725	1200	2.200E+01	6.4660E-02	6.4660E-02	6.3744E-02
20060726	1200	2.800E+01	8.0867E-02	8.0867E-02	7.9980E-02
20060727	1200	1.800E+01	5.3516E-02	5.3516E-02	5.2636E-02
20060728	1200	1.500E+01	4.5107E-02	4.5107E-02	4.4268E-02
20060729	1200	1.300E+01	3.9437E-02	3.9437E-02	3.8637E-02
20060730	1200	1.400E+01	4.2219E-02	4.2219E-02	4.1407E-02
20060731	1200	1.100E+01	3.3691E-02	3.3691E-02	3.2945E-02
20060801	1200	1.790E+02	4.5293E-01	4.5293E-01	4.5934E-01
20060802	1200	3.350E+02	8.1140E-01	8.1140E-01	8.2990E-01
20060803	1200	1.810E+02	4.5695E-01	4.5695E-01	4.6359E-01
20060804	1200	1.140E+02	2.9685E-01	2.9685E-01	2.9935E-01
20060805	1200	3.500E+01	9.8725E-02	9.8725E-02	9.8038E-02
20060806	1200	1.900E+01	5.5838E-02	5.5838E-02	5.5018E-02
20060807	1200	2.000E+01	5.8542E-02	5.8542E-02	5.7724E-02
20060808	1200	2.600E+01	7.4721E-02	7.4721E-02	7.3934E-02
20060809	1200	2.200E+01	6.3921E-02	6.3921E-02	6.3116E-02
20060810	1200	1.900E+01	5.5737E-02	5.5737E-02	5.4934E-02
20060811	1200	1.700E+01	5.0233E-02	5.0233E-02	4.9441E-02
20060812	1200	2.200E+01	6.3858E-02	6.3858E-02	6.3065E-02
20060813	1200	1.230E+02	3.1738E-01	3.1738E-01	3.2061E-01
20060814	1200	4.200E+01	1.1661E-01	1.1661E-01	1.1614E-01
20060815	1200	4.200E+01	1.1659E-01	1.1659E-01	1.1613E-01
20060816	1200	3.300E+01	9.3119E-02	9.3119E-02	9.2465E-02
20060817	1200	2.500E+01	7.1890E-02	7.1890E-02	7.1130E-02
20060818	1200	2.100E+01	6.1110E-02	6.1110E-02	6.0329E-02
20060819	1200	2.300E+01	6.6521E-02	6.6521E-02	6.5750E-02
20060820	1200	2.400E+01	6.9221E-02	6.9221E-02	6.8457E-02
20060821	1200	2.000E+01	5.8415E-02	5.8415E-02	5.7635E-02
20060822	1200	2.400E+01	6.9247E-02	6.9247E-02	6.8485E-02
20060823	1200	3.000E+01	8.5275E-02	8.5275E-02	8.4582E-02
20060824	1200	1.200E+01	3.6318E-02	3.6318E-02	3.5597E-02
20060825	1200	2.200E+01	6.3915E-02	6.3915E-02	6.3139E-02
20060826	1200	2.900E+01	8.2713E-02	8.2713E-02	8.2003E-02
20060827	1200	2.900E+01	8.2752E-02	8.2752E-02	8.2040E-02
20060828	1200	2.600E+01	7.4784E-02	7.4784E-02	7.4033E-02

20060829	1200	4.500E+01	1.2475E-01	1.2475E-01	1.2438E-01
20060830	1200	4.400E+01	1.2224E-01	1.2224E-01	1.2184E-01
20060831	1200	3.400E+01	9.6197E-02	9.6197E-02	9.5556E-02
20060901	1200	2.800E+01	8.0334E-02	8.0334E-02	7.9593E-02
20060902	1200	2.500E+01	7.2338E-02	7.2338E-02	7.1562E-02
20060903	1200	2.700E+01	7.7779E-02	7.7779E-02	7.7017E-02
20060904	1200	3.800E+01	1.0703E-01	1.0703E-01	1.0645E-01
20060905	1200	3.300E+01	9.3934E-02	9.3934E-02	9.3247E-02
20060906	1200	2.900E+01	8.3358E-02	8.3358E-02	8.2603E-02
20060907	1200	2.600E+01	7.5369E-02	7.5369E-02	7.4574E-02
20060908	1200	3.300E+01	9.4214E-02	9.4214E-02	9.3505E-02
20060909	1200	4.600E+01	1.2852E-01	1.2852E-01	1.2810E-01
20060910	1200	3.800E+01	1.0769E-01	1.0769E-01	1.0706E-01
20060911	1200	3.300E+01	9.4534E-02	9.4534E-02	9.3798E-02
20060912	1200	2.900E+01	8.3914E-02	8.3914E-02	8.3111E-02
20060913	1200	2.500E+01	7.3169E-02	7.3169E-02	7.2320E-02
20060914	1200	1.800E+01	5.3947E-02	5.3947E-02	5.3087E-02
20060915	1200	2.980E+02	7.3801E-01	7.3801E-01	7.5379E-01
20060916	1200	5.480E+02	1.3033E+00	1.3033E+00	1.3421E+00
20060917	1200	2.630E+02	6.5881E-01	6.5881E-01	6.7160E-01
20060918	1200	1.150E+02	3.0535E-01	3.0535E-01	3.0779E-01
20060919	1200	1.080E+02	2.8844E-01	2.8844E-01	2.9046E-01
20060920	1200	2.110E+02	5.3907E-01	5.3907E-01	5.4769E-01
20060921	1200	2.830E+02	7.0972E-01	7.0972E-01	7.2384E-01
20060922	1200	2.710E+02	6.8278E-01	6.8278E-01	6.9586E-01
20060923	1200	2.980E+02	7.4718E-01	7.4718E-01	7.6237E-01
20060924	1200	2.240E+02	5.7375E-01	5.7375E-01	5.8307E-01
20060925	1200	1.820E+02	4.7371E-01	4.7371E-01	4.7997E-01
20060926	1200	1.530E+02	4.0373E-01	4.0373E-01	4.0805E-01
20060927	1200	8.800E+01	2.4163E-01	2.4163E-01	2.4237E-01
20060928	1200	8.400E+01	2.3182E-01	2.3182E-01	2.3235E-01
20060929	1200	8.100E+01	2.2453E-01	2.2453E-01	2.2489E-01
20060930	1200	8.000E+01	2.2238E-01	2.2238E-01	2.2266E-01
20061001	1200	7.700E+01	2.1503E-01	2.1503E-01	2.1516E-01
20061002	1200	6.400E+01	1.8137E-01	1.8137E-01	1.8100E-01
20061003	1200	3.200E+01	9.5287E-02	9.5287E-02	9.4202E-02
20061004	1200	2.700E+01	8.1509E-02	8.1509E-02	8.0385E-02
20061005	1200	4.300E+01	1.2602E-01	1.2602E-01	1.2502E-01
20061006	1200	2.580E+02	6.7015E-01	6.7015E-01	6.8088E-01
20061007	1200	4.250E+02	1.0690E+00	1.0690E+00	1.0933E+00
20061008	1200	2.790E+02	7.2402E-01	7.2402E-01	7.3608E-01
20061009	1200	1.540E+02	4.1723E-01	4.1723E-01	4.2069E-01
20061010	1200	1.060E+02	2.9531E-01	2.9531E-01	2.9621E-01
20061011	1200	6.800E+01	1.9575E-01	1.9575E-01	1.9514E-01
20061012	1200	1.800E+01	5.6879E-02	5.6879E-02	5.5702E-02
20061013	1200	1.300E+01	4.2102E-02	4.2102E-02	4.1046E-02
20061014	1200	1.300E+01	4.2203E-02	4.2203E-02	4.1136E-02
20061015	1200	1.300E+01	4.2306E-02	4.2306E-02	4.1227E-02
20061016	1200	3.100E+01	9.5309E-02	9.5309E-02	9.3919E-02
20061017	1200	1.630E+02	4.4841E-01	4.4841E-01	4.5166E-01
20061018	1200	5.100E+01	1.5231E-01	1.5231E-01	1.5101E-01
20061019	1200	1.500E+01	4.8828E-02	4.8828E-02	4.7625E-02
20061020	1200	1.700E+01	5.5009E-02	5.5009E-02	5.3728E-02
20061021	1200	2.000E+01	6.4168E-02	6.4168E-02	6.2791E-02
20061022	1200	2.000E+01	6.4336E-02	6.4336E-02	6.2939E-02
20061023	1200	2.100E+01	6.7505E-02	6.7505E-02	6.6065E-02
20061024	1200	3.100E+01	9.7292E-02	9.7292E-02	9.5681E-02
20061025	1200	2.500E+01	7.9836E-02	7.9836E-02	7.8271E-02
20061026	1200	2.500E+01	8.0051E-02	8.0051E-02	7.8461E-02
20061027	1200	2.800E+01	8.9207E-02	8.9207E-02	8.7543E-02
20061028	1200	4.400E+01	1.3629E-01	1.3629E-01	1.3451E-01
20061029	1200	4.000E+01	1.2505E-01	1.2505E-01	1.2323E-01
20061030	1200	3.700E+01	1.1661E-01	1.1661E-01	1.1476E-01
20061031	1200	3.500E+01	1.1103E-01	1.1103E-01	1.0917E-01

20061101	1200	3.400E+01	1.0838E-01	1.0838E-01	1.0648E-01
20061102	1200	3.400E+01	1.0868E-01	1.0868E-01	1.0675E-01
20061103	1200	3.400E+01	1.0899E-01	1.0899E-01	1.0702E-01
20061104	1200	3.500E+01	1.1229E-01	1.1229E-01	1.1027E-01
20061105	1200	3.700E+01	1.1859E-01	1.1859E-01	1.1651E-01
20061106	1200	3.800E+01	1.2192E-01	1.2192E-01	1.1979E-01
20061107	1200	3.800E+01	1.2226E-01	1.2226E-01	1.2010E-01
20061108	1200	3.900E+01	1.2562E-01	1.2562E-01	1.2340E-01
20061109	1200	4.100E+01	1.3199E-01	1.3199E-01	1.2971E-01
20061110	1200	4.300E+01	1.3837E-01	1.3837E-01	1.3603E-01
20061111	1200	4.200E+01	1.3576E-01	1.3576E-01	1.3338E-01
20061112	1200	4.200E+01	1.3615E-01	1.3615E-01	1.3373E-01
20061113	1200	4.300E+01	1.3957E-01	1.3957E-01	1.3709E-01
20061114	1200	1.000E+02	3.0725E-01	3.0725E-01	3.0510E-01
20061115	1200	1.270E+02	3.8498E-01	3.8498E-01	3.8339E-01
20061116	1200	4.600E+01	1.4992E-01	1.4992E-01	1.4725E-01
20061117	1200	4.300E+01	1.4119E-01	1.4119E-01	1.3852E-01
20061118	1200	4.200E+01	1.3853E-01	1.3853E-01	1.3582E-01
20061119	1200	4.100E+01	1.3585E-01	1.3585E-01	1.3311E-01
20061120	1200	4.000E+01	1.3314E-01	1.3314E-01	1.3038E-01
20061121	1200	4.000E+01	1.3353E-01	1.3353E-01	1.3072E-01
20061122	1200	4.000E+01	1.3391E-01	1.3391E-01	1.3105E-01
20061123	1200	4.100E+01	1.3742E-01	1.3742E-01	1.3449E-01
20061124	1200	4.100E+01	1.3782E-01	1.3782E-01	1.3484E-01
20061125	1200	4.100E+01	1.3821E-01	1.3821E-01	1.3519E-01
20061126	1200	4.100E+01	1.3861E-01	1.3861E-01	1.3553E-01
20061127	1200	4.200E+01	1.4216E-01	1.4216E-01	1.3901E-01
20061128	1200	4.300E+01	1.4572E-01	1.4572E-01	1.4249E-01
20061129	1200	4.300E+01	1.4613E-01	1.4613E-01	1.4286E-01
20061130	1200	4.100E+01	1.4018E-01	1.4018E-01	1.3692E-01
20061201	1200	4.100E+01	1.4058E-01	1.4058E-01	1.3726E-01
20061202	1200	4.100E+01	1.4097E-01	1.4097E-01	1.3760E-01
20061203	1200	4.000E+01	1.3815E-01	1.3815E-01	1.3476E-01
20061204	1200	3.900E+01	1.3530E-01	1.3530E-01	1.3191E-01
20061205	1200	3.900E+01	1.3567E-01	1.3567E-01	1.3223E-01
20061206	1200	3.900E+01	1.3604E-01	1.3604E-01	1.3255E-01
20061207	1200	3.900E+01	1.3641E-01	1.3641E-01	1.3288E-01
20061208	1200	3.200E+01	1.1376E-01	1.1376E-01	1.1049E-01
20061209	1200	2.100E+01	7.7035E-02	7.7035E-02	7.4391E-02
20061210	1200	2.900E+01	1.0434E-01	1.0434E-01	1.0116E-01
20061211	1200	3.200E+01	1.1467E-01	1.1467E-01	1.1128E-01
20061212	1200	2.800E+01	1.0152E-01	1.0152E-01	9.8322E-02
20061213	1200	2.700E+01	9.8392E-02	9.8392E-02	9.5221E-02
20061214	1200	2.800E+01	1.0205E-01	1.0205E-01	9.8778E-02
20061215	1200	2.800E+01	1.0231E-01	1.0231E-01	9.9004E-02
20061216	1200	2.800E+01	1.0257E-01	1.0257E-01	9.9228E-02
20061217	1200	2.800E+01	1.0282E-01	1.0282E-01	9.9450E-02
20061218	1200	2.800E+01	1.0308E-01	1.0308E-01	9.9671E-02
20061219	1200	2.700E+01	9.9889E-02	9.9889E-02	9.6516E-02
20061220	1200	2.500E+01	9.3202E-02	9.3202E-02	8.9941E-02
20061221	1200	2.500E+01	9.3426E-02	9.3426E-02	9.0135E-02
20061222	1200	2.400E+01	9.0152E-02	9.0152E-02	8.6908E-02
20061223	1200	2.400E+01	9.0364E-02	9.0364E-02	8.7090E-02
20061224	1200	2.400E+01	9.0573E-02	9.0573E-02	8.7270E-02
20061225	1200	2.400E+01	9.0780E-02	9.0780E-02	8.7448E-02
20061226	1200	2.500E+01	9.4513E-02	9.4513E-02	9.1070E-02
20061227	1200	2.700E+01	1.0177E-01	1.0177E-01	9.8134E-02
20061228	1200	2.900E+01	1.0901E-01	1.0901E-01	1.0519E-01
20061229	1200	2.800E+01	1.0573E-01	1.0573E-01	1.0196E-01
20061230	1200	2.700E+01	1.0243E-01	1.0243E-01	9.8701E-02
20061231	1200	2.600E+01	9.9094E-02	9.9094E-02	9.5421E-02
20070101	1200	2.700E+01	1.0285E-01	1.0285E-01	9.9067E-02
20070102	1200	2.600E+01	9.9499E-02	9.9499E-02	9.5768E-02
20070103	1200	2.600E+01	9.9696E-02	9.9696E-02	9.5938E-02

20070104	1200	2.800E+01	1.0703E-01	1.0703E-01	1.0307E-01
20070105	1200	2.900E+01	1.1080E-01	1.1080E-01	1.0673E-01
20070106	1200	3.000E+01	1.1457E-01	1.1457E-01	1.1039E-01
20070107	1200	3.000E+01	1.1478E-01	1.1478E-01	1.1057E-01
20070108	1200	3.000E+01	1.1499E-01	1.1499E-01	1.1075E-01
20070109	1200	3.100E+01	1.1877E-01	1.1877E-01	1.1441E-01
20070110	1200	3.100E+01	1.1897E-01	1.1897E-01	1.1458E-01
20070111	1200	3.200E+01	1.2275E-01	1.2275E-01	1.1825E-01
20070112	1200	3.200E+01	1.2295E-01	1.2295E-01	1.1842E-01
20070113	1200	3.200E+01	1.2315E-01	1.2315E-01	1.1859E-01
20070114	1200	3.200E+01	1.2334E-01	1.2334E-01	1.1875E-01
20070115	1200	3.200E+01	1.2353E-01	1.2353E-01	1.1891E-01
20070116	1200	3.200E+01	1.2371E-01	1.2371E-01	1.1907E-01
20070117	1200	3.200E+01	1.2389E-01	1.2389E-01	1.1922E-01
20070118	1200	3.200E+01	1.2406E-01	1.2406E-01	1.1936E-01
20070119	1200	3.200E+01	1.2422E-01	1.2422E-01	1.1950E-01
20070120	1200	3.200E+01	1.2438E-01	1.2438E-01	1.1964E-01
20070121	1200	3.200E+01	1.2454E-01	1.2454E-01	1.1977E-01
20070122	1200	3.200E+01	1.2469E-01	1.2469E-01	1.1990E-01
20070123	1200	3.200E+01	1.2484E-01	1.2484E-01	1.2002E-01
20070124	1200	3.200E+01	1.2497E-01	1.2497E-01	1.2014E-01
20070125	1200	3.200E+01	1.2511E-01	1.2511E-01	1.2025E-01
20070126	1200	3.200E+01	1.2524E-01	1.2524E-01	1.2036E-01
20070127	1200	3.200E+01	1.2536E-01	1.2536E-01	1.2046E-01
20070128	1200	3.200E+01	1.2548E-01	1.2548E-01	1.2056E-01
20070129	1200	3.200E+01	1.2559E-01	1.2559E-01	1.2065E-01
20070130	1200	3.200E+01	1.2569E-01	1.2569E-01	1.2074E-01
20070131	1200	1.780E+02	6.2250E-01	6.2250E-01	6.1139E-01
20070201	1200	2.390E+02	8.1978E-01	8.1978E-01	8.0820E-01
20070202	1200	2.510E+02	8.5867E-01	8.5867E-01	8.4700E-01
20070203	1200	2.600E+02	8.8790E-01	8.8790E-01	8.7615E-01
20070204	1200	2.790E+02	9.4877E-01	9.4877E-01	9.3700E-01
20070205	1200	3.000E+02	1.0157E+00	1.0157E+00	1.0040E+00
20070206	1200	3.100E+02	1.0477E+00	1.0477E+00	1.0360E+00
20070207	1200	3.490E+02	1.1706E+00	1.1706E+00	1.1592E+00
20070208	1200	3.590E+02	1.2023E+00	1.2023E+00	1.1909E+00
20070209	1200	3.810E+02	1.2712E+00	1.2712E+00	1.2601E+00
20070210	1200	3.620E+02	1.2125E+00	1.2125E+00	1.2010E+00
20070211	1200	3.990E+02	1.3279E+00	1.3279E+00	1.3169E+00
20070212	1200	5.230E+02	1.7090E+00	1.7090E+00	1.7009E+00
20070213	1200	6.520E+02	2.0989E+00	2.0989E+00	2.0950E+00
20070214	1200	7.450E+02	2.3768E+00	2.3768E+00	2.3764E+00
20070215	1200	8.200E+02	2.5991E+00	2.5991E+00	2.6019E+00
20070216	1200	8.710E+02	2.7494E+00	2.7494E+00	2.7545E+00
20070217	1200	8.290E+02	2.6256E+00	2.6256E+00	2.6287E+00
20070218	1200	8.350E+02	2.6431E+00	2.6431E+00	2.6464E+00
20070219	1200	8.850E+02	2.7899E+00	2.7899E+00	2.7954E+00
20070220	1200	9.250E+02	2.9067E+00	2.9067E+00	2.9140E+00
20070221	1200	8.830E+02	2.7829E+00	2.7829E+00	2.7882E+00
20070222	1200	8.820E+02	2.7792E+00	2.7792E+00	2.7844E+00
20070223	1200	9.120E+02	2.8662E+00	2.8662E+00	2.8728E+00
20070224	1200	9.470E+02	2.9674E+00	2.9674E+00	2.9758E+00
20070225	1200	9.110E+02	2.8609E+00	2.8609E+00	2.8675E+00
20070226	1200	9.220E+02	2.8917E+00	2.8917E+00	2.8989E+00
20070227	1200	9.400E+02	2.9427E+00	2.9427E+00	2.9508E+00
20070228	1200	9.600E+02	2.9993E+00	2.9993E+00	3.0084E+00
20070301	1200	9.360E+02	2.9276E+00	2.9276E+00	2.9356E+00
20070302	1200	1.010E+03	3.1405E+00	3.1405E+00	3.1524E+00
20070303	1200	1.140E+03	3.5129E+00	3.5129E+00	3.5320E+00
20070304	1200	1.200E+03	3.6820E+00	3.6820E+00	3.7047E+00
20070305	1200	1.230E+03	3.7646E+00	3.7646E+00	3.7893E+00
20070306	1200	1.240E+03	3.7898E+00	3.7898E+00	3.8153E+00
20070307	1200	1.260E+03	3.8432E+00	3.8432E+00	3.8701E+00
20070308	1200	1.270E+03	3.8679E+00	3.8679E+00	3.8956E+00

20070309	1200	1.310E+03	3.9773E+00	3.9773E+00	4.0076E+00
20070310	1200	1.280E+03	3.8883E+00	3.8883E+00	3.9170E+00
20070311	1200	1.270E+03	3.8558E+00	3.8558E+00	3.8841E+00
20070312	1200	1.270E+03	3.8514E+00	3.8514E+00	3.8800E+00
20070313	1200	1.270E+03	3.8468E+00	3.8468E+00	3.8757E+00
20070314	1200	1.270E+03	3.8421E+00	3.8421E+00	3.8713E+00
20070315	1200	1.240E+03	3.7527E+00	3.7527E+00	3.7803E+00
20070316	1200	1.220E+03	3.6914E+00	3.6914E+00	3.7182E+00
20070317	1200	1.210E+03	3.6582E+00	3.6582E+00	3.6847E+00
20070318	1200	1.210E+03	3.6530E+00	3.6530E+00	3.6799E+00
20070319	1200	1.190E+03	3.5915E+00	3.5915E+00	3.6176E+00
20070320	1200	1.190E+03	3.5861E+00	3.5861E+00	3.6126E+00
20070321	1200	1.210E+03	3.6367E+00	3.6367E+00	3.6647E+00
20070322	1200	1.230E+03	3.6868E+00	3.6868E+00	3.7165E+00
20070323	1200	1.210E+03	3.6250E+00	3.6250E+00	3.6540E+00
20070324	1200	1.180E+03	3.5354E+00	3.5354E+00	3.5629E+00
20070325	1200	1.180E+03	3.5293E+00	3.5293E+00	3.5573E+00
20070326	1200	1.180E+03	3.5232E+00	3.5232E+00	3.5516E+00
20070327	1200	1.180E+03	3.5169E+00	3.5169E+00	3.5458E+00
20070328	1200	1.260E+03	3.7317E+00	3.7317E+00	3.7663E+00
20070329	1200	1.370E+03	4.0268E+00	4.0268E+00	4.0693E+00
20070330	1200	1.270E+03	3.7452E+00	3.7452E+00	3.7815E+00
20070331	1200	1.190E+03	3.5181E+00	3.5181E+00	3.5497E+00
20070401	1200	1.100E+03	3.2632E+00	3.2632E+00	3.2896E+00
20070402	1200	1.060E+03	3.1462E+00	3.1462E+00	3.1706E+00
20070403	1200	9.790E+02	2.9156E+00	2.9156E+00	2.9358E+00
20070404	1200	9.660E+02	2.8736E+00	2.8736E+00	2.8934E+00
20070405	1200	9.700E+02	2.8786E+00	2.8786E+00	2.8992E+00
20070406	1200	9.660E+02	2.8614E+00	2.8614E+00	2.8822E+00
20070407	1200	7.860E+02	2.3561E+00	2.3561E+00	2.3673E+00
20070408	1200	6.340E+02	1.9243E+00	1.9243E+00	1.9284E+00
20070409	1200	5.850E+02	1.7814E+00	1.7814E+00	1.7836E+00
20070410	1200	5.280E+02	1.6154E+00	1.6154E+00	1.6156E+00
20070411	1200	4.800E+02	1.4748E+00	1.4748E+00	1.4734E+00
20070412	1200	4.780E+02	1.4656E+00	1.4656E+00	1.4645E+00
20070413	1200	4.660E+02	1.4279E+00	1.4279E+00	1.4266E+00
20070414	1200	3.430E+02	1.0707E+00	1.0707E+00	1.0657E+00
20070415	1200	3.720E+02	1.1520E+00	1.1520E+00	1.1481E+00
20070416	1200	2.890E+02	9.0827E-01	9.0827E-01	9.0242E-01
20070417	1200	1.440E+02	4.7338E-01	4.7338E-01	4.6621E-01
20070418	1200	1.860E+02	5.9939E-01	5.9939E-01	5.9241E-01
20070419	1200	2.180E+02	6.9320E-01	6.9320E-01	6.8671E-01
20070420	1200	1.960E+02	6.2618E-01	6.2618E-01	6.1961E-01
20070421	1200	1.540E+02	4.9886E-01	4.9886E-01	4.9221E-01
20070422	1200	9.100E+01	3.0473E-01	3.0473E-01	2.9871E-01
20070423	1200	1.510E+02	4.8726E-01	4.8726E-01	4.8087E-01
20070424	1200	1.590E+02	5.0993E-01	5.0993E-01	5.0371E-01
20070425	1200	1.390E+02	4.4869E-01	4.4869E-01	4.4256E-01
20070426	1200	1.110E+02	3.6286E-01	3.6286E-01	3.5696E-01
20070427	1200	6.100E+01	2.0713E-01	2.0713E-01	2.0226E-01
20070428	1200	6.500E+01	2.1917E-01	2.1917E-01	2.1425E-01
20070429	1200	6.600E+01	2.2170E-01	2.2170E-01	2.1682E-01
20070430	1200	6.300E+01	2.1171E-01	2.1171E-01	2.0699E-01
20070501	1200	1.130E+02	3.6395E-01	3.6395E-01	3.5860E-01
20070502	1200	1.510E+02	4.7553E-01	4.7553E-01	4.7041E-01
20070503	1200	2.230E+02	6.8197E-01	6.8197E-01	6.7823E-01
20070504	1200	3.560E+02	1.0516E+00	1.0516E+00	1.0525E+00
20070505	1200	3.320E+02	9.8261E-01	9.8261E-01	9.8284E-01
20070506	1200	2.840E+02	8.4715E-01	8.4715E-01	8.4586E-01
20070507	1200	2.180E+02	6.6023E-01	6.6023E-01	6.5715E-01
20070508	1200	1.150E+02	3.6275E-01	3.6275E-01	3.5819E-01
20070509	1200	6.300E+01	2.0643E-01	2.0643E-01	2.0233E-01
20070510	1200	1.800E+01	6.4026E-02	6.4026E-02	6.1783E-02
20070511	1200	1.300E+01	4.7135E-02	4.7135E-02	4.5312E-02

20070512	1200	1.700E+01	6.0356E-02	6.0356E-02	5.8233E-02
20070513	1200	4.900E+01	1.6146E-01	1.6146E-01	1.5792E-01
20070514	1200	1.310E+02	4.0260E-01	4.0260E-01	3.9888E-01
20070515	1200	1.970E+02	5.8715E-01	5.8715E-01	5.8498E-01
20070516	1200	2.020E+02	5.9929E-01	5.9929E-01	5.9744E-01
20070517	1200	1.780E+02	5.3112E-01	5.3112E-01	5.2877E-01
20070518	1200	1.910E+02	5.6554E-01	5.6554E-01	5.6372E-01
20070519	1200	1.900E+02	5.6116E-01	5.6116E-01	5.5948E-01
20070520	1200	2.080E+02	6.0878E-01	6.0878E-01	6.0785E-01
20070521	1200	2.240E+02	6.5043E-01	6.5043E-01	6.5026E-01
20070522	1200	2.530E+02	7.2647E-01	7.2647E-01	7.2764E-01
20070523	1200	2.280E+02	6.5744E-01	6.5744E-01	6.5781E-01
20070524	1200	1.870E+02	5.4498E-01	5.4498E-01	5.4404E-01
20070525	1200	1.540E+02	4.5348E-01	4.5348E-01	4.5169E-01
20070526	1200	1.330E+02	3.9444E-01	3.9444E-01	3.9226E-01
20070527	1200	8.400E+01	2.5630E-01	2.5630E-01	2.5345E-01
20070528	1200	1.500E+01	5.1296E-02	5.1296E-02	4.9642E-02
20070529	1200	1.180E+02	3.4981E-01	3.4981E-01	3.4765E-01
20070530	1200	2.320E+02	6.5495E-01	6.5495E-01	6.5683E-01
20070531	1200	1.490E+02	4.3230E-01	4.3230E-01	4.3118E-01
20070601	1200	4.800E+01	1.5000E-01	1.5000E-01	1.4748E-01
20070602	1200	1.700E+01	5.6839E-02	5.6839E-02	5.5173E-02
20070603	1200	1.800E+01	5.9784E-02	5.9784E-02	5.8089E-02
20070604	1200	2.000E+01	6.5772E-02	6.5772E-02	6.4011E-02
20070605	1200	3.400E+01	1.0756E-01	1.0756E-01	1.0542E-01
20070606	1200	2.570E+02	7.0655E-01	7.0655E-01	7.1099E-01
20070607	1200	4.820E+02	1.2659E+00	1.2659E+00	1.2849E+00
20070608	1200	3.140E+02	8.4691E-01	8.4691E-01	8.5497E-01
20070609	1200	2.230E+02	6.1402E-01	6.1402E-01	6.1728E-01
20070610	1200	1.770E+02	4.9378E-01	4.9378E-01	4.9504E-01
20070611	1200	1.230E+02	3.5082E-01	3.5082E-01	3.5016E-01
20070612	1200	8.500E+01	2.4796E-01	2.4796E-01	2.4638E-01
20070613	1200	9.000E+01	2.6084E-01	2.6084E-01	2.5944E-01
20070614	1200	9.200E+01	2.6555E-01	2.6555E-01	2.6428E-01
20070615	1200	9.100E+01	2.6218E-01	2.6218E-01	2.6096E-01
20070616	1200	8.800E+01	2.5347E-01	2.5347E-01	2.5225E-01
20070617	1200	7.800E+01	2.2595E-01	2.2595E-01	2.2457E-01
20070618	1200	1.900E+01	6.0431E-02	6.0431E-02	5.9003E-02
20070619	1200	1.800E+01	5.7319E-02	5.7319E-02	5.5941E-02
20070620	1200	1.700E+01	5.4212E-02	5.4212E-02	5.2884E-02
20070621	1200	1.400E+01	4.5128E-02	4.5128E-02	4.3926E-02
20070622	1200	1.400E+01	4.5020E-02	4.5020E-02	4.3832E-02
20070623	1200	1.400E+01	4.4914E-02	4.4914E-02	4.3740E-02
20070624	1200	1.800E+01	5.6639E-02	5.6639E-02	5.5348E-02
20070625	1200	1.700E+01	5.3576E-02	5.3576E-02	5.2330E-02
20070626	1200	1.800E+01	5.6380E-02	5.6380E-02	5.5122E-02
20070627	1200	1.700E+01	5.3335E-02	5.3335E-02	5.2120E-02
20070628	1200	1.600E+01	5.0293E-02	5.0293E-02	4.9122E-02
20070629	1200	2.100E+01	6.4662E-02	6.4662E-02	6.3390E-02
20070630	1200	2.200E+01	6.7383E-02	6.7383E-02	6.6112E-02
20070701	1200	2.200E+01	6.7241E-02	6.7241E-02	6.5988E-02
20070702	1200	1.400E+01	4.4031E-02	4.4031E-02	4.2973E-02
20070703	1200	1.900E+01	5.8412E-02	5.8412E-02	5.7242E-02
20070704	1200	1.700E+01	5.2554E-02	5.2554E-02	5.1440E-02
20070705	1200	2.900E+01	8.6287E-02	8.6287E-02	8.5055E-02
20070706	1200	2.000E+01	6.0911E-02	6.0911E-02	5.9770E-02
20070707	1200	1.800E+01	5.5109E-02	5.5109E-02	5.4016E-02
20070708	1200	1.700E+01	5.2153E-02	5.2153E-02	5.1092E-02
20070709	1200	1.800E+01	5.4907E-02	5.4907E-02	5.3840E-02
20070710	1200	2.200E+01	6.6082E-02	6.6082E-02	6.4977E-02
20070711	1200	2.400E+01	7.1540E-02	7.1540E-02	7.0436E-02
20070712	1200	1.700E+01	5.1787E-02	5.1787E-02	5.0774E-02
20070713	1200	1.300E+01	4.0262E-02	4.0262E-02	3.9348E-02
20070714	1200	1.100E+01	3.4401E-02	3.4401E-02	3.3554E-02

20070715	1200	1.400E+01	4.3004E-02	4.3004E-02	4.2082E-02
20070716	1200	1.100E+01	3.4294E-02	3.4294E-02	3.3462E-02
20070717	1200	1.300E+01	4.0012E-02	4.0012E-02	3.9132E-02
20070718	1200	2.900E+01	8.4399E-02	8.4399E-02	8.3408E-02
20070719	1200	2.300E+01	6.7905E-02	6.7905E-02	6.6919E-02
20070720	1200	1.900E+01	5.6751E-02	5.6751E-02	5.5800E-02
20070721	1200	1.800E+01	5.3891E-02	5.3891E-02	5.2959E-02
20070722	1200	2.700E+01	7.8538E-02	7.8538E-02	7.7595E-02
20070723	1200	3.000E+01	8.6534E-02	8.6534E-02	8.5624E-02
20070724	1200	2.100E+01	6.1988E-02	6.1988E-02	6.1064E-02
20070725	1200	1.900E+01	5.6403E-02	5.6403E-02	5.5499E-02
20070726	1200	4.100E+01	1.1538E-01	1.1538E-01	1.1468E-01
20070727	1200	2.840E+02	6.9947E-01	6.9947E-01	7.1328E-01
20070728	1200	2.920E+02	7.1708E-01	7.1708E-01	7.3161E-01
20070729	1200	2.070E+02	5.1995E-01	5.1995E-01	5.2813E-01
20070730	1200	1.180E+02	3.0773E-01	3.0773E-01	3.1029E-01
20070731	1200	1.040E+02	2.7333E-01	2.7333E-01	2.7518E-01

North Fork Weber River near West Warren, Utah

```
#############################################################################
#
#  LOADEST Calibration File
#
#  Weber River at West Warren
#
#  Total Se (dissolved + particulate)
#  Updated with thru 6/2007; however, no data for 2/2007.
#  Artificial data was removed, because minimum sample size was met
#
#############################################################################
#
#CDATE      CTIME    CFLOW   CCONC
#
#############################################################################
20060517     1325     49     0.184
20060606     1030     48     0.216
20060712     0930     45     0.232
20060808     0945     52     0.148
20060907     0910     38     0.205
20061012     0930     66     0.121
20061109     0930     59     0.193
20061220     1245     27     0.192
20070302     1420     6     0.248
20070416     1245     29     0.269
20070517     1530     39     0.22
20070620     1025     11     0.211
```

```
################################################################################
#
#  LOADEST Estimation File
#
#  Weber River at West Warren
#
#
#
################################################################################
#
#  Number of observations per day, NOBSPD (col. 1-5)
#
################################################################################
1
################################################################################
#
# EDATE    ETIME   EFLOW
#
################################################################################
20060511    1200    101
20060512    1200    92
20060513    1200    67
20060514    1200    49
20060515    1200    47
20060516    1200    47
20060517    1200    49
20060518    1200    54
20060519    1200    68
20060520    1200    73
20060521    1200    55
20060522    1200    55
20060523    1200    55
20060524    1200    59
20060525    1200    53
20060526    1200    41
20060527    1200    28
20060528    1200    31
20060529    1200    69
20060530    1200    95
20060531    1200    96
20060601    1200    77
20060602    1200    52
20060603    1200    43
20060604    1200    38
20060605    1200    35
20060606    1200    48
20060607    1200    93
20060608    1200    107
20060609    1200    103
20060610    1200    108
20060611    1200    120
20060612    1200    127
20060613    1200    115
20060614    1200    97
20060615    1200    70
20060616    1200    47
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20060624	1200	34
20060625	1200	35
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20060627	1200	38
20060628	1200	38
20060629	1200	41
20060630	1200	42
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20060704	1200	45
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20060710	1200	46
20060711	1200	46
20060712	1200	45
20060713	1200	45
20060714	1200	45
20060715	1200	44
20060716	1200	43
20060717	1200	43
20060718	1200	31
20060719	1200	9.6
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20060724	1200	39
20060725	1200	41
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20060818	1200	35
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20060830	1200	46
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20061004	1200	61
20061005	1200	62
20061006	1200	70

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20061228	1200	51
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20070113	1200	51
20070114	1200	52
20070115	1200	49
20070116	1200	42
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20070122	1200	36
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20070126	1200	25

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20070514	1200	36
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20070618	1200	13
20070619	1200	10
20070620	1200	11
20070621	1200	13
20070622	1200	12
20070623	1200	8.9
20070624	1200	7.2
20070625	1200	8.1
20070626	1200	9.3
20070627	1200	11
20070628	1200	13
20070629	1200	14
20070630	1200	13
20070701	1200	12
20070702	1200	12
20070703	1200	12
20070704	1200	13
20070705	1200	16
20070706	1200	17
20070707	1200	16
20070708	1200	15
20070709	1200	12
20070710	1200	11
20070711	1200	15
20070712	1200	17
20070713	1200	18

20070714	1200	20
20070715	1200	22
20070716	1200	22
20070717	1200	20
20070718	1200	16
20070719	1200	12
20070720	1200	9.8
20070721	1200	10
20070722	1200	11
20070723	1200	12
20070724	1200	13
20070725	1200	16
20070726	1200	20
20070727	1200	23
20070728	1200	25
20070729	1200	26
20070730	1200	26
20070731	1200	26

LOADEST
A Program to Estimate Constituent Loads
U.S. Geological Survey, Version: MOD36 (Sep 2004)

Weber River at West Warren

Constituent: selenium

Constituent Output File Part Ia: Calibration (Load Regression)

Number of Observations : 12
Number of Uncensored Observations: 12
"center" of Decimal Time : 2006.920
"center" of Ln(Q) : 3.0078
Period of record : 2006-2007

Model Evaluation Criteria Based on AMLE Results

Model #	AIC	SPPC
1	-0.256	1.052
2	-0.343	1.329
3	-0.074	-0.283
4	-0.264	0.614
5	-0.152	-0.056
6	-0.256	0.327
7	-0.050	-0.910
8	-0.034	-1.250
9	0.040	-1.937

Model # 2 selected

Selected Model:

Ln(Load) = a0 + a1 LnQ + a2 LnQ^2

where:
Load = constituent load [kg/d]
LnQ = Ln(Q) - center of Ln(Q)

Model Coefficients

a0 a1 a2

AMLE	-4.4001	0.8402	-0.1997
MLE	-4.4001	0.8402	-0.1997
LAD	-4.5137	0.8881	-0.0149

AMLE Regression Statistics

R-Squared [%] : 93.32
Prob. Plot Corr. Coeff. (PPCC) : 0.9508
Serial Correlation of Residuals: -.2685

Coeff.	Std.Dev.	t-ratio	P Value
a0	0.1051	-41.86	1.758E-15
a1	0.0758	11.09	1.376E-08
a2	0.1182	-1.69	6.909E-02

Correlation Between Explanatory Variables

Explanatory variable corresponding to:

	a1
a2	0.0000

Additional Regression Statistics

	Residual Variance	Turnbull-Weiss Stat	DF	PL
AMLE	0.032	1.36	1	2.437E-01
MLE	0.032	1.36	1	2.437E-01

Constituent Output File Part Ib: Calibration (Concentration Regression)

AMLE Regression Statistics

Model # 2 was selected for the load regression (PART Ia) and is used here:

Ln(Conc) = a0 + a1 LnQ + a2 LnQ^2

where:
Conc = constituent concentration
LnQ = Ln(Q) - center of Ln(Q)

Concentration Regression Results

R-Squared [%] : 44.78
Residual Variance : 0.0324

Coeff.	Value	Std.Dev.	t-ratio	P Value
a0	-1.3948	0.1051	-13.27	1.706E-09
a1	-0.1598	0.0758	-2.11	2.820E-02
a2	-0.1997	0.1182	-1.69	6.909E-02

Constituent Output File Part IIa: Estimation (test for extrapolation)

Load Estimates for 20060511-20070731

Streamflow Summary Statistics [cfs]

Data	Mean	Minimum	10th Pct	25th Pct	Median	75th Pct	90th Pct	Maximum
Cal.	39.	6.	8.	28.	42.	51.	64.	66.
Est.	41.	3.	12.	27.	38.	52.	66.	127.

WARNING: The maximum estimation data set steamflow exceeds the maximum calibration data set streamflow. Load estimates require extrapolation.

Maximum Estimation Streamflow : 1.2700E+02
Maximum Calibration Streamflow: 6.6000E+01

Constituent Output File Part IIb: Estimation (Load Estimates)

Load Estimates for 20060511-20070731

Load Estimates [KG/DAY]

AMLE Load Estimates

	N	Mean Load	95% Conf.Intervals Lower	95% Conf.Intervals Upper	Std Error Prediction	Standard Error
Est. Period	447	1.832E-02	1.631E-02	2.051E-02	1.074E-03	1.061E-03

MLE Load Estimates

	N	Mean Load	Standard Error

Est. Period	447	1.832E-02	1.059E-03

LAD Load Estimates

	N	Mean Load	Standard Error
Est. Period	447	1.922E-02	2.480E-03

Summary Statistics - Estimated Loads [KG/DAY]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.001	0.016	0.020	0.023	0.025	0.027	0.028	0.028
MLE	0.001	0.016	0.020	0.023	0.025	0.027	0.028	0.028
LAD	0.002	0.014	0.019	0.024	0.030	0.038	0.046	0.052

Summary Statistics - Estimated Concentrations [UG/L]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.091	0.179	0.208	0.231	0.253	0.258	0.259	0.259
MLE	0.091	0.179	0.208	0.231	0.253	0.258	0.259	0.259
LAD	0.17	0.19	0.20	0.21	0.23	0.24	0.25	0.25

Individual Load Estimates for Weber River near West Warren, uT.
Selenium looad in kg/day

			Loads Estimated by:		
Date	Time	Flow	AMLE	MLE	LAD
20060511	1200	1.010E+02	2.7911E-02	2.7911E-02	4.2865E-02
20060512	1200	9.200E+01	2.7561E-02	2.7561E-02	3.9626E-02
20060513	1200	6.700E+01	2.5458E-02	2.5458E-02	3.0285E-02
20060514	1200	4.900E+01	2.2393E-02	2.2393E-02	2.3160E-02
20060515	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20060516	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20060517	1200	4.900E+01	2.2393E-02	2.2393E-02	2.3160E-02
20060518	1200	5.400E+01	2.3419E-02	2.3419E-02	2.5180E-02
20060519	1200	6.800E+01	2.5583E-02	2.5583E-02	3.0669E-02
20060520	1200	7.300E+01	2.6149E-02	2.6149E-02	3.2578E-02
20060521	1200	5.500E+01	2.3607E-02	2.3607E-02	2.5580E-02
20060522	1200	5.500E+01	2.3607E-02	2.3607E-02	2.5580E-02
20060523	1200	5.500E+01	2.3607E-02	2.3607E-02	2.5580E-02
20060524	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20060525	1200	5.300E+01	2.3226E-02	2.3226E-02	2.4778E-02
20060526	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20060527	1200	2.800E+01	1.5982E-02	1.5982E-02	1.4232E-02
20060528	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20060529	1200	6.900E+01	2.5704E-02	2.5704E-02	3.1053E-02
20060530	1200	9.500E+01	2.7697E-02	2.7697E-02	4.0713E-02
20060531	1200	9.600E+01	2.7738E-02	2.7738E-02	4.1073E-02
20060601	1200	7.700E+01	2.6537E-02	2.6537E-02	3.4088E-02
20060602	1200	5.200E+01	2.3027E-02	2.3027E-02	2.4376E-02
20060603	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20060604	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060605	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060606	1200	4.800E+01	2.2169E-02	2.2169E-02	2.2752E-02
20060607	1200	9.300E+01	2.7608E-02	2.7608E-02	3.9989E-02
20060608	1200	1.070E+02	2.8056E-02	2.8056E-02	4.4993E-02
20060609	1200	1.030E+02	2.7966E-02	2.7967E-02	4.3577E-02
20060610	1200	1.080E+02	2.8074E-02	2.8074E-02	4.5345E-02
20060611	1200	1.200E+02	2.8171E-02	2.8172E-02	4.9525E-02
20060612	1200	1.270E+02	2.8139E-02	2.8140E-02	5.1924E-02
20060613	1200	1.150E+02	2.8156E-02	2.8157E-02	4.7794E-02
20060614	1200	9.700E+01	2.7776E-02	2.7776E-02	4.1433E-02
20060615	1200	7.000E+01	2.5821E-02	2.5821E-02	3.1436E-02
20060616	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20060617	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20060618	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20060619	1200	1.400E+01	8.8564E-03	8.8564E-03	7.6860E-03
20060620	1200	1.700E+01	1.0647E-02	1.0647E-02	9.1468E-03
20060621	1200	2.300E+01	1.3775E-02	1.3775E-02	1.1966E-02
20060622	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20060623	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20060624	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20060625	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060626	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20060627	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060628	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060629	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20060630	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20060701	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20060702	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20060703	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20060704	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02

20060705	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20060706	1200	4.600E+01	2.1701E-02	2.1701E-02	2.1931E-02
20060707	1200	4.800E+01	2.2169E-02	2.2169E-02	2.2752E-02
20060708	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20060709	1200	4.600E+01	2.1701E-02	2.1701E-02	2.1931E-02
20060710	1200	4.600E+01	2.1701E-02	2.1701E-02	2.1931E-02
20060711	1200	4.600E+01	2.1701E-02	2.1701E-02	2.1931E-02
20060712	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20060713	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20060714	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20060715	1200	4.400E+01	2.1204E-02	2.1204E-02	2.1105E-02
20060716	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20060717	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20060718	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20060719	1200	9.600E+00	5.9299E-03	5.9299E-03	5.4634E-03
20060720	1200	2.200E+01	1.3292E-02	1.3292E-02	1.1505E-02
20060721	1200	2.800E+01	1.5982E-02	1.5982E-02	1.4232E-02
20060722	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20060723	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060724	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20060725	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20060726	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20060727	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20060728	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20060729	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060730	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20060731	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060801	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20060802	1200	4.400E+01	2.1204E-02	2.1204E-02	2.1105E-02
20060803	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20060804	1200	5.600E+01	2.3788E-02	2.3789E-02	2.5978E-02
20060805	1200	5.300E+01	2.3226E-02	2.3226E-02	2.4778E-02
20060806	1200	5.200E+01	2.3027E-02	2.3027E-02	2.4376E-02
20060807	1200	5.100E+01	2.2822E-02	2.2822E-02	2.3972E-02
20060808	1200	5.200E+01	2.3027E-02	2.3027E-02	2.4376E-02
20060809	1200	4.800E+01	2.2169E-02	2.2169E-02	2.2752E-02
20060810	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20060811	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20060812	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060813	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060814	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060815	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060816	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20060817	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060818	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060819	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060820	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060821	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060822	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060823	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20060824	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20060825	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20060826	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20060827	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20060828	1200	4.600E+01	2.1701E-02	2.1701E-02	2.1931E-02
20060829	1200	4.800E+01	2.2169E-02	2.2169E-02	2.2752E-02
20060830	1200	4.600E+01	2.1701E-02	2.1701E-02	2.1931E-02
20060831	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20060901	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20060902	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20060903	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20060904	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20060905	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20060906	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02

20060907	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060908	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20060909	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20060910	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20060911	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20060912	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20060913	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20060914	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20060915	1200	4.900E+01	2.2393E-02	2.2393E-02	2.3160E-02
20060916	1200	7.700E+01	2.6537E-02	2.6537E-02	3.4088E-02
20060917	1200	1.060E+02	2.8036E-02	2.8036E-02	4.4640E-02
20060918	1200	1.140E+02	2.8149E-02	2.8149E-02	4.7446E-02
20060919	1200	1.040E+02	2.7992E-02	2.7992E-02	4.3932E-02
20060920	1200	8.900E+01	2.7404E-02	2.7404E-02	3.8533E-02
20060921	1200	8.800E+01	2.7347E-02	2.7347E-02	3.8168E-02
20060922	1200	9.100E+01	2.7511E-02	2.7511E-02	3.9263E-02
20060923	1200	9.300E+01	2.7608E-02	2.7608E-02	3.9989E-02
20060924	1200	9.200E+01	2.7561E-02	2.7561E-02	3.9626E-02
20060925	1200	7.600E+01	2.6445E-02	2.6445E-02	3.3712E-02
20060926	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20060927	1200	5.500E+01	2.3607E-02	2.3607E-02	2.5580E-02
20060928	1200	5.800E+01	2.4136E-02	2.4136E-02	2.6772E-02
20060929	1200	6.200E+01	2.4770E-02	2.4770E-02	2.8344E-02
20060930	1200	6.300E+01	2.4917E-02	2.4917E-02	2.8734E-02
20061001	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061002	1200	6.000E+01	2.4463E-02	2.4463E-02	2.7560E-02
20061003	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20061004	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061005	1200	6.200E+01	2.4770E-02	2.4770E-02	2.8344E-02
20061006	1200	7.000E+01	2.5821E-02	2.5821E-02	3.1436E-02
20061007	1200	8.000E+01	2.6793E-02	2.6793E-02	3.5211E-02
20061008	1200	9.300E+01	2.7608E-02	2.7608E-02	3.9989E-02
20061009	1200	9.400E+01	2.7654E-02	2.7654E-02	4.0351E-02
20061010	1200	7.900E+01	2.6711E-02	2.6711E-02	3.4838E-02
20061011	1200	6.700E+01	2.5458E-02	2.5458E-02	3.0285E-02
20061012	1200	6.600E+01	2.5329E-02	2.5329E-02	2.9899E-02
20061013	1200	6.600E+01	2.5329E-02	2.5329E-02	2.9899E-02
20061014	1200	6.500E+01	2.5196E-02	2.5196E-02	2.9512E-02
20061015	1200	6.600E+01	2.5329E-02	2.5329E-02	2.9899E-02
20061016	1200	6.900E+01	2.5704E-02	2.5704E-02	3.1053E-02
20061017	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20061018	1200	4.400E+01	2.1204E-02	2.1204E-02	2.1105E-02
20061019	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20061020	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20061021	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20061022	1200	5.600E+01	2.3788E-02	2.3789E-02	2.5978E-02
20061023	1200	6.000E+01	2.4463E-02	2.4463E-02	2.7560E-02
20061024	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061025	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061026	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061027	1200	6.400E+01	2.5059E-02	2.5059E-02	2.9124E-02
20061028	1200	6.400E+01	2.5059E-02	2.5059E-02	2.9124E-02
20061029	1200	6.300E+01	2.4917E-02	2.4917E-02	2.8734E-02
20061030	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061031	1200	6.000E+01	2.4463E-02	2.4463E-02	2.7560E-02
20061101	1200	6.000E+01	2.4463E-02	2.4463E-02	2.7560E-02
20061102	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20061103	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20061104	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20061105	1200	5.800E+01	2.4136E-02	2.4136E-02	2.6772E-02
20061106	1200	5.800E+01	2.4136E-02	2.4136E-02	2.6772E-02
20061107	1200	5.800E+01	2.4136E-02	2.4136E-02	2.6772E-02
20061108	1200	5.700E+01	2.3965E-02	2.3965E-02	2.6376E-02
20061109	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02

20061110	1200	5.900E+01	2.4302E-02	2.4302E-02	2.7167E-02
20061111	1200	6.200E+01	2.4770E-02	2.4770E-02	2.8344E-02
20061112	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061113	1200	6.200E+01	2.4770E-02	2.4770E-02	2.8344E-02
20061114	1200	6.700E+01	2.5458E-02	2.5458E-02	3.0285E-02
20061115	1200	8.700E+01	2.7287E-02	2.7287E-02	3.7801E-02
20061116	1200	9.600E+01	2.7738E-02	2.7738E-02	4.1073E-02
20061117	1200	8.300E+01	2.7022E-02	2.7022E-02	3.6326E-02
20061118	1200	7.200E+01	2.6043E-02	2.6043E-02	3.2199E-02
20061119	1200	6.500E+01	2.5196E-02	2.5196E-02	2.9512E-02
20061120	1200	6.100E+01	2.4619E-02	2.4619E-02	2.7953E-02
20061121	1200	5.800E+01	2.4136E-02	2.4136E-02	2.6772E-02
20061122	1200	5.500E+01	2.3607E-02	2.3607E-02	2.5580E-02
20061123	1200	5.300E+01	2.3226E-02	2.3226E-02	2.4778E-02
20061124	1200	5.200E+01	2.3027E-02	2.3027E-02	2.4376E-02
20061125	1200	5.100E+01	2.2822E-02	2.2822E-02	2.3972E-02
20061126	1200	5.000E+01	2.2611E-02	2.2611E-02	2.3567E-02
20061127	1200	5.000E+01	2.2611E-02	2.2611E-02	2.3567E-02
20061128	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20061129	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20061130	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20061201	1200	4.600E+01	2.1701E-02	2.1701E-02	2.1931E-02
20061202	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20061203	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20061204	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20061205	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20061206	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20061207	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20061208	1200	2.800E+01	1.5982E-02	1.5982E-02	1.4232E-02
20061209	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20061210	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20061211	1200	2.800E+01	1.5982E-02	1.5982E-02	1.4232E-02
20061212	1200	2.800E+01	1.5982E-02	1.5982E-02	1.4232E-02
20061213	1200	2.800E+01	1.5982E-02	1.5982E-02	1.4232E-02
20061214	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20061215	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20061216	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20061217	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20061218	1200	3.200E+01	1.7526E-02	1.7526E-02	1.5999E-02
20061219	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20061220	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20061221	1200	2.500E+01	1.4698E-02	1.4698E-02	1.2880E-02
20061222	1200	2.500E+01	1.4698E-02	1.4698E-02	1.2880E-02
20061223	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20061224	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20061225	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20061226	1200	4.900E+01	2.2393E-02	2.2393E-02	2.3160E-02
20061227	1200	5.100E+01	2.2822E-02	2.2822E-02	2.3972E-02
20061228	1200	5.100E+01	2.2822E-02	2.2822E-02	2.3972E-02
20061229	1200	5.500E+01	2.3607E-02	2.3607E-02	2.5580E-02
20061230	1200	6.200E+01	2.4770E-02	2.4770E-02	2.8344E-02
20061231	1200	6.400E+01	2.5059E-02	2.5059E-02	2.9124E-02
20070101	1200	6.000E+01	2.4463E-02	2.4463E-02	2.7560E-02
20070102	1200	5.400E+01	2.3419E-02	2.3419E-02	2.5180E-02
20070103	1200	5.800E+01	2.4136E-02	2.4136E-02	2.6772E-02
20070104	1200	6.400E+01	2.5059E-02	2.5059E-02	2.9124E-02
20070105	1200	6.300E+01	2.4917E-02	2.4917E-02	2.8734E-02
20070106	1200	6.700E+01	2.5458E-02	2.5458E-02	3.0285E-02
20070107	1200	6.400E+01	2.5059E-02	2.5059E-02	2.9124E-02
20070108	1200	6.200E+01	2.4770E-02	2.4770E-02	2.8344E-02
20070109	1200	6.000E+01	2.4463E-02	2.4463E-02	2.7560E-02
20070110	1200	5.100E+01	2.2822E-02	2.2822E-02	2.3972E-02
20070111	1200	4.700E+01	2.1938E-02	2.1939E-02	2.2343E-02
20070112	1200	4.800E+01	2.2169E-02	2.2169E-02	2.2752E-02

20070113	1200	5.100E+01	2.2822E-02	2.2822E-02	2.3972E-02
20070114	1200	5.200E+01	2.3027E-02	2.3027E-02	2.4376E-02
20070115	1200	4.900E+01	2.2393E-02	2.2393E-02	2.3160E-02
20070116	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20070117	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070118	1200	3.200E+01	1.7526E-02	1.7526E-02	1.5999E-02
20070119	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20070120	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20070121	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070122	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070123	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20070124	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20070125	1200	2.100E+01	1.2795E-02	1.2795E-02	1.1040E-02
20070126	1200	2.500E+01	1.4698E-02	1.4698E-02	1.2880E-02
20070127	1200	2.400E+01	1.4243E-02	1.4243E-02	1.2425E-02
20070128	1200	2.400E+01	1.4243E-02	1.4243E-02	1.2425E-02
20070129	1200	2.300E+01	1.3775E-02	1.3775E-02	1.1966E-02
20070130	1200	2.400E+01	1.4243E-02	1.4243E-02	1.2425E-02
20070131	1200	2.500E+01	1.4698E-02	1.4698E-02	1.2880E-02
20070201	1200	1.700E+01	1.0647E-02	1.0647E-02	9.1468E-03
20070202	1200	7.000E+00	4.0430E-03	4.0430E-03	4.0921E-03
20070203	1200	8.000E+00	4.7801E-03	4.7801E-03	4.6256E-03
20070204	1200	8.000E+00	4.7801E-03	4.7801E-03	4.6256E-03
20070205	1200	7.000E+00	4.0430E-03	4.0430E-03	4.0921E-03
20070206	1200	7.000E+00	4.0430E-03	4.0430E-03	4.0921E-03
20070207	1200	7.000E+00	4.0430E-03	4.0430E-03	4.0921E-03
20070208	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070209	1200	1.800E+01	1.1209E-02	1.1209E-02	9.6255E-03
20070210	1200	1.600E+01	1.0068E-02	1.0068E-02	8.6641E-03
20070211	1200	2.300E+01	1.3775E-02	1.3775E-02	1.1966E-02
20070212	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070213	1200	2.600E+01	1.5139E-02	1.5139E-02	1.3333E-02
20070214	1200	1.700E+01	1.0647E-02	1.0647E-02	9.1468E-03
20070215	1200	9.600E+00	5.9299E-03	5.9299E-03	5.4634E-03
20070216	1200	8.400E+00	5.0713E-03	5.0713E-03	4.8368E-03
20070217	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070218	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070219	1200	9.400E+00	5.7884E-03	5.7884E-03	5.3596E-03
20070220	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070221	1200	7.700E+00	4.5602E-03	4.5602E-03	4.4664E-03
20070222	1200	5.300E+00	2.7734E-03	2.7734E-03	3.1647E-03
20070223	1200	5.200E+00	2.6988E-03	2.6988E-03	3.1093E-03
20070224	1200	4.900E+00	2.4755E-03	2.4755E-03	2.9422E-03
20070225	1200	4.100E+00	1.8879E-03	1.8879E-03	2.4915E-03
20070226	1200	3.500E+00	1.4607E-03	1.4607E-03	2.1478E-03
20070227	1200	5.000E+00	2.5498E-03	2.5498E-03	2.9980E-03
20070228	1200	3.400E+00	1.3912E-03	1.3913E-03	2.0901E-03
20070301	1200	4.700E+00	2.3273E-03	2.3273E-03	2.8302E-03
20070302	1200	6.300E+00	3.5213E-03	3.5213E-03	3.7136E-03
20070303	1200	5.000E+00	2.5498E-03	2.5498E-03	2.9980E-03
20070304	1200	3.500E+00	1.4607E-03	1.4607E-03	2.1478E-03
20070305	1200	2.600E+00	8.6230E-04	8.6246E-04	1.6220E-03
20070306	1200	4.200E+00	1.9604E-03	1.9604E-03	2.5482E-03
20070307	1200	6.500E+00	3.6707E-03	3.6707E-03	3.8222E-03
20070308	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070309	1200	2.300E+01	1.3775E-02	1.3775E-02	1.1966E-02
20070310	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070311	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20070312	1200	4.400E+01	2.1204E-02	2.1204E-02	2.1105E-02
20070313	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070314	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20070315	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20070316	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20070317	1200	3.200E+01	1.7526E-02	1.7526E-02	1.5999E-02

20070318	1200	3.000E+01	1.6777E-02	1.6777E-02	1.5120E-02
20070319	1200	3.000E+01	1.6777E-02	1.6777E-02	1.5120E-02
20070320	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20070321	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20070322	1200	2.600E+01	1.5139E-02	1.5139E-02	1.3333E-02
20070323	1200	1.100E+01	6.9000E-03	6.9000E-03	6.1824E-03
20070324	1200	6.600E+00	3.7453E-03	3.7453E-03	3.8764E-03
20070325	1200	6.700E+00	3.8199E-03	3.8199E-03	3.9305E-03
20070326	1200	1.400E+01	8.8564E-03	8.8564E-03	7.6860E-03
20070327	1200	2.100E+01	1.2795E-02	1.2795E-02	1.1040E-02
20070328	1200	2.600E+01	1.5139E-02	1.5139E-02	1.3333E-02
20070329	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20070330	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070331	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070401	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20070402	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20070403	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070404	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070405	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070406	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070407	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20070408	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20070409	1200	5.200E+01	2.3027E-02	2.3027E-02	2.4376E-02
20070410	1200	5.600E+01	2.3788E-02	2.3789E-02	2.5978E-02
20070411	1200	5.200E+01	2.3027E-02	2.3027E-02	2.4376E-02
20070412	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20070413	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070414	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20070415	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20070416	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20070417	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20070418	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20070419	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20070420	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20070421	1200	2.800E+01	1.5982E-02	1.5982E-02	1.4232E-02
20070422	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20070423	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070424	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070425	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070426	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070427	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20070428	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20070429	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20070430	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20070501	1200	3.100E+01	1.7157E-02	1.7157E-02	1.5560E-02
20070502	1200	3.000E+01	1.6777E-02	1.6777E-02	1.5120E-02
20070503	1200	2.900E+01	1.6385E-02	1.6385E-02	1.4677E-02
20070504	1200	3.300E+01	1.7884E-02	1.7884E-02	1.6435E-02
20070505	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20070506	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20070507	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20070508	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20070509	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20070510	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070511	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070512	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02
20070513	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070514	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070515	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070516	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20070517	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20070518	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070519	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20070520	1200	4.000E+01	2.0118E-02	2.0118E-02	1.9432E-02

20070521	1200	4.500E+01	2.1456E-02	2.1456E-02	2.1519E-02
20070522	1200	4.900E+01	2.2393E-02	2.2393E-02	2.3160E-02
20070523	1200	6.000E+01	2.4463E-02	2.4463E-02	2.7560E-02
20070524	1200	6.600E+01	2.5329E-02	2.5329E-02	2.9899E-02
20070525	1200	5.500E+01	2.3607E-02	2.3607E-02	2.5580E-02
20070526	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20070527	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070528	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20070529	1200	3.600E+01	1.8898E-02	1.8898E-02	1.7731E-02
20070530	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070531	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20070601	1200	4.300E+01	2.0944E-02	2.0944E-02	2.0689E-02
20070602	1200	4.100E+01	2.0402E-02	2.0402E-02	1.9853E-02
20070603	1200	3.900E+01	1.9827E-02	1.9827E-02	1.9009E-02
20070604	1200	3.700E+01	1.9217E-02	1.9217E-02	1.8159E-02
20070605	1200	3.500E+01	1.8570E-02	1.8570E-02	1.7301E-02
20070606	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20070607	1200	1.500E+01	9.4713E-03	9.4713E-03	8.1773E-03
20070608	1200	9.700E+00	6.0003E-03	6.0003E-03	5.5151E-03
20070609	1200	7.100E+00	4.1172E-03	4.1172E-03	4.1459E-03
20070610	1200	2.000E+01	1.2282E-02	1.2282E-02	1.0572E-02
20070611	1200	2.700E+01	1.5567E-02	1.5567E-02	1.3784E-02
20070612	1200	3.800E+01	1.9526E-02	1.9526E-02	1.8585E-02
20070613	1200	4.200E+01	2.0677E-02	2.0677E-02	2.0272E-02
20070614	1200	3.400E+01	1.8232E-02	1.8232E-02	1.6869E-02
20070615	1200	2.300E+01	1.3775E-02	1.3775E-02	1.1966E-02
20070616	1200	2.000E+01	1.2282E-02	1.2282E-02	1.0572E-02
20070617	1200	1.700E+01	1.0647E-02	1.0647E-02	9.1468E-03
20070618	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070619	1200	1.000E+01	6.2106E-03	6.2107E-03	5.6701E-03
20070620	1200	1.100E+01	6.9000E-03	6.9000E-03	6.1824E-03
20070621	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070622	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070623	1200	8.900E+00	5.4319E-03	5.4319E-03	5.0991E-03
20070624	1200	7.200E+00	4.1913E-03	4.1913E-03	4.1995E-03
20070625	1200	8.100E+00	4.8531E-03	4.8531E-03	4.6785E-03
20070626	1200	9.300E+00	5.7174E-03	5.7174E-03	5.3077E-03
20070627	1200	1.100E+01	6.9000E-03	6.9000E-03	6.1824E-03
20070628	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070629	1200	1.400E+01	8.8564E-03	8.8564E-03	7.6860E-03
20070630	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070701	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070702	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070703	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070704	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070705	1200	1.600E+01	1.0068E-02	1.0068E-02	8.6641E-03
20070706	1200	1.700E+01	1.0647E-02	1.0647E-02	9.1468E-03
20070707	1200	1.600E+01	1.0068E-02	1.0068E-02	8.6641E-03
20070708	1200	1.500E+01	9.4713E-03	9.4713E-03	8.1773E-03
20070709	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070710	1200	1.100E+01	6.9000E-03	6.9000E-03	6.1824E-03
20070711	1200	1.500E+01	9.4713E-03	9.4713E-03	8.1773E-03
20070712	1200	1.700E+01	1.0647E-02	1.0647E-02	9.1468E-03
20070713	1200	1.800E+01	1.1209E-02	1.1209E-02	9.6255E-03
20070714	1200	2.000E+01	1.2282E-02	1.2282E-02	1.0572E-02
20070715	1200	2.200E+01	1.3292E-02	1.3292E-02	1.1505E-02
20070716	1200	2.200E+01	1.3292E-02	1.3292E-02	1.1505E-02
20070717	1200	2.000E+01	1.2282E-02	1.2282E-02	1.0572E-02
20070718	1200	1.600E+01	1.0068E-02	1.0068E-02	8.6641E-03
20070719	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03
20070720	1200	9.800E+00	6.0706E-03	6.0706E-03	5.5669E-03
20070721	1200	1.000E+01	6.2106E-03	6.2107E-03	5.6701E-03
20070722	1200	1.100E+01	6.9000E-03	6.9000E-03	6.1824E-03
20070723	1200	1.200E+01	7.5709E-03	7.5709E-03	6.6889E-03

20070724	1200	1.300E+01	8.2230E-03	8.2230E-03	7.1900E-03
20070725	1200	1.600E+01	1.0068E-02	1.0068E-02	8.6641E-03
20070726	1200	2.000E+01	1.2282E-02	1.2282E-02	1.0572E-02
20070727	1200	2.300E+01	1.3775E-02	1.3775E-02	1.1966E-02
20070728	1200	2.500E+01	1.4698E-02	1.4698E-02	1.2880E-02
20070729	1200	2.600E+01	1.5139E-02	1.5139E-02	1.3333E-02
20070730	1200	2.600E+01	1.5139E-02	1.5139E-02	1.3333E-02
20070731	1200	2.600E+01	1.5139E-02	1.5139E-02	1.3333E-02

GSL Farmington Bay Outflow at Causeway Bridge

```
#############################################################################
#
#  LOADEST Calibration File
#
#  Farmington Bay outflow
#
#
#  Total Se (dissolved + particulate)
#
#############################################################################
#
#CDATE      CTIME    CFLOW     CCONC
#
#############################################################################
20060508     1500     118     0.427
20060509     1500     729     0.596
20060510     1500     457     0.853
20060511     1500     412     0.628
20060513     1500     685     0.586
20060517     1500     484     0.755
20060520     1500     210     0.882
20060523     1500     653     0.741
20060524     1130     347     0.608
20060525     1100     361     0.679
20060526     1130     491     0.751
20060529     1130     128     0.646
20060601     1130     306     0.614
20060603     1130     436     0.55
20060609     1129      84     0.662
20060718     1100     186     0.269
20060808     1245      68     0.455
20060907     1220     355     0.503
20061010     1100     474     0.479
20061121     1115     423     0.374
20061220     1615     296     0.468
20070202     1250     273     0.484
20070305     1350     230     0.64
20070419     1045     858     0.543
20070420     1100     398     0.667
20070421     1100     831     0.623
20070422     1100     920     0.622
20070424     1100      50     0.613
20070425     1100     664     0.585
20070427     1100     376     0.682
20070429     1100     562     0.679
20070501     1100     495     0.693
20070503     1100     0.0001     0.702
20070509     1115     0.0001     0.693
20070511     1115     0.0001     0.559
20070514     1115     0.0001     0.624
20070518     1430     442     0.573
20070519     1115     305     0.617
20070524     1215     800     0.615
```

20070527	1215	559	0.556
20070529	1215	0.0001	0.657
20070531	1215	255	0.586
20070602	1215	167	0.57
20070606	1215	0.0001	0.742
20070607	1215	0.0001	0.591
20070619	1410	323	0.389
20070717	1400	125	0.588

```
#################################################################################
#
#  LOADEST Estimation File
#
#  Farmington Bay outflow
# **all negative flow values set to 0.0001**
# Before 10/10/06 Missing discharge values calculated from
# Surplus-Goggin+Jordan. After 10/10/06 missing values average of
# values bordering missing period (usually less than 5 days)
#
#
#
#################################################################################
#
#  Number of observations per day, NOBSPD (col. 1-5)
#
#################################################################################
1
#################################################################################
#
# EDATE         ETIME      EFLOW
#
#################################################################################
20060503        1200        262
20060504        1200        313
20060505        1200        255
20060506        1200        149.2
20060507        1200        150
20060508        1200        118.3
20060509        1200        729
20060510        1200        457
20060511        1200        412
20060512        1200        431
20060513        1200        685
20060514        1200        485
20060515        1200        435
20060516        1200        451
20060517        1200        484
20060518        1200        462
20060519        1200        303
20060520        1200        210
20060521        1200        460
20060522        1200        621
20060523        1200        653
20060524        1200        347
20060525        1200        361
20060526        1200        491
20060527        1200        462
20060528        1200        204
20060529        1200        128
20060530        1200        285
20060531        1200        273
20060601        1200        306
20060602        1200        337
20060603        1200        436
20060604        1200        350
```

20060605	1200	465
20060606	1200	320
20060607	1200	350
20060608	1200	387
20060609	1200	84
20060610	1200	345
20060611	1200	323
20060612	1200	312
20060613	1200	116
20060614	1200	248
20060615	1200	116
20060616	1200	113
20060617	1200	170
20060618	1200	230
20060619	1200	359
20060620	1200	336
20060621	1200	319
20060622	1200	299
20060623	1200	317
20060624	1200	338
20060625	1200	355
20060626	1200	357
20060627	1200	342
20060628	1200	370
20060629	1200	398
20060630	1200	591
20060701	1200	366
20060702	1200	339
20060703	1200	370
20060704	1200	52
20060705	1200	444
20060706	1200	395
20060707	1200	304
20060708	1200	644
20060709	1200	280
20060710	1200	322
20060711	1200	0.0001
20060712	1200	283
20060713	1200	425
20060714	1200	385
20060715	1200	384
20060716	1200	394
20060717	1200	419
20060718	1200	186
20060719	1200	127
20060720	1200	426
20060721	1200	415
20060722	1200	431
20060723	1200	502
20060724	1200	718
20060725	1200	502
20060726	1200	485
20060727	1200	308
20060728	1200	429
20060729	1200	371
20060730	1200	477

20060731	1200	497
20060801	1200	398
20060802	1200	185
20060803	1200	0.0001
20060804	1200	0.0001
20060805	1200	115
20060806	1200	0.0001
20060807	1200	0.0001
20060808	1200	68
20060809	1200	468
20060810	1200	228
20060811	1200	297
20060812	1200	328
20060813	1200	661
20060814	1200	136
20060815	1200	0.0001
20060816	1200	0.0001
20060817	1200	657
20060818	1200	550
20060819	1200	264
20060820	1200	244
20060821	1200	199
20060822	1200	164
20060823	1200	57
20060824	1200	392
20060825	1200	450
20060826	1200	558
20060827	1200	189
20060828	1200	132
20060829	1200	0.0001
20060830	1200	340
20060831	1200	366
20060901	1200	374
20060902	1200	371
20060903	1200	361
20060904	1200	370
20060905	1200	387
20060906	1200	360
20060907	1200	355
20060908	1200	372
20060909	1200	366
20060910	1200	371
20060911	1200	363
20060912	1200	364
20060913	1200	366
20060914	1200	466
20060915	1200	448
20060916	1200	315
20060917	1200	319
20060918	1200	396
20060919	1200	350
20060920	1200	357
20060921	1200	221
20060922	1200	445
20060923	1200	252
20060924	1200	279

20060925	1200	292
20060926	1200	289
20060927	1200	335
20060928	1200	320
20060929	1200	312
20060930	1200	316
20061001	1200	306
20061002	1200	358
20061003	1200	401
20061004	1200	371
20061005	1200	403
20061006	1200	344
20061007	1200	263
20061008	1200	179
20061009	1200	275
20061010	1200	596
20061011	1200	751
20061012	1200	731
20061013	1200	704
20061014	1200	694
20061015	1200	743
20061016	1200	357
20061017	1200	0.0001
20061018	1200	588
20061019	1200	719
20061020	1200	0.0001
20061021	1200	750
20061022	1200	838
20061023	1200	708
20061024	1200	746
20061025	1200	0.0001
20061026	1200	608
20061027	1200	780
20061028	1200	803
20061029	1200	781
20061030	1200	308
20061031	1200	641
20061101	1200	720
20061102	1200	717
20061103	1200	725
20061104	1200	709
20061105	1200	700
20061106	1200	696
20061107	1200	684
20061108	1200	343
20061109	1200	273
20061110	1200	777
20061111	1200	614
20061112	1200	596
20061113	1200	889
20061114	1200	0.0001
20061115	1200	522
20061116	1200	397
20061117	1200	424
20061118	1200	396
20061119	1200	379

20061120	1200	346
20061121	1200	396
20061122	1200	323
20061123	1200	93
20061124	1200	326
20061125	1200	343
20061126	1200	338
20061127	1200	388
20061128	1200	0.0001
20061129	1200	0.0001
20061130	1200	420
20061201	1200	298
20061202	1200	286
20061203	1200	342
20061204	1200	297
20061205	1200	273
20061206	1200	279
20061207	1200	276
20061208	1200	259
20061209	1200	255
20061210	1200	247
20061211	1200	272
20061212	1200	306
20061213	1200	291
20061214	1200	363
20061215	1200	237
20061216	1200	221
20061217	1200	252
20061218	1200	321
20061219	1200	348
20061220	1200	337
20061221	1200	340
20061222	1200	293
20061223	1200	320
20061224	1200	325
20061225	1200	312
20061226	1200	315
20061227	1200	299
20061228	1200	0.0001
20061229	1200	0.0001
20061230	1200	388
20061231	1200	341
20070101	1200	319
20070102	1200	300
20070103	1200	281
20070104	1200	298
20070105	1200	241
20070106	1200	264
20070107	1200	269
20070108	1200	261
20070109	1200	250
20070110	1200	261
20070111	1200	268
20070112	1200	288
20070113	1200	295
20070114	1200	302

20070115	1200	360
20070116	1200	322
20070117	1200	262
20070118	1200	272
20070119	1200	265
20070120	1200	266
20070121	1200	274
20070122	1200	292
20070123	1200	274
20070124	1200	274
20070125	1200	274
20070126	1200	274
20070127	1200	274
20070128	1200	274
20070129	1200	274
20070130	1200	255
20070131	1200	274
20070201	1200	251
20070202	1200	273
20070203	1200	283
20070204	1200	273
20070205	1200	252
20070206	1200	259
20070207	1200	259
20070208	1200	262
20070209	1200	256
20070210	1200	263
20070211	1200	297
20070212	1200	304
20070213	1200	350
20070214	1200	336
20070215	1200	382
20070216	1200	294
20070217	1200	350
20070218	1200	335
20070219	1200	282
20070220	1200	326
20070221	1200	315
20070222	1200	324
20070223	1200	16
20070224	1200	344
20070225	1200	458
20070226	1200	254
20070227	1200	7.3
20070228	1200	114
20070301	1200	0.0001
20070302	1200	0.0001
20070303	1200	383
20070304	1200	204
20070305	1200	230
20070306	1200	257
20070307	1200	207
20070308	1200	227
20070309	1200	118
20070310	1200	0.0001
20070311	1200	201

20070312	1200	187
20070313	1200	166
20070314	1200	60
20070315	1200	0.0001
20070316	1200	169
20070317	1200	148
20070318	1200	63
20070319	1200	37
20070320	1200	0.0001
20070321	1200	0.0001
20070322	1200	0.0001
20070323	1200	0.0001
20070324	1200	0.0001
20070325	1200	256
20070326	1200	156
20070327	1200	432
20070328	1200	0.0001
20070329	1200	0.0001
20070330	1200	591
20070331	1200	400
20070401	1200	101
20070402	1200	0.0001
20070403	1200	0.0001
20070404	1200	265
20070405	1200	58
20070406	1200	182
20070407	1200	225
20070408	1200	416
20070409	1200	637
20070410	1200	637
20070411	1200	637
20070412	1200	637
20070413	1200	637
20070414	1200	637
20070415	1200	637
20070416	1200	637
20070417	1200	637
20070418	1200	637
20070419	1200	858
20070420	1200	398
20070421	1200	831
20070422	1200	920
20070423	1200	108
20070424	1200	50
20070425	1200	664
20070426	1200	97
20070427	1200	376
20070428	1200	594
20070429	1200	562
20070430	1200	140
20070501	1200	495
20070502	1200	469
20070503	1200	0.0001
20070504	1200	0.0001
20070505	1200	0.0001
20070506	1200	0.0001

20070507	1200	0.0001
20070508	1200	0.0001
20070509	1200	0.0001
20070510	1200	0.0001
20070511	1200	0.0001
20070512	1200	0.0001
20070513	1200	0.0001
20070514	1200	0.0001
20070515	1200	0.0001
20070516	1200	126
20070517	1200	744
20070518	1200	442
20070519	1200	305
20070520	1200	27
20070521	1200	0.0001
20070522	1200	0.0001
20070523	1200	0.0001
20070524	1200	800
20070525	1200	580
20070526	1200	472
20070527	1200	559
20070528	1200	0.0001
20070529	1200	0.0001
20070530	1200	301
20070531	1200	255
20070601	1200	258
20070602	1200	167
20070603	1200	123
20070604	1200	274
20070605	1200	408
20070606	1200	0.0001
20070607	1200	0.0001
20070608	1200	855
20070609	1200	724
20070610	1200	374
20070611	1200	0.0001
20070612	1200	298
20070613	1200	500
20070614	1200	200
20070615	1200	139
20070616	1200	216
20070617	1200	0.0001
20070618	1200	471
20070619	1200	323
20070620	1200	374
20070621	1200	178
20070622	1200	286
20070623	1200	179
20070624	1200	59
20070625	1200	0.0001
20070626	1200	158
20070627	1200	316
20070628	1200	426
20070629	1200	287
20070630	1200	91
20070701	1200	121

20070702	1200	62
20070703	1200	0.0001
20070704	1200	108
20070705	1200	177
20070706	1200	320
20070707	1200	51
20070708	1200	122
20070709	1200	163
20070710	1200	71
20070711	1200	73
20070712	1200	272
20070713	1200	204
20070714	1200	265
20070715	1200	101
20070716	1200	242
20070717	1200	125
20070718	1200	470
20070719	1200	165
20070720	1200	64
20070721	1200	132
20070722	1200	51
20070723	1200	239
20070724	1200	157
20070725	1200	97
20070726	1200	29
20070727	1200	98
20070728	1200	0.0001
20070729	1200	121
20070730	1200	182
20070731	1200	127

LOADEST
A Program to Estimate Constituent Loads
U.S. Geological Survey, Version: MOD36 (Sep 2004)

Farmington Bay

Constituent: selenium

Constituent Output File Part Ia: Calibration (Load Regression)

Number of Observations : 47
Number of Uncensored Observations: 47
"center" of Decimal Time : 2006.893
"center" of Ln(Q) : -1.5796
Period of record : 2006-2007

Model Evaluation Criteria Based on AMLE Results

Model #	AIC	SPPC
1	-0.214	3.186
2	-0.222	2.436
3	-0.178	1.417
4	-0.552	9.263
5	-0.194	0.855
6	-0.516	7.505
7	-0.540	8.069
8	-0.508	6.392
9	-0.481	4.829

Model # 4 selected

Selected Model:

Ln(Load) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime)

where:
Load = constituent load [kg/d]
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Model Coefficients

	a0	a1	a2	a3
AMLE	-8.2500	0.9966	0.1500	-0.1918
MLE	-8.2500	0.9966	0.1500	-0.1918
LAD	-8.2055	0.9954	0.0721	-0.1648

AMLE Regression Statistics

R-Squared [%] : 99.90
Prob. Plot Corr. Coeff. (PPCC) : 0.9414
Serial Correlation of Residuals: 0.0295

Coeff.	Std.Dev.	t-ratio	P Value
a0	0.0550	-149.88	5.929E-66
a1	0.0049	205.40	2.134E-72
a2	0.0600	2.50	1.152E-02
a3	0.0511	-3.75	2.636E-04

Correlation Between Explanatory Variables

Explanatory variable corresponding to:

	a1	a2
a2	0.0379	
a3	0.1799	-0.1061

Additional Regression Statistics

	Residual Variance	Turnbull-Weiss Stat	DF	PL
AMLE	0.031	12.70	6	4.808E-02
MLE	0.031	12.70	6	4.808E-02

Constituent Output File Part Ib: Calibration (Concentration Regression)

AMLE Regression Statistics

Model # 4 was selected for the load regression (PART Ia) and is used here:

Ln(Conc) = a0 + a1 LnQ + a2 Sin(2 pi dtime) + a3 Cos(2 pi dtime)

where:
Conc = constituent concentration
LnQ = Ln(Q) - center of Ln(Q)
dtime = decimal time - center of decimal time

Concentration Regression Results

R-Squared [%] : 36.29
Residual Variance : 0.0310

Coeff.	Value	Std.Dev.	t-ratio	P Value

a0	-0.6574	0.0550	-11.94	1.122E-16
a1	-0.0034	0.0049	-0.70	4.684E-01
a2	0.1500	0.0600	2.50	1.152E-02
a3	-0.1918	0.0511	-3.75	2.636E-04

Constituent Output File Part IIa: Estimation (test for extrapolation)

Load Estimates for 20060503-20070731

Streamflow Summary Statistics [cfs]

Data	Mean	Minimum	10th Pct	25th Pct	Median	75th Pct	90th Pct	Maximum
Cal.	348.	0.	0.	125.	347.	491.	743.	920.
Est.	307.	0.	0.	166.	299.	397.	637.	920.

The maximum estimation data set steamflow does not exceed the maximum calibration data set streamflow. No extrapolation is required.

Constituent Output File Part IIb: Estimation (Load Estimates)

Load Estimates for 20060503-20070731

Load Estimates [KG/DAY]

AMLE Load Estimates

	N	Mean Load	95% Conf.Intervals Lower	95% Conf.Intervals Upper	Std Error Prediction	Standard Error
Est. Period	455	0.39	0.36	0.42	0.02	0.02

MLE Load Estimates

	N	Mean Load	Standard Error
Est. Period	455	0.39	0.02

LAD Load Estimates

	N	Mean Load	Standard Error
Est. Period	455	0.40	0.04

Summary Statistics - Estimated Loads [KG/DAY]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.000	0.222	0.364	0.510	0.729	0.944	1.224	1.465
MLE	0.000	0.222	0.364	0.510	0.729	0.944	1.224	1.465
LAD	0.000	0.231	0.369	0.525	0.769	0.941	1.227	1.403

Summary Statistics - Estimated Concentrations [UG/L]

	Min.	25th Pct	Med.	75th Pct	90th Pct	95th Pct	99th Pct	Max.
AMLE	0.40	0.45	0.53	0.62	0.65	0.66	0.68	0.68
MLE	0.40	0.45	0.53	0.62	0.65	0.66	0.68	0.68
LAD	0.44	0.47	0.55	0.61	0.63	0.65	0.67	0.67

Individual Load Estimates for Farmington Bay Outflow in kg/day

			Loads Estimated by:		
Date	Time	Flow	AMLE	MLE	LAD
20060503	1200	2.620E+02	4.1518E-01	4.1518E-01	4.0241E-01
20060504	1200	3.130E+02	4.9506E-01	4.9506E-01	4.8026E-01
20060505	1200	2.550E+02	4.0307E-01	4.0307E-01	3.9154E-01
20060506	1200	1.492E+02	2.3593E-01	2.3593E-01	2.2958E-01
20060507	1200	1.500E+02	2.3684E-01	2.3684E-01	2.3073E-01
20060508	1200	1.183E+02	1.8665E-01	1.8665E-01	1.8209E-01
20060509	1200	7.290E+02	1.1412E+00	1.1412E+00	1.1123E+00
20060510	1200	4.570E+02	7.1534E-01	7.1534E-01	6.9841E-01
20060511	1200	4.120E+02	6.4400E-01	6.4400E-01	6.2959E-01
20060512	1200	4.310E+02	6.7237E-01	6.7237E-01	6.5808E-01
20060513	1200	6.850E+02	1.0649E+00	1.0649E+00	1.0430E+00
20060514	1200	4.850E+02	7.5341E-01	7.5341E-01	7.3911E-01
20060515	1200	4.350E+02	6.7463E-01	6.7463E-01	6.6274E-01
20060516	1200	4.510E+02	6.9790E-01	6.9790E-01	6.8644E-01
20060517	1200	4.840E+02	7.4719E-01	7.4719E-01	7.3578E-01
20060518	1200	4.620E+02	7.1177E-01	7.1177E-01	7.0184E-01
20060519	1200	3.030E+02	4.6643E-01	4.6643E-01	4.6074E-01
20060520	1200	2.100E+02	3.2292E-01	3.2292E-01	3.1954E-01
20060521	1200	4.600E+02	7.0376E-01	7.0376E-01	6.9667E-01
20060522	1200	6.210E+02	9.4678E-01	9.4678E-01	9.3816E-01
20060523	1200	6.530E+02	9.9290E-01	9.9290E-01	9.8512E-01
20060524	1200	3.470E+02	5.2742E-01	5.2742E-01	5.2437E-01
20060525	1200	3.610E+02	5.4718E-01	5.4719E-01	5.4473E-01
20060526	1200	4.910E+02	7.4145E-01	7.4145E-01	7.3887E-01
20060527	1200	4.620E+02	6.9590E-01	6.9590E-01	6.9448E-01
20060528	1200	2.040E+02	3.0729E-01	3.0729E-01	3.0737E-01
20060529	1200	1.280E+02	1.9257E-01	1.9257E-01	1.9299E-01
20060530	1200	2.850E+02	4.2635E-01	4.2635E-01	4.2748E-01
20060531	1200	2.730E+02	4.0726E-01	4.0726E-01	4.0893E-01
20060601	1200	3.060E+02	4.5494E-01	4.5494E-01	4.5739E-01
20060602	1200	3.370E+02	4.9933E-01	4.9933E-01	5.0267E-01
20060603	1200	4.360E+02	6.4345E-01	6.4345E-01	6.4847E-01
20060604	1200	3.500E+02	5.1529E-01	5.1529E-01	5.2019E-01
20060605	1200	4.650E+02	6.8175E-01	6.8175E-01	6.8898E-01
20060606	1200	3.200E+02	4.6824E-01	4.6824E-01	4.7408E-01
20060607	1200	3.500E+02	5.1030E-01	5.1030E-01	5.1735E-01
20060608	1200	3.870E+02	5.6217E-01	5.6217E-01	5.7069E-01
20060609	1200	8.400E+01	1.2225E-01	1.2225E-01	1.2450E-01
20060610	1200	3.450E+02	4.9795E-01	4.9795E-01	5.0702E-01
20060611	1200	3.230E+02	4.6469E-01	4.6469E-01	4.7387E-01
20060612	1200	3.120E+02	4.4734E-01	4.4734E-01	4.5685E-01
20060613	1200	1.160E+02	1.6629E-01	1.6629E-01	1.7027E-01
20060614	1200	2.480E+02	3.5333E-01	3.5333E-01	3.6198E-01
20060615	1200	1.160E+02	1.6510E-01	1.6510E-01	1.6953E-01
20060616	1200	1.130E+02	1.6026E-01	1.6026E-01	1.6480E-01
20060617	1200	1.700E+02	2.3987E-01	2.3987E-01	2.4691E-01
20060618	1200	2.300E+02	3.2298E-01	3.2298E-01	3.3282E-01
20060619	1200	3.590E+02	5.0147E-01	5.0147E-01	5.1722E-01
20060620	1200	3.360E+02	4.6767E-01	4.6767E-01	4.8309E-01
20060621	1200	3.190E+02	4.4239E-01	4.4239E-01	4.5765E-01
20060622	1200	2.990E+02	4.1314E-01	4.1314E-01	4.2805E-01
20060623	1200	3.170E+02	4.3623E-01	4.3623E-01	4.5257E-01
20060624	1200	3.380E+02	4.6320E-01	4.6321E-01	4.8121E-01
20060625	1200	3.550E+02	4.8451E-01	4.8451E-01	5.0402E-01
20060626	1200	3.570E+02	4.8530E-01	4.8530E-01	5.0555E-01
20060627	1200	3.420E+02	4.6312E-01	4.6312E-01	4.8315E-01

20060628	1200	3.700E+02	4.9889E-01	4.9889E-01	5.2115E-01
20060629	1200	3.980E+02	5.3435E-01	5.3435E-01	5.5892E-01
20060630	1200	5.910E+02	7.8918E-01	7.8918E-01	8.2624E-01
20060701	1200	3.660E+02	4.8754E-01	4.8754E-01	5.1143E-01
20060702	1200	3.390E+02	4.4985E-01	4.4985E-01	4.7257E-01
20060703	1200	3.700E+02	4.8882E-01	4.8882E-01	5.1416E-01
20060704	1200	5.200E+01	6.8877E-02	6.8877E-02	7.2712E-02
20060705	1200	4.440E+02	5.8139E-01	5.8139E-01	6.1306E-01
20060706	1200	3.950E+02	5.1529E-01	5.1529E-01	5.4415E-01
20060707	1200	3.040E+02	3.9528E-01	3.9528E-01	4.1810E-01
20060708	1200	6.440E+02	8.3173E-01	8.3173E-01	8.8015E-01
20060709	1200	2.800E+02	3.6114E-01	3.6114E-01	3.8303E-01
20060710	1200	3.220E+02	4.1338E-01	4.1338E-01	4.3893E-01
20060711	1200	1.000E-04	1.3424E-07	1.3424E-07	1.4559E-07
20060712	1200	2.830E+02	3.6042E-01	3.6042E-01	3.8374E-01
20060713	1200	4.250E+02	5.3824E-01	5.3824E-01	5.7352E-01
20060714	1200	3.850E+02	4.8570E-01	4.8570E-01	5.1824E-01
20060715	1200	3.840E+02	4.8240E-01	4.8240E-01	5.1536E-01
20060716	1200	3.940E+02	4.9283E-01	4.9283E-01	5.2713E-01
20060717	1200	4.190E+02	5.2178E-01	5.2179E-01	5.5874E-01
20060718	1200	1.860E+02	2.3130E-01	2.3130E-01	2.4821E-01
20060719	1200	1.270E+02	1.5747E-01	1.5747E-01	1.6926E-01
20060720	1200	4.260E+02	5.2380E-01	5.2380E-01	5.6288E-01
20060721	1200	4.150E+02	5.0818E-01	5.0818E-01	5.4674E-01
20060722	1200	4.310E+02	5.2549E-01	5.2549E-01	5.6599E-01
20060723	1200	5.020E+02	6.0918E-01	6.0918E-01	6.5675E-01
20060724	1200	7.180E+02	8.6659E-01	8.6659E-01	9.3491E-01
20060725	1200	5.020E+02	6.0411E-01	6.0411E-01	6.5271E-01
20060726	1200	4.850E+02	5.8130E-01	5.8130E-01	6.2877E-01
20060727	1200	3.080E+02	3.6820E-01	3.6820E-01	3.9890E-01
20060728	1200	4.290E+02	5.1015E-01	5.1015E-01	5.5305E-01
20060729	1200	3.710E+02	4.3959E-01	4.3959E-01	4.7712E-01
20060730	1200	4.770E+02	5.6239E-01	5.6239E-01	6.1084E-01
20060731	1200	4.970E+02	5.8350E-01	5.8350E-01	6.3436E-01
20060801	1200	3.980E+02	4.6573E-01	4.6573E-01	5.0695E-01
20060802	1200	1.850E+02	2.1617E-01	2.1617E-01	2.3574E-01
20060803	1200	1.000E-04	1.2196E-07	1.2196E-07	1.3573E-07
20060804	1200	1.000E-04	1.2147E-07	1.2147E-07	1.3531E-07
20060805	1200	1.150E+02	1.3299E-01	1.3299E-01	1.4551E-01
20060806	1200	1.000E-04	1.2051E-07	1.2051E-07	1.3448E-07
20060807	1200	1.000E-04	1.2003E-07	1.2003E-07	1.3406E-07
20060808	1200	6.800E+01	7.7855E-02	7.7855E-02	8.5455E-02
20060809	1200	4.680E+02	5.3026E-01	5.3026E-01	5.8118E-01
20060810	1200	2.280E+02	2.5798E-01	2.5798E-01	2.8321E-01
20060811	1200	2.970E+02	3.3447E-01	3.3447E-01	3.6735E-01
20060812	1200	3.280E+02	3.6786E-01	3.6786E-01	4.0428E-01
20060813	1200	6.610E+02	7.3679E-01	7.3679E-01	8.0967E-01
20060814	1200	1.360E+02	1.5185E-01	1.5185E-01	1.6730E-01
20060815	1200	1.000E-04	1.1644E-07	1.1644E-07	1.3085E-07
20060816	1200	1.000E-04	1.1601E-07	1.1601E-07	1.3046E-07
20060817	1200	6.570E+02	7.2172E-01	7.2172E-01	7.9525E-01
20060818	1200	5.500E+02	6.0240E-01	6.0240E-01	6.6432E-01
20060819	1200	2.640E+02	2.8886E-01	2.8886E-01	3.1901E-01
20060820	1200	2.440E+02	2.6612E-01	2.6612E-01	2.9410E-01
20060821	1200	1.990E+02	2.1644E-01	2.1644E-01	2.3939E-01
20060822	1200	1.640E+02	1.7789E-01	1.7789E-01	1.9689E-01
20060823	1200	5.700E+01	6.1840E-02	6.1840E-02	6.8570E-02
20060824	1200	3.920E+02	4.2112E-01	4.2112E-01	4.6609E-01
20060825	1200	4.500E+02	4.8162E-01	4.8162E-01	5.3322E-01
20060826	1200	5.580E+02	5.9486E-01	5.9486E-01	6.5871E-01
20060827	1200	1.890E+02	2.0159E-01	2.0159E-01	2.2360E-01
20060828	1200	1.320E+02	1.4052E-01	1.4052E-01	1.5600E-01
20060829	1200	1.000E-04	1.1106E-07	1.1106E-07	1.2573E-07
20060830	1200	3.400E+02	3.5860E-01	3.5860E-01	3.9792E-01

20060831	1200	3.660E+02	3.8478E-01	3.8478E-01	4.2707E-01
20060901	1200	3.740E+02	3.9202E-01	3.9202E-01	4.3521E-01
20060902	1200	3.710E+02	3.8777E-01	3.8777E-01	4.3062E-01
20060903	1200	3.610E+02	3.7629E-01	3.7629E-01	4.1799E-01
20060904	1200	3.700E+02	3.8458E-01	3.8458E-01	4.2727E-01
20060905	1200	3.870E+02	4.0110E-01	4.0110E-01	4.4569E-01
20060906	1200	3.600E+02	3.7222E-01	3.7222E-01	4.1371E-01
20060907	1200	3.550E+02	3.6612E-01	3.6612E-01	4.0699E-01
20060908	1200	3.720E+02	3.8262E-01	3.8262E-01	4.2536E-01
20060909	1200	3.660E+02	3.7554E-01	3.7554E-01	4.1754E-01
20060910	1200	3.710E+02	3.7974E-01	3.7974E-01	4.2222E-01
20060911	1200	3.630E+02	3.7070E-01	3.7070E-01	4.1220E-01
20060912	1200	3.640E+02	3.7087E-01	3.7087E-01	4.1240E-01
20060913	1200	3.660E+02	3.7207E-01	3.7207E-01	4.1372E-01
20060914	1200	4.660E+02	4.7231E-01	4.7231E-01	5.2502E-01
20060915	1200	4.480E+02	4.5317E-01	4.5317E-01	5.0375E-01
20060916	1200	3.150E+02	3.1837E-01	3.1837E-01	3.5402E-01
20060917	1200	3.190E+02	3.2176E-01	3.2176E-01	3.5774E-01
20060918	1200	3.960E+02	3.9836E-01	3.9837E-01	4.4275E-01
20060919	1200	3.500E+02	3.5159E-01	3.5159E-01	3.9076E-01
20060920	1200	3.570E+02	3.5795E-01	3.5795E-01	3.9775E-01
20060921	1200	2.210E+02	2.2157E-01	2.2157E-01	2.4630E-01
20060922	1200	4.450E+02	4.4435E-01	4.4435E-01	4.9342E-01
20060923	1200	2.520E+02	2.5172E-01	2.5172E-01	2.7963E-01
20060924	1200	2.790E+02	2.7817E-01	2.7817E-01	3.0889E-01
20060925	1200	2.920E+02	2.9066E-01	2.9066E-01	3.2265E-01
20060926	1200	2.890E+02	2.8729E-01	2.8729E-01	3.1881E-01
20060927	1200	3.350E+02	3.3241E-01	3.3241E-01	3.6869E-01
20060928	1200	3.200E+02	3.1718E-01	3.1718E-01	3.5169E-01
20060929	1200	3.120E+02	3.0891E-01	3.0891E-01	3.4240E-01
20060930	1200	3.160E+02	3.1251E-01	3.1251E-01	3.4624E-01
20061001	1200	3.060E+02	3.0234E-01	3.0234E-01	3.3483E-01
20061002	1200	3.580E+02	3.5319E-01	3.5319E-01	3.9089E-01
20061003	1200	4.010E+02	3.9511E-01	3.9511E-01	4.3701E-01
20061004	1200	3.710E+02	3.6534E-01	3.6534E-01	4.0392E-01
20061005	1200	4.030E+02	3.9644E-01	3.9644E-01	4.3803E-01
20061006	1200	3.440E+02	3.3835E-01	3.3835E-01	3.7371E-01
20061007	1200	2.630E+02	2.5876E-01	2.5876E-01	2.8572E-01
20061008	1200	1.790E+02	1.7625E-01	1.7625E-01	1.9459E-01
20061009	1200	2.750E+02	2.7025E-01	2.7025E-01	2.9803E-01
20061010	1200	5.960E+02	5.8395E-01	5.8395E-01	6.4296E-01
20061011	1200	7.510E+02	7.3500E-01	7.3500E-01	8.0852E-01
20061012	1200	7.310E+02	7.1531E-01	7.1531E-01	7.8634E-01
20061013	1200	7.040E+02	6.8885E-01	6.8885E-01	7.5676E-01
20061014	1200	6.940E+02	6.7903E-01	6.7903E-01	7.4543E-01
20061015	1200	7.430E+02	7.2678E-01	7.2678E-01	7.9719E-01
20061016	1200	3.570E+02	3.5008E-01	3.5008E-01	3.8404E-01
20061017	1200	1.000E-04	1.0291E-07	1.0291E-07	1.1520E-07
20061018	1200	5.880E+02	5.7580E-01	5.7580E-01	6.3027E-01
20061019	1200	7.190E+02	7.0379E-01	7.0379E-01	7.6953E-01
20061020	1200	1.000E-04	1.0299E-07	1.0299E-07	1.1500E-07
20061021	1200	7.500E+02	7.3456E-01	7.3456E-01	8.0175E-01
20061022	1200	8.380E+02	8.2082E-01	8.2082E-01	8.9499E-01
20061023	1200	7.080E+02	6.9426E-01	6.9426E-01	7.5645E-01
20061024	1200	7.460E+02	7.3184E-01	7.3184E-01	7.9661E-01
20061025	1200	1.000E-04	1.0326E-07	1.0326E-07	1.1479E-07
20061026	1200	6.080E+02	5.9773E-01	5.9773E-01	6.4955E-01
20061027	1200	7.800E+02	7.6681E-01	7.6681E-01	8.3222E-01
20061028	1200	8.030E+02	7.9005E-01	7.9005E-01	8.5656E-01
20061029	1200	7.810E+02	7.6922E-01	7.6922E-01	8.3316E-01
20061030	1200	3.080E+02	3.0462E-01	3.0462E-01	3.2998E-01
20061031	1200	6.410E+02	6.3311E-01	6.3311E-01	6.8447E-01
20061101	1200	7.200E+02	7.1170E-01	7.1170E-01	7.6850E-01
20061102	1200	7.170E+02	7.0962E-01	7.0962E-01	7.6544E-01

20061103	1200	7.250E+02	7.1846E-01	7.1846E-01	7.7411E-01
20061104	1200	7.090E+02	7.0363E-01	7.0363E-01	7.5731E-01
20061105	1200	7.000E+02	6.9574E-01	6.9574E-01	7.4798E-01
20061106	1200	6.960E+02	6.9282E-01	6.9282E-01	7.4401E-01
20061107	1200	6.840E+02	6.8200E-01	6.8200E-01	7.3155E-01
20061108	1200	3.430E+02	3.4336E-01	3.4336E-01	3.6819E-01
20061109	1200	2.730E+02	2.7396E-01	2.7396E-01	2.9351E-01
20061110	1200	7.770E+02	7.7840E-01	7.7840E-01	8.3186E-01
20061111	1200	6.140E+02	6.1673E-01	6.1673E-01	6.5848E-01
20061112	1200	5.960E+02	5.9986E-01	5.9986E-01	6.3971E-01
20061113	1200	8.890E+02	8.9532E-01	8.9532E-01	9.5316E-01
20061114	1200	1.000E-04	1.0619E-07	1.0619E-07	1.1547E-07
20061115	1200	5.220E+02	5.2884E-01	5.2884E-01	5.6196E-01
20061116	1200	3.970E+02	4.0344E-01	4.0344E-01	4.2831E-01
20061117	1200	4.240E+02	4.3175E-01	4.3175E-01	4.5774E-01
20061118	1200	3.960E+02	4.0425E-01	4.0425E-01	4.2807E-01
20061119	1200	3.790E+02	3.8787E-01	3.8787E-01	4.1021E-01
20061120	1200	3.460E+02	3.5506E-01	3.5506E-01	3.7506E-01
20061121	1200	3.960E+02	4.0718E-01	4.0718E-01	4.2948E-01
20061122	1200	3.230E+02	3.3319E-01	3.3319E-01	3.5106E-01
20061123	1200	9.300E+01	9.6582E-02	9.6582E-02	1.0178E-01
20061124	1200	3.260E+02	3.3803E-01	3.3803E-01	3.5521E-01
20061125	1200	3.430E+02	3.5656E-01	3.5656E-01	3.7414E-01
20061126	1200	3.380E+02	3.5235E-01	3.5235E-01	3.6923E-01
20061127	1200	3.880E+02	4.0542E-01	4.0542E-01	4.2419E-01
20061128	1200	1.000E-04	1.0995E-07	1.0995E-07	1.1738E-07
20061129	1200	1.000E-04	1.1027E-07	1.1027E-07	1.1756E-07
20061130	1200	4.200E+02	4.4258E-01	4.4258E-01	4.6112E-01
20061201	1200	2.980E+02	3.1533E-01	3.1533E-01	3.2823E-01
20061202	1200	2.860E+02	3.0360E-01	3.0360E-01	3.1559E-01
20061203	1200	3.420E+02	3.6396E-01	3.6397E-01	3.7773E-01
20061204	1200	2.970E+02	3.1722E-01	3.1722E-01	3.2881E-01
20061205	1200	2.730E+02	2.9261E-01	2.9261E-01	3.0291E-01
20061206	1200	2.790E+02	2.9999E-01	2.9999E-01	3.1010E-01
20061207	1200	2.760E+02	2.9776E-01	2.9776E-01	3.0736E-01
20061208	1200	2.590E+02	2.8041E-01	2.8041E-01	2.8907E-01
20061209	1200	2.550E+02	2.7703E-01	2.7703E-01	2.8519E-01
20061210	1200	2.470E+02	2.6929E-01	2.6929E-01	2.7684E-01
20061211	1200	2.720E+02	2.9748E-01	2.9748E-01	3.0535E-01
20061212	1200	3.060E+02	3.3571E-01	3.3571E-01	3.4405E-01
20061213	1200	2.910E+02	3.2045E-01	3.2045E-01	3.2796E-01
20061214	1200	3.630E+02	4.0087E-01	4.0087E-01	4.0958E-01
20061215	1200	2.370E+02	2.6305E-01	2.6305E-01	2.6853E-01
20061216	1200	2.210E+02	2.4625E-01	2.4625E-01	2.5104E-01
20061217	1200	2.520E+02	2.8171E-01	2.8171E-01	2.8674E-01
20061218	1200	3.210E+02	3.5989E-01	3.5989E-01	3.6569E-01
20061219	1200	3.480E+02	3.9153E-01	3.9153E-01	3.9723E-01
20061220	1200	3.370E+02	3.8063E-01	3.8063E-01	3.8565E-01
20061221	1200	3.400E+02	3.8548E-01	3.8548E-01	3.9001E-01
20061222	1200	2.930E+02	3.3364E-01	3.3364E-01	3.3715E-01
20061223	1200	3.200E+02	3.6570E-01	3.6570E-01	3.6899E-01
20061224	1200	3.250E+02	3.7285E-01	3.7285E-01	3.7567E-01
20061225	1200	3.120E+02	3.5940E-01	3.5940E-01	3.6163E-01
20061226	1200	3.150E+02	3.6428E-01	3.6428E-01	3.6603E-01
20061227	1200	2.990E+02	3.4722E-01	3.4722E-01	3.4843E-01
20061228	1200	1.000E-04	1.2224E-07	1.2224E-07	1.2511E-07
20061229	1200	1.000E-04	1.2273E-07	1.2273E-07	1.2544E-07
20061230	1200	3.880E+02	4.5565E-01	4.5565E-01	4.5522E-01
20061231	1200	3.410E+02	4.0226E-01	4.0226E-01	4.0140E-01
20070101	1200	3.190E+02	3.7794E-01	3.7794E-01	3.7665E-01
20070102	1200	3.000E+02	3.5696E-01	3.5696E-01	3.5530E-01
20070103	1200	2.810E+02	3.3581E-01	3.3581E-01	3.3382E-01
20070104	1200	2.980E+02	3.5753E-01	3.5753E-01	3.5492E-01
20070105	1200	2.410E+02	2.9055E-01	2.9055E-01	2.8813E-01

20070106	1200	2.640E+02	3.1951E-01	3.1951E-01	3.1639E-01
20070107	1200	2.690E+02	3.2690E-01	3.2690E-01	3.2329E-01
20070108	1200	2.610E+02	3.1854E-01	3.1854E-01	3.1462E-01
20070109	1200	2.500E+02	3.0643E-01	3.0643E-01	3.0230E-01
20070110	1200	2.610E+02	3.2122E-01	3.2122E-01	3.1647E-01
20070111	1200	2.680E+02	3.3119E-01	3.3119E-01	3.2587E-01
20070112	1200	2.880E+02	3.5732E-01	3.5732E-01	3.5112E-01
20070113	1200	2.950E+02	3.6752E-01	3.6752E-01	3.6068E-01
20070114	1200	3.020E+02	3.7779E-01	3.7779E-01	3.7031E-01
20070115	1200	3.600E+02	4.5198E-01	4.5198E-01	4.4240E-01
20070116	1200	3.220E+02	4.0613E-01	4.0613E-01	3.9710E-01
20070117	1200	2.620E+02	3.3208E-01	3.3208E-01	3.2439E-01
20070118	1200	2.720E+02	3.4616E-01	3.4616E-01	3.3774E-01
20070119	1200	2.650E+02	3.3870E-01	3.3870E-01	3.3009E-01
20070120	1200	2.660E+02	3.4140E-01	3.4140E-01	3.3235E-01
20070121	1200	2.740E+02	3.5311E-01	3.5311E-01	3.4335E-01
20070122	1200	2.920E+02	3.7780E-01	3.7780E-01	3.6692E-01
20070123	1200	2.740E+02	3.5607E-01	3.5607E-01	3.4547E-01
20070124	1200	2.740E+02	3.5755E-01	3.5755E-01	3.4653E-01
20070125	1200	2.740E+02	3.5904E-01	3.5904E-01	3.4760E-01
20070126	1200	2.740E+02	3.6053E-01	3.6053E-01	3.4868E-01
20070127	1200	2.740E+02	3.6202E-01	3.6202E-01	3.4976E-01
20070128	1200	2.740E+02	3.6351E-01	3.6351E-01	3.5085E-01
20070129	1200	2.740E+02	3.6500E-01	3.6500E-01	3.5193E-01
20070130	1200	2.550E+02	3.4115E-01	3.4115E-01	3.2865E-01
20070131	1200	2.740E+02	3.6797E-01	3.6797E-01	3.5412E-01
20070201	1200	2.510E+02	3.3855E-01	3.3855E-01	3.2553E-01
20070202	1200	2.730E+02	3.6959E-01	3.6959E-01	3.5502E-01
20070203	1200	2.830E+02	3.8462E-01	3.8462E-01	3.6910E-01
20070204	1200	2.730E+02	3.7254E-01	3.7255E-01	3.5722E-01
20070205	1200	2.520E+02	3.4534E-01	3.4534E-01	3.3087E-01
20070206	1200	2.590E+02	3.5629E-01	3.5629E-01	3.4107E-01
20070207	1200	2.590E+02	3.5768E-01	3.5768E-01	3.4211E-01
20070208	1200	2.620E+02	3.6320E-01	3.6320E-01	3.4712E-01
20070209	1200	2.560E+02	3.5628E-01	3.5628E-01	3.4024E-01
20070210	1200	2.630E+02	3.6738E-01	3.6738E-01	3.5056E-01
20070211	1200	2.970E+02	4.1626E-01	4.1627E-01	3.9685E-01
20070212	1200	3.040E+02	4.2764E-01	4.2764E-01	4.0739E-01
20070213	1200	3.500E+02	4.9393E-01	4.9393E-01	4.7013E-01
20070214	1200	3.360E+02	4.7598E-01	4.7598E-01	4.5276E-01
20070215	1200	3.820E+02	5.4288E-01	5.4288E-01	5.1597E-01
20070216	1200	2.940E+02	4.1969E-01	4.1969E-01	3.9876E-01
20070217	1200	3.500E+02	5.0111E-01	5.0111E-01	4.7573E-01
20070218	1200	3.350E+02	4.8140E-01	4.8140E-01	4.5677E-01
20070219	1200	2.820E+02	4.0688E-01	4.0688E-01	3.8592E-01
20070220	1200	3.260E+02	4.7175E-01	4.7175E-01	4.4713E-01
20070221	1200	3.150E+02	4.5743E-01	4.5743E-01	4.3335E-01
20070222	1200	3.240E+02	4.7203E-01	4.7203E-01	4.4694E-01
20070223	1200	1.600E+01	2.3624E-02	2.3624E-02	2.2441E-02
20070224	1200	3.440E+02	5.0437E-01	5.0437E-01	4.7706E-01
20070225	1200	4.580E+02	6.7302E-01	6.7302E-01	6.3609E-01
20070226	1200	2.540E+02	3.7517E-01	3.7517E-01	3.5469E-01
20070227	1200	7.300E+00	1.0945E-02	1.0945E-02	1.0390E-02
20070228	1200	1.140E+02	1.6989E-01	1.6989E-01	1.6065E-01
20070301	1200	1.000E-04	1.5628E-07	1.5628E-07	1.5063E-07
20070302	1200	1.000E-04	1.5675E-07	1.5675E-07	1.5103E-07
20070303	1200	3.830E+02	5.7350E-01	5.7350E-01	5.4100E-01
20070304	1200	2.040E+02	3.0699E-01	3.0699E-01	2.8974E-01
20070305	1200	2.300E+02	3.4695E-01	3.4695E-01	3.2732E-01
20070306	1200	2.570E+02	3.8860E-01	3.8860E-01	3.6649E-01
20070307	1200	2.070E+02	3.1407E-01	3.1407E-01	2.9622E-01
20070308	1200	2.270E+02	3.4522E-01	3.4522E-01	3.2550E-01
20070309	1200	1.180E+02	1.8031E-01	1.8031E-01	1.7012E-01
20070310	1200	1.000E-04	1.6021E-07	1.6021E-07	1.5409E-07

20070311	1200	2.010E+02	3.0813E-01	3.0813E-01	2.9046E-01
20070312	1200	1.870E+02	2.8743E-01	2.8743E-01	2.7095E-01
20070313	1200	1.660E+02	2.5585E-01	2.5585E-01	2.4120E-01
20070314	1200	6.000E+01	9.3006E-02	9.3006E-02	8.7788E-02
20070315	1200	1.000E-04	1.6211E-07	1.6211E-07	1.5586E-07
20070316	1200	1.690E+02	2.6220E-01	2.6220E-01	2.4718E-01
20070317	1200	1.480E+02	2.3021E-01	2.3021E-01	2.1706E-01
20070318	1200	6.300E+01	9.8475E-02	9.8475E-02	9.2957E-02
20070319	1200	3.700E+01	5.8052E-02	5.8052E-02	5.4840E-02
20070320	1200	1.000E-04	1.6378E-07	1.6378E-07	1.5751E-07
20070321	1200	1.000E-04	1.6408E-07	1.6408E-07	1.5783E-07
20070322	1200	1.000E-04	1.6437E-07	1.6437E-07	1.5813E-07
20070323	1200	1.000E-04	1.6466E-07	1.6466E-07	1.5843E-07
20070324	1200	1.000E-04	1.6493E-07	1.6493E-07	1.5873E-07
20070325	1200	2.560E+02	4.0324E-01	4.0324E-01	3.8045E-01
20070326	1200	1.560E+02	2.4651E-01	2.4651E-01	2.3278E-01
20070327	1200	4.320E+02	6.8127E-01	6.8127E-01	6.4271E-01
20070328	1200	1.000E-04	1.6591E-07	1.6591E-07	1.5984E-07
20070329	1200	1.000E-04	1.6613E-07	1.6613E-07	1.6011E-07
20070330	1200	5.910E+02	9.3465E-01	9.3465E-01	8.8234E-01
20070331	1200	4.000E+02	6.3417E-01	6.3417E-01	5.9918E-01
20070401	1200	1.010E+02	1.6106E-01	1.6106E-01	1.5248E-01
20070402	1200	1.000E-04	1.6689E-07	1.6689E-07	1.6109E-07
20070403	1200	1.000E-04	1.6705E-07	1.6705E-07	1.6131E-07
20070404	1200	2.650E+02	4.2239E-01	4.2239E-01	3.9999E-01
20070405	1200	5.800E+01	9.3001E-02	9.3001E-02	8.8273E-02
20070406	1200	1.820E+02	2.9092E-01	2.9092E-01	2.7589E-01
20070407	1200	2.250E+02	3.5963E-01	3.5963E-01	3.4116E-01
20070408	1200	4.160E+02	6.6392E-01	6.6392E-01	6.2973E-01
20070409	1200	6.370E+02	1.0157E+00	1.0157E+00	9.6346E-01
20070410	1200	6.370E+02	1.0161E+00	1.0161E+00	9.6449E-01
20070411	1200	6.370E+02	1.0165E+00	1.0165E+00	9.6547E-01
20070412	1200	6.370E+02	1.0168E+00	1.0168E+00	9.6640E-01
20070413	1200	6.370E+02	1.0171E+00	1.0171E+00	9.6728E-01
20070414	1200	6.370E+02	1.0172E+00	1.0172E+00	9.6812E-01
20070415	1200	6.370E+02	1.0173E+00	1.0173E+00	9.6891E-01
20070416	1200	6.370E+02	1.0173E+00	1.0173E+00	9.6965E-01
20070417	1200	6.370E+02	1.0173E+00	1.0173E+00	9.7033E-01
20070418	1200	6.370E+02	1.0171E+00	1.0171E+00	9.7097E-01
20070419	1200	8.580E+02	1.3683E+00	1.3683E+00	1.3068E+00
20070420	1200	3.980E+02	6.3622E-01	6.3622E-01	6.0868E-01
20070421	1200	8.310E+02	1.3246E+00	1.3246E+00	1.2672E+00
20070422	1200	9.200E+02	1.4653E+00	1.4653E+00	1.4029E+00
20070423	1200	1.080E+02	1.7319E-01	1.7319E-01	1.6638E-01
20070424	1200	5.000E+01	8.0347E-02	8.0347E-02	7.7329E-02
20070425	1200	6.640E+02	1.0570E+00	1.0570E+00	1.0151E+00
20070426	1200	9.700E+01	1.5531E-01	1.5531E-01	1.4964E-01
20070427	1200	3.760E+02	5.9879E-01	5.9879E-01	5.7656E-01
20070428	1200	5.940E+02	9.4367E-01	9.4367E-01	9.0905E-01
20070429	1200	5.620E+02	8.9218E-01	8.9218E-01	8.6037E-01
20070430	1200	1.400E+02	2.2309E-01	2.2309E-01	2.1570E-01
20070501	1200	4.950E+02	7.8453E-01	7.8453E-01	7.5823E-01
20070502	1200	4.690E+02	7.4262E-01	7.4262E-01	7.1852E-01
20070503	1200	1.000E-04	1.6627E-07	1.6627E-07	1.6436E-07
20070504	1200	1.000E-04	1.6606E-07	1.6606E-07	1.6433E-07
20070505	1200	1.000E-04	1.6583E-07	1.6583E-07	1.6429E-07
20070506	1200	1.000E-04	1.6560E-07	1.6560E-07	1.6424E-07
20070507	1200	1.000E-04	1.6536E-07	1.6536E-07	1.6419E-07
20070508	1200	1.000E-04	1.6510E-07	1.6510E-07	1.6412E-07
20070509	1200	1.000E-04	1.6484E-07	1.6484E-07	1.6404E-07
20070510	1200	1.000E-04	1.6456E-07	1.6456E-07	1.6396E-07
20070511	1200	1.000E-04	1.6427E-07	1.6427E-07	1.6387E-07
20070512	1200	1.000E-04	1.6397E-07	1.6397E-07	1.6377E-07
20070513	1200	1.000E-04	1.6367E-07	1.6367E-07	1.6366E-07

20070514	1200	1.000E-04	1.6335E-07	1.6335E-07	1.6354E-07
20070515	1200	1.000E-04	1.6302E-07	1.6302E-07	1.6342E-07
20070516	1200	1.260E+02	1.9583E-01	1.9583E-01	1.9290E-01
20070517	1200	7.440E+02	1.1469E+00	1.1469E+00	1.1288E+00
20070518	1200	4.420E+02	6.8106E-01	6.8106E-01	6.7159E-01
20070519	1200	3.050E+02	4.6950E-01	4.6950E-01	4.6377E-01
20070520	1200	2.700E+01	4.1809E-02	4.1809E-02	4.1471E-02
20070521	1200	1.000E-04	1.6085E-07	1.6085E-07	1.6249E-07
20070522	1200	1.000E-04	1.6046E-07	1.6046E-07	1.6231E-07
20070523	1200	1.000E-04	1.6006E-07	1.6006E-07	1.6212E-07
20070524	1200	8.000E+02	1.2124E+00	1.2124E+00	1.2043E+00
20070525	1200	5.800E+02	8.7770E-01	8.7770E-01	8.7329E-01
20070526	1200	4.720E+02	7.1286E-01	7.1286E-01	7.1041E-01
20070527	1200	5.590E+02	8.4146E-01	8.4146E-01	8.3955E-01
20070528	1200	1.000E-04	1.5793E-07	1.5793E-07	1.6105E-07
20070529	1200	1.000E-04	1.5749E-07	1.5749E-07	1.6082E-07
20070530	1200	3.010E+02	4.5020E-01	4.5020E-01	4.5137E-01
20070531	1200	2.550E+02	3.8049E-01	3.8049E-01	3.8208E-01
20070601	1200	2.580E+02	3.8380E-01	3.8380E-01	3.8594E-01
20070602	1200	1.670E+02	2.4804E-01	2.4804E-01	2.4990E-01
20070603	1200	1.230E+02	1.8231E-01	1.8231E-01	1.8401E-01
20070604	1200	2.740E+02	4.0374E-01	4.0374E-01	4.0769E-01
20070605	1200	4.080E+02	5.9845E-01	5.9845E-01	6.0488E-01
20070606	1200	1.000E-04	1.5366E-07	1.5366E-07	1.5869E-07
20070607	1200	1.000E-04	1.5316E-07	1.5316E-07	1.5839E-07
20070608	1200	8.550E+02	1.2386E+00	1.2386E+00	1.2562E+00
20070609	1200	7.240E+02	1.0459E+00	1.0459E+00	1.0625E+00
20070610	1200	3.740E+02	5.3966E-01	5.3966E-01	5.4943E-01
20070611	1200	1.000E-04	1.5109E-07	1.5109E-07	1.5715E-07
20070612	1200	2.980E+02	4.2734E-01	4.2734E-01	4.3645E-01
20070613	1200	5.000E+02	7.1320E-01	7.1320E-01	7.2901E-01
20070614	1200	2.000E+02	2.8516E-01	2.8516E-01	2.9220E-01
20070615	1200	1.390E+02	1.9771E-01	1.9771E-01	2.0298E-01
20070616	1200	2.160E+02	3.0565E-01	3.0565E-01	3.1408E-01
20070617	1200	1.000E-04	1.4785E-07	1.4785E-07	1.5512E-07
20070618	1200	4.710E+02	6.5978E-01	6.5978E-01	6.7932E-01
20070619	1200	3.230E+02	4.5134E-01	4.5134E-01	4.6558E-01
20070620	1200	3.740E+02	5.2036E-01	5.2036E-01	5.3746E-01
20070621	1200	1.780E+02	2.4734E-01	2.4734E-01	2.5605E-01
20070622	1200	2.860E+02	3.9524E-01	3.9524E-01	4.0952E-01
20070623	1200	1.790E+02	2.4681E-01	2.4681E-01	2.5623E-01
20070624	1200	5.900E+01	8.1340E-02	8.1340E-02	8.4673E-02
20070625	1200	1.000E-04	1.4337E-07	1.4337E-07	1.5215E-07
20070626	1200	1.580E+02	2.1538E-01	2.1538E-01	2.2458E-01
20070627	1200	3.160E+02	4.2803E-01	4.2803E-01	4.4658E-01
20070628	1200	4.260E+02	5.7412E-01	5.7412E-01	5.9964E-01
20070629	1200	2.870E+02	3.8576E-01	3.8576E-01	4.0365E-01
20070630	1200	9.100E+01	1.2230E-01	1.2230E-01	1.2832E-01
20070701	1200	1.210E+02	1.6180E-01	1.6180E-01	1.6994E-01
20070702	1200	6.200E+01	8.2753E-02	8.2753E-02	8.7105E-02
20070703	1200	1.000E-04	1.3880E-07	1.3880E-07	1.4894E-07
20070704	1200	1.080E+02	1.4270E-01	1.4270E-01	1.5051E-01
20070705	1200	1.770E+02	2.3250E-01	2.3250E-01	2.4543E-01
20070706	1200	3.200E+02	4.1775E-01	4.1775E-01	4.4126E-01
20070707	1200	5.100E+01	6.6720E-02	6.6720E-02	7.0719E-02
20070708	1200	1.220E+02	1.5847E-01	1.5847E-01	1.6801E-01
20070709	1200	1.630E+02	2.1063E-01	2.1063E-01	2.2353E-01
20070710	1200	7.100E+01	9.1621E-02	9.1621E-02	9.7456E-02
20070711	1200	7.300E+01	9.3797E-02	9.3797E-02	9.9897E-02
20070712	1200	2.720E+02	3.4646E-01	3.4646E-01	3.6889E-01
20070713	1200	2.040E+02	2.5901E-01	2.5901E-01	2.7622E-01
20070714	1200	2.650E+02	3.3474E-01	3.3474E-01	3.5732E-01
20070715	1200	1.010E+02	1.2746E-01	1.2746E-01	1.3638E-01
20070716	1200	2.420E+02	3.0321E-01	3.0321E-01	3.2450E-01

20070717	1200	1.250E+02	1.5631E-01	1.5631E-01	1.6762E-01
20070718	1200	4.700E+02	5.8260E-01	5.8260E-01	6.2453E-01
20070719	1200	1.650E+02	2.0440E-01	2.0440E-01	2.1964E-01
20070720	1200	6.400E+01	7.9205E-02	7.9205E-02	8.5303E-02
20070721	1200	1.320E+02	1.6227E-01	1.6227E-01	1.7482E-01
20070722	1200	5.100E+01	6.2636E-02	6.2636E-02	6.7632E-02
20070723	1200	2.390E+02	2.9077E-01	2.9077E-01	3.1374E-01
20070724	1200	1.570E+02	1.9048E-01	1.9048E-01	2.0586E-01
20070725	1200	9.700E+01	1.1739E-01	1.1739E-01	1.2708E-01
20070726	1200	2.900E+01	3.5093E-02	3.5093E-02	3.8085E-02
20070727	1200	9.800E+01	1.1761E-01	1.1761E-01	1.2759E-01
20070728	1200	1.000E-04	1.2498E-07	1.2498E-07	1.3827E-07
20070729	1200	1.210E+02	1.4392E-01	1.4392E-01	1.5641E-01
20070730	1200	1.820E+02	2.1529E-01	2.1529E-01	2.3410E-01
20070731	1200	1.270E+02	1.4980E-01	1.4980E-01	1.6312E-01

Table 1. Streamflow-gaging stations with continuous records adjacent to Great Salt Lake, Utah, where stream discharge and water-quality samples were collected to simulate selenium loads.

[*, missing discharge record reconstructed with adjacent streamflow gages]

Field ID	USGS station identification number	USGS station name	Number of selenium samples collected for model calibration	Time period for which loads were simulated
BR	411403112200801	Bear River Bay Outflow at GSL Minerals Corp Bridge	42	03/21/06 thru 07/31/2007*
WR	411316112132201	North Fork Weber River near West Warren, Utah	12	05/11/06 thru 07/31/2007
GD	10172630	Goggin Drain near Magna, Utah	41	05/03/06 thru 07/31/2007
LC	10172640	Lee Creek near Magna, Utah	14	05/18/06 thru 07/31/2007
KUCC	10172650	Kennecott Drain near Magna, Utah	134	10/01/2005 thru 07/31/2007
FB	410401112134801	GSL Farmington Bay Outflow at Causeway Bridge	47	05/03/2006 thru 07/31/2007*

Table 2. Results of field process blanks and sample replicates collected at inflow sites to Great Salt Lake from May 2006 through July 2007. Location of each site shown in Figure 1.

[BR, Bear River Bay Outflow at GSL Minerals Corp. Bridge; FB, GSL Farmington Bay Outflow at Causeway Bridge; GD, Goggin Drain near Magna, Utah; LC, Lee Creek near Magna, Utah; WR, North Fork Weber River near West Warren, Utah; FA, filtered and acidified; RA, unfiltered and acidified; ug/L, micrograms per liter; U, analyte was not detected at reporting limit; J, analyte concentration is considered estimated due to QC outlier]

Process blank results

Site ID	Sample type	Sample date (dd/mm/yyyy)	Sample time hh:mm	Se concentration, in ug/L	Validation flag	Reporting limit, in ug/L
BR	FA	6/21/2006	14:20	0.05	U	0.05
BR	FA	10/10/2006	16:30	0.05	U	0.05
BR	RA	6/21/2006	14:20	0.05	U	0.05
FB	FA	5/8/2006	16:00	0.05	U	0.05
FB	FA	9/7/2006	12:25	0.05	U	0.05
FB	FA	11/20/2006	11:20	0.05	U	0.05
FB	RA	5/8/2006	16:00	0.05	U	0.05
FB	RA	9/7/2006	12:25	0.05	U	0.05
FB	RA	11/20/2006	11:20	0.05	U	0.05
GD	FA	5/17/2006	9:40	0.05	U	0.05
GD	FA	11/9/2006	13:05	0.05	U	0.05
GD	RA	5/17/2006	9:40	0.05	U	0.05
GD	RA	11/9/2006	13:05	0.05	U	0.05
LC	FA	8/10/2006	9:10	0.05	U	0.05
LC	FA	12/21/2006	12:20	0.05		0.05
LC	RA	8/10/2006	9:10	0.05	U	0.05
LC	RA	12/21/2006	12:20	0.05	U	0.05
LC	FA	4/18/2007	12:15	0.05		0.05
LC	RA	4/18/2007	12:15	0.05	U	0.05
LC	RA	7/19/2007	11:20	0.05	U	0.05
LC	FA	7/19/2007	11:20	0.05	U	0.05
LC	RA	2/1/2007	9:25	0.05	U	0.05
LC	FA	2/1/2007	9:25	0.05	U	0.05
WR	FA	8/8/2006	10:30	0.05	U	0.05

Site ID	Sample type	Sample date (dd/mm/yyyy)	Sample time hh:mm	Se concentration, in ug/L	Validation flag	Reporting limit, in ug/L
WR	FA	10/12/2006	9:35	0.05	U	0.05
WR	RA	8/8/2006	10:30	0.05	U	0.05
WR	RA	10/12/2006	9:35	0.05	U	0.05
FB	FA	3/5/2007	13:55	0.05	U	0.05
FB	RA	3/5/2007	13:55	0.05	U	0.05
GSL99	FA	4/5/2007	16:20	0.05	U	0.05
GSL99	RA	4/5/2007	16:20	0.05	U	0.05
FB	FA	5/18/2007	13:20	0.05	U	0.05
FB	RA	5/18/2007	13:20	0.05	U	0.05
WR	FA	6/20/2007	10:20	0.05	U	0.05
WR	RA	6/20/2007	10:20	0.05	U	0.05

Table 2. Results of field process blanks and sample replicates collected at inflow sites to Great Salt Lake from May 2006 through July 2007—continued.

Site ID	Sample type	Sample date (mm/dd/yyyy)	Sample time (hh:mm)	Se concentration, in ug/L	Validation flag	Original-replicate, in ug/L
BR	FA	5/3/2006	14:20	0.219		
BR	FA	5/3/2006	14:25	0.242		-0.023
BR	RA	5/3/2006	14:20	0.307		
BR	RA	5/3/2006	14:25	0.366		-0.059
BR	FA	5/25/2006	14:30	0.301		
BR	FA	5/25/2006	14:35	0.460		-0.159
WR	RA	8/8/2006	9:45	0.148	J	
WR	RA	8/8/2006	9:50	0.153	J	-0.005
WR	FA	8/8/2006	9:45	0.062		
WR	FA	8/8/2006	9:50	0.101		-.039
LC	FA	8/10/2006	9:00	1.53		
LC	FA	8/10/2006	9:05	1.57		-0.04
LC	RA	8/10/2006	9:00	1.64		
LC	RA	8/10/2006	9:05	1.62		0.02
GD	FA	9/5/2006	8:20	1.07	J	
GD	FA	9/5/2006	8:25	1.13	J	-0.06
GD	RA	9/5/2006	8:20	1.17	J	
GD	RA	9/5/2006	8:25	1.16	J	0.01
WR	FA	12/20/2006	12:45	0.189		
WR	FA	12/20/2006	12:50	0.646		-0.457
WR	RA	12/20/2006	12:45	0.192		
WR	RA	12/20/2006	12:50	0.195		-0.003
WR	FA	7/16/2007	14:00	0.236		
WR	FA	7/16/2007	14:05	0.232		0.004
WR	RA	7/16/2007	14:00	0.210		
WR	RA	7/16/2007	14:05	0.218		-0.008
WR	FA	5/17/2007	15:30	0.207		
WR	FA	5/17/2007	15:35	0.214		-0.007
WR	RA	5/17/2007	15:30	0.220		
WR	RA	5/17/2007	15:35	0.192		0.028
GD	FA	1/31/2007	14:35	1.67		
GD	FA	1/31/2007	14:40	1.62		0.05
GD	RA	1/31/2007	14:35	1.68		
GD	RA	1/31/2007	14:40	1.57		0.11
GD	FA	6/18/2007	11:25	1.22		
GD	FA	6/18/2007	11:30	1.21		0.01
GD	RA	6/18/2007	11:25	1.19		
GD	RA	6/18/2007	11:30	1.22		-0.03
FB	FA	4/19/2007	10:45	0.372		
FB	FA	4/19/2007	10:50	0.392		-0.020
FB	RA	4/19/2007	10:45	0.543		
FB	RA	4/19/2007	10:50	0.541		0.002

Table 3. Regression models considered during the automated selection option in LOADEST (Runkel et al., 2004).

[a_0 thru a_6, model-determined regression coefficients; ln, natural log; Q, discharge; dtime, decimal time; pi, 3.141593]

Model number	Regression model
1	$a_0 + a_1 \ln Q$
2	$a_0 + a_1 \ln Q + a_2 \ln Q^2$
3	$a_0 + a_1 \ln Q + a_2 dtime$
4	$a_0 + a_1 \ln Q + a_2 \sin(2\pi dtime) + a_3 \cos(2\pi dtime)$
5	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 dtime$
6	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime)$
7	$a_0 + a_1 \ln Q + a_2 \sin(2\pi dtime) + a_3 \cos(2\pi dtime) + a_4 dtime$
8	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime$
9	$a_0 + a_1 \ln Q + a_2 \ln Q^2 + a_3 \sin(2\pi dtime) + a_4 \cos(2\pi dtime) + a_5 dtime + a_6 dtime^2$

Table 4. Instantaneous discharge and associated total (dissolved + particulate) selenium loads measured from May 2006 through May 2007, at measurement sites along the railroad causeway, Great Salt Lake, Utah. Locations of measurement sites shown in Figure 1.

[cfs, cubic feet per second; kg, kilograms]

Site	Date (MM/DD/YY)	North-to-south discharge, in cfs	South-to-north discharge, in cfs	North-to-south selenium load, in kg/day	South-to-north selenium load, in kg/day*	Net selenium load to Gilbert Bay, in kg/day#
Causeway breach (CB)	05/25/06	0	3,120	0.00	3.79	-3.79
East culvert (EC)	05/25/06	98	294	< 0.06	0.36	> -0.30
West culvert (WC)	05/25/06	131	100	0.12	0.12	0.00
Causeway breach (CB)	09/28/06	0	1,380	0.00	2.06	-2.06
East culvert (EC)	09/26/06	151	173	0.11	0.12	0.01
West culvert (WC)	09/26/06	234	39	0.22	0.06	0.16
Causeway breach (CB)	01/09/07	0	1,720	0.00	2.14	-2.14
East culvert (EC)	01/09/07	92	139	0.07	0.17	-0.10
West culvert (WC)	01/09/07	147	56	<0.09	0.07	< 0.02

Table 4. Instantaneous discharge and associated total (dissolved + particulate) selenium loads measured from May 2006 through May 2007, at measurement sites along the railroad causeway, Great Salt Lake, Utah—continued.

Site	Date (MM/DD/YY)	North-to-south discharge, in cfs	South-to-north discharge, in cfs	North-to-south selenium load, in kg/day	South-to-north selenium load, in kg/day*	Net selenium load to Gilbert Bay, in kg/day#
Causeway breach (CB)	03/19/07	0	1,880	0.00	3.00	-3.00
East culvert (EC)	03/19/07	218	158	0.46	0.25	0.21
West culvert (WC)	03/19/07	285	59	0.54	0.10	0.44
Causeway breach (CB)	05/30/07	0	1,560	0.00	2.44	-2.44
East culvert (EC)	05/30/07	264	186	0.51	0.29	0.22
West culvert (WC)	05/30/07	464	86	0.86	0.14	0.72

* Calculated using unfiltered selenium concentration at 0.2 meter sample depth at site 2565

Negative value indicates a loss of selenium from Gilbert Bay to the North arm of Great Salt Lake

Table 5. Summary of Mann-Kendall statistical trend analysis conducted on water samples analyzed for dissolved selenium, Great Salt Lake, Utah.

Site identi-fication	Sample depth, in meters	Sampling date range	Number of samples	Calc-ulated Z score	Expected Z score at 95-percent confidence level	Occurrence of upward trend in concentra-tion at 95 percent confidence level	Occurrence of upward trend in concentra-tion at 90 percent confidence level
2267	0.2	5/2006 thru 6/2007	12	1.8515	1.6546	Yes	Yes
2767	0.2	5/2006 thru 6/2007	11	2.1798	1.6546	Yes	Yes
3510	0.2	5/2006 thru 6/2007	12	1.5122	1.6546	No	Yes
2565	0.2	5/2006 thru 6/2007	11	1.3275	1.6546	No	Yes

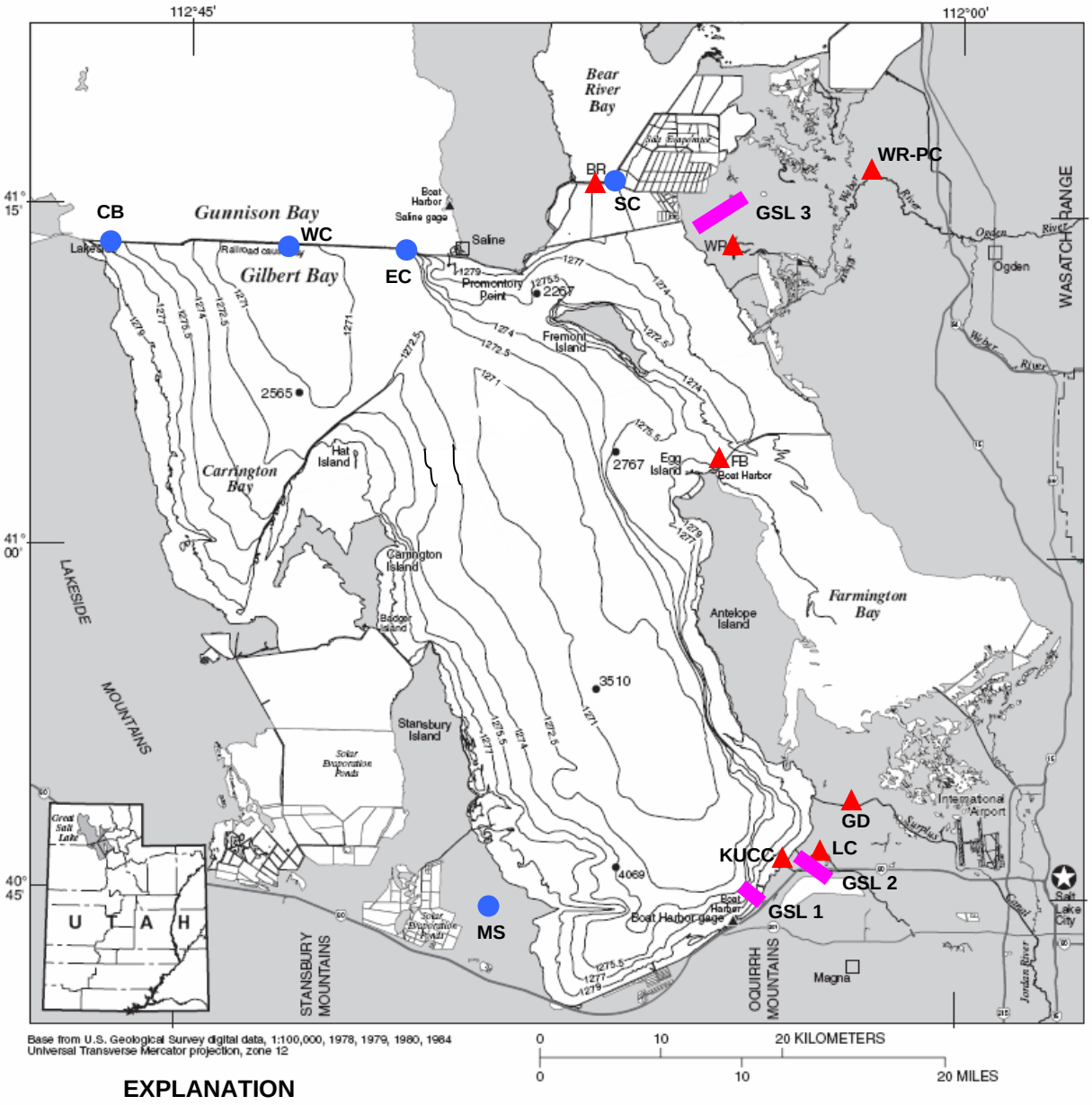
Table 6. Selenium concentration increases expected from riverine inputs compared to observed selenium concentration increase at four lake sites from May 15, 2006 through July 31, 2007, Great Salt Lake, Utah.

Site	#Selenium concentration, in ug/L, on May 15, 2006	#Selenium concentration, in ug/L, on July 31, 2007	^Net change in selenium concentration during monitoring period, in ug/L	*Net change in open water selenium concentration, in ug/L, based on selenium input from May 15, 2006 to July 31, 2007
2767	0.30 (0.50)	0.60 (0.75)	+0.30 (+0.25)	+ 0.17
2267	0.34 (0.50)	0.68 (0.78)	+0.34 (+0.28)	+ 0.17
3510	0.38 (0.48)	0.66 (0.73)	+0.28 (+0.25)	+ 0.17
2565	0.36 (0.46)	0.52 (0.73)	+0.16 (+0.27)	+ 0.17

#Selenium concentration determined from regression model developed from site-specific monitoring data dissolved and (total) collected from May 2006 through July 2007.

^Net change in selenium concentration during monitoring period May 15, 2006 through July 31, 2007, in ug/L dissolved and (total).

*Net change in selenium concentration calculated by dividing total mass of riverine selenium (dissolved + filtered) input to GSL from May 15, 2006 to July 31, 2007 (1,540 kg) divided by measured lake volume on July 31, 2007 of 9.19 X 10^{12} liters (Baskin, 2005).



EXPLANATION

BR Continuous stream gage and sample collection site

WC Non-continuous stream gage and sample collection site

1279 Lake bottom elevation in meters above sea level (Baskin and Allen, 2005)

2565 Lake-monitoring site

GSL 1 Exposed sediment transect

Figure 1. Location of continuous and non-continuous stream gages, lake monitoring sites, and exposed sediment transects adjacent to and within Great Salt Lake, Utah.

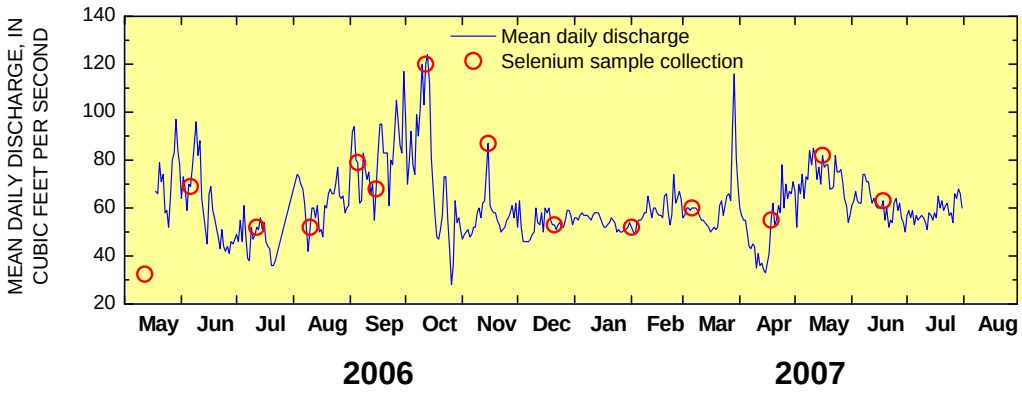


Figure 2. Stream discharge and dates when selenium samples were collected at the Lee Creek gaging station.

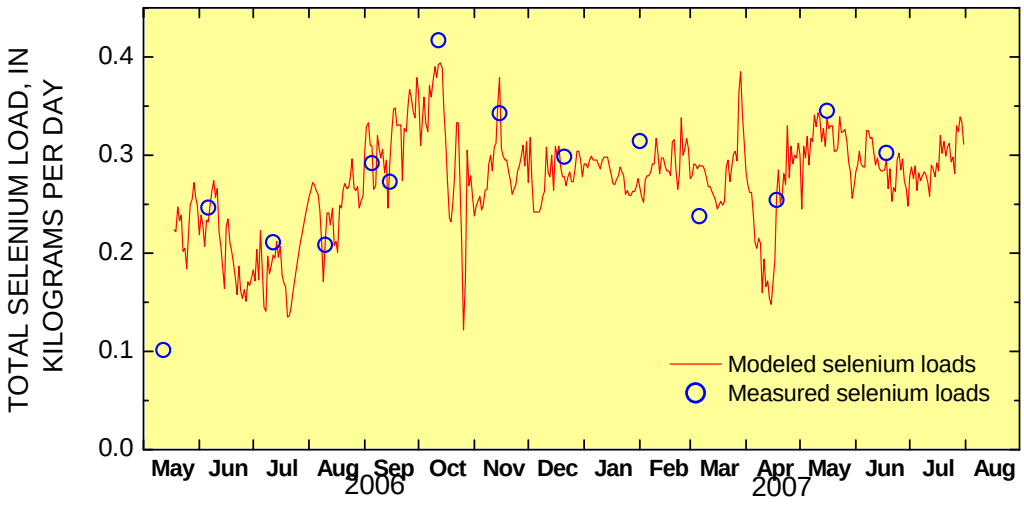


Figure 3. Measured and simulated loads of total Se at the Lee Creek streamflow-gaging station near Magna, Utah during May 2006 through July 2007.

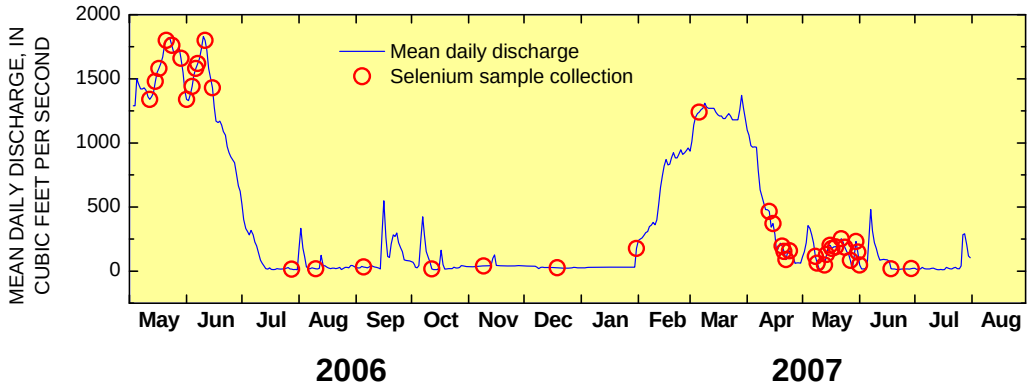


Figure 4. Stream discharge and dates when selenium samples were collected at the Goggin Drain gaging station.

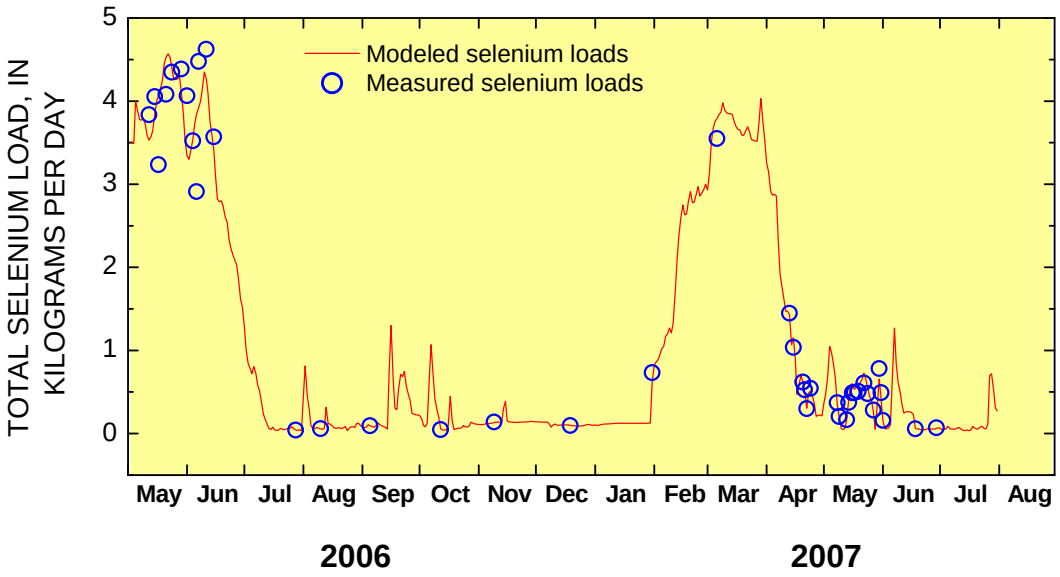


Figure 5. Measured and simulated loads of total Se at the Goggin Drain streamflow-gaging station near Magna, Utah during May 2006 through July 2007.

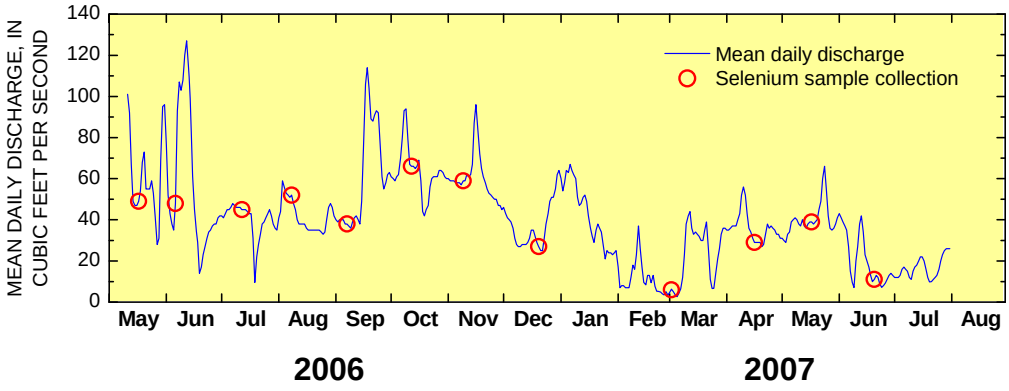


Figure 6. Stream discharge and dates when selenium samples were collected at the Weber River gaging station.

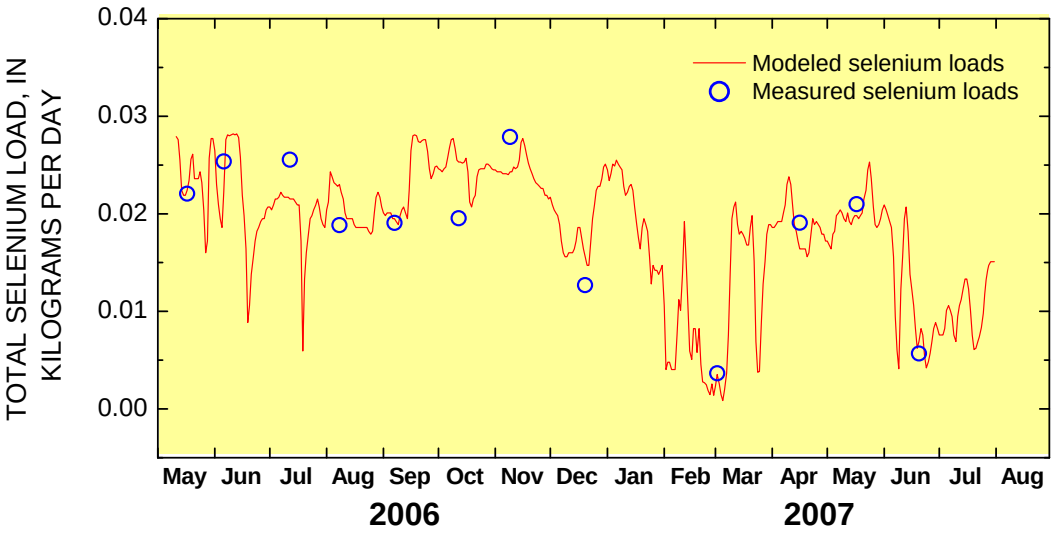


Figure 7. Measured and simulated loads of total Se at the Weber River streamflow-gaging station near West Warren, Utah during May 2006 through July 2007.

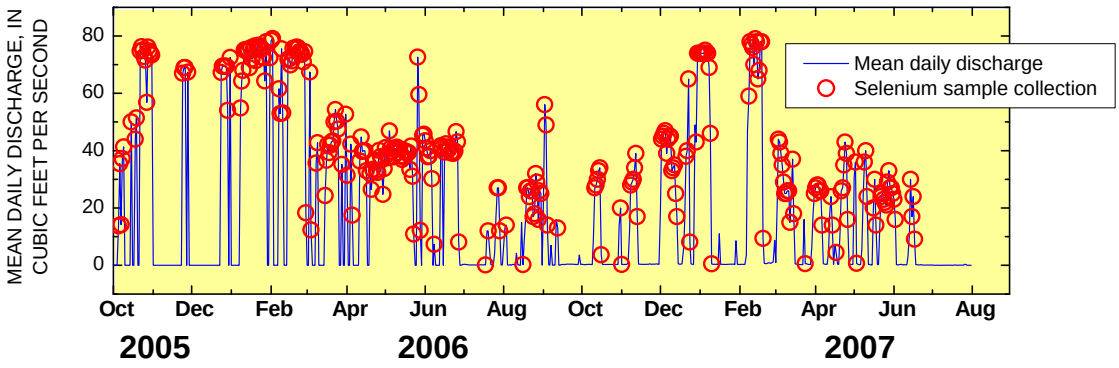


Figure 8. Stream discharge and dates when selenium samples were collected at the KUCC gaging station. Discharge and selenium data prior to June 30, 2006 provided by KUCC (K. Payne, written commun., 2006). Selenium data after June 30, 2006 provided by KUCC and USGS.

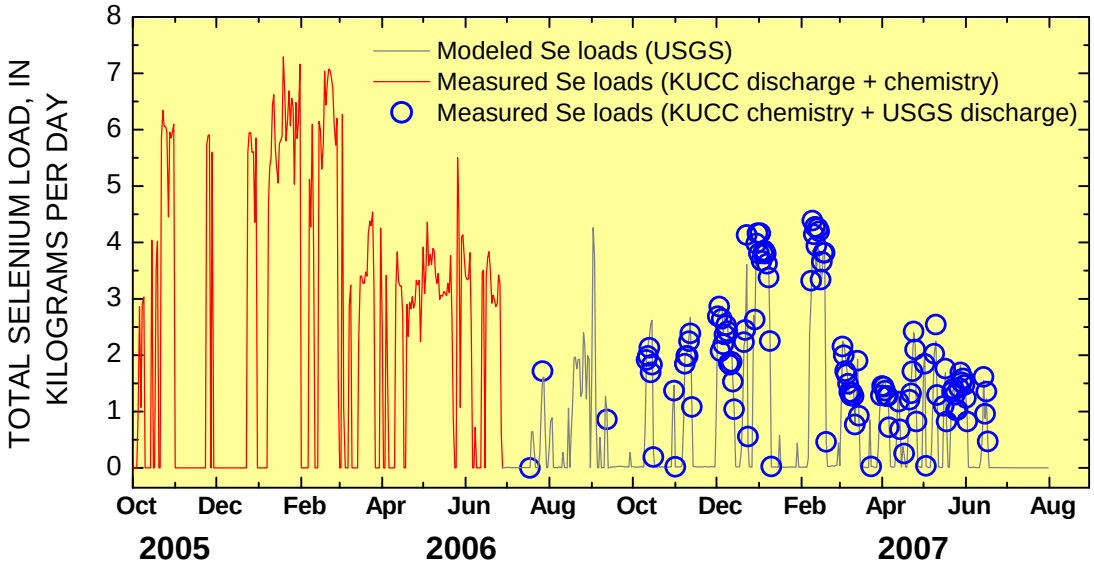


Figure 9. Measured and simulated loads of total Se at the Kennecott Drain streamflow-gaging station near Magna, Utah from October 2005 through July 2007.

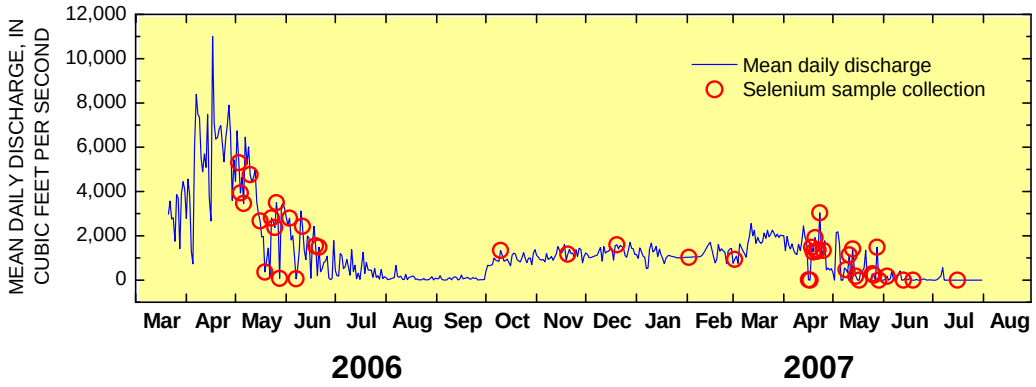


Figure 10. Stream discharge and dates when selenium samples were collected at the Bear River Bay outflow gaging station. Negative mean daily discharge values (wind-driven flow into Bear River Bay) were assigned a discharge value of 0.0001 cubic feet per second. Discharge data between October 1, 2006 and April 15, 2007 were calculated using a simulated mean daily discharge based on an upstream USGS gage (10126000 Bear River near Corinne, Utah).

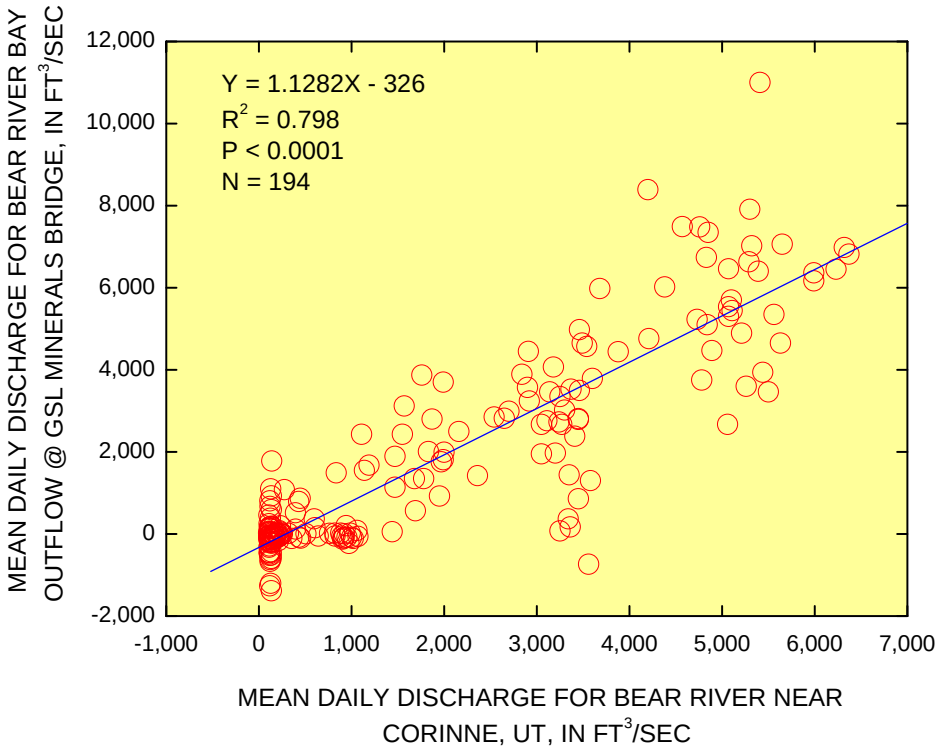


Figure 11. Stream discharge and dates when selenium samples were collected at the Bear River Bay outflow gaging station. Negative mean daily discharge values (wind-driven flow into Bear River Bay) were assigned a discharge value of 0.0001 cubic feet per second. Discharge data between October 1, 2006 and April 15, 2007 were calculated using a simulated mean daily discharge based on an upstream USGS gage (10126000 Bear River near Corinne, Utah).

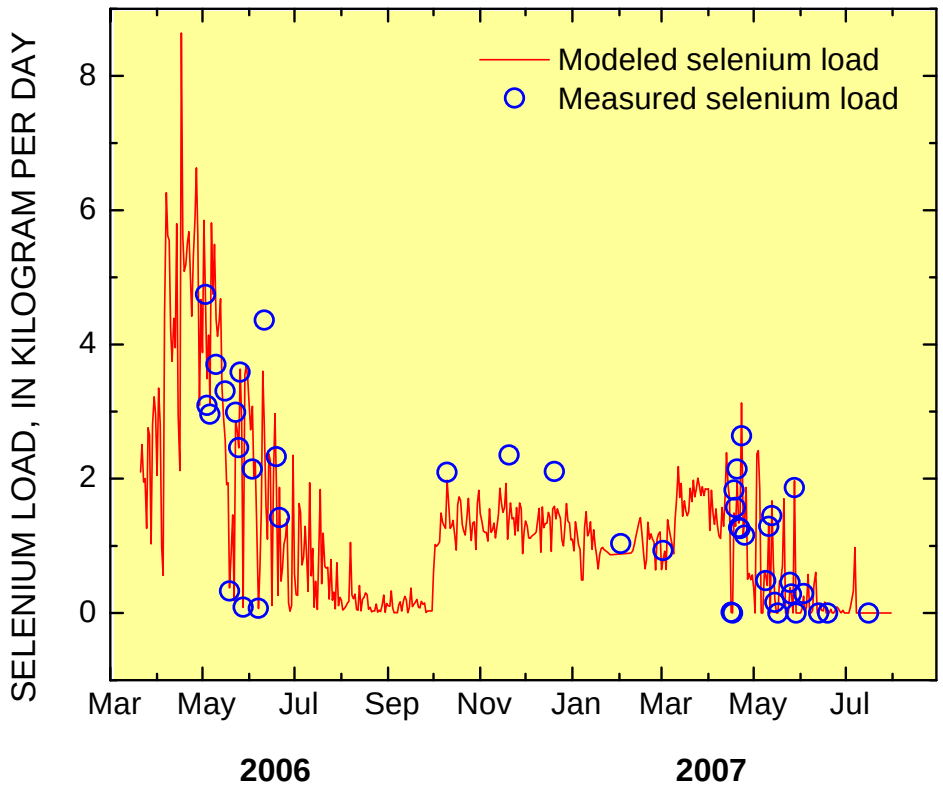


Figure 12. Measured and simulated loads of total selenium at the Bear River Bay Outflow streamflow-gaging station. Load estimates between 10/1/2006 and 04/14/2007 were calculated using a simulated mean daily discharge based on an upstream USGS gage (10126000 Bear River near Corinne, Utah).

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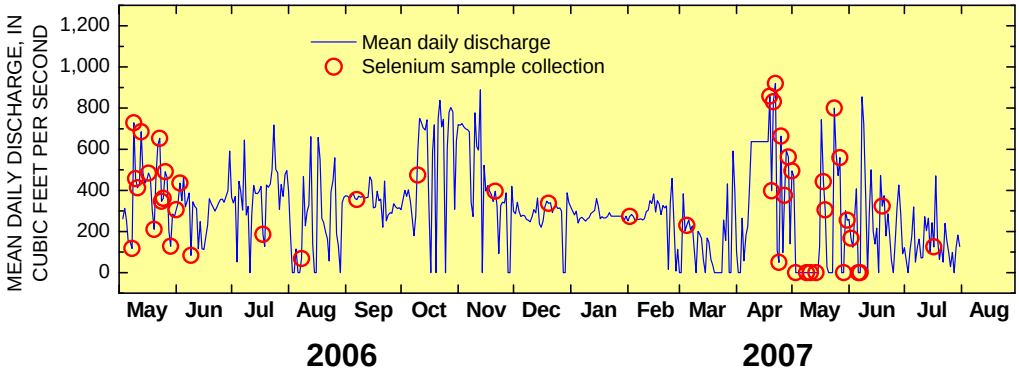


Figure 13. Stream discharge and dates when selenium samples were collected at the Farmington Bay Outflow gaging station. Negative mean daily discharge values (wind-driven flow into Farmington Bay) were assigned a discharge value of 0.0001 cubic feet per second. Because of intermittent periods of missing discharge record, discharge was estimated using the following formula: $Q_{FB} = (Q_{SC} + Q_{JR}) – Q_{GD}$; where Q is the mean daily discharge in cubic feet per second; FB is Farmington Bay Outflow; SC, is the Surplus Canal; JR, is the Jordan River at 1700 South; and GD, is the Goggin Drain. The locations of these sites are shown in Figure 14.

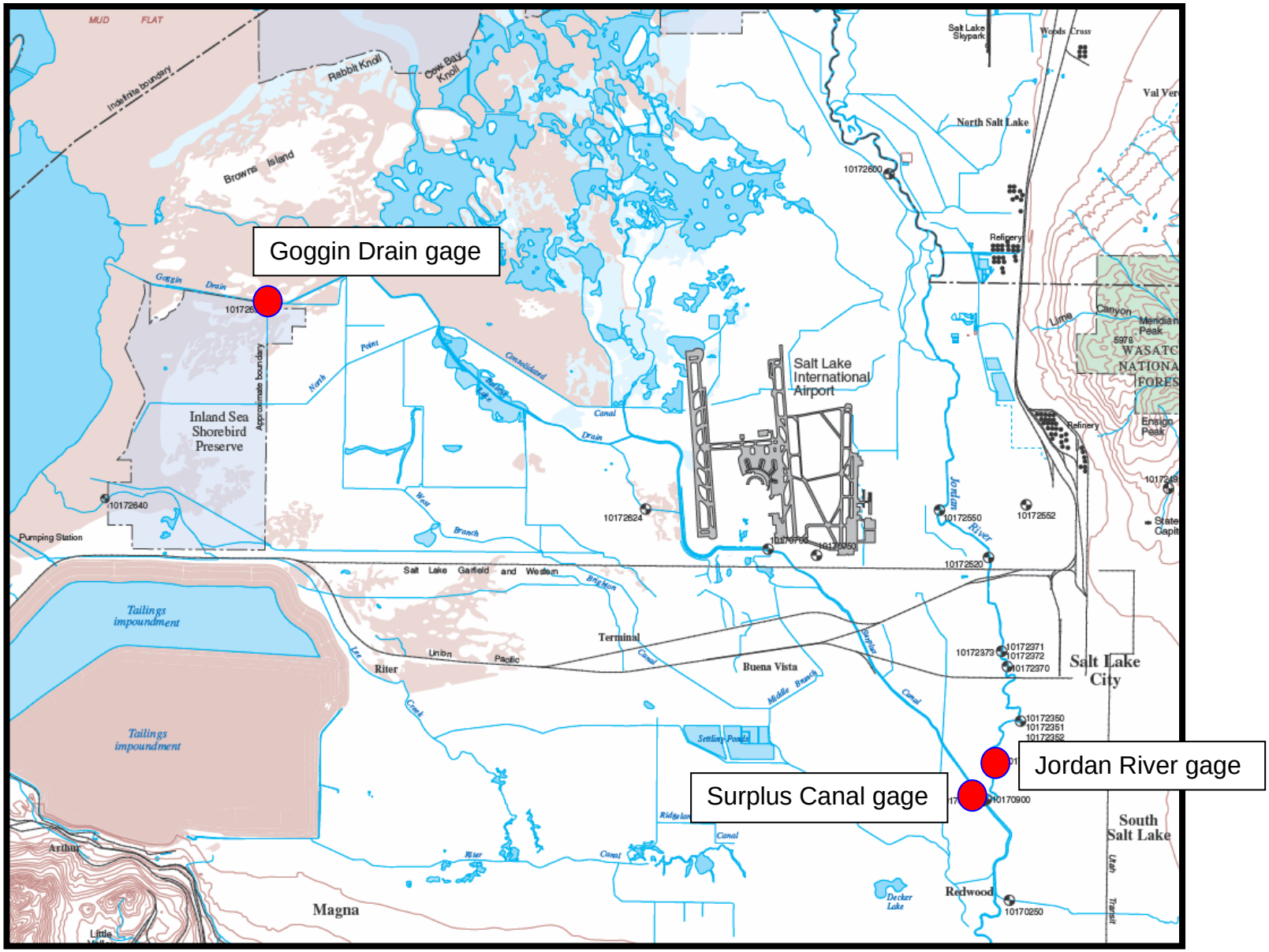


Figure 14. Locations of gages used to estimate mean daily discharge at the Farmington Bay Outflow gage site during periods of missing record.

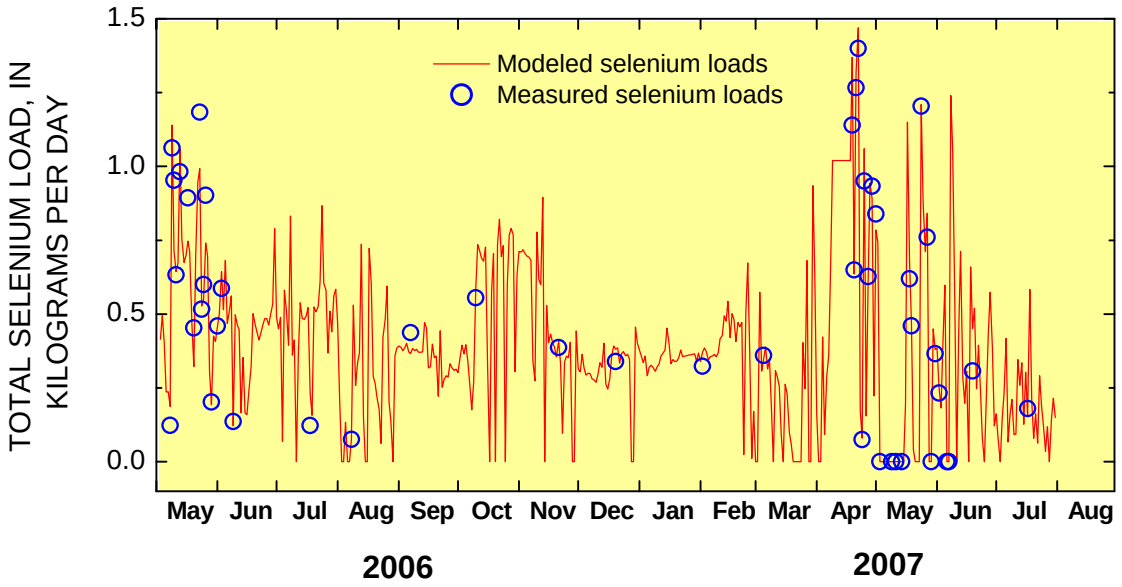


Figure 15. Measured and simulated loads of total selenium at the Farmington Bay outflow streamflow-gaging station. Because of intermittent periods of missing discharge record during 2006, selected selenium load estimates were based on calculated discharge estimates using the following formula: (Q_{FB} = Q_{SC} + Q_{JR}) – Q_{GD}; where Q is the mean daily discharge in cubic feet per second, FB is Farmington Bay Outflow; SC, is the Surplus Canal; JR, is the Jordan River at 1700 South; and GD, is the Goggin Drain. Locations of these additional gage sites are shown in Figure 14.

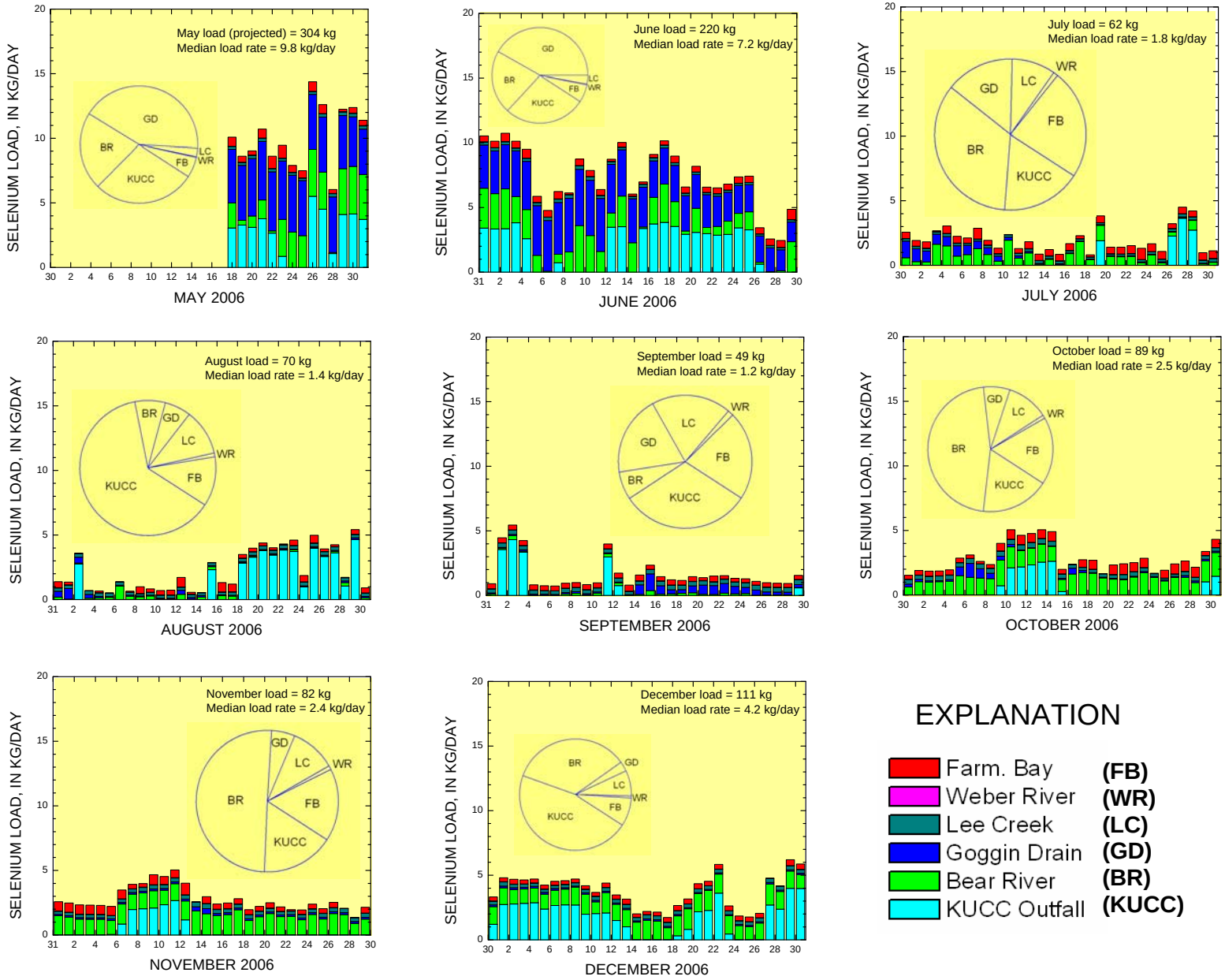


Figure 16. Modeled total (dissolved + particulate) daily selenium loads from May 2006 through July 2007, at the six major inflow sites to Great Salt Lake, Utah. Pie charts indicate relative load contributed by each inflow site.

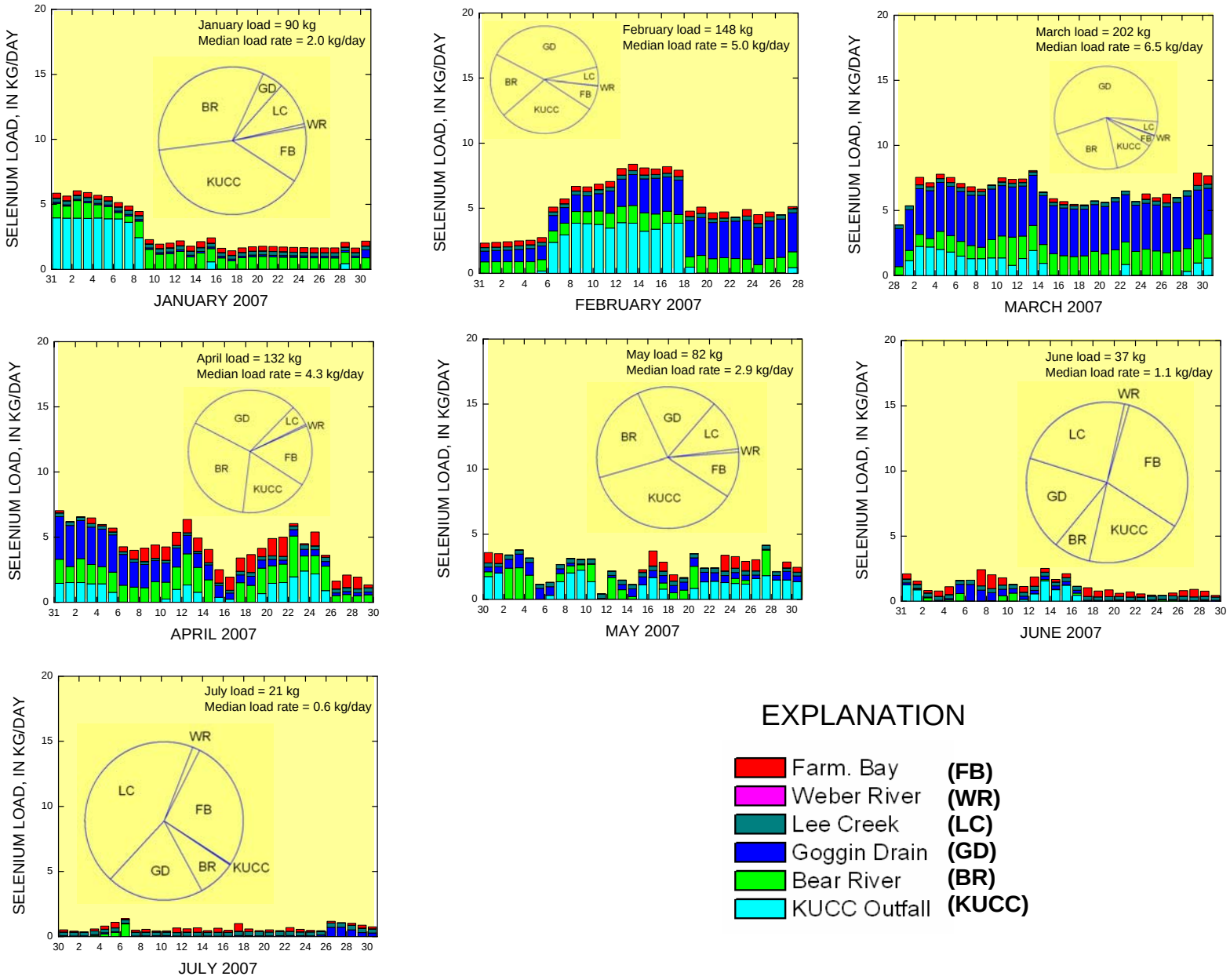


Figure 16. Modeled total (dissolved + particulate) daily selenium loads from May 2006 through July 2007, at the six major inflow sites to Great Salt Lake, Utah—continued.

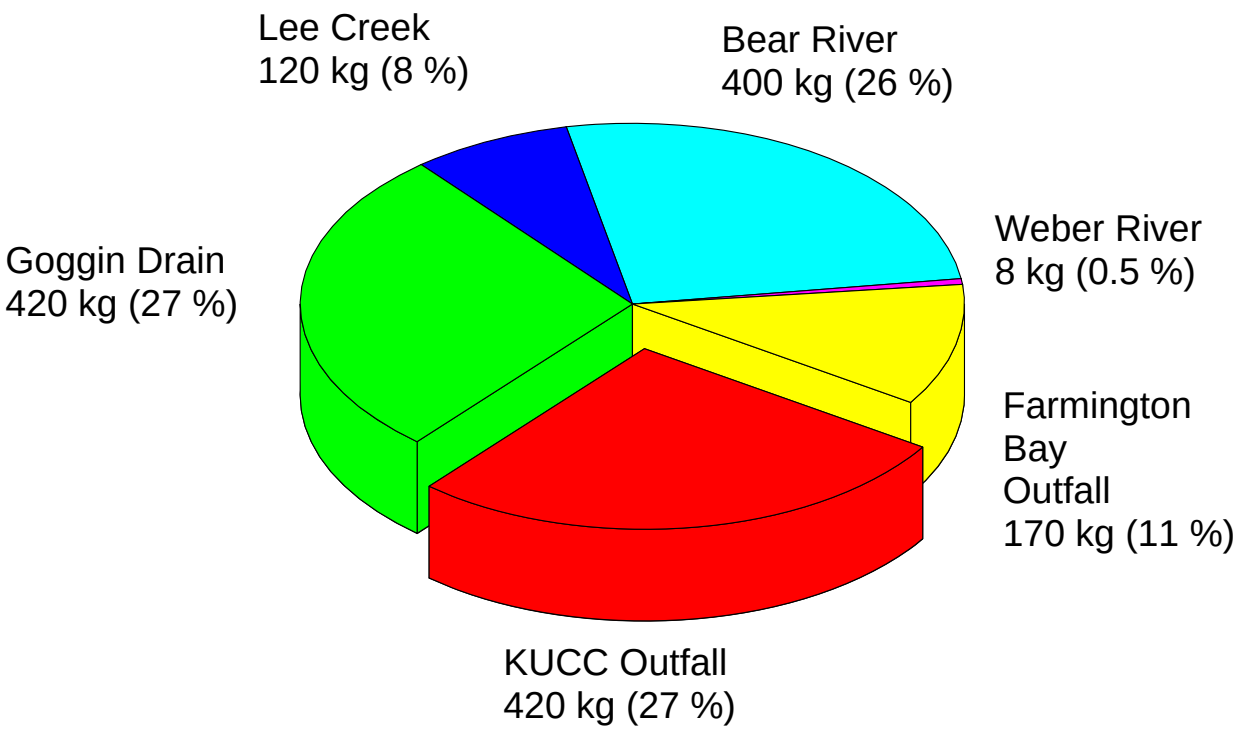


Figure 17. Distribution of total selenium loads contributed to Great Salt Lake from each inflow site from May 18, 2006 to July 31, 2007.

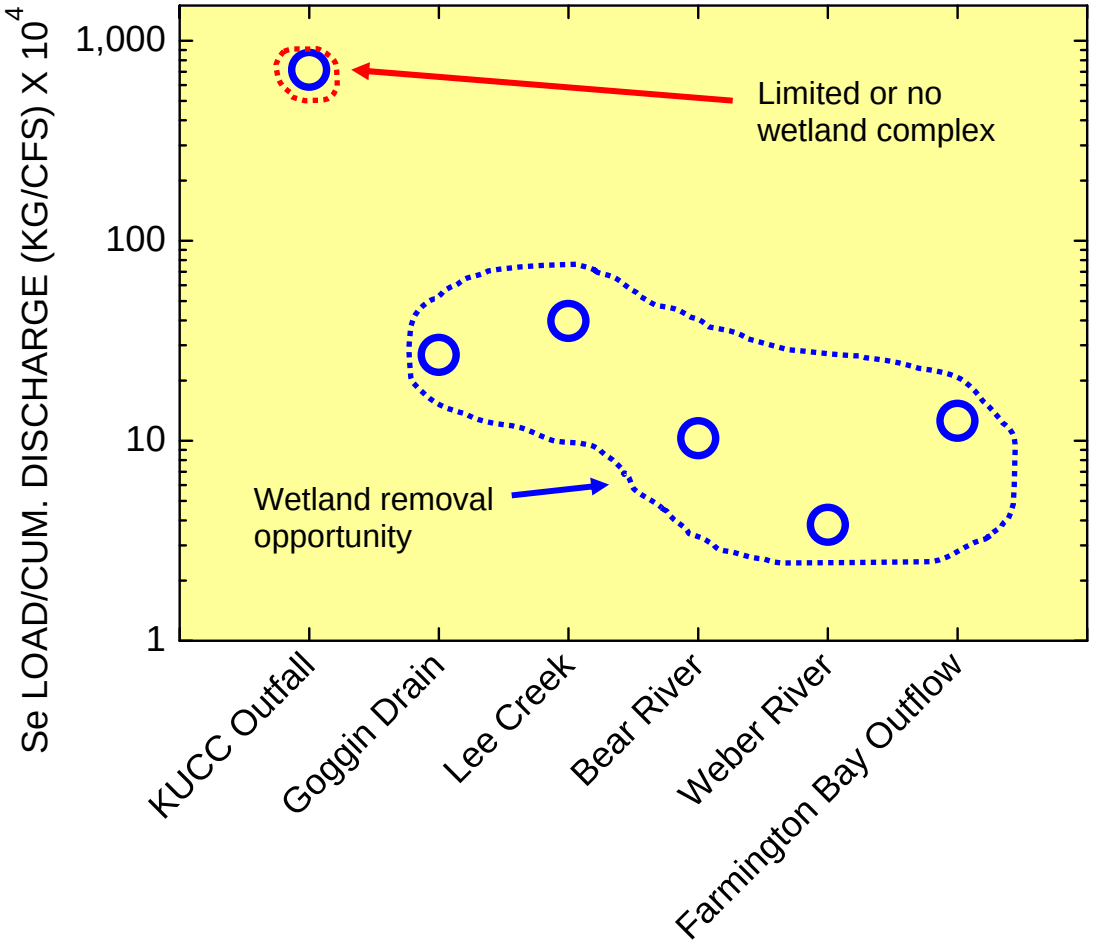


Figure 18. Comparison of cumulative selenium load (May thru December, 2006) divided by cumulative discharge (May 18 thru December 31, 2006) for the six major inflow sources to Great Salt Lake, Utah.

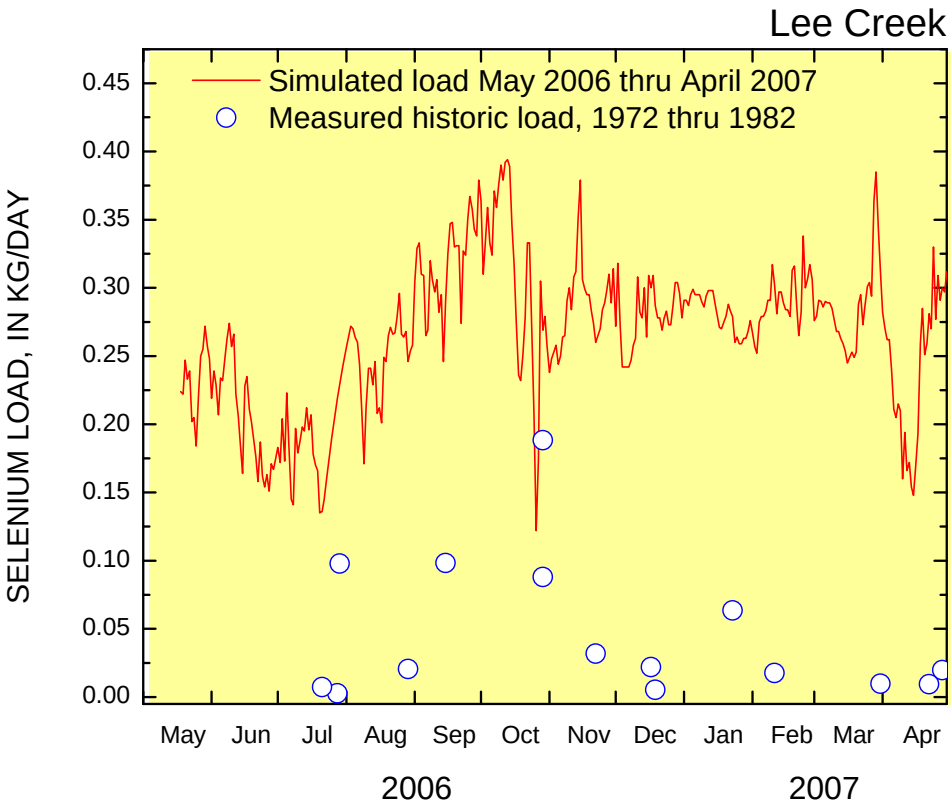


Figure 19. Comparison of simulated daily total (dissolved + particulate) selenium loads (May 2006 through April 2007) with measured historic dissolved (0.45 micron) selenium loads (1972 through 1982) at the Lee Creek gage site.

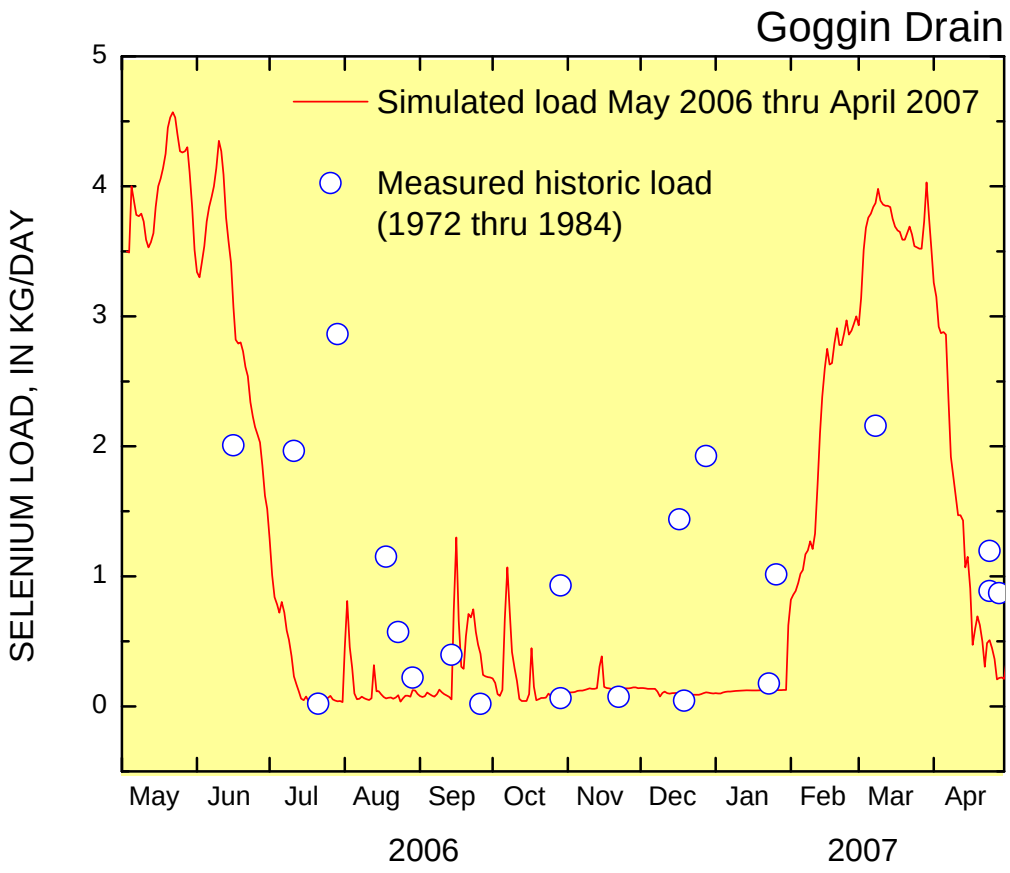


Figure 20. Comparison of simulated daily total (dissolved + particulate) selenium loads (May 2006 through April 2007) with measured historic dissolved (0.45 micron) selenium loads (1972 through 1984) at the Goggin Drain gage site.

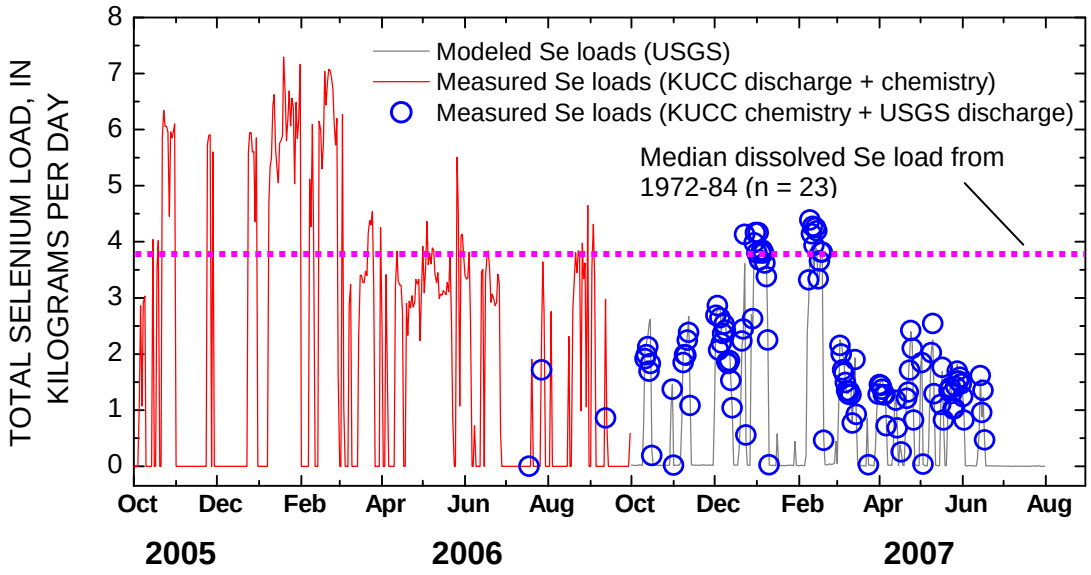


Figure 21. Comparison of present day measured and simulated loads of total Se at the Kennecott Drain streamflow-gaging station to the median dissolved Se loads measured from 1972 to 1984.

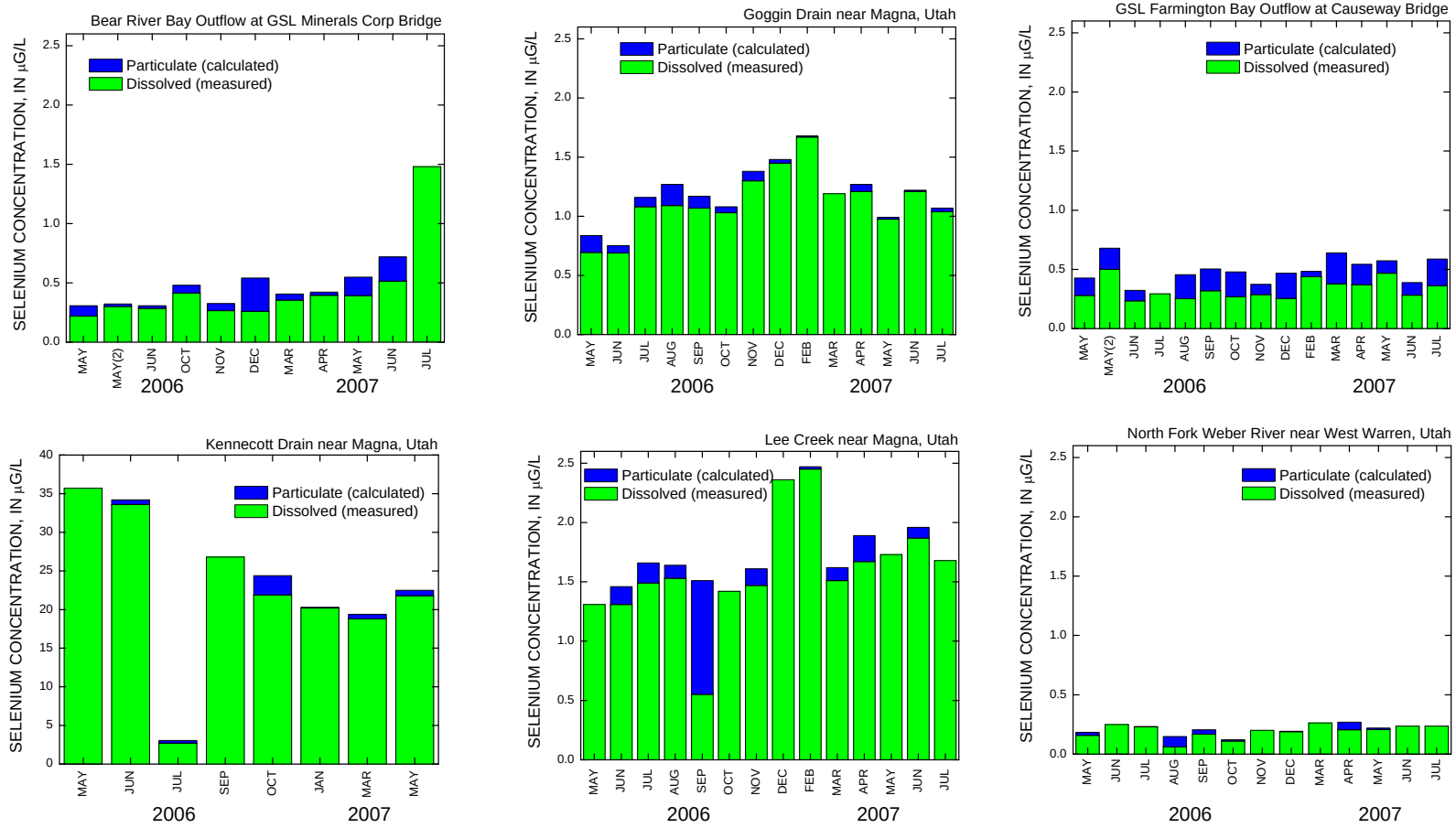


Figure 22. Distribution of dissolved and particulate selenium in water samples collected from inflow sites to Great Salt Lake during May 2006 through July 2007. Note the difference in scale for the KUCC Drain in comparison to other sites.

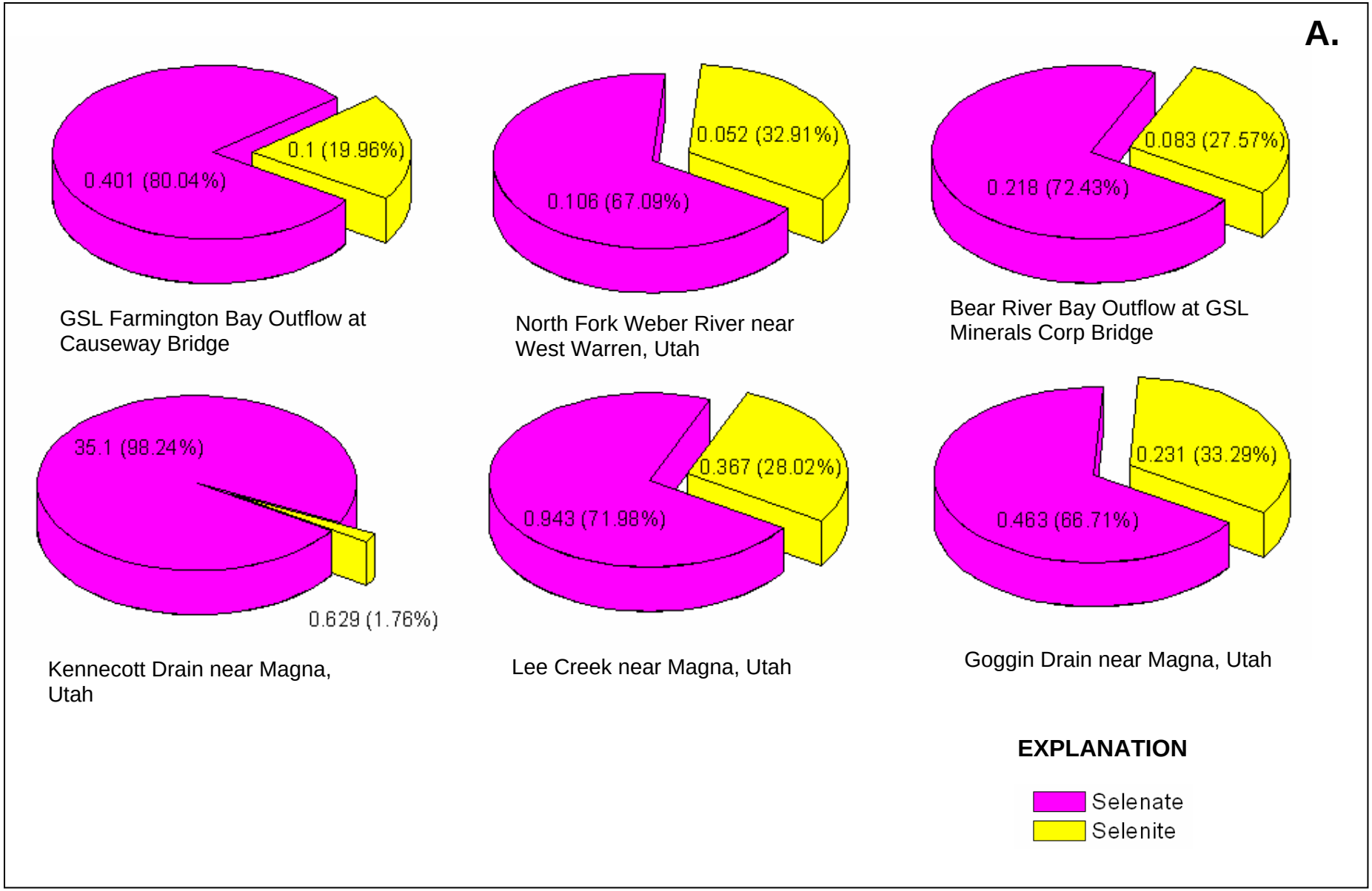


Figure 23. Distribution of selenate and selenite, in ug/L and (percentage of total selenium) in filtered water samples collected from inflow sites to Great Salt Lake during May 2006 (A) and May 2007 (B).

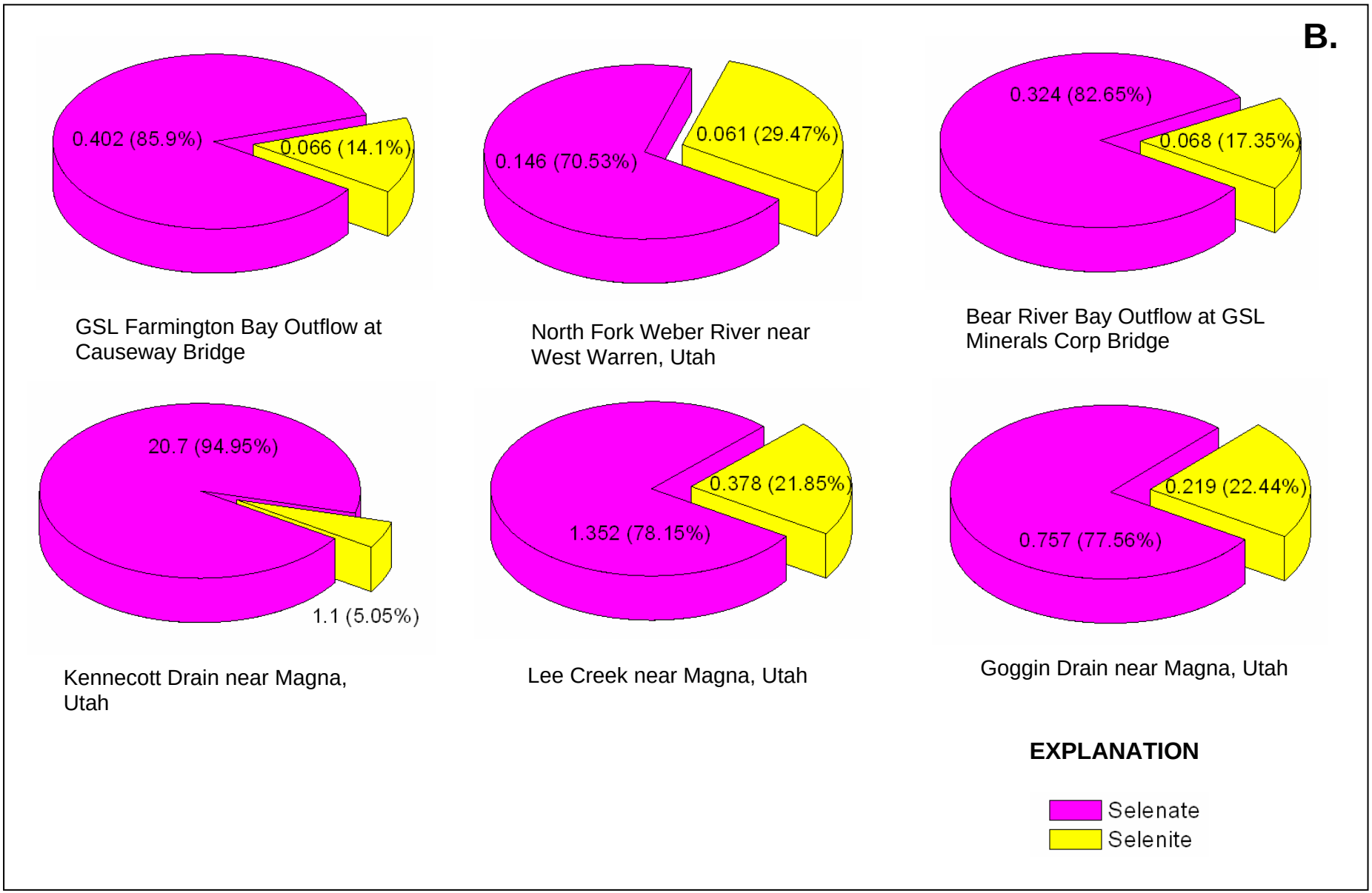


Figure 23. Distribution of selenate and selenite, in ug/L and (percentage of total selenium) in filtered water samples collected from inflow sites to Great Salt Lake during May 2006 (A) and May 2007 (B)--continued.

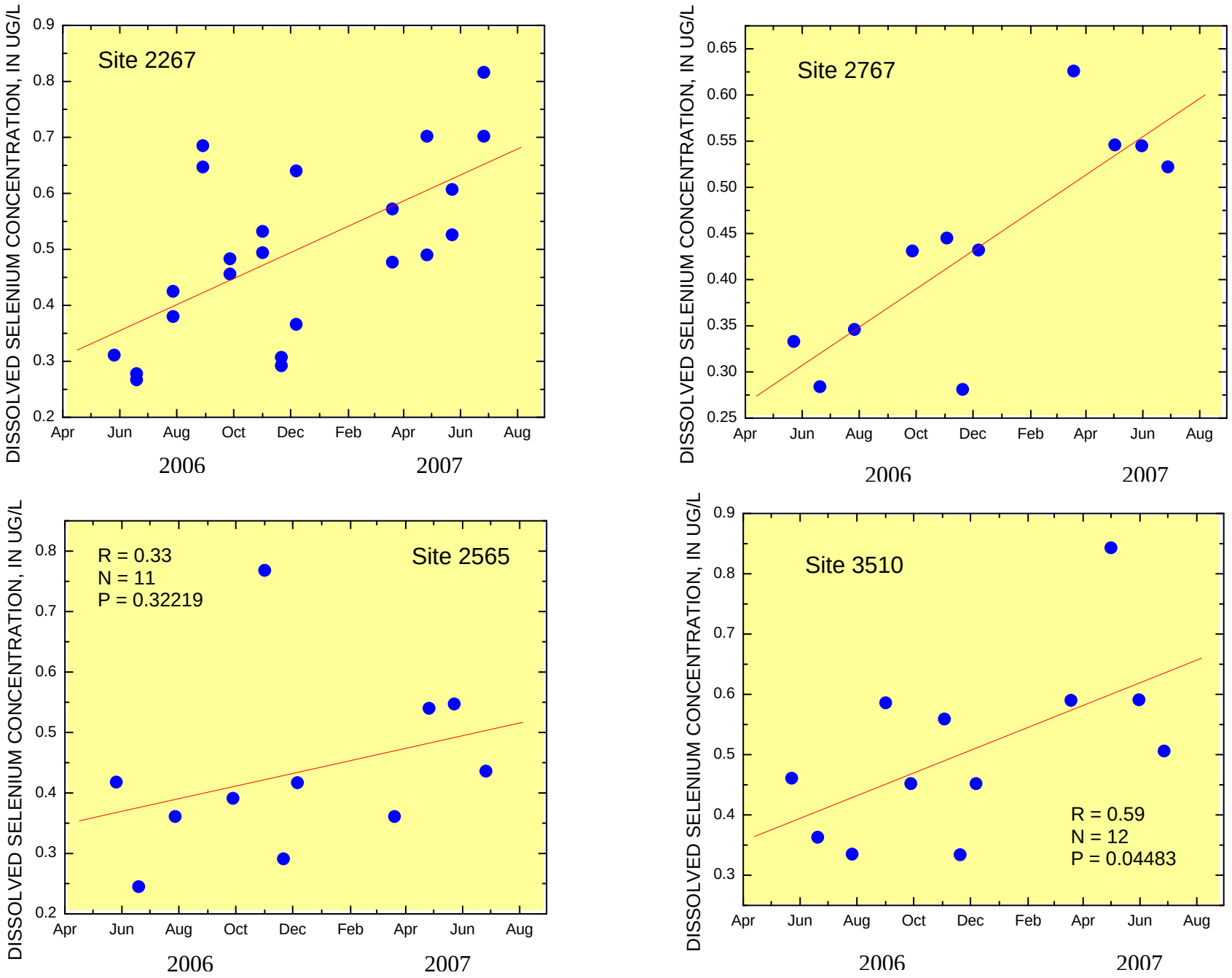
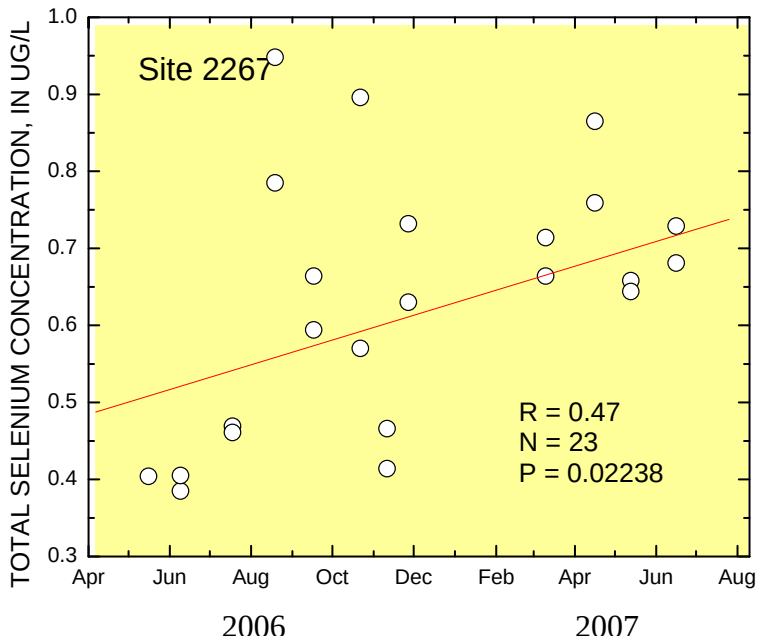
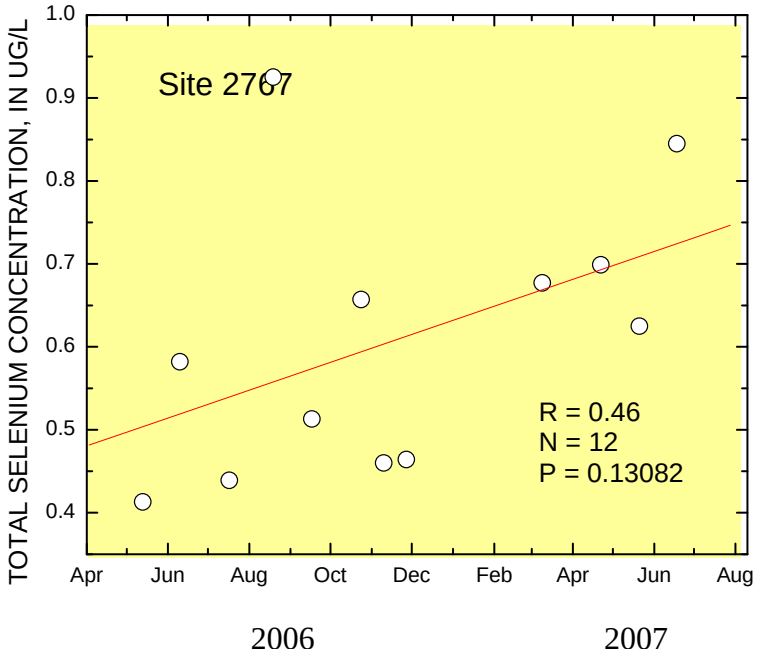
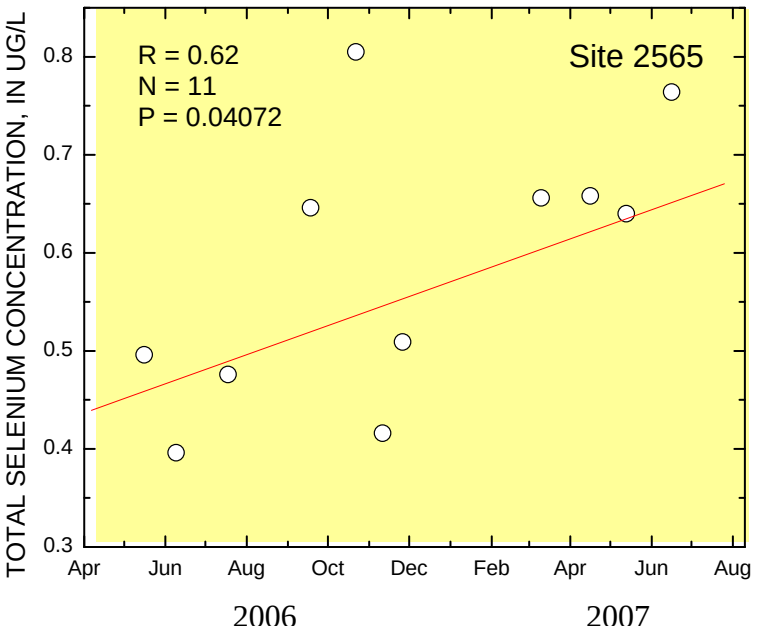


Figure 24. Trends in dissolved (0.45 micron) selenium concentration (A) and total selenium concentration (B) from May 2006 through June 2007 at open water sites, Great Salt Lake, Utah.

B







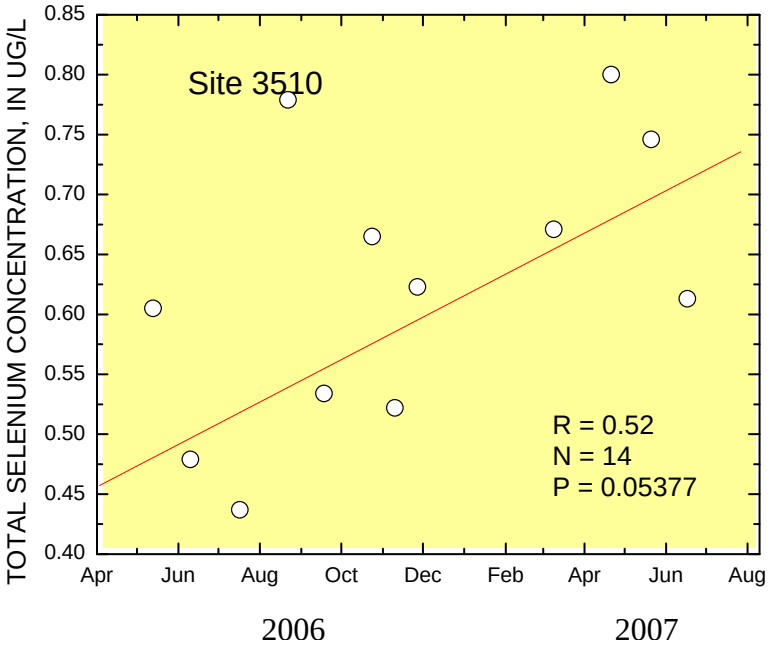


Figure 24. Trends in dissolved (0.45 micron) selenium concentration (A) and total selenium concentration (B) from May 2006 through June 2007 at open water sites, Great Salt Lake, Utah -- continued.

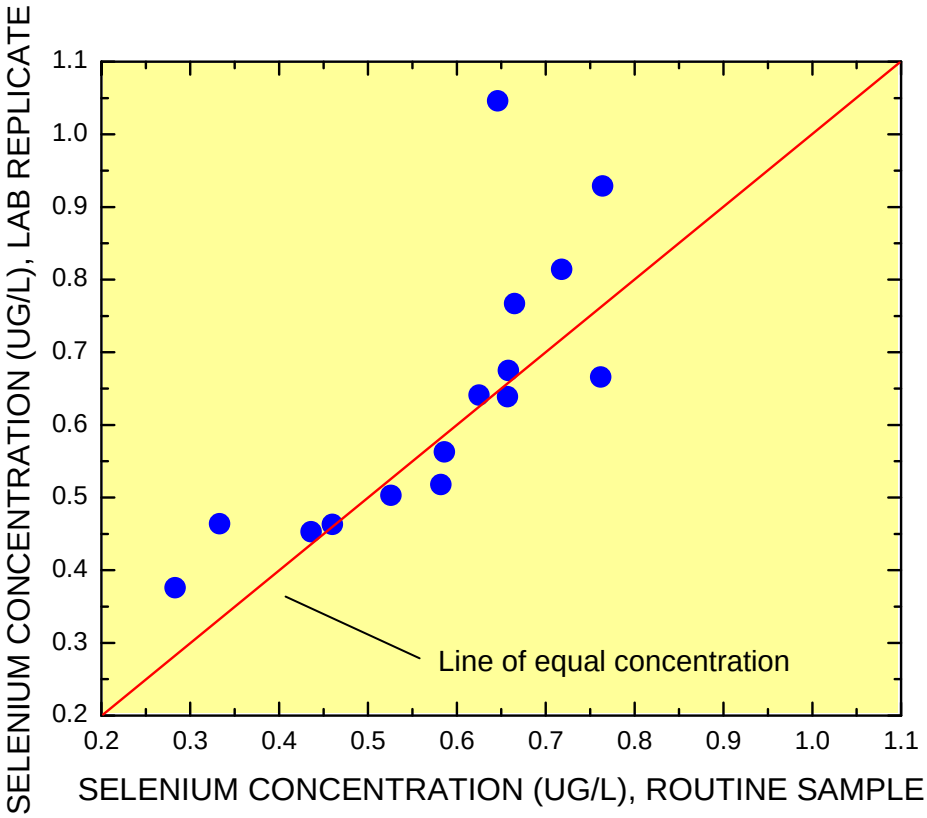


Figure 25. Comparison of dissolved (< 0.45 micron) selenium concentration in laboratory replicates with routine samples collected from near-surface depths at sites 2267, 2767, 2565, and 3510 from May 2006 through June 2007. The mean difference between routine and replicate samples is +/- 15 percent (n = 15). Elimination of the outlier results in a mean difference of +/- 12 percent (n = 14).

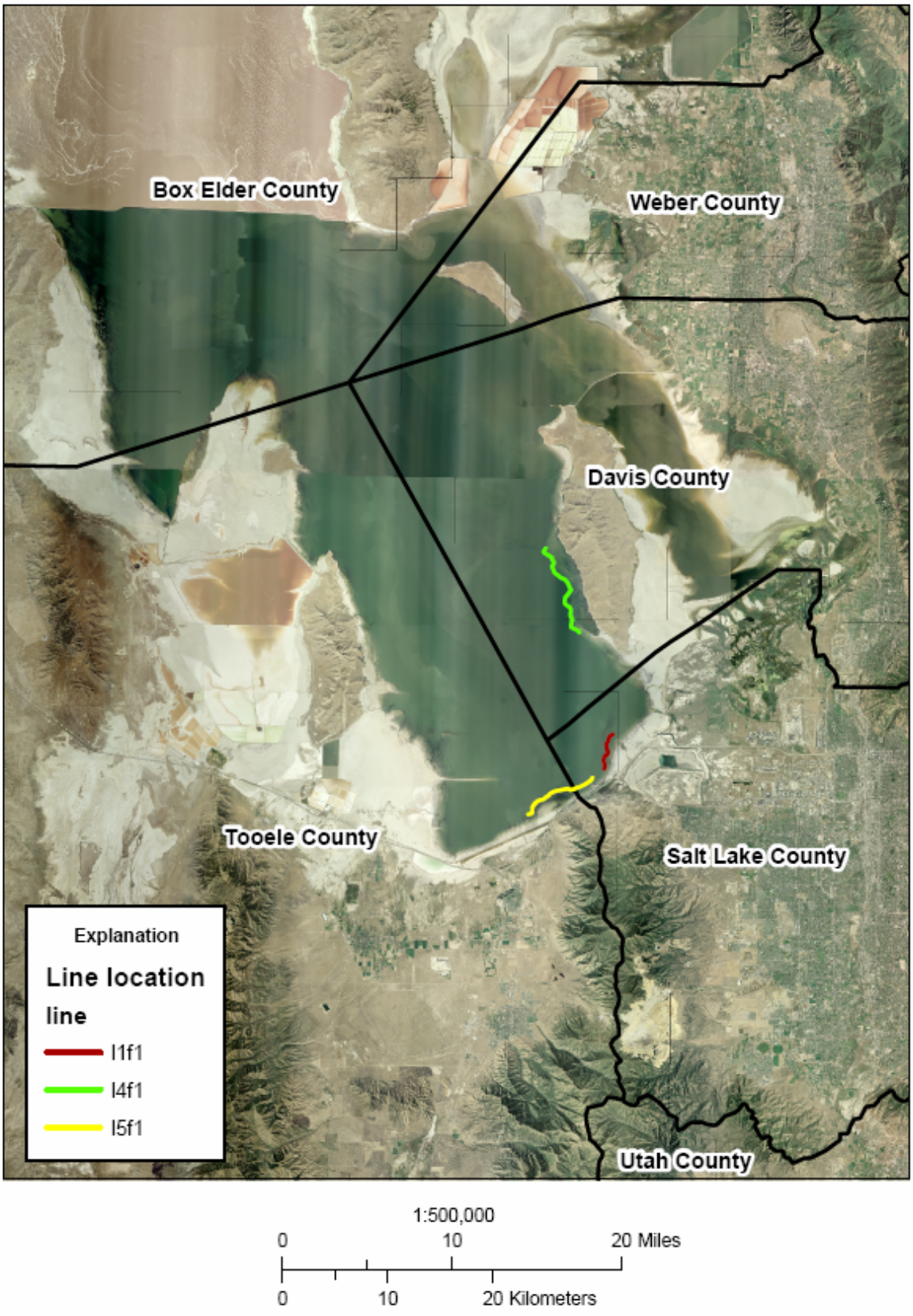


Figure 26. Location of continuous resistivity survey profiles collected during September 2007, Great Salt Lake, Utah.

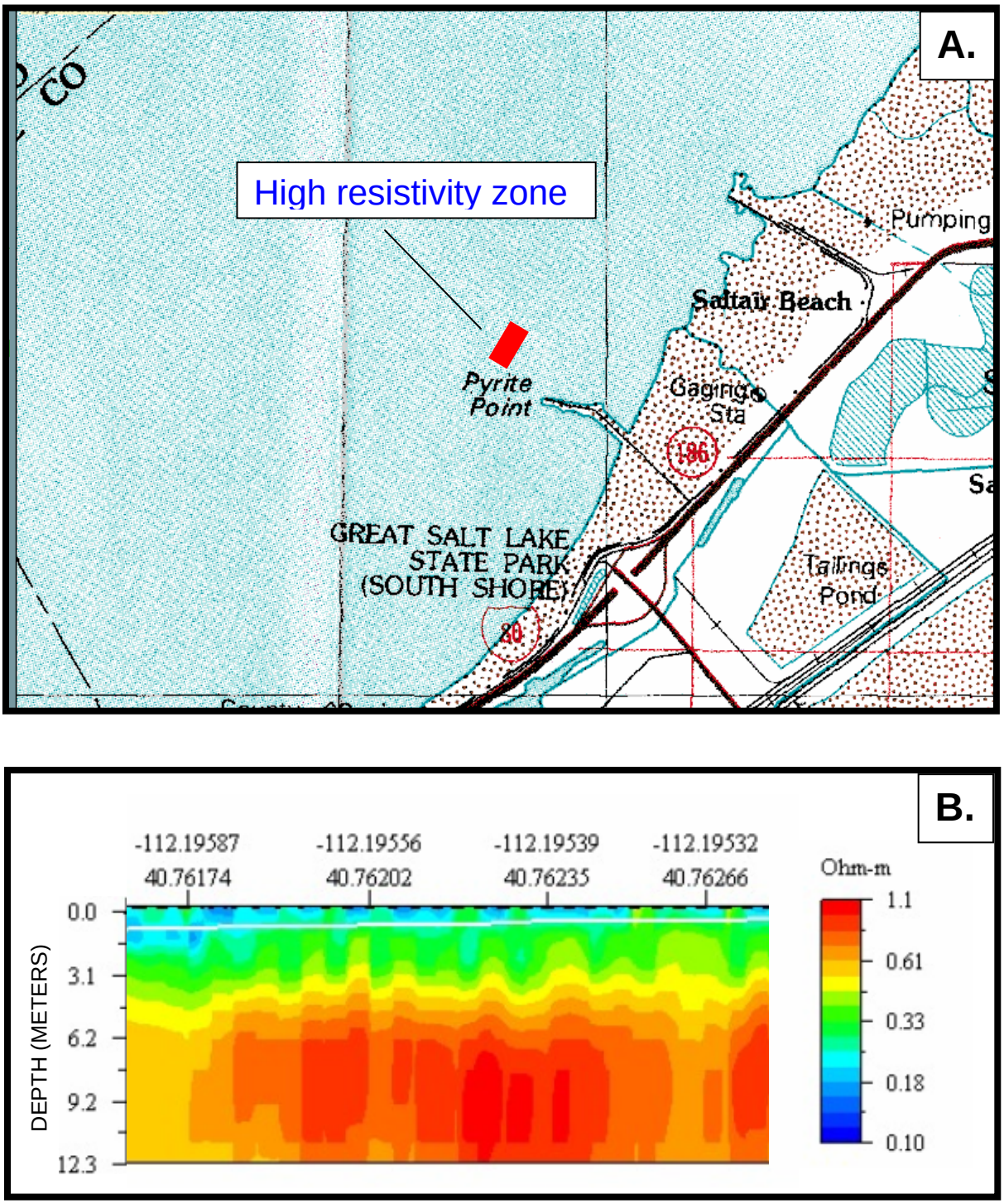


Figure 27. Location of high resistivity zone along transect l1f1 (A) and cross section of resistivity values (B). White horizontal line on resistivity cross section denotes approximate position of surface water/sediment interface.

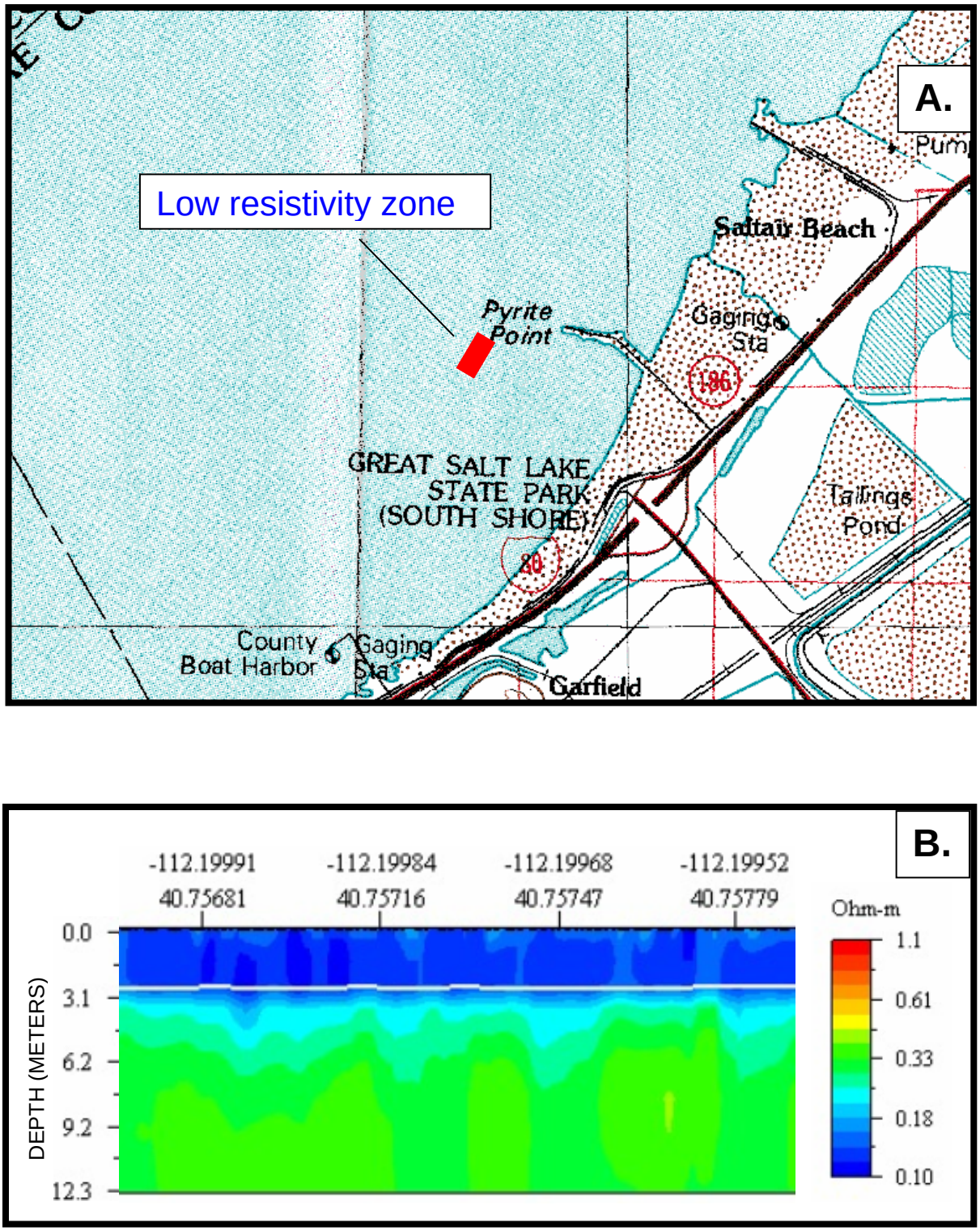


Figure 28. Location of low resistivity zone along transect l1f1 (A) and cross section of resistivity values (B). White horizontal line on resistivity cross section denotes approximate position of surface water/sediment interface.

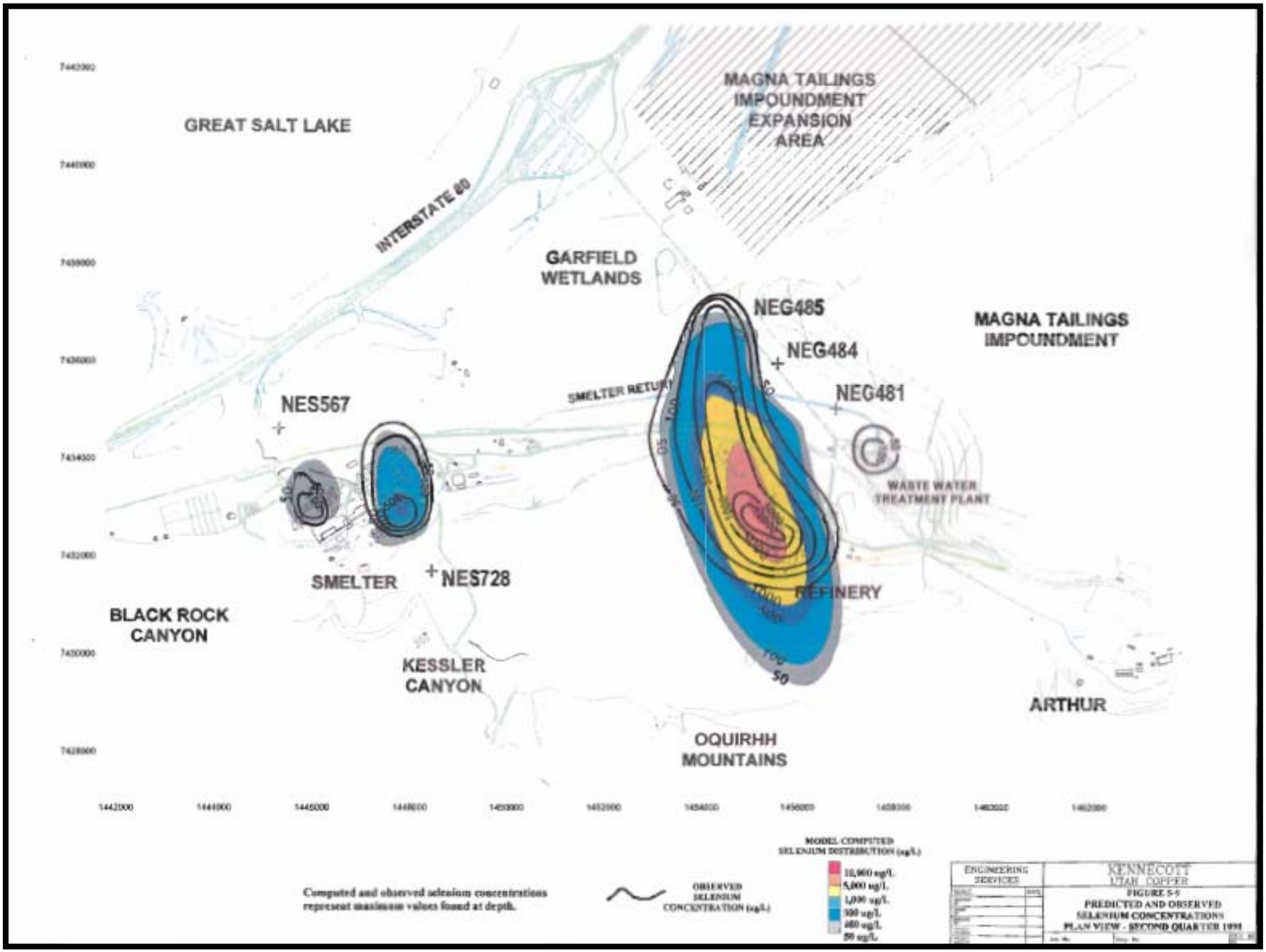
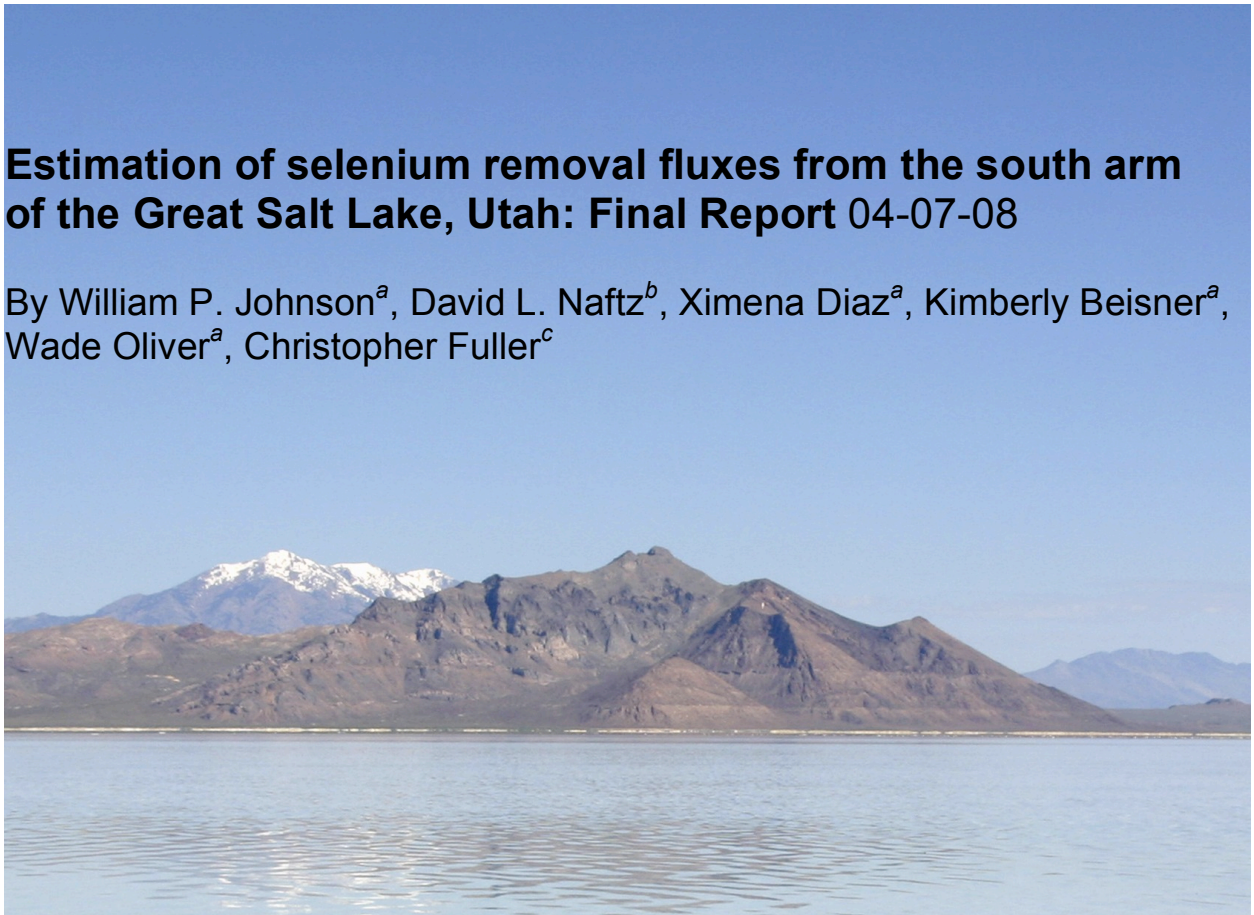


Figure 29. Predicted and observed extent of groundwater contaminant plume containing elevated concentrations of selenium located on the south margin of GSL (KUCC, 1999).

Estimation of selenium removal fluxes from the south arm of the Great Salt Lake, Utah: Final Report 04-07-08

By William P. Johnson[a], David L. Naftz[b], Ximena Diaz[a], Kimberly Beisner[a], Wade Oliver[a], Christopher Fuller[c]



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Executive Summary

Measurements were made during the period March 2006 through September 2007 to examine the existing distribution of selenium in the water and sediment of the south arm of the Great Salt Lake, and to measure Se fluxes between water, sediment, and the atmosphere at the Great Salt Lake. Results of these measurements are summarized in six sections below.

Great Salt Lake Characteristics

The average selenium (Se) concentration from May 2006 to July 2007 for unfiltered acidified (RA) samples was 0.64 ± 0.28 μg/L, whereas the filtered acidified (FA) samples showed an average Se concentration of 0.49 ± 0.25 μg/L for the same period. Differences between total and dissolved Se concentrations showed that a significant but minor fraction of Se was carried in particulate phases, more so in the deep brine layer relative to the shallow brine layer, but in either layer, the Se mass was dominantly dissolved rather than particulate. In terms of temporal variation, increases in the measured total (RA) and dissolved (FA) Se concentrations were observed in both the deep and shallow brine layers during the period of the investigation (Figure 7), constituting a net increase ranging between 0.16 and 0.34 μg/L over the period of the investigation (Naftz et al., 2007).

Volatilization

The average concentration of volatile Se in the water column was 3.0 ng/L, but this measured concentration varied over two orders of magnitude spatially and temporally. The measured volatile Se concentrations increased with depth for paired measurements in the shallow brine layer. Comparison of measured to estimated volatile Se flux showed reasonable agreement, indicating that Se flux to the atmosphere could be integrated from measured volatile Se concentrations, wind speeds, and water temperatures. The resulting estimated annual volatile Se flux to the atmosphere from the Great Salt Lake is 2108 Kg/yr. This estimate is considered accurate to within a factor of 1.5 (within a 68% confidence interval), yielding a potential range between 1380 to 3210 Kg/yr. The large range in estimated flux results from the spatial and temporal variability of volatile Se concentrations. Despite the variability, the results demonstrate that Se volatilization is the major mechanism of Se removal from the Great Salt Lake.

Downward Sedimentation

Downward sedimentation fluxes were highest where influenced by the Bear River inflow, and were lowest in the shallow brine layer at sites located near the northwest-southeast axis of the south arm. Notably, sediment accumulation rates in the deep brine layer were much greater than corresponding shallow layer sediment accumulation rates, suggesting that re-suspension accounted for most of the sediment accumulation at depth. The influence of re-suspension on sediment accumulation in the Great Salt Lake was also indicated by ^{7}Be analyses in sediment cores.

Permanent (Net) Sedimentation

The permanent Se removal flux via sedimentation was estimated at 520 Kg/yr, based on ^{210}Pb profiles from ten sediment cores in the south arm. This estimated

sedimentation flux is considered accurate within a range of uncertainty between 45 and 990 Kg/yr.

Re-suspension – Re-solubilization

Temperature readings from six depths at two sites in the south arm demonstrate periodic equilibration events consistent with temporary displacement of the deep brine layer via seiche transmission in the lake. This observation suggests that anoxic sediments are periodically and ephemerally placed into contact with oxic shallow brine layer, potentially leading to re-solubilization of Se from the anoxic sediment. Short term (24 hour) batch studies indicate that Se re-solubilization during these ephemeral events yields negligible change in Se concentration in the water column. Longer term contact between oxic shallow brine and anoxic sediment may occur via shrinkage of the deep brine layer. Longer term (week to month) batch studies indicate that a significant mass (e.g. 25 Kg) may be contributed by these longer term events.

Mass Balance

The combined sedimentation and volatilization fluxes total to about 2650 Kg/yr (based on the geometric means). Comparison of volatilization to sedimentation flux demonstrates that sedimentation is NOT the major mechanism of removal of Se from the Great Salt Lake. Rather, volatilization is demonstrated to be the major mechanism of Se removal from the Great Salt Lake. These measured loss fluxes balance (more than) the measured annual load (1,500 Kg/yr) during the study period. The observed increase in total Se concentration during the period of the study indicates that most Se loads to the lake are not yet measured, and that continued monitoring of Se concentrations is needed. However, it should be noted that the inefficiency of in-lake mixing processes complicates comparison of measured Se concentrations to measured Se loads and removal fluxes.

Table of Contents

1. Introduction

Characterization of the existing distribution of selenium (Se) in the water and sediment of the south arm of the Great Salt Lake, and measurement of Se fluxes between water, sediment, and the atmosphere at the Great Salt Lake are motivated by the goal of setting a Se standard for the open waters of the Great Salt Lake.

The open waters of the Great Salt Lake are protected for their current beneficial uses (Class 5) through the application of the narrative criteria clause. Existing EPA-promulgated numeric standards for inland lakes cannot by applied to the Great Salt Lake due to its highly individual nature, i.e. large, terminal, hypersaline, and meromictic (i.e. multiple, stable layers).

The development of an open water standard for Se requires a working knowledge of the biological significance of existing Se concentrations in the Great Salt Lake, as well as a working understanding of the likely changes in these concentrations over time given existing and proposed loads to the system. This "working knowledge" has been previously represented in a conceptual model (Johnson et al., 2006) that accounts for Se in various "stocks" in the system (e.g. water, sediment, biota) and the "flow" of Se between stocks (e.g., precipitation and settling, volatilization, and bioconcentration).

The conceptual model serves as the basis for five investigations conducted during the period April 2006 to October 2007. These investigations involved: 1) Characterization of Se concentrations and effects in avian species associated with the south arm of the Great Salt Lake; 2) Characterization of Se concentrations and effects in brine shrimp, seston, and benthic organisms in the south arm of the Great Salt Lake; 3) Characterization of Se uptake kinetics in brine shrimp; 4) Determination of annual Se loads to the south arm of the Great Salt Lake; 5) Characterization of the distribution of Se in water and sediment and determination of selenium removal fluxes via sedimentation and volatilization in the south arm of the Great Salt Lake. This report describes findings of the 5th investigation.

2. Methods

2.1 Water column

Aqueous chemical conditions were characterized in the field at 19 locations across the main body of the Great Salt Lake (Figure 1). Four of these stations (2267, 2565, 2767 and 3510) were characterized at 7 to 13 depths (varying by station), ranging from 0.2 to 8 m depth below lake surface. The remaining stations were characterized at three depths (3, 6 & 8 m). Aqueous characteristics included temperature, conductivity, pH, oxidation-reduction potential (ORP), and dissolved oxygen (DO), as measured using a Hydrolab Troll 9000 (In-Situ Inc., Fort Collins, CO).

Samples for major and trace element analysis were collected in acid-rinsed polyethylene bottles from four stations (2267, 2565, 2767 and 3510). At two stations (2267 & 2767), samples were collected from two depths representing the shallow brine layer (0.2 m (both sites) and 4 m (2267) or 2.5 m (2767)). At the remaining two stations (2565 & 3510), samples were collected from three depths representing the shallow and deep brine layers and the interface between them (0.2, 8, and 6.5 m, respectively). Replicate samples (4 x 250 mL) were collected from each location using a peristaltic pump with acid-rinsed C-flex tubing (Cole-Parmer's Masterflex, Vernon Hills, IL). Two of the replicates were filtered (0.45 μm pore size, capsule-type filter). All four replicates were stored on ice, acidified (trace metals grade nitric acid, 2 mL, 7.7 N), and transferred to a refrigerator. One each of the filtered-acidified and raw-acidified samples were sent to a contract lab (Frontier Geoscience, Seattle, WA) for total Se analysis as described below. The other replicates were stored at 4^{o}C for major and trace elements analyses (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, Pb, S, Sb, Sc, Sr, Ti, Tl, U, V, Zn) via inductively coupled plasma mass spectrometry (ICP-MS) as described below.

At the 19 locations in Figure 1, analyses were performed for volatile Se concentrations and total dissolved gas pressure, at multiple depths (representing deep and shallow brine layers). Semi-monthly samples were taken at those locations and multiple depths in the south arm of the Great Salt Lake to explore temporal variations in volatile Se concentrations. Collection of volatile Se using the purge and cryo-focusing trap process was performed in-situ at the respective sampling sites on the lake in order to avoid any degradation of the water sample (as described in the Analyses section).

Direct measurements of volatilization of Se were taken at two primary (3510 and 2267) and one secondary (2565) location in the south arm of the Great Salt Lake. The flux measurements were taken concurrently with characterizations of the parameters used in estimating volatile Se flux: surface water temperature, wind velocity, and volatile Se concentration, in order to assess the accuracy of the predictive model.

At an additional twelve locations in the deep brine layer (Figure 1), samples were taken for total organic carbon (TOC) analysis (GS1, GS3, GS4, GS5, GS8, GS9, GS11, GS12, GS14, GS15, GS18, GS20).

At sites 2565 and 3510 (Figure 1), temperature was measured at 6 depths spanning the interface between the deep and shallow brine layers. Temperature was measured using thermistors (StowAway®, TidbiT™, model #89419) attached to the sediment trap cables. For site 2565, thermistor distances above the anchor were 1.75, 2.10, 2.45, 2.81, 3.15 and 3.51 meters. In August 2006, the chain at the base of the site 2565 trap was shortened by one meter to decrease the distance of each thermistor above the base by 1 meter. For site 3510, thermistor distances above the anchor were 1.86, 2.21, 2.61, 3.02, 3.38 and 3.73 meters. At both sites (2565 and 3510), thermistor spacing was increased (on September 28, 2006) to 0.5 m to yield distances above the anchor of 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 meters (Figure 2a). Thermistor readings were taken at 6-minute intervals, and were downloaded approximately monthly with an optical reader device that connects to a computer. Once the data had been offloaded from the thermistors, Boxcar® software was used to view the data and export data files to Excel.

2.2 Sediments

2.2.1 Sediment traps

2.2.1.1 Description

The sediment traps used for sampling in the Great Salt Lake consist of balanced pairs of detachable cylindrical acrylic sampling traps (72 mm internal diameter, 450 mm length) mounted in stainless steel holders located above their center of gravity to keep them vertical (Figure 2). The holders were attached to a stainless steel cable strung between a cement anchor and a buoy.

The traps were deployed at three sites representing three distinct locations in the main body of the Great Salt Lake (Figure 1). Site 2267 was located near the mouth of the Bear River, the largest contributor of flow to the lake (70% of inflows). Sites 2565 and 3510 represent northern and southern basins in the main body of the lake. At site 2267, the top of a sediment trap pair was placed at 2.8 m below the lake surface (Figure 2b), where the water depth was 4.1 m. At sites 2565 and 3510, where the water depths were 8.1 and 8.4 m, respectively, the trap pair tops were placed at two depths, approximately 3.7 m and 7 m below the lake surface (Figure 2c), corresponding to the shallow and deep brine layers, respectively.

2.2.1.2 Collection and processing of trap sediments

Sediments from sediment traps were collected approximately monthly starting March 3, 2006 for sites 2267 and 2565, and starting June 27, 2006 for site 3510.

After retrieving the sediment traps from the water, most of the water was drained using a peristaltic pump. The remaining water was swirled to make slurry, which was collected in 1-L polyethylene bottles and kept on ice until transfer to a refrigerator.

Processing involved filtering the slurry onto a Millipore vacuum filtration system (1.2 μm pore size, glass microfibre filter). The filter cake was freeze-dried, digested and analyzed by ICP-MS as described below. Salinity corrections for the filter cake mass were performed as described below for the core segments.

2.2.2 Cores

2.2.2.1 Collection and sub-sampling

Historical and contemporary sedimentation rates and sediment Se concentrations were investigated by analysis of sediment cores taken at various sites in the South Arm of the Great Salt Lake in order to estimate permanent Se removal by sedimentation.

Shallow cores (~6 cm) were taken at 20 sites (yielding quantifiable sedimentation rates in 13 sites) during June, 2007 across the south arm of the Great Salt Lake. A preliminary linear sedimentation rate was determined in each core based on ^{210}Pb decay at intervals of 0-1 cm and 4-5 cm using the CF-CS (constant flux-constant sedimentation) method (described below). Though these rates did not account for compaction of sediment, they were useful for determining relative differences in sedimentation rates, and were used as a guide to select the five additional deep coring sites occupied in 2007.

Deep core sediments were collected at sites 2267, 2565 and 3510 during July, 2006 and at sites DD-C, DD-Q, DD-I, DD-L, and DD-R during July, 2007 (Figure 2d). Each of the 2007 cores was sliced into a minimum of 10 1-cm increments. At site 2267 (total water depth of 4.1 m), one gravity core of 88 cm in length was recovered. The top ten centimeters were sliced in 2-cm intervals, whereas the remainder of the core was sliced in 3-cm intervals. At site 2565 (total water depth of 8.1 m), two gravity cores (32 and 35 cm) were collected. Both were sliced in 2-cm intervals. For site 3510 (total water depth of 8.4 m), two core samples were collected. A box corer was used to collect a 12.5-cm sediment core. This device was used to avoid compaction of this shallow sediment, in order to provide the best possible determination of age as a function of depth (and sedimentation rate). This sample was sectioned in-situ in 1-cm intervals. The core slices were placed into individual plastic containers and were stored on ice until transfer to a freezer. Also at site 3510, a gravity coring device was used to collect a 38-cm long core, which was sliced in 2-cm intervals. The 2007 cores were collected with a gravity core device, cut into 1-cm slices and processed in a similar manner as the 2006 cores.

All deep core slices were freeze-dried as described below and ground using a ceramic mortar and pestle. After grinding, the samples were homogenized by mechanical mixing and divided into four fractions.

The homogenized core slices were divided into four fractions. One fraction was analyzed for sedimentation rate using the CF-CS method for more precise determination of sediment mass accumulation rates (MAR) in these cores (at the USGS, Menlo Park, CA). In the CF-CS method, the natural logarithm of unsupported ^{210}Pb (dpm/g) in each 1-cm increment is plotted against the cumulative dry mass (g/cm^2) of sediment. The decay constant for ^{210}Pb divided by the slope of the linear trendline on the above plot yields the sediment MAR in g/cm^2/yr.

In eight cores, the second fraction was sent to the contract lab (LET Incorporated, Columbia, MO) for Se analysis. To reflect contemporary Se removal by sedimentation,

only the top 2 cm of sediment were included in calculating the average Se concentration for each core.

Lab results for Se concentration in the above-mentioned cores required correction for salt content. The mass of salt and additional selenium deposited on the sample from the saline pore water during the drying process was removed using the following equation and solving for [Se_{sed}]:

$$[Se_{sed}] = \frac{[Se_{dry}] - \frac{Mass_{water} \times \%\text{Salinity}}{Mass_{dry}} \times [Se_{salt}]}{\frac{Mass_{dry} - (Mass_{water} \times \%\text{Salinity})}{Mass_{dry}}}$$

where [Se_{dry}] is the concentration of selenium in the dry sample, $Mass_{water}$ is the mass of pore water in the sample found by subtracting the dry weight from the wet weight, % Salinity is the percent salinity of the pore water, $Mass_{dry}$ is the total dry mass of the sample, [Se_{salt}] is the selenium concentration in the salt calculated from the percent salinity and a 0.5 μg/L aqueous concentration, and [Se_{sed}] is the selenium concentration in the sediment corrected for salt content.

In the three cores taken in 2006, a third fraction was analyzed for minor and major elements by ICP-MS at the University of Utah as described below. The fourth fraction was archived at room temperature.

2.2.2.2 Estimating Selenium Removal by Sedimentation

Annual Se removal by sedimentation was estimated from core analysis results. Holocene sediment thicknesses were estimated by David Dinter (University of Utah) and Steven Colman (USGS, Woods Hole, MA) by analysis of 30 Chirp (variable frequency) and Geopulse high-resolution seismic reflection transects (Dinter, 2007; Colman, 2002), as shown in the Results section. These Holocene thickness contours were plotted in ArcGIS along with the shallow core results in order to develop contours delineating qualitative zones of very high to very low contemporary sedimentation rates. Average MAR in each zone was determined by comparison of sedimentation zones to the MARs from the eight deep cores. The Se concentrations in the top 2 cm of the eight deep cores provided average contemporary sediment selenium concentrations for each zone.

With Se concentration, mass accumulation rate, and area known for each of the sedimentation zones described above, the following equation was used to determine the permanent Se removal by sedimentation for each zone:

$$\text{Se Removed}\left(\frac{Kg_{Se}}{yr}\right) = \text{Se Conc.}\left(\frac{\mu g}{g_{sed}}\right) \times \text{MAR}\left(\frac{\text{g}_{\text{sed}}}{\text{cm}^2 yr}\right) \times \text{Area}\left(Km^2\right) \times 10\left(\frac{cm^2}{Km^2}\frac{Kg_{Se}}{\mu g_{Se}}\right),$$

The sum of the sedimentation fluxes in each of the zones yielded the total mass of Se removed by sedimentation over the entire south arm.

2.2.3 Bed sediment samples

2.2.3.1 Collection and treatment

Thirty bed sediment samples were collected at 15 locations (ranging from 6.8 to 9.4 m in depth) in the main body of the Great Salt Lake using an Eckman dredge on May 31, June 2, 26 and 27, 2006 (Figure 1, GS sites). The sediment surface was typically coated with what appeared to be an organic-rich ooze. Hence, 10 ooze layer samples (top 1-2 cm) were taken at 12 locations (GS1, GS4, GS5, GS8, GS9, GS11, GS12, GS14, GS18, GS20) (two locations did not have an ooze layer: GS3 & GS15), using a plastic spoon to scoop this surface off the collected sediment. Eight samples corresponded to composite sediments (mixture of ooze and underlying mineral sediment). The remaining 12 sediment samples corresponded to the mineral layer. Composite, ooze, and mineral layer samples were collected in glass jars and kept on ice until transfer to a refrigerator.

Each sample was subdivided in the laboratory and stored in pure water-rinsed plastic centrifuge tubes in a freezer. Bed sediment subsamples were sent to a contract lab (LET Incorporated, Columbia, MO) for Se analysis using proprietary digestion procedures. Bed sediment subsamples were also analyzed for major and trace elements (including Se) via ICP-MS at the University of Utah as described below. Prior to analysis, bed samples were thawed to allow drainage of water, and then were freeze-dried, digested and analyzed as described below. Se and TOC concentrations were corrected for salinity as described in section 2.2..2.1.

2.2.3.2 Batch tests

Batch equilibration tests were performed to determine whether significant Se would be re-solubilized from anoxic bed sediment upon equilibration with shallow brine layer water (e.g. via re-suspension or displacement of the deep brine layer). Shallow brine layer water (15 g) collected from site 2267 in December 2006 was equilibrated with anoxic bed sediment (7.5 g) in a 50-ml plastic centrifuge tube. The equilibration test was performed for sub-samples from all 15 bed sediment sampling sites. In order to avoid direct addition of atmospheric oxygen to the sample, the bed sediment container was opened and a sub-sample was added to the shallow brine layer water in a nitrogen glove bag. In order to examine the influence of the availability of oxygen on Se re-mobilization into the shallow brine layer, two batch equilibration replicates were performed for each bed sediment sample; one with nitrogen, and the other with air, in the centrifuge tube headspace (25 ml). The centrifuge tubes were placed upright on a shaking table (130 rpm) for 24 hours. Following equilibration, centrifuge tubes were centrifuged at 5500 rpm for 3 minutes, and supernatant was removed and acidified to pH < 2 by addition of 0.8% nitric acid by volume. Batch equilibration tests were repeated over week and month time scales to determine if selenium release over longer periods of exposure with shallow brine water would be significant. Air was used for the

headspace of these longer term samples since no statistically significant difference was observed for air versus nitrogen headspace replicates in the 24 hour batch experiment. In the longer term samples, the headspace (vapor) was replaced once per day, and samples were shaken in upright tubes on a shaking table (130 rpm) for 5 minutes per day. Major and trace element concentrations were analyzed via ICP-MS. Equivalent batch experiments were performed on exposed shore zone sediments; however, these results are described in the report concerning Se loads to the south arm of the Great Salt Lake.

2.2.4 Freeze-drying, extraction, and chemical analyses

Sediment samples were freeze-dried under vacuum using a liquid nitrogen trap. Wet and dry weights were recorded. Salt content was corrected based on water weight and salinity.

Extraction of metals from freeze-dried sediment (approximately 0.5 g) was performed serially in trace metal grade nitric acid (3 mL, 15.8 N) and trace metal grade hydrochloric acid (5 mL, 12 N) using a Savillex 60-mL teflon closed reactor heated by microwave oven at 50% power for 2.5 min per reactor. The extraction solution was collected in a 50-mL centrifuge tube and made up to a volume of 50 mL with milliQ water. The mixture was centrifuged at 5000 rpm for 30 minutes. The supernatant was collected in a pure water-rinsed centrifuge tube while the sediments were collected in a glass Petri dish and dried at 110^{o}C prior to weighing. For each 10th sample, a duplicate was treated via the extraction procedure and analyzed independently.

Elemental analyses of the extraction solutions were carried out using ICP-MS at the University of Utah Center for Water, Ecosystems, and Climate Sciences (CWECS) laboratory facility.

Sediments were analyzed for Se and 29 other major and minor elements (Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Sr, Ti, Tl, V, U, Zn) using ICP-MS. Although Hg is another element of interest, it cannot be reliably measured in most aquatic systems using ICP-MS.

For sediment samples greater than 4 grams, a representative split was sent to a commercial analytical laboratory (LET Incorporated, Columbia, MO) for Se analysis.

2.3 Analysis

2.3.1 Major and minor elements

2.3.1.1 Water

ICP-MS analyses in water were carried out in an Agilent 7500 ce. Interferences were minimized by collision or reaction with gas in a collision cell. Se, As and Cr were analyzed using hydrogen gas in the collision cell, while analyses for the rest used helium as a collision cell gas. Indium (7 μg/L equivalent concentration) was used as

internal standard. General conditions used in the ICP-MS for water sample analyses are presented in Table 1a.

Dilution of Great Salt Lake samples was required to prevent salt accumulation and consequent decrease of ICP-MS signal. Major elements (Ba, Ca, Cl, K, Li, Mg, Na, S) were diluted 100:1 or 900:1 prior to being analyzed. Minor elements, including Se, were diluted 50:1 or 30:1 prior to being analyzed. Methanol (3%) and HNO_3 (ultra high purity, 0.1%) was used as a dilution matrix. A synthetic Great Salt Lake matrix was used in the preparation of standards and quality control samples. The chemical recipe for this solution is given in Table 1b.

Quality control was carried out using the US EPA Multi-Media, Multi-Concentration, Inorganic Analytical Service for Superfund (ILM05.3) for ICP-MS, released in February 2004 and upgraded in January 2007 (Table 1c). The samples used for QA/QC (quality assurance/quality control) included an initial calibration blank (ICB), initial calibration verification (ICV), CRQL check standard (CRI), continuing calibration verification (CCV), continuing calibration blank (CCB), and interference check sample (ICS). For each 10 samples, a duplicate, spike, spike duplicated, serial dilution, CCV, and CCB were run.

The limit of determination (LoD) for all elements except Se were calculated as three times the standard deviation of counts for all of the CCBs divided by the slope of the calibration curve and multiplied by the dilution. For Se, for which the CCBs showed decreasing trends throughout each run, three CCBs were run sequentially following each set of nine samples and two CCVs. For each group of triplicate CCBs the standard deviation was calculated. The LoD was calculated from the average of all the triplet standard deviations by multiplying by three and multiplying by the dilution.

2.3.1.2 Sediments

As described below, sediment samples were freeze-dried, digested and analyzed by ICP-MS for 30 elements. Solution samples were diluted 20:1 using 3% methanol and 0.1% HNO_3 (ultra high purity) as a dilution matrix. The same matrix was used in the preparation of standards and quality control samples. The same QA/QC protocol used for analyses of water samples was used for sediment samples.

2.3.2 Total Se analysis

2.3.3 Water

2.3.3.1 Hydride generation

Frontier Geoscience (Seattle, WA) analyzed total Se in water by a hydride generation and atomic fluorescence spectrometry (HG-AFS).

2.3.4 Sediments

2.3.4.1 Hydride generation

Total Se in sediments was analyzed at LET Inc. (Columbia, MO) laboratory by hydride generation – atomic absorption spectrometry on acid-digested samples. Maximum detection limit for Se was 0.4 mg/Kg.

2.3.4.2 ICP-MS

Sediment samples were freeze-dried, digested and analyzed for total Se by ICP-MS at the CWECS laboratory facility. Samples were diluted 20:1 and analyzed as described above. Maximum detection limit for Se was 0.01 mg/Kg.

2.3.5 Volatile Se analysis

2.3.5.1 Water

2.3.5.1.1 Purge and cryo trap system

Collection of volatile Se from the water involved a cryo-focusing trap system (Figure 3a) following concepts used by researchers at the University of Pau in France (Amouroux and Donard, 1996).

The system consisted of a reactor (a modified desiccator) with a diffuser connected to a helium line. The reactor sparges 7 liters of hypersaline water. The vapor swept from the reactor moved via Teflon tubing to a glass water trap (-55^{o}C, dry ice/ethanol) to remove water from the flowing vapor. The vapor then entered a glass trap (-196^{o}C, liquid nitrogen) to trap the volatile compounds collected from the water. Studies demonstrate that the entire volume of water can be sparged at a helium flow rate of 300 mL/min for approximately 15 minutes. After collection, nitric acid was added to the glass trap to oxidize volatile Se compounds and convert them to their stable aqueous species. The closed trap was digested in a water bath at 75^{o}C for 3 hours, and the solution was analyzed for Se by ICP-MS at the University of Utah CWECS laboratory facility.

The purge and cryo-focusing trap system was calibrated with dimethyl selenide (DMeSe) (AlfaAesar, 99% purity), which is reported to be the most stable volatile Se compound in seawater (Amouroux et al., 2000). This system was tested in the laboratory using Great Salt Lake water spiked with pure dimethyl selenide. The analyzed spiked dimethyl selenide concentrations were equivalent to the expected value (within the 95% confidence limit) based on the calibration curve (Figure 3b). Since measurements of pure water yield apparent volatile Se concentrations of 0.04 ± 0.01 ng/L, the practical detection limit for volatile Se using the purge and trap system is 0.04 ng/L. These results demonstrate that the system can quantify volatile Se concentrations in the nanogram per liter (ng/L or ppt) range. This resolution is 100 to 1000 times greater than typical analyses used for aquatic contaminants. It should be noted that the

regressed recovery of volatile Se was 25% due to losses in the system. Therefore, measured values were corrected for 25% recovery according to the regression on Figure 3b. The losses yielding the 25% recovery likely include partitioning to stainless steel, ceramic, glass and teflon surfaces in the chamber and tubing, and to epoxy sealant in holding the lid of the chamber (which was a modified dessiccator). Between samples, the entire system was thoroughly cleaned by rinsing five times with nitric acid (4 L, 2%) and deionized water (4 L). Tests demonstrated that volatile Se concentrations returned to background concentrations after cleaning. The calibration curve was used to correct the values measured in the field.

Laboratory tests were run using pure water and Great Salt Lake shallow brine water with and without spiking of DMeSe to determine the analytical. This error was determined to be 13%, which includes the error associated with the ICP-MS analyses.

2.3.5.2 Fluxes calculations, different temperatures and wind velocities

2.3.5.2.1 Models

To estimate the volatile Se flux from the Great Salt Lake to the atmosphere, several models are available in the literature. These models have been used for estimating fluxes in fresh and sea water.

The general equation for mass transfer flux for a volatile compound between two phases is defined in terms of the overall mass transfer velocity ($k_{ph1/ph2}$) and the concentration gradient between the phases (Schwarzenbach et al., 2003). An expression for the volatile Se flux in the Great Salt Lake is given below with the assumption that mass transfer is kinetically controlled in the water phase, as opposed to mass transfer in the vapor phase being the kinetically limiting process.

$$Flux = ak_w\left(C_{water}^{VSe} - C_{water}^{VSe,eq}\right) = ak_w\left(C_{water}^{VSe} - \frac{C_{air}^{VSe}}{K'_{H_{GSL}}}\right) \text{ (mol/m}^2\text{/yr)}$$

where: a is a unit correction factor (= 0.24); k_w is the water transfer velocity in the air-water interface (cm/h); C_{water}^{VSe} is the concentration of volatile Se in water (mol/m^3); $C_{water}^{VSe,eq}$ is the equilibrium concentration of volatile Se in water (mol/m^3); C_{air}^{VSe} is the concentration of volatile Se in air (mol/m^3); $K'_{H_{GSL}}$ is the dimensionless Henry's constant for volatile Se for the Great Salt Lake.

In our case, concentrations of volatile Se in the water have been measured. Concentrations of volatile Se in the air can potentially be measured; however, in the estimations below we assume this concentration to be zero.

2.3.5.2.1.1 Dimensionless Henry's constant correction

The dimensionless Henry's constant ($K'_{H_{GSL}}$) and the water mass transfer velocity in the air-water interface (k_w) were determined using empirical models from the literature. These models are based on wind velocity, water temperature, viscosity and diffusivity of the volatile species. The viscosity, diffusivity, and dimensionless Henry's constant each require corrections for the salinity of the Great Salt Lake, which is 3-5 times greater than that of the ocean.

An equation to estimate the dimensionless Henry's constant for DMeSe as a function of temperature was developed by Guo et al. (2000), whereas a salinity correction was provided by Schwarzenbach et al. (2003), yielding:

$$K''_{H_{GSL}} = 0.0248\ exp(0.0418T) * 10^{K^s [salt]_{tot}}$$

where K^s is the salinity constant, and $[salt]_{tot}$ is the total molar concentration of salt. Dimethyl selenide (DMeSe) is the most important volatile Se compound found in air; and in fresh and saline waters (Atkinson et al., 1990; Neumann, 2003; Tessier et al., 2003), and therefore is an appropriate species on which to base our estimations. The K^s for DMeSe was not available from the literature, whereas a value for dimethyl sulfide (DMeS) was available, and was used on the basis of its similarity to DMeSe (Amouroux, 1995).

2.3.5.2.1.2 Water transfer velocity - Estuarine model

To calculate the water transfer velocity, an approximation used in the Hudson estuary by Clark et al. (1995), corrected for the Schmidt number according to the boundary layer model (Schwarzenbach et al., 2003). This so-called Estuarine model is as follows:

$$k_w(cm/h) = \left(\frac{Sc}{600}\right)^{-1/2}\left(2 + 0.24u_{10}^2\right) \text{ for } u_{10} > 5 \text{ m/s}$$

$$k_w(cm/h) = \left(\frac{Sc}{600}\right)^{-2/3}\left(2 + 0.24u_{10}^2\right) \text{ for } u_{10} \leq 5 \text{ m/s}$$

where Sc is the Schmidt number, and u_{10} is the wind velocity measured 10 m over the surface of the lake.

Saltzman et al. (1993) defined a Schmidt number for DMeS as a function of water temperature (°C) and corrected for the sea water salinity (via coefficients) as follows:

$$Sc_{DMeS}^{sea\ water} = 2674.0 - 147.12T + 3.726T^2 - 0.038T^3$$

2.3.5.2.1.3 Water transfer velocity - modified Liss and Merlivat model

An alternative approach is provided by the modified Liss and Merlivat model (Livingstone and Imboden, 1993; Liss and Merlivat, 1986), the results of which largely corroborate the Estuarine model. This model, which was also corrected for the Schmidt number according to the boundary layer model (Schwarzenbach et al., 2003), defined three wind velocity regimes:

$$k_w(cm/h) = \left(\frac{Sc}{600}\right)^{-2/3} \left(0.65 * 3.6\right) \quad \text{for } u_{10} < 4.2 \text{ m/s}$$

$$k_w(cm/h) = \left(\frac{Sc}{600}\right)^{-1/2} \left(0.79u_{10} - 2.68\right) * 3.6 \quad \text{for } 4.2 \text{ m/s} < u_{10} < 13 \text{ m/s}$$

$$k_w(cm/h) = \left(\frac{Sc}{600}\right)^{-1/2} \left(1.64u_{10} - 13.69\right) * 3.6 \quad \text{for } u_{10} > 13.6 \text{ m/s}$$

2.3.5.2.1.4 Diffusive flux

The diffusive flux can be calculated assuming that diffusion is the limiting mass transfer process, as follows:

$$J = D_e \frac{\Delta C}{\Delta x}$$

where: J is the diffusive flux (g/cm^2/yr); D_e is the effective diffusion coefficient (cm/s), ΔC is the concentration gradient (ng/L); and, Δx is the difference in depth (m).

The diffusion coefficient for DMeSe can be calculated using the diffusion coefficient for DMeS as function of temperature, corrected for sea water, according to Saltzman et al. (1993):

$$D_{DMeSe} \approx D_{DMeS} = 0.0192 \exp(-18.1/RT)$$

where: R is the gas constant (kJ/mole K) and T is the temperature (K)

2.3.6 Wind velocity, atmospheric temperature, lake elevation, lake surface area

2.3.6.1 Wind velocity and atmospheric temperature

Wind velocity and atmospheric temperature data from January 2006 to August 2007 were obtained from the MesoWest station at Hat Island. Weekly surface water temperatures were obtained using AVHRR (advanced very high resolution radiometer). The AVHRR is a scanner mounted on National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites for measuring visible and infrared radiation reflected from vegetation, cloud cover, shorelines, water, snow, and ice. (ESRI Support Center, http://support.esri.com/index.cfm?fa=homepage.homepage). The data

were obtained for the period January 2006 to December 2006, from the Department of Meteorology at the University of Utah. Comparisons were made between the AVHRR data (January 2006 to December 2006) and thermistor measurements in Gunnision Bay (January 2006 to August 2007) to ensure that the AVHRR data correctly represented water surface temperature during the period of study (Figure 3c)

The estimated error for wind velocity measurement is 2.5 m/s (Horel, 2007). The estimated error for temperature measurement from an AVHRR is 0.5 – 1^{o}C (Crosman and Horel, 2006).

2.3.6.2 Lake elevation and lake surface area

Lake elevation data were obtained from the USGS gage at the Saltair boat harbor. Surface area of the lake, used to calculate the cumulative volatile Se flux from the lake, was corrected for lake elevation (in 0.5-ft intervals) according the data summarized by Baskin (2005). Water-surface elevations reported at the USGS Great Salt Lake gages are considered to be accurate within +/- 0.10 foot of the datum in use (http://ut.water.usgs.gov/gsl%20corr/gslcorrection.htm).

2.3.6.3 Direct measurements of volatilization

Direct measurements of volatilization of Se were taken at two primary locations (3510 and 2267) and one secondary location (2565) in the south arm of the Great Salt Lake. The flux measurements were taken concurrently with characterizations of the parameters used in estimating volatile Se flux: surface water temperature, wind velocity, and volatile Se concentration, in order to assess the accuracy of the predictive model.

An emission isolation flux chamber (St. Croix Sensory, Inc.) was used to collect volatilized Se from the surface of the lake (Figure 4a). The bottom of the stainless steel chamber is a cylinder that circumscribes a capture area for volatile compounds. Helium gas was released from a compressed helium tank and swept through the chamber (while it floated on the lake surface) to drive volatile gases coming from the lake into a cryo-trap. The sweep rate was set to approximately 3 L/min to prevent accumulation of volatilized Se (and other gases) within the chamber. A constant sweep rate was used in lieu of variable rate matching environmental conditions because studies have shown that high sweep rates can induce convection in the water column and subsequently bias flux results high (Card et al., 2002). A sweep rate of 3 L/min corresponds to approximately 1 chamber volume being swept every 6 min and is consistent with the manufacturer's recommendations.

The gas mixture in the chamber was then pumped (Universal 44XR Single Pump, SKC West Inc.) at an equivalent rate through Teflon tubing to a glass finger-trap in acetone/dry ice slush (-20°C) to remove any water vapor. Downstream of the water trap, volatile Se was cryo-focused onto glass wool in a finger-trap held at -170°C by liquid nitrogen and a Watlow PID temperature controller connected to a temperature sensor (PT-103-AM Platinum RTD, Lakeshore Cryotronics, Inc.) and cartridge heater (3039-002, Cryogenic Control Systems, Inc.). Figure 4b depicts the apparatus used to hold the glass finger-trap in the liquid nitrogen. Designed with the assistance of Dr. Kip

Solomon (University of Utah) and Erwin McPherson (University of Utah), the device was placed in a Dewar flask filled with liquid nitrogen. The "heat" of the liquid nitrogen was conducted through the brass rod to the copper block and tube surrounding the finger-trap. The length of brass rod necessary for optimal temperature controller performance was determined experimentally to be 1 cm, at which point the cartridge heater embedded in the copper block was activated approximately 25% of the time. The stainless steel shield prevented any direct contact between the liquid nitrogen and the copper block and tube.

After a substantial sampling time (typically between 1.5 and 3 hours), the sample in the cryo-trap was acidified with 5 mL of 14% nitric acid to stabilize volatile Se compounds as oxidized aqueous species. The sealed trap was then digested in a water bath at 75°C for 3 hours and analyzed for Se by ICP-MS at the University of Utah CC-ICP-MS facility. The resulting measured concentration was then converted to a mass of Se and divided by the area under the flux chamber (0.13 m^2) and the period of sampling in order to yield a flux rate.

Wind velocity measurements used for developing predicted fluxes were taken at 3 meters above the water surface using a Kestrel 1000 Wind Meter. These measurements were then projected to a height of 10 meters by the method described by Wind Energy Department of Risoe National Laboratory and Det Norske Veritas (2001) for use in flux prediction calculations. Surface water temperature and volatile Se concentration measurement techniques are described in sections 2.1 and 2.4.5.1, respectively.

To ensure that the sampling system was operating properly, tests were performed to quantify the background level of Se, examine response of the system to qualitative changes in volatilization rate, and verify reproducibility of measurements. Three flux samples were taken in the laboratory by placing the chamber over a nitric acid-washed pan filled with pure water (Milli-Q) to determine the background "flux" that is measured in a pure sample. All background samples were low, with a mean of 1.60 ng/m^2h and a maximum of 2.67 ng/m^2h. To test response of the system, two more samples were taken at Saltair marina for 30 minutes each. During the first sampling, a diffuser hanging 1 m below the surface bubbled helium through the water column into the flux chamber to produce a high flux rate. For the second sample the diffuser was turned off, producing a low flux rate. Analyses yielded an order of magnitude higher flux rate for the first sample relative to the second, indicating that the system responded appropriately. Finally, reproducibility was demonstrated by two 2-hour samples taken during the same day at site 2267. The results showed similar Se flux rates with a slightly higher flux rate corresponding to the sample that was taken under conditions of increased surface chop.

The effect on measured flux of sweep rate, sweep gas composition (helium versus nitrogen), and concentration of dissolved volatile Se was also investigated. In the laboratory, a stainless steel basin was filled with 50 L of Great Salt Lake water and spiked with various masses of DMeSe to yield concentrations from about 2 to 27 ng/L. Seven liters of this water was analyzed for volatile Se concentration using the purge and cryo-trap system described above. Other input variables were held constant with a steady water temperature and no wind. The flux of volatile Se from the solution

remaining in the stainless steel basin was measured using the system described above. Sweep rates were 2 and 3 L/min for helium, and were 2,3, and 6 L/min for nitrogen. All 5 flux measurements were higher than those observed on the Great Salt Lake, consistent with the higher dissolved volatile Se concentration in the chamber relative to the lake (Table 1d). The measured fluxes were also highly reproducible regardless of whether nitrogen or helium gas was used, and the values did not change as a result of changing sweep rate. The influence of concentration is discussed in the results section.

A recovery test was performed in the laboratory in order to quantify the response of the direct measurement system to the introduction of a known mass of Se. A DMSe spike solution was prepared to a concentration of approximately 125 μg/L. Drops of the spike solution were placed on a glass Petri dish and immediately set inside a large cylindrical Pyrex basin. The flux chamber was then fitted tightly over the basin and a 1-hour direct measurement was performed as the drops of spike solution evaporated into the flux chamber headspace. No outside heat was applied to speed evaporation. Three recovery tests were performed with 50, 100, and 150 μL of spike solution. The mass of spiked Se was verified independently by analysis of equivalent volumes of spike solution by ICP-MS using the digestion procedure described above. The results of the flux recovery tests are discussed below.

2.3.7 Total dissolved gas pressure, hydrostatic pressure, barometric pressure

2.3.7.1 Water

Total dissolved gas pressures were measured at 12 locations (GS1, GS3, GS4, GS5, GS8, GS9, GS11, GS12, GS14, GS15, GS18, GS20) and 6 depths (between 1.5 and 8 m) in the main body of the Great Salt Lake (Figure 1) by using a total dissolved gas (TDG) sensor (In-Situ Inc., Fort Collins, CO). The TDG probe needed at least 7 minutes for stabilization. The probed was zeroed at the lake surface before starting to measure the total dissolved gas pressure. TDG measurements were achieved each two months from May 31 to November 17, 2006. Hydrostatic and barometric pressure were measured at the same locations, depths and times given above, using a Hydrolab Troll 9000 (In-Situ Inc., Fort Collins, CO).

All TDG measurements made during spring, 2006 were well below hydrostatic pressure indicating insignificant exsolution of gas (including volatile Se), or exsolution of gas in discreet zones not corresponding to the TDG sites. The TDG measurements were discontinued in summer, 2006.

2.3.8 Thermistor analysis

2.3.8.1 Lake Mixing

2.3.8.1.1 Thermal mixing

Temperature equilibration events in the water column may represent genuine mixing of the deep and shallow brine layers. Complete mixing or homogenization of the water column should yield an intermediate temperature between the two temperatures of the stratified column.

The expected intermediate temperature can be determined from an energy balance, under the assumption that despite density and temperature differences among water column strata, the specific heats of these strata are equal. Since heat energy lost by one layer must equal the heat energy gained by the other layer, the intermediate temperature can be determined from the mass (m), specific heat (c), and temperature difference between the initial (T_1 and T_2) and final (T_3) temperatures for both strata:

$$m_1 c(T_1 - T_3) = m_2 c(T_3 - T_2)$$

Substituting density and volume for masses of the two water column strata, and considering a water column with a given cross sectional area with heights h_1 and h_2 for the strata:

$$\rho_1 h_1 (T_1 - T_3) = \rho_2 h_2 (T_3 - T_2)$$

The intermediate temperature can be determined as follows:

$$T_3 = \frac{\rho_1 h_1 T_1 + \rho_2 h_2 T_2}{\rho_1 h_1 + \rho_2 h_2}$$

For example, on June 14 the temperature of the deep brine layer was 16°C and the temperature of the shallow brine layer was 21°C and the thermal mixing of these two layers would yield:

$$T_3 = \frac{1.10 \frac{g}{cm^3}(6\ m)(21^oC) + 1.16 \frac{g}{cm^3}(2\ m)(16^oC)}{1.10 \frac{g}{cm^3}(6\ m) + 1.16 \frac{g}{cm^3}(2\ m)}$$

$$T_3 = 19.7^oC$$

2.3.8.2 Seiche periodicity

A seiche is a prolonged oscillating wave in a body of water initiated by atmospheric effects such as wind. The period of an internal seiche is related to the length of the lake (*l*) and the physical characteristics of the layers within the lake. In the Great Salt Lake, the layering (density stratification) is defined by salinity (deep and shallow brine layers) rather than temperature. The characteristics of the layers, epilimnion ($_e$) and hypolimnion ($_h$), are thickness (z) and density (ρ) (Wetzel, 2001).

$$t = \frac{2l}{\sqrt{\frac{g(\rho_h - \rho_e)}{\frac{\rho_h}{z_h} + \frac{\rho_e}{z_e}}}}$$

2.3.9 TOC analysis

2.3.9.1 Water

Water samples for total organic carbon (TOC) analysis were collected in acid-rinsed amber glass 250-mL bottles from the deep brine layer at 12 stations (GS1, GS3, GS4, GS5, GS8, GS9, GS11, GS12, GS14, GS15, GS18, GS20) (Figure 1). Samples were collected from each location using a peristaltic pump with acid-rinsed C-flex tubing (Cole-Parmer's Masterflex, Vernon Hills, IL), stored on ice and transferred to a refrigerator. TOC analysis were carried out at the U of U CWECS laboratory facility using a TOC-5000 (Shimadzu, Columbia, MD) where water samples were analyzed sequentially for total carbon (TC) and inorganic carbon (IC), the TOC being the difference between TC and IC. In both analyses, the carbon contained in the sample was converted in CO_2 and analyzed by an infrared CO_2 analyzer. For the TC, the sample was heated at 680^{o}C, while for the IC, the sample was acidified with H_3PO_4 (25%). QC samples included a duplicate, spike, check standard, spike standard, and a blank.

2.3.9.2 Sediments

TOC analyses in 31 bed sediment samples were carried out by LET Inc. (Columbia, MO) by using a LECO combustion carbon analyzer, based on National Soil Center Method 4H2. Sediment samples were heated in the combustion chamber in an atmosphere of pure oxygen, which converted the organic carbon in the sample into carbon dioxide gas. The quantity of carbon dioxide gas evolved from the sample was measured by an infrared CO_2 analyzer and automatically converted into a percent carbon value for the sample.

2.3.10 Isotope analysis

2.3.11 Sediments

Subsections of the freeze-dried sediment cores were analyzed at the U.S. Geological Survey (Menlo Park, CA) for ^{210}Pb, ^{226}Ra, ^{234}Th, ^{7}Be, and ^{137}Cs activities for determination of sediment accumulation rates. Wet and dry weights were recorded to determine water content of sediment. Sediment bulk density was assumed to be 2.6 g/cm^3. Sediment dry weights were corrected for salt content of sediment porewater assuming a salinity of 171 g/L (17.1 %). The assumed salinity value was based on averaging measured salinity values of the deep brine layer obtained during late Summer and Fall, 2006.

Activities of total ^{210}Pb, ^{226}Ra, ^{234}Th, ^{7}Be, and ^{137}Cs were measured simultaneously by gamma spectrometry based on previously published methods (Van Metre et al., 2006; Fuller et al., 1999). Subsamples of dried sediment samples were sealed in 7-mL

scintillation vials and counted using a high-resolution intrinsic germanium well detector. The upper 3 cm of the core was counted within two weeks of collection for determining ^{7}Be and unsupported ^{234}Th (half lives 53 and 24 days, respectively) as indicators of recent sediment deposition and reworking by mixing or resuspension processes.

^{210}Pb activity as a function of depth in the sediment provides an estimate of the sedimentation rate. ^{210}Pb in core sediments results from the decay of two isotopes: ^{222}Rn (referred to as unsupported lead) and the long-lived ^{226}Ra (referred to as supported lead). ^{222}Rn decays in the atmosphere to ^{210}Pb, and is deposited onto the lake surface where it becomes associated with settling particles and it is deposited in the accumulating sediment. ^{210}Pb has a half-life of 22.3 years; hence, the rate of ^{210}Pb decrease with depth corresponds to the rate of burial. However, another source of ^{210}Pb is present in the sediment (^{226}Ra) and must be accounted for.

The supported ^{210}Pb activity, defined by its long-lived progenitor, ^{226}Ra activity, was determined on each interval from the 352 KeV and 609 KeV gamma emission lines of ^{214}Pb and ^{214}Bi daughters of ^{226}Ra, respectively. Supported ^{234}Th activity was determined by re-analyzing the samples 5 months later, after decay of unsupported ^{234}Th activity. Self-absorption of the 46 KeV ^{210}Pb and 63 KeV ^{234}Th gamma emission lines was corrected using the attenuation factor for each counting vial that was calculated via an empirical relationship between self absorption and bulk density (Cutshall et al., 1983). Self-absorption of the ^{214}Pb, ^{214}Bi, 474 KeV ^{7}Be and the 661.5KeV ^{137}Cs gamma emission lines was negligible. Detector efficiency for each isotope was determined from NIST traceable standards. NIST and IAEA reference materials were used to check detector calibration. The reported uncertainty in the measured activity was calculated from the random counting error of samples and background spectra at the one standard deviation level, and was typically within ±10%. The measured activities of replicate analyses of material from the same interval agreed to within ±15%.

Sedimentation rate was determined using the constant flux–constant sedimentation rate (CF-CS), method of Appleby and Oldfield (1992). The CF-CS method assumes a steady state accumulation of sediments and a constant unsupported ^{210}Pb activity per gram of depositing sediment particles.

3. Results

3.1 Great Salt Lake characteristics

3.1.1 Water

3.1.1.1 Spatial, depth, and temporal variation

Total Se concentrations in water samples (raw acidified) showed similar results among the four sites sampled (Figure 5), as represented by the data collected for May, 2006. This similarity was apparent in all other months sampled (Table 2); however, important differences with depth and over time were observed, as described below.

The average Se concentration from May 2006 to July 2007 for unfiltered acidified (RA) samples was 0.64 ± 0.28 μg/L, whereas the filtered acidified (FA) samples showed an average Se concentration of 0.49 ± 0.25 μg/L for the same period of time. The geometric means for Se were 0.60 ± 0.31 μg/L and 0.45 ± 0.21 μg/L for all RA and FA water samples, respectively, for the same period of time. The medians for RA and FA water samples were 0.64 and 0.46 μg/L, respectively (Table 2d), indicating a limited number of outliers. Quartile analysis for outliers indicates that the value obtained for site 2767 during June, 2007 (2.77 μg/L) corresponds to an extreme outlier, although it does reflect the trend of increasing total Se concentration during the period of the study (described below). Table 2 includes arithmetic and geometric means, median, standard deviation, and lowest and highest values for Se, calculated for each site (2267, 2767, 2565 and 3510).

In terms of depth, the major changes in water chemistry coincided with transition to the deep brine layer, where dissolved oxygen (DO), oxidation-reduction potential and pH decreased, conductivity increased and temperature increased or decreased depending on season (Figure 6).

Total Se (RA) concentrations also changed dramatically upon transition from the shallow to the deep brine layer (Figure 7c), either increasing or decreasing with no apparent relationship to season. In contrast, the vast majority of dissolved Se (FA) concentrations decreased upon transition from the shallow to the deep brine layer. These results indicate that particulate phases (if defined as RA minus filtered acidified, or FA) bear a significant but minor fraction of the Se mass in these samples.

Results for trace metals other than Se are shown in Table 3 and Figure 8. Notably, total As concentrations averaged 147 ± 6.3 μg/L (with a geometric mean of 147 μg/L and a median of 147 μg/L) in the shallow brine layer (Table 3 a & b). Total As concentration in the deep brine layer was 163 ± 16.7 μg/L (with a geometric mean of 163 μg/L and a median of 162 μg/L) (Table 3 c & d). Elements such as Al, Fe, Mn, Mo, and Pb showed significantly higher concentrations in the deep brine layer relative to the shallow brine layer (Figure 8 a & b). Particulate concentrations of some trace metals (Pb, Mo, Cu, Fe, Co, Ni, Zn, Ti, V) tended to be higher in the deep brine layer relative to

the shallow brine layer (Figure 9), possibly reflecting the formation of sulfide particulates and increased adsorption under the reduced conditions in the deep brine layer.

In terms of temporal variation, increases in the measured total (RA) and dissolved (FA) Se concentrations (measured at Frontier Geosciences, Inc.) were observed in both the deep and shallow brine layers during the period of the investigation (Figure 7a-d), constituting a net increase ranging between 0.16 and 0.34 μg/L among the four sites in the Great Salt Lake (Naftz et al., 2007).

In contrast to the results using hydride generation (252 samples – May 2006 to July 2007), the total and dissolved Se concentrations analyzed via ICP-MS at the University of Utah (132 samples – September 2006 to July 2007) showed slight to insignificant increases during the course of the study (Figure 7e & 7f, Table 2e – 2g). This contrast may result from the lesser number of samples (and/or lesser period) analyzed via ICP-MS and by the large scatter in the data.

3.1.2 TOC

3.1.2.1 Spatial and temporal variations

Concentrations of total organic carbon (TOC) in the deep brine layer showed no spatial trend, as shown for June, 2006 (Figure 10). The lack of a spatial trend was observed for all other months. The TOC concentration remained constant over the sampling period, demonstrating no temporal variation (TOC averaging approximately 95 mg/L) (Figure 10).

3.1.3 Bed sediment

3.1.3.1 Se concentrations

3.1.3.1.1 Spatial variation

Total Se concentrations in bed sediment samples showed no spatial variation in either the ooze or mineral layer, or in the composite of the two (Figure 11).

At 7 of 10 sites where ooze was present, the Se concentration in the mineral layer was greater than the corresponding Se concentration in the ooze. The average Se concentration in the ooze layer was 1.29 ± 0.41 mg/Kg, whereas the average Se concentration in the mineral layer was 1.59 ± 0.59 mg/Kg.

TOC concentrations in bed sediment showed no spatial trend for any of the sediment samples retrieved (ooze, mineral layer, and composite) (Figure 12). Average TOC concentrations in the ooze and mineral layers were not significantly different, 6.16 ± 4.1% versus 4.75 ± 2.2%, respectively.

Se concentrations were slightly correlated to TOC in the bed sediments (Figure 13). The correlation was most significant (but still weak) in the mineral layer samples (r^2 =

0.43) (Figure 13). Se concentrations in the ooze and composite samples showed no correlation with TOC concentrations.

3.2 Volatile selenium flux

3.2.1 Volatile Se concentrations

3.2.1.1 Spatially and with depth

Concentrations of volatile Se showed no spatial trend in the main body of the lake (Figure 14). Volatile Se concentrations increased with depth in the shallow brine layer (Figure 15a), for all sampling periods and sites where multiple depths were measured in the shallow brine layer. Volatile Se concentrations for depths below 5 to 6.5 m apparently decreased with depth, for all sampling periods and sites where multiple depths were measured (Figure 15b).

3.2.1.2 Temporal

The average volatile Se concentrations in water were reduced during the winter and elevated during spring, summer, and fall (Figure 16a and Table 4 a-c), coincident with warmer temperatures and increased primary productivity. During the course of the investigation, average concentrations (across the entire lake and entire water column) of volatile Se ranged from 2.4 ± 2.6 ng/L in September 2006 to 0.31 ± 0.47 ng/L in early December 2006 and 6.9 ± 6.9 ng/L in July 2007. This temporal trend is also reflected in the two-depth plots and three-depth plots shown in Figure 15a for the shallow brine. The same temporal trend occurred in the deep brine layer (Figure 15b).

The decrease in volatile Se concentrations in the shallow brine layer during winter 2006 corresponded to decreased temperature, and decreased primary productivity, which can be expected since phyto- and zoo-plankton are the expected main producers of volatile Se (Amouroux and Donard, 1996).

The average volatile Se concentration from September 2006 to August 2007 was 3.0 ± 4.4 ng/L. This value represents 0.6% of the average total Se concentration in the water column. Although this fraction seems negligible, its significance depends on the residence time of volatile Se in the lake. For example, water vapor represents only 0.001% of the global water budget whereas the great importance of water vapor (clouds) in transferring water across the surface of earth is undeniable, and arises from the short residence time of water in the vapor phase. The flux of Se from the lake to the overlying atmosphere must be known in order to assess its significance.

3.2.2 Volatilization flux estimates

Recalling that a near-surface volatile Se concentration gradient was observed (Figure 15), a diffusive flux was calculated assuming that diffusion is the limiting mass transfer

process. The estimated diffusive flux was calculated for temperatures and concentration gradients observed in the lake (Table 5). The average diffusive flux yielded 3.9×10^{-12} g Se/cm^2/yr, which translates to 7.3×10^{-2} Kg/yr. This extremely small flux would represent the quiescent lake, which we believe is far too conservative a condition for this shallow large surface area lake. Furthermore, such a low volatilization flux is not consistent with observed Se concentrations in the Great Salt Lake, as described below.

The estimated water transfer velocities corresponding to wind-driven mixing (both models) are shown in Table 6a. The volatile Se fluxes were estimated using an average volatile Se concentration of 3 ng/L, and the water transfer velocities corresponding to wind velocities of 5 and 25 miles per hour. Assuming a negligible volatile Se concentration in the overlying air, the corresponding volatile Se fluxes from the lake are shown in Table 6a.

The estimated volatile Se fluxes range from 4.2×10^{-8} or 2.4×10^{-8} g Se/cm^2/yr under cold, low-wind conditions to 8.2×10^{-7} or 5.6×10^{-7} g Se/cm^2/yr under hot, high-wind conditions. This flux can be converted to a mass transfer rate by multiplying the known surface area of the lake (1842 km^2) (Baskin, 2005). The estimated Se mass transfer rates via volatilization range from 766 or 450 Kg/yr under cold, low-wind conditions to 15,030 or 10,395 Kg/yr under hot, high-wind conditions.

3.2.3 Direct measurement of volatilization flux

The results of measured volatile Se fluxes from Great Salt Lake are shown in Table 6b along with the corresponding predicted flux rates (Estuarine model) and input variables (wind velocity, surface water temperature, surface volatile Se concentration). Measured fluxes ranged from 2 to 20 ng/m^{2}h in the ten samples taken on the Great Salt Lake with average wind velocities of 1 to 4 m/s, water temperatures of 12 to 28°C, and volatile Se concentrations of 0.04 to 4.6 ng/L.

The measured volatile Se fluxes were highly sensitive to near-surface volatile Se concentrations. For example, despite similar wind and wave conditions, samples 1C and 2C yielded volatile Se fluxes of 2.08 and 20.13 ng/m^{2}h corresponding to measured near-surface volatile Se concentrations of 0.05 and 1.43 ng/L respectively.

Measured volatile Se fluxes did not change appreciably with changes in wind speed under the relatively calm conditions examined. For example, in two samples taken on 5/24/2007 to show reproducibility, measured flux rates were 10.7 and 8.0 for average wind velocities at 10 meters above the water surface of 5.1 and 6.7 m/s respectively. Though counterintuitive, the surface roughness during the first sample was significantly higher than the second resulting in the slightly higher flux rate for the first (assumes constant volatile Se concentration and water temperature). This observation is consistent with the fact that surface matrix effects, rather than wind speed, dominate liquid-to-atmosphere fluxes on liquid surfaces (Schmidt, 2007). Although increasing wind can increase surface roughness of a water body, the extent of convection also depends on wind direction and surrounding geography.

3.2.3.1 Correlation between measured and predicted fluxes

In order to account for the background Se flux measured by the system, the average background flux (1.6 ng/m^{2}h) was subtracted from each measured flux value. This assumes the background flux rate is constant as opposed to the system measuring a constant background mass (and therefore not dependent on the time of sample). The implications of this assumption are insignificant, however, because subtracting the average background mass recovered gives an almost identical result to subtracting the background flux. In the majority of measurements, the background correction was small relative to the measured value.

The majority of measured flux rates fell significantly below their corresponding predicted flux values (Figure 16b). This was most clearly seen under the higher predicted flux condition driven by the higher volatile Se concentration of sample 3C (Table 6b). Measured flux in this sample was an order of magnitude below the predicted flux (9.28 and 105.89 ng/m2h respectively). The low measured flux relative to predicted flux indicated inefficiency in the flux measurement or inadequacy of the model to reflect volatilization in the Great Salt Lake.

To explore possible inefficiencies in the flux measurements, DMSe recovery was examined in tests (described above) involving addition of small drops DMSe spike solution under the chamber. Results ranged from 7% to 24% of the input mass of Se (Table 6c). The cause of low mass recovery is unknown, but a likely possibility is the adsorption of DMSe vapor to surfaces, which appears to be especially significant in absence of other vapors (e.g. water) that may compete with DMSe for surfaces. Inefficiency via loss of DMSe to surfaces is supported by calibration tests for the purge and cryo-trap system (described in Appendix A) which show a consistent 25% recovery that is attributed to partitioning of Se, primarily in the vapor phase, to various surfaces in the system. The loss of DMSe from the aqueous phase to surfaces appears to be low relative to loss from the vapor phase, as indicated by measurements of aqueous DMSe concentrations under controlled conditions (described below). The apparent lower recovery of the direct flux measurement system relative to the purge and cryo-trap system is consistent with the much larger surface area in former relative to the latter. Another possible contributor to the low recovery in the direct flux measurement system is the lack of water vapor due to addition of small drops (50 to 150 μL) to the system. The presence of water vapor in the purge and cryo-trap system may contribute to the higher recoveries observed in that system.

Inefficiencies in the direct flux measurements were explored under controlled conditions that reflected the presence of water vapor in the system under field conditions. Fifty liters of GSL water was spiked with DMSe in a stainless steel container (described above) and the flux was measured over this container. Figure 16c (and Table 1d) show the measured flux determined under controlled laboratory conditions (zero wind, constant temperature). Volatile Se concentrations ranged from zero in the background samples to 27 ng/L and were independently verified by the purge and cryo-trap system described in Appendix A. Measured fluxes exhibited a strong 1/10 linear direct relationship with the predicted fluxes under these controlled conditions, indicating that the flux measurement system was 10% efficient in measuring the actual DMSe flux. We

conclude, that the 1/10 relationship between measured and predicted fluxes under controlled conditions is due to systemic inefficiency in the direct flux measurement, likely resulting from partitioning of volatile Se to surfaces in the vapor phase.

To account for measurement inefficiency determined above, corrections were applied to the flux measurements taken on the GSL. In each sample, the measured flux rate after background subtraction was multiplied by 10 to correct for the 1/10 measurement inefficiency observed under controlled laboratory conditions. Figure 16d shows the corrected flux rates from the GSL. The majority of corrected measured fluxes are close to, but higher than the predicted fluxes. Two points (samples 1B and 2C) are significantly higher than their corresponding predicted fluxes. No obvious differences in conditions were observed during these two samples to cause this discrepancy.

The high measured flux (after correction) relative to the predicted flux could result from a number of factors. One possibility is the underestimation of flux by the predictive model, which could potentially result from influences of the high salinity of the GSL. The air-water transfer velocity (kw) is inversely proportional to the Schmidt Number (Sc) to a power between ½ and 2/3. Sc is a dimensionless ratio of kinematic viscosity to molecular diffusivity, both of which are influenced by salinity. Unfortunately, the rate of change in each of these parameters as a function salinity at levels of the GSL could not be determined; hence, we can only suggest that the hyper salinity of the GSL may play a role in the discrepancy between measured and predicted fluxes.

Another possibility is that the corrected measured fluxes are biased high relative to the actual flux rates from the GSL. At higher flux rates, accumulation of volatilized Se in the vapor phase in the chamber may occur, leading to a lower concentration gradient between the water and vapor phases, and resulting in inhibited flux. Since a majority of the laboratory flux tests using GSL water spiked with DMSe simulate higher flux conditions, the measured flux rate may have been inhibited to a greater extent than that which occurred in the lower flux conditions in the field. The result would be a slight over-correction of the field flux measurements from the 1/10 relationship between measured and observed fluxes in the laboratory. However, the laboratory tests under controlled conditions negate this possibility; since the measured flux rate was constant despite changes in sweep rate (see Methods and Table 1d).

A third possibility is that the differences between measured and predicted fluxes are magnified because of the relatively narrow range of fluxes that could be measured on the GSL. If multiple flux measurements could have been made under more turbulent conditions (i.e. higher flux), the discrepancy may have been reduced in significance.

Though the exact cause of the discrepancy is unclear, the proximity of measured fluxes to predicted fluxes within the limited dataset of direct measurements leads us to conclude that a correction of the predicted fluxes is not warranted. The predictive model is an appropriate means of estimating annual removal of Se from the GSL by volatilization.

3.2.4 Integration of the volatile Se flux

The annual Se flux is obtained by integration of calculated volatile Se fluxes using recorded wind and temperature data. The volatile Se flux estimates from the Estuarine model were integrated over time using measured wind velocities (10 m above lake surface), water temperatures (at lake surface), and lake surface areas for the 1-year period of study. The integration assumed an instantaneous response of volatile selenium flux to changes in wind velocity and water temperature. The measured parameter values are shown for the period of study in Figure 17a.

The volatile Se concentrations were discretely sampled and were temporally and spatially variable (areally and with depth). Flux estimates were based on volatile Se concentrations at depths of 0.2 to 0.5 m from the surface. Although these data are limited, they indicate decreased volatile Se concentration during winter (Figure 17b), and so were fitted using a sinusoidal function shown in Figure 17b, according to the following equation:

$$C_{water}^{VSe} = 10^{\left\{A+B*sin\left[(t-C)\pi/D\right]\right\}} \text{ (ng Se/L)}$$

where A,B,C, and D are constants.

The concentration values span nearly two orders of magnitude; therefore the geometric mean is the better descriptor of the data than the arithmetic mean. The geometric mean (μ_g) is the n^{th} root of the product of n values, as follows:

$$\mu_g = \sqrt[n]{x_1 \cdot x_2 \cdot \ldots \cdot x_n}$$

The geometric standard deviation (σ_g) is determined from the geometric mean as follows:

$$\sigma_g = \exp\left(\sqrt{\frac{\sum_{i=1}^{n}\left(\ln X_i - \ln \mu_g\right)^2}{n}}\right)$$

The geometric standard deviation is the ratio of the geometric mean to the 84th percentile (or inverse ratio to the 16th percentile) of the distribution of values, thereby describing 68% of the data (1st standard deviation).

The constants A through D were adjusted to yield the geometric mean (0.938 ng/L) and the geometric standard deviation (5.5) of the data for the period where volatile Se concentrations were actually measured (measurements were not taken between December 15th, 2006 and April 15th, 2007, due to logistical reasons). The corresponding values of the constants are shown in the equation below.

$$C_{water}^{VSe} = 10^{\left\{-0.5815+1.5741*sin\left[(t-30)\pi/185\right]\right\}}$$

During integration, the following data frequencies were used for the lake area, temperature, and wind data: daily average for lake area, weekly average for water

temperature and 1.5-hour intervals for wind speed. The cumulative integrated flux is shown as a function of time in Figure 17c.

Integration of the volatile Se flux yielded 2108 Kg of volatile Se lost to the atmosphere in 1 year.

3.2.4.1 Propagation of error in the calculation of the volatile Se flux

To determine error associated with the integrated flux, the estimated error for each parameter required to estimate flux was propagated. The individual errors were associated with near-surface water temperature, wind velocity, and volatile Se concentration (Table 6d), as described below.

The near-surface water temperature was incorporated into the Schmidt number shown below:

$$Sc_{DMeS}^{sea\ water}(T) = 2674.0 - 147.12T + 3.726T^2 - 0.038T^3$$

The error for this polynomial function was calculated using the derivative of the function, where:

$$\Delta Sc_{DMeS}^{sea\ water}(T) = 147.12\Delta T + 3.726 * 2\Delta T * T + 0.038 * 3\Delta T * T^2$$

where ΔSc is the error for the Sc number, ΔT is the error associated with measurement of the near-surface water temperature (± 0.5 ^{o}C).

The wind velocity (u_{10}) was incorporated into the air/water transfer velocity (k_w), shown below:

$$k_w(cm/h) = \left(\frac{Sc(T)}{600}\right)^{-1/2}\left(2 + 0.24u_{10}^2\right) \text{ for } u_{10} > 5 \text{ m/s}$$

$$k_w(cm/h) = \left(\frac{Sc(T)}{600}\right)^{-2/3}\left(2 + 0.24u_{10}^2\right) \text{ for } u_{10} \le 5 \text{ m/s}$$

The error propagation for these functions can be calculated as follows:

for $u_{10} > 5$ m/s

$$\Delta k_w(cm/h) = \left(\frac{2}{600}\right)^{-1/2} * \frac{\Delta Sc}{2 * Sc^{3/2}} + \left(\frac{0.24}{600}\right)^{-1/2} * \left(\frac{\Delta Sc}{2 * Sc} + \frac{2 * \Delta u_{10}}{u_{10}}\right) * Sc^{-1/2} * u_{10}^2$$

for $u_{10} \le 5$ m/s

$$\Delta k_w(cm/h) = \left(\frac{2}{600}\right)^{-2/3} * \frac{2 * \Delta Sc}{3 * Sc^{5/3}} + \left(\frac{0.24}{600}\right)^{-2/3} * \left(\frac{2 * \Delta Sc}{3 * Sc} + \frac{2 * \Delta u_{10}}{u_{10}}\right) * Sc^{-2/3} * u_{10}^2$$

where Δu_{10} is the error associated to wind velocity (± 2.5 m/s) and Δk_w is the calculated error for the air/water transfer velocity.

The concentration of volatile Se (C^{VSe}_{water}) was incorporated into the expression for volatile Se flux to the atmosphere as shown below:

$$Flux = ak_w\left(C^{VSe}_{water}\right) * Area$$

where Area is the area of the South Arm of the Great Salt Lake.

The error associated with the volatile Se flux can therefore be determined as follows:

$$\Delta Flux = Flux * \left(\frac{\Delta k_w}{k_w} + \frac{\Delta\left(C^{VSe}_{water}\right)}{\left(C^{VSe}_{water}\right)} + \frac{\Delta Area}{Area}\right)$$

where $\Delta C^{VSe,eq}_{water}$ is the error associated with volatile Se concentration (factor of 5.9) and ΔArea is the error due to the variation in the lake area (± 427 acres per 0.1 stage inaccuracy).

The estimated error associated with k_w is approximately 100%, whereas estimated ΔArea was only a factor of 1E-3 relative to Area. By far the largest contributor to Δ*Flux* is ΔC^{VSe}_{water} for which the geometric standard deviation is 5.9.

The uncertainty range for the volatile Se flux was estimated using confidence intervals. The 95% (2σ) and the 68% (1σ) confidence intervals (Figures 17d and 17e) for the near-surface volatile Se concentration were determined using the logarithms of the volatile Se concentration data obtained from the sinusoidal function (expected data) and the measured data. The anti-log transformed arithmetic mean (of the log transformed data) yielded the geometric mean of the arithmetic data. The ratios of the arithmetic (anti-log transformed) confidence intervals to the geometric mean yielded the geometric standard deviation around this mean. Values of 2σ (geometric) ranged from 2.0 to 3.8 (2.6 average) for the 95% confidence interval; and values of σ (geometric) ranged from 1.4 to 1.8 (1.5 average) for the 68% confidence interval (Figures 17d and 17e).

The geometric standard deviation represents a factor describing the range around the geometric mean. The resulting estimated volatile Se fluxes therefore range (around the mean of 2108 Kg Se/yr) from 820 Kg Se/yr to 5450 Kg Se/yr within the 95% confidence interval, and from 1380 Kg Se/yr to 3210Kg Se/yr within the 68% confidence interval.

3.3 Sedimentation fluxes

3.3.1 Downward sedimentation flux

The mass of sediment that accumulated in the traps over the period of deployment represents the downward sedimentation flux at that location over the period of deployment.

Sedimentation fluxes showed significant spatial variations (Figure 18 a-c and Table 7a). The sediment trap at shallow site (2267) yielded an average downward sediment flux of 2.95 g/cm^2/yr for the period 03/23/06 to 06/26/07, which is an order of magnitude higher than any of the other average sediment fluxes measured during that period. The next-highest apparent sedimentation rates occurred at the two deep sites (2565 & 3510, Tables 7b & 7d), which were 0.53 and 0.35 g/cm^2/yr, respectively. The shallow sediment traps at sites 2565 and 3510 (Tables 7c & 7e) yielded very low downward sedimentation rates (0.035 and 0.068 g/cm^2/yr) that were approximately an order of magnitude below those of the corresponding deep traps.

The high sedimentation rates at shallow site (2267) correspond to its location in a relatively narrow channel between the Promontory Point and Fremont Island near the outlet of the Bear River. The observed peak sedimentation rate in spring corresponds to peak discharge from the Bear River. For this reason, results from this trap are not considered representative of the rest of the lake.

The high sedimentation rates in the deep traps relative to the shallow traps at Sites 2565 and 3510 likely reflect re-suspension and lateral focusing of sediment from the lake bottom, since it is unlikely that it represents increased sediment generation at intermediate depths. Had the material in the deep traps originated from shallower water, it would have also been collected in the shallow traps. This observation indicates significant re-suspension and lateral focusing of lake-bottom sediment. The topic of re-suspension will be further described below.

In terms of temporal variation, all sites showed higher sedimentation rates in spring and early summer relative to late summer and fall (Figure 18 a-c and Table 7a).

The average Se downward fluxes mirror the spatial trends in downward sediment fluxes (Figure 18 and Table 7), where the average downward Se flux at shallow site 2267 (1.44×10^{-6} g Se/cm^2/yr) was one to two orders of magnitude larger than those at the deep sites (2565 & 3510, Tables 7b & 7d), which were 1.53×10^{-7} and 3.88×10^{-8} g Se/cm^2/yr, respectively. The downward Se flux obtained at the shallow sediment traps at sites 3510 and 2565 yielded 3.18×10^{-8} g Se/cm^2/yr and 4.30×10^{-8} g Se/cm^2/yr (Tables 7e & 7c).

Regarding temporal variations, peak downward Se fluxes did not correspond to peak sedimentation fluxes (Figure 18), and did not show an apparent correspondence to season. However, the limited data would not be expected to yield a clear trend.

Collected sediment included mineral particles and organic material (e.g. phyto- and zoo-plankton, and brine shrimp). Based on visual inspection, mineral particles dominated the matrix at site 2267, whereas accumulated sediments at the other sites appeared to have mostly organic material. A notable exception occurred at site 2565 in April, 2006 when the matrix was dominated by mineral particles and the sedimentation flux was relatively high.

The downward sedimentation rates will be compared to net sedimentation rates below.

3.4 Permanent sedimentation or net sedimentation

3.4.1 Mass accumulation rates

Mass accumulation rates (MAR) were determined from ^{210}Pb and ^{226}Ra activity changes with depth in the sediment cores. Figure 19 presents a ^{226}Ra profile for site 3510, which is relatively constant in the core profile, whereas the total ^{210}Pb profile decreases with depth. Figure 20 shows the corresponding unsupported ^{210}Pb (^{210}Pb minus ^{226}Ra) profile for site 3510, which decreases exponentially with depth (cumulative sediment mass). This profile was used to calculate the net sedimentation rate as well as the date of the sediment profile.

The slope of the linear regression of Figure 20 determines the MAR. As an example, the permanent sedimentation rate for site 3510 was calculated to be 0.043 g/cm^2/yr. The MARs in the cores ranged from 0.010 to 0.049 g/cm^2/yr with an average of 0.032 g/cm^2/yr and two failing to yield sufficient ^{210}Pb activity for use in MAR estimation (Table 9).

Sediment chronologies are shown as a function of depth for site 3510 in Figure 21a. The zone of near-constant ^{210}Pb activity between 0 and 3 cm may reflect a period of increased accumulation or mixing of the sediment due to physical processes, such as episodic re-suspension and re-deposition Re-suspension is confirmed by the presence of ^{7}Be at 2 cm depth in the sediment (Figure 21b), indicating that all of the sediment in this interval was exposed to the water column within the past year.

Since the half-life of ^{137}Cs is 26 years, it can be used to confirm the dates obtained with unsupported ^{210}Pb. However, in this case the two methods disagreed. Figure 22 shows poor agreement between unsupported ^{210}Pb and ^{137}Cs, consistent with ^{137}Cs remobilization via desorption of ^{137}Cs from clays by cation exchange for ammonium ions produced during diagenesis. Subsequent diffusion of dissolved ^{137}Cs results in deeper penetration of the radionuclide, and upward migration of the activity maximum (Anderson et al., 1987), which is demonstrated in Figure 22.

In core samples from sites 2267 and 2565, the unsupported ^{210}Pb activities were too low to estimate MAR (Figures 23 & 24). In core 2267, unsupported ^{210}Pb was detected in the upper-most (0-2 cm) interval; whereas no measurable unsupported ^{210}Pb was observed in core 2565. The ^{210}Pb data may be indicative of very low sediment accumulation rates (< 2 cm/100 years at 2267; and likely much lower at 2565). ^{137}Cs was undetectable by 8 and 6 cm in depth in cores 2267 and 2565, respectively (Figures 25 & 26). The greater depth of measurable ^{137}Cs compared to unsupported ^{210}Pb in these cores is consistent with diagenetic remobilization of ^{137}Cs. ^{7}Be was detected in the surface interval (0-2 cm) in cores 2267 and 2565, suggesting some resuspension of this interval occurred during the past year. However, the much lower ^{7}Be activities in these cores relative to core 3510 indicate that resuspension occurs to a much lesser extent in these cores relative to core 3510.

3.4.2 Downward sedimentation vs. net sedimentation

A representative downward sedimentation flux from the shallow sediment traps at sites 2565 and 3510 can be considered to be representative of the main body of the Great Salt Lake. Representative sedimentation fluxes cannot be obtained from site 2267 due to its proximity to the Bear River. Nor can such a flux be obtained from the deep sediment traps at sites 2565 and 3510, due to the influence of re-suspension and lateral focusing. The average sedimentation rate for these two shallow sediment traps is 0.016 g/cm^2/yr. This value is lower than the net sedimentation rate from the core at site 3510 (0.043 g/cm^2/yr), indicating that the net sedimentation rate does not reflect through-fall from the surface. This discrepancy indicates that re-suspension and lateral transport of newly deposited sediment to permanent deposition zones is significant, in agreement with the ^{7}Be results.

Regarding downward Se sedimentation rate, the single significant value for the shallow sediment trap at site 3510 was 1.19x10^{-8} g Se/cm^2/yr. This value is smaller than the net Se sedimentation rate from the core at site 3510 (4.2x10^{-8} g Se/cm^2/yr). Based on relative overall sedimentation rates, one might have expected the downward Se sedimentation rate to exceed the net Se sedimentation rate at site 3510 (reflecting re-suspension). However, lateral redistribution of Se is expected to occur as a result of re-suspension in the deep brine layer. Recall that Se accumulation in the deep traps at site 3510 was 1.4x10^{-8} g Se/cm^2/yr, which matches the order of the net Se sedimentation rate (4.2x10^{-8} g Se/cm^2/yr).

3.4.3 Estimation of Se removal by sedimentation

Assignment of Se concentration, MAR, and area to qualitative sedimentation zones indicates that about 520 Kg of Se are removed annually by sedimentation. Results of shallow core sedimentation rates overlain on Holocene isopach contours developed by Dr. David Dinter (University of Utah) and Steven Colman (USGS, Menlo Park, CA) are shown on the map in Figure 27a. The geophysical measurements used in the development of these contours are described in Colman et al. (2002). Quantifiable shallow core linear sedimentation rates ranged from 0.02 to 0.67 cm/yr. The linear sedimentation rate for core DD-I was determined to be 95 cm/yr, but is considered an outlier since it is 2 orders of magnitude greater than the remaining 12 quantifiable cores. Seven cores showed negligible ^{210}Pb activity and are interpreted to indicate very low sedimentation rates at these locations (DD-A, DD-D, DD-G, DD-H, DD-K, DD-O, DD-S).

In general, Holocene thickness and sedimentation rates were high along the fault slightly west of the shore of western Antelope Island. East of this line, Holocene thickness decreased dramatically. West of the fault, the sedimentation rates and Holocene thicknesses fell more slowly and continued to decline to the western shore of the south arm of the Great Salt Lake (Dinter, 2007). The contours bounding the zones developed to reflect different sedimentation rates are shown in Figure 27b. In the south basin of the south arm of the GSL, Holocene sediment thicknesses matched relatively well with shallow core results making development of the sedimentation zones straightforward. Areas with sediment thicknesses 2 meters and below consistently

showed insufficient ^{210}Pb to determine a linear sedimentation rate, indicating very low sedimentation. Areas near thicker Holocene sediment (>8 m) such as DD-C and DD-R showed the highest sedimentation rates (0.67 and 0.25 cm/yr respectively). This agreement did not, however, extend to the northwest basin of the south arm. Two shallow cores (DD-I and DD-H) and one deep core (2565) fell within this basin. Holocene sediment thicknesses indicate medium to high sedimentation rates over much of the area for the past ~10,000 years. However, cores DD-H and 2565 did not contain sufficient ^{210}Pb for a sedimentation rate determination. Though the shallow core results for core DD-I indicate that it may be an outlier, the MAR determined from the long core at this location is of similar magnitude to other cores. The discrepancy between Holocene isopach contours and shallow core results may be due to the northwest basin's proximity to the Southern Pacific Railroad (SPRR) causeway. The sedimentation regime of this basin has likely been altered since construction. Since the shallow cores more closely represent contemporary sedimentation, Thiessen polygons were developed for the basin bounded on the west by the SW-NE trending Carrington Fault (Colman, 2002). The Thiessen polygon surrounding core DD-I was designated as a "very high" sedimentation zone. The polygons surrounding cores DD-H and 2565 were designated as "very low" sedimentation zones and grouped together. Overall, the qualitative "very low" sedimentation zone had the largest area, with areas decreasing with each increasing step in sedimentation rate.

The average Se concentration in each sedimentation zone was determined by averaging the Se concentrations in the 0-2 cm interval (e.g. Figure 27c) for all cores falling within each zone. The average salinity corrected Se concentrations from 0-2 cm in the 8 cores are shown in Table 8. The concentrations ranged from 0.79 to 3.02 μg/g with an average of 2.01 μg/g. Though an MAR for cores 2565 and 2267 could not be determined, the Se concentrations in the upper 2 cm of these cores were still used because they represent the Se concentration of the most recent sediment deposited in these locations. The Holocene thickness-based "very high SE" sedimentation zone did not contain any cores, and so was assigned a Se concentration based on that in the "high" sedimentation zone, as described below.

Average mass accumulation rate (MAR) in each zone was determined by interpretation of the MAR results from the deep cores (Table 9). MARs in the "medium," "high," and "very high NW" zones were found by averaging the cores that fell within them. The MAR for the "low" sedimentation zone was calculated by averaging the two cores with sufficient ^{210}Pb activity (DD-Q and 3510) with a sedimentation rate of zero for core 2267 (based on insufficient ^{210}Pb indicating very low sedimentation rate) – yielding an average MAR of 0.018 g/cm^2/yr. The "very low" sedimentation zone did not contain any cores with sufficient ^{210}Pb activity to estimate a MAR. Therefore, the representative MAR for this zone was estimated to be a factor of 2 below the value for the "low" sedimentation zone. The MAR for the "very high SE" sedimentation zone was estimated as 0.049 g/cm^2/yr, 25% higher than the "high" zone value. This value is also consistent with the representative MAR for the "very high NW" zone.

Table 10 show the Se concentration, MAR, area, and calculated mass of Se removed annually within each sedimentation zone. Results indicate that about 520 Kg of Se are permanently removed from the Great Salt Lake by sedimentation each year.

3.4.3.1 Estimating uncertainty in Se removal by sedimentation

In order to estimate uncertainty in the mass of Se removed by sedimentation, an uncertainty was determined for each step in the sedimentation removal calculation. These steps involved determining the representative sediment Se concentration for each qualitative sedimentation zone, the representative mass accumulation rate (MAR) for each zone, and the area of each zone. For the Se concentration and MAR determinations above, 2.6 in-diameter cores were used to represent the 5 zones with a total area of 2080 Km^2. The strength of this extrapolation (i.e. the greater number of cores in each zone, the stronger the confidence in the value) is incorporated into the uncertainty calculations as described below.

3.4.3.1.1 Estimating uncertainty in Se concentration

Uncertainty in the annual Se mass removed by sedimentation was determined by estimating uncertainty for, and propagating uncertainty through, each step in the Se removal calculation. These steps involved determining the representative sediment Se concentration, mass accumulation rate (MAR), and the area for each qualitative sedimentation zone. For the Se concentration and MAR determinations above, 2.6 in-diameter cores were used to represent the 6 zones with a total area of 2083 Km^2. The strength of this extrapolation (i.e. the greater number of cores in each zone, the stronger the confidence in the value) is incorporated into the uncertainty calculations as described below.

Uncertainty in representative Se concentration for each zone was determined. Eight cores were used to describe the area of the south arm of the Great Salt Lake. In each core, the top 2 cm were sliced into 1 or 2 slices and analyzed for Se content. These concentrations were corrected for salinity as described above. Since uncertainty was not determined by the laboratory for Se concentrations in these samples, and since no replicate analyses were made, the uncertainty was estimated as 2 times the reporting limit (RL) for each core slice, and the uncertainties for each slice were propagated into an uncertainty in Se concentration for the core as shown, for example, for core DD-Q:

$$\sigma_{DD-Q} = \sqrt{\sigma_{0-1cm}{}^2 + \sigma_{1-2cm}{}^2} = \sqrt{0.4^2 + 0.4^2} = 0.57 \ \ mg/Kg$$

where $\sigma_{DD\text{-}Q}$ is the estimated uncertainty of the average Se concentration in the top 2 cm of the core and $\sigma_{x\text{-}y}$ is the uncertainty in the Se concentration in the slice of the core from depths 0 to 1 or 1 to 2 cm.

The Se concentrations in the top 2 cm of cores that fall within a single sedimentation zone were averaged together to find the representative Se concentration for that zone. For example, the “low” sedimentation zone calculation of uncertainty in Se concentration is:

$$\sigma_{\text{"low" Avg}} = \sqrt{\sigma_{2267}^2 + \sigma_{DD-Q}^2 + \sigma_{3510}^2}$$

$$\sigma_{\text{"low" Avg}} = \sqrt{0.8^2 + 0.57^2 + 1.13^2} = 1.50 \ \ mg/Kg$$

where $\sigma_{\text{"low" Avg}}$ is the uncertainty associated with averaging the Se concentration values that fall within the "low" sedimentation zone.

The uncertainty in the sediment Se concentration for the entire lake is estimated as the relative standard deviation of all cores:

$$RSD_{Lake} = \frac{\sigma}{\bar{x}} \times 100\% = \frac{0.86}{2.01} \times 100\% = 43\%$$

where RSD_{Lake}, σ, and $\bar{x}$ are the relative standard deviation, standard deviation, and mean of the 8 cores respectively. This is used as the background uncertainty of the entire dataset because it represents the uncertainty if the sedimentation zones described above had not been developed. These zones, though qualitative in nature, were developed to increase confidence in the estimation of Se removal by recognizing the spatial variation in sedimentation rates as controlled by lake bottom topography.

The RSD for each zone was developed from RSD_{Lake} by comparing the number of cores contributing information for the area. The 8 cores in the 2083 Km^2 lake yield an area/core ratio of 260 Km^2 of lake area per core. Division of RSD_{Lake} by this value, and multiplication of the quotient by the ratio of the zone area to the number of cores in that zone yielded the RSD for each zone. The RSD for the qualitative "low" sedimentation zone (420.9 Km^2) is shown below as an example:

$$\text{RSD}_{\text{"low" ext.}} = \frac{43\% \ \text{RSD}_{\text{Lake}}}{260.4 \ Km^2 / core} \times \frac{404.6 \ Km^2}{3 \ cores} = 22\%$$

The high area/core ratio in the "low" zone relative to that of the entire lake serves to decrease the uncertainty from the background of 43%; whereas a zone with a lower area/core ratio would have a higher RSD than 43%. This process is applied to all of the sedimentation zones, with the exception of the "very high SE" zone because no cores fell within it. The uncertainty of the "high" sedimentation zone is applied to the "very high" zone.

To combine the uncertainties associated with Se concentration to those associated with extrapolation to larger areas, the RSDs are converted back to standard deviations, which are then combined as shown above. This error propagation process was repeated for each core and sedimentation zone.

Uncertainty in mass accumulation rate for each zone was determined by a similar method as Se concentration. However, due to the method of analysis of ^{210}Pb decay (use of the slope of the trendline of the natural logarithm of unsupported ^{210}Pb), standard deviation errors for unsupported ^{210}Pb could not be propagated directly through to the final MAR value for each core. In order to determine the error associated

with the MAR determination in each core, a Monte Carlo method was implemented by randomly generating an unsupported ^{210}Pb value in each core slice using the laboratory reported unsupported ^{210}Pb value as the mean and the 1-sigma uncertainty as the standard deviation. This was performed in Microsoft Excel using the NORMINV function paired with RAND(), which generates a random value between 0 and 1. The NORMINV function reads the RAND() value as a percentile based on the defined mean and standard deviation. For example, a mean of 2 and a standard deviation of 1 would be input as NORMINV(RAND(),2,1). If the RAND() value was 0.16, the output of the function would be 1 standard deviation below the mean (16th percentile) yielding a value of 1. This approach was applied to each core slice to randomly generate a new unsupported ^{210}Pb profile, from which the slope of the linear trendline (using the SLOPE function) of the natural logarithm was determined and converted into an MAR. The process was repeated 10,000 times for each core. The uncertainty in MAR for each core was then defined by the standard deviation of the 10,000 MAR results. Figure 27d shows the convergence of the standard deviation of MAR as a function of the number of MAR values included. The standard deviations from different sized populations (10, 20, 50, 100, etc.) were determined for 10 different randomly chosen populations among the 10,000 MAR results. From this plot we observe that the range in estimated standard deviations converges to a constant after several hundred values; hence, we conclude that 10,000 repetitions is sufficient for representing the uncertainty in MAR for each core.

The process described for Se concentration above, propagating the uncertainty for each core to the average of the cores within a zone and then incorporating the uncertainty due to the extrapolation, was also followed for MAR uncertainty. Two cores (2565 and 2267) did not have an associated standard deviation because no MAR could be reported. In core 2565 representing the “very low” sedimentation zone, an uncertainty of 100% or 0.009 g/cm2/yr was assigned. This uncertainty was assigned in order to incorporate the interpreted MAR of the core (0 g/cm2/yr) with the assigned MAR for the zone (0.009 g/cm2/yr). Though an MAR of zero is assigned to core 2267, an uncertainty of 0.009 was assigned to this as well to be consistent with the uncertainty for 2565. The RSD of the “high” sedimentation zone (12.5%) was assigned to the “very high SE” sedimentation zone because no cores fell within this zone.

Uncertainty in the areal extent of each sedimentation zone was determined. The uncertainty associated with the areal extent of the lake is 1.73 Km^2 due to a 0.03 m stage inaccuracy in the USGS gage for lake elevation. This uncertainty was translated into uncertainties for the areal extent of each sedimentation zone by the equation:

$$\sigma_{\text{zone area}} = \text{Area}_{\text{zone}} \times \frac{\sigma_{\text{lake area}}}{\text{Area}_{\text{lake}}}$$

where $\sigma_{\text{zone area}}$ is the uncertainty in the areal extent of each zone and $\sigma_{\text{lake area}}$ is the uncertainty in the area of the entire lake, 1.73 Km^2.

With uncertainties established for the sediment Se concentration, MAR, and area in each zone, the uncertainty of the mass of Se removed by sedimentation was calculated.

The uncertainty was converted into a relative standard deviation for each factor in calculating the mass of Se removed:

$$\mathrm{RSD} = \frac{\sigma}{\bar{x}}$$

where RSD is the relative standard deviation, σ is the uncertainty, and $\bar{x}$ is the average value within each zone. This process was done for Se concentration, MAR, and areal extent for each sedimentation zone.

The RSDs were then propagated through to the mass of Se removed in each zone and converted back into an uncertainty:

$$\mathrm{RSD}_{\text{mass removed}} = \sqrt{RSD_{[Se]}^2 + RSD_{MAR}^2 + RSD_{area}^2}$$

$$\sigma_{\text{mass removed}} = \mathrm{RSD}_{\text{mass removed}} \times \mathrm{Mass}_{\text{Se removed}}$$

where $\sigma_{\text{mass removed}}$ represents the uncertainty in the mass of Se removed for a particular sedimentation zone. Table 11a shows the RSD and $\sigma_{\text{mass removed}}$ values for each sedimentation zone.

Since the masses of Se removed in each zone are summed to determine the mass removed for the lake, the $\sigma_{\text{mass removed}}$ values for each scenario are propagated to define the uncertainty range:

$$\sigma_{\text{total mr}} = \sqrt{\sigma_{\text{"very low" mr}}^2 + \sigma_{\text{"low" mr}}^2 + \sigma_{\text{"medium" mr}}^2 + \sigma_{\text{"high" mr}}^2 + \sigma_{\text{"very high" mr}}^2}$$

where “mr” stands for mass removed and $\sigma_{\text{total mr}}$ is the uncertainty of the total mass removed. The result is a possible range between about 45 and 990 Kg Se per year, with about 520 Kg representing the mean estimate. Table 11b shows the propagation of uncertainty from the $\mathrm{RSD}_{\text{mass removed}}$ for each zone to the final range of uncertainty of Se mass removed by sedimentation.

3.4.4 Sediment trace element analysis

Trace element concentrations as a function of depth at site 3510, show maxima at a depth of several cm (Figure 28). In contrast, trace elements concentrations at the two other sites analyzed show maximum values near the surface (Figures 29 & 30). The trace elements that show increased concentrations near the sediment surface are those expected from mining activities and urban development. These increases in the top 10 cm correspond to development of the basin (past 100 years), according to the chronology from site 3510. However, diagenetic changes may have influenced the concentration-depth profiles such that historical trends may not be accurately recorded (Callendar, 2000).

3.5 Re-suspension – Re-solubilization

3.5.1 Temperature stratification

3.5.1.1 Seasonal trends

Temperature in the water column of the Great Salt Lake varies seasonally with highest temperatures observed in summer and lowest in the winter (Figures 31a & b). At sites 2565 and 3510 (Figure 1) the water column is stratified due to the presence of the deep brine layer. During the summer the deep brine layer was cooler than shallow brine layer and reversed in the winter when the deep brine layer was warmer than the shallow brine layer (Figures 31a & b).

Periodic events punctuate the record of temperature stratification when temperatures equilibrate to a single value across the measured depth of the water column (Figure 31c). At least eight of these equilibration events occurred during the 6-month period of observation from June to December 2006. From January through June 2007 at least six temperature equilibration events were recorded. Five of the events at site 2565 during that 6-month period occurred within a ten day period during the month of April (Figure 31c). Equilibration events ranged in duration from 12 to 24 hours. All significant equilibration events were associated with wind speeds greater than about 30 mph (e.g., Figures 32 a & b), signaling that wind speed drove the equilibration process. The wind direction may also influence the temperature equilibration process as indicated by the muted response at site 3510 relative to site 2565 to the increase in wind speed on October 16th. A change in wind direction from 250 to 360 (or zero) degrees yielded a strong temperature equilibration response at site 3510 (Figure 32b), indicating that this northerly wind yielded great influence at site 3510 relative to the westerly wind. The different responses of the two sites are likely related to their being located in two different sub-basins in the south arm of the Great Salt Lake, as shown by the bathymetric map (Figure 1).

3.5.1.2 Lake Mixing

3.5.1.3 Langmuir circulations

Temperature equilibration events in the water column may represent genuine mixing of the deep and shallow brine layers. One means of achieving this vertical mixing is Langmuir circulation (Wetzel, 2001), which involves helical advection within the water column in response to wind shear. The diagnostic feature of Langmuir circulation is longitudinal streaks oriented with the dominant wind direction.

At wind velocities of 2-7 m/s or greater, streaks of aerated water and floating materials are observed at the water surface (Wetzel, 2001). The spacing between streaks is proportional to the depth over which helical circulation occurs (mixing depth). Assuming symmetric helical cells, mixing depth is equal to half of the distance between adjacent streaks.

3.5.2 Seiche

An internal seiche may result from the wind loading of water in response to atmospheric pressure changes. The loading of water forces the displacement of water at depth, producing an internal wave that may be transmitted across the water body. In a stratified system, deeper layers of the water column may be temporarily displaced in the zone of the internal wave. Displacement of the anoxic deep brine layer may put oxic shallow water in contact with sediment that was previously anoxic. This change in redox potential may cause the release of trace metals back into the water column.

3.5.3 Mechanism of temperature equilibration events

Langmuir circulation is a candidate mechanism to drive actual mixing of the water column. The maximum depth of the water column in the south arm of the Great Salt Lake is about 9 m. In order to mix the water column to this depth, the spacing between Langmuir circulation-produced surface streaks would need to be 18 m. Streaks associated with Langmuir circulations have been observed on the Great Salt Lake in this study and have been previously documented (Stommel, 1951). Although to our knowledge no quantitative measurements of streak spacing have been performed on the Great Salt Lake, observed streak spacing was qualitatively consistent with magnitude needed to mix the deep brine layer. Such mixing depths have been observed in lakes of much smaller areal extent. Maximum mixing depth observed at Lake George, NY was between 10 and 15 m (Langmuir, 1938).

If the temperature equilibration events represent true mixing of the entire water column, one would expect the final temperature to reflect mixing of the initially stratified water column temperatures. The final temperature calculated using the thermal mixing approach for an equilibration event on June 14, 2006, yields 19.7°C. The measured temperature during this event remained near 21°C (Figure 32a), suggesting that actual mixing of the entire water column did not occur.

The nature of the temperature equilibration events, in terms of time passed during equilibration and re-stratification of temperature; can also be used to deduce the mechanism. The response of temperature was rapid, with equilibration often occurring over periods less than an hour. For example, on June 14, 2006 at site 2565, the temperature of the deepest thermistor increased from 17°C to 21°C (temperature of shallow thermistors) over the 70-minute period from 02:27 to 03:39 MDT (Figure 32a). The termination of temperature equilibration and return to stratified temperature conditions also occurred over short time periods (Figures 32 a & b).

Another clue to the mechanism of temperature equilibration is provided by the observation that equilibrated temperature was always that of the shallow brine layer regardless of which layer (shallow or deep brine) was warmer. This observation indicates that temperature equilibration occurred via displacement of the deep brine layer, which is an effect that is consistent with a seiche-driven internal wave. Historical evidence of surface seiche activity has been documented on the south arm of the Great Salt Lake (Lin, 1977). Increase in the lake level at the north end of the lake (Promontory Point) corresponds with a decrease in lake level at the south end of the

lake (Silver Sands) following a strong wind event (Figure 33a). Ranges in the magnitude of the lake level change associated with a seiche event vary with distance across the lake (Figure 33b).

Evidence of surface seiche activity on the lake was recorded at the USGS Saltair Gauge for both temperature equilibration events discussed above. Gauge elevation increased from 0.5 ft to 1 ft after a wind event, and elevation oscillated after initial surge about the initial lake elevation value (Figures 31c, 34a and 34b). The duration of the period over which lake elevation oscillated significantly was similar to the duration of the period over which temperatures responded and periodically equilibrated to the shallow brine temperature. Furthermore, the timing of individual complete temperature equilibration events corresponded to peaks in the lake elevation oscillations, demonstrating a strong relationship between lake elevation oscillation and temperature equilibration. This indicates that loading of water at the surface of the lake induced an internal seiche that displaced the deep brine layer as it passed.

Assuming that the period of an internal seiche corresponds to the period of temperature equilibration, a comparison can be made between the estimated period of an internal seiche and the period of temperature equilibration. The observed duration of temperature equilibration events was sometimes long; for example, the June 14, 2006 equilibration event included a 24-hour period of complete equilibration. This long period of equilibration is similar to what is predicted by the expression for the period of a uninodal internal seiche, which is 25.6 hours for a 40-Km length corresponding to the basin south of the submerged ridge of the Carrington fault. Obviously the actual seiche may not be uninodal, and so the estimated period is based only on a simplified approximation. Another aspect of the temperature equilibration events that is suggestive transmission of an internal wave is the oscillation between complete equilibration and partial stratification that was observed during the temperature equilibration events discussed above. For example, during October 17 and 18th, 2006, site 3510 showed several of these oscillations that corresponded approximately to a 6-hour period. This period was far smaller than the estimated period of an idealized seiche; however, the oscillatory nature of these events was consistent with the transmission of an internal wave.

3.5.4 Batch equilibration tests

Total Se concentrations in bed sediment samples were analyzed at LET and the University of Utah, and results showed good correlation (Figure 35a). The average Se concentration for the 30 samples analyzed was 1.0±0.30 mg/Kg (LET) and 1.24 ± 0.22 mg/Kg (University of Utah).

Following 24 hours of contact between the bed sediments and the shallow brine water, the resultant Se concentration in water varied among the sediment samples, with the highest concentrations found in samples with air headspace.

Percent Se solubilized (of extractable) varied spatially with no discernable pattern (Figure 35b). The average percent Se solubilized in the samples with nitrogen gas headspace was 1.18 ± 0.68%, whereas the average percent Se solubilized in the

samples with air headspace was 1.16 ± 1.36%. The maximum percent solubilized was from site GS 11 composite with air headspace at 6.07% (Figure 36).

Solubilization of Se into the water column due to equilibration of anoxic sediment with shallow brine layer may occur periodically, in response to wave-induced sediment re-suspension and seiche-driven displacement of the deep brine layer. The significance of these events to Se concentration is demonstrated by an example scenario based on observed sediment re-suspension into the sediment traps. Since approximately 1 g of sediment is periodically re-suspended into the sediment traps (3.6 cm radius), a 3.6-cm column of water can be expected to equilibrate with 1 g of sediment. Assuming that the equilibrated column of water is 4 m in height, the resulting additional Se concentration from equilibration with anoxic sediment is:

$$Se_{add}\left(\frac{íg_{solubilized}}{L}\right) = \left(\frac{1.31\ íg_{extracted}}{g_{sed}}\right)\left(\frac{0.1476\ íg_{solubilized}}{2.4340\ íg_{extracted}}\right)\left(\frac{1\ g}{\pi(0.036\ m)^2(4\ m)}\right)\left(\frac{m^3}{1000\ L}\right)$$

$$Se_{add} = 0.0049\frac{íg_{solubilized}}{L}$$

Where: Se_{add} is the additional Se concentration in the water column (µg/L); Se_{sed} is the concentration of Se in the sediment (µg/g); Se_{ratio} is the amount of Se solubilized in the batch test divided by the amount of Se extracted during sediment digestion (µg/µg); w is the weight of sediment in deep sediment trap (g); r is the internal radius of a sediment trap tube (m); and h is the height of the water column over which the Se from the sediment is mixed (m).

The resultant additional Se concentration from site GS 11 is 0.0049 µg/L, which is a negligible value compared to aqueous Se concentrations measured in the lake. Site GS 11 represents the greatest potential for additional concentration based on batch test measurements. The average additional Se concentration contribution for samples with either air or nitrogen headspace is 0.0009 µg/L. Reduction of the equilibrated water column length by a factor of 10 (0.4 m) would still yield negligible additional Se concentration. The contribution from re-suspension is therefore not likely to significantly increase the concentration of Se of the water column.

Solubilization of Se into the water column may also occur in response to shrinking of the deep brine layer, since anoxic sediment present under the deep brine layer may be put into direct contact with oxic shallow brine water when the extent of the deep brine layer decreases. Lake level decreased from 4198.0 ft in June, 2006 to 4196.5 ft in September, 2006 (Table 12). During this period, the thickness of the shallow brine layer remained constant (as measured at sites 2565 and 3510); whereas the deep brine layer thickness decreased by 1.5-ft (Figure 6). This decrease in deep brine layer extent corresponds to exposure of 23,775 acres of anoxic sediment to oxic shallow brine layer water, based on bathymetric data (Baskin, 2005). The thickness of the deep brine layer depends on the dynamics of the bi-directional flow through the Pacific Railroad causeway. Loving et al. (2002) pointed out the parameters that affect the thickness of the deep brine layer in the following equation to calculate the altitude of the deep brine interface:

$$Altitude\ of\ the\ interface\ =\ ES - \Delta H * \frac{\rho_s}{\rho_n - \rho_s}$$

where: ES is the south arm lake elevation, ΔH is the head difference between the south and north arm surface elevations; and ρ_n , ρ_s are the densities in the north and south arm, respectively.

Se flux from the sediment may be influenced by the conditions of the overlying water (Byron and Ohlendorf, 2006). Anoxic conditions (DBL) would favor low redox values that would promote Se retention in the sediment while oxygenated conditions would have the opposite effect and release Se into the overlying water (Massecheleyn and Patrick, 1993).

The potential solubilization of Se from anoxic sediment into shallow brine layer water was examined in batch tests where 15 g shallow brine layer water were equilibrated with 7.5 g anoxic sediment (including pore water, taken from the top two cm) for periods ranging from one week to one month, (with daily shaking for 5 min). Samples from 8 different Great Salt Lake locations consisting of 8 composite samples and one ooze sample were tested.

Se mass released from sediment to water varied spatially with no distinct spatial pattern (Figure 37a). The amount of Se released during the week long experiment was 0.05 ± 0.03 µg. Se mass released in the batch test samples over a month of equilibration was 0.06 ± 0.03 µg per 7.5 g sediment. The corresponding percent Se solubilized (of extractible) was 2.40 ± 1.09% for the week long test and 3.01 ± 1.06% for the month long test (Figure 37b).

The corresponding Se input to the lake (Kg_{Se}) over a period of a month can be calculated if one assumes a maximum depth in the sediment from which Se is solubilized. Here, we assumed this depth to be 2 cm, which yields a 1.44 cm^2 area (for 7.5 g sediment) for a sediment bulk density of 1.6 g/cm^3:

$$Kg_{Se} = \frac{0.06\ ig_{solubilized}}{2.34\ cm^2}(23{,}775\ acres)\left(\frac{4.05E7\ cm^2}{1\ acre}\right)\left(\frac{Kg}{10^9\ ig}\right)$$

$$Kg_{Se} = 24.7Kg$$

Although this 24.7 kg load is not dominant, it is significant. Furthermore, there may be multiple such loads annually, and the estimate is based on batch equilibration tests reflecting a 2:1 ratio of water to sediment conducted over a period of one month; whereas the larger water:sediment ratios and longer equilibration times in the field may yield larger Se inputs.

Results for trace metals other than Se are given in Table 13. Several elements show negative % solubilized (of extractible) indicating that the element may have precipitated out of the water into the sediment due to change in oxidation state.

3.6 Mass balance

The total Se mass in the Great Salt Lake calculated for May 2006 was 4780 Kg. Of that, 3190 Kg (66.6%) was dissolved (< 0.45 μm) and 1596 Kg (33.4%) was bound to particulates (> 0.45 μm). In July 2007, the total Se mass in the lake water column was 7680 Kg, of which 6230 Kg (81.2%) was dissolved, and 1440 Kg (18.8%) was bound to particulates. These example values demonstrate that about 20% to 30% of Se mass in the water column of the Great Salt Lake was associated with particulates. For the sake of mass balance, we consider the total Se concentration, thereby including dissolved and particulate forms in our analysis below.

According to the loading report (Naftz et al., 2007), about 1,480 Kg Se/yr are introduced to the south arm of the Great Salt Lake annually (dissolved plus particulate). Given the present volume of the Great Salt Lake, a Se concentration of 15 μg/L would result from just 100 years of loading if Se were conservative. Clearly, given the ~10,000 year history of the lake, removal mechanisms (e.g., sedimentation, volatilization, and brine shrimp harvest) have influenced the observed concentration towards the present observed average concentration of 0.49 μg/L.

The most significant contribution from the resolubilization-resuspension analysis was 25 Kg from shrinkage of the deep brine layer. Whether this represents a new load is debatable; however, we include it in our mass balance calculation below as a new load since this magnitude is inconsequential.

The brine shrimp industry removed 16.6 million pounds of cysts and *Artemia* biomass over the 2006-2007 season (Marden, 2007). A characteristic industry estimate is 23% dry yield for the commercial harvest (Marden, 2007). The range of average tissue selenium concentrations were 1.18 μg/g dw (Marden, 2007) to 5.7 μg/g dw (Conover, 2007). The resulting range in Se mass flux via the brine shrimp harvest is from 9.9 to 48 Kg/yr.

The fluxes of Se out of the south arm of the Great Salt Lake were estimated to be: 1) a permanent sedimentation flux of 520 Kg/year (arithmetic mean); 2) an integrated volatilization flux of 2108 Kg/yr (geometric mean); and, 3) Se flux via brine shrimp harvest of 28 Kg/yr in 2006-2007 (intermediate value from above). These loss fluxes total to 2656 Kg/yr. The mean volatile and mean permanent sedimentation Se fluxes are 79% and 20%, respectively, of the overall Se removal flux based on the above estimates (Figure 38). The loss flux (2656 Kg/yr) exceeds the estimated loading (1,480 + 25 ≈ 1500 Kg/yr). The flux estimation indicates that the annual Se losses more than balance the Se loads, with the larger loss mechanism being volatilization. The results demonstrate that sedimentation is a relatively minor mechanism of Se removal from the Great Salt Lake, and that most Se removal occurs via volatilization.

Given that two parameters (sedimentation and volatilization fluxes) vary over three values (low, medium, high) for a 68% confidence interval, there are eight (2^3) possible scenarios that can represent the range of possible conditions. To simplify, we show the percentage distribution corresponding to particular scenarios, where the low or high values of both parameters (sedimentation and volatilization fluxes) coincide (Table 14a and Figure 38).

Assuming that the Se loss flux basically balances the loads (about 1500 Kg/yr), then the residence time of Se in the Great Salt Lake ranges from about 3 to 5 years, based on the observed range of 4780 Kg to 7680 Kg Se mass in the Great Salt Lake during the course of the study.

As shown in Figure 7, and as described in the loading report (Naftz et al., 2007), the aqueous Se concentration in the Great Salt Lake increased by an amount ranging from 0.16 to 0.34 μg/L during the period of observation (May 2006 to July 2007). This observation was based on Se concentrations analyzed using hydride generation (Frontier Geosciences), which was the primary analytical method used in this project. Below, we discuss these concentration trajectories relative to expectations from mass balance. We also consider the concentration trajectories determined using collision cell ICP-MS (University of Utah).

The concentration trajectories of total Se (dissolved plus particulate) over the course of the study were explored by integrating the total Se concentration over time via the following mass balance:

$$[Se]_t = [Se]_{t-1} + \frac{\left[Se_{load} - Se_{volatilization} - Se_{permanent\ sedimentation} - Se_{brine\ shrimp\ harvesting}\right]}{Volume}$$

where $[Se]_t$ and $[Se]_{t-1}$ represent the total Se concentration in μg/L for the present and previous time steps, respectively; Se_i (i = load or removal process) represents the mass flux (loading or removal) per unit time; and Volume represents the volume of the lake. The mass balance was determined from May 19, 2006 to August 1, 2007 using daily values of fluxes (loads and removal processes). The daily values for loads and volatilization were determined as described in Naftz et al. (2007) and this report, respectively; whereas the daily values for permanent sedimentation and brine shrimp harvest were determined by division of the annual values by 365. Daily values of surface area and volume of the Great Salt Lake, for the same period, were obtained from the USGS National Water Information System (http://waterdata.usgs.gov/nwis).

The trend in total Se concentration, without inclusion of removal processes (Figure 39), showed an increase during the time period of the investigation, with the final estimated total Se concentration (0.64 μg/L) nearly matching the measured value in July, 2007 (0.75 μg/L = average of the four sites). Addition of the removal processes (volatilization, permanent sedimentation and brine shrimp harvesting), yielded decreases in the estimated total Se concentration during the time period of the investigation (Figure 39). For the mean fluxes of volatilization and permanent sedimentation, the final estimated total Se concentration was (0.32 μg/L), which was low (by about 0.43 μg/L) relative to the measured value in July, 2007 (Figure 39). For the low fluxes of volatilization and permanent sedimentation, the final estimated total Se concentration was (0.47 μg/L) somewhat below (about 0.28 μg/L) the measured value in July, 2007. These results suggest that the actual volatilization flux is in the low end of the spectrum of estimated values.

Assuming conservative behavior of Se, Naftz et al. (2007) calculated the existence of an unmeasured load of approximately 1350 Kg/yr (1500 Kg during the 15-month period of study). Potential source(s) of the unmeasured Se load that were previously described by Naftz et al. (2007) include: (1) submarine groundwater discharge; (2) wet and dry atmospheric deposition falling directly on the lake surface; (3) lake sediment release into the overlying water column; and (4) poorly characterized exchange with the north arm, as described in the report regarding Se loads to the Great Salt Lake.

For all measurements made during this flux study, the dissolved volatile Se concentrations increased with depth, demonstrating that the dissolved volatile Se flux was outward (to the atmosphere) for all measured periods. However, this observation does not preclude the possibility that the total Se concentration increased with depth, since the dissolved volatile Se concentration comprises only 0.1% of the total aqueous Se concentration. Furthermore, it is possible that the near-surface Se concentration gradient differs during precipitation events, which could not be measured due to logistical limitations.

Estimated values of atmospheric Se deposition for several global sites are presented in Table 15. A highly speculative literature-based estimate of dry deposition for the Great Salt Lake (162.67 μg/m^2/yr) was developed by averaging estimated dry deposition at the Great Lakes and Chesapeake Bay. This estimated dry deposition flux yields an estimated atmospheric load of 300 Kg/yr.

When atmospheric deposition (300 Kg/yr) was included in the trajectory simulations using the low values of the estimated volatilization and sedimentation fluxes, the final estimated Se concentration was 0.68 μg/L (Figure 40), which was approximately 0.07 μg/L below the measured value. This suggests that the observed trajectories can be explained by a combination of unmeasured loads and removal fluxes that correspond to the low end of the estimated range.

As mentioned before, data from ICP-MS analysis of Se analyzed at the University of Utah (Figure 7e and 7f) did not show the strong increase in Se concentration during the course of the study that was demonstrated in the HG-AF analyses. The difference in the observed trends may represent analytical errors associated with the different methods used. In hydride generation, the analyte is removed from the confounding matrix (via exsolution as a gas) prior to analyses, whereas in collision cell ICP-MS, the analyte is removed from its confounding matrix (via kinetic attenuation of the non-analyte ions) just prior to detection. The data quality for both methods is high (Figure 42), showing good to excellent spike recoveries (Figure 42, top). Notably, the spike concentrations used to evaluate the ICP-MS data quality were much more challenging (0.03 to 2.0 μg/L range) than the spike concentrations used for HG-AFS (1.0 to 30 μg/L range. The lesser number of samples analyzed via ICP-MS, and somewhat greater scatter in results, yield lower confidence in the ICP-MS trend relative to the HG-AF trends.

The concentration trajectories of trace metals (other than Se) may provide perspective regarding the Se trajectories. Elements such as As, Sb, Mo, U, Ba and Mn showed total (RA) and dissolved (FA) concentrations that were slightly higher in summer-fall and

lower in winter-spring (Figures 42 and 43). Al and Fe showed dramatic increases in total (RA) concentration during winter-spring (Figures 42 and 43). These observations indicate that the trends in the trace elements may be influenced by both evaporative concentration and geochemical processes. The apparent cyclical nature of the trace element concentrations contrasts against the apparent monotonic increase in Se concentration during the course of the study. Clearly additional monitoring of Se concentrations is warranted to determine longer term trend in Se concentration.

3.7 Variability

The mass balance section necessarily simplified the characteristics of the Great Salt Lake in order to allow the development of a simple mass balance. In reality, the Great Salt Lake is neither vertically nor areally homogenous.

Data presented above speak to the vertical heterogeneity, that is, the density stratification of the lake. The denser Deep Brine Layer of the Great Salt Lake is anoxic, and is therefore geochemically distinct from the oxic Shallow Brine Layer. The dynamics of the Deep Brine Layer, and its influence on Se, as well as other trace metal and metalloid cycling, needs to be better understood. The evolution of the Deep Brine Layer from its origin at the north arm to its apparent assimilation via mixing at the south end of the lake needs to be investigated in order to understand the time and space scales over which anoxia occurs, and over which oxidized trace metals and metalloids are reduced to other forms. With this understanding, it may be possible to design strategies to mitigate negative influences of the Deep Brine Layer on the cycling of particular trace metals (e.g. Hg).

The measured volatile Se concentrations in the water column demonstrate vertical variation, where a distinct increase in volatile Se concentration with depth was observed in the Shallow Brine Layer (Table 5 and Figure 15a); whereas no such trend was observed in the Deep Brine Layer (Table 5 and Figure 15b). This trend may implicate phytoplankton as the generators of volatile Se. The trend seems to be more clearly established for the shallow sites (2267and 2767), possibly suggesting the bioherms as an important source of volatile Se, or possibly suggesting the importance of proximity to labile carbon sources such as the Bear and Weber rivers and Farmington Bay.

The measured downward sedimentation fluxes (Table 7 and Figure 18) demonstrate that areal variability exists with respect to downward sedimentation in the Great Salt Lake. Site 2267 in the Bear River Strait showed downward sedimentation values that were one to two orders of magnitude higher than sites 3510 and 2565. Temporal variability is also evident with orders of magnitude higher downward sedimentation fluxes during spring and summer relative to fall and winter. The higher downward sedimentation flux in the Bear River Strait is likely due to its proximity to the Bear River, which is the presumed source of the corresponding particulates.

As shown in the Naftz et al. (2007) report, the total Se concentration increased over the course of the study. This increase was also observed in the dissolved (< 0.45 μm) concentrations, with an average increase of 0.35 μg/L (Figure 41a). Areal variability is demonstrated in this data, where sites 2267 and 2767 show greater increases in Se

concentration (dissolved and total) relative to sites 2565 and 3510. The latter two sites have deep brine layers, which could potentially act as an Se sink; whereas the former two sites are located nearest to major load points (Bear and Weber Rivers, and Farmington Bay causeway), which may locally enhance Se loading. Notably, particulate-associated Se concentration trajectories did not show an increase over the course of the study (Figure 41b).

Although suspension of consideration of the above-described variability in the south arm of the Great Salt Lake was useful for ease of implementation of the mass balance, the observed variability provides clues to important processes that control the cycling of Se in the system, and warrant further investigation. Furthermore, the period of observation was merely 15 months and fortunately coincided with a transition to reduced runoff. However, a more complete understanding of the system will be achieved with continued observation, including transition to periods of increased runoff.

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TABLES

Table 1a. ICP-MS conditions for water sample analysis

Condition	Value
RF power (W)	1550
Plasma gas flowrate (L/min)	15.0
Hydrogen flowrate (mL/min)	5.0
Helium flowrate (mL/min)	6.5
Carrier flowrate (L/min)	0.73
Make-up gas (L/min)	0.21
Auxiliary gas (L/min)	1.0
Sample pump (rps)	0.1
Sample depth (mm)	8.0
Tuning solution: ^{7}Li mean (cps) ^{89}Y mean (cps) ^{205}Th mean (cps) % RSD for each cps	 30,000 29,000 64,000 < 3%
Sample nebulizer tubing: Material Internal diameter (mm)	 Tygon 1.02
Internal standard tubing: Material Internal diameter (mm)	 Tygon 0.91

Table 1b Great Salt Lake synthetic solution recipe

Salt	Concentration ($mol/g_{solution}$)	Concentration g/L	Grams in 100mL milliQ W	Salt Purity	Salt brand
NaCl	1.99E-03	116.7884	11.6788	99.999%	Sigma-Aldrich
$MgCl_2$	1.46E-04	13.9657	1.3966	99.99%	Sigma
$MgSO_4$	3.73E-05	4.4874	0.4487	99.99+%	Aldrich
K_2SO_4	3.21E-05	5.5877	0.5588	99.99%	Aldrich
$CaSO_4$	4.88E-06	0.6306	0.0631	99.99+%	Aldrich

Table 1c. Quality control summary (EPA, 2007)

QC Operation	Frequency
Instrument Calibration	Daily or each time instrument is set up.
Initial Calibration Verification (ICV)	Following each instrument calibration for each wavelength or mass used.
Initial Calibration Blank (ICB)	Following each instrument calibration, immediately after the Initial Calibration Verification (ICV).
Continuing Calibration Verification (CCV)	For each wavelength or mass used, at a frequency of 10% or every two hours of a run, whichever is more frequent, and at the beginning and end of each run.
Continuing Calibration Blank (CCB)	10% or every two hours of a run, whichever is more frequent, and at the beginning and end of each run. Performed immediately after the last Continuing Calibration Verification (CCV).
CRQL Check Standard (CRI)	Every 20 analytical samples and at the beginning and end of each run, but not before the ICV. Performed before the Interference Check Sample.
Interference Check Sample (ICS)	For ICP-AES, every 20 analytical samples and at the beginning and end of each run, immediately after the CRI. For ICP-MS, at the beginning of the run.
Serial Dilution for ICP	For each matrix type or for each SDG, whichever is more frequent.
Preparation Blank	For each SDG or each sample preparation and analysis procedure per batch of prepared samples.
Laboratory Control Sample	For each SDG or each sample preparation and analysis procedure per batch of prepared samples, except aqueous mercury and cyanide.
Spike Sample	For each matrix type or for each SDG, whichever is more frequent.
Post Digestion/Distillation Spike	Each time Spike Sample Recovery is outside QC limits.
Duplicate Sample Analysis	For each matrix type or for each SDG, whichever is more frequent.
ICP-MS Tune	Prior to calibration.
Method Detection Limit Determination	Prior to contract, annually thereafter, and after major instrument maintenance.
Inter-element Corrections	Prior to contract, quarterly thereafter, and after major instrument adjustment.
Linear Range Analysis	Prior to contract, and quarterly thereafter.

Table 1d. Results of measured volatile Se fluxes under controlled laboratory conditions with variable sweep rate and sweep gas composition.

Sample ID	Sweep Gas	Sweep Rate	Wind	Water Temp.	Vol [Se]	Measured Flux
		L/min	m/s	oC	ng/L	ng/m^2h
GT1	N2	2	0	19	2.24	5.72
GT2	N2	3	0	19	21.50	32.26
GT3	N2	6	0	19	17.45	24.65
GT4	He	3	0	19	27.36	43.11
GT5	He	2	0	19	21.90	29.51
GT7	N2	2	0	19	21.90	31.80
1X	He	3	0	19	0	2.67
2X	He	3	0	19	0	1.25
3X	He	3	0	19	0	0.87

Table 2a. Total (RA) and dissolved (FA) selenium concentrations in water, site 2267.

Site	Sampling date	Depth (m)	FA (µg/L)	RA (µg/L)
	26-May-06	0.2	0.311	0.404
	26-May-06	4	0.341	0.524
	19-Jun-06	0.2	0.267	0.311
	19-Jun-06	4	0.278	0.405
	28-Jul-06	0.2	0.425	0.469
	28-Jul-06	4	0.38	0.461
	29-Aug-06	0.2	0.685	0.785
	29-Aug-06	3.8	0.647	0.948
	28-Sep-06	0.2	0.483	0.664
	28-Sep-06	3.5	0.456	0.594
	01-Nov-06	0.2	0.532	0.57
	01-Nov-06	3.9	0.494	0.896
	21-Nov-06	0.2	0.307	0.414
	21-Nov-06	3.7	0.292	0.466
	07-Dec-06	0.2	0.366	0.63
	07-Dec-06	3.5	0.64	0.732
	20-Mar-07	0.2	0.477	0.664
	20-Mar-07	4	0.572	0.714
	26-Apr-07	0.2	0.49	0.759
	26-Apr-07	4	0.702	0.865
	23-May-07	0.2	0.526	0.644
	23-May-07	4	0.607	0.658
	26-Jun-07	0.2	0.816	0.681
	26-Jun-07	4	0.702	0.729
	24-Jul-07	0.2	0.669	0.705
	24-Jul-07	3.5	0.622	0.751
	Arithmetic average		0.50	0.63
	Geometric mean		0.48	0.61
	Median		0.49	0.66
	Standard deviation		0.16	0.16
	Geometric standard deviation		0.21	0.33
	Lowest value		0.27	0.31
2267	Highest value		0.82	0.95

Table 2b. Total (RA) and dissolved (FA) selenium concentrations in water, site 2565.

Site	Sampling date	Depth (m)	FA (µg/L)	RA (µg/L)
2565 shallow	26-May-06	0.2	0.418	0.496
	19-Jun-06	0.2	0.245	0.396
	29-Jul-06	0.2	0.361	0.476
	29-Sep-06	0.2	0.391	0.646
	2-Nov-06	0.2	0.768	0.805
	22-Nov-06	0.2	0.291	0.416
	6-Dec-06	0.2	0.417	0.509
	20-Mar-07	0.2	0.361	0.656
	26-Apr-07	0.2	0.54	0.658
	23-May-07	0.2	0.547	0.64
	26-Jun-07	0.2	0.436	0.764
	25-Jul-07	0.2	0.708	0.651
	Arithmetic average		0.46	0.59
	Geometric mean		0.43	0.58
	Median		0.42	0.64
	Standard deviation		0.16	0.13
	Geometric standard deviation		1.38	1.25
	Lowest value		0.25	0.40
	Highest value		0.77	0.81
2565 deep	26-May-06	6.5	0.366	0.504
	26-May-06	7.5	0.25	0.594
	19-Jun-06	6.5	0.205	0.446
	19-Jun-06	8	0.219	0.973
	29-Jul-06	6.5	0.25	0.25
	29-Jul-06	7.5	0.291	0.311
	29-Sep-06	6.5	0.401	0.484
	29-Sep-06	7.5	0.25	0.25
	2-Nov-06	6.5	0.584	0.643
	2-Nov-06	8	0.334	0.553
	22-Nov-06	6.5	0.25	0.25
	22-Nov-06	7.5	0.25	0.25
	6-Dec-06	6.5	0.377	0.502
	6-Dec-06	7.5	0.273	0.417
	20-Mar-07	6.5	0.463	0.682
	20-Mar-07	7.5	0.43	0.961
	26-Apr-07	6.5	0.507	0.825
	26-Apr-07	8	0.532	0.865
	23-May-07	6.5	0.632	0.709
	23-May-07	7.5	0.404	0.809
	26-Jun-07	6.5	0.433	0.616
	26-Jun-07	7.5	0.645	1.05
	25-Jul-07	6	0.574	0.864
	25-Jul-07	7	0.601	0.746
	Arithmetic average		0.40	0.61
	Geometric mean		0.37	0.55
	Median		0.39	0.61
	Standard deviation		0.14	0.25
	Geometric standard deviation		1.43	1.58
	Lowest value		0.21	0.25
	Highest value		0.65	1.05

Table 2c. Total (RA) and dissolved (FA) selenium concentrations in water, site 3510.

Site	Sampling date	Depth (m)	FA (µg/L)	RA (µg/L)
	23-May-06	0.2	0.461	0.605
	20-Jun-06	0.2	0.363	0.479
	27-Jul-06	0.2	0.335	0.437
	1-Sep-06	0.2	0.586	0.779
	29-Sep-06	0.2	0.452	0.534
	4-Nov-06	0.2	0.559	0.665
	21-Nov-06	0.2	0.334	0.522
	7-Dec-06	0.2	0.452	0.623
	19-Mar-07	0.2	0.59	0.671
	1-May-07	0.2	0.843	0.8
	31-May-07	0.2	0.591	0.746
	27-Jun-07	0.2	0.506	0.613
	25-Jul-07	0.2	0.62	0.642
	Arithmetic average		0.51	0.62
	Geometric mean		0.50	0.61
	Median		0.51	0.62
	Standard deviation		0.14	0.11
	Geometric standard deviation		1.29	1.19
3510	Lowest value		0.33	0.44
shallow	Highest value		0.84	0.80
	23-May-06	6.5	0.409	0.642
	23-May-06	8.5	0.292	0.716
	20-Jun-06	7	0.348	0.477
	20-Jun-06	8.5	0.243	0.654
	27-Jul-06	7	0.248	0.411
	27-Jul-06	8.5	0.35	0.417
	1-Sep-06	6.5	0.745	0.777
	1-Sep-06	8.5	0.461	1.14
	29-Sep-06	6.5	0.431	0.526
	29-Sep-06	8	0.25	0.251
	4-Nov-06	6.5	0.408	0.576
	4-Nov-06	8	0.349	0.548
	21-Nov-06	6.5	0.478	0.723
	21-Nov-06	8	0.549	0.551
	7-Dec-06	6.5	0.378	0.47
	7-Dec-06	8	0.25	0.523
	19-Mar-07	6.5	0.544	0.674
	19-Mar-07	8	0.681	0.812
	1-May-07	6.5	0.622	0.806
	1-May-07	8.5	0.468	0.718
	31-May-07	7	0.569	0.916
	31-May-07	8.3	0.593	0.718
	27-Jun-07	7	0.571	0.712
	27-Jun-07	8.1	0.453	0.723
	25-Jul-07	6.5	0.662	0.736
	25-Jul-07	8	0.618	0.76
	Arithmetic average		0.46	0.65
	Geometric mean		0.44	0.63
	Median		0.46	0.69
	Standard deviation		0.15	0.18
	Geometric standard deviation		1.40	1.35
3510	Lowest value		0.24	0.25
deep	Highest value		0.75	1.14

Table 2d. Total (RA) and dissolved (FA) selenium concentrations in water, site 2767.

Site	Sampling date	Depth (m)	FA (µg/L)	RA (µg/L)
	23-May-06	0.2	0.333	0.439
	23-May-06	3	0.364	0.412
	20-Jun-06	0.2	0.284	0.582
	20-Jun-06	3	0.319	0.418
	27-Jul-06	0.2	0.346	0.439
	27-Jul-06	3	0.33	0.449
	29-Aug-06	0.2	0.713	0.925
	29-Aug-06	2.7	0.762	0.844
	27-Sep-06	0.2	0.431	0.513
	27-Sep-06	2.2	0.538	0.626
	03-Nov-04	0.2	0.445	0.657
	20-Nov-06	0.2	0.281	0.46
	20-Nov-06	2.5	0.363	0.545
	07-Dec-06	0.2	0.432	0.464
	07-Dec-06	2.5	0.528	0.572
	19-Mar-07	0.2	0.626	0.677
	19-Mar-07	3	0.574	0.795
	02-May-07	0.2	0.546	0.699
	02-May-07	2.8	0.558	0.705
	31-May-07	0.2	0.545	0.625
	31-May-07	2.8	0.594	0.58
	28-Jun-07	0.2	0.522	0.845
	28-Jun-07	3	0.507	0.808
	24-Jul-07	0.2	0.662	0.68
	24-Jul-07	2.5	2.77	3.11
	Arithmetic average		0.57	0.71
	Geometric mean		0.50	0.64
	Median		0.52	0.63
	Standard deviation		0.48	0.52
	Geometric standard deviation		0.24	0.29
	Lowest value		0.28	0.41
2767	Highest value		2.77	3.11
Arith. average over total samples			**0.49**	**0.64**
Geometric mean over total samples			**0.45**	**0.60**
Median over total samples			**0.46**	**0.64**
Standard deviation over total samples			**0.25**	**0.28**
Geometric standard deviation over total samples			**0.21**	**0.31**
Lowest value			**0.21**	**0.25**
Highest value			**2.77**	**3.11**

Table 2e. Total (RA) and dissolved (FA) selenium concentrations in water, sites 2267 & 2565. Analysis via ICP-MS at the U of Utah.

Site	Sampling date	Depth (m)	FA (µg/L)	RA (µg/L)
	8/29/06	0.2	0.27	0.60
	8/29/06	3.8	0.45	0.60
	11/1/06	0.2	0.34	0.24
	11/1/06	3.9	0.20	0.40
	12/7/06	0.2	0.14	0.21
	12/7/06	3.5	0.18	0.33
	3/20/07	0.2	0.37	0.56
	3/20/07	4.0	0.50	0.46
	4/27/07	0.2	0.30	0.30
	5/24/07	0.2	0.30	0.30
	6/27/07	0.2	0.30	0.58
	7/25/07	0.2	0.30	0.46
	8/24/07	0.2	0.55	0.65
	Arithmetic average		0.32	0.44
	Geometric mean		0.30	0.41
	Median		0.30	0.46
	Standard deviation		0.12	0.15
	Lowest value		0.14	0.21
2267	Highest value		0.55	0.65
	11/1/06	0.2	0.43	0.36
	12/6/06	0.2	0.09	0.27
	3/20/07	0.2	0.47	0.60
	4/27/07	0.2	0.30	0.30
	5/24/07	0.2	0.32	0.30
	6/28/07	0.2	0.30	0.30
	7/26/07	0.2	0.41	0.30
	8/22/07	0.2	0.47	0.34
	Arithmetic average		0.35	0.34
	Geometric mean		0.32	0.33
	Median		0.36	0.30
	Standard deviation		0.13	0.10
	Lowest value		0.09	0.27
2565 shallow	Highest value		0.47	0.60
	11/1/06	6.5	0.65	1.03
	11/1/06	8.0	2.67	3.40
	12/6/06	6.5	1.07	1.09
	12/6/06	7.5	3.72	2.27
	3/20/07	6.5	0.50	0.50
	3/20/07	7.5	0.71	1.15
	4/27/07	8.0	0.40	0.40
	5/24/07	7.5	0.40	0.40
	6/27/07	7.5	0.40	0.40
	7/26/07	7.0	0.40	0.40
	8/22/07	7.8	0.40	0.40
	Arithmetic average		1.03	1.04
	Geometric mean		0.71	0.76
	Median		0.50	0.50
	Standard deviation		1.12	0.97
	Lowest value		0.40	0.40
2565 deep	Highest value		3.72	3.40

Table 2f. Total (RA) and dissolved (FA) selenium concentrations in water, site 3510. Analysis via ICP-MS at the U of Utah.

Site	Sampling date	Depth (m)	FA (µg/L)	RA (µg/L)
	9/1/06	0.2	0.41	0.60
	11/3/06	0.2	0.35	0.56
	12/7/06	0.2	0.15	0.26
	3/19/07	0.2	0.42	0.77
	5/2/07	0.2	0.30	0.32
	6/1/07	0.2	0.30	0.45
	6/28/07	0.2	0.65	0.61
	7/26/07	0.2	0.37	0.48
	8/22/07	0.2	0.83	0.79
	Arithmetic average		0.42	0.54
	Geometric mean		0.38	0.51
	Median		0.37	0.56
	Standard deviation		0.20	0.18
	Lowest value		0.15	0.26
3510 shallow	Highest value		0.83	0.79
	9/1/06	6.5	0.65	1.69
	9/1/06	8.5	1.61	3.15
	11/3/06	6.5	0.42	1.85
	12/7/06	6.5	0.96	1.19
	12/7/06	8.0	2.26	2.97
	3/19/07	6.5	0.71	1.15
	3/19/07	8.0	0.60	1.04
	5/2/07	8.5	0.40	0.40
	6/1/07	8.3	0.40	0.40
	6/28/07	8.1	0.40	0.40
	7/26/07	8.0	0.40	0.40
	8/22/07	8.0	0.40	0.40
	Arithmetic average		0.77	1.25
	Geometric mean		0.63	0.93
	Median		0.51	1.09
	Standard deviation		0.59	0.99
	Lowest value		0.40	0.40
3510 deep	Highest value		2.26	3.15

Table 2g. Total (RA) and dissolved (FA) selenium concentrations in water, site 2767. Analysis via ICP-MS at the U of Utah.

Site	Sampling date	Depth (m)	FA (µg/L)	RA (µg/L)
	8/29/06	0.2	0.41	0.41
	8/29/06	2.7	0.55	0.67
	11/3/06	0.2	0.31	0.45
	12/6/06	0.2	0.36	0.41
	12/6/06	2.5	0.09	0.16
	3/19/07	0.2	0.58	0.69
	3/19/07	3	0.57	0.74
	5/3/07	0.2	0.30	0.30
	6/1/07	0.2	0.30	0.30
	6/29/07	0.2	0.54	0.60
	7/25/07	0.2	0.30	0.30
	8/24/07	2.5	0.30	0.91
	8/24/07	0.2	0.30	0.45
	Arithmetic average		0.38	0.49
	Geometric mean		0.35	0.45
	Median		0.31	0.45
	Standard deviation		0.14	0.21
	Lowest value		0.09	0.16
2767	Highest value		0.58	0.91
Arith. average over total samples			0.55	0.70
Geometric mean over total samples			0.43	0.54
Median over total samples			0.40	0.45
Standard deviation over total samples			0.58	0.67
Lowest value			0.09	0.16
Highest value			3.72	3.40

Table 3a. Arithmetic average results (all water column sites and samples) for major and minor elements in shallow brine layer analyzed by ICP-MS. Total (RA) and dissolved (FA) results.

Element	Unit	Average for FA shallow brine	Average for RA shallow brine	Highest value FA/RA	Lowest value FA/RA
Li	mg/L	20.34 ± 0.80	20.79 ± 0.63	21.45 / 21.19	19.02 / 19.26
Na	mg/L	44891.18 ± 2004.37	46026.82 ± 1561.48	48231 / 47052	41841 / 42876
Mg	mg/L	4637.86 ± 205.44	4746.85 ± 160.21	4972.50 / 4847.40	4326.30 / 4397.40
S	mg/L	3377.62 ± 118.42	3415.25 ± 94.62	3522.60 / 3460.50	3188.70 / 3174.30
Cl	mg/L	85588.36 ± 2926.50	85968.00 ± 2384.21	89127 / 87183	81045 / 80154
K	mg/L	2603.86 ± 106.01	2654.35 ± 72.15	2685.60 / 2691.00	2402.10 / 2457.90
Ca	mg/L	270.23 ± 9.02	275.76 ± 5.78	283.14 / 283.68	258.93 / 265.14
Al	mg/L	14.52 ± 8.08	94.90 ± 35.61	26.45 / 127.80	4.65 / 21.86
Ti	µg/L	327.45 ± 14.10	338.75 ± 6.61	343.60 / 347.10	308.25 / 328.70
V	µg/L	6.06 ± 0.15	6.22 ± 0.08	6.54 / 6.37	6.02 / 6.15
Cr	µg/L	12.01 ± 0.97	12.23 ± 0.76	12.79 / 12.89	9.87 / 10.43
Mn	µg/L	20.97 ± 4.73	24.86 ± 3.54	25.63 / 26.81	13.95 / 17.94
Fe	µg/L	32.54 ± 18.61	95.50 ± 20.51	83.50 / 116.25	16.59 / 44.82
Co	µg/L	3.57 ± 0.03	3.62 ± 0.04	3.63 / 3.71	3.54 / 3.56
Ni	µg/L	4.42 ± 0.21	4.47 ± 0.12	4.78 / 4.65	4.13 / 4.17
Cu	µg/L	15.33 ± 1.52	15.50 ± 0.85	18.05 / 17.20	13.30 / 14.20
Zn	µg/L	15.20 ± 8.13	19.37 ± 16.82	31.85 / 64.50	4.68 / 6.58
As	µg/L	145.22 ± 9.98	147.44 ± 6.30	156.20 / 154.60	132.45 / 131.60
Sr	µg/L	2469.09 ± 107.58	2536.41 ± 58.01	2589.50 / 2598.00	2310.00 / 2428.00
Mo	µg/L	44.75 ± 3.20	46.13 ± 1.92	51.20 / 50.15	42.29 / 43.95
Cd	µg/L	2.60 ± 0.21	2.65 ± 0.33	2.80 / 3.08	2.12 / 1.88
Sb	µg/L	15.43 ± 0.71	15.67 ± 0.64	16.33 / 16.63	14.50 / 14.98
Ba	µg/L	124.67 ± 1.97	130.71 ± 2.64	126.85 / 133.70	120.50 / 126.80
Tl	µg/L	1.78 ± 0.04	1.77 ± 0.02	1.84 / 1.79	1.71 / 1.73
Pb	µg/L	3.41 ± 0.28	3.66 ± 0.24	3.98 / 4.01	3.04 / 3.10
U	µg/L	9.34 ± 0.41	9.55 ± 0.19	9.93 / 9.87	8.87 / 9.33

Table 3b. Geometric mean and median (all water column sites and samples) for major and minor elements in shallow brine layer analyzed by ICP-MS. Total (RA) and dissolved (FA) results

		Geometric mean -Shallow		Median - Shallow	
Element	**Units**	**FA**	**RA**	**FA**	**RA**
Li	mg/L	19.8	20.1	19.76	19.84
Na	mg/L	43707.9	44514.9	43245.00	43830.00
Mg	mg/L	4502.2	4583.3	4440.15	4509.00
S	mg/L	3302.8	3324.2	3296.70	3310.20
Cl	mg/L	83832.7	83887.4	83785.50	83245.50
K	mg/L	2541.8	2575.2	2553.75	2580.75
Ca	mg/L	268.3	272.8	268.02	270.59
Al	mg/L	12.3	85.6	12.12	98.58
Ti	**µg/L**	324.6	335.9	328.60	333.68
V	**µg/L**	6.1	6.2	6.07	6.18
Cr	**µg/L**	11.6	11.9	11.57	12.00
Mn	**µg/L**	17.9	21.9	17.89	21.40
Fe	**µg/L**	30.4	80.8	27.97	87.58
Co	**µg/L**	3.6	3.6	3.56	3.61
Ni	**µg/L**	4.4	4.4	4.41	4.46
Cu	**µg/L**	15.6	15.5	15.50	15.69
Zn	**µg/L**	13.9	16.4	14.38	14.51
As	**µg/L**	143.8	147.3	144.60	147.33
Sr	**µg/L**	2431.3	2519.7	2463.25	2521.25
Mo	**µg/L**	45.8	47.0	45.54	46.75
Cd	**µg/L**	2.5	2.5	2.54	2.59
Sb	**µg/L**	15.3	15.8	15.4	15.7
Ba	**µg/L**	123.7	129.6	124.5	129.1
Tl	**µg/L**	1.8	1.8	1.77	1.76
Pb	**µg/L**	3.5	3.6	3.59	3.64
U	**µg/L**	9.3	9.5	9.3425	9.46

Table 3c. Arithmetic average results for major and minor elements in deep brine layer (all water column sites and samples) analyzed by ICP-MS. Total (RA) and dissolved (FA) results

Element	Unit	Average for FA deep brine	Average for RA deep brine	Highest value FA/RA	Lowest value FA/RA
Li	mg/L	25.84 ± 5.61	26.15 ± 5.82	35.84 / 37.36	20.08 / 20.56
Na	mg/L	55920.38 ± 11944.08	56787.75 ± 12591.38	78561 ˜ / 81567	43812 ˜ / 44604
Mg	mg/L	5857.31 ± 1315.12	5927.74 ± 1369.95	8297.10 / 8518.50	4465.8 / 4574.7
S	mg/L	4255.99 ± 925.75	4207.50 ± 883.04	5979.60 / 5762.70	3282.3 / 3301.2
Cl	mg/L	106984.13 ± 23324.56	105842.25 ± 22193.84	152370 / 145620	81810 / 82656
K	mg/L	3275.10 ± 667.25	3309.98 ± 683.16	4508.10 / 4631.40	2577.6 / 2667.6
Ca	mg/L	293.48 ± 21.34	299.89 ± 22.80	325.26 / 335.52	268.74 / 278.19
Al	mg/L	344.48 ± 940.88	899.50 ± 1248.80	2673.00 / 3491.50	6.68 / 15.71
Ti	µg/L	374.11 ± 46.87	397.17 ± 67.83	475.55 ˜ / 538.50	328.95 ˜ / 330.75
V	µg/L	5.96 ± 1.89	7.41 ± 1.92	10.34 ˜ / 11.59	4.28 ˜ / 6.17
Cr	µg/L	14.78 ± 3.34	14.90 ± 3.29	20.34 / 20.43	10.84 / 11.26
Mn	µg/L	54.73 ± 34.96	64.75 ± 44.88	124.45 / 147.40	22.61 / 26.74
Fe	µg/L	227.75 ± 566.46	592.99 ± 706.55	1629.50 / 2040.00	17.04 / 48.79
Co	µg/L	3.64 ± 0.34	3.88 ± 0.41	4.47 / 4.76	3.40 / 3.54
Ni	µg/L	5.55 ± 1.67	5.52 ± 1.36	9.08 ˜ / 8.29	4.44 ˜ / 4.34
Cu	µg/L	16.21 ± 5.08	19.26 ± 6.29	27.13 ˜ / 31.97	11.33 ˜ / 15.02
Zn	µg/L	18.54 ± 8.66	18.32 ± 8.43	31.72 ˜ / 29.84	7.66 ˜ / 8.36
As	µg/L	163.69 ± 18.59	163.16 ± 16.65	206.80 ˜ / 192.95	149.55 ˜ / 146.65
Sr	µg/L	2816.38 ± 247.83	2797.75 ± 228.39	3199.00 / 3143.50	2509 / 2492
Mo	µg/L	33.54 ± 13.85	39.92 ± 9.41	49.28 / 52.00	13.29 / 29.43
Cd	µg/L	3.25 ± 0.55	3.08 ± 0.64	4.15 / 4.06	2.45 / 2.24
Sb	µg/L	16.43 ± 0.95	16.27 ± 1.22	17.75 / 17.76	15.01 / 14.55
Ba	µg/L	135.02 ± 13.80	145.30 ± 17.38	165.21 / 173.73	123.16 / 124.81
Tl	µg/L	1.91 ± 0.27	1.88 ± 0.12	2.56 / 2.02	1.73 / 1.71
Pb	µg/L	4.23 ± 3.56	6.90 ± 4.51	12.98 / 16.20	2.42 / 3.61
U	µg/L	9.51 ± 0.34	9.67 ± 0.35	9.89 / 10.14	8.88 / 9.11

Table 3d. Geometric mean and median (all water column sites and samples) for major and minor elements in deep brine layer analyzed by ICP-MS. Total (RA) and dissolved (FA) results

		Geometric mean-Shallow		Median - Shallow	
	Units	**FA**	**RA**	**FA**	**RA**
Li	mg/L	25.8	26.2	25.3	25.6
Na	mg/L	55920.4	56787.8	54871.2	55664.2
Mg	mg/L	5857.3	5927.7	5734.7	5798.3
S	mg/L	4256.0	4207.5	4172.3	4130.0
Cl	mg/L	106984.1	105842.3	104908.9	103906.3
K	mg/L	3275.1	3310.0	3218.3	3252.6
Ca	mg/L	293.5	299.9	292.8	299.1
Al	mg/L	344.5	899.5	21.5	297.4
Ti	**µg/L**	374.1	397.2	371.8	392.6
V	**µg/L**	6.0	7.4	5.7	7.2
Cr	**µg/L**	14.8	14.9	14.5	14.6
Mn	**µg/L**	54.7	64.7	46.0	53.1
Fe	**µg/L**	227.7	593.0	44.0	281.3
Co	**µg/L**	3.6	3.9	3.6	3.9
Ni	**µg/L**	5.5	5.5	5.4	5.4
Cu	**µg/L**	16.2	19.3	15.6	18.5
Zn	**µg/L**	18.5	18.3	16.7	16.6
As	**µg/L**	163.7	163.2	162.9	162.4
Sr	**µg/L**	2816.4	2797.8	2806.8	2789.7
Mo	**µg/L**	33.5	39.9	30.8	39.0
Cd	**µg/L**	3.3	3.1	3.2	3.0
Sb	**µg/L**	16.4	16.3	16.4	16.2
Ba	**µg/L**	135.0	145.3	134.5	144.4
Tl	**µg/L**	1.9	1.9	1.9	1.9
Pb	**µg/L**	4.2	6.9	3.5	5.9
U	**µg/L**	9.5	9.7	9.5	9.7

Table 4a. Volatile selenium concentration in the Great Salt Lake

Date	Site	Depth (m)	[Se] (ng/L)	[Se] (pmol/L)
9/1/06	3510	0.2	1.1	10.1
9/1/06	3510	1.5	1.9	17.5
9/1/06	3510	8.5	0.6	5.2
9/11/06	GS-5	7.5	6.4	58.5
9/12/06	GS-11	8	1.8	16.3
9/12/06	GS-20	7	0.3	2.4
9/12/06	3510	0.2	5.3	48.4
9/27/06	2267	0.2	0.1	1.0
9/27/06	2267	3.5	3.3	30.6
9/27/06	2767	0.2	1.1	9.6
9/27/06	2767	2.2	1.4	12.4
9/28/06	2565	0.2	9.2	84.3
9/28/06	2565	8	1.7	15.4
9/28/06	3510	0.2	1.5	13.6
9/28/06	3510	8	0.2	1.7
	Average		2.4	21.8
	Standard deviation		2.6	24.0
	Lowest value		0.1	1.0
September	Highest value		9.2	84.3
11/1/06	2565	6.5	3.0	27.2
11/3/06	3510	0.2	6.4	58.9
11/3/06	3510	6.5	0.4	3.7
11/16/06	GS-9	2.5	3.1	28.2
11/16/06	GS-5	2	2.4	21.8
11/17/06	GS-20	2.5	0.4	3.4
11/17/06	GS-18	7.7	1.8	16.6
11/17/06	GS-14	7	0.6	6.0
11/17/06	GS-12	5	3.4	31.6
11/20/06	3510	3	1.7	15.5
11/20/06	3510	7	0.0	0.2
11/20/06	2767	2	1.3	11.6
11/21/06	2267	1	1.7	15.2
11/21/06	2565	8	0.6	5.9
11/21/06	2565	0.2	1.3	12.0
	Average		1.9	17.2
	Standard deviation		1.6	15.0
	Lowest value		0.0	0.2
November	Highest value		6.4	58.9

Table 4b. Volatile selenium concentration in the Great Salt Lake

Date	Site	Depth (m)	[Se] (ng/L)	[Se] (pmol/L)
12/6/06	2565	0.5	0.0	0.4
12/6/06	2565	4	0.0	0.4
12/6/06	2767	0.5	0.0	0.4
12/6/06	2767	2.5	1.2	10.6
12/7/06	3510	0.5	0.2	1.6
12/7/06	3510	8	0.0	0.4
12/7/06	2267	0.5	0.0	0.4
12/7/06	2267	3	1.0	8.9
	Average		0.3	2.9
	Standard deviation		0.5	4.3
	Lowest value		0.0	0.4
December	Highest value		1.2	10.6
5/1/07	3510	0.2	7.1	65.4
5/1/07	3510	3	0.0	0.4
5/1/07	3510	4.5	0.0	0.4
5/1/07	3510	6.5	0.0	0.4
5/1/07	3510	8.5	0.3	2.3
5/10/07	2565	0.2	0.3	2.6
5/10/07	2565	3	1.9	17.8
5/10/07	2565	6.5	9.1	83.3
5/10/07	2565	7.5	0.5	4.6
	Average		2.1	19.7
	Standard deviation		3.5	31.8
	Lowest value		0.0	0.4
May	Highest value		9.1	83.3
6/1/07	3510	0.5	0.0	0.4
6/1/07	3510	4	8.5	78.3
6/1/07	3510	5	0.9	8.3
6/1/07	3510	6.5	3.0	27.4
6/1/07	3510	8	0.0	0.4
6/27/07	3510	0.2	0.0	0.4
6/27/07	3510	3	1.6	15.0
6/27/07	3510	5	4.3	39.7
6/27/07	3510	7	0.1	0.8
6/27/07	3510	8	0.2	2.2
	Average		1.9	17.3
	Standard deviation		2.8	25.3
	Lowest value		0.0	0.4
June	Highest value		8.5	78.3

Table 4c. Volatile selenium concentration in the Great Salt Lake

Date	Site	Depth (m)	[Se] (ng/L)	[Se] (pmol/L)
7/2/07	2267	0.2	1.6	14.8
7/2/07	2267	1	1.7	15.4
7/2/07	2267	2	4.1	37.5
7/2/07	2267	3.5	22.7	208.1
7/26/07	2267	0.2	4.6	41.9
7/26/07	2267	1.5	6.1	56.0
7/26/07	2267	2.5	7.8	71.3
7/26/07	2267	3.5	17.0	156.1
7/27/07	2565	0.2	0.1	0.6
7/27/07	2565	3	2.2	20.2
7/27/07	2565	5	7.7	70.2
7/27/07	2565	6.5	13.3	122.3
7/27/07	2565	7.5	0.6	5.1
	Average		6.9	63.0
	Standard deviation		6.9	63.4
	Lowest value		0.1	0.6
July	Highest value		22.7	208.1
8/24/07	2767	0.2	4.5	41.7
8/24/07	2767	1	2.3	21.1
8/24/07	2767	2	0.8	7.7
8/30/07	3510	0.2	3.4	31.0
8/30/07	3510	3	10.0	91.7
8/30/07	3510	5	17.8	163.5
8/30/07	3510	7	0.4	3.6
8/30/07	3510	8	0.0	0.4
	Average		4.9	45.1
	Standard deviation		6.1	56.2
	Lowest value		0.0	0.4
August	Highest value		17.8	163.5
Average over total samples			**3.0**	**27.4**
Geometric mean			**0.9**	**8.2**
Standard deviation over total samples			**4.4**	**39.9**
Lowest value over total samples			**0.0**	**0.2**
Highest value over total value			**22.7**	**208.1**

Table 5. Volatile selenium diffusive flux

Date	Site	Depth (m)	ngSe/L	T(°C)	D_{DMS} (cm^2/s)	J (g Se/cm2/yr)	Flux (Kg/yr)
9/1/06	3510	0.2	0.37	22.15	1.2E-05	5.4E-13	9.9E-03
		1.5	0.55				
9/27/06	2267	0.2	0.14	16.4	1.0E-05	7.2E-13	1.3E-02
		3.5	0.87				
9/27/06	2767	0.2	0.36	16.4	1.0E-05	1.1E-13	2.1E-03
		2.2	0.43				
12/6/06	2767	0.5	0.04	8.48	8.4E-06	4.5E-13	8.3E-03
		2.5	0.38				
12/6/06	2565	0.5	0.02	8.48	8.4E-06	4.7E-14	8.6E-04
		4	0.09				
12/7/06	2267	0.5	0.09	8.48	8.4E-06	2.6E-13	4.7E-03
		3	0.34				
5/10/07	2565	0.2	0.18	17.87	1.1E-05	4.4E-13	8.2E-03
		3	0.56	16.28	1.0E-05	1.5E-12	2.7E-02
		6.5	2.17	13.78			
6/1/07	3510	0.5	0.091	20.55	1.1E-05	1.8E-13	3.4E-03
		5	0.322	19.36	1.1E-05	1.1E-12	2.0E-02
		6.5	0.794	18.51			
6/27/07	3510	0.2	0.05	24.71	1.3E-05	6.3E-13	1.2E-02
		3	0.49	23.59	1.2E-05	1.2E-12	2.2E-02
		5	1.10	23.04			
7/2/07	2267	0.2	0.484	25.53	1.3E-05	7.8E-14	1.4E-03
		1	0.499	25.53	1.3E-05	2.2E-12	4.1E-02
		2	1.042	25.37	1.3E-05	1.2E-11	2.2E-01
		3.5	5.244	26.74			
7/26/07	2267	0.2	1.151	27.09	1.4E-05	1.1E-12	2.1E-02
		1.5	1.499	27.19	1.4E-05	1.6E-12	3.0E-02
		2.5	1.874	27.45	1.4E-05	9.0E-12	1.7E-01
		3.5	3.964	27.67			
7/27/07	2565	0.2	0.1	27.67	1.4E-05	3.3E-12	6.0E-02
		3	2.2	27.14	1.4E-05	1.2E-11	2.2E-01
		5	7.7	27.06	1.3E-05	1.6E-11	2.9E-01
		6.5	13.3	26.02			
8/30/07	3510	0.2	3.4	27.67	1.4E-05	1.0E-11	1.9E-01
		3	10.0	27.14	1.4E-05	1.7E-11	3.1E-01
		5	17.8	27.06			
Average					**1.2E-05**	**3.9E-12**	**7.3E-02**

Table 6a. Estimated water transfer velocities (k_w), volatile selenium fluxes, using an average volatile selenium concentration of 0.52 ng/L in water.

Estuarine model

Wind velocity: 5 miles/h (2.2 m/s)			
T(°C)	kw (cm/h)	Flux (gSe/cm2/yr)	Flux (Kg Se/yr)
2	1.58	4.2E-08	766
6	1.77	4.6E-08	856
10	1.98	5.2E-08	956
17	2.38	6.2E-08	1150
28	3.06	8.0E-08	1480
Wind velocity: 25 miles/h (11.2 m/s)			
T(°C)	kw (cm/h)	Flux (gSe/cm2/yr)	Flux (Kg Se/yr)
2	16.07	4.2E-07	7780
6	17.96	4.7E-07	8695
10	20.06	5.3E-07	9710
17	24.12	6.3E-07	11676
28	31.05	8.2E-07	15030

Modified Liss & Merlivat model

Wind velocity: 5 miles/h (2.2 m/s)			
T(°C)	kw (cm/h)	Flux (gSe/cm2/yr)	Flux (Kg Se/yr)
2	2.05	2.4E-08	450
6	2.37	2.8E-08	522
10	2.75	3.3E-08	605
17	3.52	4.2E-08	774
28	4.92	5.9E-08	1083
Wind velocity: 25 miles/h (11.2 m/s)			
T(°C)	kw (cm/h)	Flux (gSe/cm2/yr)	Flux (Kg Se/yr)
2	11.12	2.9E-07	5381
6	12.42	3.3E-07	6013
10	13.87	3.6E-07	6715
17	16.68	4.4E-07	8076
28	21.47	5.6E-07	10395

Table 6b. Results of measured volatile Se fluxes compared to Estuarine model predicted fluxes with environmental parameters used in calculations.

Sample ID	Site	Date	Avg. Wind Vel.	Surface Temp.	Vol Se Conc.	Measured Flux	Estuarine Pred. Flux
			m/s	°C	ng/L	ng/m^2h	ng/m^2h
1B	3510	6/1/07	2.63	20.55	0.21	11.12	6.20
1C	3510	6/27/07	3.74	24.71	0.04	2.08	2.00
2C	2267	7/2/07	1.25	25.53	1.82	20.13	39.64
3C	2267	7/26/07	1.34	27.09	4.59	9.38	105.89
4C	2565	7/27/07	1.86	27.67	0.37	3.23	10.12
1E	2267	9/27/07	3.43	12.00	0.62	7.85	19.75
2E	2267	9/27/07	1.58	12.00	0.33	3.30	5.68

Table 6c. Results of attempted flux recovery test showing significant partitioning of volatilized Se to surfaces of the measurement system.

Sample ID	Mass Added (μg)	Mass Recovered (μg)	Percent Recovery
SR1	0.0075	0.0018	24.3%
SR2	0.0119	0.0008	7.0%
SR3	0.0163	0.0022	13.5%

Table 6d. Summary of errors associated to different parameters used to calculate the volatilization flux of Se to the atmosphere.

Parameter	**Error**	**Reference**
Temperature (^{o}C)	+/- 0.5	Crosman & Horel, 2006
Wind velocity (m/s)	+/- 2.5	Horel, 2007
$C_{water}^{V/Se}$ (ng/L)	x/÷ 5.9	Geometric standard deviation
Area Great Salt Lake (acres)	+/- 427.2	Average of calculated area difference per 0.1 foot in depth

Table 7a Results of shallow (only) sediment trap analyses at site 2267

Average month	Days acum.	Average sediment weight (g)	Downward flux ($g/cm^2/year$)	[Se] (mg/Kg)	Se downward flux ($gSe/cm^2/yr$)
Apr-06	64	18.22	2.55	0.27	6.76E-07
Jun-06	24	8.81	3.29	1.54	5.07E-06
Jul-06	39	18.21	4.19	0.31	1.30E-06
Jul-06	32	9.96	2.79	0.20	5.58E-07
Sep-06	64	24.76	3.47	0.33	1.13E-06
Nov-06	36	8.49	2.12	0.20	4.23E-07
Jan-07	103	8.82	0.77	1.16	8.94E-07
Apr-07	37	21.65	5.25		
Jun-07	34	8.13	2.14		
Average			2.95	0.57	1.44E-06
Accumulative	433	127.06	2.63		

n/a – not available

Table 7b Results of deep sediment trap analyses at site 2565

Average month	Days acum.	Average sediment weight (g)	Downward flux ($g/cm^2/year$)	[Se] (mg/Kg)	Se downward flux ($gSe/cm^2/yr$)
Apr-06	64	14.29	2.00	0.02	3.00E-08
Jun-06	24	0.86	0.32	1.70	5.48E-07
Jul-06	39	0.00	0.00	n/a	n/a
Aug-06	45	0.55	0.11	1.67	1.83E-07
Oct-06	51	1.26	0.22	0.23	5.09E-08
Jan-07	139	1.24	0.08	0.51	4.04E-08
Apr-07	37	1.79	0.43	0.15	6.50E-08
Jun-07	42	5.02	1.07		
Average			0.53	0.71	1.53E-07
Accumulative	441	25.01	0.51		

n/a – not available

Table 7c Results of shallow sediment trap analyses at site 2565

Average month	Days acum.	Average sediment weight (g)	Downward flux (g/cm^2/year)	[Se] (mg/Kg)	Se downward flux ($gSe/cm^2/yr$)
Apr-06	64	0.000	0.000	n/a	n/a
Jun-06	24	0.000	0.000	n/a	n/a
Jul-06	39	0.000	0.000	n/a	n/a
Aug-06	45	0.169	0.034	1.279	4.30E-08
Oct-06	51	0.000	0.000	n/a	n/a
Jan-07	139	0.853	0.055	0.558	3.07E-08
Apr-07	37	0.512	0.124	0.445	5.52E-08
Jun-07	42	0.301	0.064		
Average			0.035	0.761	4.30E-08
Accumulative	441	1.834	0.037		

n/a – not available

Table 7d Results of deep sediment trap analyses at site 3510

Average month	Days acum.	Average sediment weight (g)	Downward flux (g/cm^2/year)	[Se] (mg/Kg)	Se downward flux ($gSe/cm^2/yr$)
Jul-06	30	3.61	1.08	0.01	1.08E-08
Aug-06	47	0.08	0.02	0.87	1.41E-08
Oct-06	52	0.85	0.15	0.18	2.55E-08
Nov-06	34	0.00	0.00	n/a	n/a
Jan-07	101	1.09	0.10	0.70	6.82E-08
Jun-07	28	2.35	0.75	0.10	7.52E-08
Average			0.35	0.31	3.88E-08
Accumulative	292	7.98	0.25		

n/a – not available

Table 7e Results of shallow sediment trap analyses at site 3510

Average month	Days acum.	Average sediment weight (g)	Downward flux ($g/cm^2/year$)	[Se] (mg/Kg)	Se downward flux ($gSe/cm^2/yr$)
Jul-06	30	0.00	0.000	n/a	n/a
Aug-06	47	0.10	0.020	1.44	2.85E-08
Oct-06	52	0.35	0.061	0.20	1.19E-08
Nov-06	34	0.00	0.000	n/a	n/a
Jan-07	101	0.82	0.072	0.76	5.50E-08
Jun-07	28	0.79	0.252	< 0.01	< 2.52E-09
Average			0.068	0.40	3.18E-08
Accumulative	292	2.06	0.063		

n/a – not available

Table 8. Average Se concentration between 0 and 2 cm. in cores and their corresponding sedimentation region

CoreID	Sed Region	Sed Se Conc. (µg/L)
DD-C	High	3.02
2267-2	Low	1.03
DD-Q	Low	3.12
DD-I	Very High NW	1.70
3510-BOX	Low	2.35
DD-L	Medium	2.44
DD-R	Medium	1.65
2565-3	Very Low	0.79
	Average	**2.01**
	St. Dev.	**0.86**

Table 9. Average mass accumulation rate (MAR) in each core

CoreID	MAR ($g/cm^2/yr$)
DD-C	0.036
2267-2	0.000
DD-Q	0.010
DD-I	0.049
3510-BOX	0.043
DD-L	0.025
DD-R	0.027
2565-3	0.000
Average	**0.024**
St. Dev.	**0.019**

Table 10. Average 0-2 cm Se concentration, MAR, area, and calculated mass of selenium removed annually within each sedimentation zone

Sed Region	Area of Zone (Km^2)	Avg. [Se] 0-2 cm (μg/g)	MAR (g/cm2/yr)	Mass of Se Removed (Kg/yr)
Very Low	1233.2	0.79	0.009	86.06
Low	404.6	2.16	0.018	154.63
Medium	358.5	2.04	0.026	190.15
High	47.9	3.02	0.036	52.08
Very High SE	4.6	3.02	0.045	6.25
Very High NW	34.3	1.70	0.049	28.49
			Total	**517.65**

Table 11a. Relative standard deviation (RSD) for Se concentration, area, and mass accumulation rate (MAR) propagated through to a relative standard deviation for each sedimentation region

Sed Region	RSD [Se]	RSD Area	RSD MAR	Total Zone RSD
Very Low	2.27	0.00083	3.89	4.51
Low	0.73	0.00083	0.70	1.01
Medium	0.49	0.00083	1.03	1.14
High	0.20	0.00083	0.19	0.28
Very High SE	0.20	0.00083	0.19	0.28
Very High NW	0.34	0.00083	0.17	0.38

Table 11b. Estimation of total uncertainty and range of Se removal by sedimentation based on a mean removal of 517.65 Kg_{Se}/yr

Sed Region	Total Zone RSD	Mass of Se Removed (Kg/yr)	Total Zone Uncertainty (Kg/yr)
Very Low	4.51	86.06	387.69
Low	1.01	154.63	156.38
Medium	1.14	190.15	217.55
High	0.28	52.08	14.57
Very High SE	0.28	6.25	1.75
Very High NW	0.38	28.49	10.82
	Total	**517.65**	**471.61**
	Range of Removal	**46.05**	**989.26**

Table 12. Change in elevation of the deep brine layer (DBL) corresponds to change in lake surface elevation, site 2565. Depth measurement determined from monthly water column profile.

Date	Depth to DBL (m.)	Saltair lake elevation (ft.)	Elevation of DBL (ft.)
6/19/06	6.5	4198.0	4176.7
7/28/06	6.5	4197.2	4175.9
9/28/06	6.5	4196.4	4175.1
11/1/06	6.5	4196.5	4175.2
11/21/06	6.5	4196.5	4175.2
12/6/06	6.5	4196.6	4175.3
3/20/07	6.5	4197.5	4176.2
4/26/07	6.5	4197.5	4176.2
5/10/07	6.5	4197.4	4176.1
5/23/07	6.5	4197.3	4176.0
6/26/07	6.5	4196.9	4175.6
7/25/07	6.5	4196.3	4175.0

Table 13. Arithmetic average values of batch test results for selenium and other trace metals given as percent solubilized (of extractible). Negative values indicate a decrease in water concentration compared to the shallow brine water used in the experiment.

Element	24 hour (air headspace)	Week	Month
Se	1.16 ± 1.36 %	2.40 ± 1.09 %	3.01 ± 1.06 %
As	2.04 ± 2.60 %	6.53 ± 4.19 %	-0.85 ± 3.40 %
Cd	0.58 ± 0.64 %	1.25 ± 1.38 %	2.05 ± 2.88 %
Co	0.62 ± 0.57 %	0.12 ± 0.10 %	1.13 ± 1.14 %
Cu	0.37 ± 0.57 %	-0.07 ± 0.08 %	0.70 ± 0.95 %
Mn	0.86 ± 0.64 %	0.76 ± 0.33 %	0.98 ± 0.85 %
Ni	0.49 ± 0.50 %	0.26 ± 0.08 %	0.74 ± 0.59 %
Pb	0.69 ± 0.74 %	-0.05 ± 0.04 %	1.04 ± 1.57 %
Sb	2.07 ± 5.82 %	5.85 ± 6.32 %	-4.01 ± 11.36 %
U	2.91 ± 2.05 %	4.99 ± 3.31 %	3.29 ± 4.26 %
Zn	1.00 ± 0.88 %	-0.04 ± 0.06 %	0.84 ± 0.98 %

Table 14a. Low, medium and high fluxes used in the removal processes distribution. Volatilization flux range was determined for 68% confidence interval (CI).

	LOW FLUXES (Kg/yr)	MEDIUM FLUXES (Kg/yr)	HIGH FLUXES (Kg/yr)
Volatilization (68% CI)	1380	2108	3210
Permanent sedimentation	45	520	990
Brine shrimp harvesting	28	28	28
TOTAL	1453	2656	4228

Table 14b. Low, medium and high fluxes used in the removal processes distribution. Volatilization flux range was determined for 95% confidence interval (CI).

	LOW FLUXES (Kg/yr)	MEDIUM FLUXES (Kg/yr)	HIGH FLUXES (Kg/yr)
Volatilization (95% CI)	820	2108	5450
Permanent sedimentation	45	520	990
Brine shrimp harvesting	28	28	28
TOTAL	893	2656	6468

Table 15. Estimated values for wet and dry Se atmospheric deposition flux at different locations.

	Estimated Se atmospheric deposition flux	**Reference**
Wet depositional flux, Bermuda ($\mu mol/m^2/yr$)	0.42	Cutter&Cutter, 1998
Wet depositional flux, Mace Head, Ireland ($\mu mol/m^2/yr$)	0.78	Cutter&Cutter, 1998
Total (wet+dry) deposition, Amazon River ($nmol/m^2/yr$)	1772	Cutter&Cutter, 2001
Wet deposition, Barbados ($nmol/m^2/yr$)	1440	Cutter&Cutter, 2001
Lake Superior, dry deposition ($\mu g/m^2/yr$)	52	Sweet et al,1998
Lake Superior, wet deposition ($\mu g/m^2/yr$)	520	Sweet et al,1998
Lake Michigan, dry deposition ($\mu g/m^2/yr$)	52	Sweet et al,1998
Lake Michigan, wet deposition ($\mu g/m^2/yr$)	520	Sweet et al,1998
Lake Erie, dry deposition ($\mu g/m^2/yr$)	95	Sweet et al,1998
Lake Erie wet deposition ($\mu g/m^2/yr$)	630	Sweet et al,1998
Chesapeake Bay- average, dry deposition ($\mu g/m^2/yr$)	259	Baker et al, 1994
Chesapeake Bay- average, wet deposition ($\mu g/m^2/yr$)	130	Baker et al, 1994
Chesapeake Bay- average- total deposition ($\mu g/m^2/yr$)	389	Baker et al, 1994

FIGURES

Figure 1. Great Salt Lake sampling locations. GS sites are located within the 6-m-depth boundary (in red) (Map courtesy of the USGS)

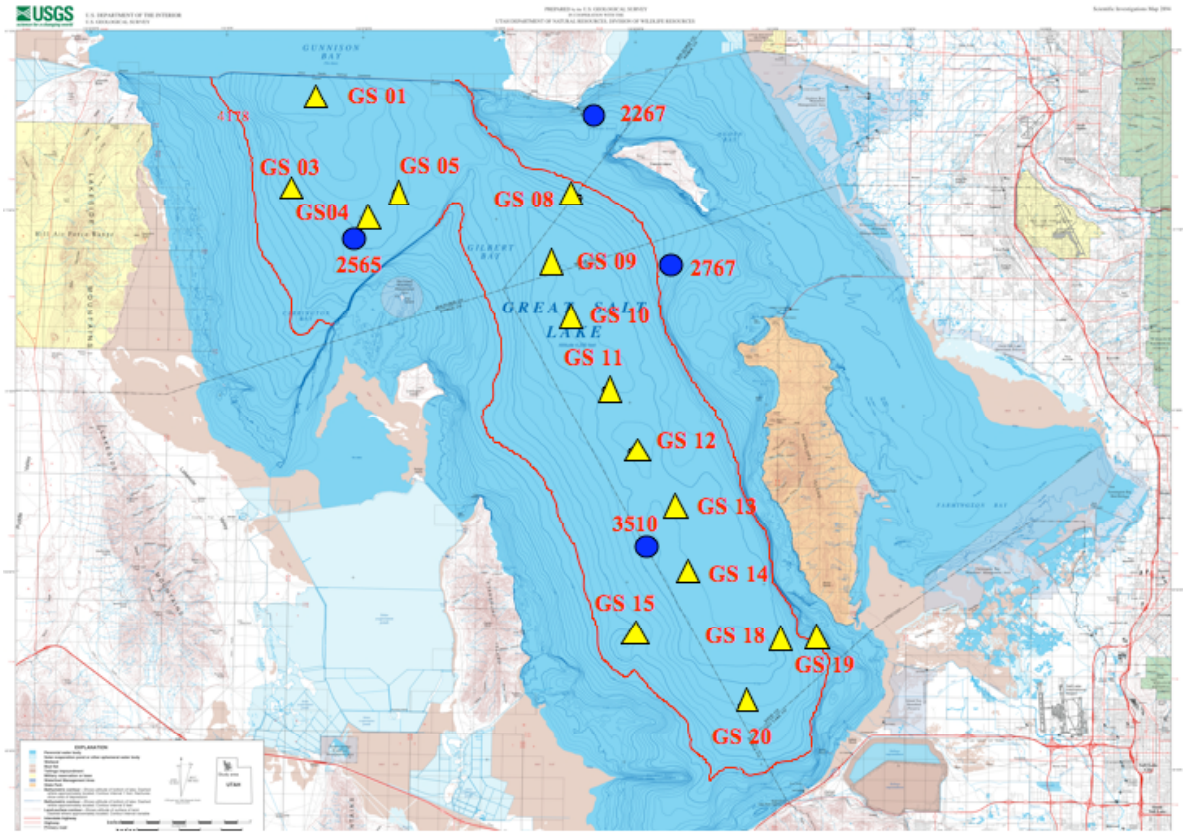


Figure 2a. Schematic representation of thermistor positions in sediment traps. .

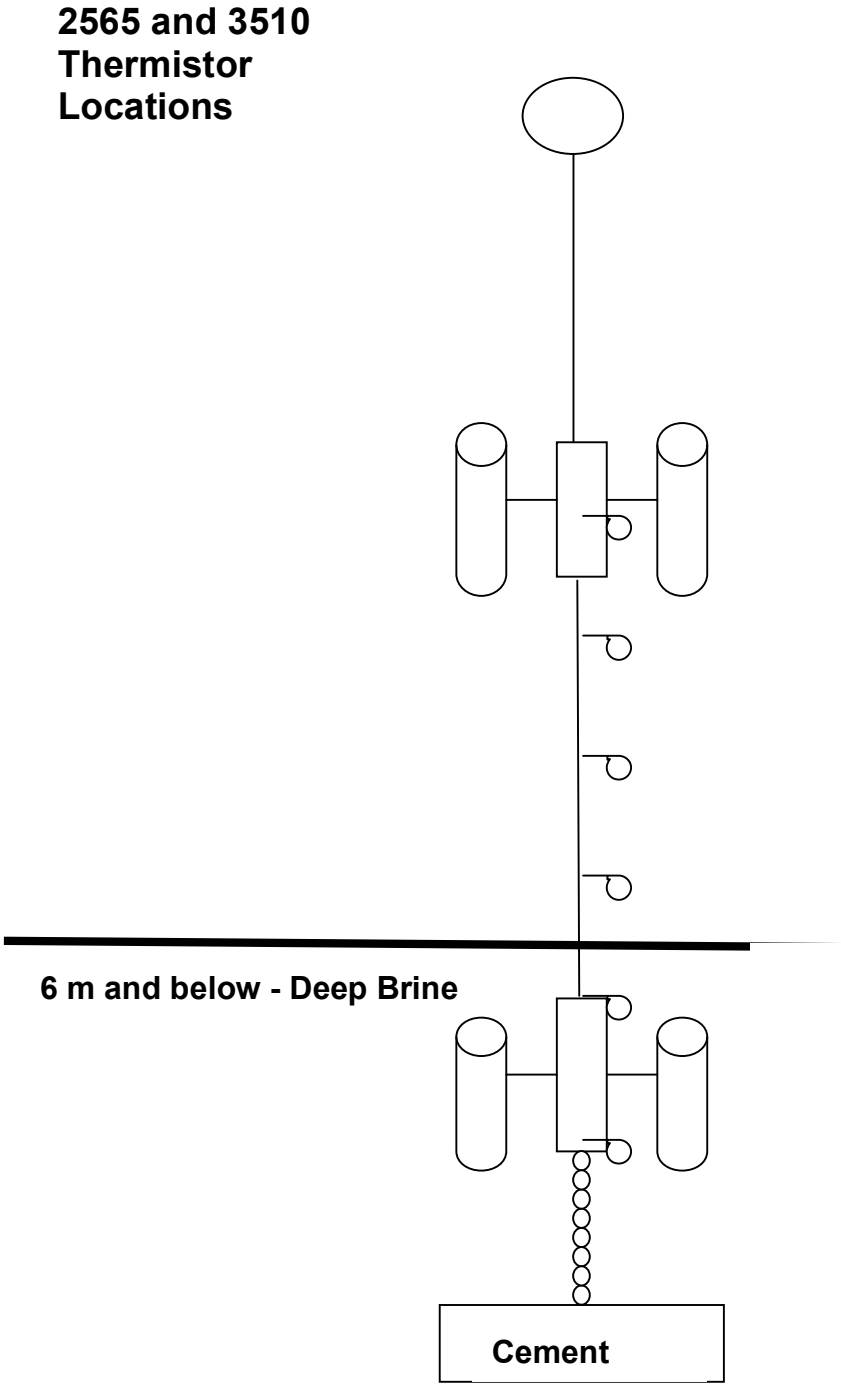


Figure 2b. Schematic of sediment traps for shallow site (2267)

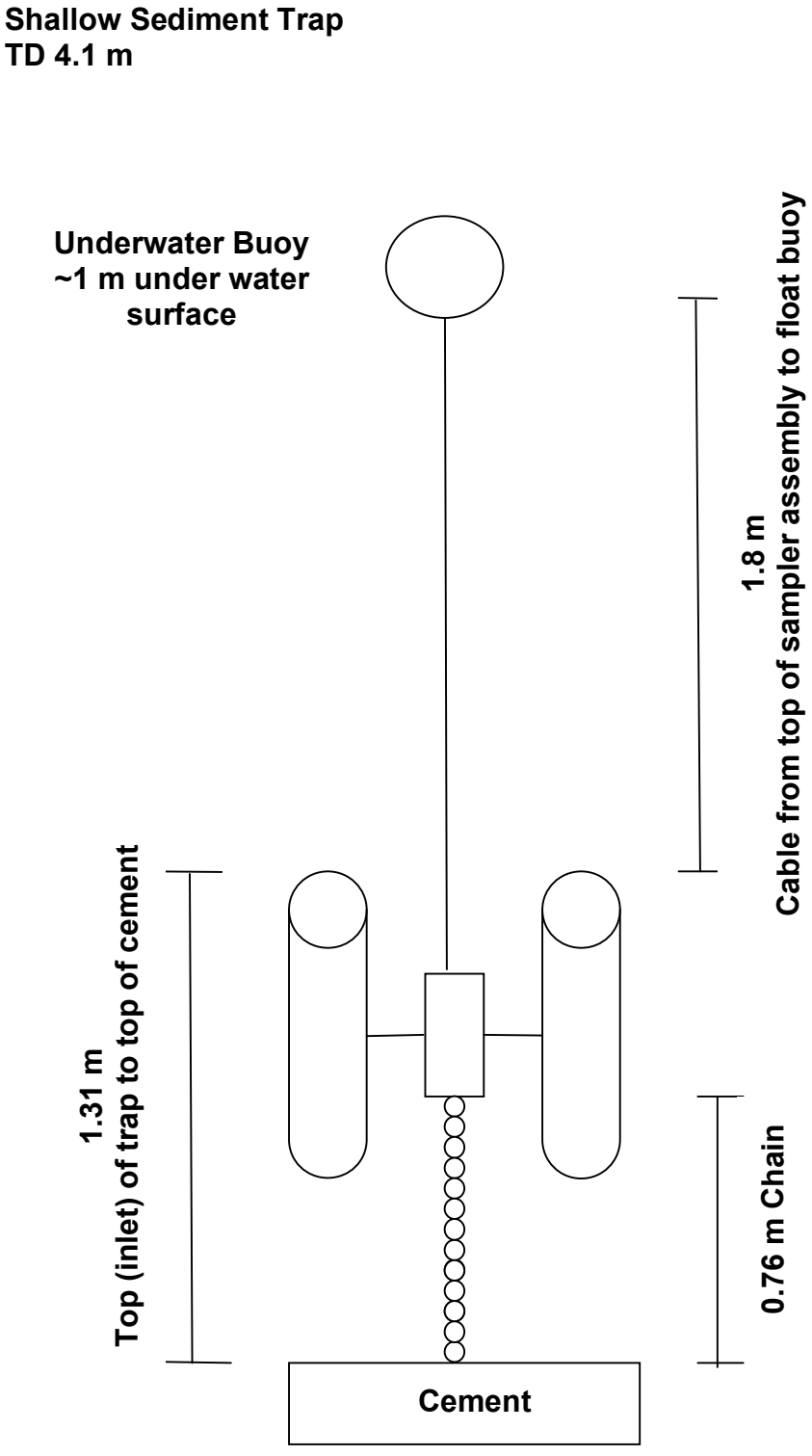


Figure 2c. Schematic of sediment traps for deep sites (2565 and 3510)

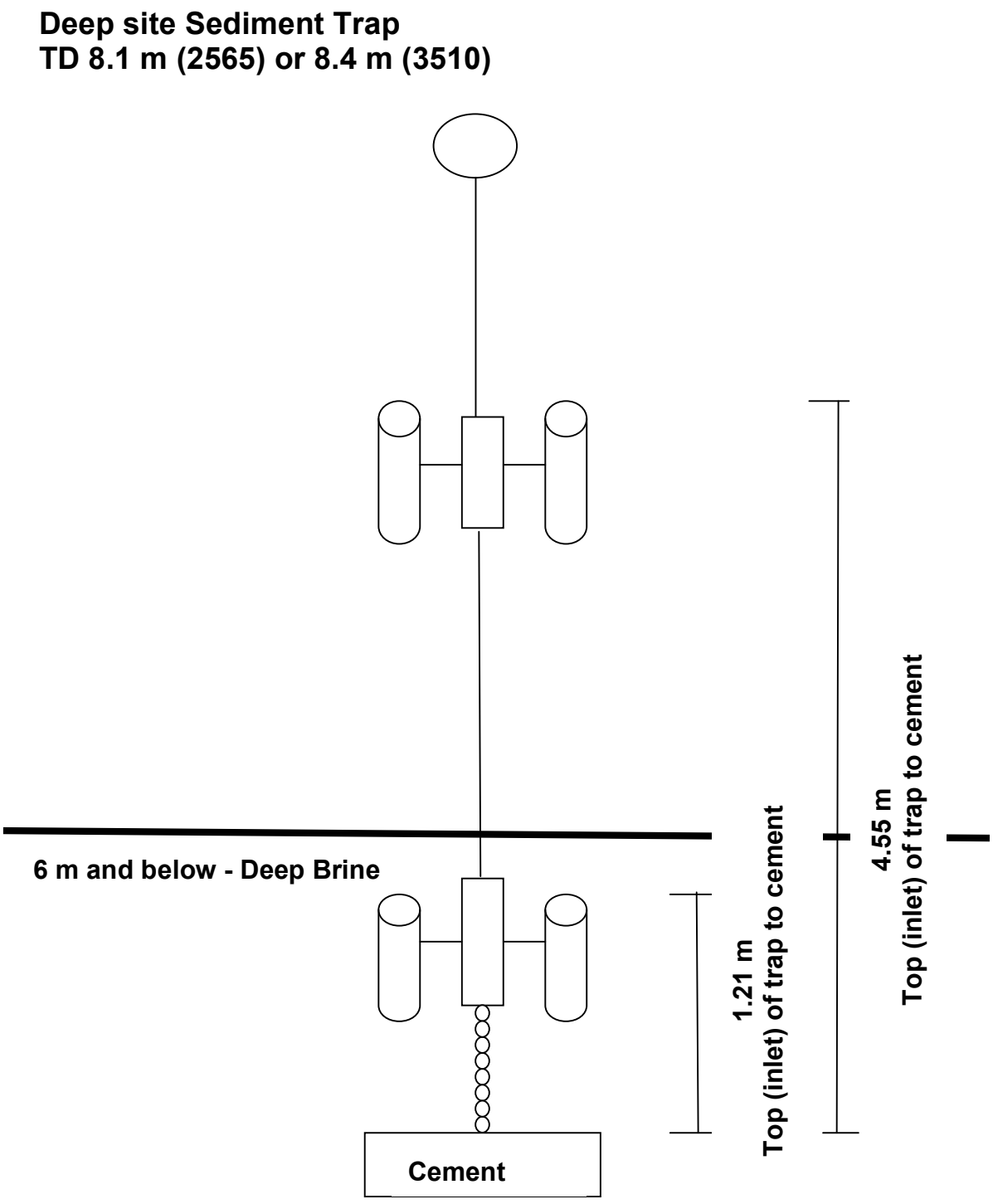


Figure 2d. Long core sampling locations

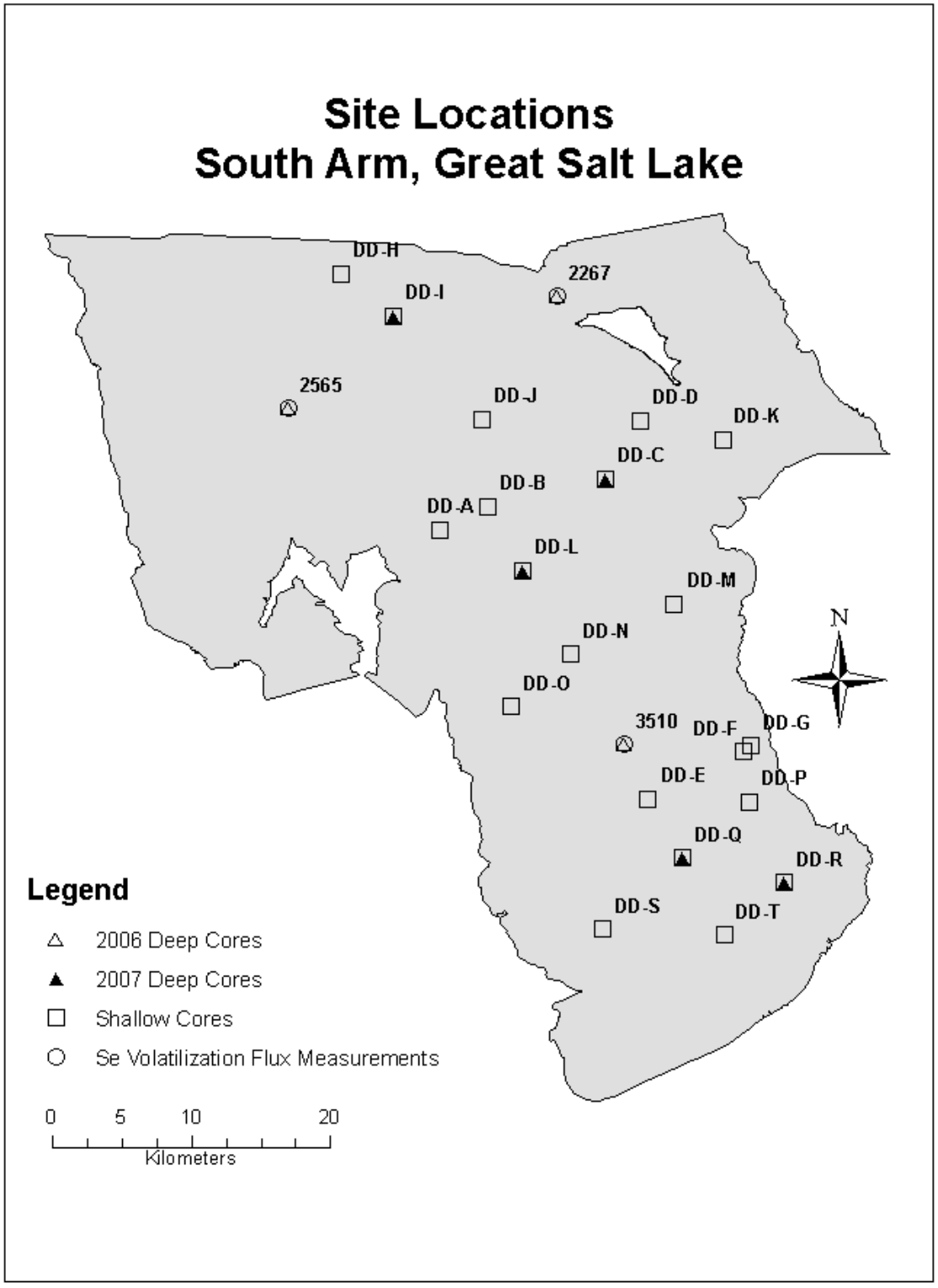


Figure 3a. Schematic representation of the volatile selenium cryo-focusing trap collection system

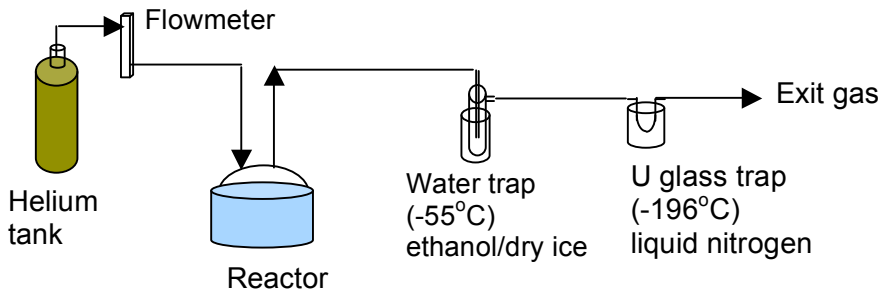


Figure 3b. Calibration curve for dimethyl selenide using the purge and trap system.

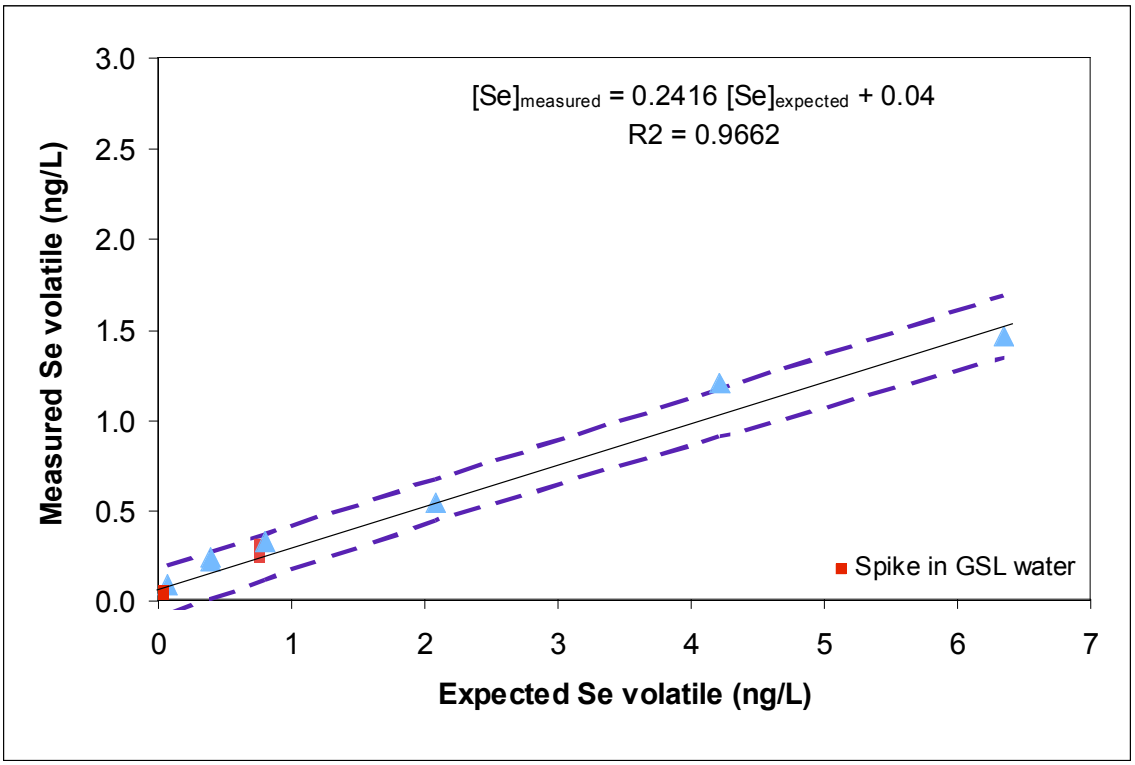
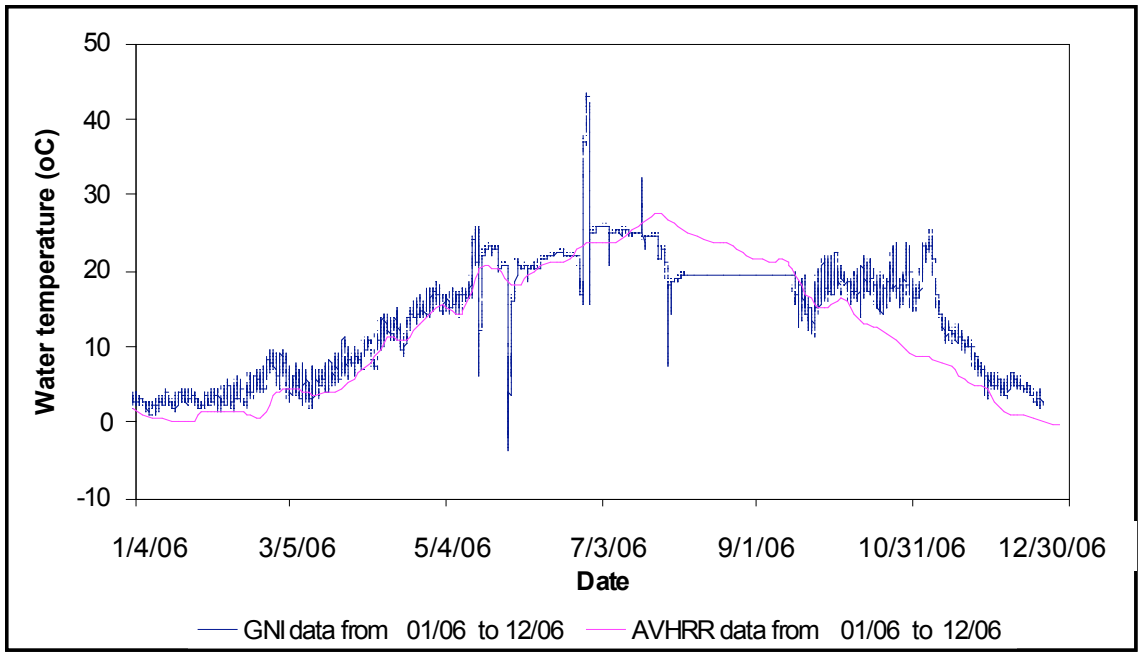


Figure 3c. AVHRR temperature compared with measured temperature at Gunnison Island weather station from January to December 2006 (top). Same comparison for Gunnison Island temperatures from September 2006 to August 2007 (bottom) with the AVHRR data from 2006.



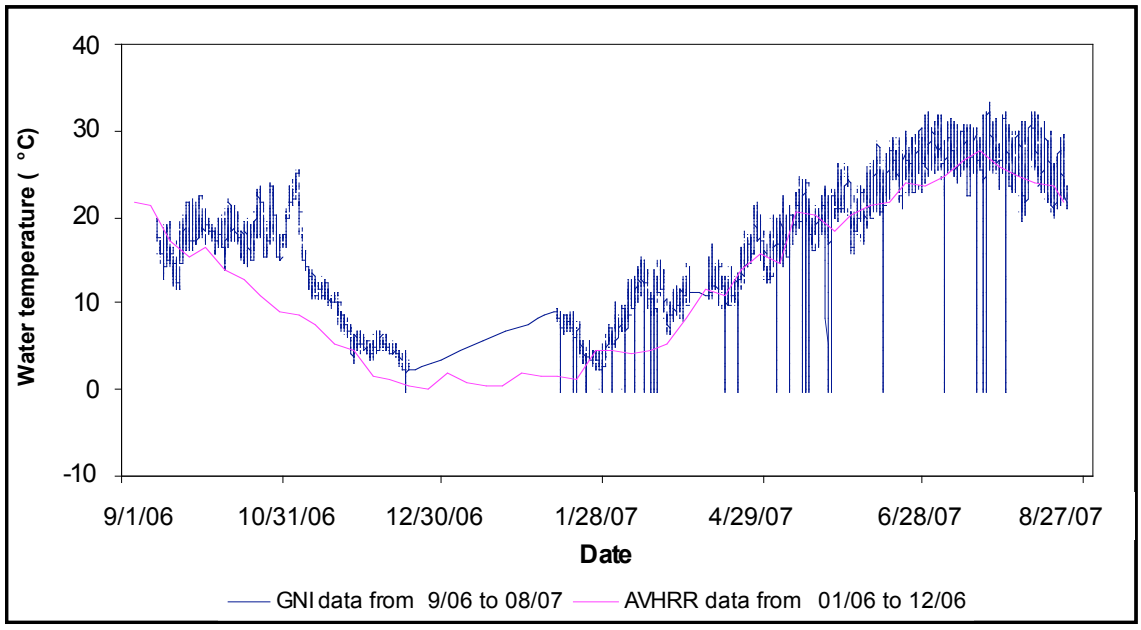


Figure 4a. St Croix Sensory, Inc. Emission Isolation Flux Chamber during sample collection on calm day.

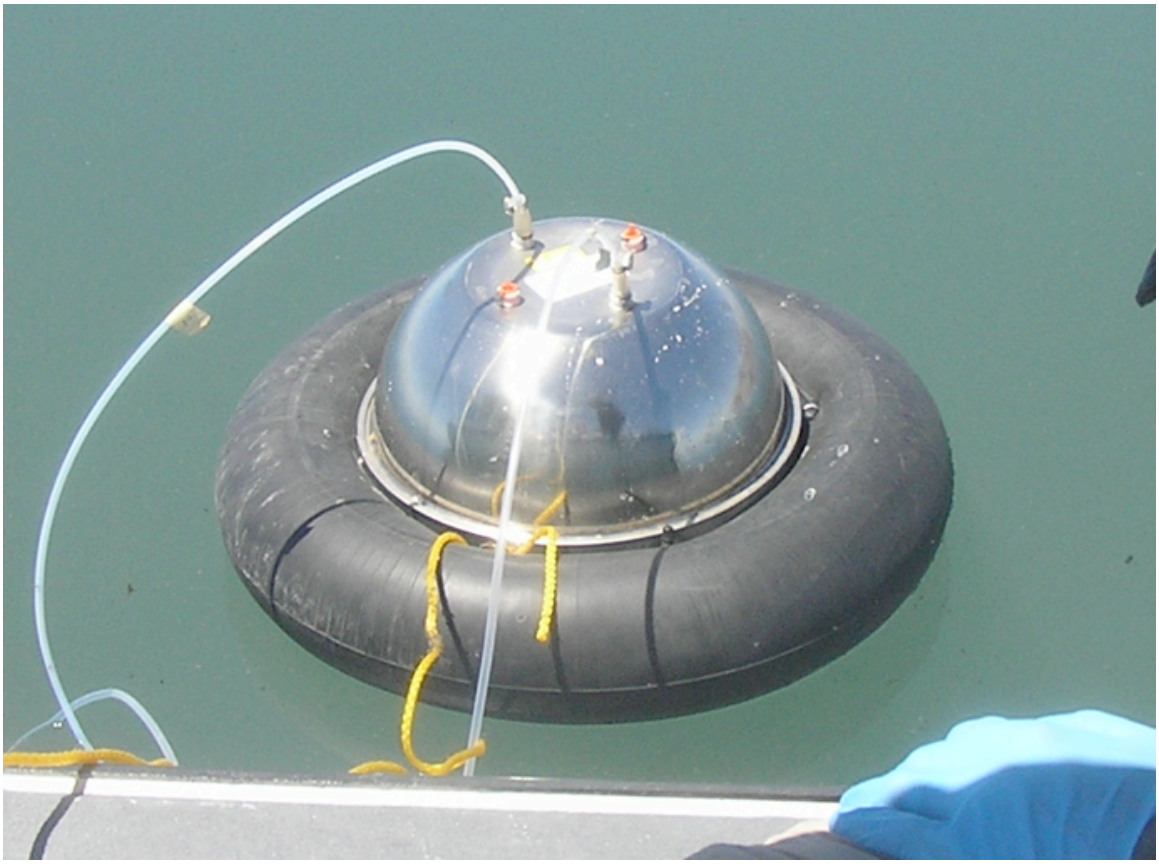


Figure 4b. Diagram of temperature-controlled cryo-focusing system for collection of volatilized selenium from GSL.

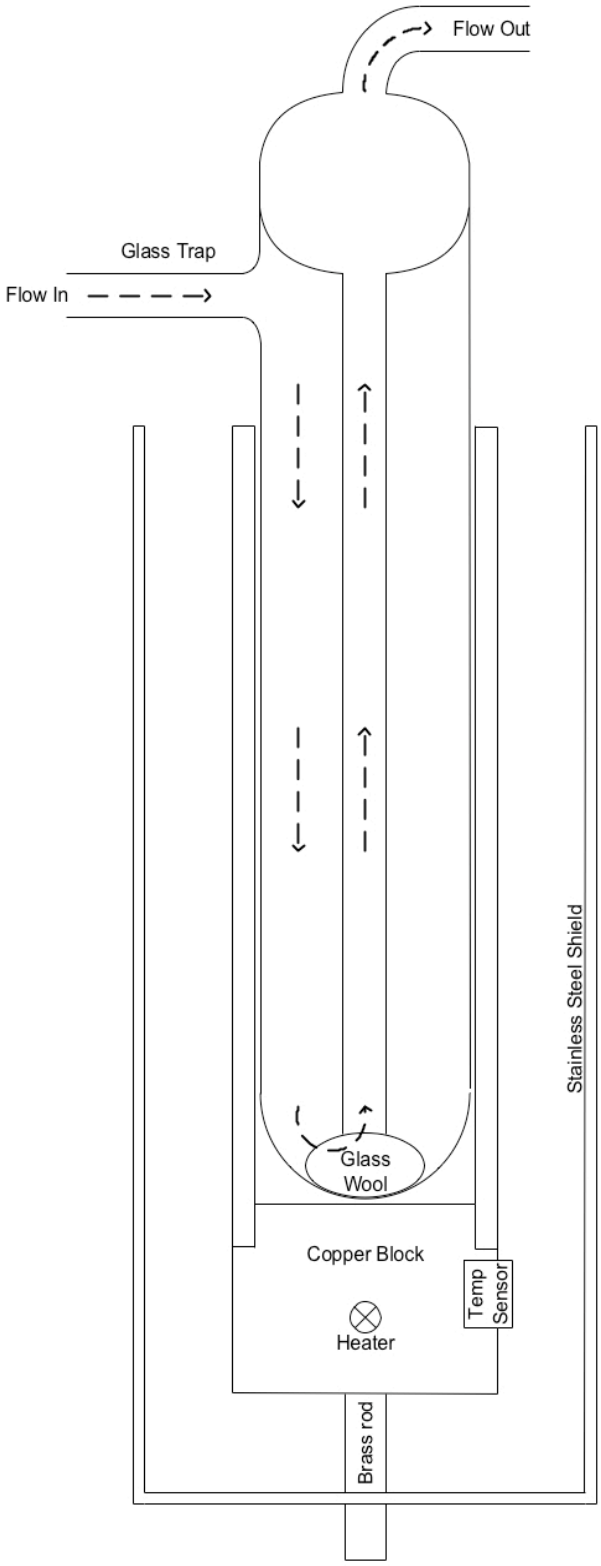
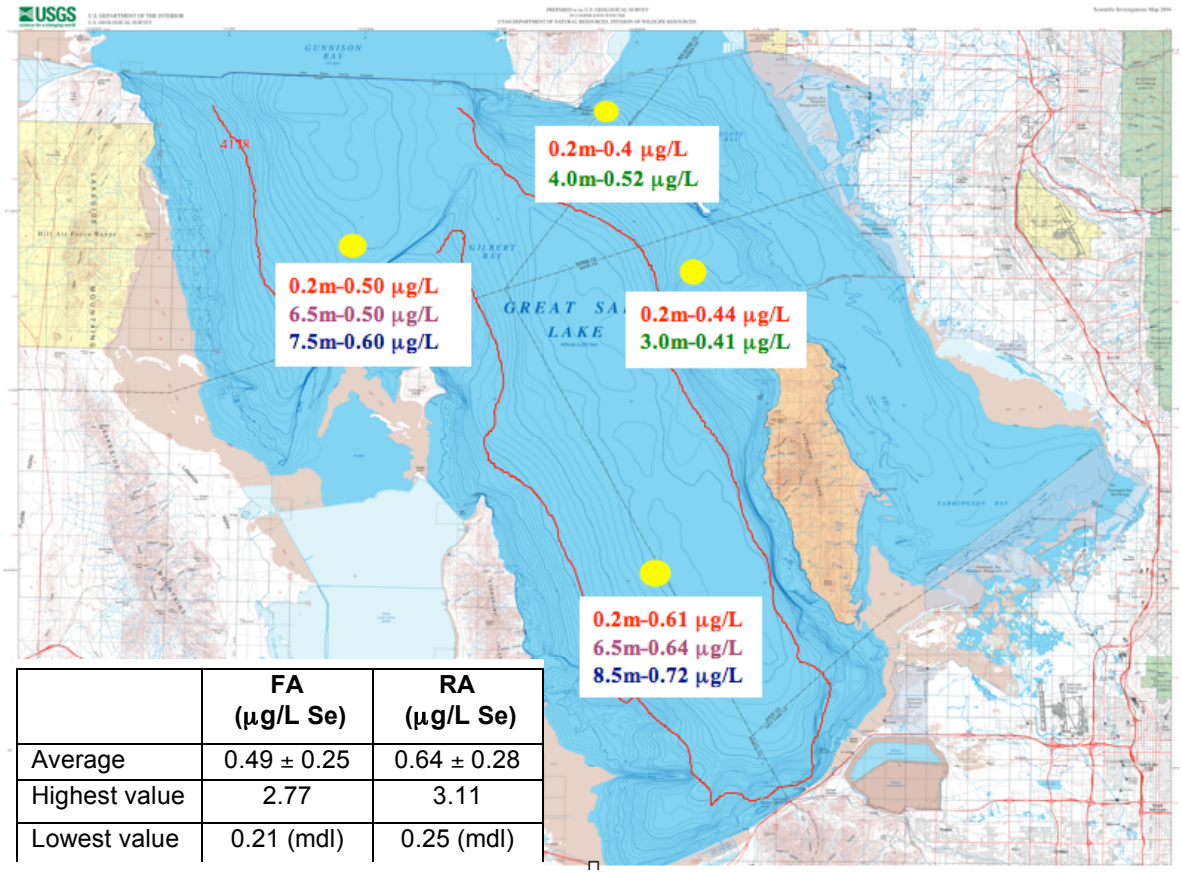


Figure 5. Spatial distribution of total (RA) aqueous selenium concentrations from May 2006. Average, high, and low concentrations (n = 128) for period from May 2006 to July, 2007. RA refers to “raw acidified”, FA refers to “filtered acidified”. (Map courtesy of the USGS).



	FA (µg/L Se)	RA (µg/L Se)
Average	0.49 ± 0.25	0.64 ± 0.28
Highest value	2.77	3.11
Lowest value	0.21 (mdl)	0.25 (mdl)

mdl: method detection limit

Figure 6a. Dissolved oxygen (DO) profiles.

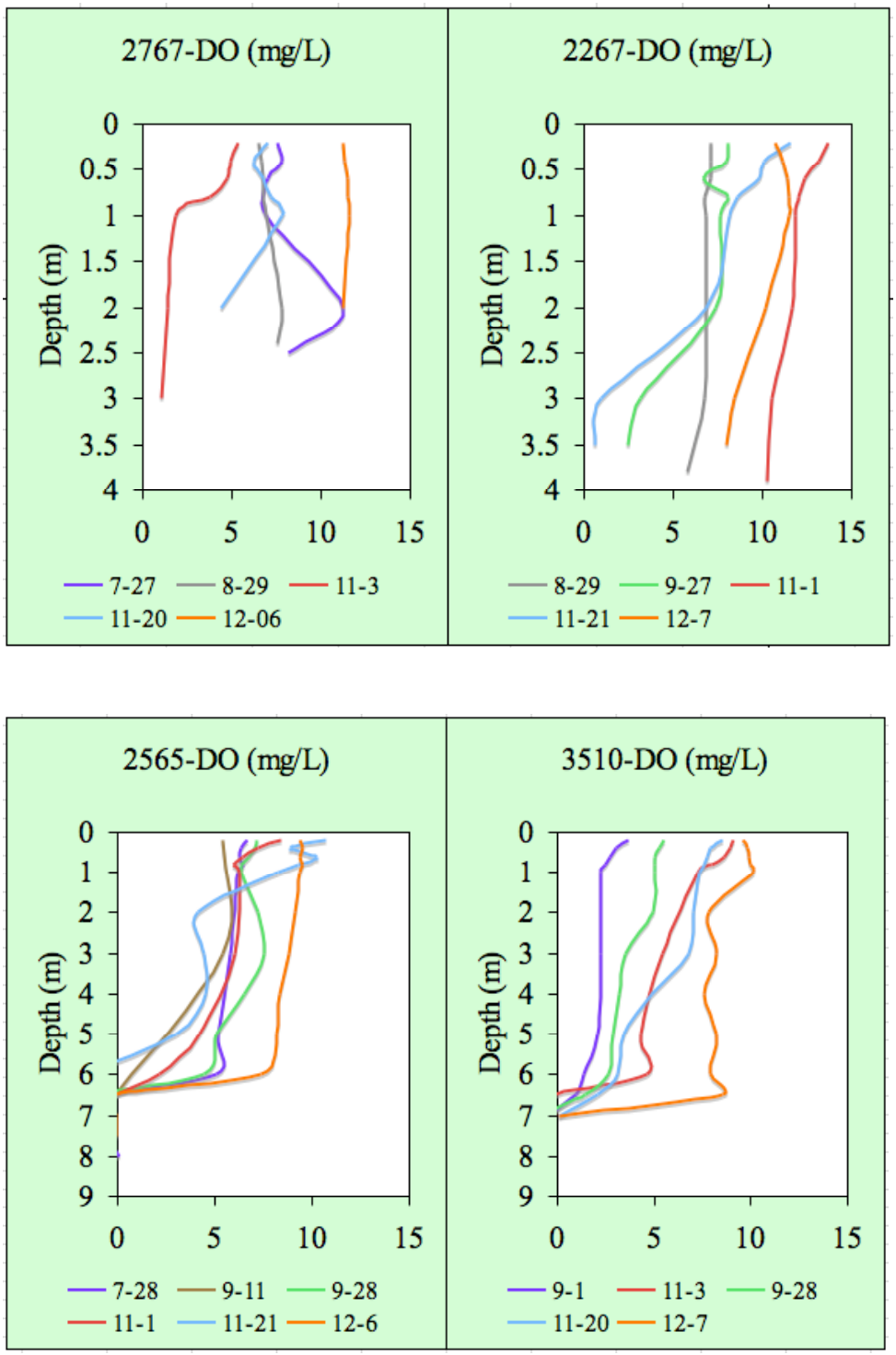
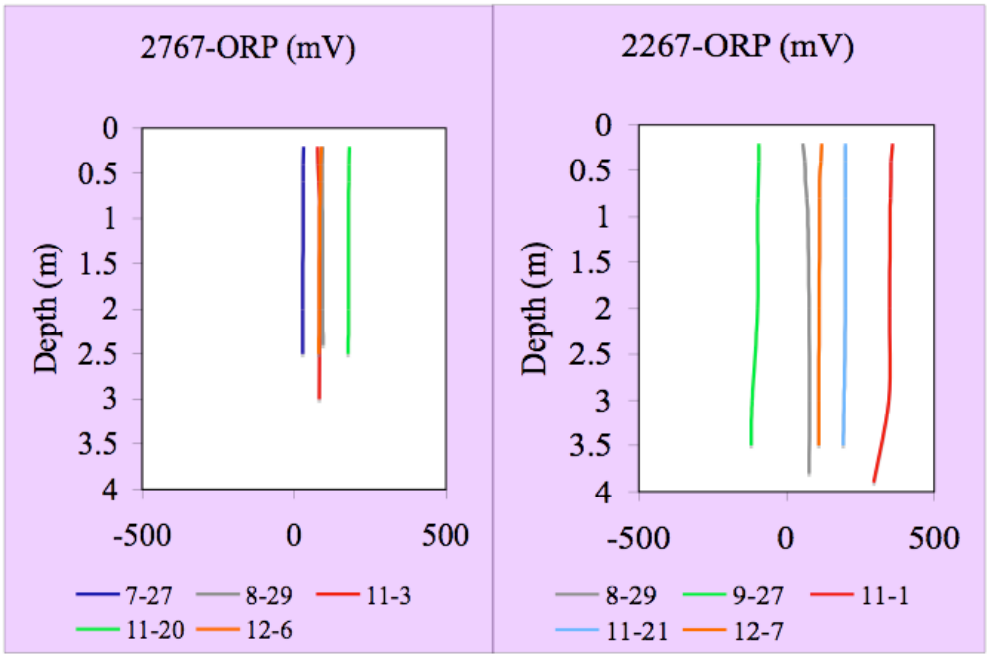


Figure 6b. Oxidation reduction potential (ORP) profiles.



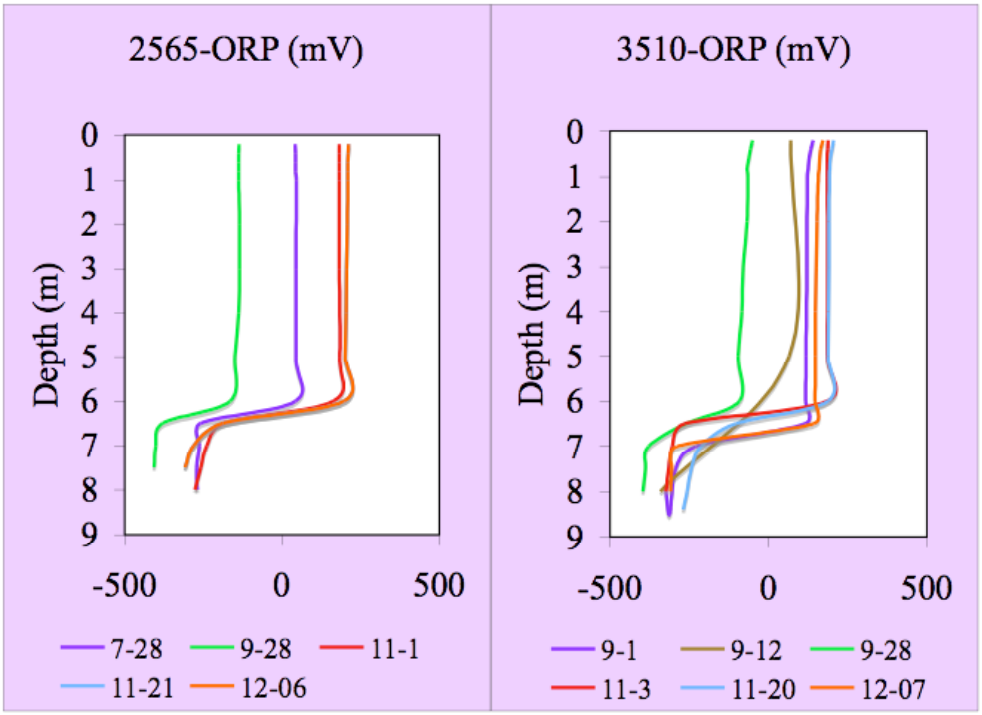


Figure 6c. Conductivity profiles.

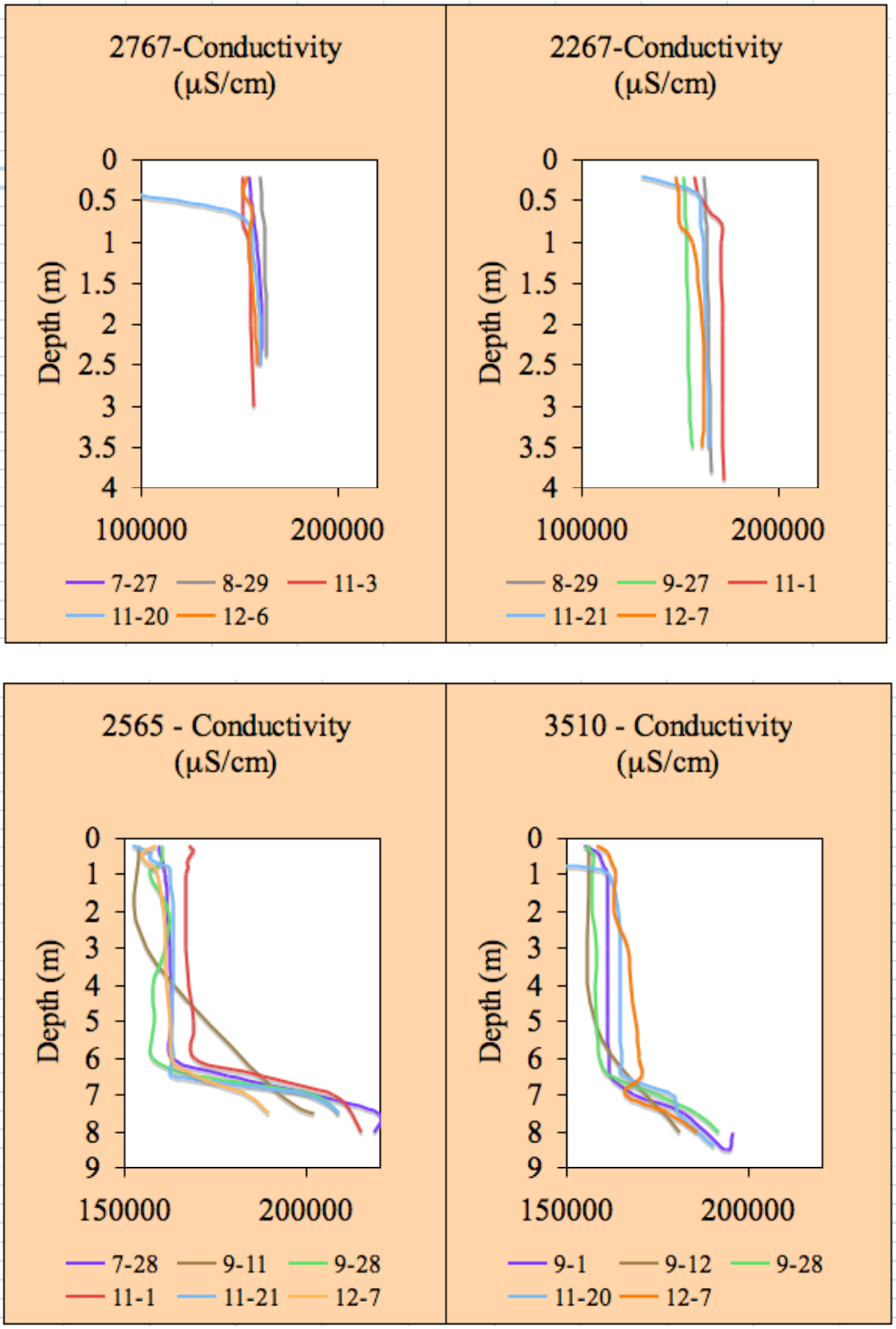
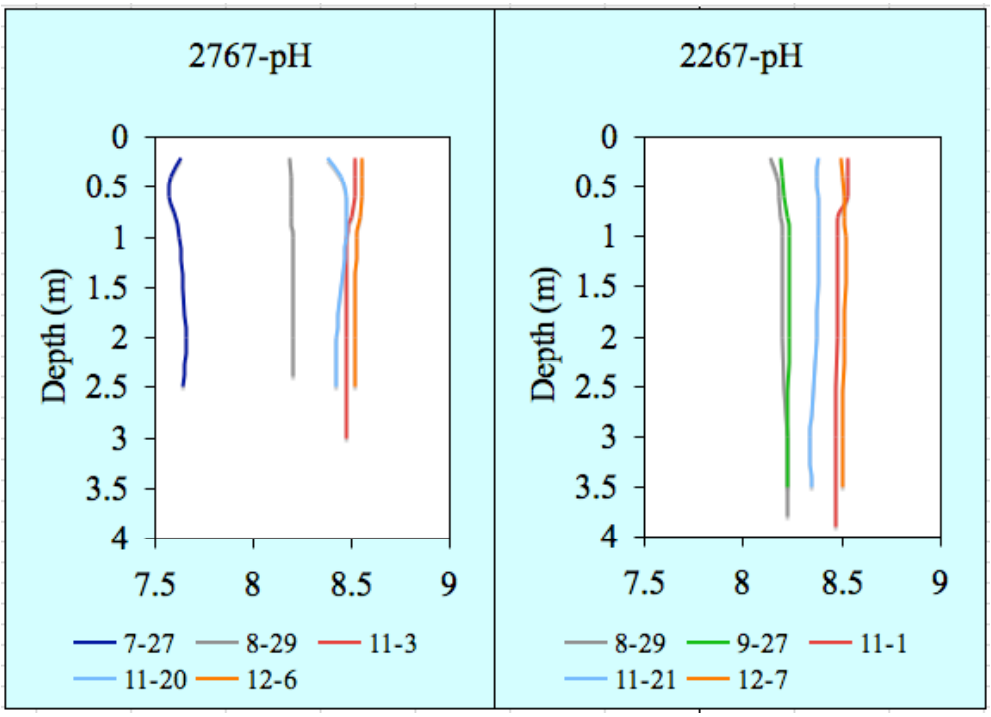


Figure 6d. pH profiles.



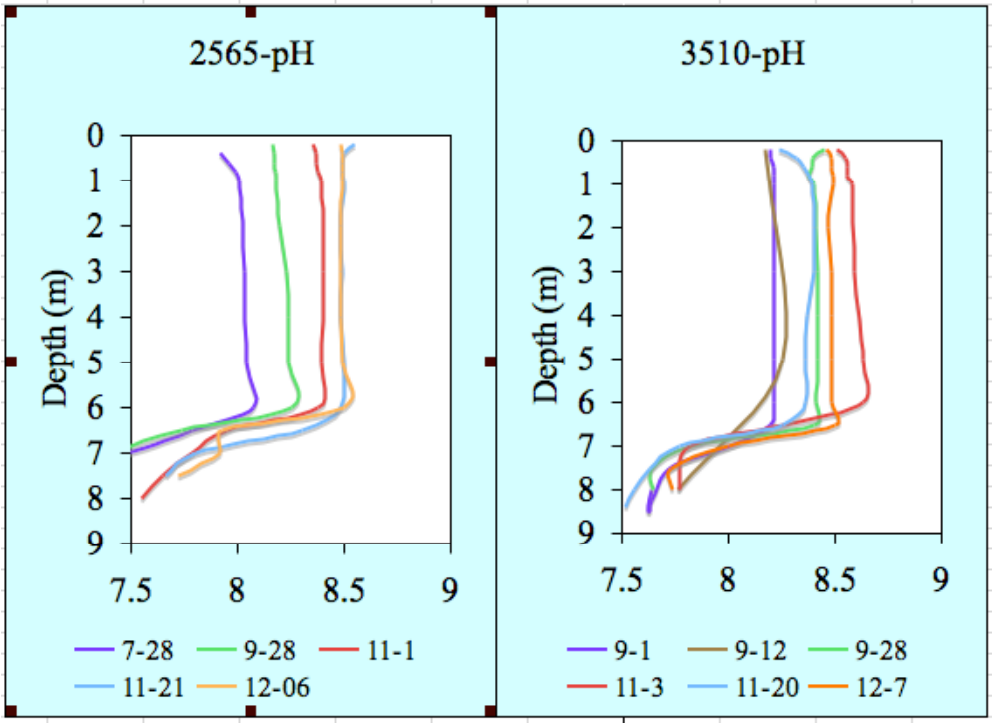
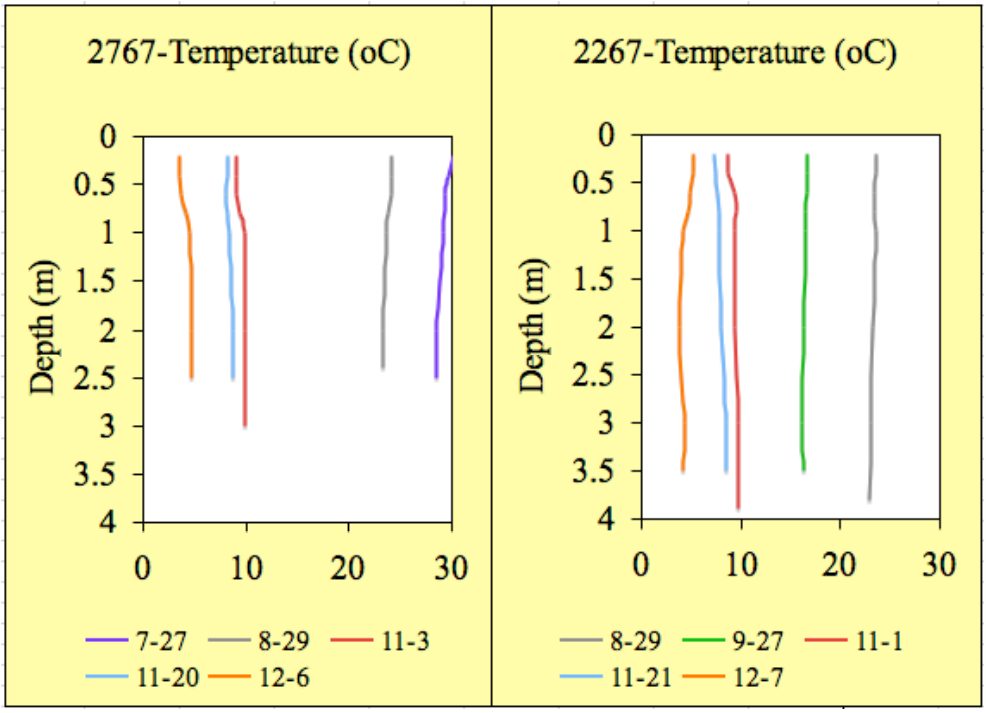


Figure 6e. Temperature profiles.



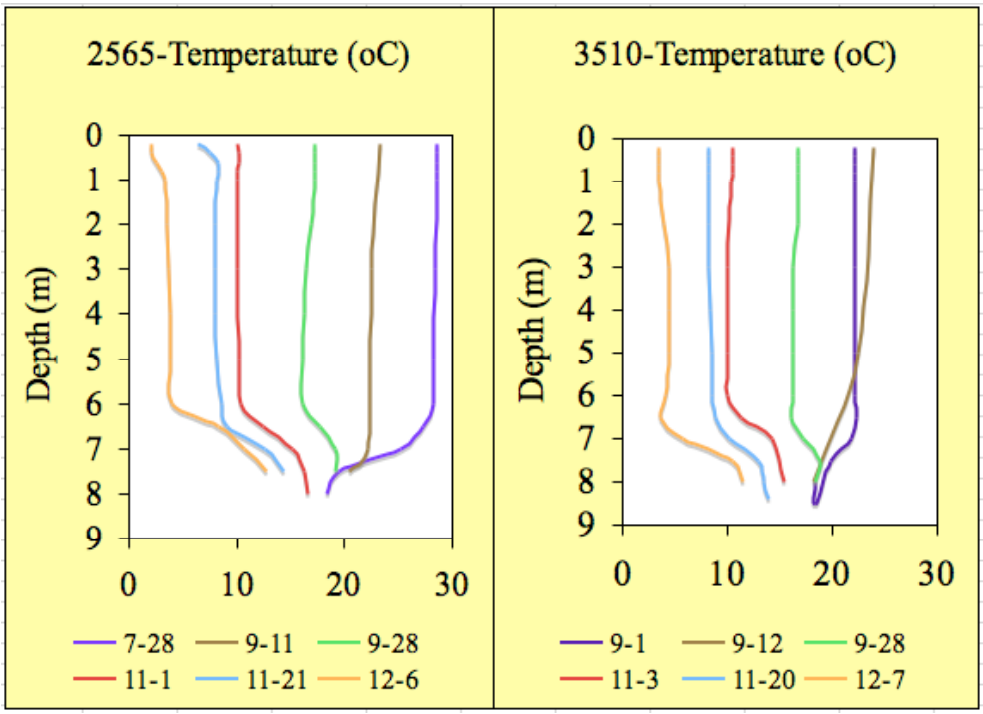


Figure 7a. Total (RA) and dissolved (FA) selenium aqueous concentrations at site 2267.

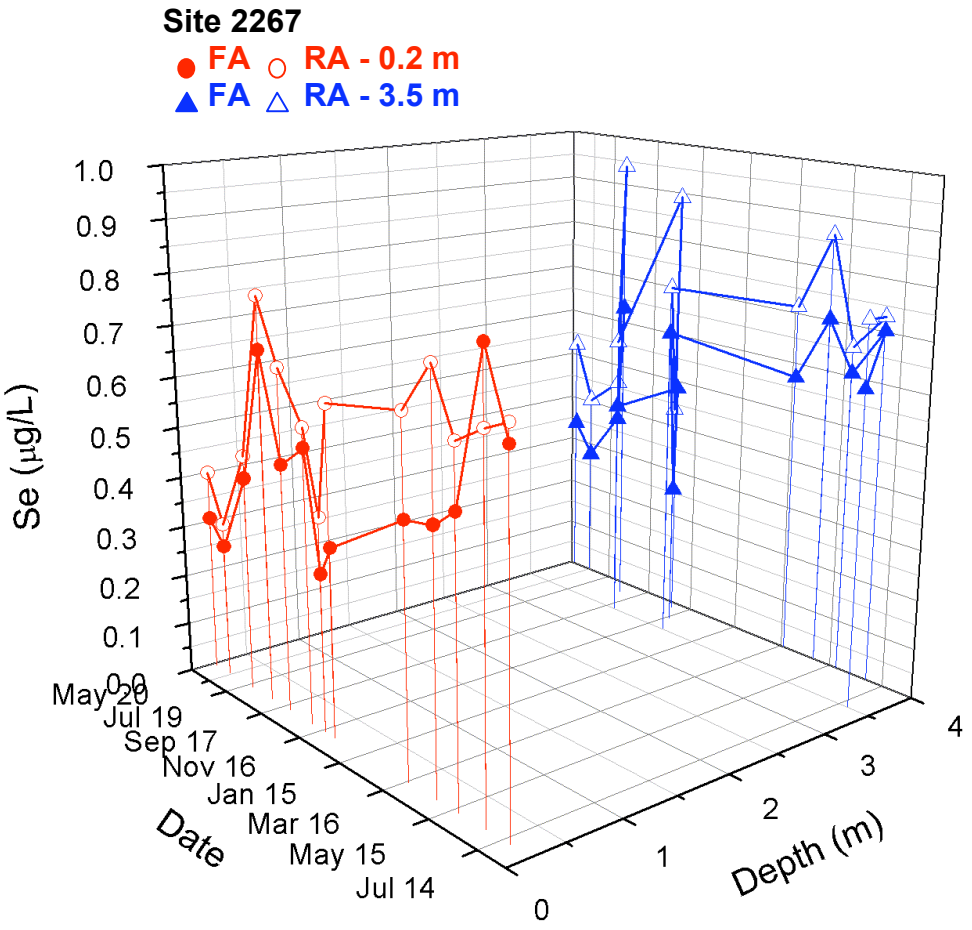


Figure 7b. Total (RA) and dissolved (FA) aqueous selenium concentrations at site 2767.

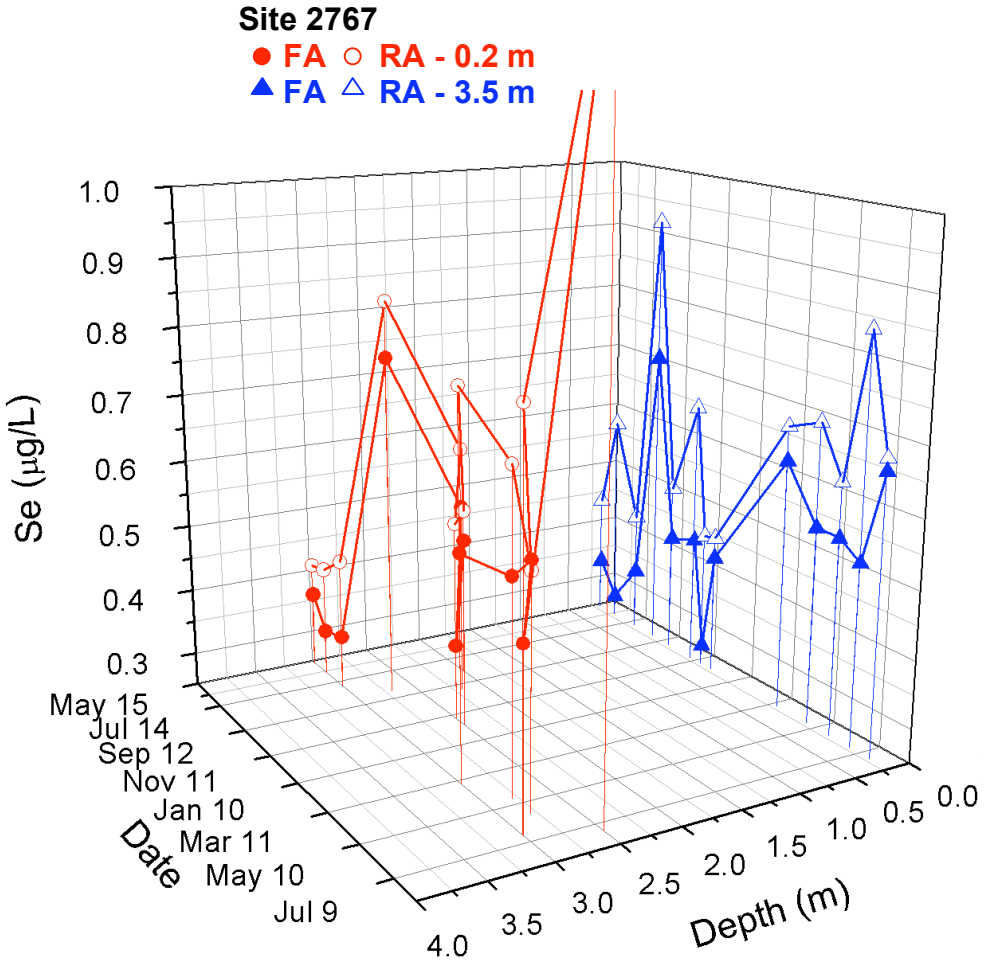


Figure 7c. Total (RA) and dissolved (FA) aqueous selenium concentrations at site 2565.

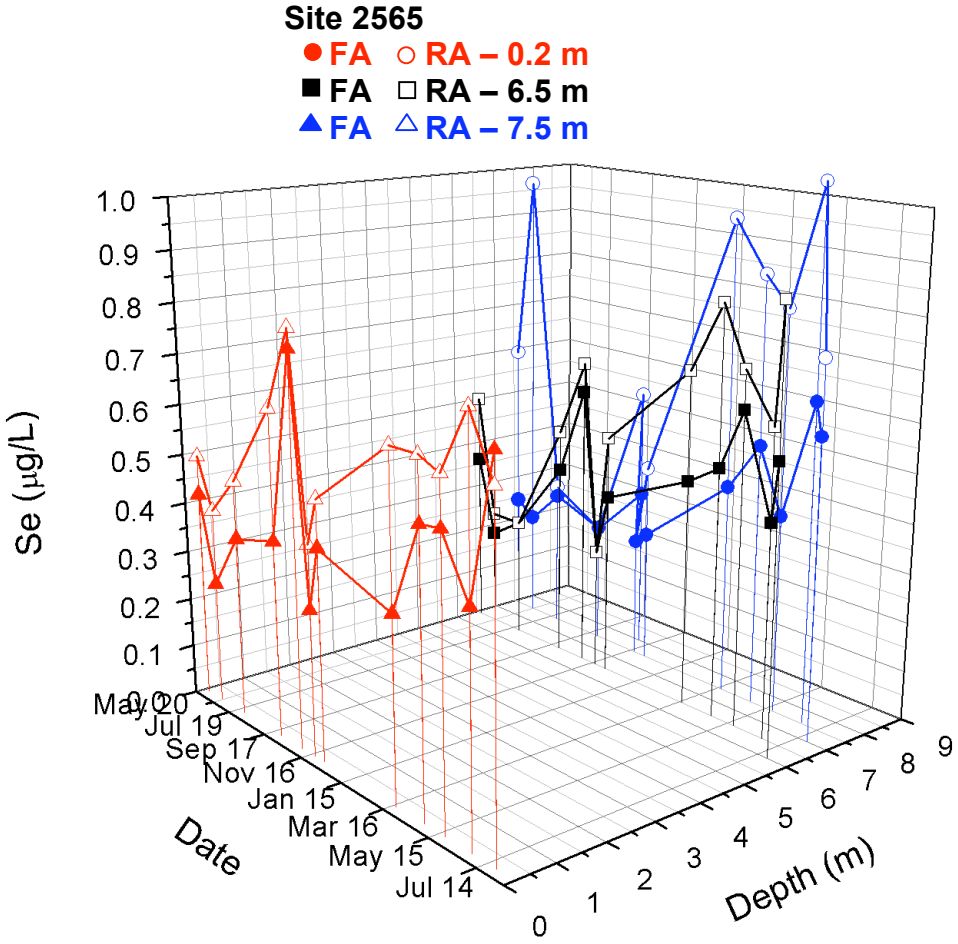


Figure 7d. Total (RA) and dissolved (FA) aqueous selenium concentrations at site 3510.

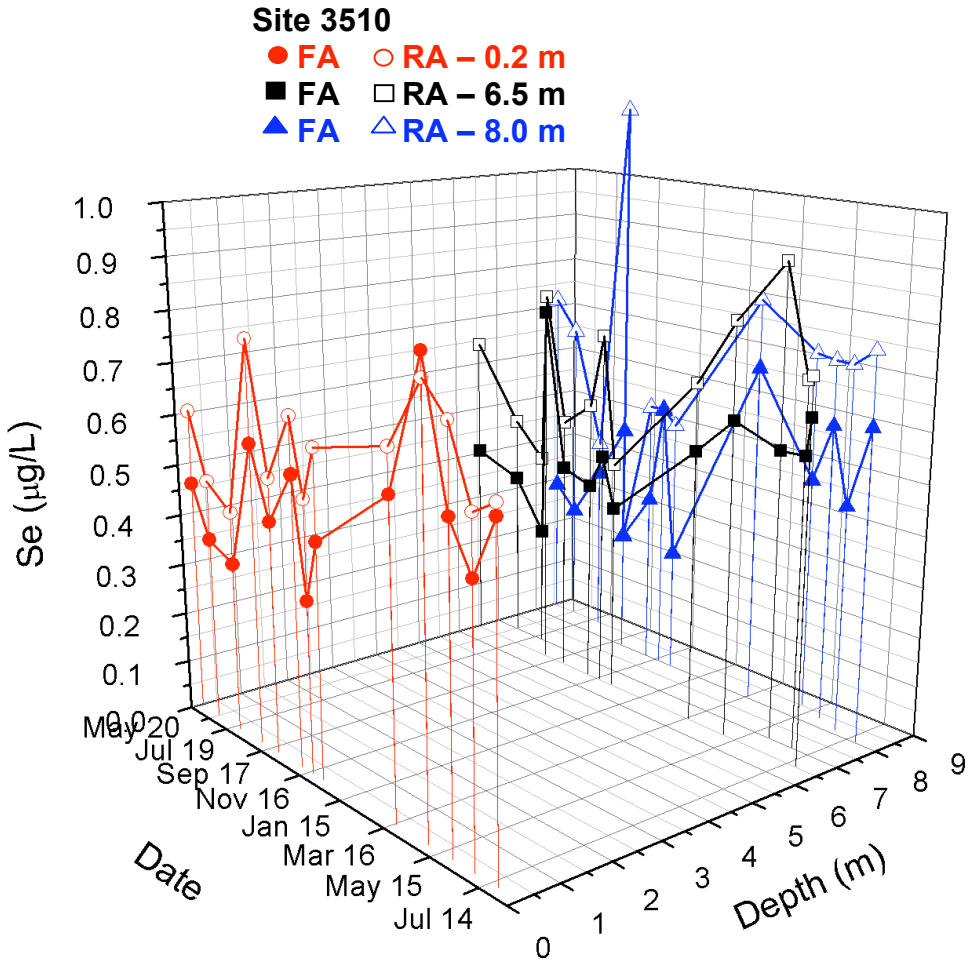


Figure 7e. Total Se concentration trend in water samples analyzed at the U of Utah via ICP-MS

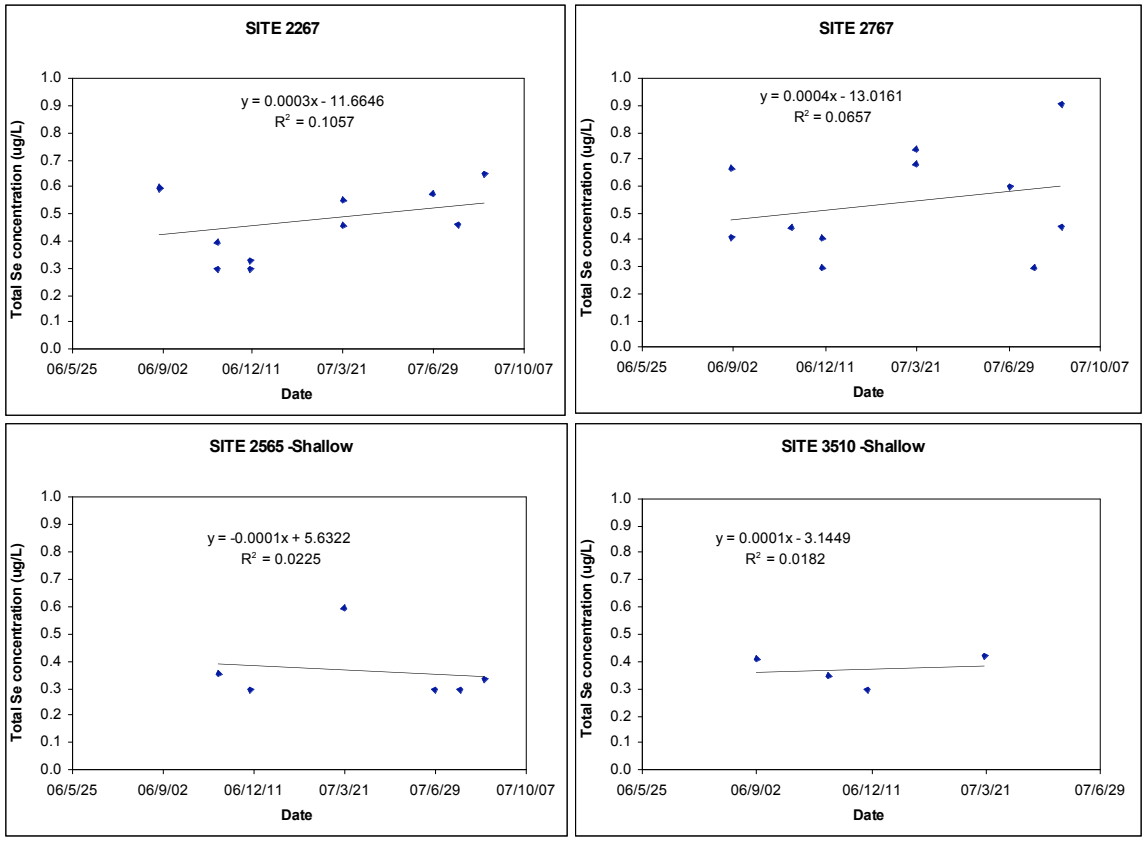


Figure 7f. Dissolved Se concentration trend in water samples analyzed at the U of Utah via ICP-MS.

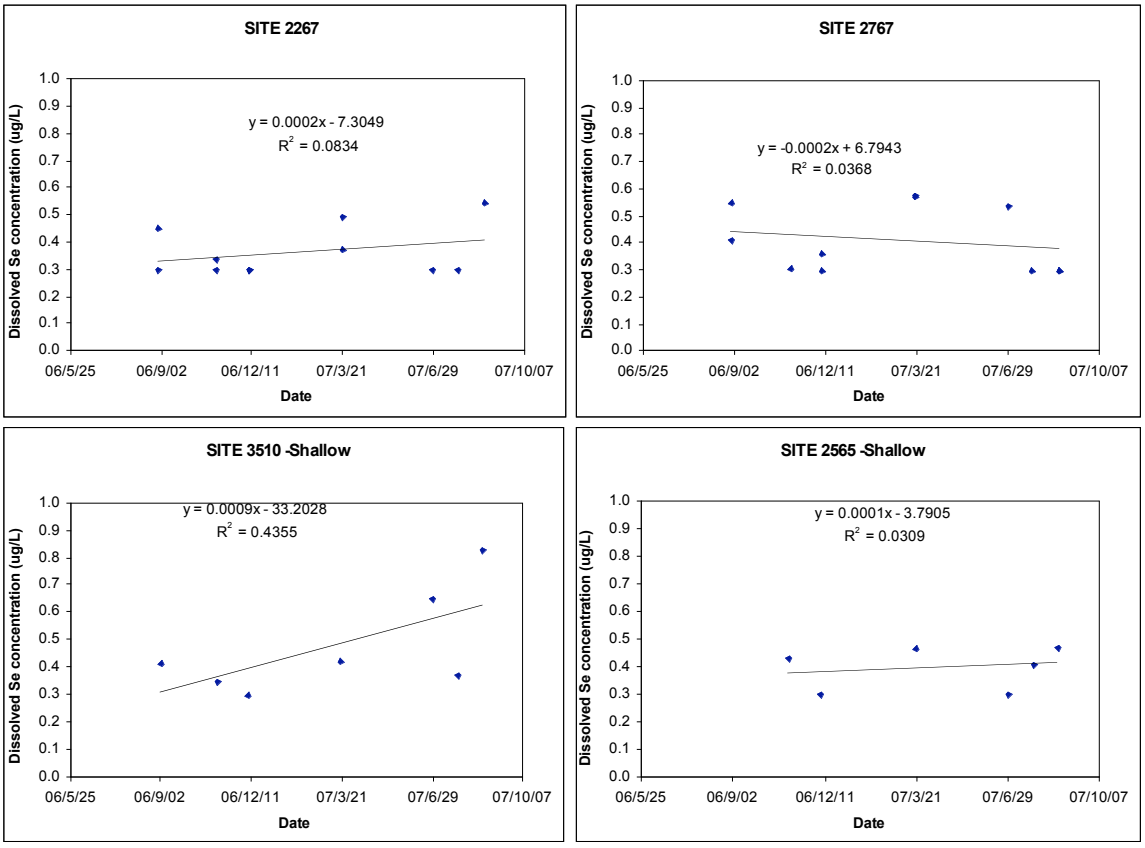


Figure 8a. Average values of dissolved trace elements in shallow and deep brine layers.

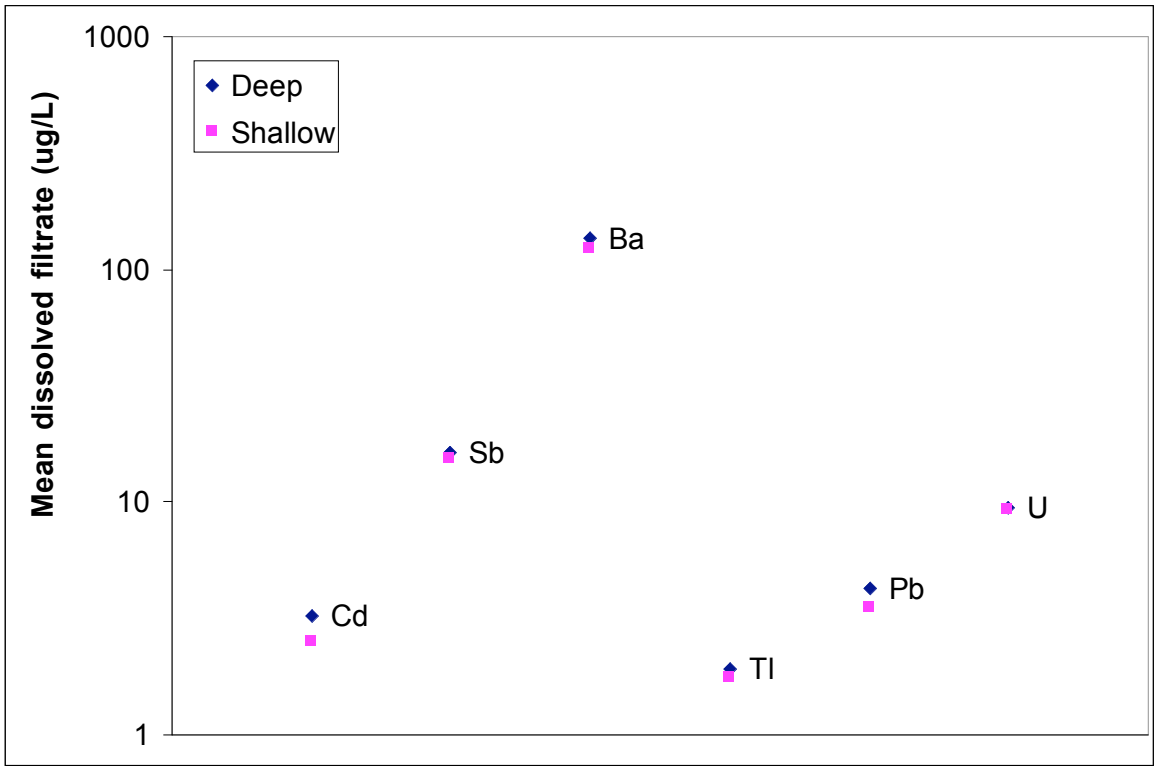


Figure 8b. Average values of dissolved trace elements in shallow and deep brine layers.

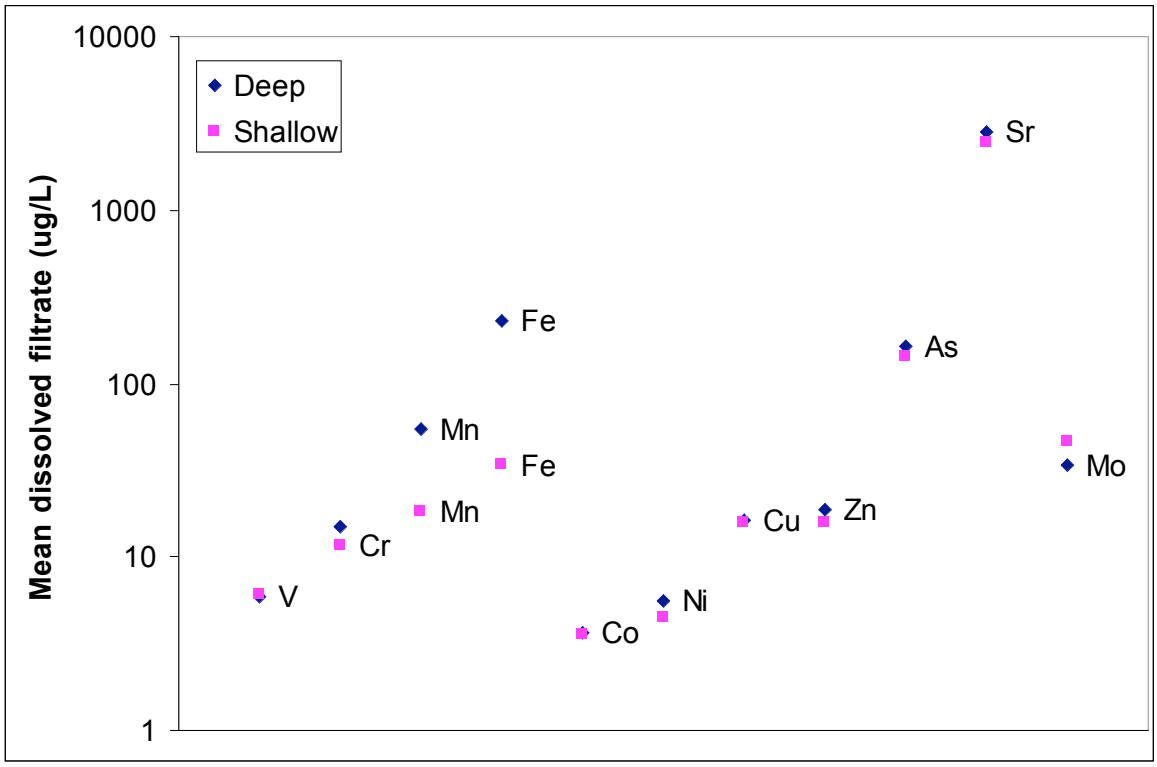


Figure 8c. Average values of dissolved major elements in shallow and deep brine layers.

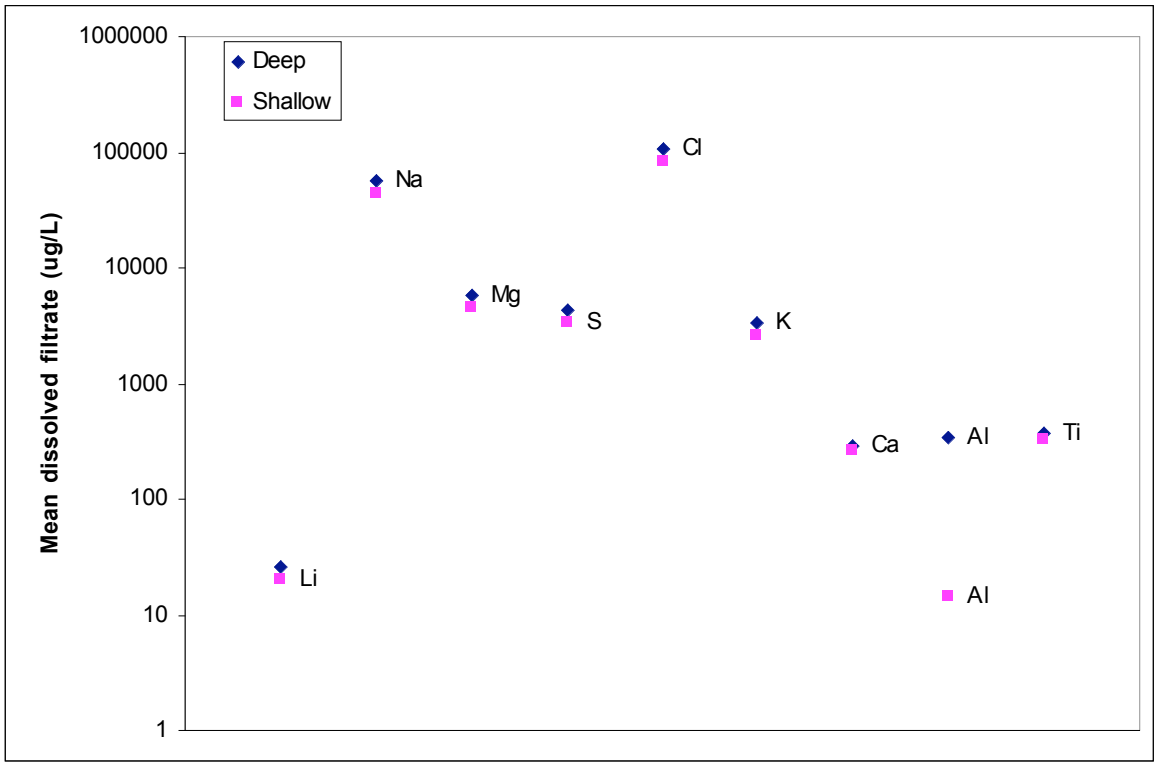


Figure 9a. Percentage of trace element concentration found to be associated with particulates

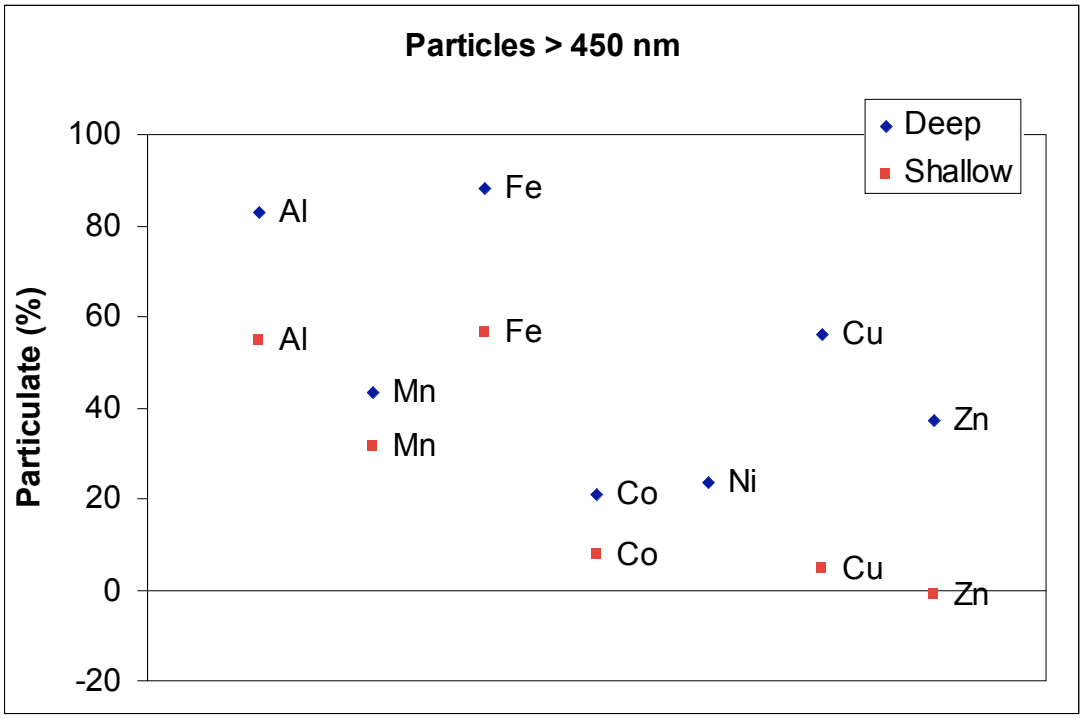


Figure 9b. Percentage of trace element concentration found to be associated with particulates

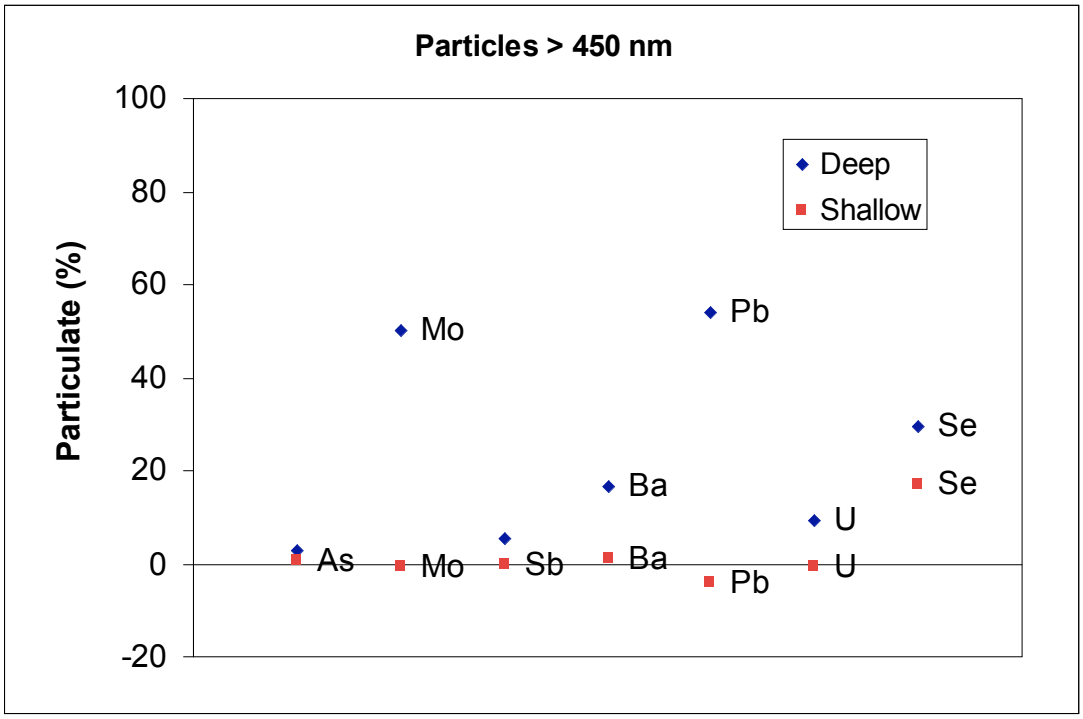


Figure 9c. Percentage of major element concentration found to be associated with particulates

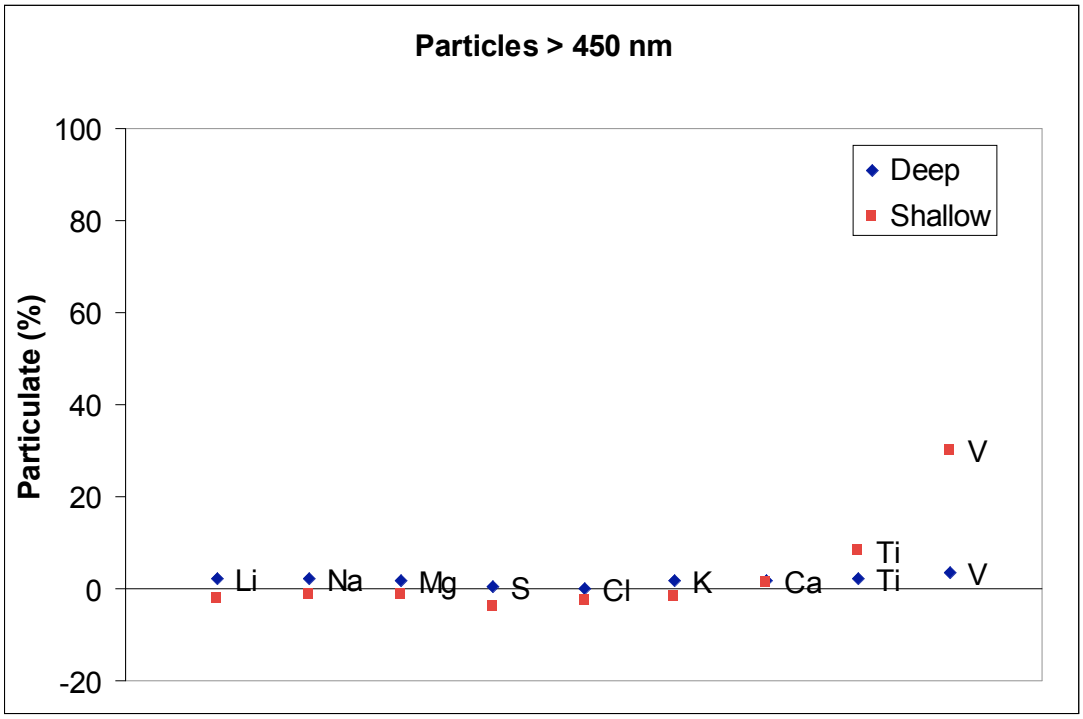
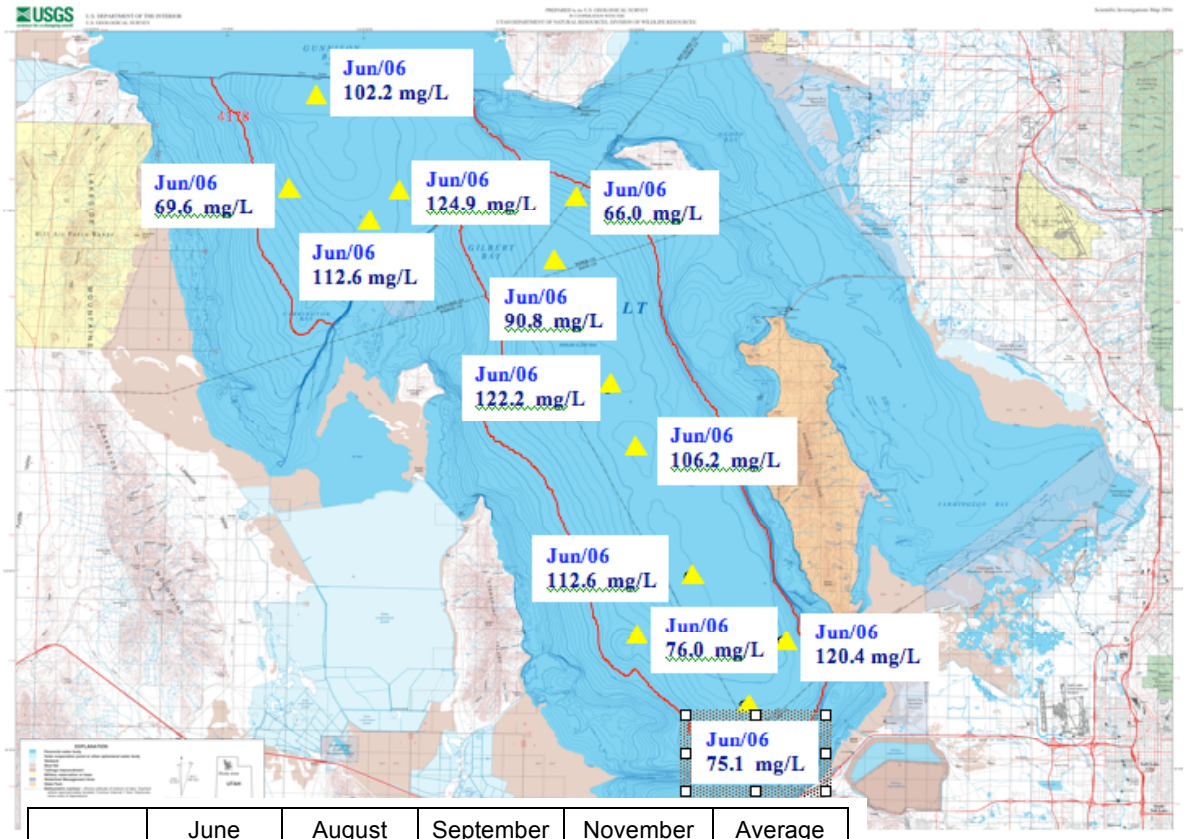
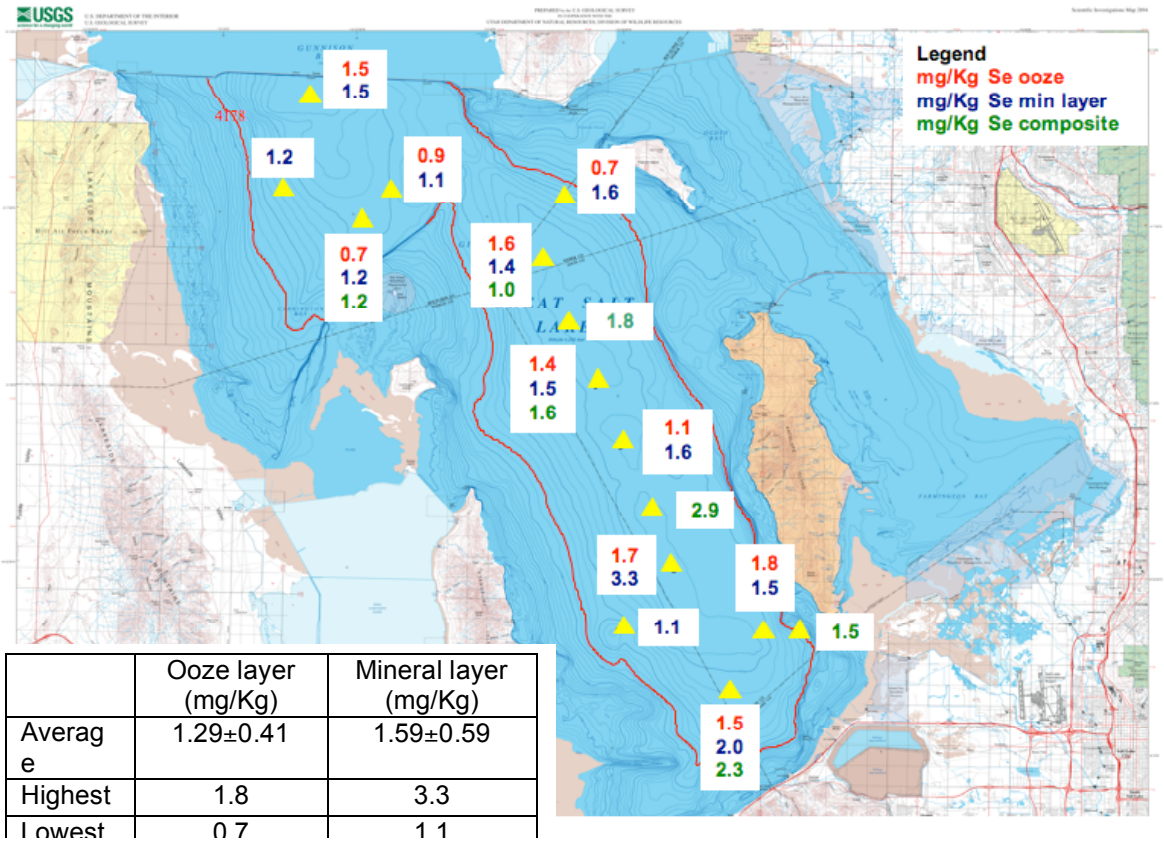


Figure 10. Spatial variation of TOC in deep brine waters (June used as an example). Average concentration of TOC by temporal variation showed in table. (Map courtesy of the USGS)



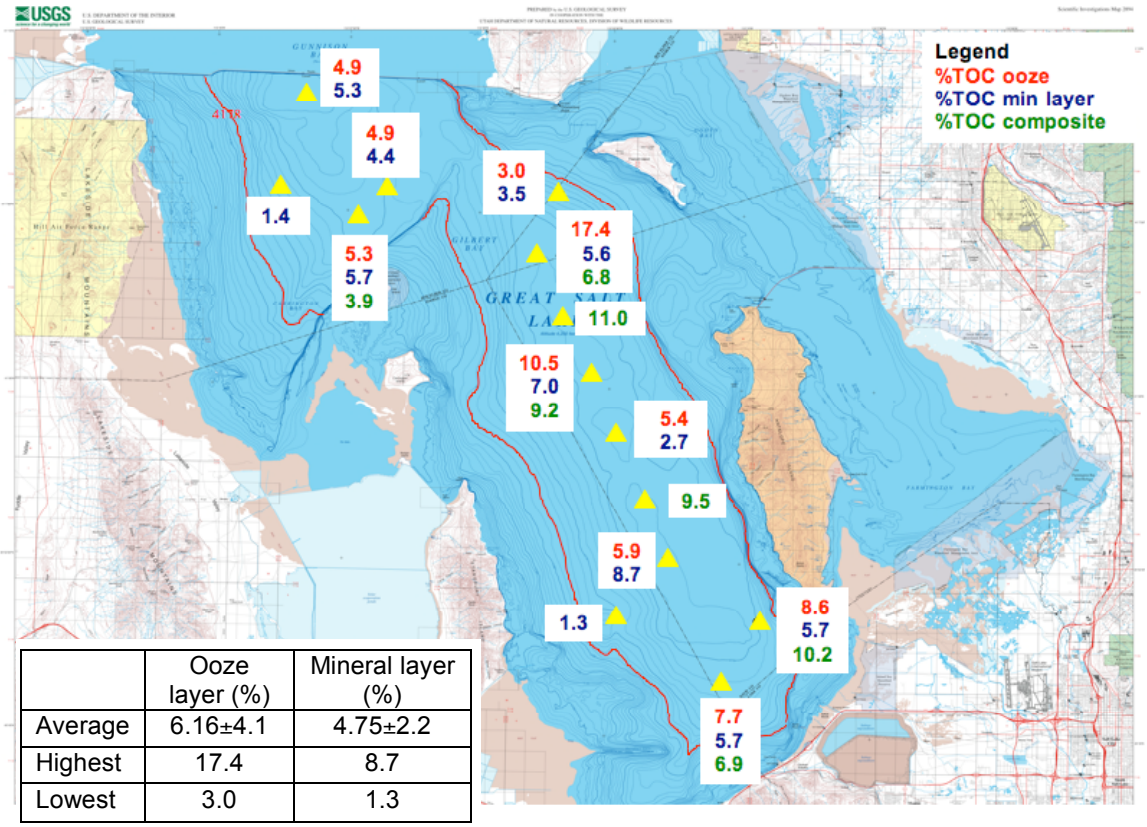
	June (mg/L)	August (mg/L)	September (mg/L)	November (mg/L)	Average (mg/L)
Average	96.1±21.5	84.4±14.4	86.8±16.3	101.9±25.1	92.3±19.3
Highest	124.9	104.2	100.6	138.7	124.9
Lowest	56	51.7	50.9	58.7	50.9

Figure 11. Selenium concentrations (mg/Kg) in bed sediments (Map courtesy of the USGS).



	Ooze layer (mg/Kg)	Mineral layer (mg/Kg)
Average	1.29±0.41	1.59±0.59
Highest	1.8	3.3
Lowest	0.7	1.1

Figure 12. Concentrations of total organic carbon (TOC) in bed sediments corrected for salinity. (Map courtesy of the USGS).



	Ooze layer (%)	Mineral layer (%)
Average	6.16±4.1	4.75±2.2
Highest	17.4	8.7
Lowest	3.0	1.3

Figure 13. Selenium concentrations in the bed sediments versus TOC in bed sediments. Trendline determined for the mineral layer samples.

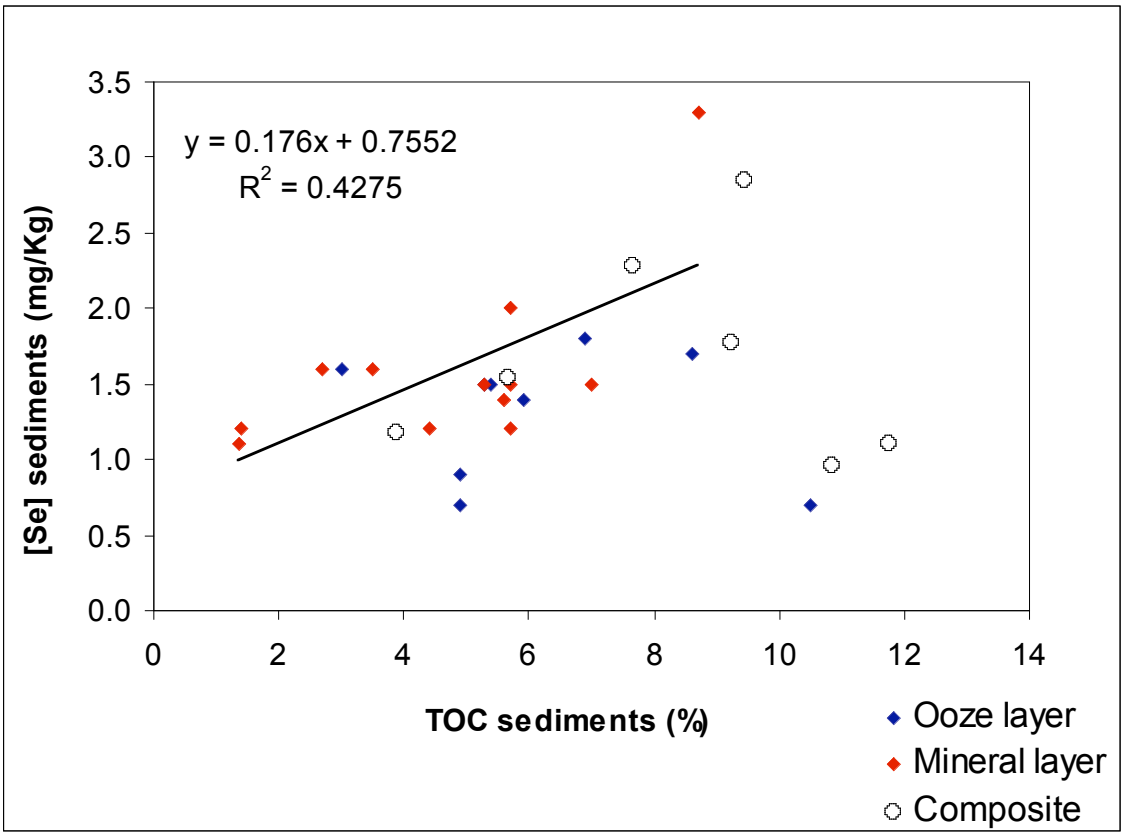
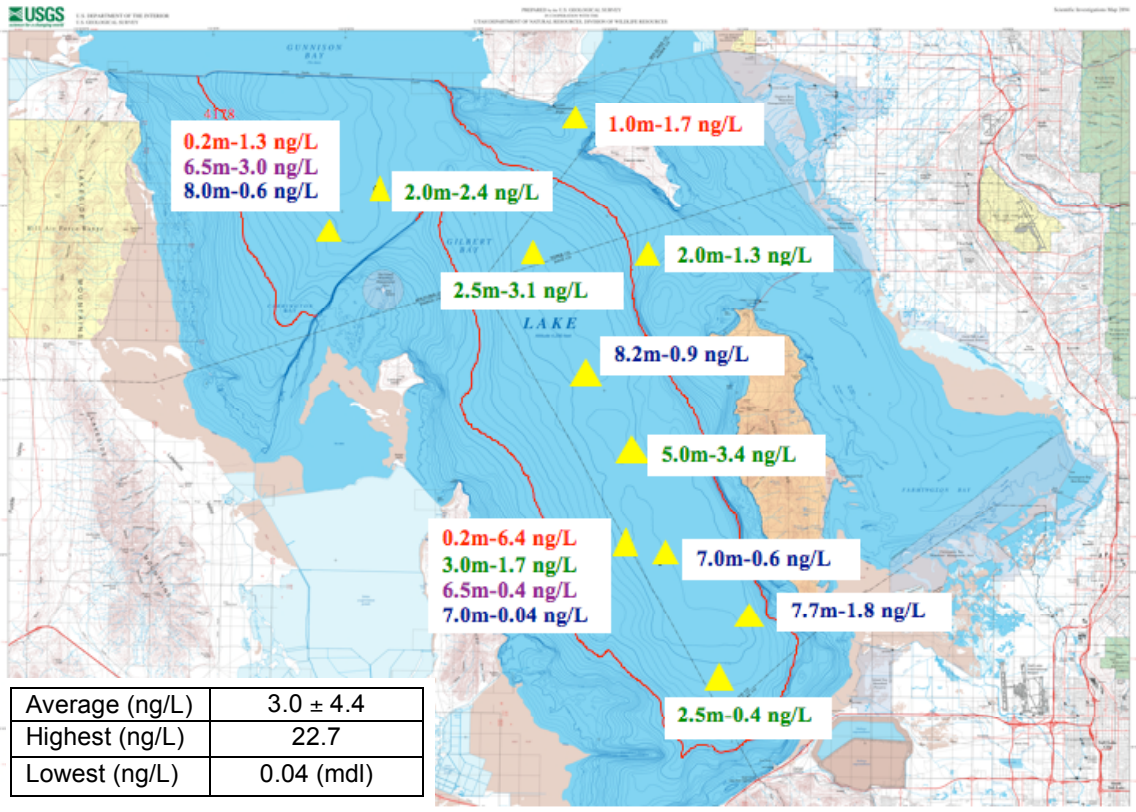


Figure 14. Volatile selenium concentrations (ng/L) in shallow and deep brine layers. (November, 2006 used as an example). (Map courtesy of the USGS).



Average (ng/L)	3.0 ± 4.4
Highest (ng/L)	22.7
Lowest (ng/L)	0.04 (mdl)

mdl: method detection limit

Figure 15a. Volatile selenium concentrations in the shallow brine layer. For any given site, the data shows same-day measurements at different depths.

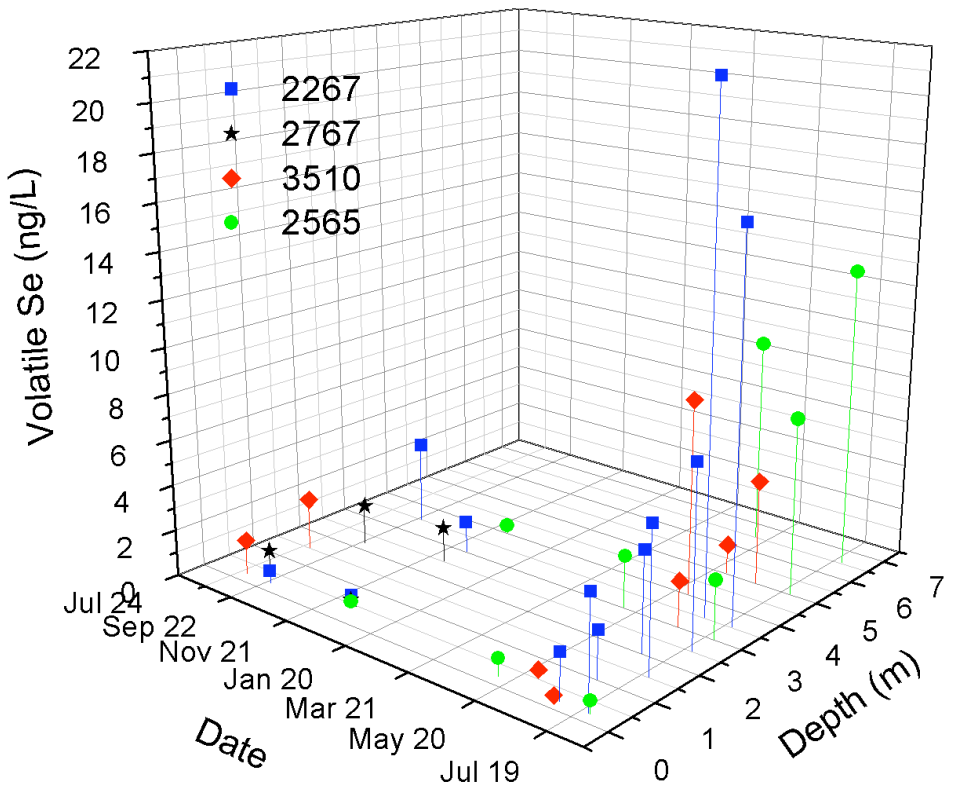


Figure 15b. Volatile selenium concentrations including deep brine layer (depths below 6.5 m). For any given site, the data shows same-day measurements at different depths.

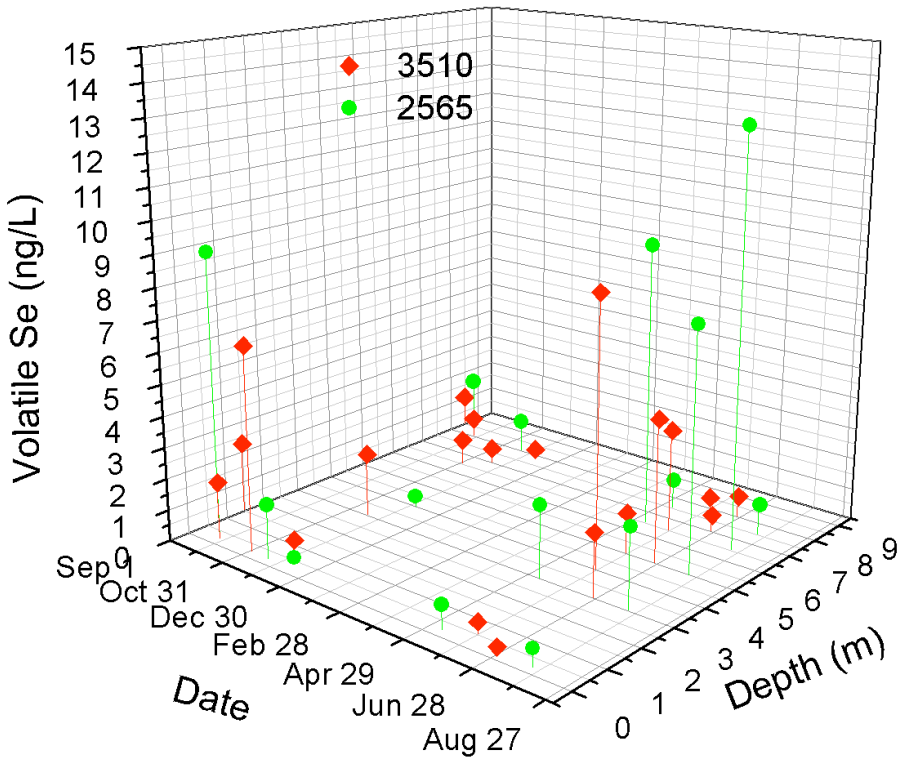
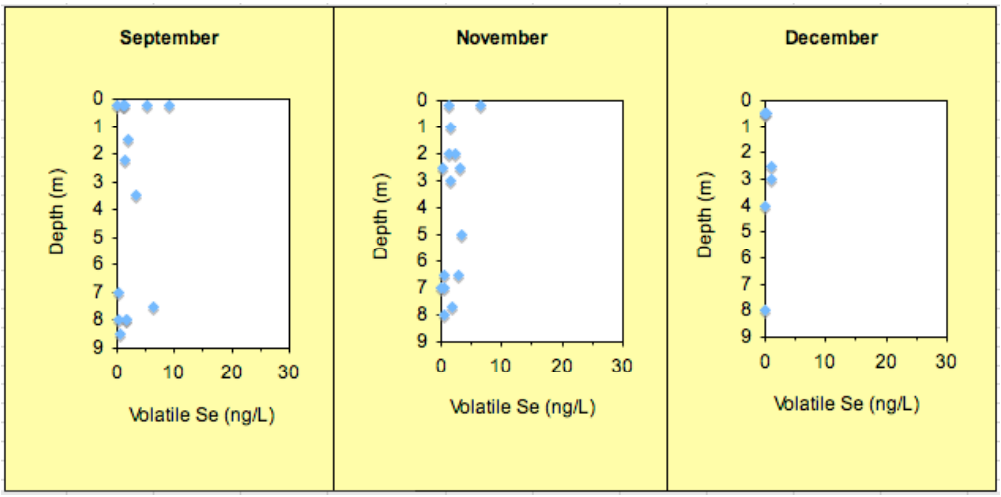


Figure 16a. Temporal variation of volatile selenium.

2006



2007

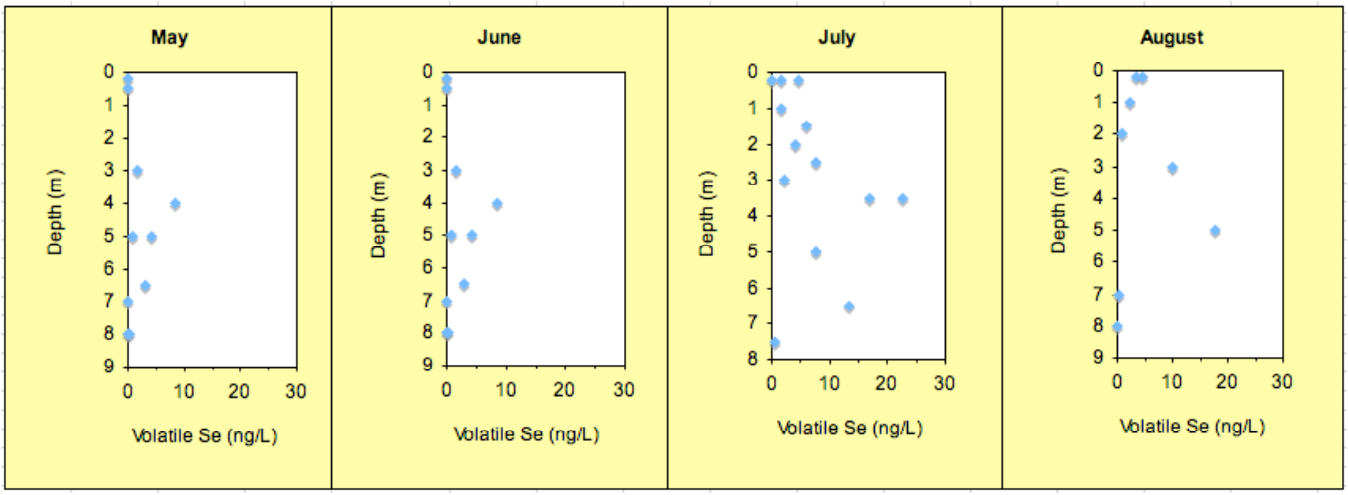
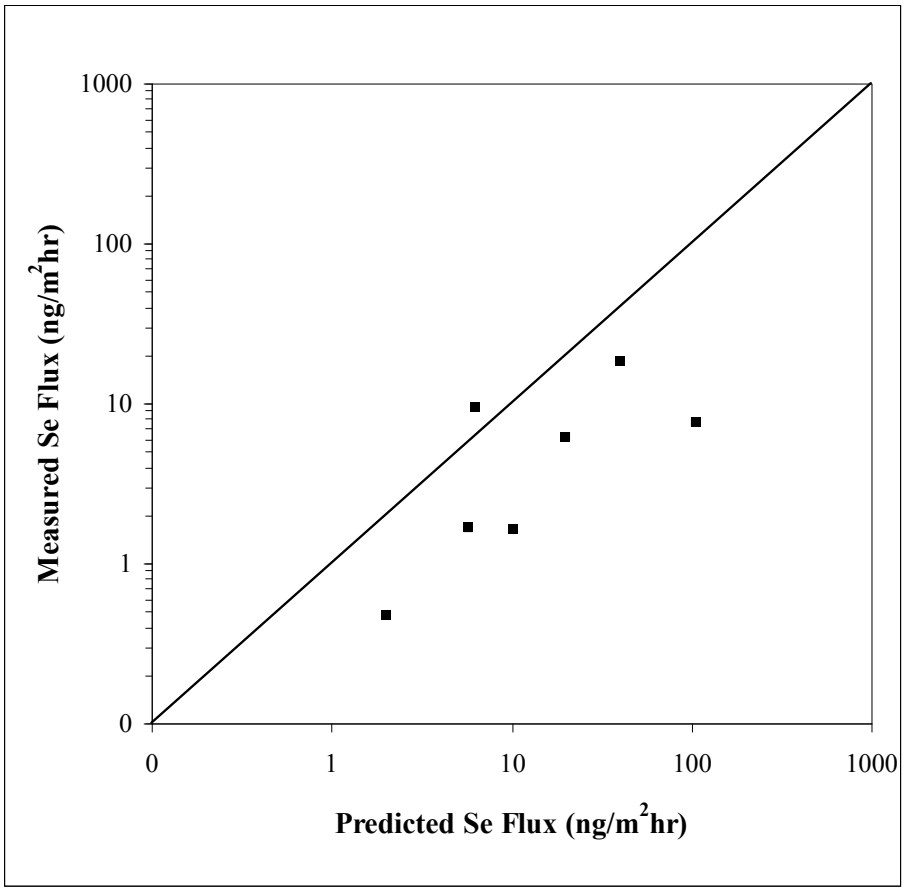


Figure 16b. Relationship between Estuarine model-predicted volatilization rates to measured volatilization rates after subtraction of average background flux of 1.6 ng/m^{2}h. Top: log axes. Bottom: linear axes.



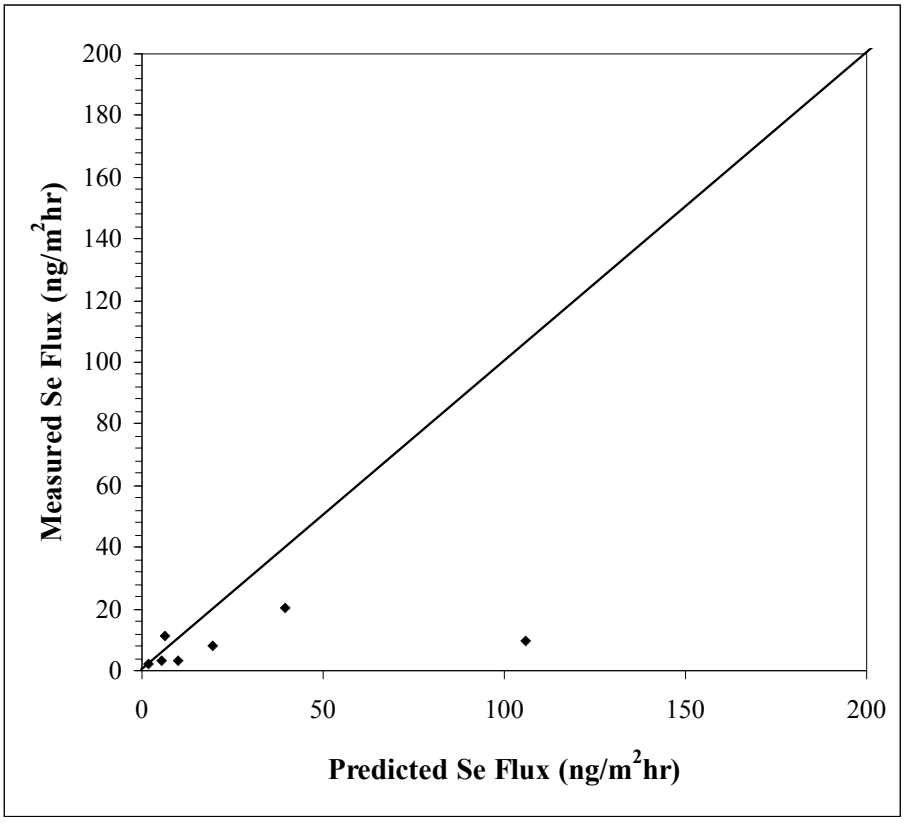


Figure 16c. Relationship between observed and Estuarine model-predicted Se fluxes under controlled laboratory conditions. Line represents the linear fit to controlled laboratory conditions.

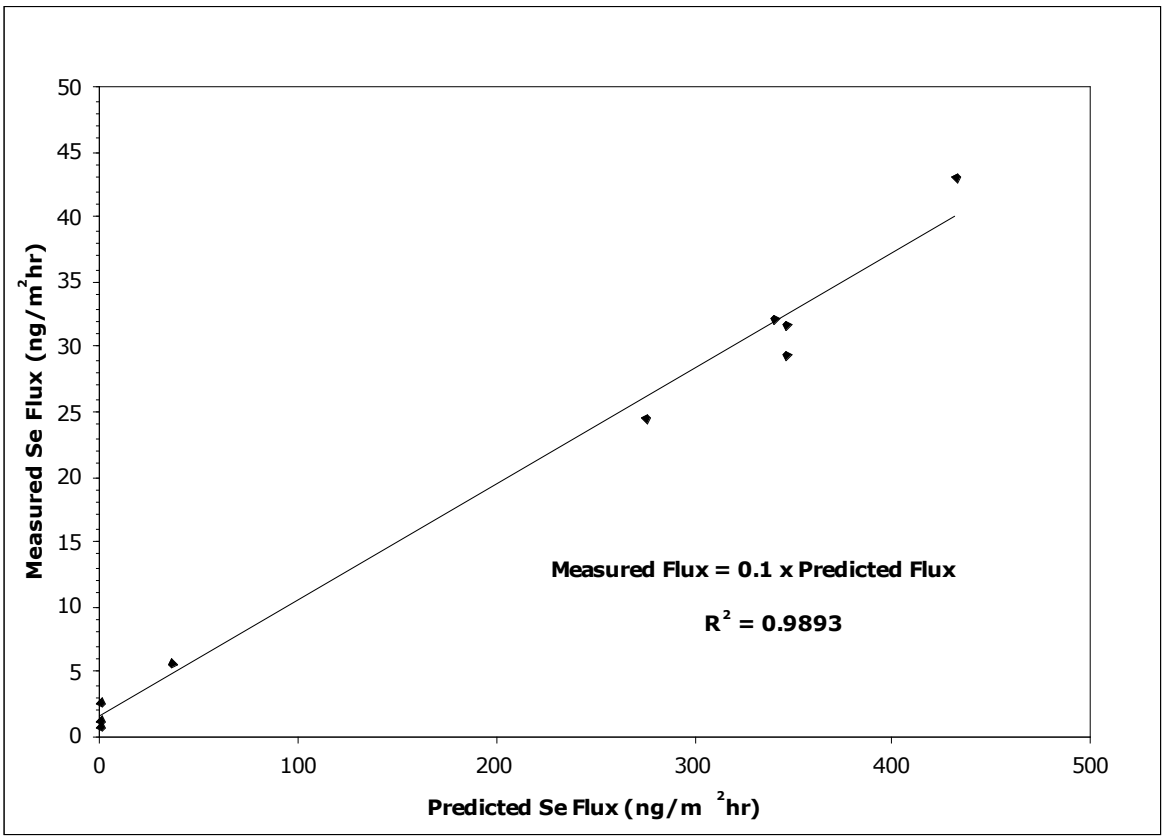
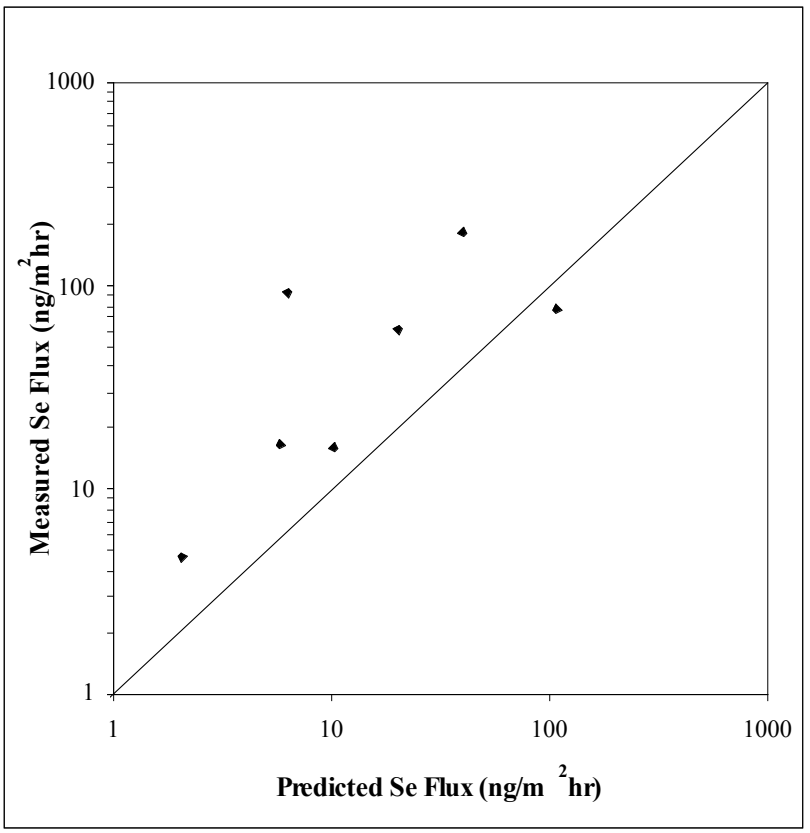


Figure 16d. Relationship between Estuarine model predicted volatilization rates to measured volatilization rates after corrections for background and measurement inefficiency. Top: log axes. Bottom: linear axes



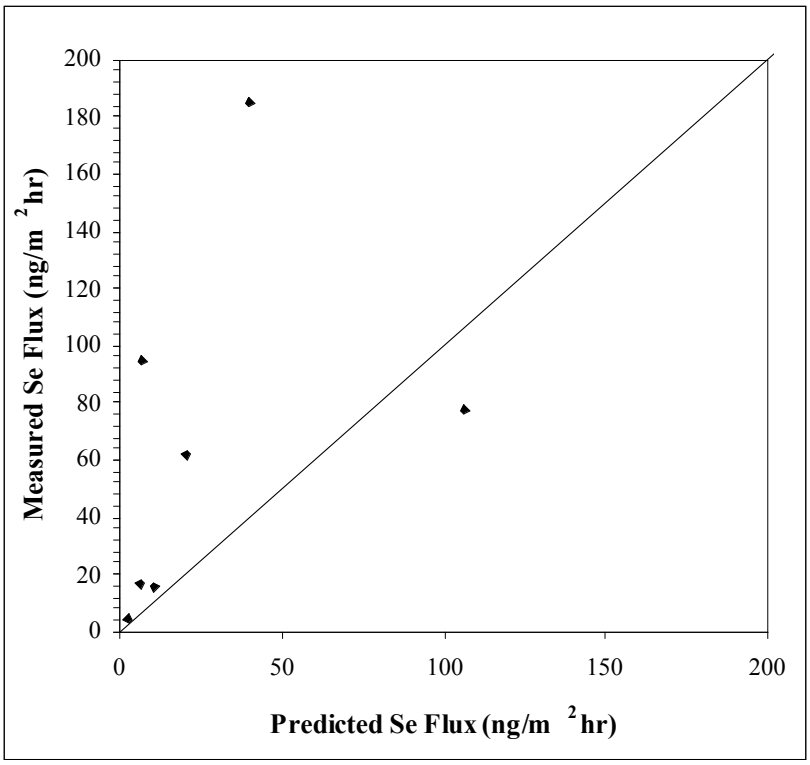


Figure 17a. Wind velocity, atmospheric temperature and lake elevation from January to December 2006.

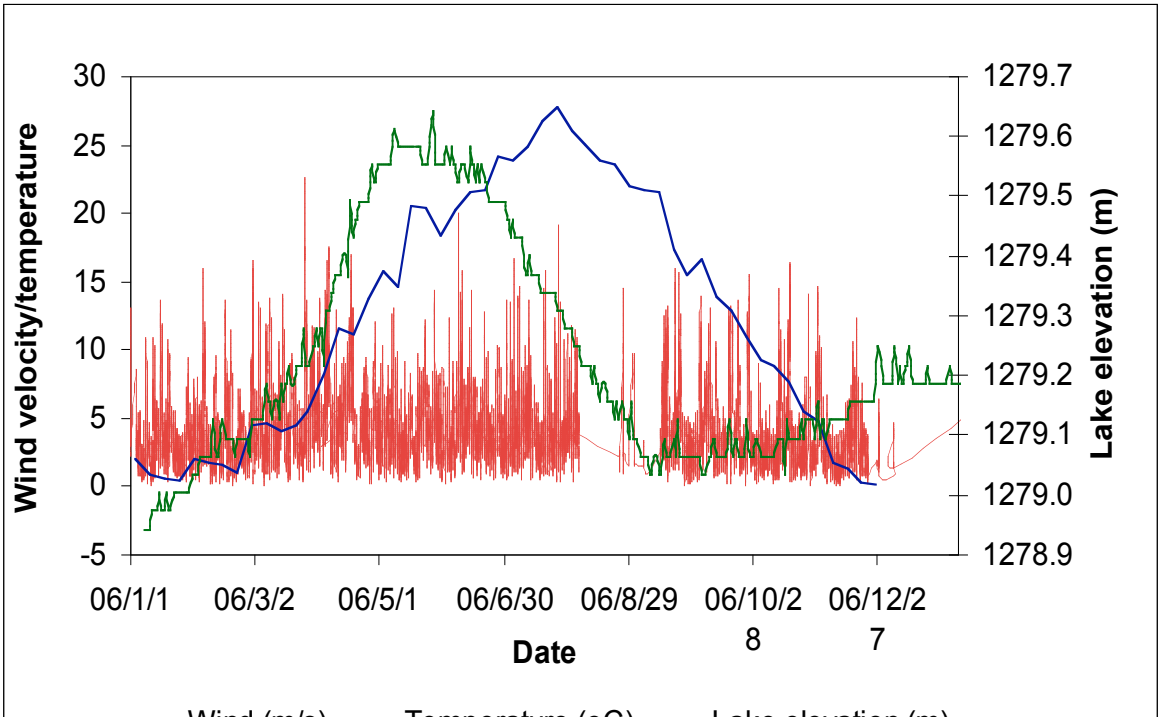


Figure 17b. Concentration of volatile Se collected at 0.2 – 0.5 m from September 2006 to August 2007. Blue trendline shows sinusoidal fit to data. Orange trendlines show the 95% confidence interval. Lower quantification limit of 0.04 ng/L is shown as dashed horizontal line.

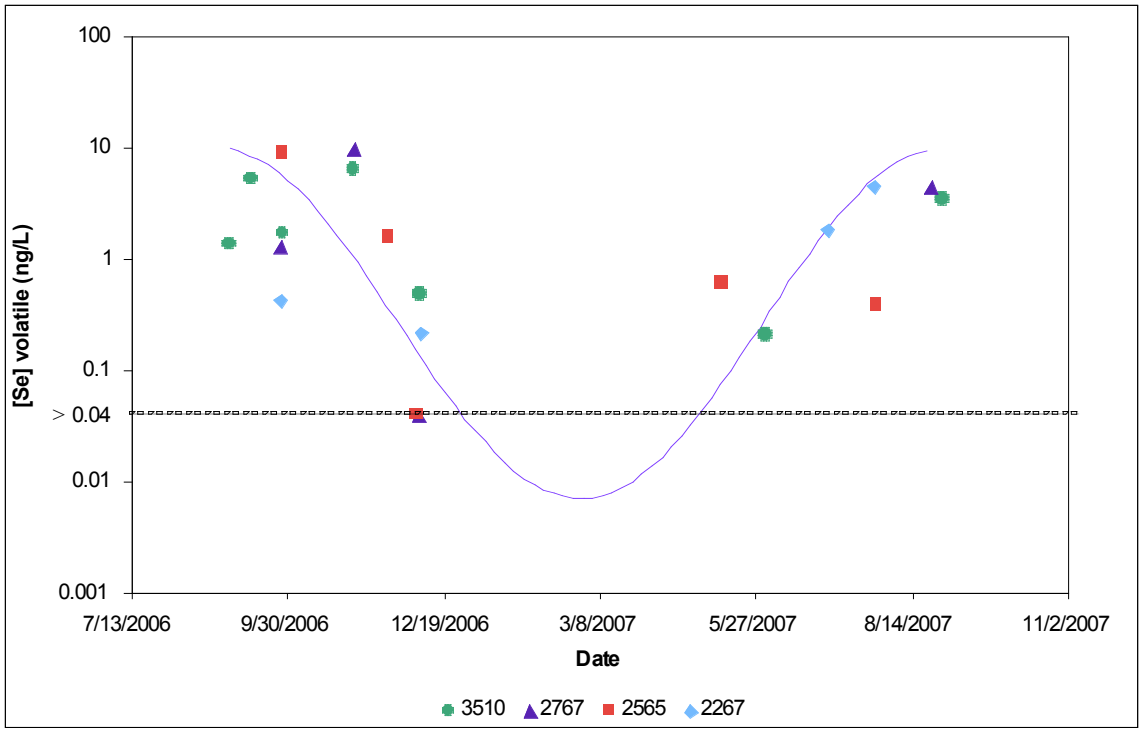


Figure 17c. Integration of annual volatile Se flux using temperature and wind data from January to December 2006, and measured volatile Se concentrations 2006-2007 (Figure 17b).

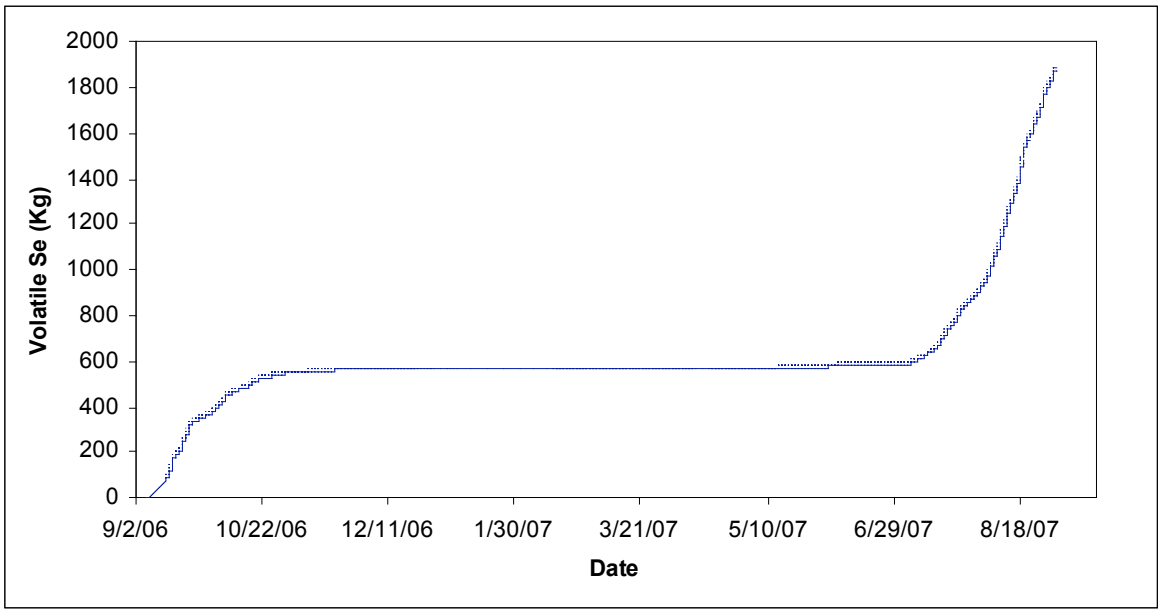
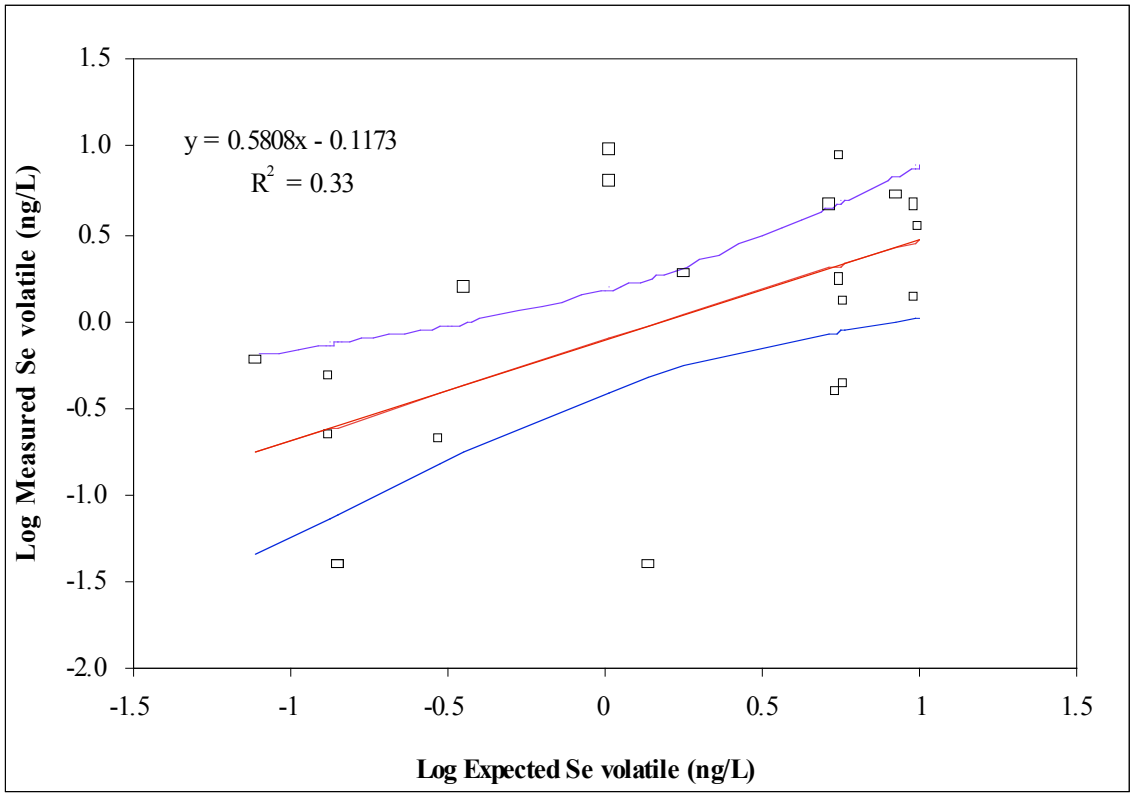


Figure 17d. Determination of the 95% confidence interval using expected vs. measured data of near surface volatile Se concentrations. Expected values obtained from the sinusoidal function. Top: log values in a normal scale. Bottom: Arithmetic values in a log scale.



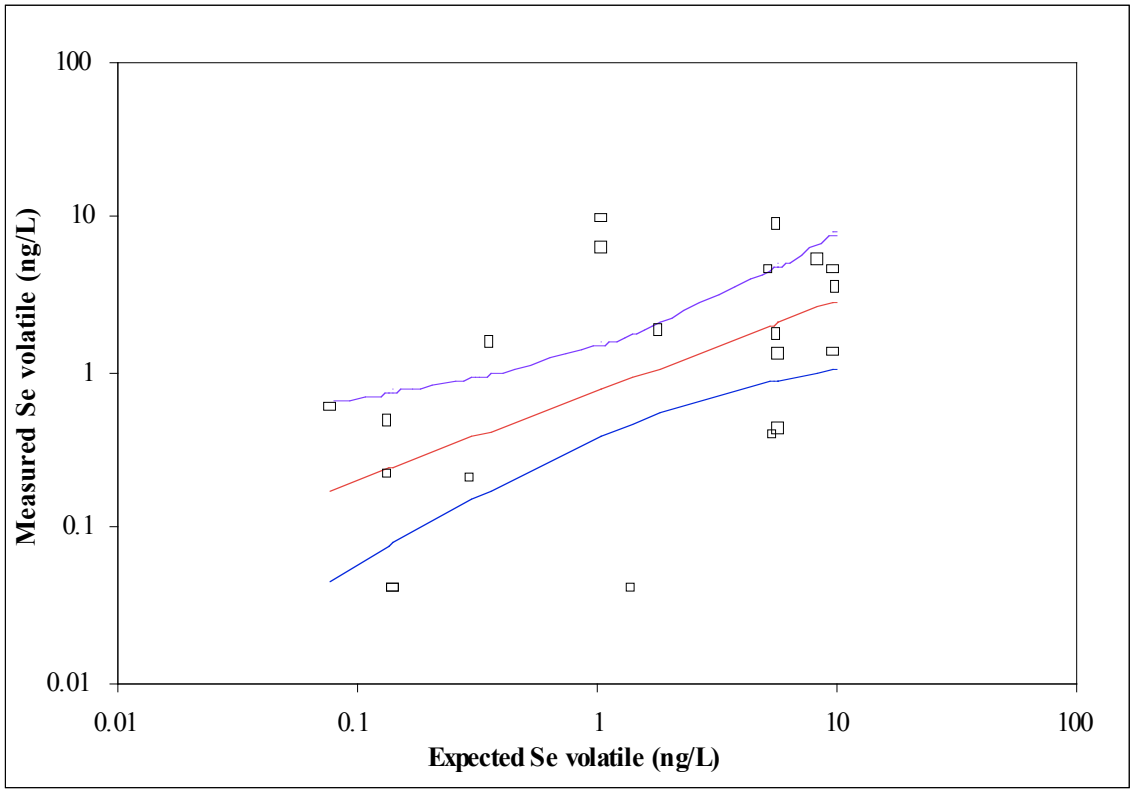
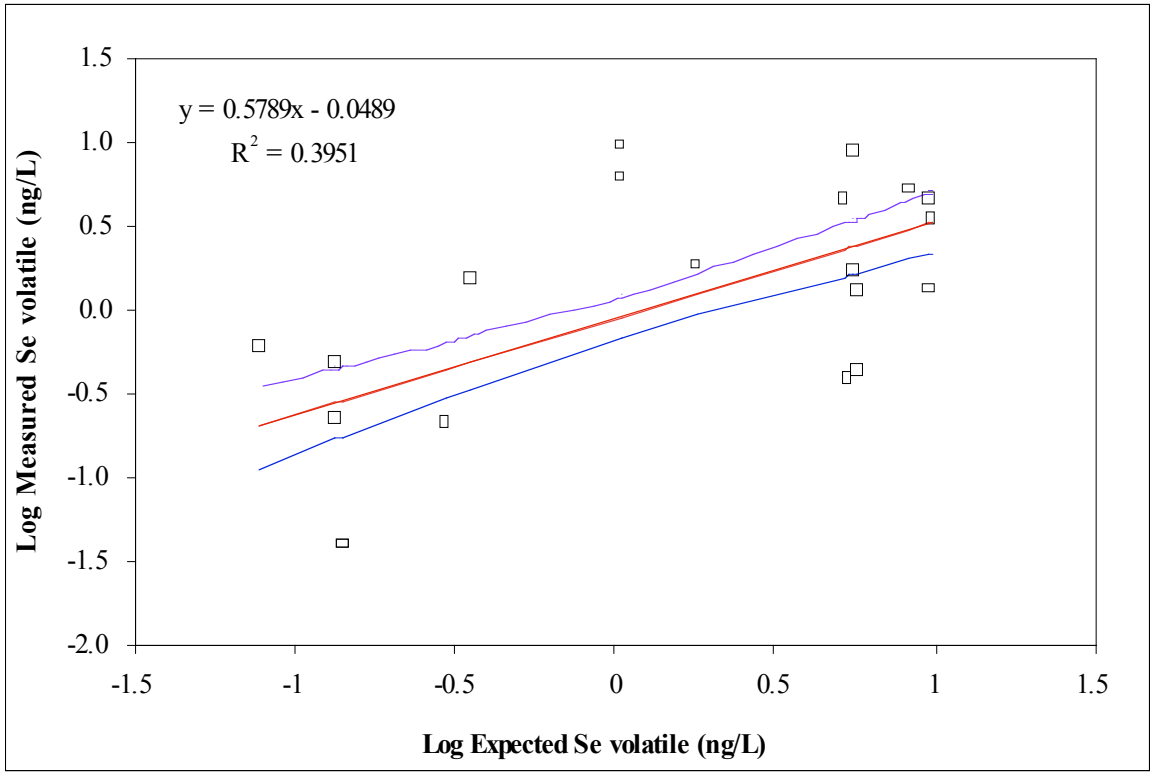


Figure 17e. Determination of the 68% confidence interval using expected vs. measured data of near surface volatile Se concentrations. Expected values obtained from the sinusoidal function. Top: log values in a normal scale. Bottom: Arithmetic values in a og scale.



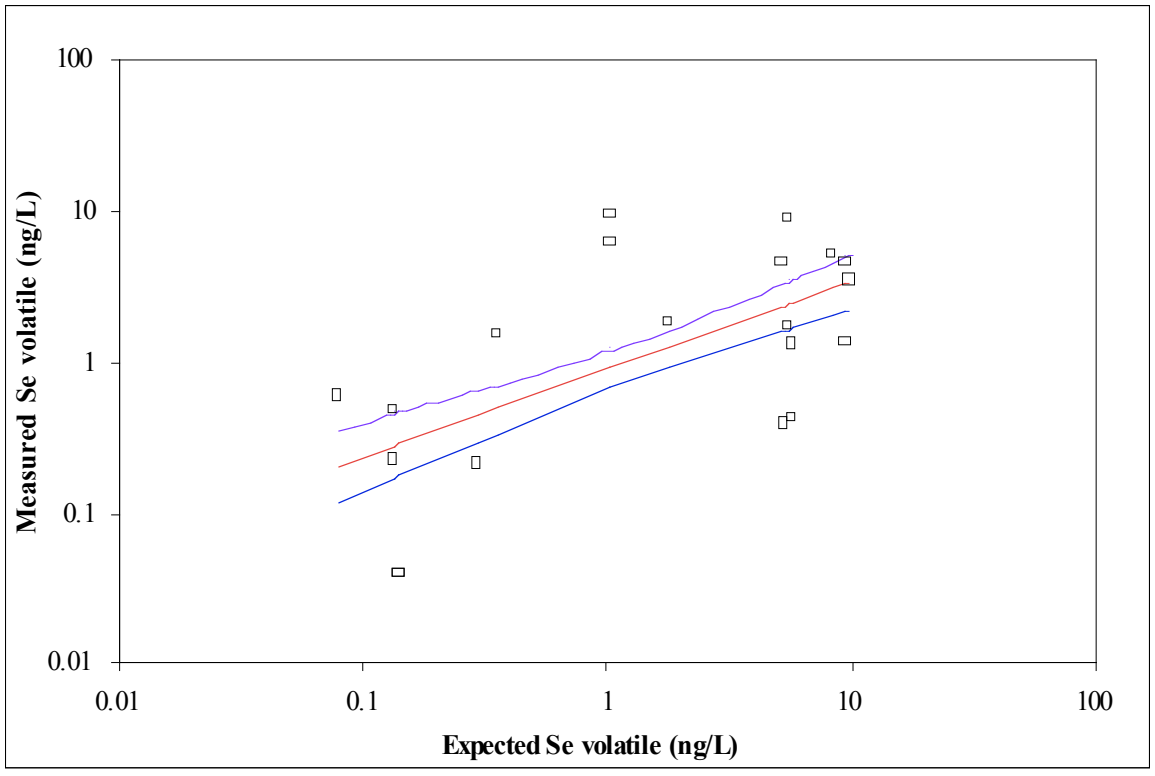


Figure 18a. Sedimentation flux and Se sedimentation flux at site 2267 (shallow site). The Se flux values plotted were multiplied by 10^6. To obtain the actual values, multiply by 10^{-6}. Period of measurement was February 2006 to July 2007.

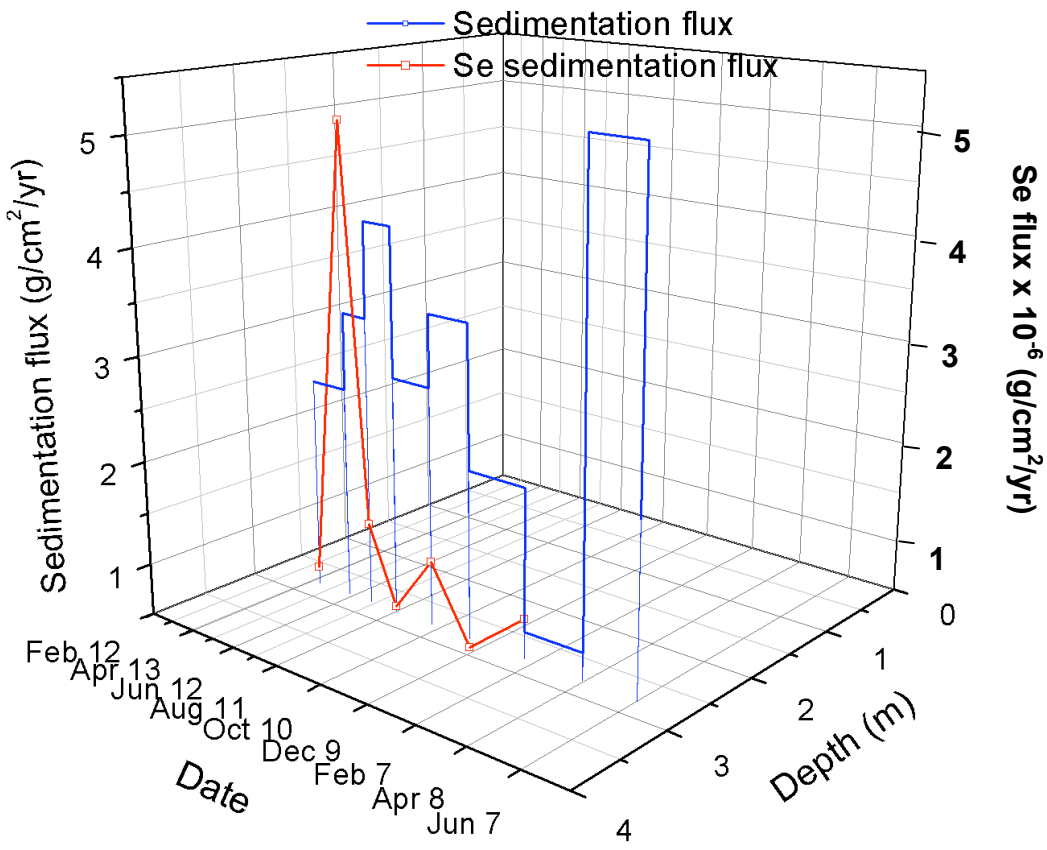


Figure 18b. Sedimentation flux and Se sedimentation flux at site 2565 (deep site). The Se flux values plotted were multiplied by 10^{7}. To obtain the actual values, multiply by $10^{=7}$. Period of measurement was February 2006 to July 2007.

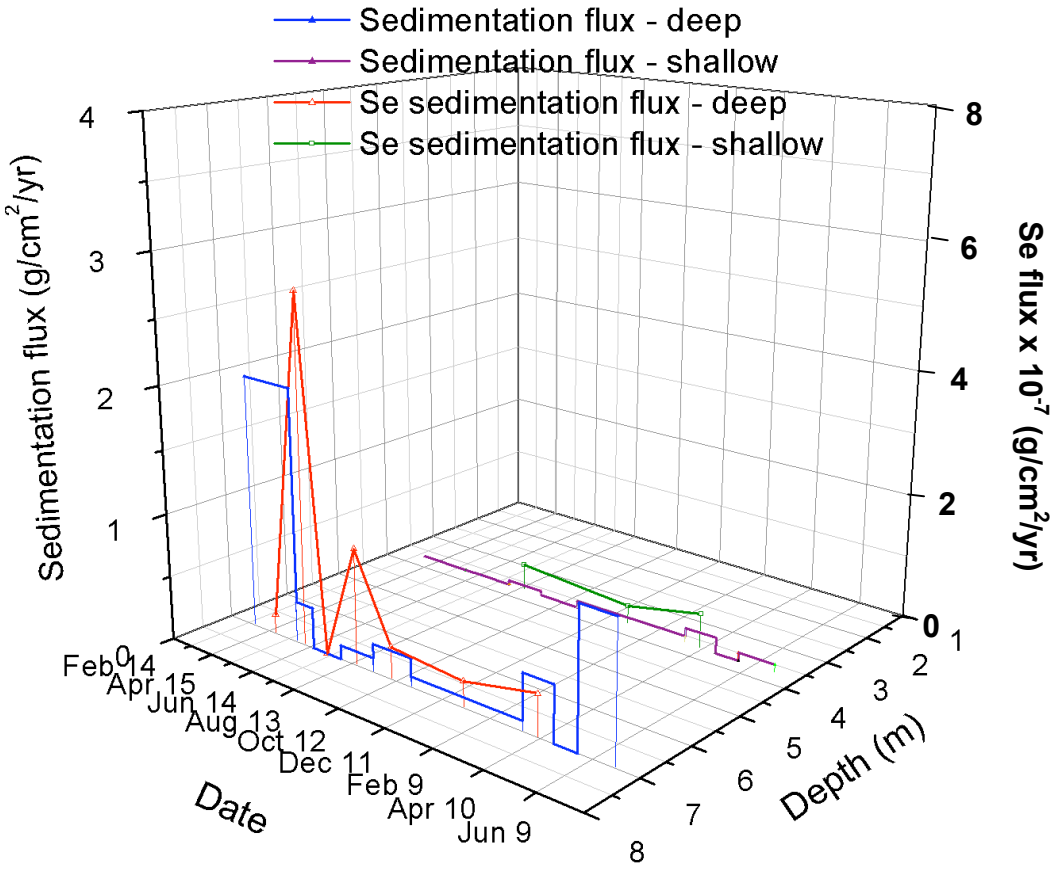


Figure 18c. Sedimentation flux and Se sedimentation flux at site 3510 (deep site). The Se flux values plotted were multiplied by 10^{8}. To obtain the actual values, multiply by 10^{-8}. Period of measurement was February 2006 to July 2007.

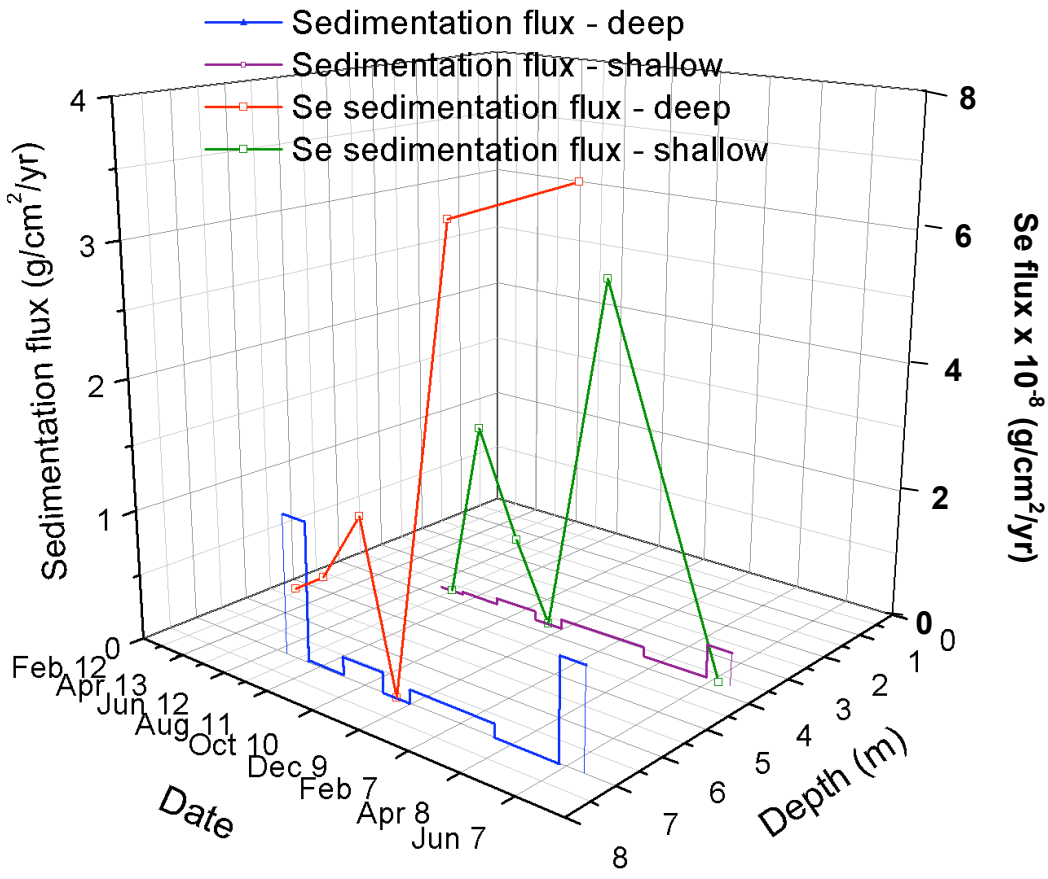


Figure 19. Total ^{210}Pb and ^{226}Ra activity, in disintegrations per minute per gram, versus depth in sediment core 3510 BOX. Horizontal error bars depict 1 sigma uncertainty in measured activity based on counting statistics.

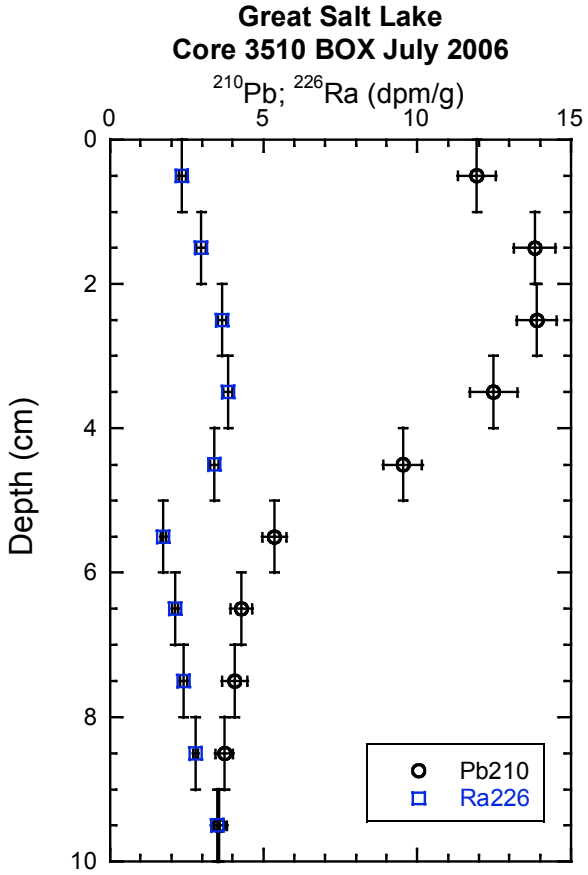


Figure 20. Natural logarithm of unsupported ^{210}Pb activity versus cumulative dry sediment mass in sediment core 3510 BOX. Unsupported ^{210}Pb is the difference between total ^{210}Pb and its long-lived progenitor, ^{226}Ra. Only data with measurable unsupported ^{210}Pb are presented. Solid line represents linear regression of the data used to derive sediment mass accumulation rate

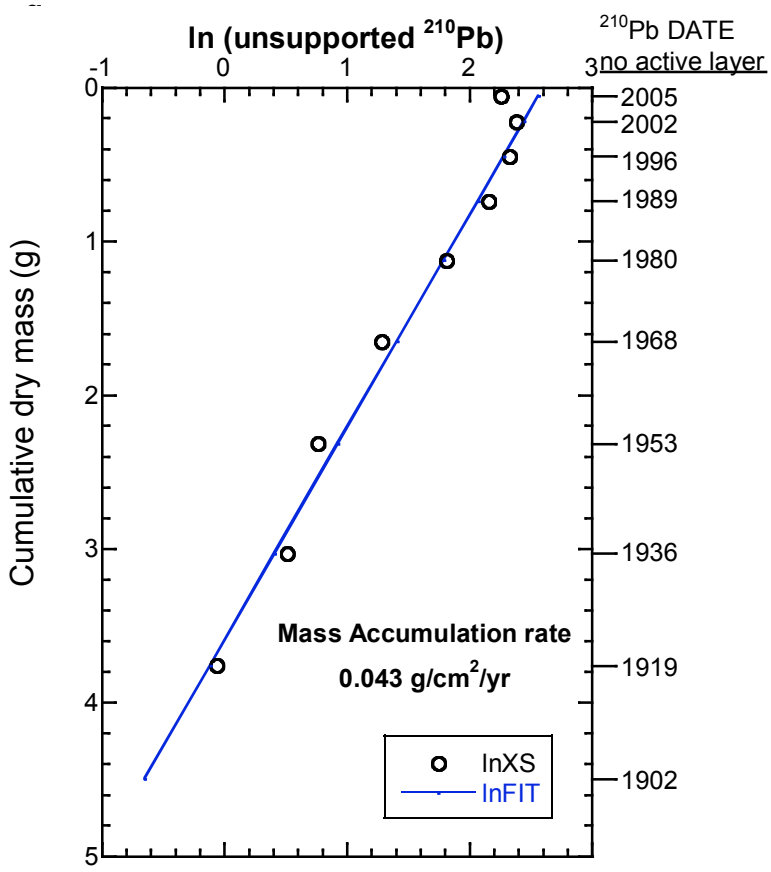


Figure 21a. Sediment deposition date as function of depth based on the sediment mass accumulations estimated from ^{210}Pb using the CF-CS method, with and without correction for 2-cm active layer. Non-linearity in deposition date versus depth is the result of sediment compaction.

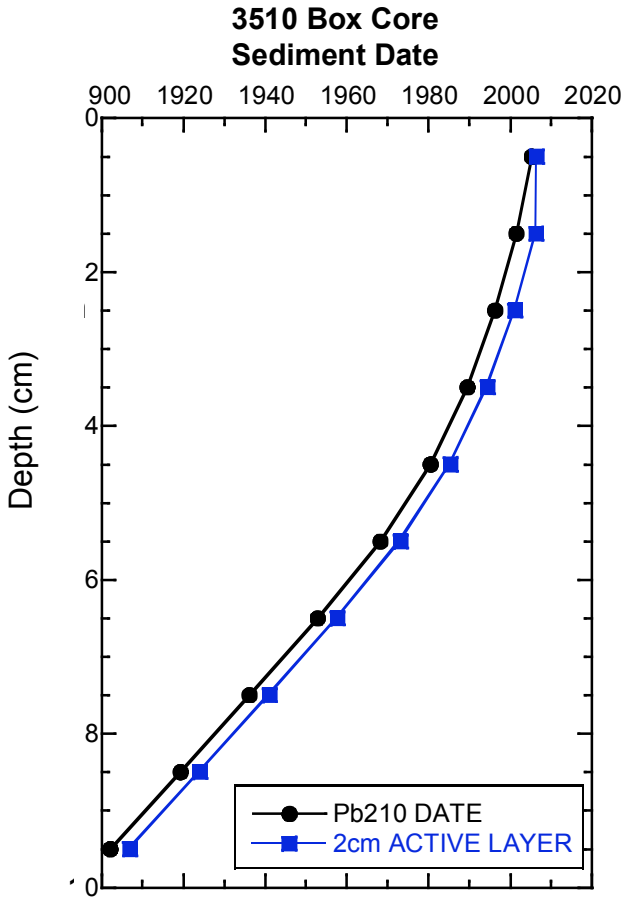


Figure 21b. ^{7}Be activity, in disintegrations per minute per gram, versus depth in sediment core 3510-BOX. Horizontal error bars depict 1 sigma uncertainty in measured activity based on counting statistics.

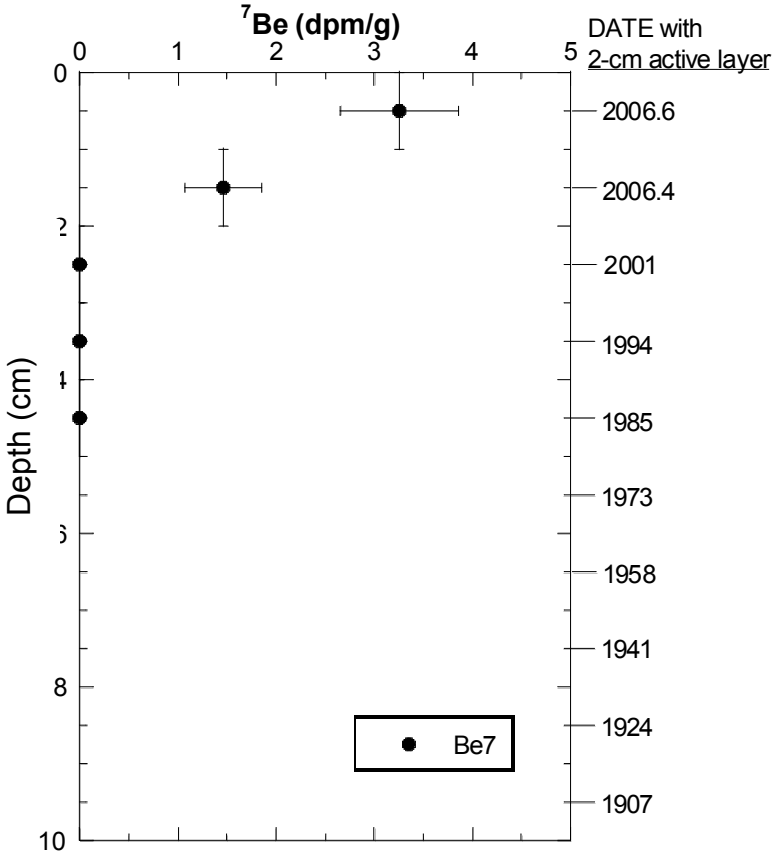


Figure 22. ^{137}Cs activities with depth in sediment core 3510-BOX.

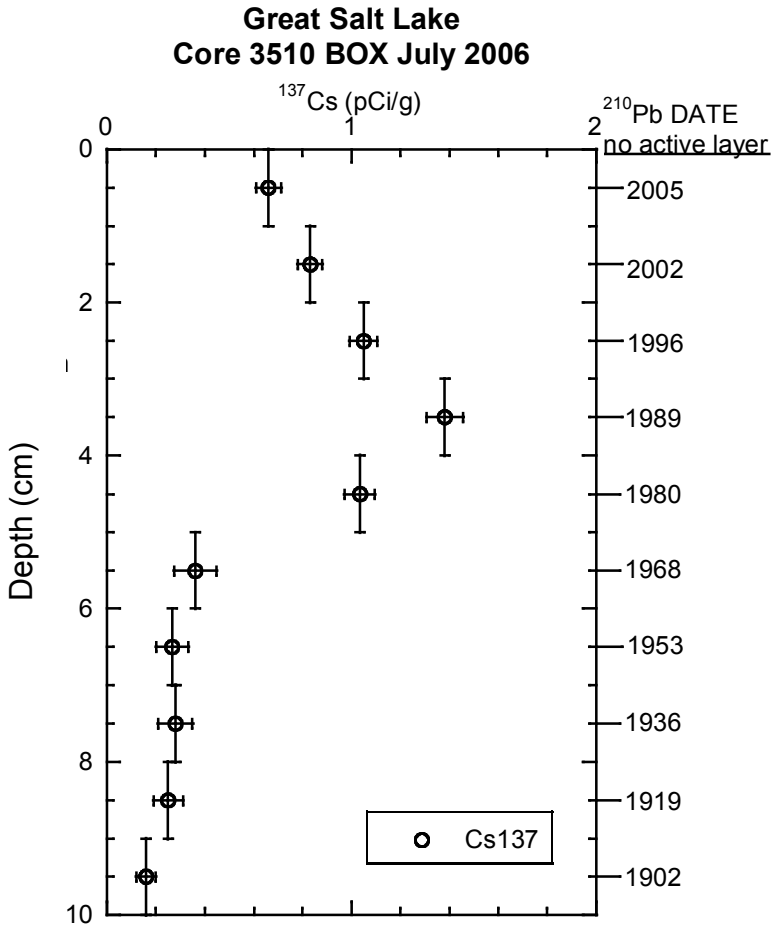


Figure 23. Total ^{210}Pb and ^{226}Ra activity, in disintegrations per minute per gram, versus depth in sediment core 2267. Horizontal error bars depict 1 sigma uncertainty in measured activity based on counting statistics.

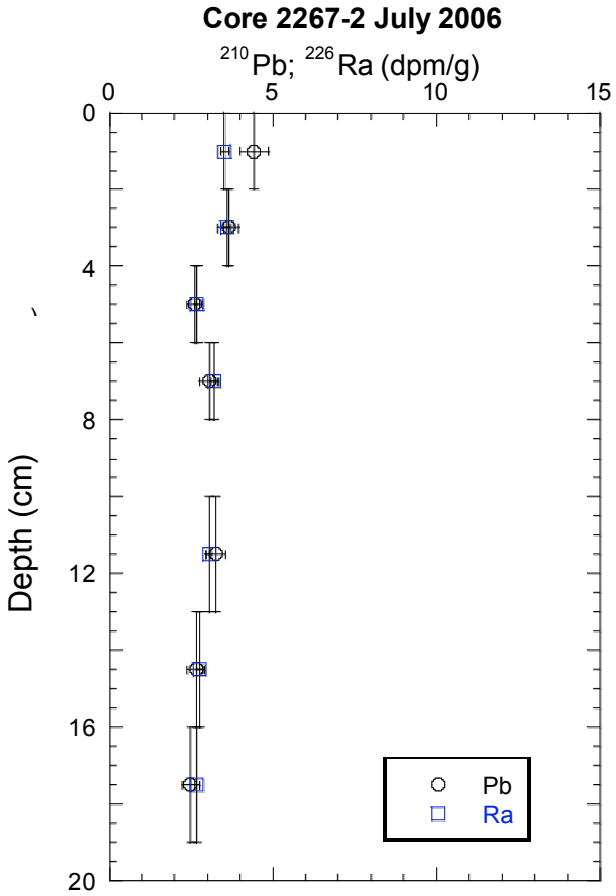


Figure 24. Total ^{210}Pb and ^{226}Ra activity, in disintegrations per minute per gram, versus depth in sediment core 2565. Horizontal error bars depict 1 sigma uncertainty in measured activity based on counting statistics.

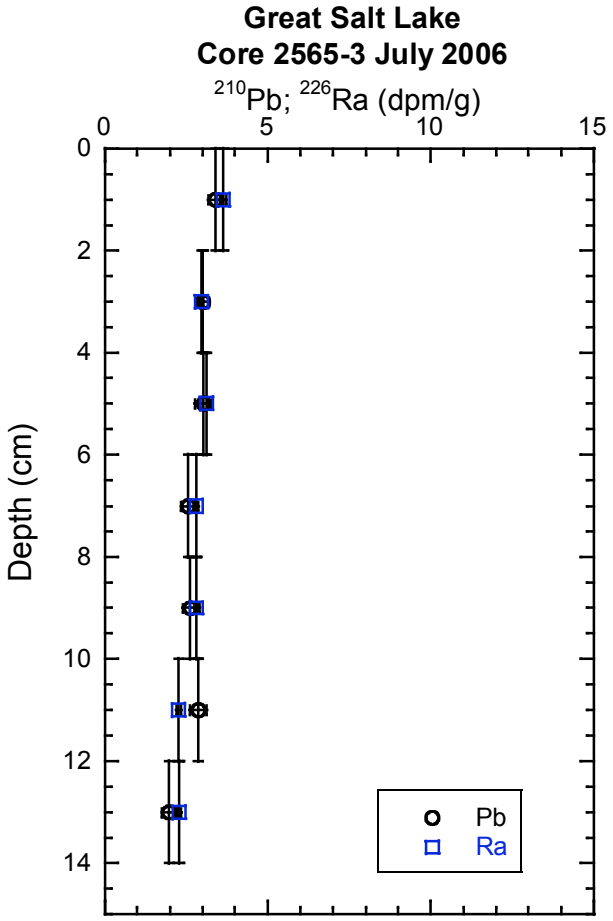


Figure 25. ^{137}Cs activity, in picoCuries per gram, and ^{7}Be, in disintegrations per minute per gram, versus sediment depth in sediment cores 2267.

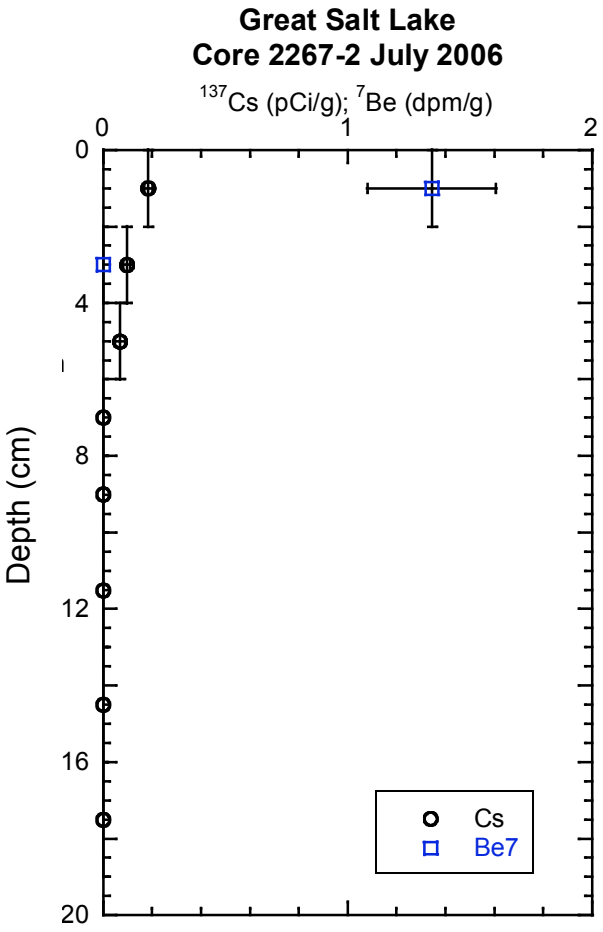


Figure 26. ^{137}Cs activity, in picoCuries per gram, and ^{7}Be, in disintegrations per minute per gram, versus sediment depth in sediment cores 2565.

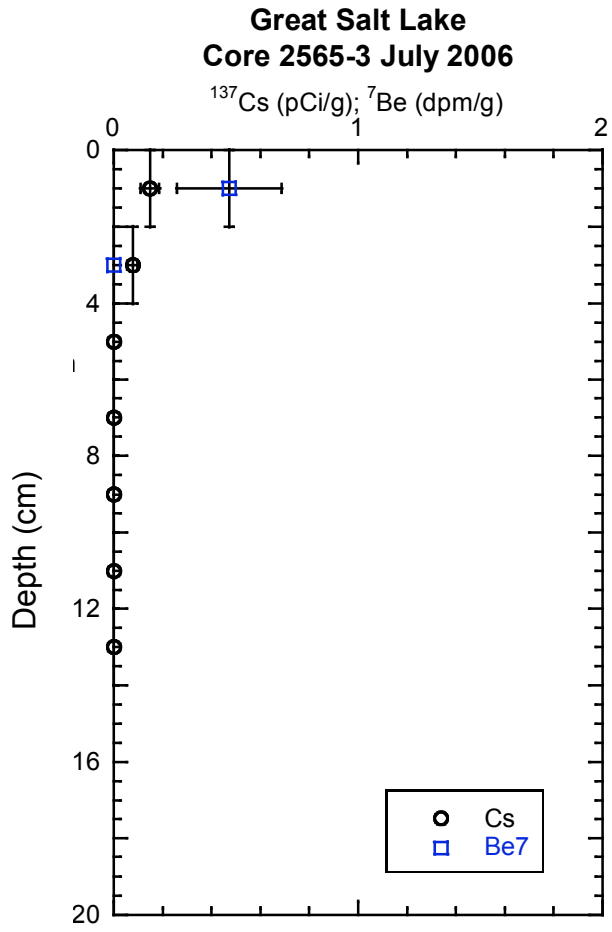


Figure 27a. Shallow core results and Holocene thickness contours

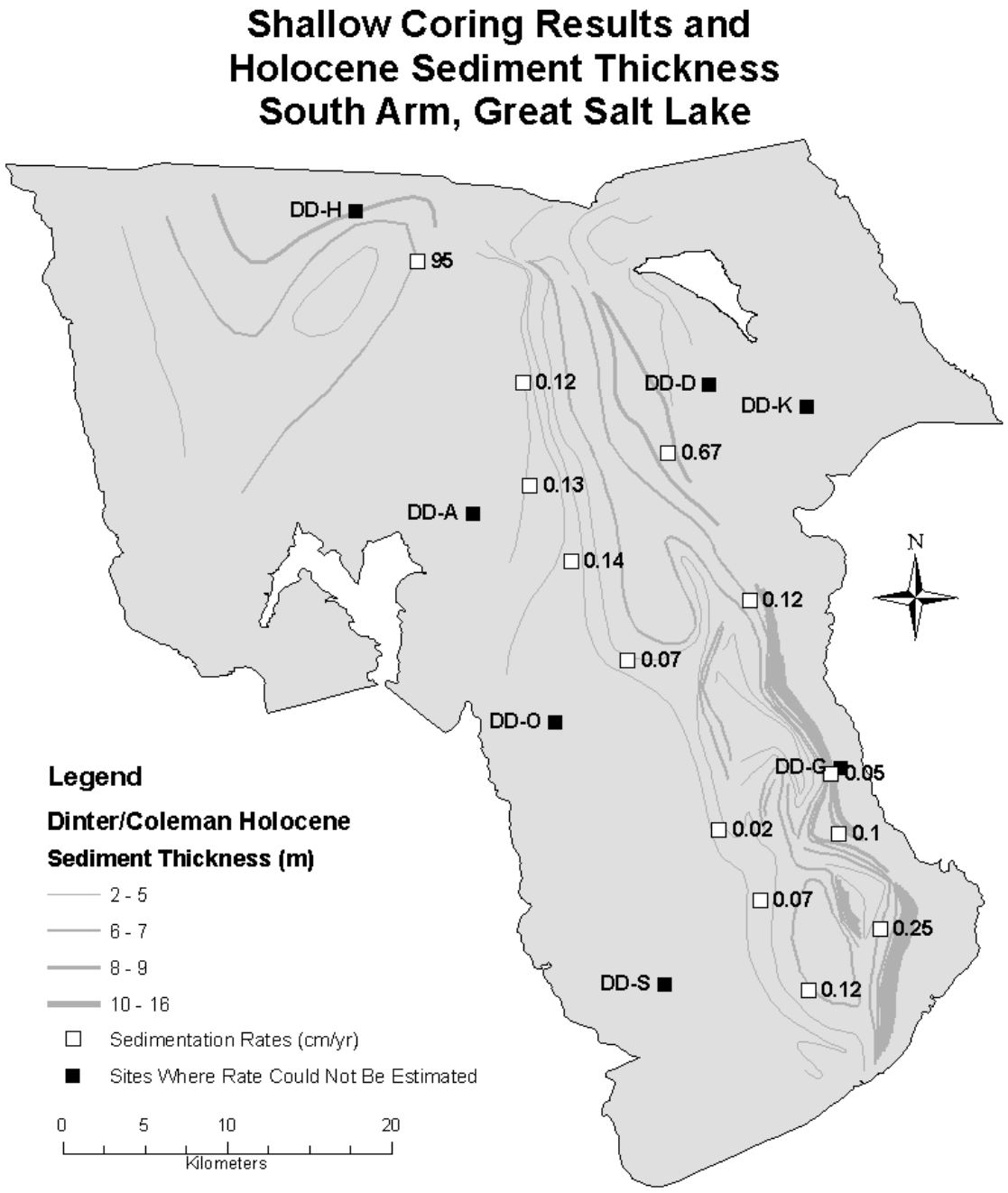


Figure 27b. Qualitative Sedimentation Zones

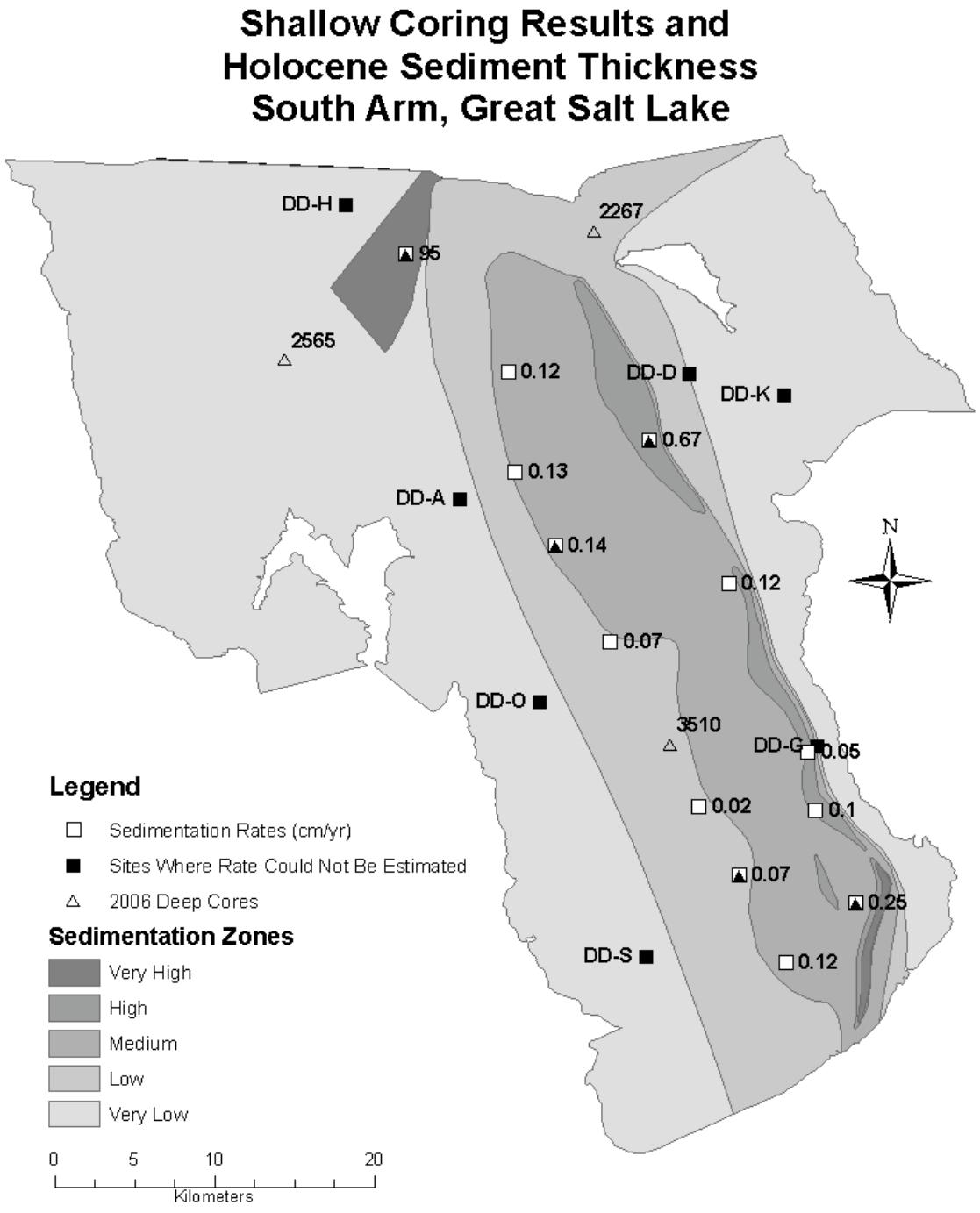


Figure 27c. Se concentration profile in cores from site 3510.

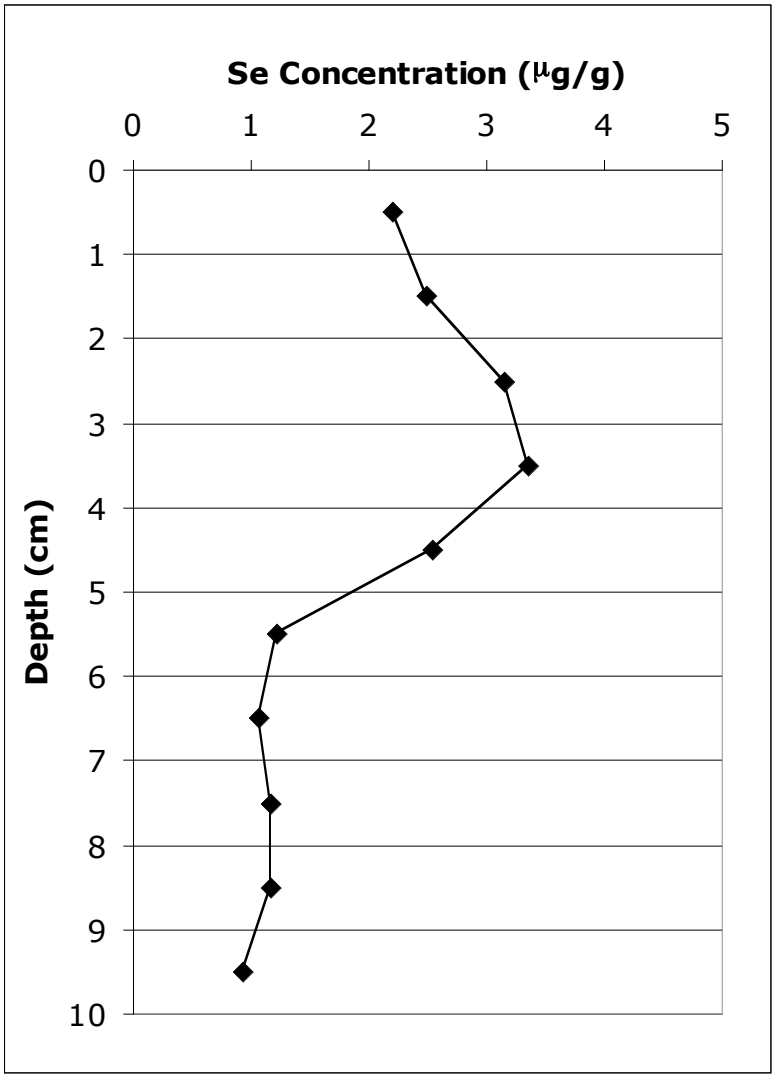


Figure 27d. Standard deviations as a function of the number of randomized MAR values assessed.

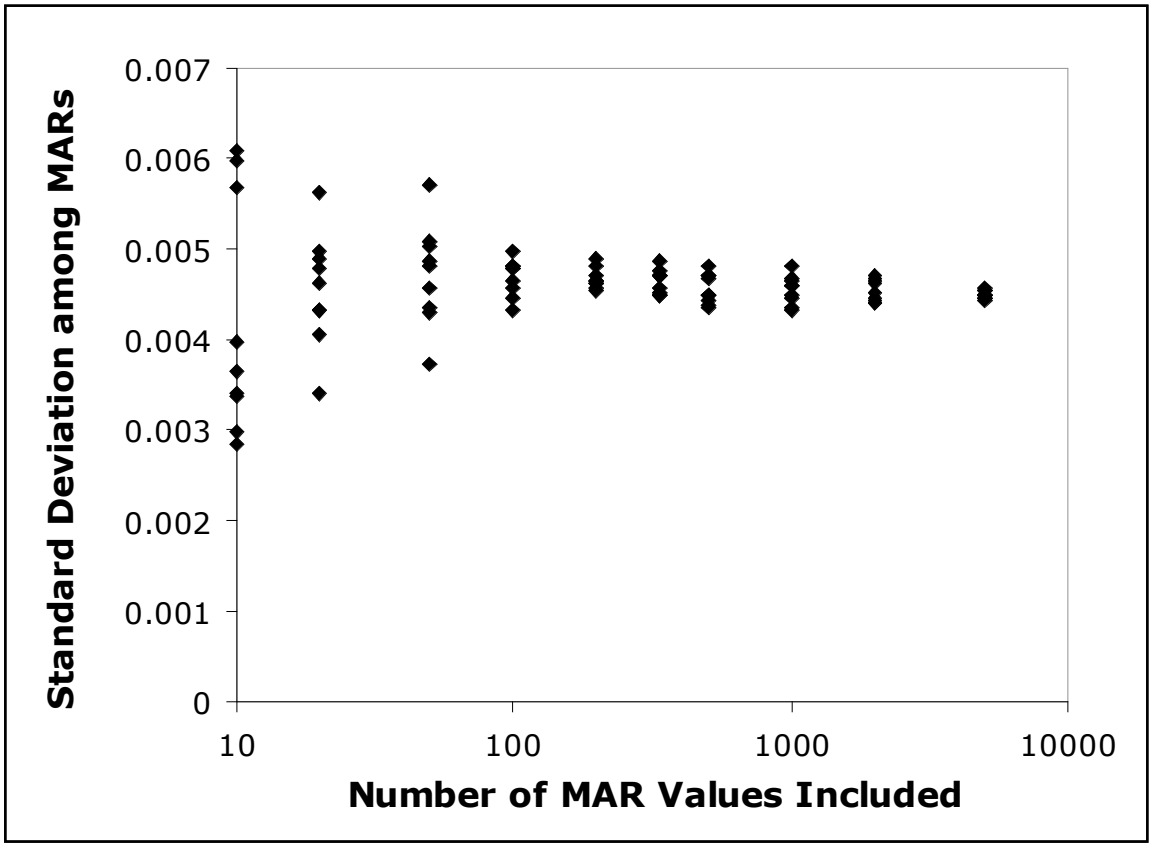


Figure 28. Major and minor elements distribution chronologically at site 3510 core

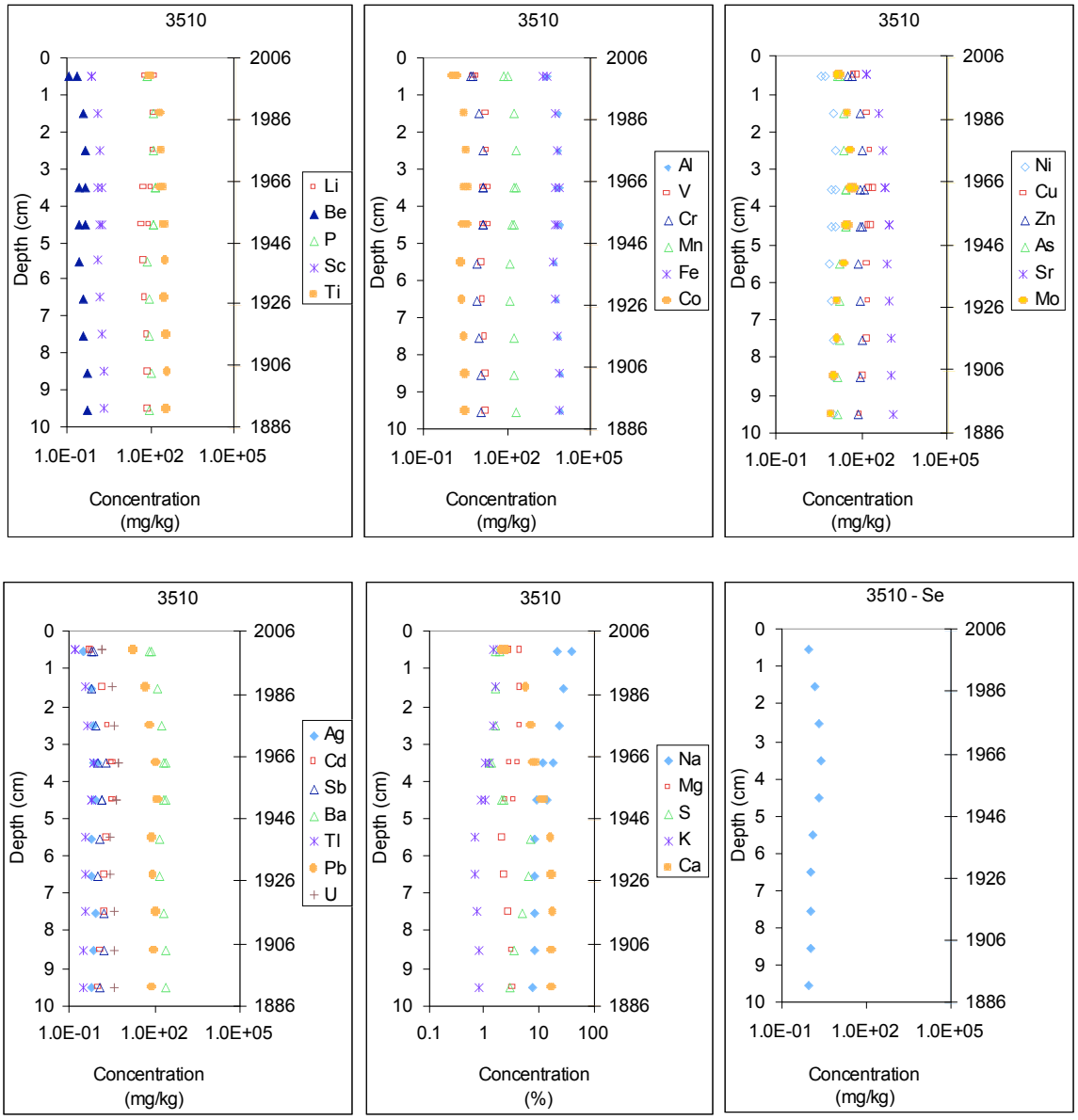


Figure 29. Major and minor elements distribution at site 2565 core

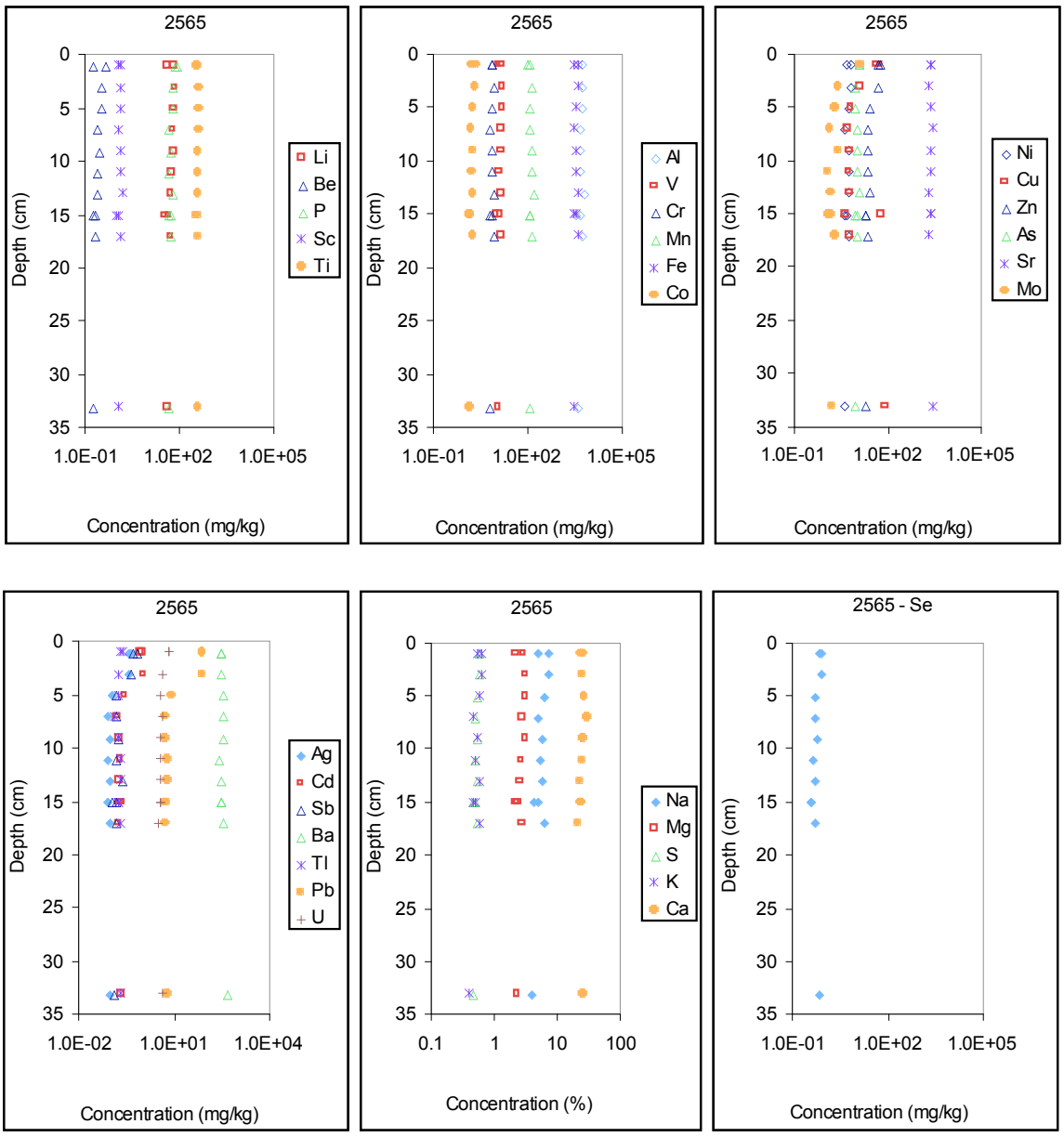


Figure 30. Major and minor elements distribution at site 2267 core

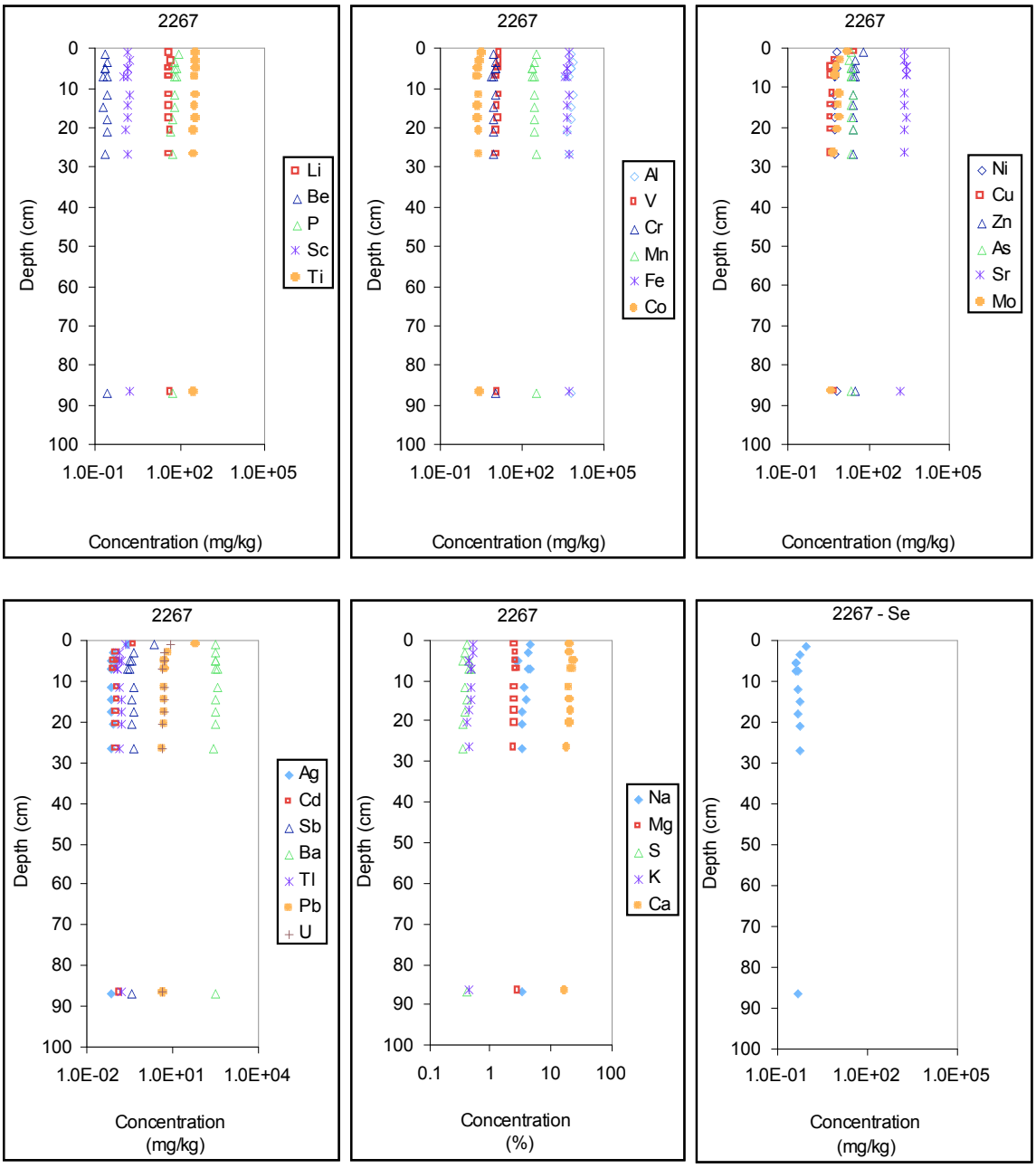


Figure 31a. Temperature variations at site 2565 during summer and fall, 2006. Warmer colors indicate shallow thermistors and cooler colors indicate deeper thermistors.

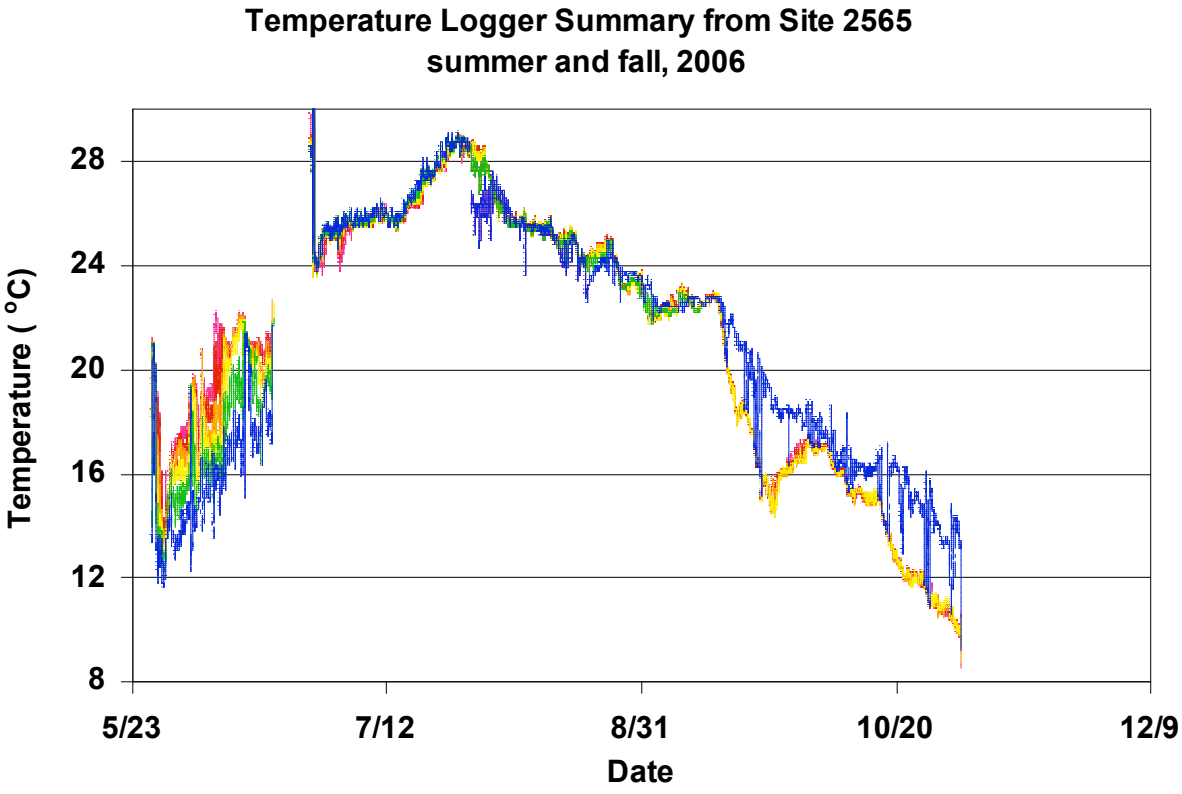


Figure 31b. Temperature variations at site 3510 during summer and fall, 2006. Warmer colors indicate shallow thermistors and cooler colors indicate deeper thermistors.

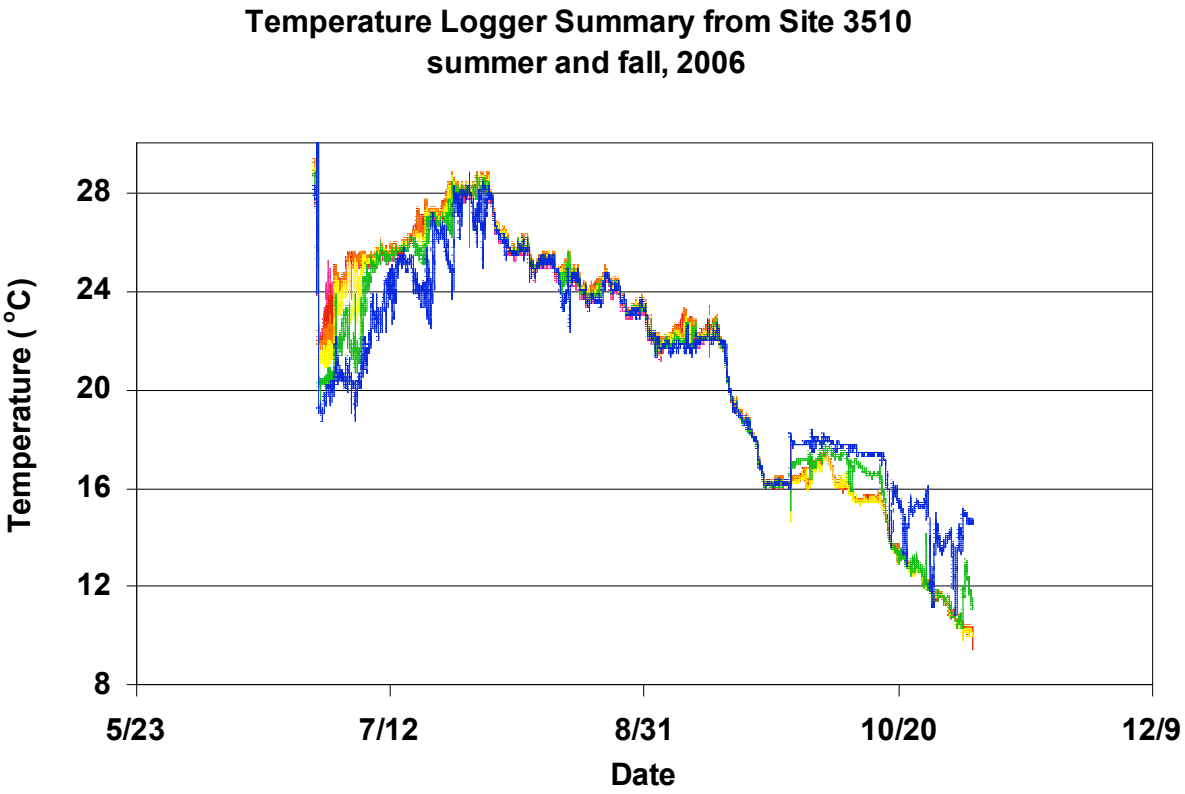


Figure 31c. Multiple temperature equilibration events at site 2565 during April, 2007 correlate with lake level fluctuations at Saltair Gauge (bottom series in plot).

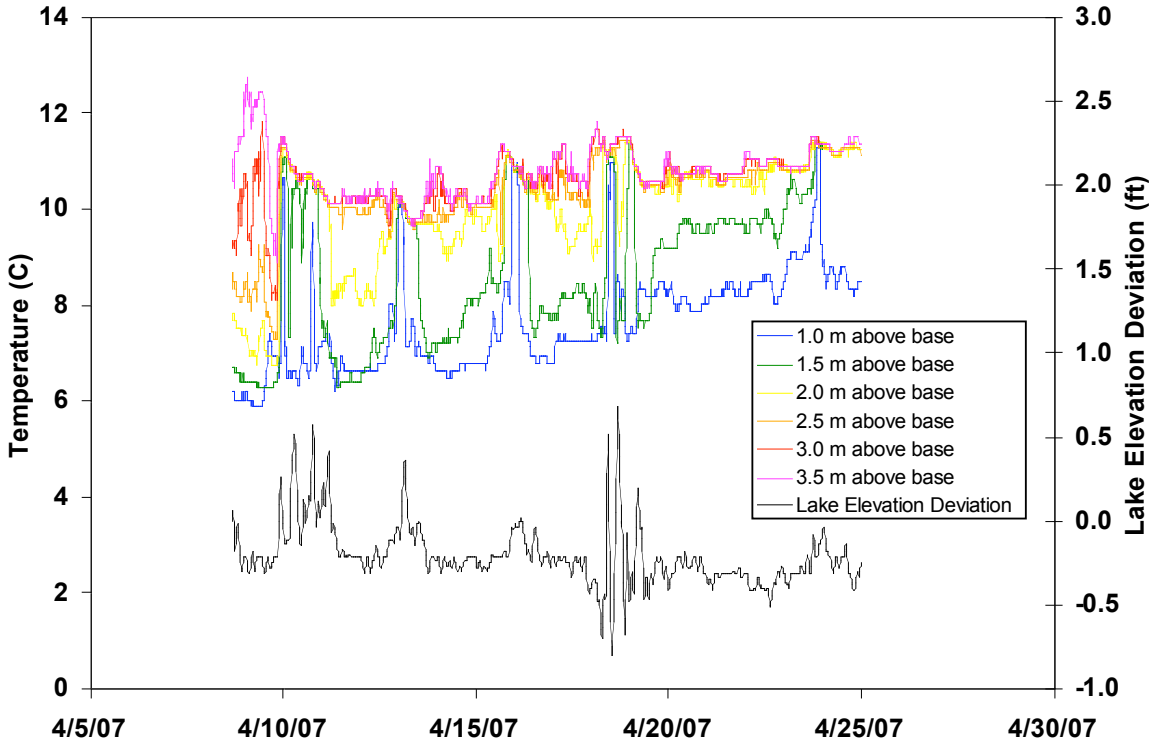


Figure 32a. June temperature record from site 2565, tick marks represent midnight (MDT) and values represent distance above lake bottom. Lowest figure shows wind speed (black) and wind direction (orange) at Hat Island.

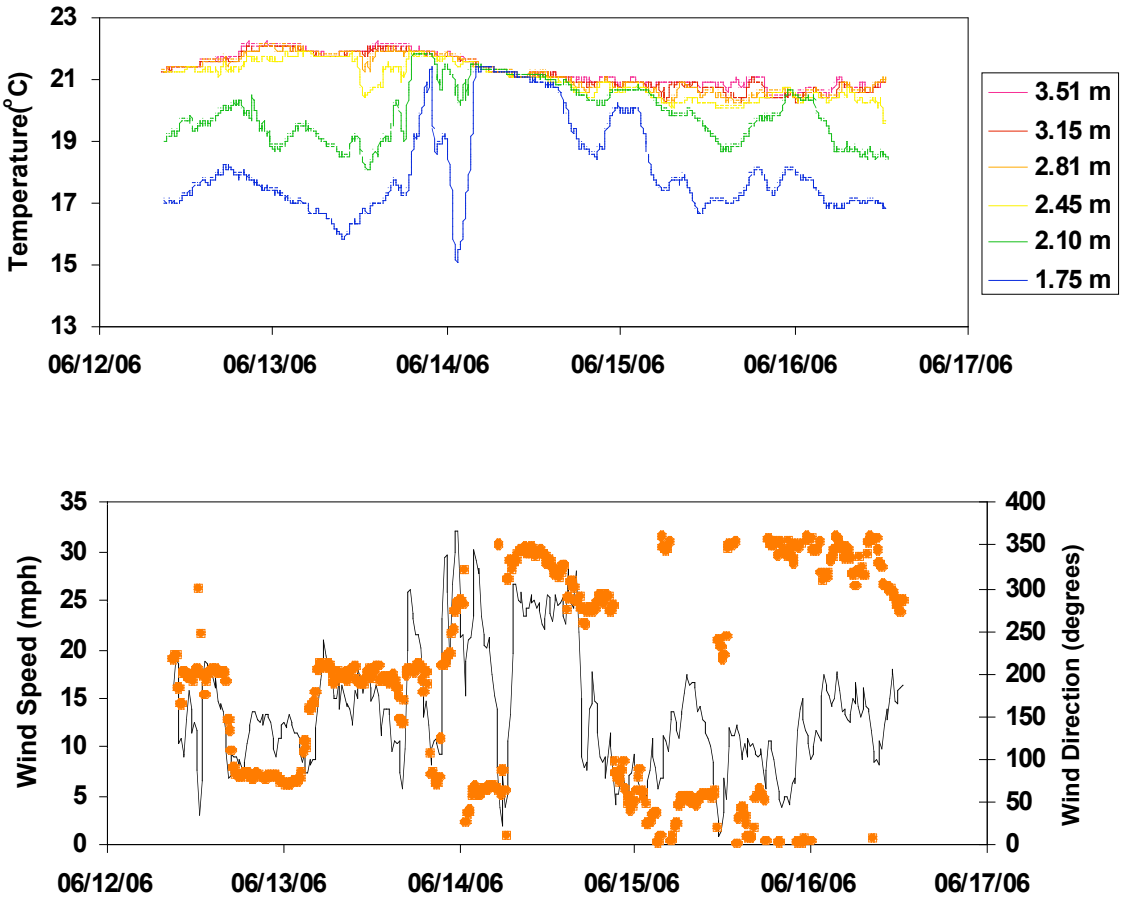


Figure 32b. October temperature records 3510 (top) and 2565 (middle). Tick marks represent midnight (MDT) and values represent distance above lake bottom. Lowest figure shows wind speed (black) and wind direction (orange) at Hat Island.

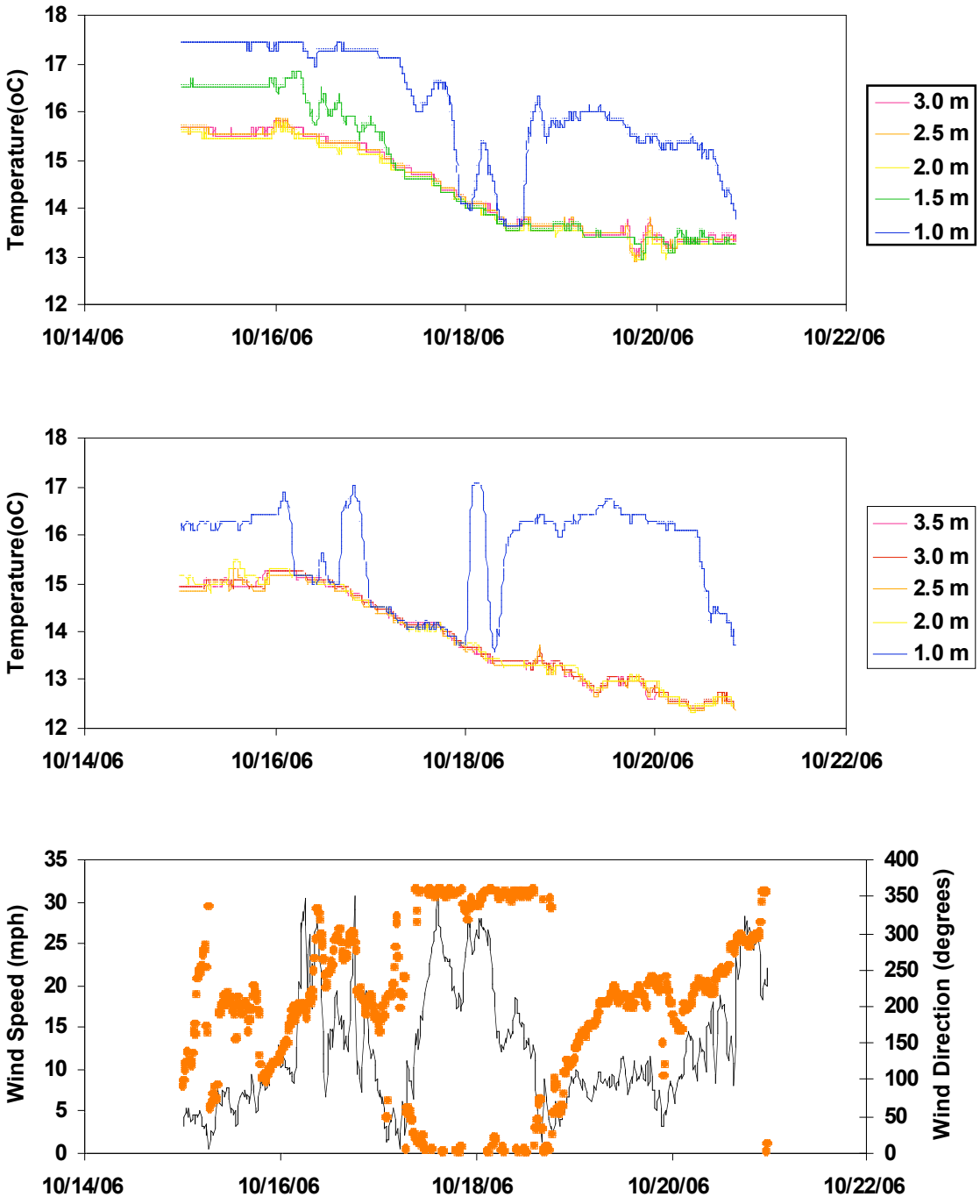


Figure 33a. Lake level oscillation as a result of a strong wind event. Note the inverse correlation between the lake level at opposite ends of the lake (Lin, 1977).

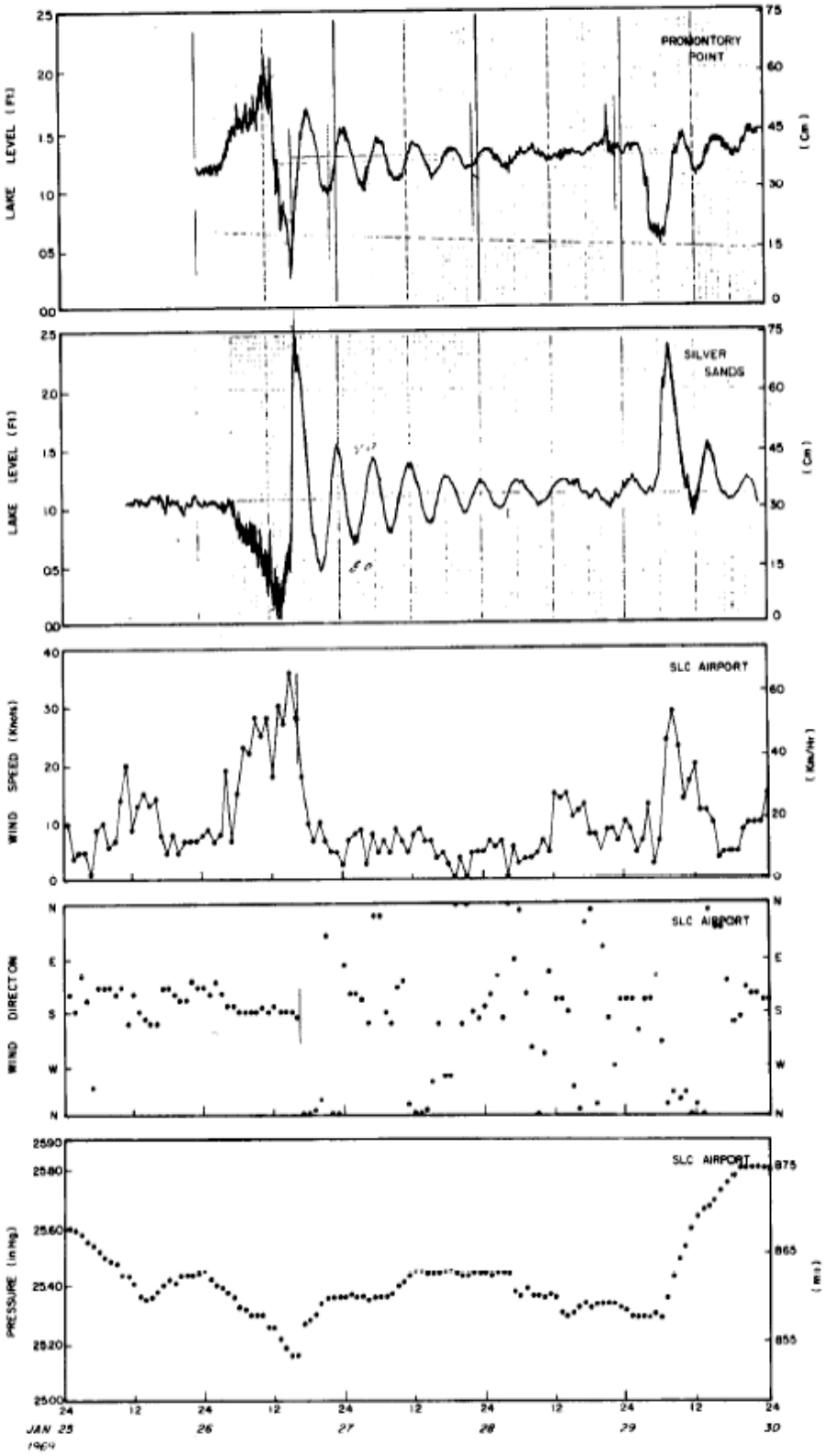


Figure 33b. Magnitude of seiche across the Great Salt Lake (Lin, 1977).

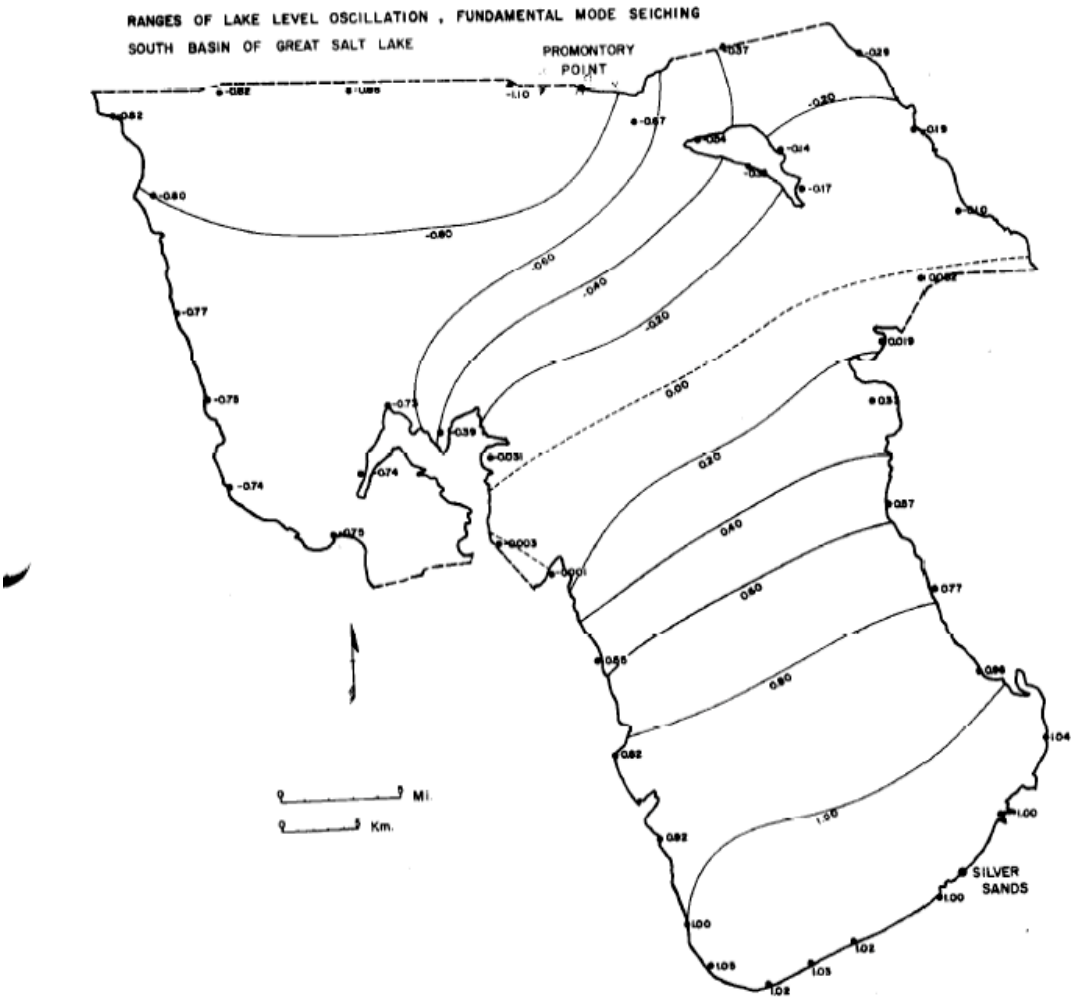


Figure 34a. Initiation of site 2565 temperature equilibration event in June, 2006 corresponds to fluctuations at USGS Saltair Gauge Station. Values on legend are distance above the bottom of the lake.

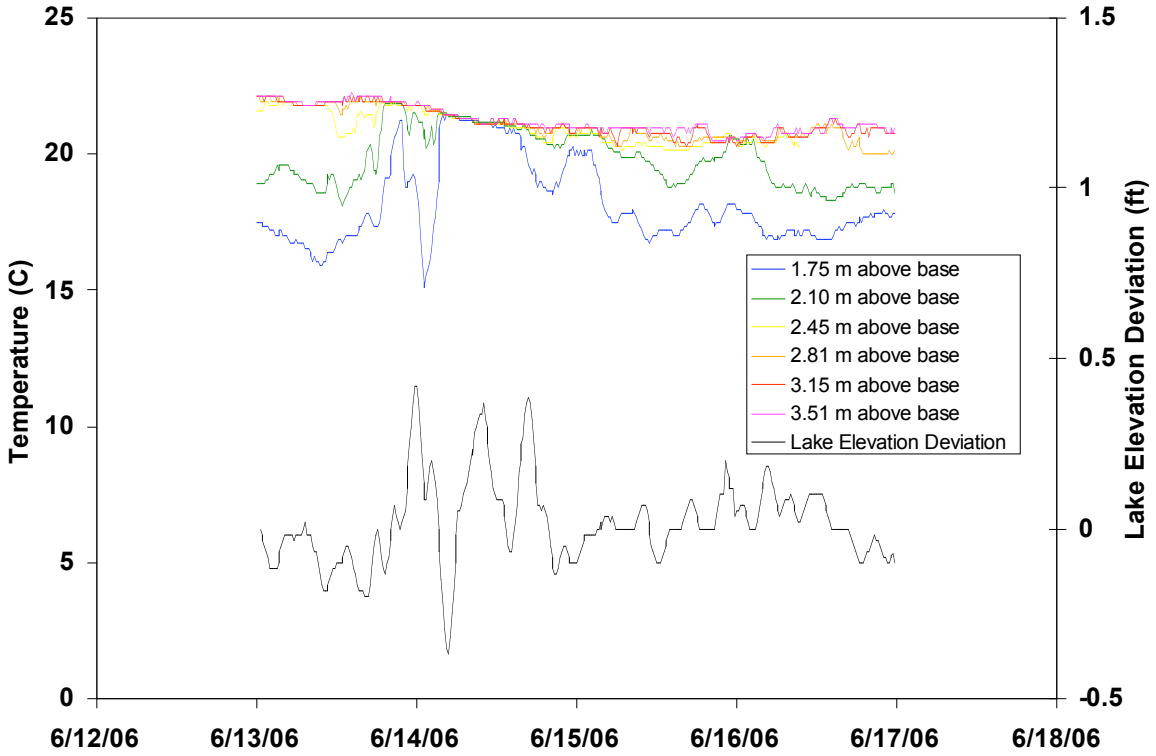


Figure 34b. Initiation of the October, 2006 temperature equilibration event at site 3510 occurred hours after rise in lake elevation at Saltair Gauge. Values on legend are distance above the bottom of the lake.

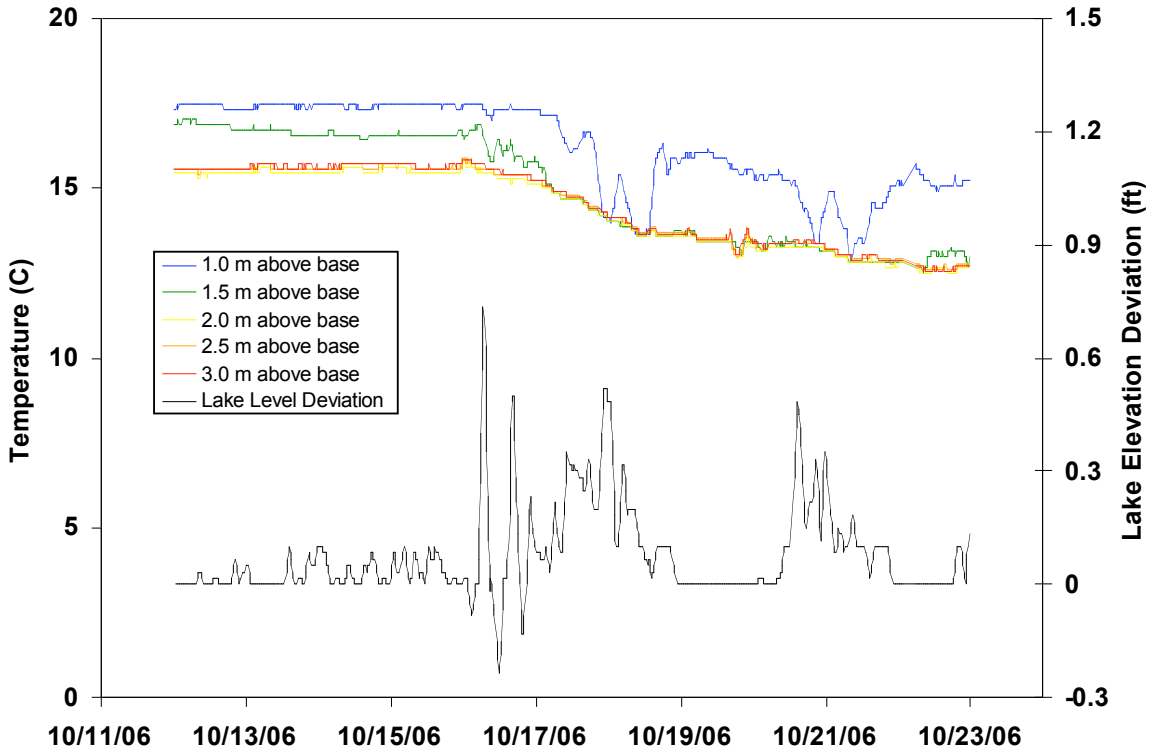


Figure 35a. Selenium concentration in the bed sediments beneath the deep brine layer as analyzed by contract lab (LET) and University of Utah ICP-MS lab.

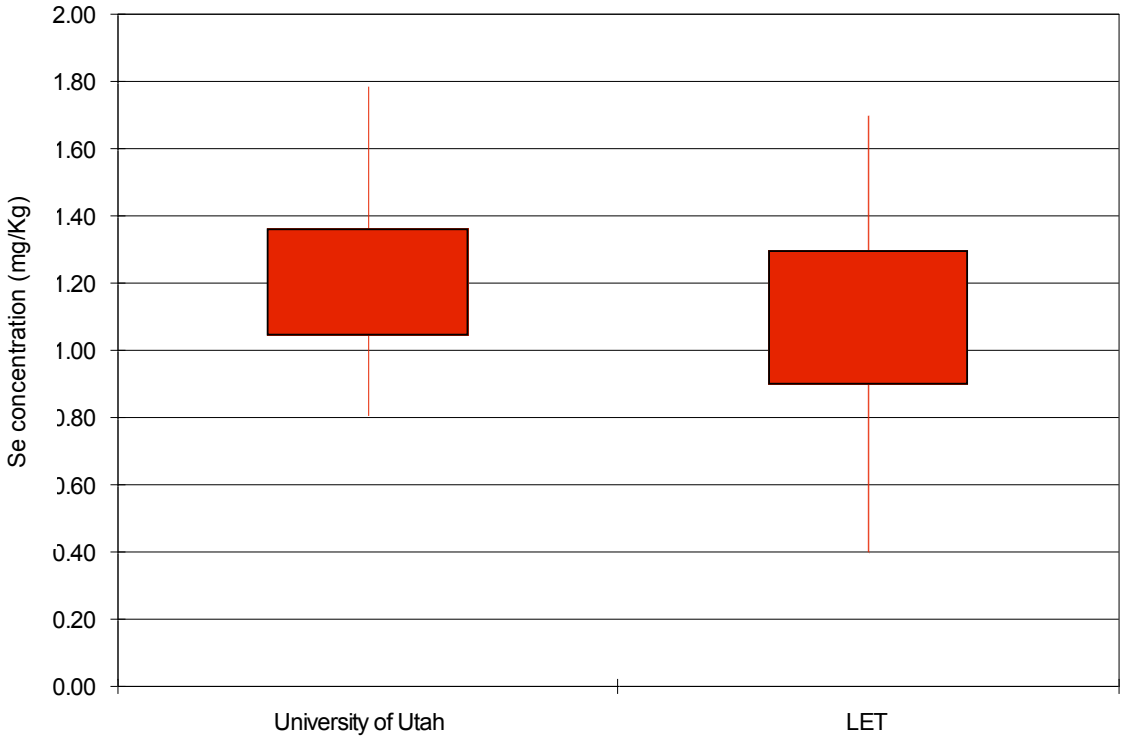


Figure 35b. Se solubilized into the shallow brine water during 24 hour duration batch equilibration experiments as a percent of Se extracted from the bed sediment using HCL/HNO_3.

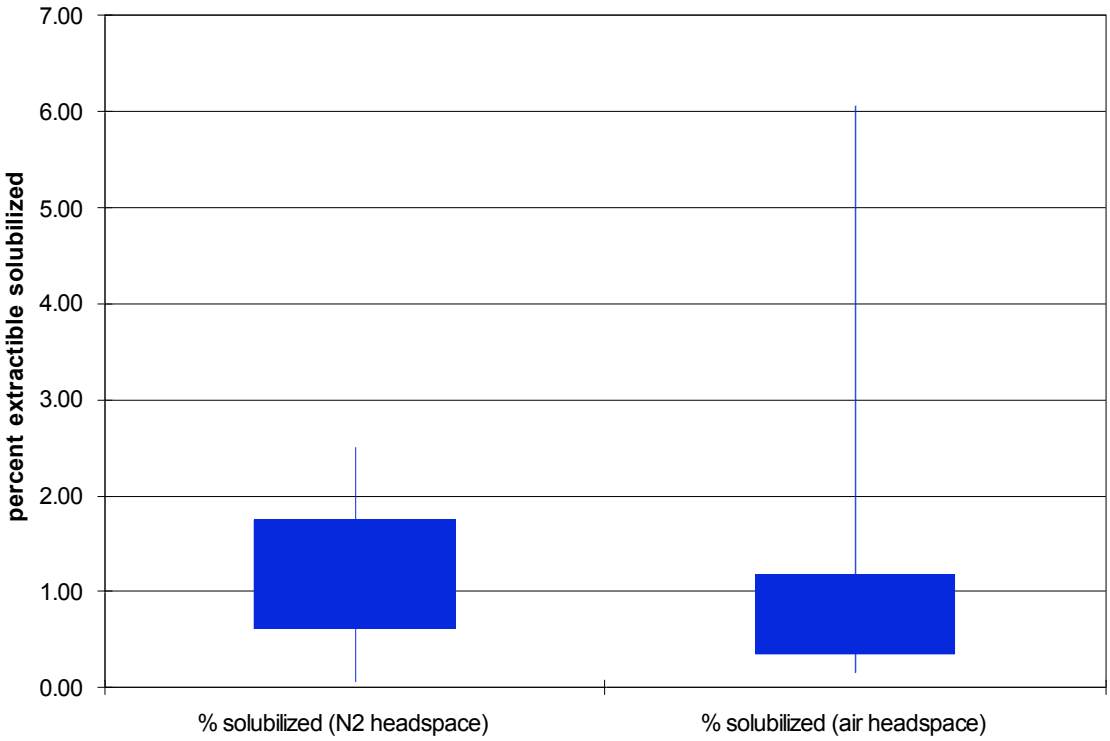


Figure 36. Resultant additional selenium concentration to 4 m of the water column after mixing event determined from results of the 24 hour duration batch test. Note the variability between samples and differences based on headspace gas.

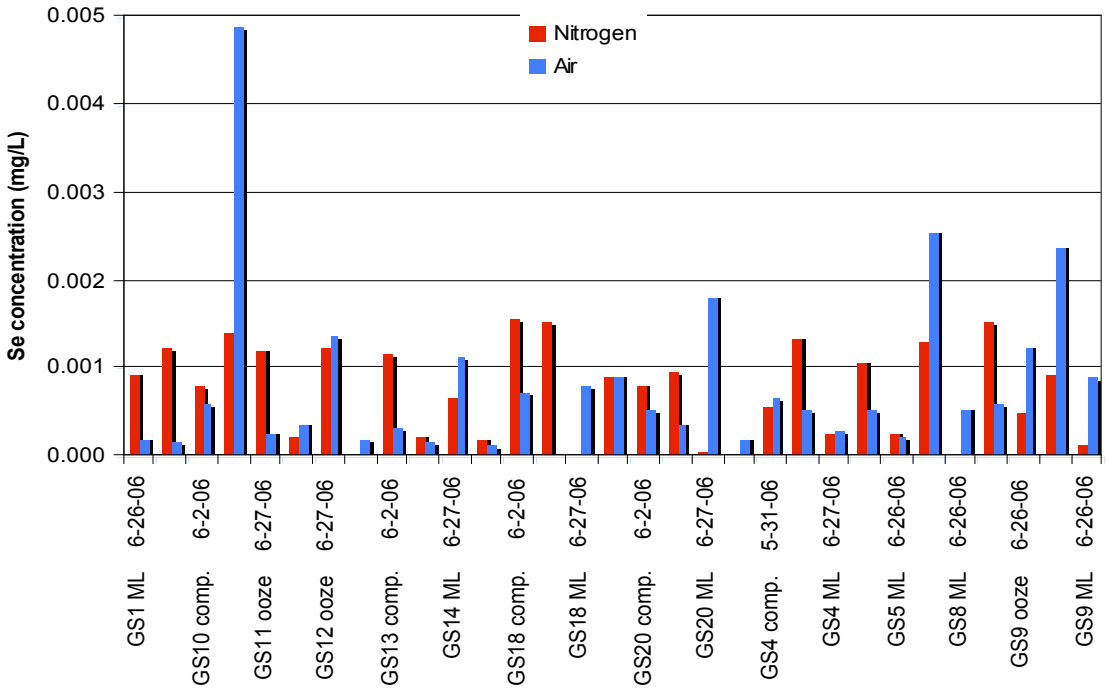


Figure 37a. Se mass (μg) released during week and month batch equilibration experiment.

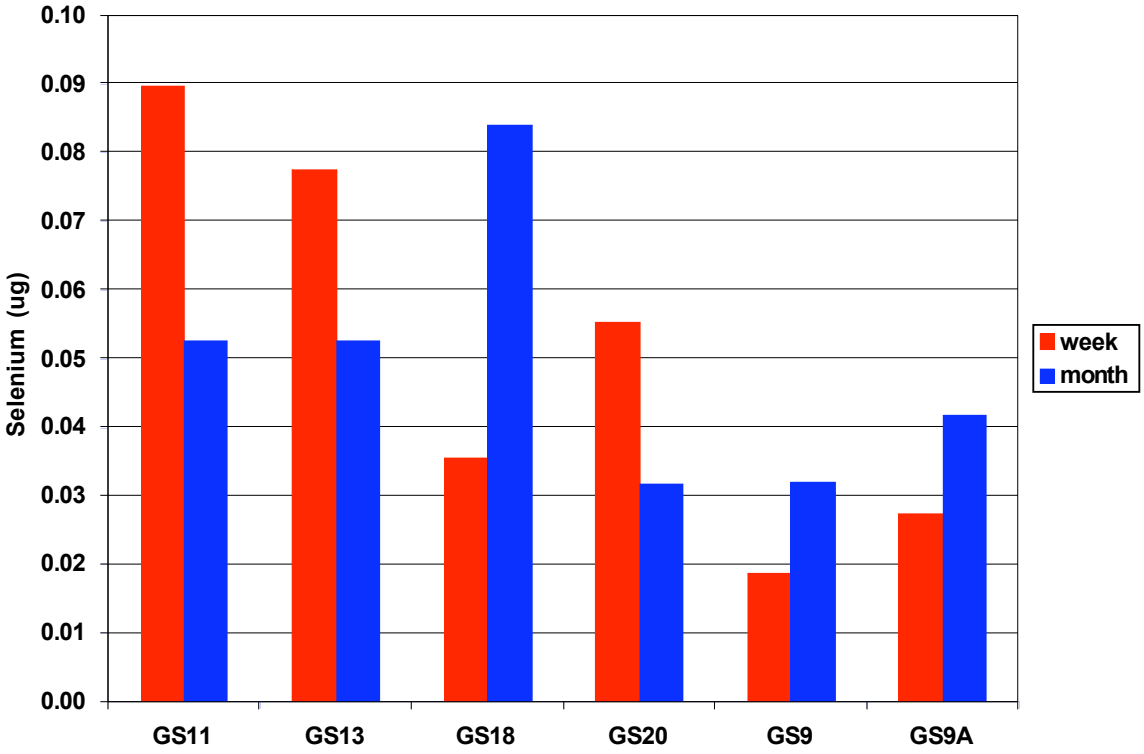


Figure 37b. Time series variation of average percent Se solubilized (of extractible) from all batch equilibration experiments. Bars represent one standard deviation on both sides of the average value.

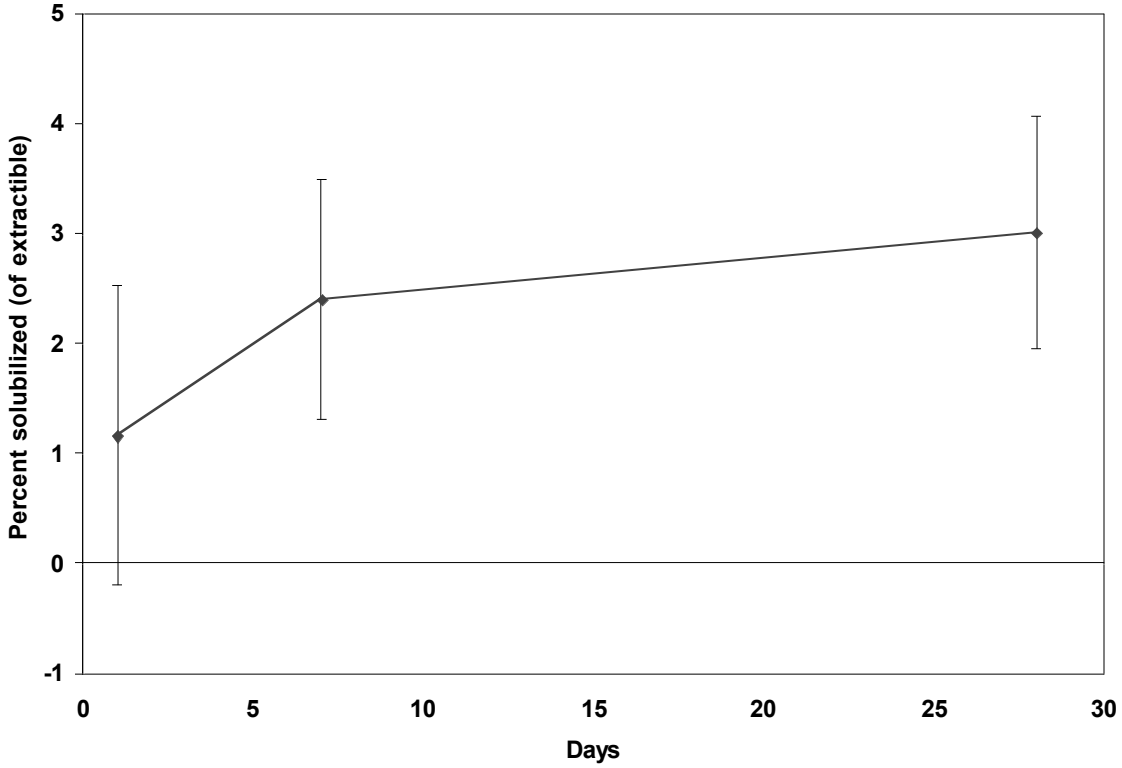


Figure 38. Selenium removal fluxes from volatilization, permanent sedimentation and brine shrimp harvesting.

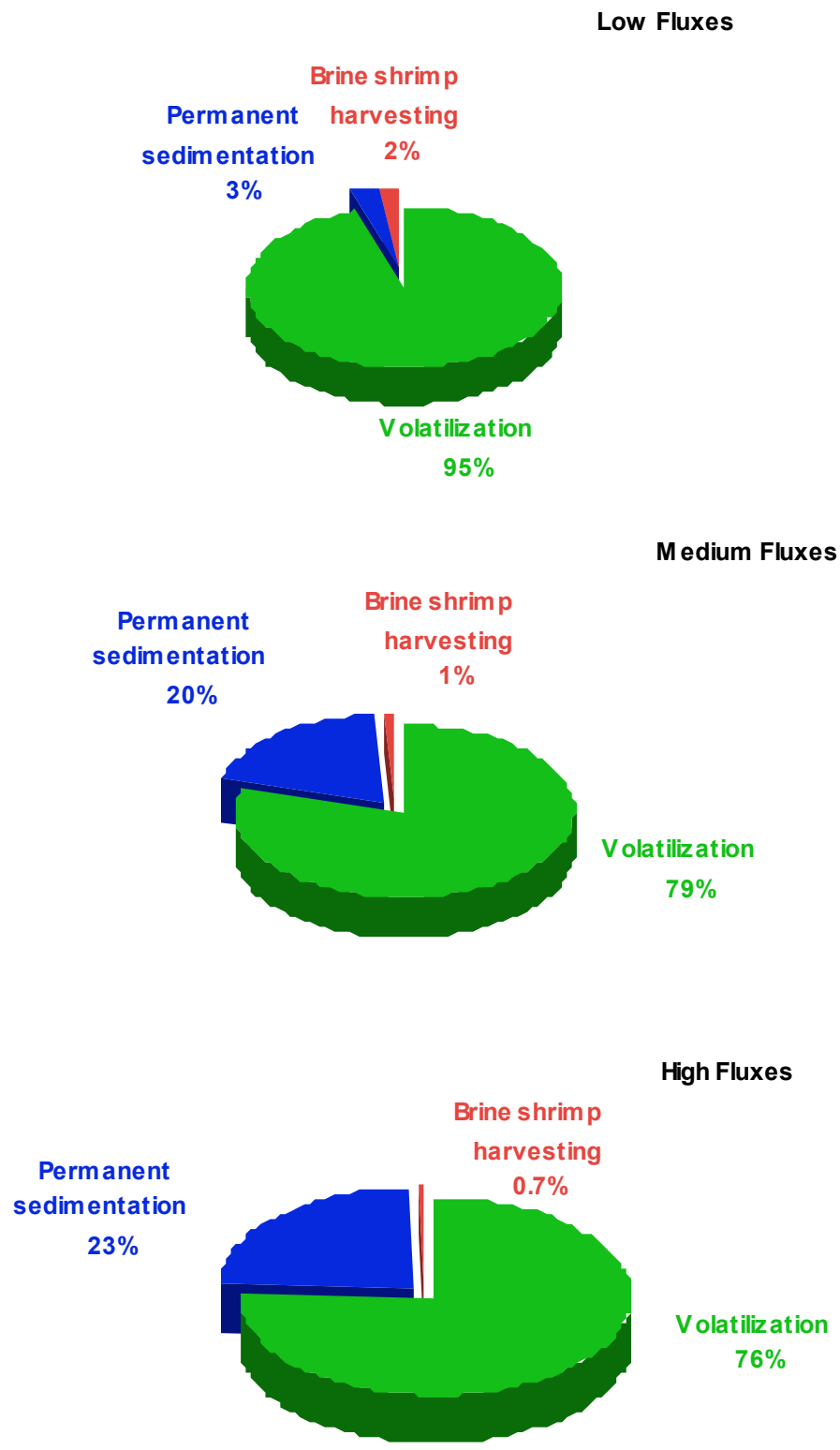


Figure 39. Top: Mass balance integration of Se concentration in the GSL without atmospheric deposition. Blue diamond represents measured final total Se concentration (average of the four sites). Bottom: Daily fluxes used in the mass balance integration.

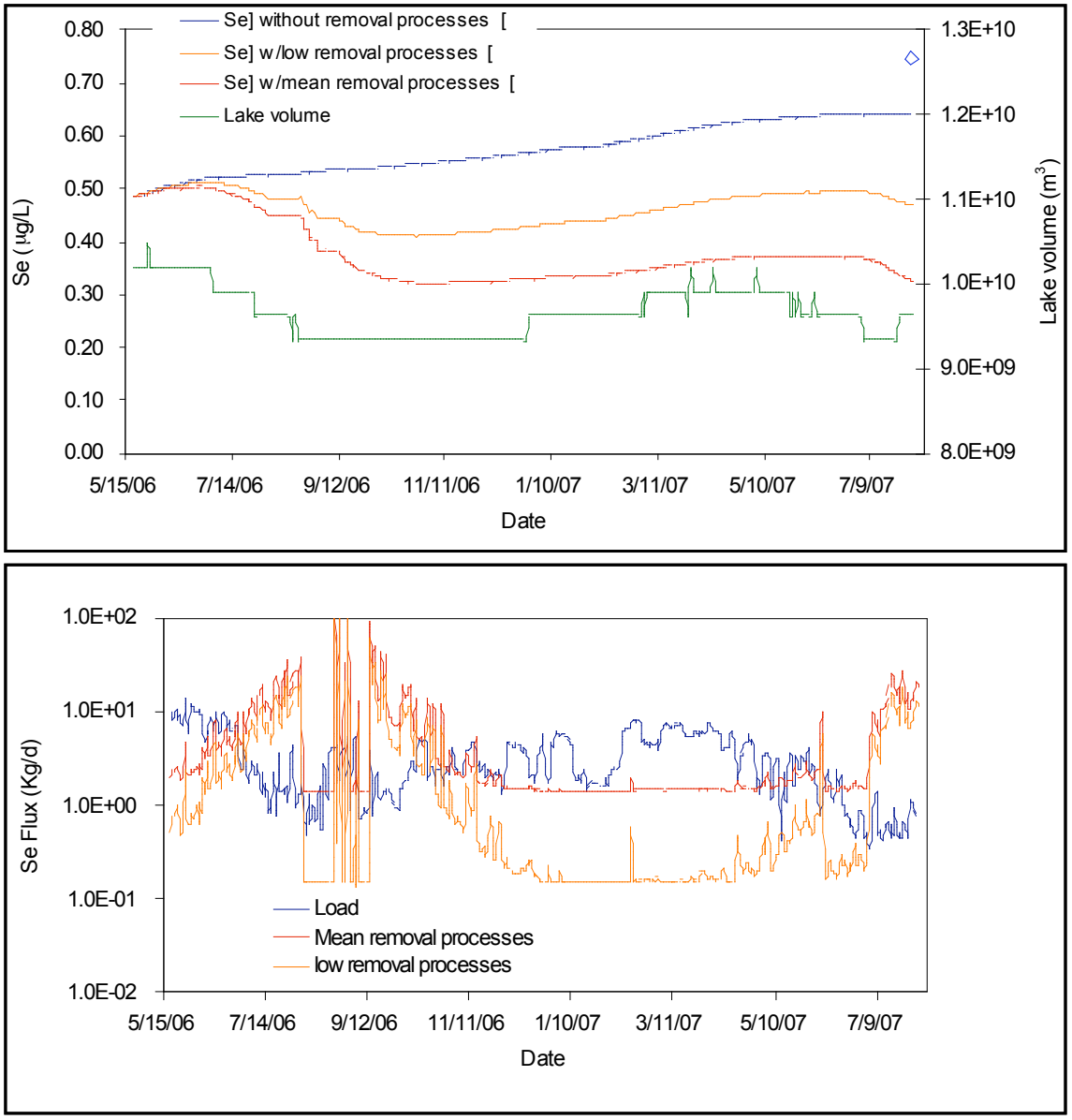
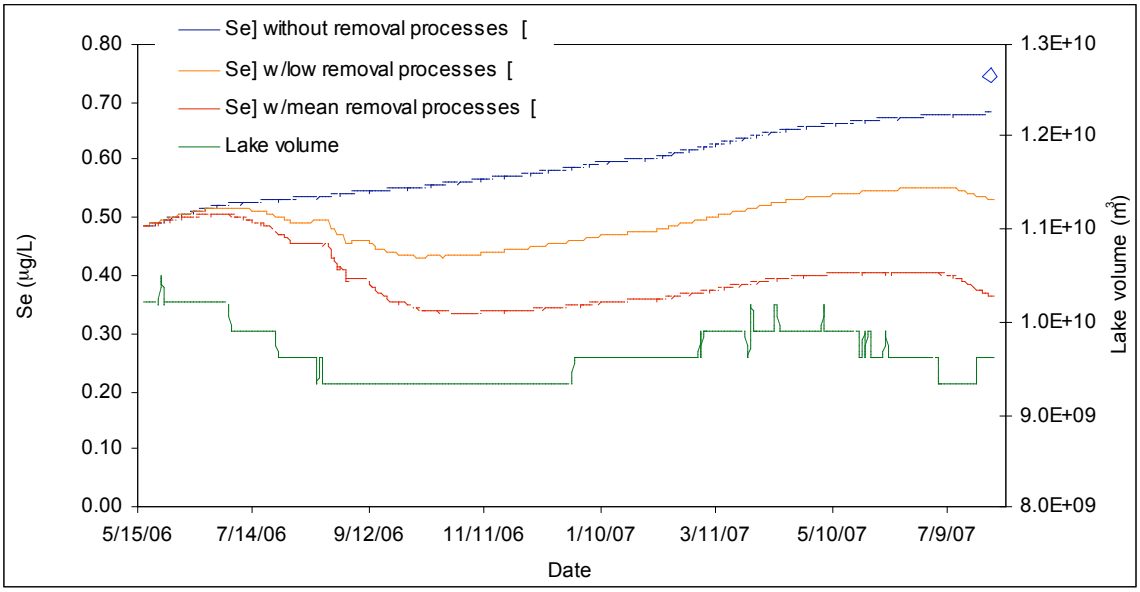


Figure 40. Top: Mass balance integration of Se concentration in the GSL with atmospheric deposition. Blue diamond represents measured final total Se concentration (average of the four sites). Bottom: Daily fluxes used in the mass balance integration.



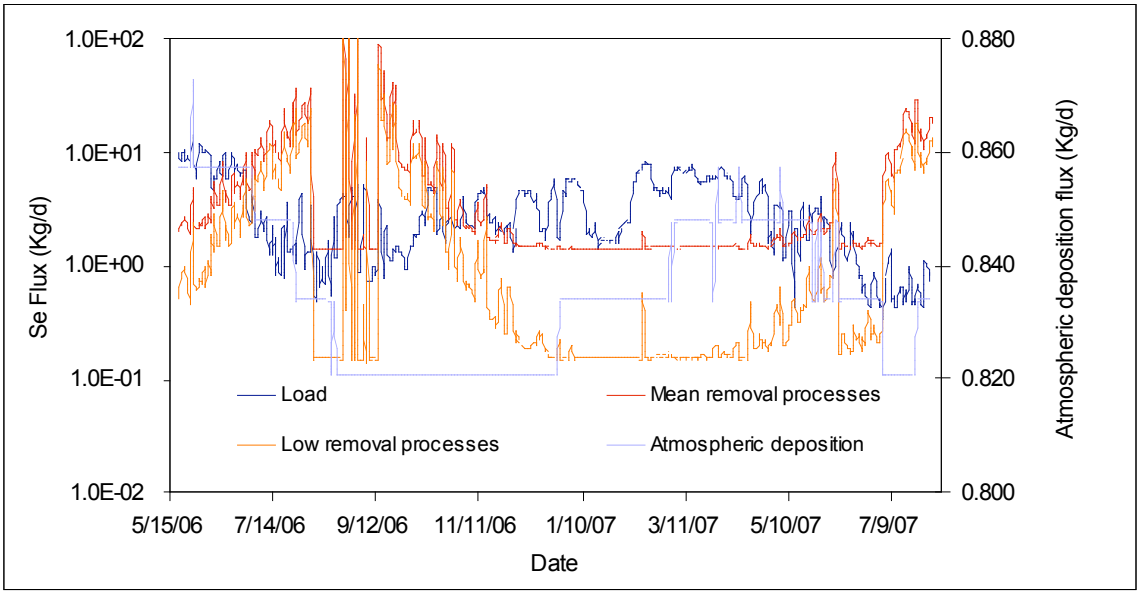


Figure 41a. Dissolved Se concentration trajectories (data from Frontier Geosciences).

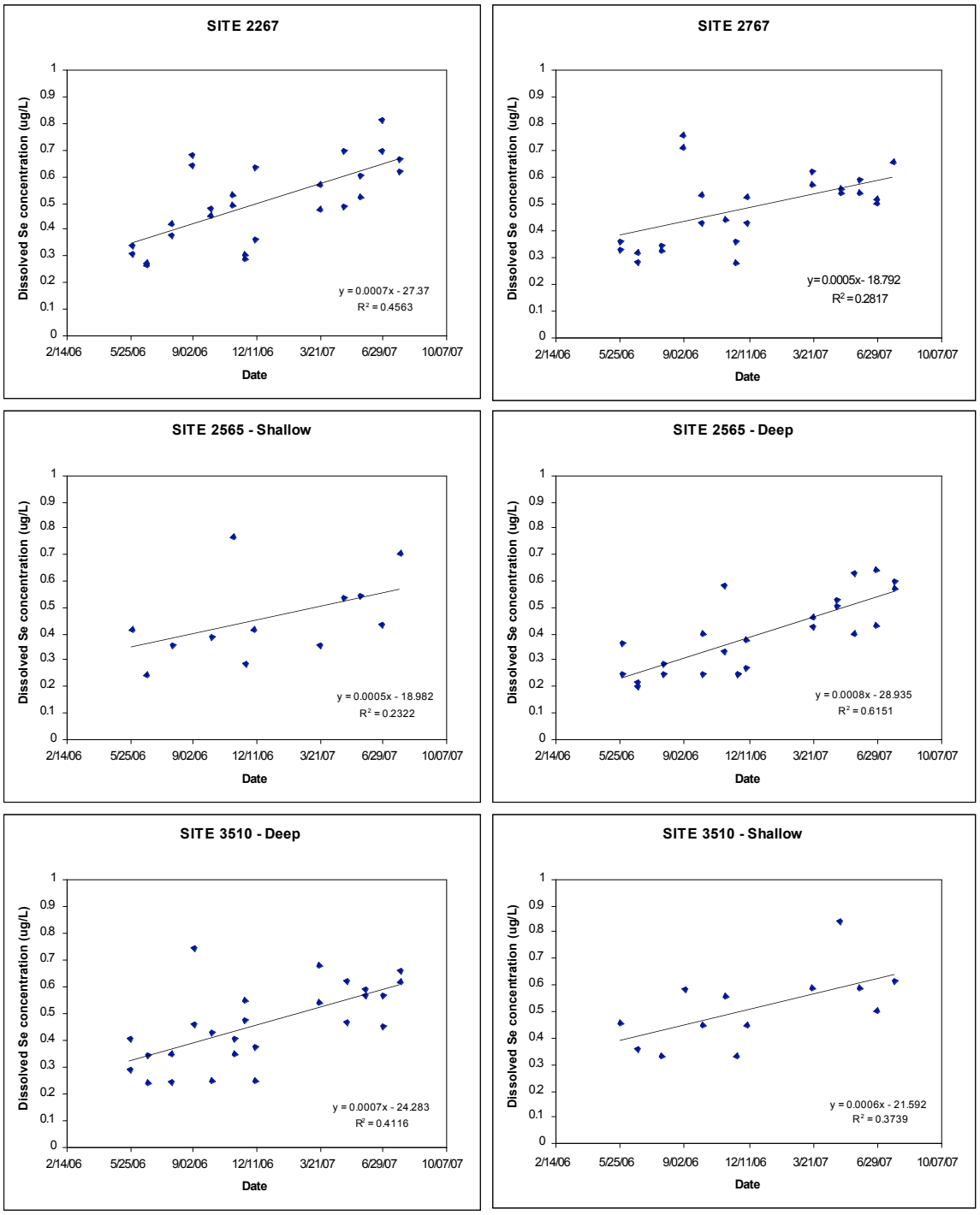


Figure 41b. Se concentration trajectories (associated with particulates) (data from Frontier Geosciences).

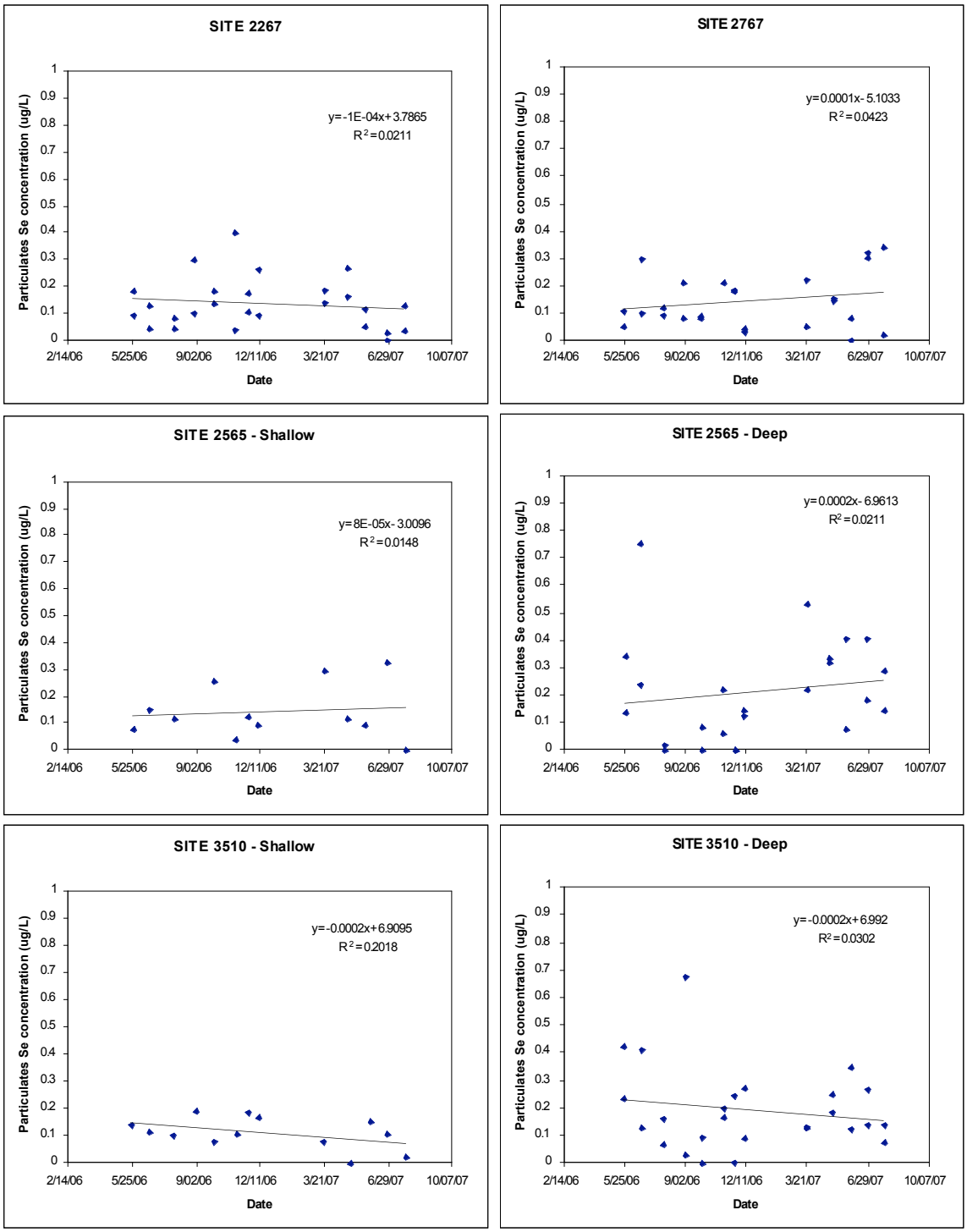


Figure 42. Quality control and quality assurance data for Se analyses by HG-AFS and ICP-MS.

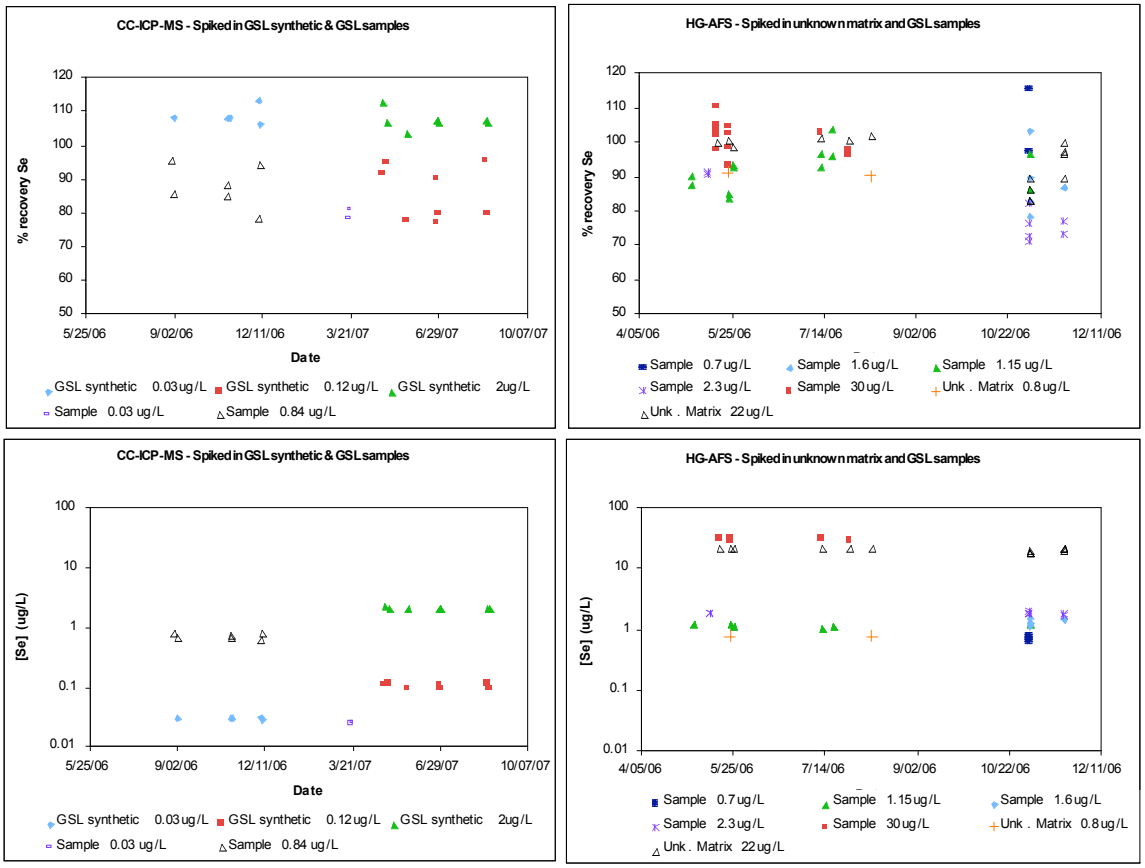


Figure 43. Multielement concentration trajectories (via ICP-MS) from site 2565 during the course of the study.

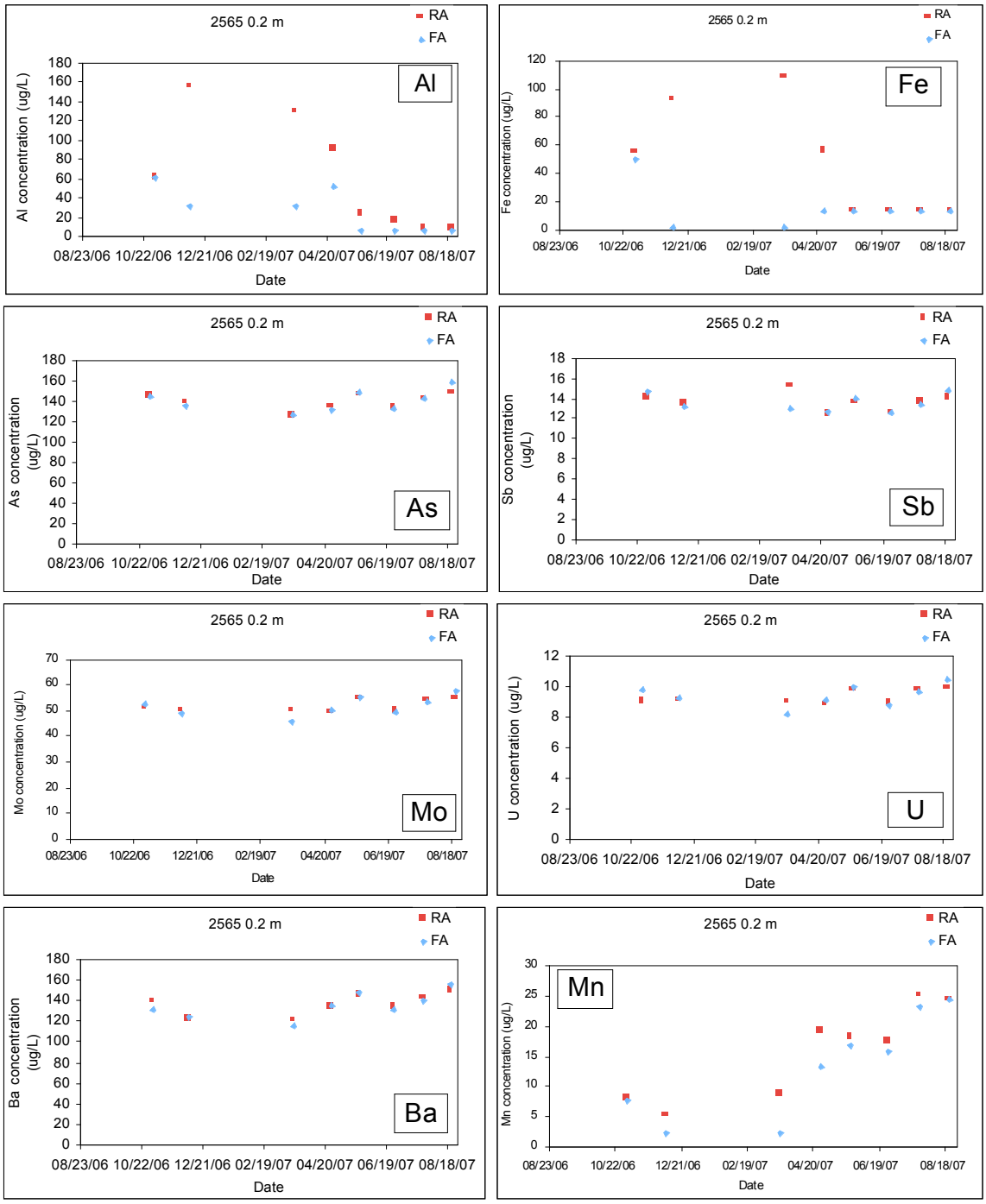
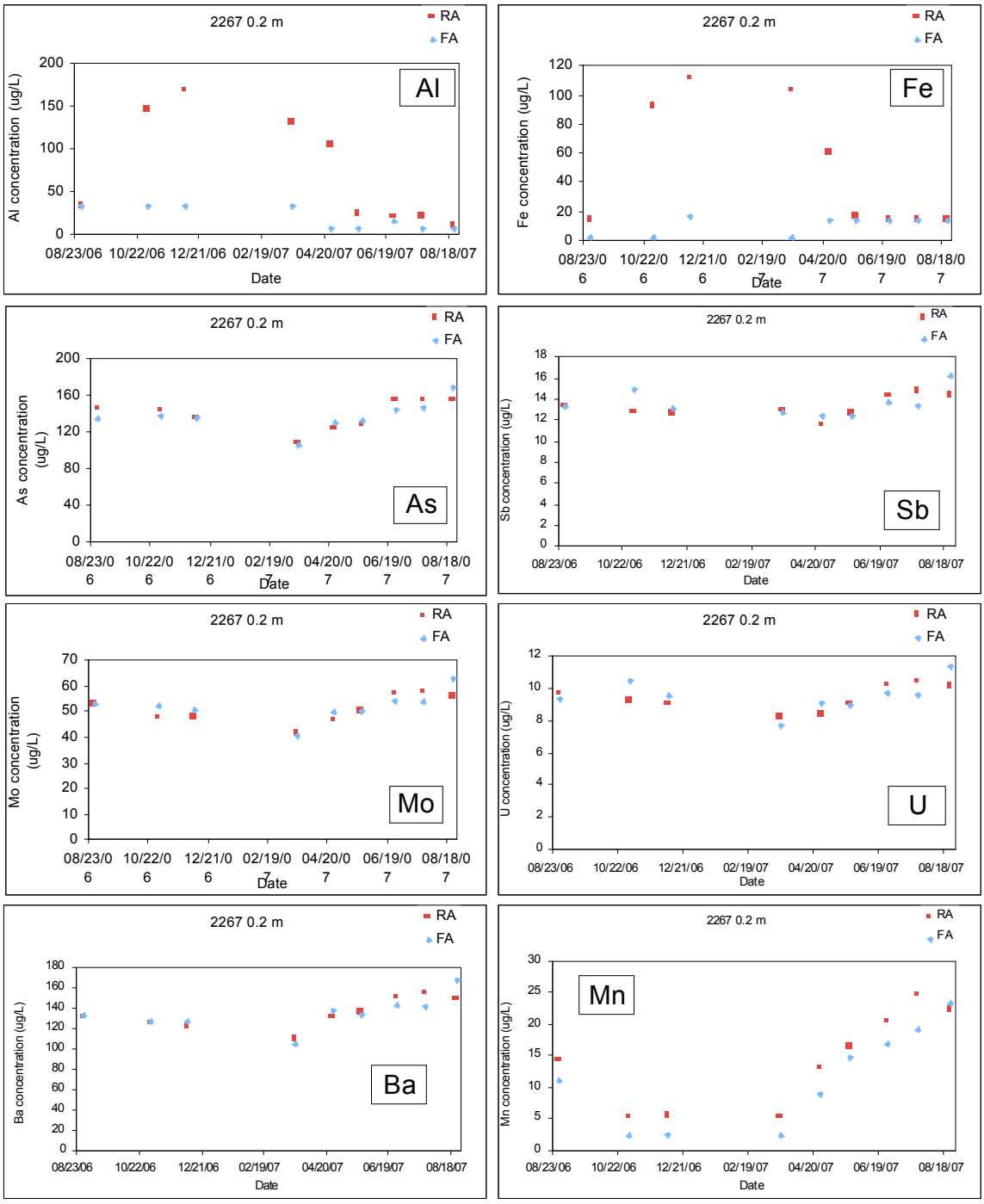


Figure 44. Multielement concentration trajectories (via ICP-MS) from site 2565 during the course of the study.



Final report for the "Brine Shrimp Kinetics Study, Project 5"

Summary

Introduction

Selenium has long been recognized as a reproductive toxicant[16,34] causing teratogenesis and chick mortality in birds[2]. The primary piscine and avian exposure pathway for selenium is the diet[1,23,24,28,33]. Consequently, environmental regulations protecting animals from selenium exposure ought to aim at maintaining selenium concentrations in relevant prey organisms below effect threshold concentrations. As such, a tissue residue criterion (TRC) rather than traditional water-quality criteria has recently been proposed for selenium by the USEPA[42].

A TRC approach, however, is sensitive to variation in bioaccumulation of the element in question, which potentially varies with site-specific conditions (water and sediment chemistry) and other environmental factors. Furthermore, bioaccumulation of chemicals is often species specific and may be subject to homeostatic control, complicated uptake kinetics and excretion or elimination in the organisms of interest[1,6,9,30,40]. Similar concerns apply to standard water quality criteria and a TRC approach combined with biodynamic modeling provide an elegant solution to these problems because steady state concentrations can be predicted from measured rates of uptake and elimination in the organism of interest[8,30] (see below for details).

Great Salt Lake, Utah is an important staging, wintering, and breeding area for many migratory waterfowl and shorebirds. The high salinity of Great Salt Lake (3-10 times that of seawater) limits the aquatic fauna; the highly abundant brine shrimp, *Artemia franciscana*, is the largest aquatic predator/consumer and serves as one of the principal avian food sources[12,26]. Because of the unusual water chemistry in Great Salt Lake, standard water quality criteria do not apply and a TRC approach is currently applied for selenium discharge from the Kennecott copper smelting facility. Using an estimated dietary effect threshold for avifauna of 5 mg/kg dw[23,41] and *in situ* measurements of total waterborne selenium concentrations and corresponding concentrations in brine shrimp[5], the current water quality discharge limit is set at 27 µg/L. The *in situ* measurements from the Kennecott copper smelting facility[5] provide a site-relevant foundation for the establishment of discharge limits in providing a relationship between ambient selenium concentrations and selenium accumulation in *Artemia* but are associated with some uncertainty. This uncertainty is a consequence of relatively limited field-derived data with low resolution of exposure concentrations (consisting of waterborne selenium concentrations below 5, around 30, and >80 µg/l, L) at concentrations that appear to bracket the "knee" in the selenium accumulation curve[5] (see Fig 7 for definition of the term "knee"). The data forming the basis for the current discharge limit were analyzed by simple linear regression (which errs on the conservative side) yielding predicted brine shrimp selenium concentrations of 5 mg/kg dw at 27 µg/l. Despite the conservative approach taken in the analysis these data, it is important to recognize that considerable uncertainties remain. The data set is small, exposure times are uncertain and life stages of

the brine shrimp varied. Considerable error may therefore be associated with this estimated “safe” level.

The main objective of the present study was to provide reliable predictions of selenium accumulation in *Artemia franciscana* under conditions realistic for the populations residing in the Great Salt Lake (GSL), Utah. Controlled laboratory experiments were performed to address this uncertainty and to better define the relationship between ambient selenium concentrations and concentrations of accumulated selenium in brine shrimp.

This main objective was addressed by pursuing the following specific objectives:

1) Determine the influence of salinity on selenium uptake and feeding rate by *Artemia franciscana*.
2) Determine selenium uptake rates in *Artemia franciscana* from dissolved selenium concentrations in artificial GSL water (uptake kinetics).
3) Determine dietary selenium intake and subsequent selenium assimilation efficiency in *Artemia franciscana* fed a diet of selenium-loaded algae cells (*Dunaliella viridis*).
4) Determine selenium elimination rates from *Artemia franciscana* following selenium accumulation from elevated ambient concentrations.

5) Model selenium accumulation in *Artemia franciscana* based on the results from objectives 1-3 to provide predictions of selenium accumulation during realistic exposure scenarios.
6) Determine the "knee" of the dissolved selenium accumulation rate curve in *Artemia franciscana*.
7) Investigate possible regulation of selenium accumulation in *Artemia franciscana* during prolonged exposure to selenium.

Materials and Methods

Organisms

The algae *Dunaliella viridis*, which is indigenous to the GSL and available for mono-culturing, was used in the present project and was obtained as a gift from Marjorie Brooks (then at the University of Wyoming). Cultures of *D. viridis* were maintained in artificial GSL medium (Table 1) for the present project and subcultures were raised in appropriate selenium concentrations as described below. The brine shrimp, *Artemia franciscana*, were obtained as cysts from M&M Suppliers, Bothell, WA and were hatched in natural seawater from Bear Cut Florida. Salinities in the Great Salt Lake are reported to range from 125 to 142 (parts per thousand [ppt]). However for practical reasons, *Artemia* were maintained in bulk culture at 73.5 ppt salinity artificial GSL water. For subsequent experiments examining Se uptake at higher salinities (100 and 160 ppt), *Artemia* were acclimated to these salinities in artificial GSL waters for a period of at least 48 hours prior to experimentation. *Artemia* were maintained in mass culture in 4 individual aerated 10-gallon tanks with partial water renewal as necessary and were fed

commercially available dried algae daily. Specifically, 1 gram of Wardley Premium Algae Discs (Secaucus, NJ) was homogenized in 20 mls of deionized water and offered to artemia according to culture density. Feeding amount was adjusted such that artemia were able to completely clear the water between feedings.

General experimental procedures

Only adult (>4 mg whole animal wet weight) artemia were used in the present experiments and a radioisotope labeling procedure was employed to facilitate fast, yet accurate measurements of low levels of selenium in a highly saline matrix. ^{75}Selenium as selenate (specific activity) was obtained from the University of Missouri, Columbia research reactor. Secondary ^{75}Se stock solutions (of varying specific activity serving experimental needs) were prepared in deionized water for individual experiments, and the specific activity of these stock solutions were verified by measuring the total selenium concentrations by graphite furnace atomic absorption spectrometry (see below) and the 75Se radioactivity. From the ratio of ^{75}Se radioactivity and total selenium concentration in the stock solutions (specific activity; SA) and corresponding ^{75}Se radioactivity from artificial GSL water, algae and artemia, selenium concentrations were determined as:

^{75}Se radioactivity (cpm) / SA

And

^{75}Se radioactivity (dpm) * (cpm/µg Se) = µg Se

	Artificial GSL for culturing (g/L)	Artificial GSL for experiments (g/L)	Algae Media (g/L)
NaCl	50.960	69.306	52.596
$MgCl_2$ ($6H_20$)	10.572	14.378	1.500
$MgSO_4$ ($7H_20$)	8.628	11.734	0.500
KCl	2.632	3.580	0.200
$CaCl_2$ ($2H_20$)	0.147	0.200	0.200
$NaHCO_3$	0.164	0.223	0.043
$CaSO_4$ ($2H_20$)	0.397	0.540	--
KNO_3	--	--	1.000
KH_2PO_4	--	--	0.035
Trace Metals	--	--	10 ml/L
Iron Solution	--	--	10 ml/L

Table 1. *Composition of artificial GSL media and D. viridis culture medium*

Analytical procedures

Gamma activity arising from the Se-75 isotope was detected directly on undigested, sometimes alive material, in water or in dried samples by a Packard, Cobra II auto gamma counter D5003 using a counting window from 60-467 keV. Total selenium concentrations in stock solutions were determined by graphite furnace atomic absorption spectrometry (Varian, 220Z). A sample injection volume of 10 µl and 10 µl of modifier (1 mg Ni/ml) were co-injected with deionized water for a total injection volume of 25 µl. Following evaporation, an ashing step of 1000°C for 8 seconds preceded the atomization step of 2600 °C (detection limit: 0.6 µg/L). Absorbance recorded from samples was compared to the absorbance obtained from automatically generated dilutions of a certified selenium standard (Aldrich) to determine selenium concentrations.

Algal dry weight was determined by filtering 15 mls of an algae culture of known cell density (determined by cell counting on a hemacytometer) through a pre-weighed 47-mm

glass microfibre filter (Whatman) and then rinsing the filtered cells with 10 mls of 0.5 M ammonium formate to remove high density salts. The filters were then dried for 24 hrs at 80 °C and re-weighed. Dry weight was estimated by dividing mass of the dried algae by the number of algae cells in the 15 ml sample.

Artemia dry weight was determined by sampling and gently blotting dry 12 adult artemia on a paper towel, then placing them on 1-cm^2 pieces of pre-weighed aluminum foil. These artemia were weighed to determine wet weights, then dried for 24 hours at 80 °C and re-weighed to determine dry weights.

Data presentation and statistical evaluation

Data are reported as means ± SEM throughout. Non-linear regressions were performed using SigmaPlot version 8.0 and statistical comparisons were performed using Student's two-tailed *t*-tests.

Influence of salinity on selenium uptake from the water and feeding rates (objective 1)

To examine the effect of salinity on selenium uptake from the water, 24-hour and 48-hour selenium uptake was measured in individual artemia at 100 and 160 g/L GSL medium at 1.75 ± 0.05 and 1.83 ± 0.08

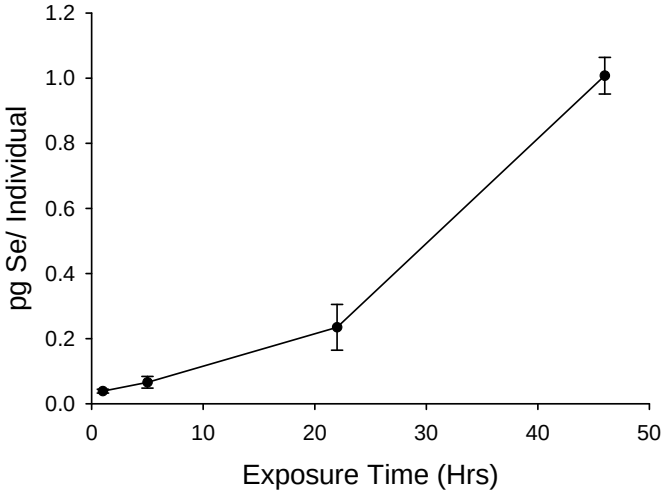


Fig. 1. Selenium accumulation in artemia during a 48-hour exposure to 13 ng Se/L as ^{75}Se-labeled selenate. Values are expressed as pg Se/individual. Mean ± SEM, n=10.

µg Se/L respectively. Measurements were performed in triplicate treatments, each with 15 adult artemia and otherwise as outlined in the SOP provided below. A 24-hour exposure duration was chosen based on experiments demonstrating linear Se accumulation for at least 24 hours (Fig.1) and initial experiments demonstrated that Se exposure concentrations remained relatively constant over at least 24 hours of exposure (Fig. 2).

Feeding rates were also determined in adult artemia fed *D. viridis* at 100 and 160 g/L GSL medium. Adult artemia (n= 15) in 30 mls of GSL media were offered a density of 93.4 $\cdot 10^6$ *D. viridis* cells and cell density was monitored every 10 minutes for a total of 30 minutes by measuring the absorbance of water samples at 750 nm. Preliminary experiments revealed a good correlation between cell count (cells/mm^2) and absorbance (Fig. 3). The feeding rate experiments were performed in triplicate and otherwise as described in the SOP.

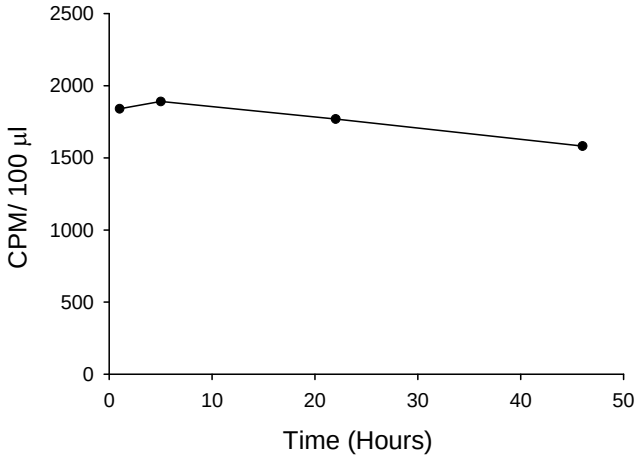


Fig. 2. Levels of ^{75}Se in GSL medium during a 48-hour exposure of artemia to 13 ng Se/L as selenate under conditions employed in the present study (see text for details).

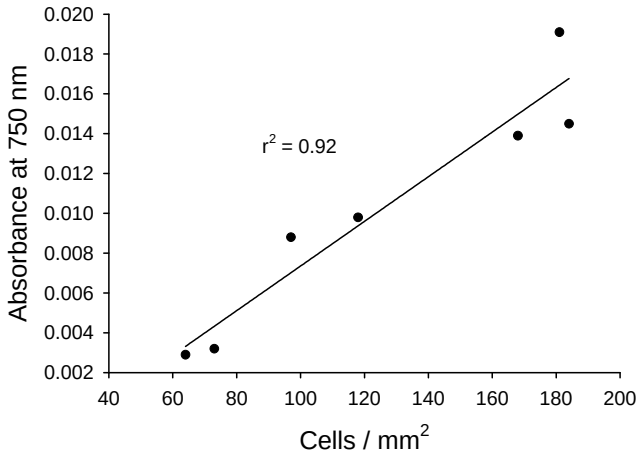


Fig. 3. Correlation between absorbance at 750 nm and cell count. See text for further details.

Determination of selenium uptake rates in brine shrimp from dissolved selenium concentrations in GSL water (Objective 2 & 6)

Based on findings from the salinity experiments above, all subsequent experiments were performed at 100 g/L unless otherwise stated. Adult artemia (n=15) were placed in 25 ml

artificial GSL medium in 50-ml PYREX glass beakers that were gently aerated to ensure oxygenation and mixing and were exposed to ^{75}Se (as selenate) for 24 hours at nominal concentrations ranging from 1 to 80 µg/L. Artemia were allowed to recover from handling for 10 min prior to isotope addition; water samples were obtained from the exposure medium 15 minutes after isotope addition and immediately prior to exposure termination at 24 hours. After 24 hours of exposure, individual artemia were collected from the exposure medium and rinsed three times in isotope-free media to remove ^{75}Se loosely associated with the surface. Individual artemia were blotted dry on paper towels and their wet weight determined to the nearest 100 µg prior to ^{75}Se radioactivity determination. These experiments were repeated in artificial GSL medium at lower concentrations more closely matching concentrations normally found in natural GSL water (0.3-0.6 µg/L). These experiments were designed to also include a nominal concentration of 1 µg/L to provide direct comparison between the two sets of experiments determining selenium uptake from artificial GSL medium. In addition, to these experiments, a set of experiments employing nominal selenium concentrations ranging from 0.3 to 1.0 µg/L were performed in natural GSL water (2336 mOsm; collected). For these experiments with natural GSL medium in which background levels of selenium were expected, water samples from the isotope uptake experiments were verified by analysis of total selenium by Frontier Geosciences, Inc. and measured total selenium concentrations were included in the calculations of selenium uptake.

Determination of dietary selenium intake and subsequent selenium assimilation efficiency in artemia fed a diet of selenium-loaded algae cells (objective 3).

D. viridis cultured in presence of different selenium concentrations served as the dietary source of selenium for artemia. *D. viridis* was cultured under constant light at 18ºC in artificial GSL media (Table 1) in gently aerated Erlenmeyer flasks and media selenium concentrations were monitored daily and adjusted as necessary by addition of ^{75}Se stock solutions or selenium-free media to elevate or reduce media selenium concentrations, respectively. The time required to reach steady state selenium concentrations in *D. viridis* was determined in an initial 40-day experiment and subsequent exposures were 21 days in duration. In addition to daily monitoring of media selenium concentrations, algal density and algal selenium concentrations were determined in algal cells sampled from the cultures and rinsed in ^{75}Se free medium prior to ^{75}Se detection.

D. viridis was harvested for artemia feeding studies at day 20-21 of exposure at which point steady state was achieved. Algae raised at four different media selenium concentrations ranging from 1.2 to 60.4 µg Se/L were used in the present study. Algae were isolated by centrifugation in a microcentrifuge at 8000 rpm which leaves the cells intact after which the radioactive supernatant (algae media) was discarded and cells were rinsed by resuspension in selenium-free media followed by additional centrifugation and media replacement. Radioactivity in the cleansed algal preparations was measured, and algal density in this concentrated cell suspension was determined using a Bright-Line Hemacytometer (Hausser Scientific, Horsham PA) for direct counting using a light microscope.

For each algae selenium concentration, a total of 20 adult artemia were placed in 4 L of GSL medium in a 5-L plastic beaker gently aerated to ensure oxygen saturation and continuous mixing and suspension of algal cells. A total of $37 \cdot 10^6$ cells/L were added to the 4 L of GSL media and artemia were allowed to feed for 60 minutes after which they were removed, rinsed and transferred alive to a gamma counting vial containing 3 ml GSL media. This protocol was chosen from initial experiments to prevent depletion of algal cell density during the feeding experiments and to allow for accurate determination of ingestion rates. Initial experiments monitoring dietary selenium ingestion during a 90-minute period revealed a gut passage time of around 60 minutes at a cell density of approximately $20 \cdot 10^6$ cells/L (Fig. 4), and subsequent feeding experiments were restricted to this duration. Note that linear accumulation of dietary selenium during short term exposure (min), as seen in Fig 4, demonstrates that all ingested selenium is retained in the organism. Plateau of this accumulation curves seen after 60 min means that fecal selenium is being lost at a rate comparable to the rate of ingestion. Gamma counting of individual artemia was conducted immediately and then individual artemia were transferred to 15 ml falcon tubes containing 10 ml of selenium-free GSL medium. The artemia were subsequently fed a non-radioactive algae diet to allow for depuration of unassimilated food overnight

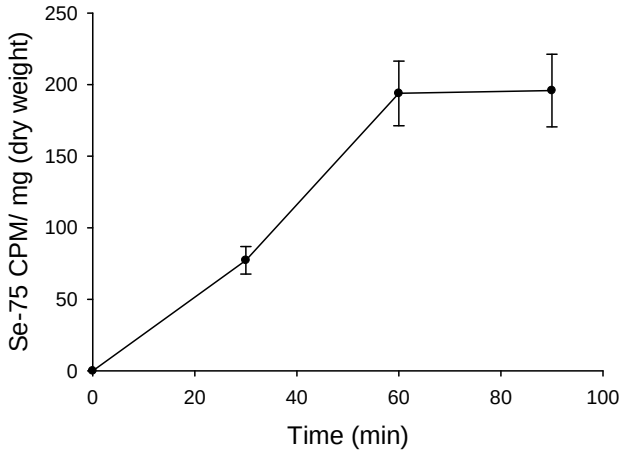


Fig. 4. Selenium accumulation in individual artemia during a 90-minute feeding trail during which artemia were fed *D. viridis* at a cell density of about 20 million cells/L.

after which individual artemia were rinsed and transferred to fresh gamma counting vials containing 3 ml of GSL media in preparation for a second gamma counting. Following this second gamma radioactivity determination, artemia wet weight was determined as above.

Fecal matter from the 15 ml falcon tubes was collected and its ^{75}Se content was determined via gamma counting.

Assimilation efficiency was determined as the ratio of assimilated ^{75}Se to ingested ^{75}Se. The ingestion rate of individual artemia in these studies was determined from the ^{75}Se accumulated during the 60 minutes of feeding and the corresponding selenium concentration in algal cells.

Determination of selenium elimination rates from artemia following selenium accumulation from elevated ambient concentrations (objective 4).

Selenium elimination rate constants were determined for artemia exposed to waterborne and dietary selenium. For the waterborne exposure a total of 30 adult artemia were exposed to 72 µg Se/l for 48 hours without feeding while dietary selenium accumulation in 20 adult artemia was ensured by a 1 hour exposure to ^{75}Se-containing algae. Following the initial exposure individual artemia were rinsed (3 times for the waterborne exposure and once for the dietary exposure) and placed in 3 ml GSL medium in individual gamma counting vials for ^{75}Se determination. After ^{75}Se counting, artemia were placed in 50-ml falcon tubes containing 30 ml GSL medium each and were fed daily. Following this

initial ^{75}Se determination, measurements were performed on a regular basis for a minimum of 20 days allowing for more than 50% depuration of the initial ^{75}Se levels.

Investigate possible regulation of selenium accumulation in artemia during prolonged exposure to selenium (objective 7).

The potential influence of prolonged exposure on selenium accumulation from the water and on assimilation efficiency for dietary exposures was evaluated. To examine uptake rates after long-term selenium exposure a group of adult artemia were exposed to 2.87 ± 0.14 µg Se/L for 14 days. To avoid ^{75}Se accumulation in this group of selenium pre-exposed artemia, these organisms were exposed to non-radioactive selenium. A parallel group of artemia was exposed to identical conditions using radio-labeled ^{75}Se in the water to allow for measurements of selenium concentrations during the 14 days of exposure. Exposure concentrations were adjusted in both these groups of artemia according to ^{75}Se measurements in the radio-labeled group. The ^{75}Se group acted simply as a parallel surrogate to the non-radioactive 14-day exposure to ensure constant and characterized exposure concentrations. In addition to these two groups of artemia, a third group was maintained under control conditions without selenium added. All three groups consisted of 20 adults maintained in 1L gently aerated GSL media (100 g/L) and were fed *D. viridis* daily 3-4 hours prior to adjustments of Se exposure concentrations.

After 14 days of exposure, uptake rates from ^{75}Se-containing GSL medium were determined for the controls and for the artemia exposed to non-radioactive selenium.

These ^{75}Se uptake rate experiments were performed at 2.55 ± 0.11 µg Se/L according to procedures outlined for waterborne experiments elsewhere.

To examine the potential influence of prolonged exposure to dietary selenium on subsequent assimilation efficiencies, *D. viridis* were raised in the presence (resulting in 2.68 µg Se/g dry weight) and absence of selenium. Two algae cultures were raised in presence of selenium, one in which ^{75}Se was employed and one containing the same concentration of non-radioactive selenium. The culture medium selenium concentrations were adjusted in parallel in the two cultures based on measurements of ^{75}Se in the radioactive medium to ensure constant exposure conditions. In parallel with these two selenium-containing cultures, a selenium-free control algae culture was raised simultaneously. All algae cultures were maintained for a minimum of 20 days to ensure steady state selenium concentrations.

Two groups of 30 adult artemia were maintained in 1 L gently aerated GSL (100 g/L) and were fed daily with algae raised in presence or absence of unlabelled selenium (not ^{75}Se). During the 14 days of exposure, exposure beakers were siphoned daily and water was replaced twice weekly.

After these 14 days of exposure to either control or non-radioactive selenium loaded algae (2.68 µg Se/g dry weight), 25 individuals from each group were transferred to 4 L of GSL media and ingestion rate as well as assimilation efficiency were determined as above using a ^{75}Se labeled algae culture (3.73 µg Se/g dry weight).

Verification of the isotope dilution technique

A subset of water and selenium stock solution samples was submitted to Frontier Geosciences, Inc. for total selenium concentration measurements to seek independent analytical verification of the isotope dilution technique. Water samples subjected to total selenium analysis included samples representing all exposure concentrations from the second replicate of the selenium water-borne uptake kinetic experiments with artemia, samples of natural GSL medium used in the parallel selenium uptake experiments as well as a subsample of one of our stock solutions and a commercially available certified stock solution employed in the Grosell laboratory at University of Miami as reference material. Because Frontier Geosciences, Inc. are not licensed to handle radioactive samples, parallel radioactive and non-radioactive stock solutions were made up side by side and both were spiked into GSL media. Total selenium concentrations were determined in both radioactive and non-radioactive stock solutions at University of Miami (Graphite Furnace Atomic Absorption) and both sets of stock solutions were spiked into GSL media. Media spiked with the radioactive stock solutions were used for measurements of selenium uptake in artemia and exposure concentrations were verified using the isotope dilution method. Media spiked with non-radioactive stock solutions were treated similarly to the media spiked with radioactive stock solutions and the predicted selenium concentrations in these solutions were calculated from the measured concentration in the non-radioactive stock solution and the amount added to the GSL medium (Graphite Furnace Atomic Absorption). These non-radioactive GSL media samples were forwarded to Frontier Geosciences, Inc. for selenium analysis.

Results

Evaluation of the isotope dilution technique

Near perfect agreement between selenium measurements performed in the Grosell laboratory at the University of Miami (Graphite Furnace Atomic Absorption) and Frontier Geosciences is evident from Table 2. Furthermore, these two sets of total selenium measurements are in excellent agreement with the results from the isotope dilution technique with the exception of the natural GSL samples. The discrepancy between the isotope dilution technique measurements and the total selenium measurements for these natural GSL samples was expected and reflects selenium concentrations in the GSL medium (not added as part of the University of Miami experiments). The difference between the two sets of measurements range from 0.39 to 0.55 µg Se/L which is in good agreement with commonly occurring concentrations in natural GSL water (Brad Marden's report).

Sample	Isotope dilution	Graphite furnace	Frontier Geosciences
0.3 µg/L, 100 g/L GSL	0.32 (#)	0.32 (*)	0.313
0.6 µg/L, 100 g/L GSL	0.64 (#)	0.65 (*)	0.598
1.0 µg/L, 100 g/L GSL	1.02 (#)	1.08 (*)	1.01
0.3 µg/L, natural GSL	0.33 (#,**)	0.32 (*)	0.868
0.6 µg/L, natural GSL	0.65 (#,**)	0.65 (*)	1.15
1.0 µg/L, natural GSL	1.14 (#,**)	1.08 (*)	1.53
Diluted cold Se stock	N/A	1.35	1.23
Diluted certified Se stock	N/A	0.96	0.923

Table 2. *Measured selenium concentrations in various aqueous media by the isotope dilution technique and the graphite furnace method at the University of Miami compared to values reported by Frontier Geosciences, Inc. (as measured by ICP-MS) for the same samples. * denotes calculated values based on measured Se concentration in "diluted*

*cold Se stock", ** these values do not account for selenium found in natural GSL water prior to experiments. # denotes concentrations determined by the isotope dilution method in samples from actual experiments measuring selenium accumulation in artemia from the water.*

Effects of salinity

To examine the influence of salinity on Se uptake, we exposed *Artemia* to Se under relatively low (100 ppt) and high (160) GSL media salinities for 24H. These values bracket the recorded salinities from GSL. As predicted, selenium uptake from the water was reduced at 160 ppt compared to 100 ppt (Fig 5). However, in contrast to expectations, elevated salinity (160 ppt) resulted in an apparent reduced feeding rate compared to that seen at 100 ppt (Fig 6). Thus, all subsequent experiments were performed at 100 ppt.

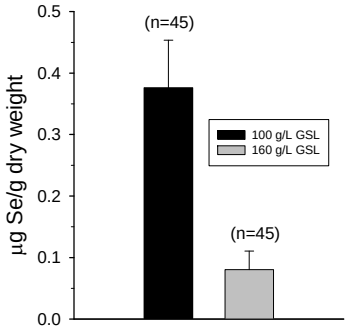


Fig. 5. Influence of salinity on ^{75}Se uptake in adult artemia during a 24-hour exposure to selenium in GSL medium

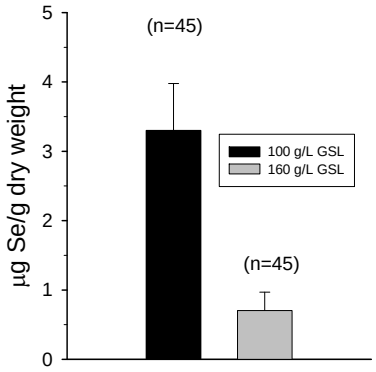


Fig. 6. Average feeding rates determined in three separate experiments from the depletion of algal cells evident from change in absorbance at 750 nm (cell density)

Selenium uptake by artemia from the water

A general trend of increasing selenium uptake rates with increasing ambient selenium concentrations was observed in experiments exposing adult artemia to a range of selenium concentration in GSL media for 24-hour periods (Fig. 7). Upon closer examination, however, an uptake-kinetics saturation pattern is observed for selenium concentrations below 10 µg/L after which selenium uptake rates appear to increase in

proportion to ambient concentrations at 20 and 40 µg/L. We mathematically describe the saturation kinetics by the equation:

Se ug/g dry weight = $((660.2 \cdot C_w)/(1.20+C_w))$

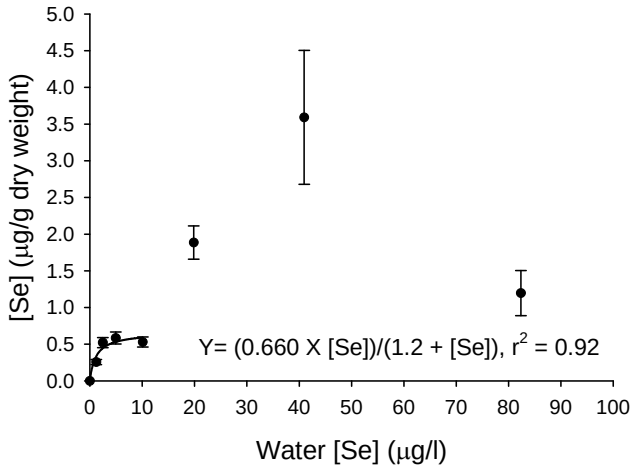


Fig. 7. Selenium accumulation in individual adult artemia as a function of ambient selenium concentrations following a 24-hour exposure. Note the apparent saturation kinetics at concentrations below 10 µg Se/L and the clear elevated increase in uptake at concentrations above 10 µg Se/L identifying the "knee" to be between 10 and 20 µg Se/L.

ku value is surprisingly high relative to other values reported from pelagic saltwater crustaceans (0.024 to 0.027) in the literature[36,43], but is as one would expect lower than that reported from the freshwater cladoceran Daphnia magna (0.187-2.74)[45]. Replication of these measurements using lower selenium concentrations also revealed linear selenium uptake with increasing ambient selenium

At an extreme Se concentration (~80 ug/l), a tendency for reduced selenium accumulation was observed. A near-perfect linear fit describes selenium uptake at ambient selenium concentrations below 2.5 µg/L equivalent of a K_u of 0.211 L/g dry weight/day. This

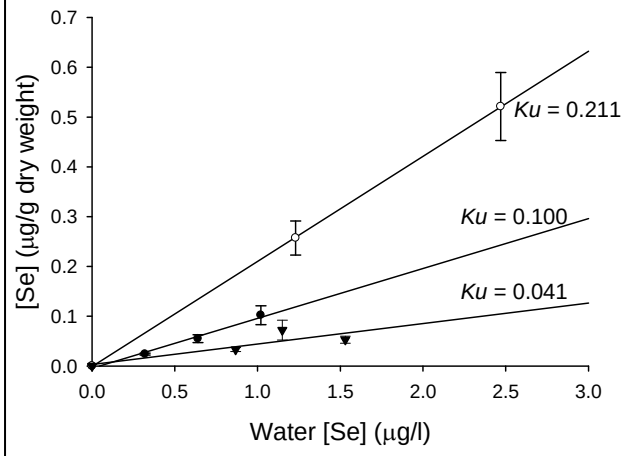


Fig. 8. Selenium uptake by artemia from the water. Comparison of a subset of data presented in Fig. 7. focusing on low ambient selenium concentrations (open symbols) to the second replicate experiments in artificial GSL medium employing more environmentally realistic selenium concentration (filled circles). Selenium accumulation in artemia exposed to similar selenium concentrations in natural GSL water (filled triangles) is lower than corresponding uptake in artificial medium.

concentrations below 1.02 µg/L equivalent to a slightly lower k_u of 0.100 L/g dry weight/day (Fig 8). Furthermore, experiments performed in natural GSL water revealed a lower k_u of 0.041 L/g dry weight/day.

Selenium accumulation in Dunaliella viridis exposed to elevated media selenium.

An unexpected tri-phasic pattern of selenium accumulation in *D. viridis* was observed during an initial 40-day exposure to 2.17 µg Se/L characterized by an initial rapid increase in algal selenium concentrations followed by apparent depuration and subsequent stabilization (Fig. 9). Steady-state selenium concentrations in *D. viridis* appear to be reached in approximately 20 days and subsequent algae selenium loading experiments were performed over this exposure period.

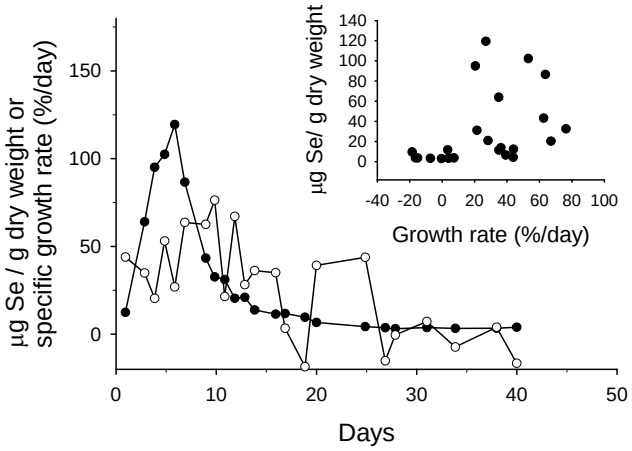


Fig. 9. Selenium concentration in *D. viridis* (dark circles) and specific growth rate (open circles) during 40 days of culturing in the presence of 2.17 µg Se/L. **Insert**: Selenium concentration in algae as a function of specific growth rate

An additional four experiments employing different media selenium concentrations were performed at concentrations ranging from an average 1.2 to 60 µg Se/L and all exhibited a similar pattern of fast initial accumulation followed by depuration and stabilization (Fig. 10). Our radio-isotopic approach allowing for rapid detection of selenium

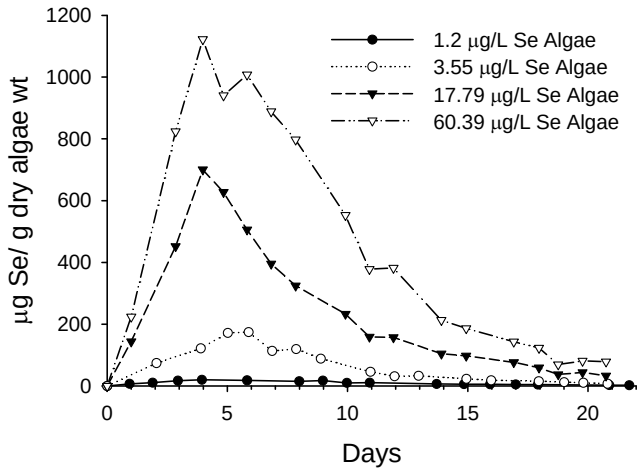


Fig. 10. Time course of selenium accumulation in *D. viridis* raised at four different selenium concentrations. Average media selenium concentrations are indicated on the figure and measured media selenium concentrations throughout the 21 days of culturing are reported in Fig. 10.

concentrations in the exposure media and prompt adjustments ensured relatively stable exposure concentrations during the 20 days of culturing (Fig. 11). Considering the algae selenium concentrations after 21 days of culturing, a less than linear increase in cell selenium concentrations as a function of ambient selenium was observed pointing to lower bioconcentration factors at higher ambient concentrations (Fig. 12).

Comparing the growth rates (as indicated by absorbance at 750 nm throughout 21 days) of algae cultures at different selenium concentrations to growth rates in absence of added selenium revealed highest growth rate at ~18 µg/L (Fig. 13). The lowest growth rate was observed in absence of added selenium and it

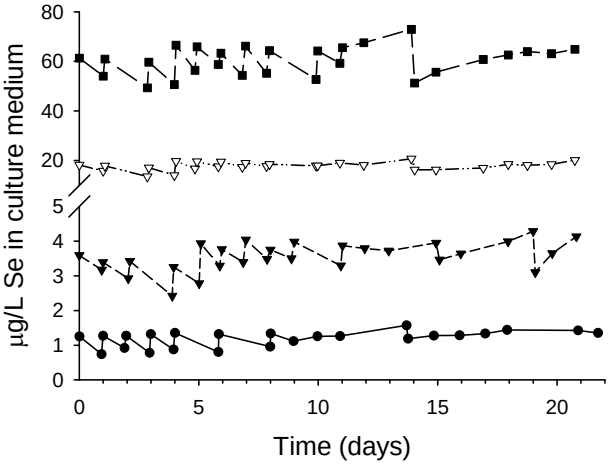


Fig. 11. Media selenium concentrations during 21-day culturing of *D. viridis*. The near-daily fluctuations represent uptake or excretion from the algae cells and corresponding adjustments of exposure concentrations by addition of selenium stock solution or selenium-free culture medium as appropriate.

appeared that the highest employed selenium concentration (60 µg/L) tended to reduce growth of *D. viridis* somewhat (Fig. 14).

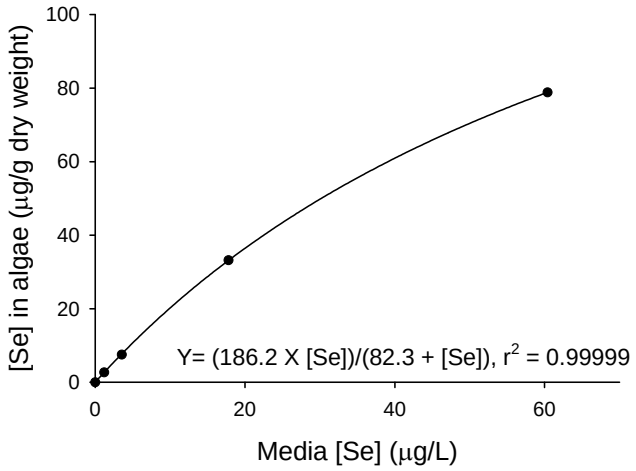


Fig. 12. Steady state selenium concentrations in *D. viridis* after 21 days of exposure as a function of media selenium concentrations

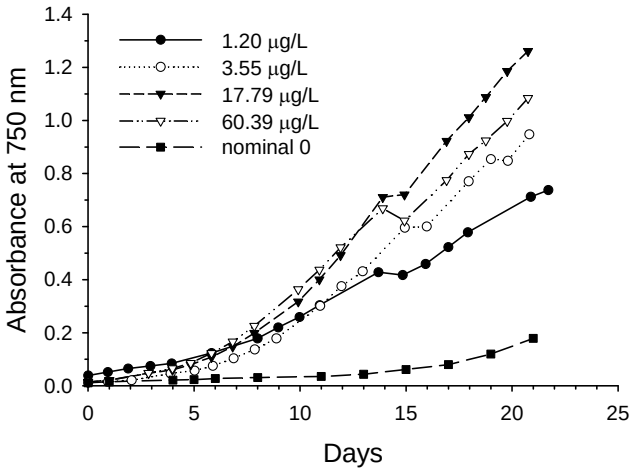


Fig. 13. *D. viridis* growth in culture media of different selenium concentrations.

D. viridis ingestion rate, dietary selenium intake and assimilation efficiency in artemia

The 1-hour feeding experiments revealed feeding rates of 0.185 g/g (dry weight)/day and demonstrated increasing selenium ingestion and assimilation with increasing algae selenium concentrations (Fig. 14). Selenium assimilation efficiency showed a 2nd order exponential decay relationship with a minimum assimilation efficiency of 74% at higher dietary selenium concentrations and a near 100% at low selenium concentrations (Fig. 15 and 16).

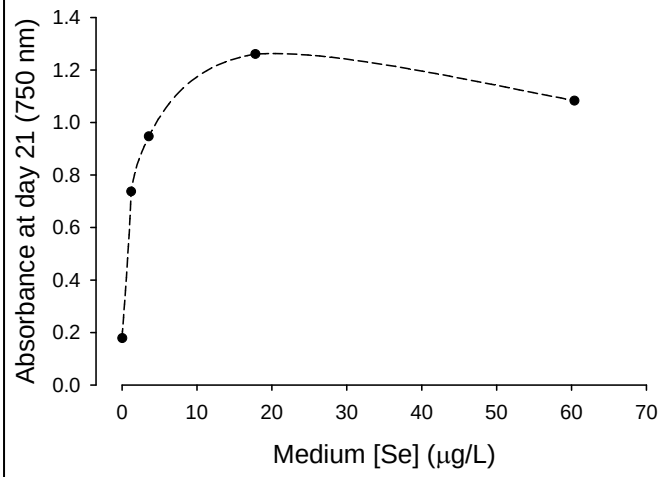


Fig. 14. Cell density after 21 days of culturing at different selenium concentrations.

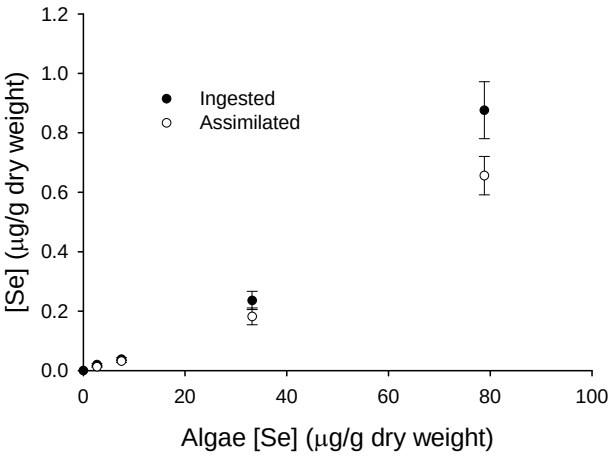


Fig. 15. Ingested (dark symbols) and assimilated (open symbols) selenium in individual artemia following a 60-minute feeding at four different algae selenium concentrations

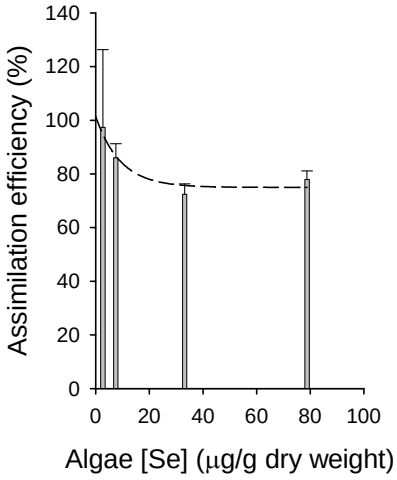


Fig. 16. Assimilation efficiencies for four different algae selenium concentrations calculated from the observations presented in Fig. 14. Data adhere to an exponential decay equation (see text for details), $r^2 = 0.95$.

Selenium elimination rates constants

The possibility of distinct elimination rates for selenium accumulated from the water and the diet was considered. For waterborne selenium, an initial rapid elimination was observed during the first 24 hours following termination of exposure. From day 1 and onward, a simple exponential decay equation describes selenium concentrations in artemia well (r^2=0.99) with a 6.79 % daily selenium loss (Fig. 17). The dietary selenium elimination

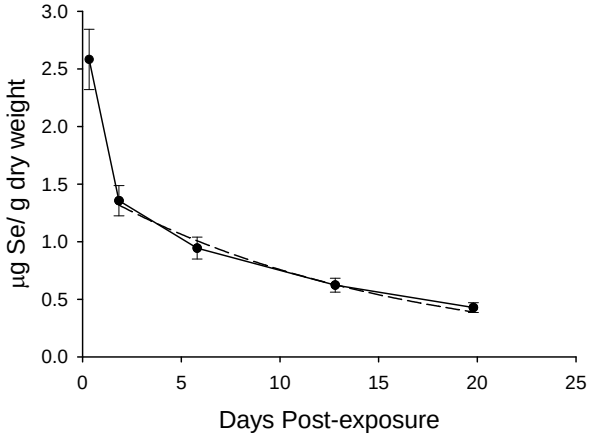


Fig. 17. Elimination of selenium from adult artemia exposed to waterborne selenium (72 µg Se/L) for 48 hours. An elimination rate constant of 0.0679 was obtained from the fitted curve, r^2=0.99.

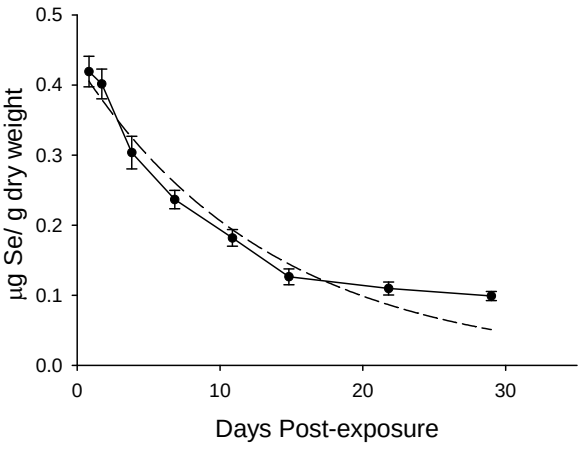


Fig. 18. Elimination of selenium from adult artemia exposed to dietary selenium for 24 hours. An elimination rate constant of 0.0737 was obtained from the fitted curve, $r^2 = 0.95$.

rates of 7.37 % per day remained constant at least during the first 14 days of depuration after which an apparent reduction in elimination rates is evident (Fig.18). The elimination rates were determined from the fitted exponential decay curves (doted lines). Despite initial accumulated selenium concentrations approximately 6-fold higher in waterborne compared to dietary exposures, elimination rates appeared slightly lower for waterborne selenium.

Influence of prolonged exposure on selenium uptake rates.

Two weeks of exposure to elevated, yet environmentally relevant, selenium concentrations tended to reduce selenium uptake rates from the water and assimilation efficiency from the diet. Waterborne exposure to selenium resulted in an apparent 23% reduction in subsequent ^{75}Se labeled selenium uptake although this difference escapes statistical significance (Fig. 19). Similarly, prolonged exposure to dietary selenium concentrations of

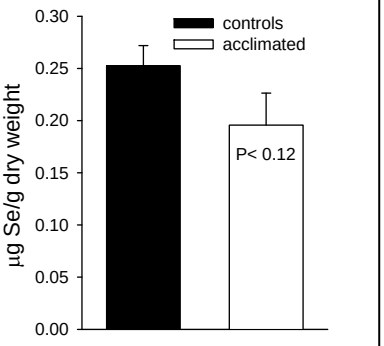


Fig. 19. Selenium uptake from the water at 2.55 ± 0.11 µg Se/L in control artemia and artemia acclimated to 2.87 ± 0.14 µg Se/L for 14 days.

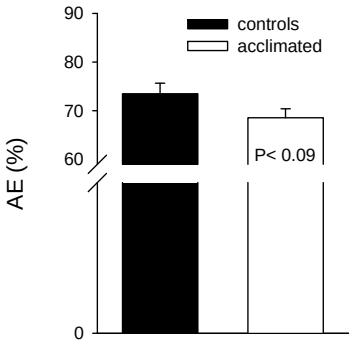


Fig. 20. Assimilation efficiency (AE) from algae containing 3.73 µg Se/g dry weight in control artemia and in artemia acclimated to dietary selenium at 2.68 µg Se/g dry weight for 14 days.

environmental relevance resulted in a modest (not statistically significant) reduction in subsequent assimilation efficiency from 73.5 to 68.6% equivalent to a 7% reduction in total dietary selenium assimilation (Fig. 20).

Discussion

Independent analytical verification by Frontier Geosciences, Inc. confirms the utility of the isotope dilution technique and further demonstrates that background selenium concentrations in media used at the University of Miami are below detection as measured total selenium never exceeds concentrations calculated using the isotope dilution method. The isotope dilution technique continues to be a cost effective, fast and reliable method for determining exposure concentrations in solutions with matrix interference potential and for measuring low concentrations in samples of limited mass. For context, the present project involved the analysis of more than 2400 samples, the majority of which were on the order of 5 mg or less (individual adult artemia).

Initial experiments revealed that 24 hours of exposure to waterborne selenium resulted in linear accumulation in artemia and revealed that exposure concentrations remained constant during this period. Furthermore, it was revealed that 60 minutes of duration for feeding experiments is appropriate for determination of ingestion rates and quantification of selenium ingestion and subsequent assimilation efficiency.

No mortality was observed during selenium uptake experiments and less than 10% mortality was observed in depuration experiments in which repeated handling of individual artemia likely was the cause of mortality.

Influence of salinity

In agreement with expectations, increased GSL salinity from 100 to 160 ppt resulted in a significant reduction in selenium uptake by artemia. Although it is unknown which component(s) of the ionic matrix in the GSL medium is responsible for this observation it appears likely that sulfate is the anion competing with selenium uptake, especially since the artificial GSL medium did not contain phosphate. Early studies demonstrated a direct antagonistic relation between sulfate and selenium uptake in plants[25] and several subsequent studies have revealed that elevated sulfate protects against acute selenium toxicity in algae as well as aquatic organisms, including artemia in freshwater and hypersaline environments[7,14,37].

In contrast, elevated dietary selenium intake (feeding rate) was expected at 160 compared to 100 ppt. Elevated salinity can be expected to be associated with an increased metabolic demand from osmoregulatory processes and such an elevated metabolic cost was expected to be associated with higher feeding rates and thus higher dietary selenium intake in artemia fed *ad lib*. While the reason for apparently reduced selenium ingestion at higher salinities is unknown, the brief duration of the feeding experiments allows for the conclusion that feeding rate is lower at 160 ppt compared to 100 ppt and that ingested/assimilated selenium levels likely are not influenced directly by ambient sulfate levels that might be ingested with food.

Selenium uptake from the water

Selenium uptake from the water displayed a complex pattern of saturation kinetics at concentrations below 10 µg Se/L followed by a sharp increase in selenium uptake rates with a threshold somewhere between 10 and 20 µg Se/L. In addition it appears that selenium uptake is down-regulated at concentrations above 40 µg Se/L, although this later observation is based on a single high selenium concentration. In the following, "high affinity, low capacity system" will refer to the selenium uptake at concentrations below 10 µg Se/L and "low affinity, high capacity system" will refer to the uptake pathways dominating at higher concentrations.

The apparent saturation pattern at relatively low selenium concentrations indicates that selenium is taken up from the water, presumably via the respiratory surface, via protein carriers in epithelial cells. Saturation uptake patterns have also recently been reported for freshwater algae exposed to selenate[15]. Although it seems that high sulfate concentrations may interfere with selenium uptake, the specificity of this putative selenium uptake system is not known but transporters with high specificity for selenium are known from mammalian systems and from plants[4,32,38]. The apparent affinity constant for the high affinity, low capacity selenium uptake system (K_m) which denotes the ambient concentration at which the transport system is half saturated is 1.2 µg Se/L. The significance of this becomes clear when one considers the range of selenium concentrations normally observed in GSL (0.297 to 0.899 µg Se/L, Brad Marden report). Regardless of the nature of the selenium transporters responsible for this high affinity transport system, variations in ambient selenium concentrations within the range

normally observed in GSL will greatly influence the selenium uptake rates by this transport system.

The low affinity, high capacity system dominates at selenium concentrations exceeding those observed in open GSL waters and thus are not a factor for steady state selenium concentrations in GSL artemia.

A situation of an apparent dual carrier uptake system with distinct transport characteristics is not unprecedented and has been observed for copper in the freshwater rainbow trout[20]. Like selenium, copper is an essential micronutrient that is potentially highly toxic and therefore it is not surprising that these two elements might share this unusual uptake pattern.

The apparent reduction in selenium uptake at the highest concentration tested could be a consequence of down regulation of the low affinity, high capacity selenium uptake system but the highest selenium concentration tested is orders of magnitude lower than concentrations considered to be acutely toxic to artemia[14]. Furthermore, the highest tested selenium concentration falls well above concentrations relevant for GSL and uncertainty associated with the reason for apparent reduced uptake at this concentration is of no consequence for predictions on steady state selenium concentrations in GSL artemia.

Selenium accumulation in D. viridis

The careful characterization of selenium accumulation on *D. viridis* for the purpose of providing a natural diet for the study of dietary selenium uptake in artemia under conditions relevant to GSL revealed a complicated pattern of selenium accumulation. An initial increase in cellular selenium concentration in algae cultured in presence of selenium was expected but the clear depuration of cellular selenium concentrations from algae cells despite continued exposure to constant ambient selenium concentrations was not anticipated. An obvious possible explanation for this pattern, growth dilution, can be dismissed based on continued low cellular selenium concentrations during the last 20 days of the 40-day culture period during which cell density remained relatively constant. During this period, net growth was minimal but no increase in cellular selenium concentrations was observed and values remained much below peak concentrations observed around day 5-8 of culturing. Furthermore, calculations of specific growth rate in the algae culture (daily % increase in cell density) revealed that growth rates were also high during the initial rapid accumulation phase observed during the first week or so of culture. A final observation of lack of correlation between algal cellular selenium concentrations and specific growth rate also argues against growth dilution as an explanation for the observed selenium depuration during continued exposure.

Two possible explanations remain that may account for the observed reduction in cellular selenium concentrations during continued exposure. For one, reduced selenium uptake as a negative feedback to elevated cellular selenium concentrations combined with constant growth and selenium elimination would result in reduced cellular selenium concentrations. A second possibility is that selenium elimination is stimulated by elevated

cellular selenium concentrations which, even when combined with constant uptake, would result in reduced cellular selenium concentrations. Obviously, a combination of reduced uptake and stimulated excretion cannot be dismissed as a possibility. Indeed, selenium biotransformation by salinity tolerant phytoplankton has been described to include the formation of volatile alkylselenides which may account for the apparent selenium excretion[13].

While activation of a selenium export system is the only way to account for selenium excretion, reduced uptake could potentially be accounted for by a down regulation (reduction in numbers) of selenium uptake proteins or be explained by cellular excretion of substances rendering ambient selenium less available for cellular uptake. This latter explanation could be highly important in algal culture situations where cell densities are extremely high compared to natural situations but might be less important under natural conditions. In contrast, a down regulation of selenium uptake proteins would have the same effect in algal cultures as in natural algae populations.
In any case, the employed long-term exposures of algae in the present study ensures that algal biotransformation of selenium to organic forms which is significant for dietary selenium availability occurred.

The bioconcentration factors for *D. viridis* at steady state were $2.23 \cdot 10^3$, $2.16 \cdot 10^3$, $1.87 \cdot 10^3$ and $1.31 \cdot 10^3$ at 1.2, 3.6, 17.8 and 60.4 µg Se/L, respectively (calculated from the data in Fig 12) and thus adhere to what appears to be a general pattern of reduced bioconcentration factors with increasing exposure concentrations[31]. An important

consequence of the dynamic Se accumulation pattern over time in *D. viridis* is that bioconcentration factors will differ depending on what point in time during exposure the algal selenium concentrations are considered. The above bioconcentration factors, although somewhat higher, compare favorably to an overall bioconcentration factor for seston in GSL of $0.64 \cdot 10^3$ (based on mean concentrations from 2006, Brad Marden report), although they are somewhat higher. A possible explanation for the higher bioconcentration factors for *D. viridis* under laboratory conditions compared to the field may reflect that seston from GSL is comprised in part of organic material without cellular metabolic activity and thus selenium concentrating processes.

Trophic selenium transfer to artemia

Gut retention time for artemia fed *D. viridis* is 60 minutes and ingestion rates at the cell densities employed for the present study were 0.021 g algae dry weight/day/g artemia wet weight, which is equivalent to 0.185 g algae dry weight/day/g artemia dry weight. This ingestion rate is comparable to feeding rates reported for marine zooplankton including copepods and mysids although slightly lower than the reported range from 0.33 and 0.44 g algae dry weight/day/g artemia dry weight[30].

The assimilation efficiencies determined in the present study were not constant across exposure concentrations. To the best of our knowledge no studies to date have considered the influence of dietary exposure concentrations on selenium assimilation efficiency and it is generally assumed to be constant regardless of concentration for metals[30]. The exponential decay equation describing the relationship between dietary selenium

concentration and assimilation illustrates that selenium assimilation efficiency in artemia fed *D. viridis* ranges from 75% at high concentrations to 100% at very low selenium concentrations. This relationship is in agreement with the saturation pattern observed for uptake of selenium from the water and strongly suggests that intestinal selenium uptake is mediated by specific transport pathways that become limiting for uptake at higher selenium concentrations. The assimilation efficiencies observed in the present study (>75%) compare favorably with earlier reports ranging from 30-86%[29,36,39,44] but cannot be assumed to be constant across exposure concentrations. The assimilation efficiencies determined as part of the present study represent a suspension feeding/algae relationship that is directly relevant to GSL and considers algae in steady state with respect to selenium concentrations. While using algae at steady state represents a realistic situation for chronic exposures, it is unknown how factors like cell density (and thus feeding rate) and seston (rather than pure algae) as a food source might influence dietary selenium assimilation.

Selenium elimination by artemia

Considering first elimination of selenium accumulated from the water, an 80% depuration was obtained during a 20-day period with an initial rapid selenium loss during the first 24 hours following termination of exposure. An elimination rate constant of 6.79%/day was determined from fitted exponential decay curves based on data points collected after the initial rapid depuration phase. Similar observations of rapid initial elimination of metals have been reported previously and are believed to be associated with dissociation of surface-bound metal. The rapid initial elimination phase was not considered when

deriving elimination rate constants because it most likely does not reflect the physiology of organisms chronically exposed in natural environments[8,10,11].

Considering next the elimination of dietary selenium originating from a *D. viridis* diet, a near 80% depuration was also obtained approximately 20 days after ingestion of a ^{75}Se labeled algae diet. The elimination rate constant for dietary selenium was 7.37 ± 0.33%/day and thus tended to be slightly higher than the 6.79 ± 0.34%/day observed for waterborne selenium. From both the waterborne and dietary selenium elimination experiments it appears that elimination rate constants are independent of accumulated selenium concentrations, which is consistent with most earlier studies. Although slightly different, the elimination rate constants observed in the present study for waterborne and dietary selenium are in agreement with elimination rate constants reported for many other invertebrates for a number of different metals[30].

A model to predict steady state selenium concentrations in artemia (Objective 5)

The development of a model to predict steady state selenium concentrations in *artemia* under conditions relevant to GSL was inspired by the DYMBAM model approach[35]. In brief, the differential equations describing this model have been solved to determine selenium concentrations at steady state (constant selenium concentration in the organism, *C*ss) as:

$$Css = [(k_u \cdot C_w) + (AE \cdot IR \cdot C_f)]/(k_e + g)$$

where:

k_u = is the uptake rate constant from water

C_w = waterborne selenium concentration

AE = dietary assimilation efficiency

IR = ingestion rate

C_f = dietary selenium concentration

k_e = elimination rate constant

g = growth dilution

The approach presented in the following deviates slightly from the original DYMBAM model in that in considers the two (slightly) different k_e's, one for waterborne Se (k_ew) and one for dietary Se (k_ef) discussed above.

Thus the principal model developed for the steady state selenium concentrations in brine shrimp in the GSL is as follows:

$$\mathbf{Ss[Se] = ((}k_u \cdot \mathbf{C_w)}/k_e\mathbf{w) + ((AE \cdot IR \cdot C_f)}/k_e\mathbf{f)}$$

Note that growth dilution "g" is omitted from the model since it has been developed for adult artemia.

In addition to this deviation, uptake rate from the water (k_u) is considered in two different ways: in scenario I a traditional k_u is used as in previous reports whereas in scenario II it

is reflected by a Michaelis-Menten kinetics equation (Fig. 21). These two different scenarios result in slightly different predicted steady state selenium concentrations but since only one apply to environmental conditions relevant for GSL, only one set of steady state concentrations are reported. Furthermore, our observations of varying assimilation efficiency (AE) depending on dietary Se concentrations prompted the use of an equation rather than a constant to describe AE.

The constants/equations used for the developed ss[Se] model are listed in Table 3.

	Waterborne		**Dietary**
Parameter	*Scenario I*	*Scenario II*	
K_u	0.211/0.100 (0.156)	$(660.2 \cdot C_w)/(1.20+C_w)$	-
C_w	Input variable		-
k_ew or k_ef	0.0679	0.0679	0.0737
AE	-	-	$(74.97+26.54^{-0.1088Cf}) \cdot 10^{-2}$
IR	-	-	0.185
C_f	-	-	Input variable

Table 3. *Individual model parameters for the ss[Se] model. Uptake parameters ingestion rates are expressed per g dry weight*

Waterborne exposure ***($\underline{(k_u \cdot C_w)/k_e w}$):***

Uptake:

Scenario I **($\underline{k_u \cdot C_w}$):**

The traditional uptake rate constant (k_u) can be determined from the near-linear part of the uptake kinetics curve to be 0.211 l/g dry weight/day) and applies to ambient selenium concentrations < 2.5 µg/L since the uptake kinetics curve is only linear below this concentration (Fig 21). The two replicate experiments revealed slightly different k_u's

(0.211 and 0.100, respectively). For predictions of selenium steady state concentrations a mean k_u of 0.156 as a traditional uptake rate constant has been applied.

Scenario II:

From the Michaelis-Menten saturation kinetics applying to selenium concentrations below 10 µg/L, an uptake rate constant (or equation rather, Fig. 21) was determined to be:

$k_u = (660.2 \cdot C_w)/(1.2 + C_w)$, $r^2 = 0.92$

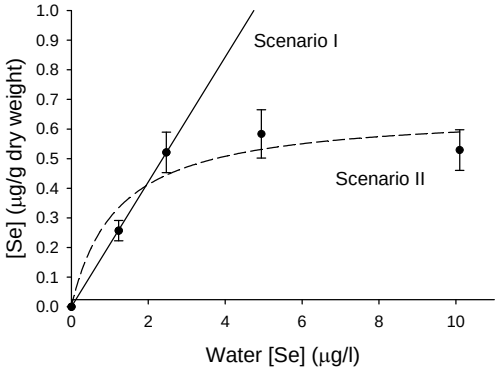


Fig. 21. Subset of data presented in Fig. 7. focusing on low ambient selenium concentrations. A traditional linear K_u applies to exposure concentrations below 2.5 µg Se/L but saturation kinetics apply to a wider range of concentrations from 0 to 10 µg Se/L.

Note that the constant in scenario I is considerably higher than previously reported k_u's for pelagic crustaceans ranging from 0.024-0.027[36,39] but is in good agreement with k_u's for estuarine macroinvertebrates[3] and that it is determined for low selenium concentrations relevant for GSL. The k_u determined for natural GSL water is in closer agreement with previously determined k_u's for pelagic crustaceans. It is unknown why natural GSL water would yield a lower k_u than observed in artificial GSL since the salinity of the natural GSL sample used was lower than that of the artificial medium. Employing scenario II for higher concentrations reveals numbers in closer agreement with the above-mentioned previous values. In contrast, employing scenario II to predict

steady state selenium concentrations at low water-borne selenium (<2 µg/L) results in higher selenium steady state selenium concentrations than scenario I. These higher predicted values for scenario II are a consequence mainly of the curve fitting and are probably unrealistic. Consequently, only model predictions using scenario I are reported in the following.

Elimination: The rate constant of loss (k_e) relevant to selenium accumulated from waterborne exposure are discussed above.

Steady state Se concentrations (ss[Se]) in artemia arising from waterborne exposures in artificial GSL water (the first part of the ss[Se] model above) can be estimated using the following equations:

Scenario I: Waterborne ss[Se] = $((0.156 \cdot C_w)/0.0679)$

Scenario II: Waterborne ss[Se] = $[((660.2 \cdot C_w)/(1.2 + C_w))]/ 0.0679$

Dietary exposure ($(AE \cdot IR \cdot C_f)/k_ef$):

Uptake: The assimilation efficiency (AE) is normally assumed to be constant in DYMBAM models regardless of dietary metal concentration. However, the present project identified that assimilation efficiency decreases with increasing dietary selenium concentrations and that it adheres to an exponential decay equation ($74.97+26.54^{-0.1088 \cdot Sef}$) that is used to predict AE in the present ss[Se] model.

Conversion from artemia wet weight to dry weight

The water content of adult artemia used in the present investigation was 88.6 ± 0.5 % (n=12).

Predicted steady state selenium concentrations (ss[Se])

Table 4 shows artemia steady state selenium concentrations according to the model parameters for scenario I described above for waterborne selenium, combined with the dietary contribution. Scenario I is used since it describes the uptake directly from the water most accurately at low concentrations relevant to GSL. Highlighted values represent mean measured concentrations from GSL (mean selenium concentrations in GSL during the period from April to December 2006; data provided by Brad Marden) and corresponding predicted ss[Se] according to the scenarios described above. Measured total selenium concentrations in artemia from GSL range from 0.5 to 3.3 with an arithmetric mean of 1.185 µg Se/g dry weight and the model prediction of 2.62 µg Se/g dry weight for scenario I and it thus in reasonable agreement. A slightly better agreement is achieved using the k_u obtained from experiments with natural GSL water for which the predicted selenium concentration at steady state is 1.62. Note that for the GSL selenium concentrations observed in April – December 2006, scenario I is the recommended model.

The model predictions and measurements of artemia selenium concentrations reported by Brad Marden are in reasonably good agreement with measured selenium concentrations in artemia collected from GSL in 2002 which range from 2.86 to 3.38 µg Se/g dry weight for artemia collected in open GSL water[5]. However, in the study by Brix and co-workers little if any effect of ambient selenium on artemia selenium concentrations was observed at concentrations below 30 µg Se/L. The "knee" in the accumulation curve appears to be somewhere between 30 and 80 µg Se/L for field-collected artemia[5], which is somewhat higher than the 10-20 µg Se/L observed in the present study. A similar pattern was observed by Brooks in a study for Kennecott Utah Copper, Inc., which reported the "knee" in laboratory studies of selenium-exposed artemia to be around 50 µg Se/L and artemia selenium concentrations of around 2-3 µg Se/g dry weight at concentrations below this threshold. Using a conservative approach, fitting a linear relationship between artemia and water selenium concentrations from field-collected samples Brix and co-workers suggested that 5 mg Se/kg dry weight in artemia would not be reached until ambient selenium concentrations reached 27 µg Se/L[5]. The models developed as part of the present study are not suited to evaluate ambient concentrations as high as 27 µg Se/L and should not be used to consider situations of selenium concentrations above 2.5 and 10 µg Se/L for scenarios I and II, respectively. However, both model scenarios agree that artemia steady-state concentrations of 5 mg/kg will be reached at concentrations considerably below 27 µg Se/L. The reason(s) for this discrepancy is unknown but it is possible that field collected artemia were not at steady state with respect to selenium concentrations due to limited residence time in the local environment sampled.

Interestingly, both field-collected and laboratory-reared artemia display the “knee” in the accumulation curve although at slightly different exposure concentrations. From the present study one can conclude that this shape of the accumulation curve can be ascribed to uptake from the water rather than the diet. This conclusion is based on the proportionality of algae selenium accumulation in relation to media selenium concentrations and artemia algae ingestion rate, which is constant across the tested dietary selenium concentrations. These observations combined cannot account for an observed pattern of selenium uptake at higher selenium concentrations. In contrast, uptake from the water shows an accumulation pattern similar to that observed in GSL collected artemia (although with different thresholds) with an greatly elevated increase in accumulated selenium above the “knee”.

An interesting observation arising from model predictions made possible through the present study is that waterborne selenium uptake contributes significantly to steady state concentrations in GSL artemia. Using the mean selenium concentrations for seston and water collected from GSL above, water contributes 52% of the steady state selenium concentrations (model scenario I). This conclusion is supported by the observation that uptake from the water likely dictates the accumulation pattern with increasing ambient concentration as waterborne uptake displays the hockey stick-shaped patterns observed for selenium accumulation in artemia collected from GSL.

The K_u determined as part of the present study for low ambient selenium concentrations is high compared to previous reports, which likely explains the relatively high waterborne

contribution to steady state selenium concentrations in artemia. However, it should be noted that since uptake from the water and assimilation efficiencies are not strict linear functions of selenium concentrations the relative contribution of the two uptake pathways will depend on environmental conditions and selenium concentrations.

Acclimation – reduced selenium uptake?

Reduced metal uptake and elevated metal excretion has been observed during prolonged exposure to essential elements[17,18,19,21,22,27] and serves to maintain stable tissue levels despite elevated environmental concentrations. Considering the essentiality of selenium, homeostatic control of selenium in artemia is likely and might involve both reduced uptake and elevated elimination. When predicting steady state concentrations using biodynamic models, such physiological responses may go unnoticed and could result in overestimation of steady state concentrations. The approach employed to determine selenium elimination in the present study involved a brief exposure but several weeks of depuration measurements which likely would have captured and included any influence of adjustments to serve homeostatic control. In contrast, the uptake measurements, dietary as well as waterborne, were performed over 1-24 hours using artemia not previously exposed to selenium. The possibility of reduced uptake from the water or reduced dietary selenium assimilation efficiency in artemia following prolonged selenium exposure was therefore examined in the present study. For both waterborne uptake and dietary assimilation efficiency, the predicted reductions following prolonged exposure were observed but were statistically insignificant. Although no statistical significance was noted, both waterborne uptake and dietary assimilation efficiency tended to drop as

predicted but only to a modest extent. The combined effect of these reductions in selenium uptake likely would not exceed a 10-20% reduction in predicted steady state selenium concentrations in artemia. This potential effect on steady state concentrations is not currently represented by the models (scenario I or II) but the models could be adjusted to accommodate for this effect should it be desired.

Conclusions

It appears that, regardless of the route of uptake, selenium accumulation is lower at higher salinities. Although the generality of this observation across a wider range of salinities remains to be demonstrated, it appears that steady-state selenium concentrations, all other factors being equal, may correlate negatively with ambient salinity.

Algae exposure time is of great importance for apparent bioconcentration factors, as algae (at least *D. viridis*) display a complex selenium accumulation pattern over time.

At steady state, *D. viridis* display a negative correlation between selenium bioconcentration factors and exposure concentration.

Homeostatic control of selenium in *D. viridis* is suggested by the reduced cellular selenium concentration during continued exposure, a reduction that cannot be accounted for by growth dilution.

Selenium uptake from the water displays saturation kinetics at low ambient concentrations (<10 µg Se/L) with a high affinity constant and relatively high K_u. At higher concentrations, a low affinity, high capacity uptake system contributed to a "hockey stick-shaped" accumulation pattern.

Selenium assimilation efficiency by artemia is not constant. Near 100% assimilation efficiency applies to low dietary (i.e., *D. viridis*) selenium concentrations while 75% is relevant for higher concentrations.

A developed set of DYMBAM-type models allows for predictions of steady-state selenium concentrations in artemia under conditions relevant to GSL. Model predictions are in good agreement with measured values from GSL and other laboratory studies.

The models ascribe waterborne uptake as a significant contribution to steady state selenium concentrations in artemia.

Acclimation (likely to occur during prolonged exposure) possibly results in a modest reduction of selenium uptake from both waterborne and dietary sources.

Recommendations

The reason for the reduced cellular selenium concentration in *D. viridis* during continued exposure remains unknown and it is uncertain if such a pattern would apply under natural conditions. It is advised that the two possible explanations for reduced selenium uptake

(reduced number of selenium transporters versus excretion of substances rendering selenium less available for uptake) are examined experimentally.

Furthermore, it is desirable to examine if selenium taken up during the early phases of algae growth and accumulation is more or less amendable to trophic transfer to artemia.

The above modeling effort and conclusions are based on experiments performed at a single and high algae cell density and a uniform, single-species algae diet. None of these conditions are completely realistic for GSL. Algae densities are always below the densities employed in the present study and seston rather than pure algae communities are the natural food source for artemia in GSL. A lower cell density might result in a lower feeding rate, which in turn may result in higher assimilation efficiency. Furthermore, seston rather than pure algae diets might reduce assimilation efficiency. The combined influence of these possible factors on dietary selenium uptake is impossible to accurately predict without further studies.

The isotopic approach has proven very effective for fast feedback on exposure concentrations and thus for the maintenance of constant exposure concentrations and for determination of selenium uptake and accumulation in a cost effective manner. In addition, the resolution and sensitivity of isotope measurements is superior to that of other analytical techniques. However, this technique is not without potential drawbacks. From a biodynamic modeling perspective it is assumed that ^{75}Se uptake, internal distribution and subsequent elimination reflect all components of selenium homeostasis

and that they are in equilibrium with internal selenium stores present in the organisms prior to isotope exposure. While this is not a problem for uptake rate measurements from the water or for dietary uptake measurements from a chronically exposed diet as used in the present study, it may influence elimination rate constant determination. The extensive duration of the depuration measurements in the present study were aimed at limiting this potential problem but it is not known for certain if ^{75}Se elimination truly reflects overall selenium elimination. A set of validation experiments comparing DYMBAM model predictions from isotope measurements to actual measured total selenium concentrations in artemia held under identical conditions would address this uncertainty.

Table 4. Scenario I: total ss[Se] (µg Se/g dry weight) in artemia

	Dietary [Se]											
Water borne [Se]	**0**	**0.2**	**0.4**	**0.504**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**
0	0	0.5	1	1.26	1.50	1.99	2.47	2.95	3.42	3.89	4.35	4.81
0.2	0.46	0.96	1.46	1.72	1.96	2.45	2.93	3.41	3.88	4.35	4.81	5.27
0.4	0.92	1.42	1.92	2.18	2.42	2.91	3.39	3.87	4.34	4.81	5.27	5.73
0.597	1.36	1.87	2.36	2.62	2.86	3.35	3.83	4.31	4.78	5.25	5.72	6.18
0.6	1.38	1.88	2.38	2.64	2.88	3.37	3.85	4.33	4.80	5.27	5.73	6.19
0.8	1.84	2.43	2.84	3.10	3.34	3.83	4.31	4.79	5.26	5.73	6.19	6.65
1.0	2.30	2.86	3.30	3.56	3.80	4.29	4.77	5.25	5.72	6.19	6.65	7.11
1.2	2.76	3.26	3.76	4.02	4.26	4.75	5.23	5.71	6.18	6.65	7.11	7.57
1.4	3.32	3.72	4.22	4.48	4.72	5.20	5.69	6.17	6.64	7.11	7.57	8.03
1.6	3.68	4.18	4.68	4.94	5.18	5.66	6.15	6.63	7.10	7.57	8.03	8.49
1.8	4.14	4.64	5.14	5.40	5.64	6.12	6.61	7.09	7.56	8.03	8.49	8.95
2.0	4.60	5.10	5.60	5.86	6.10	6.58	7.07	7.55	8.02	8.49	8.95	9.41

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STANDARD OPERATING PROCEDURES

Standard Procedures for Se-75 Experiments – Uptake from the Water

(Objectives 1, 2, 6 & 7)

1. Acclimate artemia for a minimum of 48 hours to test media (for example 100 g/L and 160 g/L GSL media) in 1-L tripour beakers containing ~ 800 mls media. Transfer approximately 50 adult artemia from culture tank to acclimation beaker by gently netting with a fine mesh fish net, and feed 1 ml of algae food daily. Brine shrimp food is made by adding 1 g of Wardley Premium Algae Discs per 20 mls of deionized water and blending thoroughly. It is kept refrigerated.
2. Prepare Se-75 stock solution in a 1.5-ml micro-centrifuge tube 24 hours prior to test initiation to allow for complete equilibration. Se-75 stock is made with Se-75 isotope, unlabelled ("cold") Se and DI water in a ratio to provide the desired Specific Activity and volume necessary for test beaker spikes and determination of radioactivity. Keep frozen (-20ºC) until ready for use to inhibit microbial activity.
3. Immediately prior to test initiation, remove 20 artemia from acclimation beaker individually with a plastic transfer pipette and place in 80 mls fresh test media in a 100-ml beaker (this is done to minimize the introduction of fouled water from the acclimation beaker into the test beaker).
4. Add 25 mls of fresh test media to a clean 50-ml beaker.
5. Carefully add 20 of the rinsed individual artemia to the beaker using a plastic transfer pipette, minimizing the amount of liquid transferred with each artemia. This density is similar to the density of the artemia in the main cultures.

6. Wait 10 minutes for the artemia to recover from handling and to acclimate to the test beaker.
7. Spike the test beaker with the appropriate volume of Se-75 stock solution to reach desired concentration. The small volume of the Se spike (i.e. 20 μl) does not significantly alter the water chemistry, including pH of the test beaker.
8. Gently aerate the beaker with capillary tubing to ensure mixing and full air saturation and cover with a glass Petri dish (Figures 1a and 1b).
9. 10 minutes after isotope addition take an initial water sample (100 μl) for determination of Se-75.
10. After 24 hours of exposure take a final water sample (100 μL) for determination of Se-75. Preliminary experiments have shown that in this experimental setup, the amount of radioactivity, and therefore the [Se], remains constant during the 24-hour exposure (Figure 2).
11. Carefully remove individual artemia with plastic transfer pipette and transfer them (individually) through a series of 3 rinses (10-15 mls each) of fresh media in a 6-well plate (Figure 3). This procedure has been tested and has revealed no remaining isotope contamination after the 2nd rinse (Figure 4).
12. After rinsing, carefully blot individuals dry on a paper towel, determine mass on weighing paper to nearest 10 μg, then place into plastic culture tube for gamma counter.
13. Rinse and weigh 10 artemia, take another final water sample (100 μL), then rinse and weigh 5 more artemia for a total of 15 individuals.

14. Dilute the Se-75 stock as appropriate to measure cold Se on the GFAAS; then take three 10-µL samples of this diluted stock to be read on gamma counter.
15. Determine CPMs of all samples on gamma counter: blank, initial water sample, blank, final water sample, 10 individuals, final water sample #2, 5 individuals, and diluted Se-75 stock.
16. Measure cold Se on GFAAS and determine specific activity of Se-75 stock by dividing: (cpm/L) / (µg Se/L) = cpm/µg Se.
17. Calculate Se uptake according to: (cpm/individual) / (cpm/µg) = µg Se/individual.

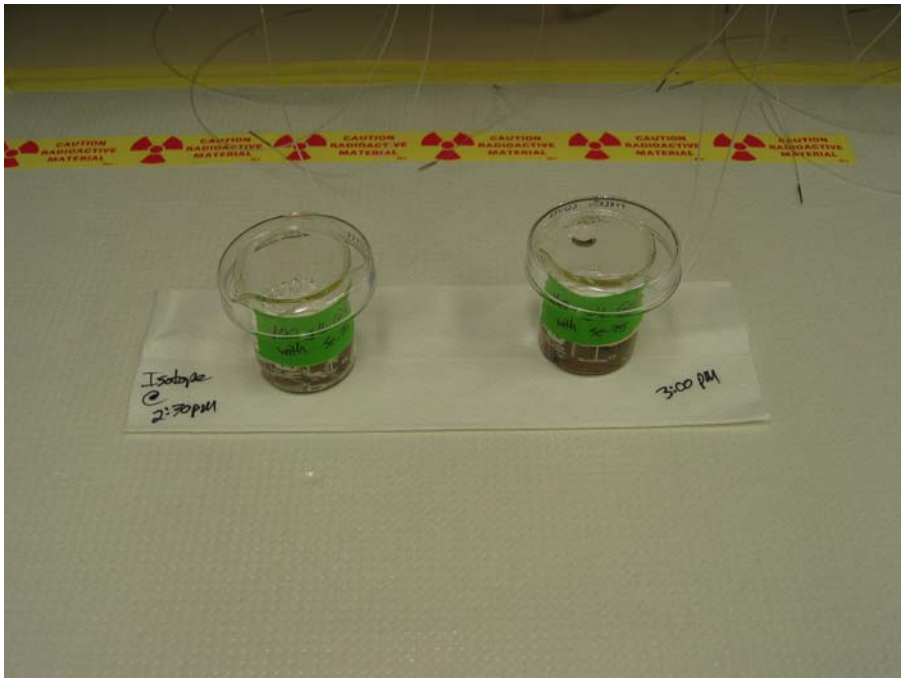


Figure 1a.

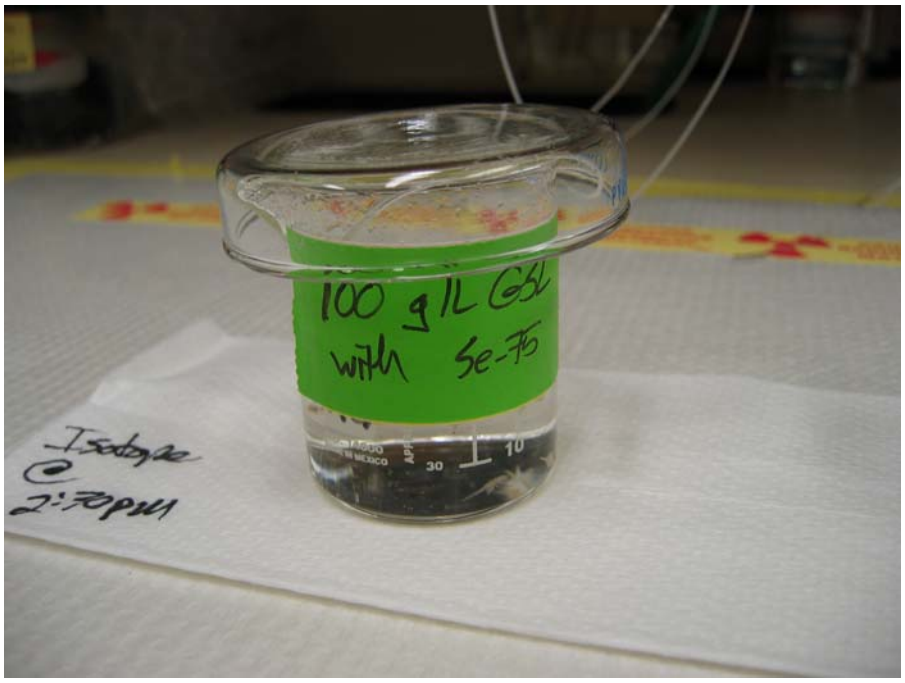


Figure 1b.

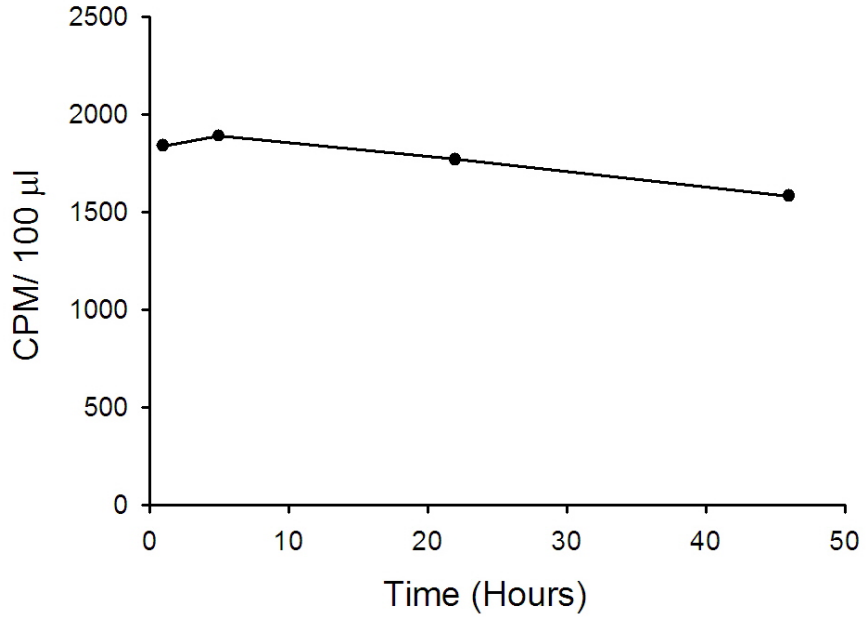


Figure 2. Radioactivity in 100-ml samples of Se-75 exposure water sampled at 1, 5, 22 and 46 hours during preliminary experiments. Radioactivity, and therefore [Se], remains relatively constant over time.

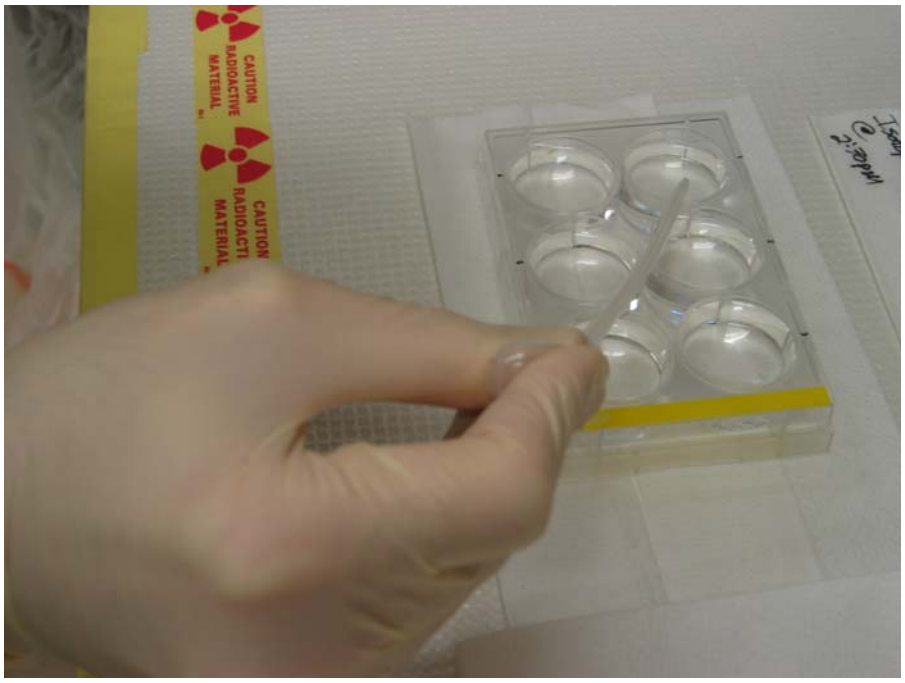


Figure 3.

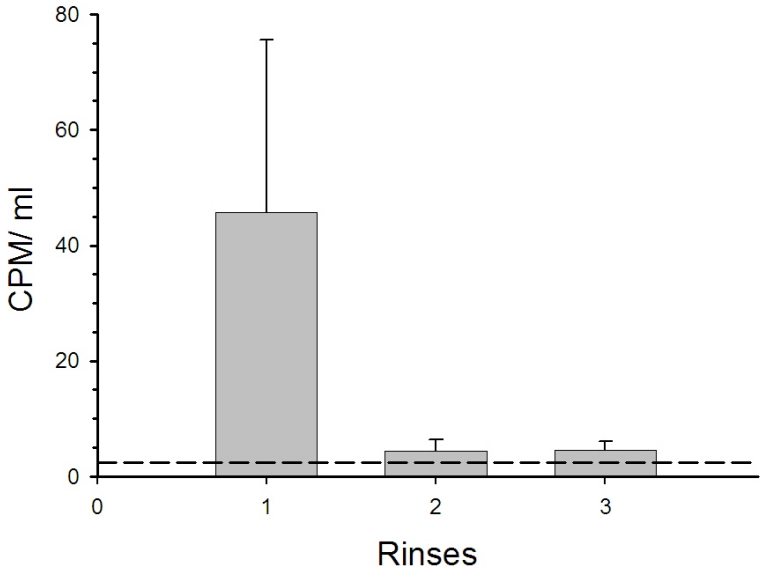


Figure 4. Radioactivity in the three rinse waters. Radioactivity in the second and third rinse waters is not significantly different from background levels (dotted line). For these experiments a total volume of 1 ml was counted for Se-75 activity.

Standard Procedures for Feeding Rate Experiment (Objective 1)

1. Remove ~100 adult, age-matched artemia from main culture tank and rinse in fresh media in a 200-ml beaker. (Artemia from the same hatch date and culture tank are very similar in size.)
2. Add 30 mls of fresh 100 g/L and 160 g/L GSL media to 50 ml centrifuge tubes.
3. Carefully transfer 15 artemia to each tube with a plastic transfer pipette, minimizing the amount of liquid transferred with each artemia.
4. Gently aerate the tube with capillary tubing to ensure even mixing and full air saturation and allow artemia a minimum of 10 min to recover from handling.
5. Add 2 mls of *Dunaliella viridis* concentrate to each tube (save sample of algae to perform cell counts for algae density).
6. Immediately take an initial water sample of 1 ml, and then take 1 ml sample every 10 minutes up to 60 minutes.
7. After thorough mixing to avoid problems with settling, measure the absorbance of all water samples on a spectrophotometer at 750 nm.
8. Plot absorbance over time and perform a linear regression on the decrease in absorbance to obtain the slope (change in absorbance per minute).
9. Divide slope by number of individuals per tube and express feeding rate as change in absorbance/ minute/ individual.

Standard Procedures for Determination of Dietary Selenium Intake

1. Grow *Dunaliella viridis* in algae media as outlined in the Scope of Work for 20 days under constant Se-75 labeled selenium concentrations (nominal 3, 15 and 50 µg/l)
2. Remove adult, size-matched *Artemia* from main culture tank and rinse in fresh media in a 200-ml beaker. (*Artemia* from the same hatch date and culture tank are very similar in size.)
3. Add 4L of fresh 100-g/L GSL media to 5 L plastic beakers.
4. Carefully transfer 20 *Artemia* to each beaker with a plastic transfer pipette, minimizing the amount of liquid transferred with each *Artemia*.
5. Aerate the beakers with an airstone (low air flow) to ensure even mixing and full air saturation and allow *Artemia* a minimum of 10 min to recover from handling.
6. Obtain a sample of *Dunaliella viridis* from the radioactive (Se-75) culture.
7. Centrifuge the sample of *Dunaliella viridis* at 8000 RPM in a microcentrifuge tube for 2 min.
8. Discard the radioactive supernatant.
9. Re-suspend the radioactive *Dunaliella viridis* in non-radioactive algae media.
10. Repeat steps 7-9.
11. Add an appropriate densitiy[1] of *Dunaliella viridis* grown in presence of Se-75 labeled selenium for 20 days.

[1] Algae cell density will be chosen to allow for sufficient Se-75 accumulation for accurate detection from preliminary experiments with the goal of feeding at densities as close to GSL algae densities as possible. Higher than desired algae cell density may have to be applied to allow for sufficient Se-75 uptake. So far our experiments have employed a cell density of approximately 2 mill cells/ml. Additional pilot experiments will determine the suited cell density for these experiments.

12. Take sub-sample of the *Dunaliella viridis* culture to measure selenium concentration in the *Dunaliella viridis* at the time of feeding.
13. Obtain sample of the *Dunaliella viridis* culture for accurate determination of cell density in the feeding experiment.
14. Obtain water samples from the feeding media at the beginning and end of the experiment to determine feeding rate.
15. After thorough mixing to avoid problems with settling perform manual cell count.
16. After 60 minutes[2], remove *Artemia* from feeding media and place them in individual gamma counting vials in 3 ml of GSL media.
17. Pass the vials through the gamma counter to determine Se-75 radioactivity in the newly fed *Artemia*.

[2] 30 and 60 min were used for the initial experiments - exact feeding time to be determined in additional pilot experiments.

Standard Procedures for Determination of Water-borne Selenium Assimilation Efficiency

1. Follow SOP for determination of water-borne selenium uptake steps 1-9. Use adult fully grown individuals.
2. Allow for a total of 48 hours of exposure (the longest exposure time we are comfortable with without feeding) to allow for selenium accumulation.
3. After 48 hours of exposure take a final water sample (100 µL) for determination of Se-75.
4. Carefully remove individual artemia with plastic transfer pipette and transfer them (individually) through a series of 3 rinses (10-15 mls each) of fresh media in a 6-well plate prior to placing them in individual gamma counting vials containing 3 mls of Se-75 free GSL media.
5. Pass these samples through a gamma counter for Se-75 determination in the live artemia.
6. After gamma counting, transfer individual artemia to separate 50-ml falcon tubes containing 30 ml GSL media. Feed animals daily and renew GSL media every other day.
7. At regular intervals (days apart), repeat steps 4-6 until significant depuration has been achieved.
8. Once depuration has been achieved and after a final rinse, carefully blot individuals dry on a paper towel and determine mass on weighing paper to nearest 10 µg.

9. Dilute the Se-75 stock as appropriate to measure cold Se on the GFAAS; then take three 10-μL samples of this diluted stock to be read on gamma counter.
10. Determine CPMs of all relevant samples on gamma counter: blank, initial water sample, blank, final water sample, 30 individuals, final water sample #2, 5 individuals, and diluted Se-75 stock.
11. Measure cold Se on GFAAS and determine specific activity of Se-75 stock by dividing: (cpm/L) / (μg Se/L) = cpm/μg Se.
12. Calculate Se accumulation and depuration according to: (cpm/individual) / (cpm/μg) = μg Se/individual.

Standard Procedures for Determination of Water-borne Selenium elimination

1. Follow SOP for determination of water-borne selenium uptake steps 1-9. Use adult fully grown individuals.
2. Allow for a total of 48 hours of exposure (the longest exposure time we are comfortable with without feeding) to allow for selenium accumulation.
3. After 48 hours of exposure take a final water sample (100 μL) for determination of Se-75.
4. Carefully remove individual artemia with plastic transfer pipette and transfer them (individually) through a series of 3 rinses (10-15 mls each) of fresh media in a 6-well plate prior to placing them in individual gamma counting vials containing 3 mls of Se-75 free GSL media.
5. Pass these samples through a gamma counter for Se-75 determination in the live artemia.
6. After gamma counting, transfer individual artemia to separate 50-ml falcon tubes containing 30 ml GSL media. Feed animals daily and renew GSL media every other day.
7. At regular intervals (days apart), repeat steps 4-6 until significant depuration has been achieved.
8. Once depuration has been achieved and after a final rinse, carefully blot individuals dry on a paper towel and determine mass on weighing paper to nearest 10 μg.
9. Dilute the Se-75 stock as appropriate to measure cold Se on the GFAAS; then take three 10-μL samples of this diluted stock to be read on gamma counter.

10. Determine CPMs of all relevant samples on gamma counter: blank, initial water sample, blank, final water sample, 30 individuals, final water sample #2, 5 individuals, and diluted Se-75 stock.
11. Measure cold Se on GFAAS and determine specific activity of Se-75 stock by dividing: (cpm/L) / (μg Se/L) = cpm/μg Se.
12. Calculate Se accumulation and depuration according to: (cpm/individual) / (cpm/μg) = μg Se/individual.

Standard Procedures for Determination of Dietary Selenium Assimilation Efficiency

1. Follow SOP for determination of dietary selenium intake steps 1-17.
2. After gamma counting, transfer *Artemia* to individual 15-ml falcon tubes containing 10 ml GLS media (100 g/l).
3. Feed the *Artemia* a Se-75-free diet and allow them to depurate fecal matter overnight.
4. Collect the *Artemia* from the 15-ml falcon tubes and recount individual *Artemia* for Se-75 as in steps 16 and 17.
5. Determine the wet weight of the individual *Artemia* and dispose.
6. Allow fecal matter in the 15-ml falcon tubes to settle; then siphon off 7 of the 10 mls of media.
7. Vortex the falcon tube now containing 3 ml of GSL media and fecal matter and rapidly transfer contents to a gamma counting vial.
8. Count these vials to determine the Se-75 content in the fecal matter.
9. Calculate dietary selenium intake from the specific Se-75 activity of the original algae culture medium and the initial Se-75 radioactivity in the *Artemia.*
10. Calculate the selenium assimilation efficiency from the Se-75 activity in the *Artemia* at the first and the second Se-75 determination. The difference equals the amount lost with fecal matter.
11. Calculate the dietary selenium uptake from the specific Se-75 activity of the original algae culture medium and the second Se-75 radioactivity measurement in the *Artemia*.

12. Validate the assimilation efficiency measurements by comparing the Se-75 lost between the initial and the final Se-75 activity measurements in the *Artemia* to the values detected in the fecal matter.

Waterborne Acclimation Experiment:

1. Remove ~100 adult, age-matched artemia from main culture tank and rinse in fresh media in a 200-ml beaker.
2. Add 1 L of 100-g/L GSL media to each of three 1-L tripour beakers.
3. Carefully transfer 30 artemia to each beaker with a plastic transfer pipette, minimizing the amount of liquid transferred with each artemia.
4. Gently aerate each beaker with capillary tubing to ensure even mixing and full air saturation.
5. Spike one beaker with an appropriate volume of Se-75 labeled Se stock (of known specific activity) to achieve 2 μg Se/L in the media. Spike another beaker with the same volume of unlabelled Se stock. The third beaker receives no addition of Se.
6. Take 3-mL initial water samples (in duplicate) from the Se-75 beaker and measure radioactivity on the gamma counter to verify exposure concentration.
7. Take duplicate 3-mL water samples daily from the Se-75 beaker, measure radioactivity, and spike with additional Se-75 labeled Se stock (or dilute with GSL media) to maintain 2 μg Se/L. Mirror the Se spikes and/or dilutions in the second beaker with unlabeled Se stock.
8. Feed each beaker daily with equal amounts of *Dunaliella viridis*. Feeding should be done 3-4 hours before water sampling and Se spiking to minimize uptake of Se by the algae cells.
9. Maintain waterborne exposures in the beakers for 2 weeks.

10. Perform waterborne uptake and depuration experiment with artemia exposed to 2 μg/L unlabeled Se (from second beaker) and artemia not exposed to Se in the media (from third beaker) according to **Standard Procedures for Se-75 Experiments – Uptake from the Water.** (Note: artemia from beaker containing Se-75 are not used in uptake and depuration experiment but simply serve to monitor exposure concentrations).

Dietary Acclimation Experiment:

11. Culture *Dunaliella viridis* in the presence of 1 μg Se/L (non-radioactive selenium) for 20 days. (This culture was prepared at the same time as the 1 μg/L Se-75 algae culture used in the dietary uptake experiment. Se spikes and dilutions made in the radioactive culture in order to maintain exposure concentrations were mirrored with unlabelled Se stock in the non-radioactive culture.)
12. Remove ~70 adult, age-matched artemia from main culture tank and rinse in fresh media in a 200-ml beaker.
13. Add 1 L of 100-g/L GSL media to each of two 1-L tripour beakers.
14. Carefully transfer 30 artemia to each beaker with a plastic transfer pipette, minimizing the amount of liquid transferred with each artemia.
15. Gently aerate each beaker with capillary tubing to ensure even mixing and full air saturation.
16. Feed each beaker equal amounts (normalized by absorbance at 750 nm to account for differences in culture density) of either non-radioactive Se-loaded *D. viridis* or normal *D. viridis* (not cultured in the presence of Se) daily for 2 weeks.
17. Remove 25 artemia from each beaker and transfer to beakers containing 4 L of 100-g/L GSL media.
18. Follow **Standard Procedures for Determination of Dietary Selenium Intake,** steps 5-17.

Appendix J

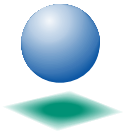
Data Quality Assessment
for the Great Salt Lake Water Quality Studies

Prepared for

The State of Utah,
Utah Department of Environmental Quality,
Division of Water Quality

October 2007

Prepared by



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Contents

Contents, Continued

Acronyms and Abbreviations

As	analytical spike
CVAA	Cold Vapor Atomic Absorption Spectroscopy
DQO	data quality objective
FB	field blank
FGS	Frontier Geosciences, Inc
HGAA	Hydride Generation Atomic Absorption Spectrometry
HGAF	Hydride Generation Atomic Fluorescence Spectrometry
LCS/LCSD	laboratory control sample/laboratory control sample duplicate
LET	Laboratory and Environmental Testing, Inc.
MS/MSD	matrix spike/matrix spike duplicate
NIST	National Institute of Standards and Technology
NRCC	National Research Council of Canada
PARCC	precision, accuracy, representativeness, completeness and comparability
PDS	post digestion spike
PI	Principal Investigator
QAPP	quality assurance project plan
QC	quality control
RL	reporting limit
SDG	sample delivery group
SRM	Standard Reference Material
USGS	United States Geological Survey

SECTION 1.0

Data Quality Assessment

1.0 Introduction

This Data Quality Assessment report contains an evaluation of the quality and usability of analytical data from environmental samples collected for the Great Salt Lake Selenium Water Quality Studies for the North Davis Sewer District in cooperation with the Utah Department of Environmental Quality, Division of Water Quality. The analytical work was conducted in accordance with the project-specific workplan and the Great Salt Lake Water Quality Studies Quality Assurance Project Plan (QAPP).

Frontier Geosciences, Inc., in Seattle, Washington, (FGS) and Laboratory and Environmental Testing, Inc., in Columbia, Missouri (LET) performed the sample analyses. After collection, the samples were packed and shipped to FGS or LET for analysis. FGS performed analysis of water samples by Hydride Generation Atomic Fluorescence Spectrometry (HGAF) for one or more of the following: total reducible selenium, dissolved reducible selenium and/or selenium IV. LET performed the sediment and tissue analyses by Hydride Generation Atomic Absorption Spectrometry (HGAA) for one or more of the following: total selenium, total organic carbon by Loss on Ignition (LOI) and/or total mercury by Cold Vapor Atomic Absorption Spectroscopy (CVAA).

The data quality from 60 sample delivery groups (SDGs) from FGS and 28 from LET were evaluated. Table 1 in Attachments 1 and 2 of this report list SDGs, identifications, and collection and analysis chronology associated with project samples for FGS and LET, respectively.

2.0 Field Sample Collection

The field effort was conducted between May 23, 2006 and August 31, 2007. FGS received 922 water samples and LET received 1,212 sediment and tissue samples. In some cases, field blanks (FBs) were collected as quality control (QC) samples by the investigators. In addition, the laboratories selected samples for matrix spike/matrix spike duplicates (MS/MSD) and laboratory duplicates for analysis in accordance with the QAPP. Table 2 in Attachments 1 and 2 (FGS and LET, respectively), include summaries of the field samples.

3.0 Data Review and Validation Process

3.1 Data Validation Definition

Analytical data from this investigation generated by FGS and LET were evaluated as described in the QAPP. All definitive analytical results were validated. In addition, cursory reviews of data generated by the University of Utah and the United States Geological Survey (USGS) were performed. This data quality assessment does not address those data

because they were used only for comparison purposes. The assessment of definitive data included a review of the following laboratory summary forms as defined in the QAPP:

- Chain-of-custody documentation
- Holding time
- QC sample frequencies
- Method blanks
- Laboratory control sample/laboratory control sample duplicates (LCS/LCSD)
- Laboratory matrix duplicate samples
- MS/MSDs
- Initial and continuing calibration information
- Case narrative review and other method-specific criteria
- Approximately 20 percent of the data were reviewed in greater detail, e.g., recalculated reported sample concentrations

Data flags were assigned using the QC acceptance limits and procedures defined in the QAPP. The reason for each flag was noted and entered into an electronic database, which is available to the data users. While multiple flags are routinely applied to a specific sample method/matrix/analyte combination, there is only one final flag. The final flag was the most conservative of the validation flags.

3.2 Overall Data Validation Findings

An overall summary of definitive data sample results and the reasons each was flagged are presented in Table 3 of Attachments 1 (A summary for LET is not available but addressed herein). Table 3 also shows each flag applied to a matrix/method/analyte. In addition, a statistical evaluation of the results is provided so that the percentage of results affected by a specific data quality condition or flag, with respect to the total results available for any target analyte/matrix, is shown. Only out-of-control conditions noted during the data validation are discussed in Attachment 1 Table 3, and in the following subsections.

3.3 Holding Time

Four samples (Program 7/Site 1/ GSL Water, Program 9/Site 7/GSL Water, Program 8/ Site 3/GSL Water, and Program 8/Site 9/GSL Water) were reanalyzed outside the holding time to verify the original results. Each of these samples had associated MS results with low recoveries that were attributed to a laboratory spiking error. To verify the parent sample result, reanalysis with an additional MS was requested for each sample. All the reanalyzed results except for sample Program 8/Site 3/GSL Water verified the original reported value. This sample had a higher result, which was attributed to sample concentration. These results were qualified as estimated and flagged "J". Additional detail regarding the spiking issue at FGS is presented in Section 3.9 "Corrective Action."

One sample exceeded the 180-day method-recommended holding time by 1 day because the sample was received by the laboratory near the expiration of the recommended holding time. This sample with a non-detected concentration was qualified as estimated and flagged "UJ".

Attachment 1, Table 4 shows the results of the samples analyzed over the holding time. All data from LET were analyzed within the QAPP-specified hold-time.

3.4 Laboratory Control Samples

LCS/LCSD samples were analyzed as required by the method. One LCS had a low-biased recovery. This also resulted in a LCS/LCSD relative percent difference exceedance. Associated samples were qualified as estimated detected results.

In Attachment 2, Table 5 shows the LCS/LCSD-qualified data. All LET laboratory spikes met QAPP criteria.

3.5 Standard Reference Materials

The results of standard reference material (SRM) provided users with information applicable to how the methodology performs in a similar matrix as the investigative samples. LET routinely used SRMs prepared by the National Institute of Standards and Technology (NIST), the National Research Council of Canada (NRCC) and Environmental Resource Associates and all recoveries/results met criteria.

3.6 Matrix Spike and Matrix Spike Duplicates

The results of MS/MSD analyses provide information about the possible influence of the matrix on either accuracy or precision of the measurements. MS/MSD recoveries showed a number of out-of-control criteria for accuracy and precision biased low. In general, out-of-control recoveries were confirmed to be associated with matrix interference through the re-extraction and reanalysis process and/or by demonstrated in-control results for LCSs and post-digestion spikes (PDS), also known as analytical spikes (AS), by FGS. All MS samples analyzed by LET met QC limits except in some instances where the amount spiked was negligible compared to the sample concentration.

Table 6 in Attachment 1 includes data qualified because of out-of-control accuracy and/or precision on the MS/MSD and PDS recoveries. When an MS and/or MSD or a PDS was outside of control limits, detected concentrations were flagged "J" and considered estimated concentrations with the exception of the sample collected from the deep brine layer. Low MS/MSD recoveries were observed in most of the samples selected for spiking. A detailed study was performed to ascertain the impact to the data quality of the samples generated by the method. Ultimately, it was determined that the low MS/MSD recoveries did not have a deleterious impact on data use. Attachment 3 contains a detailed memorandum describing the study and the factors leading to the conclusion that the data are acceptable for project decision-making.

LET also performed AS analyses because available sample mass was limited. The AS was prepared by splitting an aliquot of the sample digestate and spiking with a known amount of selenium. All AS criteria were met or the results were not meaningful because the amount spiked was negligible compared to the sample concentration.

3.7 Laboratory Duplicate Samples

Laboratory matrix duplicate samples were prepared and analyzed with each preparation batch. Samples 2767 0.2m_062006- RA TOTAL and 2565 0.2m_092806 RA analyzed by FGS exceeded the QAPP criteria. The aforementioned sample results were considered estimated values and flagged "J".

3.8 Blank Contamination

Method blanks were prepared and analyzed in triplicate as required by the QAPP. One set of method blanks analyzed by FGS had a mean recovery that exceeded the reporting limit (RL). In addition, there was FB contamination that exceeded the RL. This suggests that field sample results associated with the method blanks and FB may be due to blank contamination. Table 7 in Attachment 1 shows the results of samples associated to blank contamination.

3.9 Corrective Action/Laboratory Studies

Several studies were performed in support of corrective action when data did not meet QAPP criteria and to increase the project team's confidence when data did not conform to the conceptual site model. Attachment 3 includes a technical memorandum addressing low MS recoveries in the deep brine layer of the Great Salt Lake. Also in Attachment 3, there is a brief discussion of low MS recoveries obtained for select Project 3 samples that were determined to be related to a laboratory spiking error at FGS. A comparison study was performed to verify that the selenium concentrations for blood samples were representative. Split samples were submitted to the USGS laboratory in Columbia, MO.

Deep Brine Layer

As described in Section 3.6, a number of MS/MSD recoveries were very low (less than 10 percent) in samples from the deep brine layer. An in-depth study was performed to determine what in the sampling-analytical process could have led to the low recoveries. Ultimately, the source of the loss was determined to be due to one of the steps in the laboratory preparation procedure and the removal of the step improved recoveries. The study also concluded that the data generated were of sufficient quality to make project decisions without qualification.

Project 3 Low MS Recoveries

MS/MSD samples analyzed from this sampling program demonstrated an average recovery of only 66 percent. FGS reprepared and analyzed the MS and associated samples with the lowest recoveries. These "new" MSs demonstrated acceptable recoveries. It is believed that the previous low recoveries were due to analyst error. FGS reprepared and analyzed all samples in the batches with those low MS recoveries. It was determined that the sample locations did not contain deep brine layer material. Table 1 contains a brief summary of the two data sets. All the reanalyzed results except for sample Program 8/Site 3/GSL Water verified the original reported value. This sample had a higher result that was attributed to sample concentration. These results were qualified as estimated and flagged "J".

TABLE 1
Data Sets Summary
Data Quality Assessment

Native ID	Original Result Selenium (µg/L)	Reprep Result Selenium (µg/L)
Program 10/Method Blank Begin/	0.05 UJ	0.05 UJ
Program 10/Method Blank End/Wa	0.05 U	0.053 J
Program 10/Site 1/GSL Water	0.677	0.669 J
Program 10/Site 3/GSL Water	0.648	0.706 J
Program 10/Site 4/GSL Water	0.769	0.664 J
Program 10/Site 4/GSL Water/Re	0.894	0.672 J
Program 10/Site 4/GSL Water-Dissolved	0.615	0.553 J
Program 10/Site 6/GSL Water	0.721	0.651 J
Program 10/Site 6/GSL Water/Re	0.615	0.671 J
Program 10/Site 6/GSL Water-Dissolved	0.597	0.592 J
Program 10/Site 7/GSL Water	0.664	0.692 J
Program 10/Site 9/GSL Water	0.664	0.7 J
Program 11/ Site 1/ GSL Water	0.549	0.695 J
Program 11/ Site 3/ GSL Water	0.596	0.685 J
Program 11/ Site 4/ GSL Water	0.622	0.709 J
Program 11/ Site 4/ GSL Water-	0.52	0.518 J
Program 11/ Site 4/ GSL Water/	0.555	0.677 J
Program 11/ Site 6/ GSL Water	0.586	0.676 J
Program 11/ Site 6/ GSL Water-	0.427	0.529 J
Program 11/ Site 6/ GSL Water/	0.622	0.665 J
Program 11/ Site 7/ GSL Water	0.476	0.669 J
Program 11/ Site 9/ GSL Water	0.603	0.634 J
Program 11/Method Blank Begin/	0.05 U	0.053 J
Program 11/Method Blank End/Wa	0.05 U	0.08 J
Program 7/Method Blank Begin/W	0.05 U	0.05 UJ
Program 7/Site 3/ GSL Water	0.601	0.654 J
Program 7/Site 4/ GSL Water	0.637	0.623 J
Program 7/Site 4/ GSL Water-Dissolved	0.599	0.56 J
Program 7/Site 6/ GSL Water/Re	0.605	0.637 J
Program 7/Site 6/ GSL Water-Dissolved	0.567	0.625 J
Program 7/Site 6-E/GSL Water	0.627	0.672 J
Program 7/Site 6-F/GSL Water	0.695	0.633 J
Program 7/Site 6-G/GSL Water	0.559	0.625 J
Program 7/Site 6-H/GSL Water	0.589	0.612 J
Program 7/Site 7/ GSL Water	0.654	0.76 J
Program 7/Site 9/ GSL Water	0.602	0.725 J
Program 8/Method Blank Begin/W	0.142 U	0.056 U
Program 8/Method Blank End/Wat	0.05 U	0.058 U
Program 8/Site 1/GSL Water	0.494	0.701 J

TABLE 1
Data Sets Summary
Data Quality Assessment

Native ID	Original Result Selenium (µg/L)	Reprep Result Selenium (µg/L)
Program 8/Site 4/GSL Water	0.551	0.697 J
Program 8/Site 4/GSL Water/Rep	0.67	0.688 J
Program 8/Site 4/GSL Water-Dissolved	0.399	0.606 J
Program 8/Site 6/GSL Water	0.697	0.695 J
Program 8/Site 6/GSL Water/Rep	0.502	0.652 J
Program 8/Site 6/GSL Water-Dissolved	0.608	0.559 J
Program 8/Site 7/GSL Water	0.602	0.69 J
Program 9/Method Blank Begin/W	0.057 U	0.05 UJ
Program 9/Method Blank End/Wat	0.058 U	0.05 UJ
Program 9/Site 1/GSL Water	0.815	0.672 J
Program 9/Site 3/GSL Water	0.635	0.701 J
Program 9/Site 4/GSL Water	0.632	0.64 J
Program 9/Site 4/GSL Water/Rep	0.614	0.65 J
Program 9/Site 4/GSL Water-Dissolved	0.533	0.545 J
Program 9/Site 6/GSL Water	0.644	0.647 J
Program 9/Site 6/GSL Water/Rep	0.746	0.668 J
Program 9/Site 6/GSL Water-Dissolved	0.705	0.566 J
Program 9/Site 7/GSL Water	0.899 J	0.759 J
Program 9/Site 9/GSL Water	0.681	0.726 J
Station1/sample 1/main sample-	0.455	0.62 J

Blood Comparison

The project team had concerns that the data being generated by LET for blood samples were elevated (based on expectations from bird liver and egg results) because of problems with the sample preparation and analytical procedure. Samples of the raw blood were obtained and composited for analysis by both LET and USGS. LET used blood SRMs provided by USGS along with the split samples to ensure that the data obtained were valid. The results of the study are presented in Attachment 4. The conclusion reached was the blood data generated by LET met the project objectives and they were made available for project decision-making.

3.10 Sample Chain of Custody

Samples were sent to the laboratory under chain-of custody, properly preserved, and with the necessary information. LET received one shipment of tissue samples that was thawed and received at ambient temperature. The samples were qualified as estimated detect and flagged "J". All other samples were received in good condition according to the QAPP. It should be noted that the QAPP did not mention that maintaining sediment samples for total selenium at ambient temperature is also acceptable. Lastly, some sample-specific

information from the principal investigators (PIs) is still to be gathered and will be compiled and available upon completion of the program.

4.0 Summary of Precision, Accuracy, Representativeness, Comparability, and Completeness

The quality of the field sampling efforts and laboratory results were evaluated for compliance with project data quality objectives (DQOs) through a review of overall precision, accuracy, representativeness, comparability, and completeness (PARCC). Procedures used to assess PARCC are in accordance with the respective analytical methods and QAPP requirements.

4.1 Precision

Matrix precision from MS/MSDs was generally in control as shown in Table 6 of Attachment 1 and evidenced by the fact that no LET-produced sample data were qualified. In addition, laboratory MSD results were acceptable overall. This shows that the field activities adequately collected representative samples and that the laboratory evaluated the matrix consistently.

Laboratory precision is acceptable as shown by the generally in-control performance of the LCS/LCSDs.

All results qualified from out-of-control precision are qualified as estimated concentrations. The method and matrix precision are generally acceptable.

4.2 Accuracy

Matrix accuracy and LCS/LCSD recoveries were generally in control. Therefore, the laboratory accuracy is acceptable.

The results qualified from out-of-control matrix accuracy are considered to be estimated concentrations. Overall, the laboratory and matrix accuracy are acceptable.

4.3 Representativeness

Sample data were representative of site conditions at the time of sample collection. All samples were properly stored and preserved. Analytical data were reported from an analysis within the project-specified holding time with exception of the four samples discussed in Section 3.3. The results of field and method blanks were generally less than the RLs. Overall, blank contamination was indicative of normal laboratory and field sampling operations.

4.4 Comparability

All samples were reported in industry-standard units. Analytical protocols for the methods were followed. Results obtained are comparable to industry standards in that collection and analytical techniques followed approved, documented procedures.

4.5 Completeness

Project completeness data are summarized in Table 8 of Attachment 1 and Table 3 of Attachment 2. The completeness objective of 95 percent was met.

4.6 Conclusions

The data generated from the sample analyses for the Great Salt Lake selenium water quality study are of sufficient quality and quantity to accomplish DQOs. Sample results accurately indicate the presence or absence of the target analyte at sampled locations. Samples were collected and analyzed as specified in the project work plan and the QAPP except as noted in this report.

Sample results are believed to be representative of site conditions at the time of collection. Results obtained are comparable to industry standards in that collection and analytical techniques followed approved, documented procedures (except as noted in this report and reflected in qualified data points). All results are reported in industry standard units. Although blank contamination occurred, the occurrences were representative of normal field and laboratory procedures.

5.0 Reference

CH2M HILL 2006. *Great Salt Lake Water Quality Studies Quality Assurance Project Plan.* Prepared for North Davis Sewer District in cooperation with the Utah Department of Environmental Quality, Division of Water Quality. August.

Attachment 1
Frontier Geosciences, Inc. Summary Tables

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0607033	2267 0.2m_061906- FA DISS	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2267 0.2m_061906- RA TOTAL	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2267 4.0m_061906- FA DISS	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2267 4.0m_061906- RA TOTAL	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2565 0.2m_061906- FA DISS	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2565 0.2m_061906- RA TOTAL	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2565 6.5m_061906- FA DISS	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2565 6.5m_061906- RA TOTAL	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2565 8.0m_061906- FA DISS	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2565 8.0m_061906- RA TOTAL	FGS-055	6/19/2006	7/13/2006	8/8/2006	8/21/2006
		2767 0.2m_062006- FA DISS	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		2767 0.2m_062006- RA TOTAL	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		2767 3.0m_062006- FA DISS	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		2767 3.0m_062006- RA TOTAL	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		3510 0.2m_062006- FA DISS	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		3510 0.2m_062006- RA TOTAL	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		3510 6.5m_062006- FA DISS	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		3510 6.5m_062006- RA TOTAL	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		3510 8.5m_062006- FA DISS	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		3510 8.5m_062006- RA TOTAL	FGS-055	6/20/2006	7/13/2006	8/8/2006	8/21/2006
		BR1_062106- FA DISS	FGS-055	6/21/2006	7/13/2006	8/8/2006	8/21/2006
		BR1_062106- RA TOTAL	FGS-055	6/21/2006	7/13/2006	8/8/2006	8/21/2006
		FB1_062806- FA DISS	FGS-055	6/28/2006	7/13/2006	8/8/2006	8/21/2006
		FB1_062806- RA TOTAL	FGS-055	6/28/2006	7/13/2006	8/8/2006	8/21/2006
		GOGGIN DRAIN_060606-FA DISS	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/15/2006
		GOGGIN DRAIN_060606-RA TOTAL	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/15/2006
		KUCC_060606- FA DISS	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/21/2006
		KUCC_060606- RA TOTAL	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/21/2006
		LEE CREEK_060606- FA DISS	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/21/2006
		LEE CREEK_060606- RA TOTAL	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/21/2006
		WR_060606- FA DISS	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/15/2006
		WR_060606- RA TOTAL	FGS-055	6/6/2006	7/13/2006	8/8/2006	8/15/2006
	0608138	FB 080806 1245 D	FGS-055	8/8/2006	8/30/2006	8/31/2006	9/13/2006
		FB 080806 1245 T	FGS-055	8/8/2006	8/30/2006	8/31/2006	9/13/2006
		GD 081006 1130 D	FGS-055	8/10/2006	8/30/2006	8/31/2006	9/13/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0608138	GD 081006 1130 T	FGS-055	8/10/2006	8/30/2006	8/31/2006	9/13/2006
		LC 081006 0900 D	FGS-055	8/10/2006	8/30/2006	8/31/2006	9/13/2006
		LC 081006 0900 T	FGS-055	8/10/2006	8/30/2006	8/31/2006	9/13/2006
		LC 081006 0905 D	FGS-055	8/10/2006	8/30/2006	8/31/2006	9/13/2006
		LC 081006 0905 T	FGS-055	8/10/2006	8/30/2006	8/31/2006	9/13/2006
		WR 080806 0945 T	FGS-055	8/8/2006	8/30/2006	8/31/2006	9/13/2006
		WR 080806 0950 T	FGS-055	8/8/2006	8/30/2006	8/31/2006	9/13/2006
		WR 080806 0945 D	FGS-055	8/8/2006	8/30/2006	8/31/2006	9/13/2006
		WR 080806 0950 D	FGS-055	8/8/2006	8/30/2006	8/31/2006	9/13/2006
	0609051	FB_090706 FA	FGS-055	9/7/2006	9/14/2006	10/3/2006	10/9/2006
		FB_090706 RA	FGS-055	9/7/2006	9/14/2006	10/3/2006	10/9/2006
		GD_090506 FA	FGS-055	9/5/2006	9/14/2006	10/3/2006	10/9/2006
		GD_090506 RA	FGS-055	9/5/2006	9/14/2006	10/3/2006	10/9/2006
		GD_090506A FA	FGS-055	9/5/2006	9/14/2006	10/3/2006	10/9/2006
		GD_090506A RA	FGS-055	9/5/2006	9/14/2006	10/3/2006	10/9/2006
		KCUU_091206 FA	FGS-055	9/12/2006	9/14/2006	10/3/2006	10/9/2006
		KCUU_091206 RA	FGS-055	9/12/2006	9/14/2006	10/3/2006	10/9/2006
		LC_090506 FA	FGS-055	9/5/2006	9/14/2006	10/3/2006	10/9/2006
		LC_090506 RA	FGS-055	9/5/2006	9/14/2006	10/3/2006	10/9/2006
		SALT CANAL_090706 RA	FGS-055	9/7/2006	9/14/2006	10/3/2006	10/9/2006
		WR_090706 FA	FGS-055	9/7/2006	9/14/2006	10/3/2006	10/9/2006
		WR_090706 RA	FGS-055	9/7/2006	9/14/2006	10/3/2006	10/9/2006
	0609112	2267 0.2M-FA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		2267 0.2M-RA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		2267 3.8M-FA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		2267 3.8M-RA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		2767 0.2M-FA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		2767 0.2M-RA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		2767 2.7M-FA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		2767 2.7M-RA	FGS-055	8/29/2006	9/29/2006	10/12/2006	10/19/2006
		3510 0.2M-FA	FGS-055	9/1/2006	9/29/2006	10/12/2006	10/19/2006
		3510 0.2M-RA	FGS-055	9/1/2006	9/29/2006	10/12/2006	10/19/2006
		3510 6.5M-FA	FGS-055	9/1/2006	9/29/2006	10/12/2006	10/19/2006
		3510 6.5M-RA	FGS-055	9/1/2006	9/29/2006	10/12/2006	10/19/2006
		3510 8.5M-FA	FGS-055	9/1/2006	9/29/2006	10/12/2006	10/19/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0609112	3510 8.5M-RA	FGS-055	9/1/2006	9/29/2006	10/12/2006	10/19/2006
		BR-030606-RA	FGS-055	6/3/2006	9/29/2006	10/12/2006	10/19/2006
		BR-040506-RA	FGS-055	5/3/2006	9/29/2006	10/12/2006	10/19/2006
		BR-060506-RA	FGS-055	5/6/2006	9/29/2006	10/12/2006	10/19/2006
		BR-060506-RA_050406	FGS-055	5/4/2006	9/29/2006	10/12/2006	10/19/2006
		BR-070606-RA	FGS-055	6/7/2006	9/29/2006	10/12/2006	10/19/2006
		BR-100506-RA	FGS-055	5/10/2006	9/29/2006	10/12/2006	10/19/2006
		BR-110606-RA	FGS-055	6/11/2006	9/29/2006	10/12/2006	10/19/2006
		BR-160506-RA	FGS-055	5/16/2006	9/29/2006	10/12/2006	10/19/2006
		BR-190506-RA	FGS-055	5/19/2006	9/29/2006	10/12/2006	10/19/2006
		BR-190606-RA	FGS-055	6/19/2006	9/29/2006	10/12/2006	10/19/2006
		BR-210606-RA	FGS-055	6/21/2006	9/29/2006	10/12/2006	10/19/2006
		BR-230506-RA	FGS-055	5/23/2006	9/29/2006	10/12/2006	10/19/2006
		BR-250506-RA	FGS-055	5/25/2006	9/29/2006	10/12/2006	10/19/2006
		BR-260506-RA	FGS-055	5/26/2006	9/29/2006	10/12/2006	10/19/2006
		BR-280506-RA	FGS-055	5/28/2006	9/29/2006	10/12/2006	10/19/2006
		FB-010606-RA	FGS-055	6/1/2006	9/29/2006	10/12/2006	10/19/2006
		FB-030606-RA	FGS-055	6/3/2006	9/29/2006	10/12/2006	10/19/2006
		FB-080506-RA	FGS-055	5/8/2006	9/29/2006	10/12/2006	10/19/2006
		FB-090506-RA	FGS-055	5/9/2006	9/29/2006	10/12/2006	10/19/2006
		FB-090606-RA	FGS-055	6/9/2006	9/29/2006	10/12/2006	10/19/2006
		FB-10506-RA	FGS-055	5/10/2006	9/29/2006	10/12/2006	10/19/2006
		FB-110506-RA	FGS-055	5/11/2006	9/29/2006	10/12/2006	10/19/2006
		FB-130506-RA	FGS-055	5/13/2006	9/29/2006	10/12/2006	10/19/2006
		FB-170506-RA	FGS-055	5/17/2006	9/29/2006	10/12/2006	10/19/2006
		FB-200506-RA	FGS-055	5/20/2006	9/29/2006	10/12/2006	10/19/2006
		FB-230506-RA	FGS-055	5/23/2006	9/29/2006	10/12/2006	10/19/2006
		FB-240506-RA	FGS-055	5/24/2006	9/29/2006	10/12/2006	10/19/2006
		FB-250506-RA	FGS-055	5/25/2006	9/29/2006	10/12/2006	10/19/2006
		FB-260506-RA	FGS-055	5/26/2006	9/29/2006	10/12/2006	10/19/2006
		FB-290506-RA	FGS-055	5/29/2006	9/29/2006	10/12/2006	10/19/2006
		GD-010606-RA	FGS-055	6/1/2006	9/29/2006	10/12/2006	10/19/2006
		GD-040606-RA	FGS-055	6/4/2006	9/29/2006	10/12/2006	10/19/2006
		GD-060606-RA	FGS-055	6/6/2006	9/29/2006	10/12/2006	10/19/2006
		GD-070606-RA	FGS-055	6/7/2006	9/29/2006	10/12/2006	10/19/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0609112	GD-090506-RA	FGS-055	5/9/2006	9/29/2006	10/12/2006	10/19/2006
		GD-110606-RA	FGS-055	6/11/2006	9/29/2006	10/12/2006	10/19/2006
		GD-120506-RA	FGS-055	5/12/2006	9/29/2006	10/12/2006	10/19/2006
		GD-150506-RA	FGS-055	5/15/2006	9/29/2006	10/12/2006	10/19/2006
		GD-150606-RA	FGS-055	6/15/2006	9/29/2006	10/12/2006	10/19/2006
		GD--170506-RA	FGS-055	5/17/2006	9/29/2006	10/12/2006	10/19/2006
		GD-210506-RA	FGS-055	5/21/2006	9/29/2006	10/12/2006	10/19/2006
		GD-240506-RA	FGS-055	5/24/2006	9/29/2006	10/12/2006	10/19/2006
		GD-290506-RA	FGS-055	5/29/2006	9/29/2006	10/12/2006	10/19/2006
		LEE CREEK-RA	FGS-055	9/15/2006	9/29/2006	10/12/2006	10/19/2006
	0610027	10010020_092606-RA	FGS-055	9/26/2006	10/6/2006	10/12/2006	10/19/2006
		10010030_092606-RA	FGS-055	9/26/2006	10/6/2006	10/12/2006	10/19/2006
		10010040_092606-RA	FGS-055	9/26/2006	10/6/2006	10/24/2006	10/26/2006
		2267 0.2m_092706 FA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		2267 0.2m_092706 RA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		2267 3.5m_092706 FA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		2267 3.5m_092706 RA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		2565 0.2m_092806 FA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		2565 0.2m_092806 RA	FGS-055	9/28/2006	10/6/2006	10/12/2006	10/23/2006
		2565 6.5m_092806 FA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		2565 6.5m_092806 RA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		2565 7.5m_092806 FA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		2565 7.5m_092806 RA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		2767 0.2m_092706 FA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		2767 0.2m_092706 RA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		2767 2.2m_092706 FA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		2767 2.2m_092706 RA	FGS-055	9/27/2006	10/6/2006	10/24/2006	10/26/2006
		3510 0.2m_092806 FA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		3510 0.2m_092806 RA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		3510 6.5m_092806 FA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		3510 6.5m_092806 RA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		3510 8.0m_092806 FA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
		3510 8.0m_092806 RA	FGS-055	9/28/2006	10/6/2006	10/24/2006	10/26/2006
	0610068	BR1 10/10/06 1515 FA	FGS-055	10/10/2006	10/16/2006	10/24/2006	10/26/2006
		BR1 10/10/06 1515 RA	FGS-055	10/10/2006	10/16/2006	10/24/2006	10/26/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0610068	FR1 10/10/06 1100 FA	FGS-055	10/10/2006	10/16/2006	10/24/2006	10/26/2006
		FR1 10/10/06 1100 RA	FGS-055	10/10/2006	10/16/2006	10/24/2006	10/26/2006
		GD 10/12/06 1220 FA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
		GD 10/12/06 1220 RA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
		KCUU 10/12/06 1520 FA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
		KCUU 10/12/06 1520 RA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
		LC 10/12/06 1350 FA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
		LC 10/12/06 1350 RA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
		WR 10/12/06 0930 FA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
		WR 10/12/06 0930 RA	FGS-055	10/12/2006	10/16/2006	10/24/2006	10/26/2006
	0611047	Program 10/Method Blank Begin/	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/28/2006
		Program 10/Method Blank End/Wa	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/28/2006
		Program 10/Site 1/GSL Water	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 3/GSL Water	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 4/GSL Water	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 4/GSL Water/Re	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 4/GSL Water-Di	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 6/GSL Water	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 6/GSL Water/Re	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 6/GSL Water-Di	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 7/GSL Water	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 10/Site 9/GSL Water	FGS-055	9/24/2006	11/13/2006	11/17/2006	11/21/2006
		Program 11/ Site 1/ GSL Water	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 3/ GSL Water	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 4/ GSL Water	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 4/ GSL Water-	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 4/ GSL Water/	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 6/ GSL Water	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 6/ GSL Water-	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 6/ GSL Water/	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 7/ GSL Water	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/ Site 9/ GSL Water	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/Method Blank Begin/	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 11/Method Blank End/Wa	FGS-055	10/14/2006	11/13/2006	11/17/2006	11/28/2006
		Program 7/Method Blank Begin/W	FGS-055	7/26/2006	11/13/2006	11/17/2006	11/21/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0611047	Program 7/Site 1/ GSL Water	FGS-055	7/26/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 1/ GSL Water	FGS-055	7/26/2006	11/13/2006	4/25/2007	4/26/2007
		Program 7/Site 3/ GSL Water	FGS-055	7/26/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 4/ GSL Water	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 4/ GSL Water-Di	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 6/ GSL Water/Re	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 6/ GSL Water-Di	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 6-E/GSL Water	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 6-F/GSL Water	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 6-G/GSL Water	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 6-H/GSL Water	FGS-055	7/27/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 7/ GSL Water	FGS-055	7/26/2006	11/13/2006	11/17/2006	11/21/2006
		Program 7/Site 9/ GSL Water	FGS-055	7/26/2006	11/13/2006	11/17/2006	11/21/2006
		Program 8/Method Blank Begin/W	FGS-055	8/22/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Method Blank End/Wat	FGS-055	8/23/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 1/GSL Water	FGS-055	8/23/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 3/GSL Water	FGS-055	8/23/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 3/GSL Water	FGS-055	8/23/2006	11/13/2006	4/25/2007	4/26/2007
		Program 8/Site 4/GSL Water	FGS-055	8/22/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 4/GSL Water/Rep	FGS-055	8/22/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 4/GSL Water-Dis	FGS-055	8/22/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 6/GSL Water	FGS-055	8/23/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 6/GSL Water/Rep	FGS-055	8/23/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 6/GSL Water-Dis	FGS-055	8/23/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 7/GSL Water	FGS-055	8/22/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 9/GSL Water	FGS-055	8/22/2006	11/13/2006	11/17/2006	11/28/2006
		Program 8/Site 9/GSL Water	FGS-055	8/22/2006	11/13/2006	4/25/2007	4/26/2007
		Program 9/Method Blank Begin/W	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Method Blank End/Wat	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 1/GSL Water	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 3/GSL Water	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 4/GSL Water	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 4/GSL Water/Rep	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 4/GSL Water-Dis	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 6/GSL Water	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0611047	Program 9/Site 6/GSL Water/Rep	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 6/GSL Water-Dis	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 7/GSL Water	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Program 9/Site 7/GSL Water	FGS-055	8/28/2006	11/13/2006	4/25/2007	4/26/2007
		Program 9/Site 9/GSL Water	FGS-055	8/28/2006	11/13/2006	11/17/2006	11/21/2006
		Station1/sample 1/main sample-	FGS-055	9/28/2006	11/13/2006	11/17/2006	11/28/2006
	0611102	Program3/Method Blank Begin	FGS-055	5/22/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Method Blank End	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site1/GSL Water	FGS-055	5/24/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site2/GSL Water	FGS-055	5/24/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site3/GSL Water	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site4/GSL Water	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site4/GSL Water-Disso	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site5/GSL Wate	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site5/GSL Water-Disso	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site6/GSL Water	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site6/GSL Water-Disso	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site7/GSL Water	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site8/GSL Water	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program3/Site9/GSL Water	FGS-055	5/25/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Method Blank Begin	FGS-055	6/22/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Method Blank End	FGS-055	6/27/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site1/GSL Water	FGS-055	6/22/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site2/GSL Water	FGS-055	6/27/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site3/GSL Water	FGS-055	6/27/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site4/GSL Water	FGS-055	6/26/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site4/GSL Water-Disso	FGS-055	6/26/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site5/GSL Water	FGS-055	6/26/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site5/GSL Water-Disso	FGS-055	6/26/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site6/GSL Water	FGS-055	6/26/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site6/GSL Water-Disso	FGS-055	6/26/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site7/GSL Water	FGS-055	6/23/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site8/GSL Water	FGS-055	6/23/2006	11/17/2006	11/19/2006	12/5/2006
		Program5/Site9/GSL Water	FGS-055	6/23/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Method Blank Begin	FGS-055	7/12/2006	11/17/2006	11/19/2006	12/5/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0611102	Program6/Method Blank End	FGS-055	7/13/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site1/GSL Water	FGS-055	7/13/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site3/GSL Water	FGS-055	7/13/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site4/GSL Water	FGS-055	7/12/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site4/GSL Water-Disso	FGS-055	7/12/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site6/GSL Water	FGS-055	7/13/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site6/GSL Water-Disso	FGS-055	7/13/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site7/GSL Water	FGS-055	7/13/2006	11/17/2006	11/19/2006	12/5/2006
		Program6/Site9/GSL Water	FGS-055	7/13/2006	11/17/2006	11/19/2006	12/5/2006
		Program7/Site6-A/GSL Water	FGS-055	7/27/2006	11/17/2006	11/17/2006	11/28/2006
		Program7/Site6-B/GSL Water	FGS-055	7/27/2006	11/17/2006	11/17/2006	11/28/2006
		Program7/Site6-C/GSL Water	FGS-055	7/27/2006	11/17/2006	11/17/2006	11/28/2006
		Program7/Site6-D/GSL Water	FGS-055	7/27/2006	11/17/2006	11/17/2006	11/28/2006
	0611118	2267 0.2m_110106 FA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2267 0.2m_110106 RA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2267 3.9m_110106 FA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2267 3.9m_110106 RA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2565 0.2m_110106 FA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2565 0.2m_110106 RA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2565 6.5m_110106 FA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2565 6.5m_110106 RA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2565 8.0m_110106 FA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2565 8.0m_110106 FA	FGS-055	11/1/2006	11/20/2006	2/27/2007	3/1/2007
		2565 8.0m_110106 RA	FGS-055	11/1/2006	11/20/2006	12/18/2006	12/20/2006
		2565 8.0m_110106 RA	FGS-055	11/1/2006	11/20/2006	2/27/2007	3/1/2007
		2767 0.2m_110306 FA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		2767 0.2m_110306 RA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		3510 0.2m_110306 FA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		3510 0.2m_110306 RA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		3510 6.5m_110306 FA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		3510 6.5m_110306 RA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		3510 8.0m_110306 FA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		3510 8.0m_110306 RA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		GD_110906 FA	FGS-055	11/9/2006	11/20/2006		12/22/2006
		GD_110906 FA	FGS-055	11/9/2006	11/20/2006	12/18/2006	12/20/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0611118	GD_110906 RA	FGS-055	11/9/2006	11/20/2006	12/18/2006	12/20/2006
		LC_111506 FA	FGS-055	11/15/2006	11/20/2006		12/22/2006
		LC_111506 FA	FGS-055	11/15/2006	11/20/2006	12/18/2006	12/20/2006
		LC_111506 RA	FGS-055	11/15/2006	11/20/2006	12/18/2006	12/20/2006
		Morton Salt_110306 FA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		Morton Salt_110306 RA	FGS-055	11/3/2006	11/20/2006	12/18/2006	12/20/2006
		WR_110906 FA	FGS-055	11/9/2006	11/20/2006		12/22/2006
		WR_110906 FA	FGS-055	11/9/2006	11/20/2006	12/18/2006	12/20/2006
		WR_110906 RA	FGS-055	11/9/2006	11/20/2006	12/18/2006	12/20/2006
	0611139	2267 0.2m FA-Dissolved	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2267 0.2m RA-Total	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2267 3.7m FA-Dissolved	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2267 3.7m RA-Total	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2565 0.2m FA-Dissolved	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2565 0.2m RA-Total	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2565 6.5m FA-Dissolved	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2565 6.5m FA-Dissolved	FGS-055	11/21/2006	11/29/2006	2/27/2007	3/1/2007
		2565 6.5m RA-Total	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2565 6.5m RA-Total	FGS-055	11/21/2006	11/29/2006	2/27/2007	3/1/2007
		2565 7.5m FA-Dissolved	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2565 7.5m RA-Total	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/28/2006
		2767 0.2m FA-Dissolved	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/28/2006
		2767 0.2m RA-Total	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/28/2006
		2767 2.5m FA-Dissolved	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/28/2006
		2767 2.5m RA-Total	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/28/2006
		3510 0.2m FA-Dissolved	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/28/2006
		3510 0.2m RA-Total	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/28/2006
		3510 6.5m FA-Dissolved	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/20/2006
		3510 6.5m RA-Total	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/20/2006
		3510 8.0m FA-Dissolved	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/20/2006
		3510 8.0m RA-Total	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/20/2006
		BR1 FA-Dissolved	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/20/2006
		BR1 RA-Total	FGS-055	11/20/2006	11/29/2006	12/18/2006	12/20/2006
		FB1 FA-Dissolved	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/20/2006
		FB1 RA-Total	FGS-055	11/21/2006	11/29/2006	12/18/2006	12/20/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0612022	GSL-1	FGS-055	12/4/2006	12/6/2006	12/29/2006	1/12/2007
		GSL-2	FGS-055	12/4/2006	12/6/2006	12/29/2006	1/12/2007
		GSL-3	FGS-055	12/4/2006	12/6/2006	12/29/2006	1/12/2007
		GSL-4	FGS-055	12/4/2006	12/6/2006	12/29/2006	1/12/2007
	0612085	Program12/Method Blank Begin/W	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Method Blank End/Wat	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 1/GSL Water	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 3/GSL Water	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 4/GSL Water	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/12/2007
		Program12/Site 4/GSL Water Dis	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 4/GSL Water/Rep	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 6/GSL Water	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 6/GSL Water Dis	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 6/GSL Water/Rep	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 7/GSL Water	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program12/Site 9/GSL Water	FGS-055	11/20/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Method Blank Begin/G	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Method Blank End/GSL	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 1/GSL Water	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 3/GSL Water	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 4/GSL Water	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 4/GSL Water Dis	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 4/GSL Water/Rep	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 6/GSL Water	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 6/GSL Water Dis	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 6/GSL Water/Rep	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 7/GSL Water	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
		Program13/Site 9/GSL Water	FGS-055	12/2/2006	12/19/2006	12/29/2006	1/17/2007
	0612105	2267 0.2 M_120706 FA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		2267 0.2 M_120706 RA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		2267 3.5 M_120706 FA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		2267 3.5 M_120706 RA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		2565 0.2 M_120606 FA	FGS-055	12/6/2006	12/22/2006	1/12/2007	1/17/2007
		2565 0.2 M_120606 RA	FGS-055	12/6/2006	12/22/2006	1/12/2007	1/17/2007
		2565 6.5 M_120606 FA	FGS-055	12/6/2006	12/22/2006	1/12/2007	1/17/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0612105	2565 6.5 M_120606 RA	FGS-055	12/6/2006	12/22/2006	1/12/2007	1/17/2007
		2565 7.5 M_120606 FA	FGS-055	12/6/2006	12/22/2006	1/12/2007	1/17/2007
		2565 7.5 M_120606 RA	FGS-055	12/6/2006	12/22/2006	1/12/2007	1/17/2007
		2565 7.5 M_120606 RA	FGS-055	12/6/2006	12/22/2006	2/16/2007	2/20/2007
		2767 0.2 M_120706 FA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		2767 0.2 M_120706 RA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		2767 2.5 M_120706 FA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		2767 2.5 M_120706 RA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		3510 0.2 M_120706 FA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		3510 0.2 M_120706 RA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		3510 6.5 M_120706 FA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		3510 6.5 M_120706 RA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		3510 8.0 M_120706 FA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		3510 8.0 M_120706 FA	FGS-055	12/7/2006	12/22/2006	3/6/2007	3/8/2007
		3510 8.0 M_120706 RA	FGS-055	12/7/2006	12/22/2006	12/29/2006	1/17/2007
		3510 8.0 M_120706 RA	FGS-055	12/7/2006	12/22/2006	3/6/2007	3/8/2007
		BR_122006 RA	FGS-055	12/20/2006	12/22/2006	12/29/2006	1/17/2007
		BR_122006FA	FGS-055	12/20/2006	12/22/2006	12/29/2006	1/17/2007
		FB_122006 FA	FGS-055	12/20/2006	12/22/2006	1/12/2007	1/17/2007
		FB_122006 RA	FGS-055	12/20/2006	12/22/2006	1/12/2007	1/17/2007
		GD_121906 FA	FGS-055	12/19/2006	12/22/2006	12/29/2006	1/17/2007
		GD_121906 RA	FGS-055	12/19/2006	12/22/2006	12/29/2006	1/17/2007
		GSL MINERALS RA_121606 1030	FGS-055	12/16/2006	12/22/2006	1/12/2007	1/17/2007
		GSL MINERALS RA_121606 1035	FGS-055	12/16/2006	12/22/2006	1/12/2007	1/17/2007
		KENNECOTT RA_120406 920	FGS-055	12/4/2006	12/22/2006	12/29/2006	1/17/2007
		KENNECOTT RA_120406 925	FGS-055	12/4/2006	12/22/2006	12/29/2006	1/17/2007
		LC_122106 FA	FGS-055	12/21/2006	12/22/2006	12/29/2006	1/17/2007
		LC_122106 RA	FGS-055	12/21/2006	12/22/2006	12/29/2006	1/17/2007
		WR_122006 FA 1245	FGS-055	12/20/2006	12/22/2006	12/29/2006	1/17/2007
		WR_122006 FA 1250	FGS-055	12/20/2006	12/22/2006	12/29/2006	1/17/2007
		WR_122006 RA 1245	FGS-055	12/20/2006	12/22/2006	12/29/2006	1/17/2007
		WR_122006 RA 1250	FGS-055	12/20/2006	12/22/2006	12/29/2006	1/17/2007
	0702032	BR_020207 RA	FGS-055	2/2/2007	2/7/2007	2/13/2007	2/20/2007
		BREECH 10010020_010907 RA	FGS-055	1/9/2007	2/7/2007	2/13/2007	2/20/2007
		E CULVER 10010040_010907 RA	FGS-055	1/9/2007	2/7/2007	2/13/2007	2/20/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0702032	FB_020207 FA	FGS-055	2/2/2007	2/7/2007	2/13/2007	2/20/2007
		FB_020207 RA	FGS-055	2/2/2007	2/7/2007	2/13/2007	2/20/2007
		GD_013107 1435 FA	FGS-055	1/31/2007	2/7/2007	2/13/2007	2/20/2007
		GD_013107 1435 RA	FGS-055	1/31/2007	2/7/2007	2/13/2007	2/20/2007
		GD_013107 1440 FA	FGS-055	1/31/2007	2/7/2007	2/13/2007	2/20/2007
		GD_013107 1440 RA	FGS-055	1/31/2007	2/7/2007	2/13/2007	2/20/2007
		KCUU_010307 FA	FGS-055	1/3/2007	2/7/2007	2/13/2007	2/20/2007
		KCUU_010307 RA	FGS-055	1/3/2007	2/7/2007	2/13/2007	2/20/2007
		LC BLNK_020107 FA	FGS-055	2/1/2007	2/7/2007	2/13/2007	2/20/2007
		LC BLNK_020107 RA	FGS-055	2/1/2007	2/7/2007	2/13/2007	2/20/2007
		LC_020107 FA	FGS-055	2/1/2007	2/7/2007	2/13/2007	2/20/2007
		LC_020107 RA	FGS-055	2/1/2007	2/7/2007	2/13/2007	2/20/2007
		W CULVER 10010030_010907 RA	FGS-055	1/9/2007	2/7/2007	2/13/2007	2/20/2007
	0703166	2267 0.2m_032007 FA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2267 0.2m_032007 RA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2267 4.0m_032007 FA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2267 4.0m_032007 RA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2565 0.2m_032007 FA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2565 0.2m_032007 RA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2565 6.5m_032007 FA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2565 6.5m_032007 RA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2565 7.5m_032007 FA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2565 7.5m_032007 FANO	FGS-055	3/20/2007	3/28/2007		4/17/2007
		2565 7.5m_032007 RA	FGS-055	3/20/2007	3/28/2007	4/16/2007	4/17/2007
		2565 7.5m_032007 RANO	FGS-055	3/20/2007	3/28/2007		4/17/2007
		2767 0.2m_031907 FA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		2767 0.2m_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		2767 3.0m_031907 FA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		2767 3.0m_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 0.2m_031907 FA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 0.2m_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 6.5m_031907 FA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 6.5m_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 8.0m_031907 FA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 8.0m_031907 FANO	FGS-055	3/19/2007	3/28/2007		4/17/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0703166	3510 8.0m_031907 Kem RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 8.0m_031907 Kem RANO	FGS-055	3/19/2007	3/28/2007		4/17/2007
		3510 8.0m_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		3510 8.0m_031907 RANO	FGS-055	3/19/2007	3/28/2007		4/17/2007
		BR_030207 FA	FGS-055	3/2/2007	3/28/2007	4/16/2007	4/17/2007
		BR_030207 RA	FGS-055	3/2/2007	3/28/2007	4/16/2007	4/17/2007
		Breech10010020_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		East Culvert10010040_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		FB_030507 FA	FGS-055	3/5/2007	3/28/2007	4/16/2007	4/17/2007
		FB_030507 RA	FGS-055	3/5/2007	3/28/2007	4/16/2007	4/17/2007
		GD_030607 FA	FGS-055	3/6/2007	3/28/2007	4/16/2007	4/17/2007
		GD_030607 RA	FGS-055	3/6/2007	3/28/2007	4/16/2007	4/17/2007
		KCUU_030607 FA	FGS-055	3/6/2007	3/28/2007	4/16/2007	4/17/2007
		KCUU_030607 RA	FGS-055	3/6/2007	3/28/2007	4/16/2007	4/17/2007
		LC_030607 FA	FGS-055	3/6/2007	3/28/2007	4/16/2007	4/17/2007
		LC_030607 RA	FGS-055	3/6/2007	3/28/2007	4/16/2007	4/17/2007
		West Culvert10010030_031907 RA	FGS-055	3/19/2007	3/28/2007	4/16/2007	4/17/2007
		WR_030207 FA	FGS-055	3/2/2007	3/28/2007	4/16/2007	4/17/2007
		WR_030207 RA	FGS-055	3/2/2007	3/28/2007	4/16/2007	4/17/2007
	0705045	2267 0.2m_042607 Dissolved	FGS-055	4/26/2007	5/7/2007	5/25/2007	5/30/2007
		2267 0.2m_042607 Total	FGS-055	4/26/2007	5/7/2007	5/25/2007	5/30/2007
		2267 4.0m_042607 Dissolved	FGS-055	4/26/2007	5/7/2007	5/25/2007	5/30/2007
		2267 4.0m_042607 Total	FGS-055	4/26/2007	5/7/2007	5/25/2007	5/30/2007
		2565 0.2m_042607 Dissolved	FGS-055	4/26/2007	5/7/2007	5/29/2007	5/30/2007
		2565 0.2m_042607 Total	FGS-055	4/26/2007	5/7/2007	5/29/2007	5/30/2007
		2565 6.5m_042607 Dissolved	FGS-055	4/26/2007	5/7/2007	5/29/2007	5/30/2007
		2565 6.5m_042607 Total	FGS-055	4/26/2007	5/7/2007	5/29/2007	5/30/2007
		2565 8.0m_042607 Dissolved	FGS-055	4/26/2007	5/7/2007	5/25/2007	5/30/2007
		2565 8.0m_042607 Total	FGS-055	4/26/2007	5/7/2007	5/25/2007	5/30/2007
		2767 0.2m_050207 Dissolved	FGS-055	5/2/2007	5/7/2007	5/29/2007	5/30/2007
		2767 0.2m_050207 Total	FGS-055	5/2/2007	5/7/2007	5/29/2007	5/30/2007
		2767 2.8m_050207 Dissolved	FGS-055	5/2/2007	5/7/2007	5/29/2007	5/30/2007
		2767 2.8m_050207 Total	FGS-055	5/2/2007	5/7/2007	5/29/2007	5/30/2007
		2767 BLNK 2.8m_050207 Dissolve	FGS-055	5/2/2007	5/7/2007	5/29/2007	5/30/2007
		2767 BLNK 2.8m_050207 Total	FGS-055	5/2/2007	5/7/2007	5/29/2007	5/30/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0705045	3510 0.2m_050107 Dissolved	FGS-055	5/1/2007	5/7/2007	5/29/2007	5/30/2007
		3510 0.2m_050107 Total	FGS-055	5/1/2007	5/7/2007	5/29/2007	5/30/2007
		3510 6.5m_050107 Dissolved	FGS-055	5/1/2007	5/7/2007	5/29/2007	5/30/2007
		3510 6.5m_050107 Total	FGS-055	5/1/2007	5/7/2007	5/29/2007	5/30/2007
		3510 8.5m_050107 Dissolved	FGS-055	5/1/2007	5/7/2007	5/29/2007	5/30/2007
		3510 8.5m_050107 Total	FGS-055	5/1/2007	5/7/2007	5/29/2007	5/30/2007
		BR_041707 Dissolved	FGS-055	4/17/2007	5/7/2007	5/25/2007	5/30/2007
		BR_041707 Total	FGS-055	4/17/2007	5/7/2007	5/25/2007	5/30/2007
		FB1_041907 1045 Dissolved	FGS-055	4/19/2007	5/7/2007	5/25/2007	5/30/2007
		FB1_041907 1045 Total	FGS-055	4/19/2007	5/7/2007	5/25/2007	5/30/2007
		FB1_041907 1050 Dissolved	FGS-055	4/19/2007	5/7/2007	5/25/2007	5/30/2007
		FB1_041907 1050 Total	FGS-055	4/19/2007	5/7/2007	5/25/2007	5/30/2007
		GD_041307 Dissolved	FGS-055	4/13/2007	5/7/2007	5/25/2007	5/30/2007
		GD_041307 Total	FGS-055	4/13/2007	5/7/2007	5/25/2007	5/30/2007
		GSL1-1_040507 Dissolved	FGS-055	4/5/2007	5/7/2007		7/19/2007
		GSL1-1_040507 Total	FGS-055	4/5/2007	5/7/2007		7/19/2007
		GSL1-2_040507 Dissolved	FGS-055	4/5/2007	5/7/2007		7/19/2007
		GSL1-2_040507 Total	FGS-055	4/5/2007	5/7/2007	6/5/2007	6/6/2007
		GSL1-3_041207 Dissolved	FGS-055	4/12/2007	5/7/2007		7/19/2007
		GSL1-3_041207 Total	FGS-055	4/12/2007	5/7/2007		7/19/2007
		GSL1-4_041107 Dissolved	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL1-4_041107 Total	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL1-5_041107 Dissolved	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL1-5_041107 Total	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL2-1_041207 Dissolved	FGS-055	4/12/2007	5/7/2007	6/5/2007	6/6/2007
		GSL2-1_041207Total	FGS-055	4/12/2007	5/7/2007	6/5/2007	6/6/2007
		GSL2-2_041207 1345 Dissolved	FGS-055	4/12/2007	5/7/2007	6/5/2007	6/6/2007
		GSL2-2_041207 1345 Total	FGS-055	4/12/2007	5/7/2007	6/5/2007	6/6/2007
		GSL2-2_041207 1350 Dissolved	FGS-055	4/12/2007	5/7/2007	6/5/2007	6/6/2007
		GSL2-2_041207 1350 Total	FGS-055	4/12/2007	5/7/2007	6/5/2007	6/6/2007
		GSL2-3_041107 Dissolved	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL2-3_041107 Total	FGS-055	4/11/2007	5/7/2007	6/5/2007	6/6/2007
		GSL2-4_041107 Total	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL2-4_041107 Dissolved	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL2-5_041107 Total	FGS-055	4/11/2007	5/7/2007		7/19/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0705045	GSL2-5_041107 Dissolved	FGS-055	4/11/2007	5/7/2007		7/19/2007
		GSL3-1_040307 Total	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-1_040307 Dissolved	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-2_040307 Total	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-2_040307 Dissolved	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-3_040307 Total	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-3_040307 Dissolved	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-4_040307 Total	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-4_040307 Dissolved	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-5_040307 Total	FGS-055	4/3/2007	5/7/2007		7/19/2007
		GSL3-5_040307 Dissolved	FGS-055	4/3/2007	5/7/2007		7/19/2007
		LC BLNK_041807 Dissolved	FGS-055	4/18/2007	5/7/2007	5/25/2007	5/30/2007
		LC BLNK_041807 Total	FGS-055	4/18/2007	5/7/2007	5/25/2007	5/30/2007
		LC_041807 Dissolved	FGS-055	4/18/2007	5/7/2007	5/25/2007	5/30/2007
		LC_041807 Total	FGS-055	4/18/2007	5/7/2007	5/25/2007	5/30/2007
		WR_041607 Dissolved	FGS-055	4/16/2007	5/7/2007	5/25/2007	5/30/2007
		WR_041607 Total	FGS-055	4/16/2007	5/7/2007	5/25/2007	5/30/2007
	0706030	Program14/Method Blank Begin/W	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Method Blank End/Wat	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site1/GSL Water	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site3/GSL Water	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site3/GSL Water/0.45	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site4/GSL Water	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site4/GSL Water/Repl	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site6/GSL Water	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site6/GSL Water/0.45	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site6/GSL Water/Repl	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site7/GSL Water	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site9/GSL Water	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program14/Site9/GSL Water/0.45	FGS-055	1/26/2007	6/6/2007		7/24/2007
		Program16/Method Blank Begin/W	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Method Blank End/Wat	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site1/GSL Water	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site3/GSL Water	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site3/GSL Water/0.45	FGS-055	5/7/2007	6/6/2007		7/24/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0706030	Program16/Site4/GSL Water	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site4/GSL Water/Repl	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site6/GSL Water	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site6/GSL Water/0.45	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site6/GSL Water/Repl	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site7/GSL Water	FGS-055	5/4/2007	6/6/2007		7/24/2007
		Program16/Site9/GSL Water	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program16/Site9/GSL Water/0.45	FGS-055	5/7/2007	6/6/2007		7/24/2007
		Program17/Site3/GSL Water	FGS-055	5/23/2007	6/6/2007		7/24/2007
		Program17/Site3/GSL Water/0.45	FGS-055	5/23/2007	6/6/2007		7/24/2007
		Program17/Site6/GSL Water	FGS-055	5/23/2007	6/6/2007		7/24/2007
		Program17/Site6/GSL Water/0.45	FGS-055	5/23/2007	6/6/2007		7/24/2007
		Program17/Site6/GSL Water/Repl	FGS-055	5/23/2007	6/6/2007		7/24/2007
		Program17/Site9/GSL Water	FGS-055	5/23/2007	6/6/2007		7/24/2007
		Program17/Site9/GSL Water/0.45	FGS-055	5/23/2007	6/6/2007		7/24/2007
	0706040	2267 0.2m_052307 FA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2267 0.2m_052307 RA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2267 4.0m_052307 FA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2267 4.0m_052307 RA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2565 0.2m_052307 FA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2565 0.2m_052307 RA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2565 6.5m_052307 FA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2565 6.5m_052307 RA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2565 7.5m_052307 FA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2565 7.5m_052307 RA	FGS-055	5/23/2007	6/7/2007		8/1/2007
		2767 0.2M_053107 FA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		2767 0.2m_053107 RA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		2767 2.8m_053107 FA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		2767 2.8m_053107 RA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		3510 0.2m_053107 FA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		3510 0.2m_053107 RA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		3510 7.0m_053107 FA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		3510 7.0m_053107 RA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		3510 8.3m_053107 FA	FGS-055	5/31/2007	6/7/2007		8/1/2007
		3510 8.3m_053107 RA	FGS-055	5/31/2007	6/7/2007		8/1/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0706040	BR_051707 FA	FGS-055	5/17/2007	6/7/2007		7/10/2007
		BR_051707 FA	FGS-055	5/17/2007	6/7/2007		8/1/2007
		BR_051707 RA	FGS-055	5/17/2007	6/7/2007		8/1/2007
		BREACH_053007	FGS-055	5/30/2007	6/7/2007		8/1/2007
		East Culvert_053007	FGS-055	5/30/2007	6/7/2007		8/1/2007
		FB_051807 FA	FGS-055	5/18/2007	6/7/2007		7/10/2007
		FB_051807 FA	FGS-055	5/18/2007	6/7/2007		8/1/2007
		FB_051807 RA	FGS-055	5/18/2007	6/7/2007		8/1/2007
		GD_051607 FA	FGS-055	5/16/2007	6/7/2007		7/10/2007
		GD_051607 FA	FGS-055	5/16/2007	6/7/2007		8/1/2007
		GD_051607 RA	FGS-055	5/16/2007	6/7/2007		8/1/2007
		KUCC_051607 FA	FGS-055	5/16/2007	6/7/2007		7/10/2007
		KUCC_051607 FA	FGS-055	5/16/2007	6/7/2007		8/1/2007
		KUCC_051607 RA	FGS-055	5/16/2007	6/7/2007		8/1/2007
		LC_051607 FA	FGS-055	5/16/2007	6/7/2007		7/10/2007
		LC_051607 FA	FGS-055	5/16/2007	6/7/2007		8/1/2007
		LC_051607 RA	FGS-055	5/16/2007	6/7/2007		8/1/2007
		West Culvert_053007	FGS-055	5/30/2007	6/7/2007		8/1/2007
		WR 1530_051707 FA	FGS-055	5/17/2007	6/7/2007		7/10/2007
		WR 1530_051707 FA	FGS-055	5/17/2007	6/7/2007		8/1/2007
		WR 1530_051707 RA	FGS-055	5/17/2007	6/7/2007		8/1/2007
		WR 1535_051707 FA	FGS-055	5/17/2007	6/7/2007		7/10/2007
		WR 1535_051707 FA	FGS-055	5/17/2007	6/7/2007		8/1/2007
		WR 1535_051707 RA	FGS-055	5/17/2007	6/7/2007		8/1/2007
	0706069	Program 17/Method Blank Begin/	FGS-055	5/23/2007	6/13/2007		8/1/2007
		Program 17/Method Blank End/Wa	FGS-055	5/23/2007	6/13/2007		8/1/2007
		Program 17/Site1/GSL Water	FGS-055	5/23/2007	6/13/2007		8/1/2007
		Program 17/Site4/GSL Water	FGS-055	5/23/2007	6/13/2007		8/1/2007
		Program 17/Site4/GSL Water/Rep	FGS-055	5/23/2007	6/13/2007		8/1/2007
		Program 17/Site7/GSL Water	FGS-055	5/23/2007	6/13/2007		8/1/2007
		Program 18/Method Blank Begin/	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Method Blank End/Wa	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site1/GSL Water	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site3/GSL Water	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site3/GSL Water/0.4	FGS-055	6/9/2007	6/13/2007		8/1/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0706069	Program 18/Site4/GSL Water	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site4/GSL Water/Rep	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site6/GSL Water	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site6/GSL Water/0.4	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site6/GSL Water/Rep	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site7/GSL Water	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site9/GSL Water	FGS-055	6/9/2007	6/13/2007		8/1/2007
		Program 18/Site9/GSL Water/0.4	FGS-055	6/9/2007	6/13/2007		8/1/2007
	0707002	2267 0.2m_062607 Dissolved	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2267 0.2m_062607 Total	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2267 4.0m_062607 Dissolved	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2267 4.0m_062607 Total	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2565 0.2m_062607 Dissolved	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2565 0.2m_062607 Total	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2565 6.5m_062607 Dissolved	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2565 6.5m_062607 Total	FGS-055	6/26/2007	7/2/2007		8/9/2007
		2565 7.5m_062607 Dissolved	FGS-055	6/26/2007	7/2/2007		8/1/2007
		2565 7.5m_062607 Total	FGS-055	6/26/2007	7/2/2007		8/1/2007
		2767 0.2m_062807 Dissolved	FGS-055	6/28/2007	7/2/2007		8/9/2007
		2767 0.2m_062807 Total	FGS-055	6/28/2007	7/2/2007		8/9/2007
		2767 3.0m_062807 Dissolved	FGS-055	6/28/2007	7/2/2007		8/9/2007
		2767 3.0m_062807 Total	FGS-055	6/28/2007	7/2/2007		8/9/2007
		3510 0.2m_062707 Dissolved	FGS-055	6/27/2007	7/2/2007		8/9/2007
		3510 0.2m_062707 Total	FGS-055	6/27/2007	7/2/2007		8/9/2007
		3510 7.0m_062707 Dissolved	FGS-055	6/27/2007	7/2/2007		8/9/2007
		3510 7.0m_062707 Total	FGS-055	6/27/2007	7/2/2007		8/9/2007
		3510 8.1m _062707 Total	FGS-055	6/27/2007	7/2/2007		8/9/2007
		3510 8.1m_062707 Dissolved	FGS-055	6/27/2007	7/2/2007		8/9/2007
		BR_061907 Dissolved	FGS-055	6/19/2007	7/2/2007		8/1/2007
		BR_061907 Total	FGS-055	6/19/2007	7/2/2007		8/1/2007
		FB_061907 Dissolved	FGS-055	6/19/2007	7/2/2007		8/1/2007
		FB_061907 Total	FGS-055	6/19/2007	7/2/2007		8/1/2007
		GD 1125_061807 Dissolved	FGS-055	6/18/2007	7/2/2007		8/1/2007
		GD 1125_061807 Total	FGS-055	6/18/2007	7/2/2007		8/1/2007
		GD 1130_061807 Dissolved	FGS-055	6/18/2007	7/2/2007		8/9/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0707002	GD 1130_061807 Total	FGS-055	6/18/2007	7/2/2007		8/9/2007
		LC_061807 Dissolved	FGS-055	6/18/2007	7/2/2007		8/1/2007
		LC_061807 Total	FGS-055	6/18/2007	7/2/2007		8/1/2007
		WR_062007 Dissolved	FGS-055	6/20/2007	7/2/2007		8/1/2007
		WR_062007 Total	FGS-055	6/20/2007	7/2/2007		8/1/2007
	0707121	2267 0.2m_072407 DISS	FGS-055	7/24/2007	7/27/2007		8/16/2007
		2267 0.2m_072407 Total	FGS-055	7/24/2007	7/27/2007		8/16/2007
		2267 3.5m_072407 DISS	FGS-055	7/24/2007	7/27/2007		8/16/2007
		2267 3.5m_072407 Total	FGS-055	7/24/2007	7/27/2007		8/16/2007
		2565 0.2m_072507 Dissolved	FGS-055	7/25/2007	7/27/2007		8/16/2007
		2565 0.2m_072507 Total	FGS-055	7/25/2007	7/27/2007		8/16/2007
		2565 6.0m_072507 Dissolved	FGS-055	7/25/2007	7/27/2007		8/16/2007
		2565 6.0m_072507 Total	FGS-055	7/25/2007	7/27/2007		8/16/2007
		2565 7.0m_072507 Dissolved	FGS-055	7/25/2007	7/27/2007		8/16/2007
		2565 7.0m_072507 Total	FGS-055	7/25/2007	7/27/2007		8/16/2007
		2767 0.2m_072407 DISS	FGS-055	7/24/2007	7/27/2007		8/16/2007
		2767 0.2m_072407 Total	FGS-055	7/24/2007	7/27/2007		8/16/2007
		2767 2.5m_072407 DISS	FGS-055	7/24/2007	7/27/2007		8/16/2007
		2767 2.5m_072407 Total	FGS-055	7/24/2007	7/27/2007		8/16/2007
		3510 0.2m_072507 Dissolved	FGS-055	7/25/2007	7/27/2007		8/16/2007
		3510 0.2m_072507 Total	FGS-055	7/25/2007	7/27/2007		8/16/2007
		3510 6.5m_072507 Dissolved	FGS-055	7/25/2007	7/27/2007		8/16/2007
		3510 6.5m_072507 TOTAL	FGS-055	7/25/2007	7/27/2007		8/16/2007
		3510 8.0m_072507 DISS	FGS-055	7/25/2007	7/27/2007		8/16/2007
		3510 8.0m_072507 TOTAL	FGS-055	7/25/2007	7/27/2007		8/16/2007
		BR_041607 1120	FGS-055	4/16/2007	7/27/2007		8/16/2007
		BR_041707 1130	FGS-055	4/17/2007	7/27/2007		8/16/2007
		BR_041807 1130	FGS-055	4/18/2007	7/27/2007		8/16/2007
		BR_041907 1130	FGS-055	4/19/2007	7/27/2007		8/16/2007
		BR_042007 1130	FGS-055	4/20/2007	7/27/2007		8/16/2007
		BR_042107 1130	FGS-055	4/21/2007	7/27/2007		8/16/2007
		BR_042207 1130	FGS-055	4/22/2007	7/27/2007		8/16/2007
		BR_042307 1130	FGS-055	4/23/2007	7/27/2007		8/16/2007
		BR_042507 1130	FGS-055	4/25/2007	7/27/2007		8/16/2007
		BR_050907 1315	FGS-055	5/9/2007	7/27/2007		8/16/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0707121	BR_051107 1315	FGS-055	5/11/2007	7/27/2007		8/16/2007
		BR_051307 1315	FGS-055	5/13/2007	7/27/2007		8/16/2007
		BR_051507 1315	FGS-055	5/15/2007	7/27/2007		8/16/2007
		BR_052507 1040	FGS-055	5/25/2007	7/27/2007		8/16/2007
		BR_052607 1040	FGS-055	5/26/2007	7/27/2007		8/16/2007
		BR_052807 1040	FGS-055	5/28/2007	7/27/2007		8/16/2007
		BR_052907 1040	FGS-055	5/29/2007	7/27/2007		8/16/2007
		BR_060307 1040	FGS-055	6/3/2007	7/27/2007		8/16/2007
		BR_061307 1040	FGS-055	6/13/2007	7/27/2007		8/16/2007
		BR_061607 1040	FGS-055	6/16/2007	7/27/2007		8/16/2007
		BR_071607 Dissolved	FGS-055	7/16/2007	7/27/2007		8/16/2007
		BR_071607 Total	FGS-055	7/16/2007	7/27/2007		8/16/2007
		FB_042007 1100	FGS-055	4/20/2007	7/27/2007		8/23/2007
		FB_042107 1100	FGS-055	4/21/2007	7/27/2007		8/23/2007
		FB_042207 1100	FGS-055	4/22/2007	7/27/2007		8/23/2007
		FB_042407 1100	FGS-055	4/24/2007	7/27/2007		8/23/2007
		FB_042507 1100	FGS-055	4/25/2007	7/27/2007		8/23/2007
		FB_042707 1100	FGS-055	4/27/2007	7/27/2007		8/23/2007
		FB_042907 1100	FGS-055	4/29/2007	7/27/2007		8/23/2007
		FB_050107 1100	FGS-055	5/1/2007	7/27/2007		8/23/2007
		FB_050307 1100	FGS-055	5/3/2007	7/27/2007		8/23/2007
		FB_050907 1115	FGS-055	5/9/2007	7/27/2007		8/23/2007
		FB_051107 1115	FGS-055	5/11/2007	7/27/2007		8/23/2007
		FB_051407 1115	FGS-055	5/14/2007	7/27/2007		8/23/2007
		FB_051907 1115	FGS-055	5/19/2007	7/27/2007		8/23/2007
		FB_052407 1215	FGS-055	5/24/2007	7/27/2007		8/23/2007
		FB_052707 1215	FGS-055	5/27/2007	7/27/2007		8/23/2007
		FB_052907 1215	FGS-055	5/29/2007	7/27/2007		8/23/2007
		FB_053107 1215	FGS-055	5/31/2007	7/27/2007		8/23/2007
		FB_060207 1215	FGS-055	6/2/2007	7/27/2007		8/23/2007
		FB_060607 1215	FGS-055	6/6/2007	7/27/2007		8/23/2007
		FB_060707 1215	FGS-055	6/7/2007	7/27/2007		8/23/2007
		FB_071707 Diss	FGS-055	7/17/2007	7/27/2007		8/16/2007
		FB_071707 Total	FGS-055	7/17/2007	7/27/2007		8/16/2007
		GD_041307 1430	FGS-055	4/13/2007	7/27/2007		8/16/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0707121	GD_041507 1500	FGS-055	4/15/2007	7/27/2007		8/16/2007
		GD_042007 1500	FGS-055	4/20/2007	7/27/2007		8/16/2007
		GD_042107 1500	FGS-055	4/21/2007	7/27/2007		8/16/2007
		GD_042207 1500	FGS-055	4/22/2007	7/27/2007		8/16/2007
		GD_042407 1500	FGS-055	4/24/2007	7/27/2007		8/16/2007
		GD_050807 1130	FGS-055	5/8/2007	7/27/2007		8/23/2007
		GD_050907 1130	FGS-055	5/9/2007	7/27/2007		8/23/2007
		GD_051307 1130	FGS-055	5/13/2007	7/27/2007		8/23/2007
		GD_051407 1130	FGS-055	5/14/2007	7/27/2007		8/23/2007
		GD_051607 1130	FGS-055	5/16/2007	7/27/2007		8/23/2007
		GD_051707 1130	FGS-055	5/17/2007	7/27/2007		8/23/2007
		GD_051907 1130	FGS-055	5/19/2007	7/27/2007		8/23/2007
		GD_052207 1130	FGS-055	5/22/2007	7/27/2007		8/23/2007
		GD_052407 1130	FGS-055	5/24/2007	7/27/2007		8/23/2007
		GD_052707 1130	FGS-055	5/27/2007	7/27/2007		8/23/2007
		GD_053007 1130	FGS-055	5/30/2007	7/27/2007		8/23/2007
		GD_053107 1130	FGS-055	5/31/2007	7/27/2007		8/23/2007
		GD_060107 1130	FGS-055	6/1/2007	7/27/2007		8/23/2007
		GD_062907 1130	FGS-055	6/29/2007	7/27/2007		8/23/2007
		GD_070907 Dissolved	FGS-055	7/9/2007	7/27/2007		8/16/2007
		GD_071907 Total	FGS-055	7/19/2007	7/27/2007		8/16/2007
		LC BLNK_071907 Dissolved	FGS-055	7/19/2007	7/27/2007		8/16/2007
		LC BLNK_071907 Total	FGS-055	7/19/2007	7/27/2007		8/16/2007
		LC_071907 Dissolved	FGS-055	7/19/2007	7/27/2007		8/16/2007
		LC_071907 Total	FGS-055	7/19/2007	7/27/2007		8/16/2007
		WR_071607 Dissolved 1400	FGS-055	7/16/2007	7/27/2007		8/16/2007
		WR_071607 Dissolved 1405	FGS-055	7/16/2007	7/27/2007		8/16/2007
		WR_071607 Total 1400	FGS-055	7/16/2007	7/27/2007		8/16/2007
		WR_071607 Total 1405	FGS-055	7/16/2007	7/27/2007		8/16/2007
	0708013	Program 19/Method Blank Begin/	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Method Blank End/Wa	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site1/GSL Water	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site3/GSL Water	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site3/GSL Water/0.4	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site4/GSL Water	FGS-055	6/27/2007	8/2/2007		8/23/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0708013	Program 19/Site4/GSL Water/0.4	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site4/GSL Water/Rep	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site6/GSL Water	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site7/GSL Water	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site7/GSL Water/Rep	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site9/GSL Water	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 19/Site9/GSL Water/0.4	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 20/Method Blank Begin/	FGS-055	6/27/2007	8/2/2007		8/23/2007
		Program 20/Site4/GSL Water	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site4/GSL Water/0.4	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site4/GSL Water/Rep	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site6/GSL Water	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site6/GSL Water/0.4	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site6/GSL Water/Rep	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site7/GSL Water	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site7/GSL Water/0.4	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site7/GSL Water/Rep	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site9/GSL Water	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site9/GSL Water/0.4	FGS-055	7/27/2007	8/2/2007		8/23/2007
		Program 20/Site9/GSL Water/Rep	FGS-055	7/27/2007	8/2/2007		8/23/2007
	0708015	BD01FAW	FGS-055	6/28/2007	8/2/2007		8/29/2007
		BD01RAW	FGS-055	6/28/2007	8/2/2007		8/29/2007
		BD02FAW	FGS-055	6/28/2007	8/2/2007		8/29/2007
		BD02RAW	FGS-055	6/28/2007	8/2/2007		8/29/2007
		BD03FAW	FGS-055	6/28/2007	8/2/2007		8/29/2007
		BD03RAW	FGS-055	6/28/2007	8/2/2007		8/29/2007
		BD04FA	FGS-055	6/28/2007	8/2/2007		8/29/2007
		BD04RAW	FGS-055	6/28/2007	8/2/2007		8/29/2007
		ET01FA	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET01RA	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET02FA	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET02RA	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET03FA	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET03RA	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET04FA	FGS-055	6/30/2007	8/2/2007		8/29/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0708015	ET04FAD	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET04RA	FGS-055	6/30/2007	8/2/2007		8/29/2007
		ET04RAD	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NH01FA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NH01FAD	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NH02FA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NH03FA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NH04FA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NHO1RA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NHO1RAD	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NHO2RA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NHO3RA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NHO4RA	FGS-055	6/29/2007	8/2/2007		8/29/2007
		NT01FAD	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT01FAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT01RAD	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT01RAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT02FAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT02RAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT03FAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT03RAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT04FAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
		NT04RAW	FGS-055	6/30/2007	8/2/2007		8/29/2007
	0708182	Program21/MethodBlankBegin/Wat	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/MethodBlankEnd/Water	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site1/GSLWater	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site1/GSLWater/0.45m	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site3/GSLWater	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site3/GSLWater/0.45m	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site4/GSLWater	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site4/GSLWater/0.45m	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site4/GSLWater/Repli	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site6/GSLWater	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site6/GSLWater/0.45m	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site6/GSLWaterRepli	FGS-055	8/21/2007	8/30/2007		9/6/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0708182	Program21/Site7/GSLWater	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site7/GSLWater/0.45m	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site9/GSLWater	FGS-055	8/21/2007	8/30/2007		9/6/2007
		Program21/Site9/GSLWater/0.45m	FGS-055	8/21/2007	8/30/2007		9/6/2007
	0708195	2267 FA 0.2m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		2267 FA 3.5m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		2267 RA 0.2m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		2267 RA 3.5m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		2565 FA 0.2m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		2565 FA 7.0m	FGS-055	8/13/2007	8/31/2007		9/6/2007
		2565 FA 7.8m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		2565 RA 0.2m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		2565 RA 7.0m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		2565 RA 7.8m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		2767 FA 0.2m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		2767 FA 2.5m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		2767 RA 0.2m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		2767 RA 2.5m	FGS-055	8/23/2007	8/31/2007		9/6/2007
		3510 FA 0.2m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		3510 FA 6.5m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		3510 FA 8.0m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		3510 RA 0.2m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		3510 RA 6.5m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		3510 RA 8.0m	FGS-055	8/21/2007	8/31/2007		9/6/2007
		FB FA_081407	FGS-055	8/14/2007	8/31/2007		9/6/2007
		FB RA_081407	FGS-055	8/14/2007	8/31/2007		9/6/2007
		GD FA_081307	FGS-055	8/13/2007	8/31/2007		9/6/2007
		GD RA_081307	FGS-055	8/13/2007	8/31/2007		9/6/2007
		LC FA 1140	FGS-055	8/21/2007	8/31/2007		9/6/2007
		LC FA 1145	FGS-055	8/13/2007	8/31/2007		9/6/2007
		LC RA 1140	FGS-055	8/21/2007	8/31/2007		9/6/2007
		LC RA 1145	FGS-055	8/13/2007	8/31/2007		9/6/2007
		WR FA_081407	FGS-055	8/14/2007	8/31/2007		9/6/2007
		WR RA_081407	FGS-055	8/14/2007	8/31/2007		9/6/2007
	0709016	GSL-RA 1-1m	FGS-055	8/2/2007	9/5/2007		9/12/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	0709016	GSL-RA 1-2m	FGS-055	8/1/2007	9/5/2007		9/12/2007
		GSL-RA 1-3m	FGS-055	8/3/2007	9/5/2007		9/12/2007
		GSL-RA 1-4m	FGS-055	8/3/2007	9/5/2007		9/12/2007
		GSL-RA 1-5m	FGS-055	8/1/2007	9/5/2007		9/12/2007
		GSL-RA 2-1m	FGS-055	8/2/2007	9/5/2007		9/12/2007
		GSL-RA 2-2m	FGS-055	8/3/2007	9/5/2007		9/12/2007
		GSL-RA 2-3m	FGS-055	8/1/2007	9/5/2007		9/12/2007
		GSL-RA 2-4m	FGS-055	8/2/2007	9/5/2007		9/12/2007
		GSL-RA 2-5m	FGS-055	8/1/2007	9/5/2007		9/12/2007
		GSL-RA 3-1m	FGS-055	7/31/2007	9/5/2007		9/12/2007
		GSL-RA 3-2m (a)	FGS-055	8/1/2007	9/5/2007		9/12/2007
		GSL-RA 3-2m (b)	FGS-055	8/1/2007	9/5/2007		9/12/2007
		GSL-RA 3-3m	FGS-055	7/31/2007	9/5/2007		9/12/2007
		GSL-RA 3-4m	FGS-055	7/31/2007	9/5/2007		9/12/2007
		GSL-RA 3-5m	FGS-055	7/31/2007	9/5/2007		9/12/2007
	606025	2267 0.2M 260506 1130 FA	FGS-055	5/26/2006	6/7/2006	8/18/2006	8/21/2006
		2267 0.2M 260506 1130 RA	FGS-055	5/26/2006	6/7/2006	8/18/2006	8/21/2006
		2565 0.2M 260506 1400 FA	FGS-055	5/26/2006	6/7/2006	8/8/2006	8/15/2006
		2565 0.2M 260506 1400 RA	FGS-055	5/26/2006	6/7/2006	8/8/2006	8/15/2006
		2565 6.5M 260506 1425 FA	FGS-055	5/26/2006	6/7/2006	8/8/2006	8/15/2006
		2565 6.5M 260506 1425 RA	FGS-055	5/26/2006	6/7/2006	8/18/2006	8/21/2006
		2565 7.5M 260506 1440 FA	FGS-055	5/26/2006	6/7/2006	8/18/2006	8/21/2006
		2565 7.5M 260506 1440 RA	FGS-055	5/26/2006	6/7/2006	8/8/2006	8/15/2006
		2567 4.0M 260506 1130 FA	FGS-055	5/26/2006	6/7/2006	8/8/2006	8/15/2006
		2567 4.0M 260506 1130 RA	FGS-055	5/26/2006	6/7/2006	8/8/2006	8/15/2006
		2767 0.2M 230506 1100 FA	FGS-055	5/23/2006	6/7/2006	8/18/2006	8/21/2006
		2767 0.2M 230506 1100 RA	FGS-055	5/23/2006	6/7/2006	8/18/2006	8/21/2006
		2767 3.0M 230506 1130 FA	FGS-055	5/23/2006	6/7/2006	8/18/2006	8/21/2006
		2767 3.0M 230506 1130 RA	FGS-055	5/23/2006	6/7/2006	8/18/2006	8/21/2006
		3510 0.2M 230506 1230 FA	FGS-055	5/23/2006	6/7/2006	8/8/2006	8/15/2006
		3510 0.2M 230506 1230 RA	FGS-055	5/23/2006	6/7/2006	8/8/2006	8/15/2006
		3510 6.5M 230506 1250 FA	FGS-055	5/23/2006	6/7/2006	8/8/2006	8/15/2006
		3510 6.5M 230506 1250 RA	FGS-055	5/23/2006	6/7/2006	8/8/2006	8/15/2006
		3510 8.5M 230506 1315 FA	FGS-055	5/23/2006	6/7/2006	8/8/2006	8/15/2006
		3510 8.5M 230506 1315 RA	FGS-055	5/23/2006	6/7/2006	8/8/2006	8/15/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	606025	BR1 030506 1420 FA	FGS-055	5/3/2006	6/7/2006	8/18/2006	8/21/2006
		BR1 030506 1420 RA	FGS-055	5/3/2006	6/7/2006	8/18/2006	8/21/2006
		BR1 030506 1425 FA	FGS-055	5/3/2006	6/7/2006	8/18/2006	8/21/2006
		BR1 030506 1425 RA	FGS-055	5/3/2006	6/7/2006	8/18/2006	8/21/2006
		BR1 040506 1130 RA	FGS-055	5/4/2006	6/7/2006	8/8/2006	8/15/2006
		BR1-250506 1430 FA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/8/2006
		BR1-250506 1430 FA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		BR1-250506 1430 RA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		BR1-250506 1435 FA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		FB1 080506 1500 FA	FGS-055	5/8/2006	6/7/2006	8/8/2006	8/15/2006
		FB1 080506 1500 RA	FGS-055	5/8/2006	6/7/2006	8/8/2006	8/15/2006
		FB1 250506 1100 FA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/8/2006
		FB1 250506 1100 FA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		FB1- 250506 1100 RA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		GOGGIN DRAIN 170506 1045 FA	FGS-055	5/17/2006	6/7/2006	8/8/2006	8/8/2006
		GOGGIN DRAIN 170506 1045 FA	FGS-055	5/17/2006	6/7/2006	8/18/2006	8/21/2006
		GOGGIN DRAIN 170506 1045 RA	FGS-055	5/17/2006	6/7/2006	8/18/2006	8/21/2006
		GSL BREECH 250506 1315 RA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		GSL EAST CULVERT 250506 1	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		GSL WEST CULVERT 250506 1	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		KUCC 120506 1215 FA	FGS-055	5/12/2006	6/7/2006	8/8/2006	8/8/2006
		KUCC 120506 1215 FA	FGS-055	5/12/2006	6/7/2006	8/8/2006	8/15/2006
		KUCC 120506 1215 RA	FGS-055	5/12/2006	6/7/2006	8/8/2006	8/15/2006
		LEE CREEK 120506 1015 RA	FGS-055	5/12/2006	6/7/2006	8/8/2006	8/15/2006
		LEE CREEK 120506 1017 FA	FGS-055	5/12/2006	6/7/2006	8/8/2006	8/8/2006
		LEE CREEK 120506 1017 FA	FGS-055	5/12/2006	6/7/2006	8/8/2006	8/15/2006
		N. ARM BRINE @ GSL MINERA	FGS-055	5/25/2006	6/7/2006	8/8/2006	8/15/2006
		WR 170506 1325 FA	FGS-055	5/17/2006	6/7/2006	8/8/2006	8/8/2006
		WR 170506 1325 FA	FGS-055	5/17/2006	6/7/2006	8/18/2006	8/21/2006
		WR 170506 1325 RA	FGS-055	5/17/2006	6/7/2006	8/18/2006	8/21/2006
	606126	WATER -ANTELOPE COLO	FGS-055	5/4/2006	6/27/2006	8/8/2006	8/15/2006
		WATER -GSLM COLONY	FGS-055	5/5/2006	6/27/2006	8/8/2006	8/15/2006
		WATER -HAT COLONY	FGS-055	5/12/2006	6/27/2006	8/8/2006	8/15/2006
	606128	A	FGS-055	6/21/2006	6/28/2006	8/8/2006	8/15/2006
		B	FGS-055	6/21/2006	6/28/2006	8/8/2006	8/15/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	606128	C	FGS-055	6/21/2006	6/28/2006	8/8/2006	8/15/2006
		D	FGS-055	6/21/2006	6/28/2006	8/8/2006	8/15/2006
	607051	25	FGS-055	7/14/2006	7/19/2006	8/8/2006	8/21/2006
		26	FGS-055	7/14/2006	7/19/2006	8/8/2006	8/21/2006
		27	FGS-055	7/16/2006	7/19/2006	8/8/2006	8/21/2006
		28	FGS-055	7/15/2006	7/19/2006	8/8/2006	8/21/2006
		29	FGS-055	7/15/2006	7/19/2006	8/8/2006	8/21/2006
		30	FGS-055	7/15/2006	7/19/2006	8/8/2006	8/21/2006
		31	FGS-055	7/15/2006	7/19/2006	8/8/2006	8/21/2006
	608004	ANTI-1-W	FGS-055	6/16/2006	8/2/2006	8/8/2006	8/21/2006
		ANTI-2-W	FGS-055	6/16/2006	8/2/2006	8/8/2006	8/21/2006
		ANTI-3-W	FGS-055	6/16/2006	8/2/2006	8/8/2006	8/21/2006
		OGBA-1-W	FGS-055	6/23/2006	8/2/2006	8/8/2006	8/21/2006
		OGBA-2-W	FGS-055	6/23/2006	8/2/2006	8/8/2006	8/21/2006
		OGBA-3-W	FGS-055	6/23/2006	8/2/2006	8/8/2006	8/21/2006
		SALT-1-W	FGS-055	6/14/2006	8/2/2006	8/8/2006	8/21/2006
		SALT-2-W	FGS-055	6/14/2006	8/2/2006	8/8/2006	8/21/2006
		SALT-3-W	FGS-055	6/14/2006	8/2/2006	8/8/2006	8/21/2006
	608042	2267 0.2M FA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2267 0.2M RA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2267 4.0M FA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2267 4.0M RA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2565 0.2M FA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2565 0.2M RA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2565 6.5M FA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2565 6.5M RA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2565 7.5M FA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2565 7.5M RA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		2767 0.2M FA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		2767 0.2M RA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		2767 3.0M FA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		2767 3.0M RA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		3510 0.2M FA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		3510 0.2M RA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		3510 7.0M FA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
FGS	608042	3510 7.0M RA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		3510 8.5M FA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		3510 8.5M RA	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		FB FA	FGS-055	7/18/2006	8/9/2006	8/10/2006	8/24/2006
		FB RA	FGS-055	7/18/2006	8/9/2006	8/10/2006	8/24/2006
		GD FA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		GD RA	FGS-055	7/28/2006	8/9/2006	8/10/2006	8/24/2006
		KUCC FA	FGS-055	7/18/2006	8/9/2006	8/10/2006	8/24/2006
		KUCC RA	FGS-055	7/18/2006	8/9/2006	8/10/2006	8/24/2006
		KUCC RA_072706	FGS-055	7/27/2006	8/9/2006	8/10/2006	8/24/2006
		LC FA	FGS-055	7/12/2006	8/9/2006	8/10/2006	8/24/2006
		LC RA	FGS-055	7/12/2006	8/9/2006	8/10/2006	8/24/2006
		WR FA	FGS-055	7/12/2006	8/9/2006	8/10/2006	8/24/2006
		WR RA	FGS-055	7/12/2006	8/9/2006	8/10/2006	8/24/2006

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0705045	26-Apr-07				
		WATER			
			2267 0.2m_042607 Dissolved (N)	0705045	FGS
			2267 0.2m_042607 Total (N)	0705045	FGS
			2267 4.0m_042607 Dissolved (N)	0705045	FGS
			2267 4.0m_042607 Total (N)	0705045	FGS
			2565 0.2m_042607 Dissolved (N)	0705045	FGS
			2565 0.2m_042607 Total (N)	0705045	FGS
			2565 6.5m_042607 Dissolved (N)	0705045	FGS
			2565 6.5m_042607 Total (N)	0705045	FGS
			2565 8.0m_042607 Dissolved (N)	0705045	FGS
			2565 8.0m_042607 Total (N)	0705045	FGS
			2767 0.2m_050207 Dissolved (N)	0705045	FGS
			2767 0.2m_050207 Total (N)	0705045	FGS
			2767 2.8m_050207 Dissolved (N)	0705045	FGS
			2767 2.8m_050207 Total (N)	0705045	FGS
			2767 BLNK 2.8m_050207 Dissolve (N)	0705045	FGS
			2767 BLNK 2.8m_050207 Total (N)	0705045	FGS
			3510 0.2m_050107 Dissolved (N)	0705045	FGS
			3510 0.2m_050107 Total (N)	0705045	FGS
			3510 6.5m_050107 Dissolved (N)	0705045	FGS
			3510 6.5m_050107 Total (N)	0705045	FGS
			3510 8.5m_050107 Dissolved (N)	0705045	FGS
			3510 8.5m_050107 Total (N)	0705045	FGS
			BR_041707 Dissolved (N)	0705045	FGS
			BR_041707 Total (N)	0705045	FGS
			FB1_041907 1045 Dissolved (N)	0705045	FGS
			FB1_041907 1045 Total (N)	0705045	FGS
			FB1_041907 1050 Dissolved (N)	0705045	FGS
			FB1_041907 1050 Total (N)	0705045	FGS
			GD_041307 Dissolved (N)	0705045	FGS
			GD_041307 Total (N)	0705045	FGS
			GSL1-1_040507 Dissolved (N)	0705045	FGS
			GSL1-1_040507 Total (N)	0705045	FGS
			GSL1-2_040507 Dissolved (N)	0705045	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0705045	26-Apr-07				
		WATER			
			GSL1-2_040507 Total (N)	0705045	FGS
			GSL1-3_041207 Dissolved (N)	0705045	FGS
			GSL1-3_041207 Total (N)	0705045	FGS
			GSL1-4_041107 Dissolved (N)	0705045	FGS
			GSL1-4_041107 Total (N)	0705045	FGS
			GSL1-5_041107 Dissolved (N)	0705045	FGS
			GSL1-5_041107 Total (N)	0705045	FGS
			GSL2-1_041207 Dissolved (N)	0705045	FGS
			GSL2-1_041207Total (N)	0705045	FGS
			GSL2-2_041207 1345 Dissolved (N)	0705045	FGS
			GSL2-2_041207 1345 Total (N)	0705045	FGS
			GSL2-2_041207 1350 Dissolved (N)	0705045	FGS
			GSL2-2_041207 1350 Total (N)	0705045	FGS
			GSL2-3_041107 Dissolved (N)	0705045	FGS
			GSL2-3_041107 Total (N)	0705045	FGS
			GSL2-4_041107 Total (N)	0705045	FGS
			GSL2-4_041107 Dissolved (N)	0705045	FGS
			GSL2-5_041107 Total (N)	0705045	FGS
			GSL2-5_041107 Dissolved (N)	0705045	FGS
			GSL3-1_040307 Total (N)	0705045	FGS
			GSL3-1_040307 Dissolved (N)	0705045	FGS
			GSL3-2_040307 Total (N)	0705045	FGS
			GSL3-2_040307 Dissolved (N)	0705045	FGS
			GSL3-3_040307 Total (N)	0705045	FGS
			GSL3-3_040307 Dissolved (N)	0705045	FGS
			GSL3-4_040307 Total (N)	0705045	FGS
			GSL3-4_040307 Dissolved (N)	0705045	FGS
			GSL3-5_040307 Total (N)	0705045	FGS
			GSL3-5_040307 Dissolved (N)	0705045	FGS
			LC BLNK_041807 Dissolved (N)	0705045	FGS
			LC BLNK_041807 Total (N)	0705045	FGS
			LC_041807 Dissolved (N)	0705045	FGS
			LC_041807 Total (N)	0705045	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0705045	26-Apr-07				
		WATER			
			WR_041607 Dissolved (N)	0705045	FGS
			WR_041607 Total (N)	0705045	FGS
0706030	26-Jan-07				
		WATER			
			Program14/Method Blank Begin/W (N)	0706030	FGS
			Program14/Method Blank End/Wat (N)	0706030	FGS
			Program14/Site1/GSL Water (N)	0706030	FGS
			Program14/Site3/GSL Water (N)	0706030	FGS
			Program14/Site3/GSL Water/0.45 (N)	0706030	FGS
			Program14/Site4/GSL Water (N)	0706030	FGS
			Program14/Site4/GSL Water/Repl (N)	0706030	FGS
			Program14/Site6/GSL Water (N)	0706030	FGS
			Program14/Site6/GSL Water/0.45 (N)	0706030	FGS
			Program14/Site6/GSL Water/Repl (N)	0706030	FGS
			Program14/Site7/GSL Water (N)	0706030	FGS
			Program14/Site9/GSL Water (N)	0706030	FGS
			Program14/Site9/GSL Water/0.45 (N)	0706030	FGS
			Program16/Method Blank Begin/W (N)	0706030	FGS
			Program16/Method Blank End/Wat (N)	0706030	FGS
			Program16/Site1/GSL Water (N)	0706030	FGS
			Program16/Site3/GSL Water (N)	0706030	FGS
			Program16/Site3/GSL Water/0.45 (N)	0706030	FGS
			Program16/Site4/GSL Water (N)	0706030	FGS
			Program16/Site4/GSL Water/Repl (N)	0706030	FGS
			Program16/Site6/GSL Water (N)	0706030	FGS
			Program16/Site6/GSL Water/0.45 (N)	0706030	FGS
			Program16/Site6/GSL Water/Repl (N)	0706030	FGS
			Program16/Site7/GSL Water (N)	0706030	FGS
			Program16/Site9/GSL Water (N)	0706030	FGS
			Program16/Site9/GSL Water/0.45 (N)	0706030	FGS
			Program17/Site3/GSL Water (N)	0706030	FGS
			Program17/Site3/GSL Water/0.45 (N)	0706030	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0706030	26-Jan-07				
		WATER			
			Program17/Site6/GSL Water (N)	0706030	FGS
			Program17/Site6/GSL Water/0.45 (N)	0706030	FGS
			Program17/Site6/GSL Water/Repl (N)	0706030	FGS
			Program17/Site9/GSL Water (N)	0706030	FGS
			Program17/Site9/GSL Water/0.45 (N)	0706030	FGS
0706040	23-May-07				
		WATER			
			2267 0.2m_052307 FA (N)	0706040	FGS
			2267 0.2m_052307 RA (N)	0706040	FGS
			2267 4.0m_052307 FA (N)	0706040	FGS
			2267 4.0m_052307 RA (N)	0706040	FGS
			2565 0.2m_052307 FA (N)	0706040	FGS
			2565 0.2m_052307 RA (N)	0706040	FGS
			2565 6.5m_052307 FA (N)	0706040	FGS
			2565 6.5m_052307 RA (N)	0706040	FGS
			2565 7.5m_052307 FA (N)	0706040	FGS
			2565 7.5m_052307 RA (N)	0706040	FGS
			2767 0.2M_053107 FA (N)	0706040	FGS
			2767 0.2m_053107 RA (N)	0706040	FGS
			2767 2.8m_053107 FA (N)	0706040	FGS
			2767 2.8m_053107 RA (N)	0706040	FGS
			3510 0.2m_053107 FA (N)	0706040	FGS
			3510 0.2m_053107 RA (N)	0706040	FGS
			3510 7.0m_053107 FA (N)	0706040	FGS
			3510 7.0m_053107 RA (N)	0706040	FGS
			3510 8.3m_053107 FA (N)	0706040	FGS
			3510 8.3m_053107 RA (N)	0706040	FGS
			BR_051707 FA (N)	0706040	FGS
			BR_051707 RA (N)	0706040	FGS
			BREACH_053007 (N)	0706040	FGS
			East Culvert_053007 (N)	0706040	FGS
			FB_051807 FA (N)	0706040	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0706040	23-May-07				
		WATER			
			FB_051807 RA (N)	0706040	FGS
			GD_051607 FA (N)	0706040	FGS
			GD_051607 RA (N)	0706040	FGS
			KUCC_051607 FA (N)	0706040	FGS
			KUCC_051607 RA (N)	0706040	FGS
			LC_051607 FA (N)	0706040	FGS
			LC_051607 RA (N)	0706040	FGS
			West Culvert_053007 (N)	0706040	FGS
			WR 1530_051707 FA (N)	0706040	FGS
			WR 1530_051707 RA (N)	0706040	FGS
			WR 1535_051707 FA (N)	0706040	FGS
			WR 1535_051707 RA (N)	0706040	FGS
0706069	23-May-07				
		WATER			
			Program 17/Method Blank Begin/ (N)	0706069	FGS
			Program 17/Method Blank End/Wa (N)	0706069	FGS
			Program 17/Site1/GSL Water (N)	0706069	FGS
			Program 17/Site4/GSL Water (N)	0706069	FGS
			Program 17/Site4/GSL Water/Rep (N)	0706069	FGS
			Program 17/Site7/GSL Water (N)	0706069	FGS
			Program 18/Method Blank Begin/ (N)	0706069	FGS
			Program 18/Method Blank End/Wa (N)	0706069	FGS
			Program 18/Site1/GSL Water (N)	0706069	FGS
			Program 18/Site3/GSL Water (N)	0706069	FGS
			Program 18/Site3/GSL Water/0.4 (N)	0706069	FGS
			Program 18/Site4/GSL Water (N)	0706069	FGS
			Program 18/Site4/GSL Water/Rep (N)	0706069	FGS
			Program 18/Site6/GSL Water (N)	0706069	FGS
			Program 18/Site6/GSL Water/0.4 (N)	0706069	FGS
			Program 18/Site6/GSL Water/Rep (N)	0706069	FGS
			Program 18/Site7/GSL Water (N)	0706069	FGS
			Program 18/Site9/GSL Water (N)	0706069	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0706069	23-May-07				
		WATER			
			Program 18/Site9/GSL Water/0.4 (N)	0706069	FGS
0707002	26-Jun-07				
		WATER			
			2267 0.2m_062607 Dissolved (N)	0707002	FGS
			2267 0.2m_062607 Total (N)	0707002	FGS
			2267 4.0m_062607 Dissolved (N)	0707002	FGS
			2267 4.0m_062607 Total (N)	0707002	FGS
			2565 0.2m_062607 Dissolved (N)	0707002	FGS
			2565 0.2m_062607 Total (N)	0707002	FGS
			2565 6.5m_062607 Dissolved (N)	0707002	FGS
			2565 6.5m_062607 Total (N)	0707002	FGS
			2565 7.5m_062607 Dissolved (N)	0707002	FGS
			2565 7.5m_062607 Total (N)	0707002	FGS
			2767 0.2m_062807 Dissolved (N)	0707002	FGS
			2767 0.2m_062807 Total (N)	0707002	FGS
			2767 3.0m_062807 Dissolved (N)	0707002	FGS
			2767 3.0m_062807 Total (N)	0707002	FGS
			3510 0.2m_062707 Dissolved (N)	0707002	FGS
			3510 0.2m_062707 Total (N)	0707002	FGS
			3510 7.0m_062707 Dissolved (N)	0707002	FGS
			3510 7.0m_062707 Total (N)	0707002	FGS
			3510 8.1m _062707 Total (N)	0707002	FGS
			3510 8.1m_062707 Dissolved (N)	0707002	FGS
			BR_061907 Dissolved (N)	0707002	FGS
			BR_061907 Total (N)	0707002	FGS
			FB_061907 Dissolved (N)	0707002	FGS
			FB_061907 Total (N)	0707002	FGS
			GD 1125_061807 Dissolved (N)	0707002	FGS
			GD 1125_061807 Total (N)	0707002	FGS
			GD 1130_061807 Dissolved (N)	0707002	FGS
			GD 1130_061807 Total (N)	0707002	FGS
			LC_061807 Dissolved (N)	0707002	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0707002	26-Jun-07				
		WATER			
			LC_061807 Total (N)	0707002	FGS
			WR_062007 Dissolved (N)	0707002	FGS
			WR_062007 Total (N)	0707002	FGS
0707121	24-Jul-07				
		WATER			
			2267 0.2m_072407 DISS (N)	0707121	FGS
			2267 0.2m_072407 Total (N)	0707121	FGS
			2267 3.5m_072407 DISS (N)	0707121	FGS
			2267 3.5m_072407 Total (N)	0707121	FGS
			2565 0.2m_072507 Dissolved (N)	0707121	FGS
			2565 0.2m_072507 Total (N)	0707121	FGS
			2565 6.0m_072507 Dissolved (N)	0707121	FGS
			2565 6.0m_072507 Total (N)	0707121	FGS
			2565 7.0m_072507 Dissolved (N)	0707121	FGS
			2565 7.0m_072507 Total (N)	0707121	FGS
			2767 0.2m_072407 DISS (N)	0707121	FGS
			2767 0.2m_072407 Total (N)	0707121	FGS
			2767 2.5m_072407 DISS (N)	0707121	FGS
			2767 2.5m_072407 Total (N)	0707121	FGS
			3510 0.2m_072507 Dissolved (N)	0707121	FGS
			3510 0.2m_072507 Total (N)	0707121	FGS
			3510 6.5m_072507 Dissolved (N)	0707121	FGS
			3510 6.5m_072507 TOTAL (N)	0707121	FGS
			3510 8.0m_072507 DISS (N)	0707121	FGS
			3510 8.0m_072507 TOTAL (N)	0707121	FGS
			BR_041607 1120 (N)	0707121	FGS
			BR_041707 1130 (N)	0707121	FGS
			BR_041807 1130 (N)	0707121	FGS
			BR_041907 1130 (N)	0707121	FGS
			BR_042007 1130 (N)	0707121	FGS
			BR_042107 1130 (N)	0707121	FGS
			BR_042207 1130 (N)	0707121	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0707121	24-Jul-07				
		WATER			
			BR_042307 1130 (N)	0707121	FGS
			BR_042507 1130 (N)	0707121	FGS
			BR_050907 1315 (N)	0707121	FGS
			BR_051107 1315 (N)	0707121	FGS
			BR_051307 1315 (N)	0707121	FGS
			BR_051507 1315 (N)	0707121	FGS
			BR_052507 1040 (N)	0707121	FGS
			BR_052607 1040 (N)	0707121	FGS
			BR_052807 1040 (N)	0707121	FGS
			BR_052907 1040 (N)	0707121	FGS
			BR_060307 1040 (N)	0707121	FGS
			BR_061307 1040 (N)	0707121	FGS
			BR_061607 1040 (N)	0707121	FGS
			BR_071607 Dissolved (N)	0707121	FGS
			BR_071607 Total (N)	0707121	FGS
			FB_042007 1100 (N)	0707121	FGS
			FB_042107 1100 (N)	0707121	FGS
			FB_042207 1100 (N)	0707121	FGS
			FB_042407 1100 (N)	0707121	FGS
			FB_042507 1100 (N)	0707121	FGS
			FB_042707 1100 (N)	0707121	FGS
			FB_042907 1100 (N)	0707121	FGS
			FB_050107 1100 (N)	0707121	FGS
			FB_050307 1100 (N)	0707121	FGS
			FB_050907 1115 (N)	0707121	FGS
			FB_051107 1115 (N)	0707121	FGS
			FB_051407 1115 (N)	0707121	FGS
			FB_051907 1115 (N)	0707121	FGS
			FB_052407 1215 (N)	0707121	FGS
			FB_052707 1215 (N)	0707121	FGS
			FB_052907 1215 (N)	0707121	FGS
			FB_053107 1215 (N)	0707121	FGS
			FB_060207 1215 (N)	0707121	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0707121	24-Jul-07				
		WATER			
			FB_060607 1215 (N)	0707121	FGS
			FB_060707 1215 (N)	0707121	FGS
			FB_071707 Diss (N)	0707121	FGS
			FB_071707 Total (N)	0707121	FGS
			GD_041307 1430 (N)	0707121	FGS
			GD_041507 1500 (N)	0707121	FGS
			GD_042007 1500 (N)	0707121	FGS
			GD_042107 1500 (N)	0707121	FGS
			GD_042207 1500 (N)	0707121	FGS
			GD_042407 1500 (N)	0707121	FGS
			GD_050807 1130 (N)	0707121	FGS
			GD_050907 1130 (N)	0707121	FGS
			GD_051307 1130 (N)	0707121	FGS
			GD_051407 1130 (N)	0707121	FGS
			GD_051607 1130 (N)	0707121	FGS
			GD_051707 1130 (N)	0707121	FGS
			GD_051907 1130 (N)	0707121	FGS
			GD_052207 1130 (N)	0707121	FGS
			GD_052407 1130 (N)	0707121	FGS
			GD_052707 1130 (N)	0707121	FGS
			GD_053007 1130 (N)	0707121	FGS
			GD_053107 1130 (N)	0707121	FGS
			GD_060107 1130 (N)	0707121	FGS
			GD_062907 1130 (N)	0707121	FGS
			GD_070907 Dissolved (N)	0707121	FGS
			GD_071907 Total (N)	0707121	FGS
			LC BLNK_071907 Dissolved (N)	0707121	FGS
			LC BLNK_071907 Total (N)	0707121	FGS
			LC_071907 Dissolved (N)	0707121	FGS
			LC_071907 Total (N)	0707121	FGS
			WR_071607 Dissolved 1400 (N)	0707121	FGS
			WR_071607 Dissolved 1405 (N)	0707121	FGS
			WR_071607 Total 1400 (N)	0707121	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0707121	24-Jul-07				
		WATER			
			WR_071607 Total 1405 (N)	0707121	FGS
0708013	27-Jun-07				
		WATER			
			Program 19/Method Blank Begin/ (N)	0708013	FGS
			Program 19/Method Blank End/Wa (N)	0708013	FGS
			Program 19/Site1/GSL Water (N)	0708013	FGS
			Program 19/Site3/GSL Water (N)	0708013	FGS
			Program 19/Site3/GSL Water/0.4 (N)	0708013	FGS
			Program 19/Site4/GSL Water (N)	0708013	FGS
			Program 19/Site4/GSL Water/0.4 (N)	0708013	FGS
			Program 19/Site4/GSL Water/Rep (N)	0708013	FGS
			Program 19/Site6/GSL Water (N)	0708013	FGS
			Program 19/Site7/GSL Water (N)	0708013	FGS
			Program 19/Site7/GSL Water/Rep (N)	0708013	FGS
			Program 19/Site9/GSL Water (N)	0708013	FGS
			Program 19/Site9/GSL Water/0.4 (N)	0708013	FGS
			Program 20/Method Blank Begin/ (N)	0708013	FGS
			Program 20/Site4/GSL Water (N)	0708013	FGS
			Program 20/Site4/GSL Water/0.4 (N)	0708013	FGS
			Program 20/Site4/GSL Water/Rep (N)	0708013	FGS
			Program 20/Site6/GSL Water (N)	0708013	FGS
			Program 20/Site6/GSL Water/0.4 (N)	0708013	FGS
			Program 20/Site6/GSL Water/Rep (N)	0708013	FGS
			Program 20/Site7/GSL Water (N)	0708013	FGS
			Program 20/Site7/GSL Water/0.4 (N)	0708013	FGS
			Program 20/Site7/GSL Water/Rep (N)	0708013	FGS
			Program 20/Site9/GSL Water (N)	0708013	FGS
			Program 20/Site9/GSL Water/0.4 (N)	0708013	FGS
			Program 20/Site9/GSL Water/Rep (N)	0708013	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0708015	28-Jun-07				
		WATER			
			BD01FAW (N)	0708015	FGS
			BD01RAW (N)	0708015	FGS
			BD02FAW (N)	0708015	FGS
			BD02RAW (N)	0708015	FGS
			BD03FAW (N)	0708015	FGS
			BD03RAW (N)	0708015	FGS
			BD04FA (N)	0708015	FGS
			BD04RAW (N)	0708015	FGS
			ET01FA (N)	0708015	FGS
			ET01RA (N)	0708015	FGS
			ET02FA (N)	0708015	FGS
			ET02RA (N)	0708015	FGS
			ET03FA (N)	0708015	FGS
			ET03RA (N)	0708015	FGS
			ET04FA (N)	0708015	FGS
			ET04FAD (N)	0708015	FGS
			ET04RA (N)	0708015	FGS
			ET04RAD (N)	0708015	FGS
			NH01FA (N)	0708015	FGS
			NH01FAD (N)	0708015	FGS
			NH02FA (N)	0708015	FGS
			NH03FA (N)	0708015	FGS
			NH04FA (N)	0708015	FGS
			NHO1RA (N)	0708015	FGS
			NHO1RAD (N)	0708015	FGS
			NHO2RA (N)	0708015	FGS
			NHO3RA (N)	0708015	FGS
			NHO4RA (N)	0708015	FGS
			NT01FAD (N)	0708015	FGS
			NT01FAW (N)	0708015	FGS
			NT01RAD (N)	0708015	FGS
			NT01RAW (N)	0708015	FGS
			NT02FAW (N)	0708015	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0708015	28-Jun-07				
		WATER			
			NT02RAW (N)	0708015	FGS
			NT03FAW (N)	0708015	FGS
			NT03RAW (N)	0708015	FGS
			NT04FAW (N)	0708015	FGS
			NT04RAW (N)	0708015	FGS
0708182	21-Aug-07				
		WATER			
			Program21/MethodBlankBegin/Wat (N)	0708182	FGS
			Program21/MethodBlankEnd/Water (N)	0708182	FGS
			Program21/Site1/GSLWater (N)	0708182	FGS
			Program21/Site1/GSLWater/0.45m (N)	0708182	FGS
			Program21/Site3/GSLWater (N)	0708182	FGS
			Program21/Site3/GSLWater/0.45m (N)	0708182	FGS
			Program21/Site4/GSLWater (N)	0708182	FGS
			Program21/Site4/GSLWater/0.45m (N)	0708182	FGS
			Program21/Site4/GSLWater/Repli (N)	0708182	FGS
			Program21/Site6/GSLWater (N)	0708182	FGS
			Program21/Site6/GSLWater/0.45m (N)	0708182	FGS
			Program21/Site6/GSLWaterRepli (N)	0708182	FGS
			Program21/Site7/GSLWater (N)	0708182	FGS
			Program21/Site7/GSLWater/0.45m (N)	0708182	FGS
			Program21/Site9/GSLWater (N)	0708182	FGS
			Program21/Site9/GSLWater/0.45m (N)	0708182	FGS
0708195	23-Aug-07				
		WATER			
			2267 FA 0.2m (N)	0708195	FGS
			2267 FA 3.5m (N)	0708195	FGS
			2267 RA 0.2m (N)	0708195	FGS
			2267 RA 3.5m (N)	0708195	FGS
			2565 FA 0.2m (N)	0708195	FGS
			2565 FA 7.0m (N)	0708195	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0708195	23-Aug-07				
		WATER			
			2565 FA 7.8m (N)	0708195	FGS
			2565 RA 0.2m (N)	0708195	FGS
			2565 RA 7.0m (N)	0708195	FGS
			2565 RA 7.8m (N)	0708195	FGS
			2767 FA 0.2m (N)	0708195	FGS
			2767 FA 2.5m (N)	0708195	FGS
			2767 RA 0.2m (N)	0708195	FGS
			2767 RA 2.5m (N)	0708195	FGS
			3510 FA 0.2m (N)	0708195	FGS
			3510 FA 6.5m (N)	0708195	FGS
			3510 FA 8.0m (N)	0708195	FGS
			3510 RA 0.2m (N)	0708195	FGS
			3510 RA 6.5m (N)	0708195	FGS
			3510 RA 8.0m (N)	0708195	FGS
			FB FA_081407 (N)	0708195	FGS
			FB RA_081407 (N)	0708195	FGS
			GD FA_081307 (N)	0708195	FGS
			GD RA_081307 (N)	0708195	FGS
			LC FA 1140 (N)	0708195	FGS
			LC FA 1145 (N)	0708195	FGS
			LC RA 1140 (N)	0708195	FGS
			LC RA 1145 (N)	0708195	FGS
			WR FA_081407 (N)	0708195	FGS
			WR RA_081407 (N)	0708195	FGS
0709016	02-Aug-07				
		WATER			
			GSL-RA 1-1m (N)	0709016	FGS
			GSL-RA 1-2m (N)	0709016	FGS
			GSL-RA 1-3m (N)	0709016	FGS
			GSL-RA 1-4m (N)	0709016	FGS
			GSL-RA 1-5m (N)	0709016	FGS
			GSL-RA 2-1m (N)	0709016	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
0709016	02-Aug-07				
		WATER			
			GSL-RA 2-2m (N)	0709016	FGS
			GSL-RA 2-3m (N)	0709016	FGS
			GSL-RA 2-4m (N)	0709016	FGS
			GSL-RA 2-5m (N)	0709016	FGS
			GSL-RA 3-1m (N)	0709016	FGS
			GSL-RA 3-2m (a) (N)	0709016	FGS
			GSL-RA 3-2m (b) (N)	0709016	FGS
			GSL-RA 3-3m (N)	0709016	FGS
			GSL-RA 3-4m (N)	0709016	FGS
			GSL-RA 3-5m (N)	0709016	FGS
GRSL-051206	04-May-06				
		WATER			
			WATER -ANTELOPE COLO (N)	606126	FGS
			WATER -GSLM COLONY (N)	606126	FGS
			WATER -HAT COLONY (N)	606126	FGS
GRSL-052506	26-May-06				
		WATER			
			2267 0.2M 260506 1130 FA (N)	606025	FGS
			2267 0.2M 260506 1130 RA (N)	606025	FGS
			2565 0.2M 260506 1400 FA (N)	606025	FGS
			2565 0.2M 260506 1400 RA (N)	606025	FGS
			2565 6.5M 260506 1425 FA (N)	606025	FGS
			2565 6.5M 260506 1425 RA (N)	606025	FGS
			2565 7.5M 260506 1440 FA (N)	606025	FGS
			2565 7.5M 260506 1440 RA (N)	606025	FGS
			2567 4.0M 260506 1130 FA (N)	606025	FGS
			2567 4.0M 260506 1130 RA (N)	606025	FGS
			2767 0.2M 230506 1100 FA (N)	606025	FGS
			2767 0.2M 230506 1100 RA (N)	606025	FGS
			2767 3.0M 230506 1130 FA (N)	606025	FGS
			2767 3.0M 230506 1130 RA (N)	606025	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-052506	26-May-06				
		WATER			
			3510 0.2M 230506 1230 FA (N)	606025	FGS
			3510 0.2M 230506 1230 RA (N)	606025	FGS
			3510 6.5M 230506 1250 FA (N)	606025	FGS
			3510 6.5M 230506 1250 RA (N)	606025	FGS
			3510 8.5M 230506 1315 FA (N)	606025	FGS
			3510 8.5M 230506 1315 RA (N)	606025	FGS
			BR1 030506 1420 FA (N)	606025	FGS
			BR1 030506 1420 RA (N)	606025	FGS
			BR1 030506 1425 FA (N)	606025	FGS
			BR1 030506 1425 RA (N)	606025	FGS
			BR1 040506 1130 RA (N)	606025	FGS
			BR1-250506 1430 FA (N)	606025	FGS
			BR1-250506 1430 RA (N)	606025	FGS
			BR1-250506 1435 FA (N)	606025	FGS
			FB1 080506 1500 FA (N)	606025	FGS
			FB1 080506 1500 RA (N)	606025	FGS
			FB1 250506 1100 FA (N)	606025	FGS
			FB1- 250506 1100 RA (N)	606025	FGS
			GOGGIN DRAIN 170506 1045 FA (N)	606025	FGS
			GOGGIN DRAIN 170506 1045 RA (N)	606025	FGS
			GSL BREECH 250506 1315 RA (N)	606025	FGS
			GSL EAST CULVERT 250506 1 (N)	606025	FGS
			GSL WEST CULVERT 250506 1 (N)	606025	FGS
			KUCC 120506 1215 FA (N)	606025	FGS
			KUCC 120506 1215 RA (N)	606025	FGS
			LEE CREEK 120506 1015 RA (N)	606025	FGS
			LEE CREEK 120506 1017 FA (N)	606025	FGS
			N. ARM BRINE @ GSL MINERA (N)	606025	FGS
			WR 170506 1325 FA (N)	606025	FGS
			WR 170506 1325 RA (N)	606025	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-0609112	29-Aug-06				
		WATER			
			2267 0.2M-FA (N)	0609112	FGS
			2267 0.2M-RA (N)	0609112	FGS
			2267 3.8M-FA (N)	0609112	FGS
			2267 3.8M-RA (N)	0609112	FGS
			2767 0.2M-FA (N)	0609112	FGS
			2767 0.2M-RA (N)	0609112	FGS
			2767 2.7M-FA (N)	0609112	FGS
			2767 2.7M-RA (N)	0609112	FGS
			3510 0.2M-FA (N)	0609112	FGS
			3510 0.2M-RA (N)	0609112	FGS
			3510 6.5M-FA (N)	0609112	FGS
			3510 6.5M-RA (N)	0609112	FGS
			3510 8.5M-FA (N)	0609112	FGS
			3510 8.5M-RA (N)	0609112	FGS
			BR-030606-RA (N)	0609112	FGS
			BR-040506-RA (N)	0609112	FGS
			BR-060506-RA (N)	0609112	FGS
			BR-060506-RA_050406 (N)	0609112	FGS
			BR-070606-RA (N)	0609112	FGS
			BR-100506-RA (N)	0609112	FGS
			BR-110606-RA (N)	0609112	FGS
			BR-160506-RA (N)	0609112	FGS
			BR-190506-RA (N)	0609112	FGS
			BR-190606-RA (N)	0609112	FGS
			BR-210606-RA (N)	0609112	FGS
			BR-230506-RA (N)	0609112	FGS
			BR-250506-RA (N)	0609112	FGS
			BR-260506-RA (N)	0609112	FGS
			BR-280506-RA (N)	0609112	FGS
			FB-010606-RA (N)	0609112	FGS
			FB-030606-RA (N)	0609112	FGS
			FB-080506-RA (N)	0609112	FGS
			FB-090506-RA (N)	0609112	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-0609112	29-Aug-06				
		WATER			
			FB-090606-RA (N)	0609112	FGS
			FB-10506-RA (N)	0609112	FGS
			FB-110506-RA (N)	0609112	FGS
			FB-130506-RA (N)	0609112	FGS
			FB-170506-RA (N)	0609112	FGS
			FB-200506-RA (N)	0609112	FGS
			FB-230506-RA (N)	0609112	FGS
			FB-240506-RA (N)	0609112	FGS
			FB-250506-RA (N)	0609112	FGS
			FB-260506-RA (N)	0609112	FGS
			FB-290506-RA (N)	0609112	FGS
			GD-010606-RA (N)	0609112	FGS
			GD-040606-RA (N)	0609112	FGS
			GD-060606-RA (N)	0609112	FGS
			GD-070606-RA (N)	0609112	FGS
			GD-090506-RA (N)	0609112	FGS
			GD-110606-RA (N)	0609112	FGS
			GD-120506-RA (N)	0609112	FGS
			GD-150506-RA (N)	0609112	FGS
			GD-150606-RA (N)	0609112	FGS
			GD--170506-RA (N)	0609112	FGS
			GD-210506-RA (N)	0609112	FGS
			GD-240506-RA (N)	0609112	FGS
			GD-290506-RA (N)	0609112	FGS
			LEE CREEK-RA (N)	0609112	FGS
GRSL-0611102	22-May-06				
		WATER			
			Program3/Method Blank Begin (N)	0611102	FGS
			Program3/Method Blank End (N)	0611102	FGS
			Program3/Site1/GSL Water (N)	0611102	FGS
			Program3/Site2/GSL Water (N)	0611102	FGS
			Program3/Site3/GSL Water (N)	0611102	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-0611102	22-May-06				
		WATER			
			Program3/Site4/GSL Water (N)	0611102	FGS
			Program3/Site4/GSL Water-Disso (N)	0611102	FGS
			Program3/Site5/GSL Wate (N)	0611102	FGS
			Program3/Site5/GSL Water-Disso (N)	0611102	FGS
			Program3/Site6/GSL Water (N)	0611102	FGS
			Program3/Site6/GSL Water-Disso (N)	0611102	FGS
			Program3/Site7/GSL Water (N)	0611102	FGS
			Program3/Site8/GSL Water (N)	0611102	FGS
			Program3/Site9/GSL Water (N)	0611102	FGS
			Program5/Method Blank Begin (N)	0611102	FGS
			Program5/Method Blank End (N)	0611102	FGS
			Program5/Site1/GSL Water (N)	0611102	FGS
			Program5/Site2/GSL Water (N)	0611102	FGS
			Program5/Site3/GSL Water (N)	0611102	FGS
			Program5/Site4/GSL Water (N)	0611102	FGS
			Program5/Site4/GSL Water-Disso (N)	0611102	FGS
			Program5/Site5/GSL Water (N)	0611102	FGS
			Program5/Site5/GSL Water-Disso (N)	0611102	FGS
			Program5/Site6/GSL Water (N)	0611102	FGS
			Program5/Site6/GSL Water-Disso (N)	0611102	FGS
			Program5/Site7/GSL Water (N)	0611102	FGS
			Program5/Site8/GSL Water (N)	0611102	FGS
			Program5/Site9/GSL Water (N)	0611102	FGS
			Program6/Method Blank Begin (N)	0611102	FGS
			Program6/Method Blank End (N)	0611102	FGS
			Program6/Site1/GSL Water (N)	0611102	FGS
			Program6/Site3/GSL Water (N)	0611102	FGS
			Program6/Site4/GSL Water (N)	0611102	FGS
			Program6/Site4/GSL Water-Disso (N)	0611102	FGS
			Program6/Site6/GSL Water (N)	0611102	FGS
			Program6/Site6/GSL Water-Disso (N)	0611102	FGS
			Program6/Site7/GSL Water (N)	0611102	FGS
			Program6/Site9/GSL Water (N)	0611102	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-0611102	22-May-06				
		WATER			
			Program7/Site6-A/GSL Water (N)	0611102	FGS
			Program7/Site6-B/GSL Water (N)	0611102	FGS
			Program7/Site6-C/GSL Water (N)	0611102	FGS
			Program7/Site6-D/GSL Water (N)	0611102	FGS
GRSL-061406	16-Jun-06				
		WATER			
			ANTI-1-W (N)	608004	FGS
			ANTI-2-W (N)	608004	FGS
			ANTI-3-W (N)	608004	FGS
			OGBA-1-W (N)	608004	FGS
			OGBA-2-W (N)	608004	FGS
			OGBA-3-W (N)	608004	FGS
			SALT-1-W (N)	608004	FGS
			SALT-2-W (N)	608004	FGS
			SALT-3-W (N)	608004	FGS
GRSL-061606	14-Jul-06				
		WATER			
			25 (N)	607051	FGS
			26 (N)	607051	FGS
			27 (N)	607051	FGS
			28 (N)	607051	FGS
			29 (N)	607051	FGS
			30 (N)	607051	FGS
			31 (N)	607051	FGS
GRSL-062106	21-Jun-06				
		WATER			
			A (N)	606128	FGS
			B (N)	606128	FGS
			C (N)	606128	FGS
			D (N)	606128	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-071206	28-Jul-06				
		WATER			
			2267 0.2M FA (N)	608042	FGS
			2267 0.2M RA (N)	608042	FGS
			2267 4.0M FA (N)	608042	FGS
			2267 4.0M RA (N)	608042	FGS
			2565 0.2M FA (N)	608042	FGS
			2565 0.2M RA (N)	608042	FGS
			2565 6.5M FA (N)	608042	FGS
			2565 6.5M RA (N)	608042	FGS
			2565 7.5M FA (N)	608042	FGS
			2565 7.5M RA (N)	608042	FGS
			2767 0.2M FA (N)	608042	FGS
			2767 0.2M RA (N)	608042	FGS
			2767 3.0M FA (N)	608042	FGS
			2767 3.0M RA (N)	608042	FGS
			3510 0.2M FA (N)	608042	FGS
			3510 0.2M RA (N)	608042	FGS
			3510 7.0M FA (N)	608042	FGS
			3510 7.0M RA (N)	608042	FGS
			3510 8.5M FA (N)	608042	FGS
			3510 8.5M RA (N)	608042	FGS
			FB FA (N)	608042	FGS
			FB RA (N)	608042	FGS
			GD FA (N)	608042	FGS
			GD RA (N)	608042	FGS
			KUCC FA (N)	608042	FGS
			KUCC RA (N)	608042	FGS
			KUCC RA_072706 (N)	608042	FGS
			LC FA (N)	608042	FGS
			LC RA (N)	608042	FGS
			WR FA (N)	608042	FGS
			WR RA (N)	608042	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-072706	24-Sep-06				
		WATER			
			Program 10/Method Blank Begin/ (N)	0611047	FGS
			Program 10/Method Blank End/Wa (N)	0611047	FGS
			Program 10/Site 1/GSL Water (N)	0611047	FGS
			Program 10/Site 3/GSL Water (N)	0611047	FGS
			Program 10/Site 4/GSL Water (N)	0611047	FGS
			Program 10/Site 4/GSL Water/Re (N)	0611047	FGS
			Program 10/Site 4/GSL Water-Di (N)	0611047	FGS
			Program 10/Site 6/GSL Water (N)	0611047	FGS
			Program 10/Site 6/GSL Water/Re (N)	0611047	FGS
			Program 10/Site 6/GSL Water-Di (N)	0611047	FGS
			Program 10/Site 7/GSL Water (N)	0611047	FGS
			Program 10/Site 9/GSL Water (N)	0611047	FGS
			Program 11/ Site 1/ GSL Water (N)	0611047	FGS
			Program 11/ Site 3/ GSL Water (N)	0611047	FGS
			Program 11/ Site 4/ GSL Water (N)	0611047	FGS
			Program 11/ Site 4/ GSL Water- (N)	0611047	FGS
			Program 11/ Site 4/ GSL Water/ (N)	0611047	FGS
			Program 11/ Site 6/ GSL Water (N)	0611047	FGS
			Program 11/ Site 6/ GSL Water- (N)	0611047	FGS
			Program 11/ Site 6/ GSL Water/ (N)	0611047	FGS
			Program 11/ Site 7/ GSL Water (N)	0611047	FGS
			Program 11/ Site 9/ GSL Water (N)	0611047	FGS
			Program 11/Method Blank Begin/ (N)	0611047	FGS
			Program 11/Method Blank End/Wa (N)	0611047	FGS
			Program 7/Method Blank Begin/W (N)	0611047	FGS
			Program 7/Site 1/ GSL Water (N)	0611047	FGS
			Program 7/Site 3/ GSL Water (N)	0611047	FGS
			Program 7/Site 4/ GSL Water (N)	0611047	FGS
			Program 7/Site 4/ GSL Water-Di (N)	0611047	FGS
			Program 7/Site 6/ GSL Water/Re (N)	0611047	FGS
			Program 7/Site 6/ GSL Water-Di (N)	0611047	FGS
			Program 7/Site 6-E/GSL Water (N)	0611047	FGS
			Program 7/Site 6-F/GSL Water (N)	0611047	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-072706	24-Sep-06				
		WATER			
			Program 7/Site 6-G/GSL Water (N)	0611047	FGS
			Program 7/Site 6-H/GSL Water (N)	0611047	FGS
			Program 7/Site 7/ GSL Water (N)	0611047	FGS
			Program 7/Site 9/ GSL Water (N)	0611047	FGS
			Program 8/Method Blank Begin/W (N)	0611047	FGS
			Program 8/Method Blank End/Wat (N)	0611047	FGS
			Program 8/Site 1/GSL Water (N)	0611047	FGS
			Program 8/Site 3/GSL Water (N)	0611047	FGS
			Program 8/Site 4/GSL Water (N)	0611047	FGS
			Program 8/Site 4/GSL Water/Rep (N)	0611047	FGS
			Program 8/Site 4/GSL Water-Dis (N)	0611047	FGS
			Program 8/Site 6/GSL Water (N)	0611047	FGS
			Program 8/Site 6/GSL Water/Rep (N)	0611047	FGS
			Program 8/Site 6/GSL Water-Dis (N)	0611047	FGS
			Program 8/Site 7/GSL Water (N)	0611047	FGS
			Program 8/Site 9/GSL Water (N)	0611047	FGS
			Program 9/Method Blank Begin/W (N)	0611047	FGS
			Program 9/Method Blank End/Wat (N)	0611047	FGS
			Program 9/Site 1/GSL Water (N)	0611047	FGS
			Program 9/Site 3/GSL Water (N)	0611047	FGS
			Program 9/Site 4/GSL Water (N)	0611047	FGS
			Program 9/Site 4/GSL Water/Rep (N)	0611047	FGS
			Program 9/Site 4/GSL Water-Dis (N)	0611047	FGS
			Program 9/Site 6/GSL Water (N)	0611047	FGS
			Program 9/Site 6/GSL Water/Rep (N)	0611047	FGS
			Program 9/Site 6/GSL Water-Dis (N)	0611047	FGS
			Program 9/Site 7/GSL Water (N)	0611047	FGS
			Program 9/Site 9/GSL Water (N)	0611047	FGS
			Station1/sample 1/main sample- (N)	0611047	FGS
GRSL-081006	08-Aug-06				
		WATER			
			FB 080806 1245 D (N)	0608138	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-081006	08-Aug-06				
		WATER			
			FB 080806 1245 T (N)	0608138	FGS
			GD 081006 1130 D (N)	0608138	FGS
			GD 081006 1130 T (N)	0608138	FGS
			LC 081006 0900 D (N)	0608138	FGS
			LC 081006 0900 T (N)	0608138	FGS
			LC 081006 0905 D (N)	0608138	FGS
			LC 081006 0905 T (N)	0608138	FGS
			WR 080806 0945 T (N)	0608138	FGS
			WR 080806 0950 T (N)	0608138	FGS
			WR 080806 0945 D (N)	0608138	FGS
			WR 080806 0950 D (N)	0608138	FGS
GRSL-090506	07-Sep-06				
		WATER			
			FB_090706 FA (N)	0609051	FGS
			FB_090706 RA (N)	0609051	FGS
			GD_090506 FA (N)	0609051	FGS
			GD_090506 RA (N)	0609051	FGS
			GD_090506A FA (N)	0609051	FGS
			GD_090506A RA (N)	0609051	FGS
			KCUU_091206 FA (N)	0609051	FGS
			KCUU_091206 RA (N)	0609051	FGS
			LC_090506 FA (N)	0609051	FGS
			LC_090506 RA (N)	0609051	FGS
			SALT CANAL_090706 RA (N)	0609051	FGS
			WR_090706 FA (N)	0609051	FGS
			WR_090706 RA (N)	0609051	FGS
GRSL-092706	26-Sep-06				
		WATER			
			10010020_092606-RA (N)	0610027	FGS
			10010030_092606-RA (N)	0610027	FGS
			10010040_092606-RA (N)	0610027	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-092706	26-Sep-06				
		WATER			
			2267 0.2m_092706 FA (N)	0610027	FGS
			2267 0.2m_092706 RA (N)	0610027	FGS
			2267 3.5m_092706 FA (N)	0610027	FGS
			2267 3.5m_092706 RA (N)	0610027	FGS
			2565 0.2m_092806 FA (N)	0610027	FGS
			2565 0.2m_092806 RA (N)	0610027	FGS
			2565 6.5m_092806 FA (N)	0610027	FGS
			2565 6.5m_092806 RA (N)	0610027	FGS
			2565 7.5m_092806 FA (N)	0610027	FGS
			2565 7.5m_092806 RA (N)	0610027	FGS
			2767 0.2m_092706 FA (N)	0610027	FGS
			2767 0.2m_092706 RA (N)	0610027	FGS
			2767 2.2m_092706 FA (N)	0610027	FGS
			2767 2.2m_092706 RA (N)	0610027	FGS
			3510 0.2m_092806 FA (N)	0610027	FGS
			3510 0.2m_092806 RA (N)	0610027	FGS
			3510 6.5m_092806 FA (N)	0610027	FGS
			3510 6.5m_092806 RA (N)	0610027	FGS
			3510 8.0m_092806 FA (N)	0610027	FGS
			3510 8.0m_092806 RA (N)	0610027	FGS
GRSL-101006	10-Oct-06				
		WATER			
			BR1 10/10/06 1515 FA (N)	0610068	FGS
			BR1 10/10/06 1515 RA (N)	0610068	FGS
			FR1 10/10/06 1100 FA (N)	0610068	FGS
			FR1 10/10/06 1100 RA (N)	0610068	FGS
			GD 10/12/06 1220 FA (N)	0610068	FGS
			GD 10/12/06 1220 RA (N)	0610068	FGS
			KCUU 10/12/06 1520 FA (N)	0610068	FGS
			KCUU 10/12/06 1520 RA (N)	0610068	FGS
			LC 10/12/06 1350 FA (N)	0610068	FGS
			LC 10/12/06 1350 RA (N)	0610068	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GRSL-101006	10-Oct-06				
		WATER			
			WR 10/12/06 0930 FA (N)	0610068	FGS
			WR 10/12/06 0930 RA (N)	0610068	FGS
GRSL-110106	01-Nov-06				
		WATER			
			2267 0.2m_110106 FA (N)	0611118	FGS
			2267 0.2m_110106 RA (N)	0611118	FGS
			2267 3.9m_110106 FA (N)	0611118	FGS
			2267 3.9m_110106 RA (N)	0611118	FGS
			2565 0.2m_110106 FA (N)	0611118	FGS
			2565 0.2m_110106 RA (N)	0611118	FGS
			2565 6.5m_110106 FA (N)	0611118	FGS
			2565 6.5m_110106 RA (N)	0611118	FGS
			2565 8.0m_110106 FA (N)	0611118	FGS
			2565 8.0m_110106 RA (N)	0611118	FGS
			2767 0.2m_110306 FA (N)	0611118	FGS
			2767 0.2m_110306 RA (N)	0611118	FGS
			3510 0.2m_110306 FA (N)	0611118	FGS
			3510 0.2m_110306 RA (N)	0611118	FGS
			3510 6.5m_110306 FA (N)	0611118	FGS
			3510 6.5m_110306 RA (N)	0611118	FGS
			3510 8.0m_110306 FA (N)	0611118	FGS
			3510 8.0m_110306 RA (N)	0611118	FGS
			GD_110906 FA (N)	0611118	FGS
			GD_110906 RA (N)	0611118	FGS
			LC_111506 FA (N)	0611118	FGS
			LC_111506 RA (N)	0611118	FGS
			Morton Salt_110306 FA (N)	0611118	FGS
			Morton Salt_110306 RA (N)	0611118	FGS
			WR_110906 FA (N)	0611118	FGS
			WR_110906 RA (N)	0611118	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GSL-0607033	19-Jun-06				
		WATER			
			2267 0.2m_061906- FA DISS (N)	0607033	FGS
			2267 0.2m_061906- RA TOTAL (N)	0607033	FGS
			2267 4.0m_061906- FA DISS (N)	0607033	FGS
			2267 4.0m_061906- RA TOTAL (N)	0607033	FGS
			2565 0.2m_061906- FA DISS (N)	0607033	FGS
			2565 0.2m_061906- RA TOTAL (N)	0607033	FGS
			2565 6.5m_061906- FA DISS (N)	0607033	FGS
			2565 6.5m_061906- RA TOTAL (N)	0607033	FGS
			2565 8.0m_061906- FA DISS (N)	0607033	FGS
			2565 8.0m_061906- RA TOTAL (N)	0607033	FGS
			2767 0.2m_062006- FA DISS (N)	0607033	FGS
			2767 0.2m_062006- RA TOTAL (N)	0607033	FGS
			2767 3.0m_062006- FA DISS (N)	0607033	FGS
			2767 3.0m_062006- RA TOTAL (N)	0607033	FGS
			3510 0.2m_062006- FA DISS (N)	0607033	FGS
			3510 0.2m_062006- RA TOTAL (N)	0607033	FGS
			3510 6.5m_062006- FA DISS (N)	0607033	FGS
			3510 6.5m_062006- RA TOTAL (N)	0607033	FGS
			3510 8.5m_062006- FA DISS (N)	0607033	FGS
			3510 8.5m_062006- RA TOTAL (N)	0607033	FGS
			BR1_062106- FA DISS (N)	0607033	FGS
			BR1_062106- RA TOTAL (N)	0607033	FGS
			FB1_062806- FA DISS (N)	0607033	FGS
			FB1_062806- RA TOTAL (N)	0607033	FGS
			GOGGIN DRAIN_060606-FA DISS (N)	0607033	FGS
			GOGGIN DRAIN_060606-RA TOTAL (N)	0607033	FGS
			KUCC_060606- FA DISS (N)	0607033	FGS
			KUCC_060606- RA TOTAL (N)	0607033	FGS
			LEE CREEK_060606- FA DISS (N)	0607033	FGS
			LEE CREEK_060606- RA TOTAL (N)	0607033	FGS
			WR_060606- FA DISS (N)	0607033	FGS
			WR_060606- RA TOTAL (N)	0607033	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GSL-0611139	21-Nov-06				
		WATER			
			2267 0.2m FA-Dissolved (N)	0611139	FGS
			2267 0.2m RA-Total (N)	0611139	FGS
			2267 3.7m FA-Dissolved (N)	0611139	FGS
			2267 3.7m RA-Total (N)	0611139	FGS
			2565 0.2m FA-Dissolved (N)	0611139	FGS
			2565 0.2m RA-Total (N)	0611139	FGS
			2565 6.5m FA-Dissolved (N)	0611139	FGS
			2565 6.5m RA-Total (N)	0611139	FGS
			2565 7.5m FA-Dissolved (N)	0611139	FGS
			2565 7.5m RA-Total (N)	0611139	FGS
			2767 0.2m FA-Dissolved (N)	0611139	FGS
			2767 0.2m RA-Total (N)	0611139	FGS
			2767 2.5m FA-Dissolved (N)	0611139	FGS
			2767 2.5m RA-Total (N)	0611139	FGS
			3510 0.2m FA-Dissolved (N)	0611139	FGS
			3510 0.2m RA-Total (N)	0611139	FGS
			3510 6.5m FA-Dissolved (N)	0611139	FGS
			3510 6.5m RA-Total (N)	0611139	FGS
			3510 8.0m FA-Dissolved (N)	0611139	FGS
			3510 8.0m RA-Total (N)	0611139	FGS
			BR1 FA-Dissolved (N)	0611139	FGS
			BR1 RA-Total (N)	0611139	FGS
			FB1 FA-Dissolved (N)	0611139	FGS
			FB1 RA-Total (N)	0611139	FGS
GSL-0612022	04-Dec-06				
		WATER			
			GSL-1 (N)	0612022	FGS
			GSL-2 (N)	0612022	FGS
			GSL-3 (N)	0612022	FGS
			GSL-4 (N)	0612022	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GSL-0612085	20-Nov-06				
		WATER			
			Program12/Method Blank Begin/W (N)	0612085	FGS
			Program12/Method Blank End/Wat (N)	0612085	FGS
			Program12/Site 1/GSL Water (N)	0612085	FGS
			Program12/Site 3/GSL Water (N)	0612085	FGS
			Program12/Site 4/GSL Water (N)	0612085	FGS
			Program12/Site 4/GSL Water Dis (N)	0612085	FGS
			Program12/Site 4/GSL Water/Rep (N)	0612085	FGS
			Program12/Site 6/GSL Water (N)	0612085	FGS
			Program12/Site 6/GSL Water Dis (N)	0612085	FGS
			Program12/Site 6/GSL Water/Rep (N)	0612085	FGS
			Program12/Site 7/GSL Water (N)	0612085	FGS
			Program12/Site 9/GSL Water (N)	0612085	FGS
			Program13/Method Blank Begin/G (N)	0612085	FGS
			Program13/Method Blank End/GSL (N)	0612085	FGS
			Program13/Site 1/GSL Water (N)	0612085	FGS
			Program13/Site 3/GSL Water (N)	0612085	FGS
			Program13/Site 4/GSL Water (N)	0612085	FGS
			Program13/Site 4/GSL Water Dis (N)	0612085	FGS
			Program13/Site 4/GSL Water/Rep (N)	0612085	FGS
			Program13/Site 6/GSL Water (N)	0612085	FGS
			Program13/Site 6/GSL Water Dis (N)	0612085	FGS
			Program13/Site 6/GSL Water/Rep (N)	0612085	FGS
			Program13/Site 7/GSL Water (N)	0612085	FGS
			Program13/Site 9/GSL Water (N)	0612085	FGS
GSL-0612105	07-Dec-06				
		WATER			
			2267 0.2 M_120706 FA (N)	0612105	FGS
			2267 0.2 M_120706 RA (N)	0612105	FGS
			2267 3.5 M_120706 FA (N)	0612105	FGS
			2267 3.5 M_120706 RA (N)	0612105	FGS
			2565 0.2 M_120606 FA (N)	0612105	FGS
			2565 0.2 M_120606 RA (N)	0612105	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GSL-0612105	07-Dec-06				
		WATER			
			2565 6.5 M_120606 FA (N)	0612105	FGS
			2565 6.5 M_120606 RA (N)	0612105	FGS
			2565 7.5 M_120606 FA (N)	0612105	FGS
			2565 7.5 M_120606 RA (N)	0612105	FGS
			2767 0.2 M_120706 FA (N)	0612105	FGS
			2767 0.2 M_120706 RA (N)	0612105	FGS
			2767 2.5 M_120706 FA (N)	0612105	FGS
			2767 2.5 M_120706 RA (N)	0612105	FGS
			3510 0.2 M_120706 FA (N)	0612105	FGS
			3510 0.2 M_120706 RA (N)	0612105	FGS
			3510 6.5 M_120706 FA (N)	0612105	FGS
			3510 6.5 M_120706 RA (N)	0612105	FGS
			3510 8.0 M_120706 FA (N)	0612105	FGS
			3510 8.0 M_120706 RA (N)	0612105	FGS
			BR_122006 RA (N)	0612105	FGS
			BR_122006FA (N)	0612105	FGS
			FB_122006 FA (N)	0612105	FGS
			FB_122006 RA (N)	0612105	FGS
			GD_121906 FA (N)	0612105	FGS
			GD_121906 RA (N)	0612105	FGS
			GSL MINERALS RA_121606 1030 (N)	0612105	FGS
			GSL MINERALS RA_121606 1035 (N)	0612105	FGS
			KENNECOTT RA_120406 920 (N)	0612105	FGS
			KENNECOTT RA_120406 925 (N)	0612105	FGS
			LC_122106 FA (N)	0612105	FGS
			LC_122106 RA (N)	0612105	FGS
			WR_122006 FA 1245 (N)	0612105	FGS
			WR_122006 FA 1250 (N)	0612105	FGS
			WR_122006 RA 1245 (N)	0612105	FGS
			WR_122006 RA 1250 (N)	0612105	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GSL-0702032	02-Feb-07				
		WATER			
			BR_020207 RA (N)	0702032	FGS
			BREECH 10010020_010907 RA (N)	0702032	FGS
			E CULVER 10010040_010907 RA (N)	0702032	FGS
			FB_020207 FA (N)	0702032	FGS
			FB_020207 RA (N)	0702032	FGS
			GD_013107 1435 FA (N)	0702032	FGS
			GD_013107 1435 RA (N)	0702032	FGS
			GD_013107 1440 FA (N)	0702032	FGS
			GD_013107 1440 RA (N)	0702032	FGS
			KCUU_010307 FA (N)	0702032	FGS
			KCUU_010307 RA (N)	0702032	FGS
			LC BLNK_020107 FA (N)	0702032	FGS
			LC BLNK_020107 RA (N)	0702032	FGS
			LC_020107 FA (N)	0702032	FGS
			LC_020107 RA (N)	0702032	FGS
			W CULVER 10010030_010907 RA (N)	0702032	FGS
GSL-0703166	20-Mar-07				
		WATER			
			2267 0.2m_032007 FA (N)	0703166	FGS
			2267 0.2m_032007 RA (N)	0703166	FGS
			2267 4.0m_032007 FA (N)	0703166	FGS
			2267 4.0m_032007 RA (N)	0703166	FGS
			2565 0.2m_032007 FA (N)	0703166	FGS
			2565 0.2m_032007 RA (N)	0703166	FGS
			2565 6.5m_032007 FA (N)	0703166	FGS
			2565 6.5m_032007 RA (N)	0703166	FGS
			2565 7.5m_032007 FA (N)	0703166	FGS
			2565 7.5m_032007 FANO (N)	0703166	FGS
			2565 7.5m_032007 RA (N)	0703166	FGS
			2565 7.5m_032007 RANO (N)	0703166	FGS
			2767 0.2m_031907 FA (N)	0703166	FGS
			2767 0.2m_031907 RA (N)	0703166	FGS

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
GSL-0703166	20-Mar-07				
		WATER			
			2767 3.0m_031907 FA (N)	0703166	FGS
			2767 3.0m_031907 RA (N)	0703166	FGS
			3510 0.2m_031907 FA (N)	0703166	FGS
			3510 0.2m_031907 RA (N)	0703166	FGS
			3510 6.5m_031907 FA (N)	0703166	FGS
			3510 6.5m_031907 RA (N)	0703166	FGS
			3510 8.0m_031907 FA (N)	0703166	FGS
			3510 8.0m_031907 FANO (N)	0703166	FGS
			3510 8.0m_031907 Kem RA (N)	0703166	FGS
			3510 8.0m_031907 Kem RANO (N)	0703166	FGS
			3510 8.0m_031907 RA (N)	0703166	FGS
			3510 8.0m_031907 RANO (N)	0703166	FGS
			BR_030207 FA (N)	0703166	FGS
			BR_030207 RA (N)	0703166	FGS
			Breech10010020_031907 RA (N)	0703166	FGS
			East Culvert10010040_031907 RA (N)	0703166	FGS
			FB_030507 FA (N)	0703166	FGS
			FB_030507 RA (N)	0703166	FGS
			GD_030607 FA (N)	0703166	FGS
			GD_030607 RA (N)	0703166	FGS
			KCUU_030607 FA (N)	0703166	FGS
			KCUU_030607 RA (N)	0703166	FGS
			LC_030607 FA (N)	0703166	FGS
			LC_030607 RA (N)	0703166	FGS
			West Culvert10010030_031907 RA (N)	0703166	FGS
			WR_030207 FA (N)	0703166	FGS
			WR_030207 RA (N)	0703166	FGS

TABLE 3

Site Completeness by Analyte – Flagging Statistics

Matrix	Method	Analyte	Number of Samples				
Water							
	FGS-055						
		Selenium			885		
Validation Flag Category:		Blank	1	U	Flags	(0.11%)	for Laboratory blank contamination greater than the RL
Validation Flag Category:		Blank	12	U	Flags	(1.36%)	for Field blank concentration greater than the RL
Validation Flag Category:		Blank	3	U	Flags	(0.34%)	for Field blank concentration greater than the RL
Validation Flag Category:		Duplicate	2	J	Flags	(0.23%)	for Lab duplicate exceeds RPD criteria
Validation Flag Category:		HoldingTime	1	UJ	Flags	(0.11%)	for Holding time exceeded
Validation Flag Category:		HoldingTime	4	J	Flags	(0.45%)	for Holding time exceeded
Validation Flag Category:		LaboratoryControlSample	7	J	Flags	(0.79%)	for LCSD RPD criteria exceeded
Validation Flag Category:		LaboratoryControlSample	7	J	Flags	(0.79%)	for LCS recovery less than lower control limit
Validation Flag Category:		LaboratoryControlSample	6	J	Flags	(0.68%)	for LCSD RPD criteria exceeded
Validation Flag Category:		LaboratoryControlSample	6	J	Flags	(0.68%)	for LCS recovery less than lower control limit
Validation Flag Category:		Matrix	23	J	Flags	(2.60%)	for Matrix spike recovery less than lower limit
Validation Flag Category:		Matrix	1	J	Flags	(0.11%)	for Matrix spike recovery greater than upper limit
Validation Flag Category:		Matrix	17	J	Flags	(1.92%)	for Matrix spike duplicate recovery criteria less than lower limit
Validation Flag Category:		Matrix	5	J	Flags	(0.56%)	for Post digestion spike failed
Validation Flag Category:		Matrix	2	J	Flags	(0.23%)	for Matrix spike recovery less than lower limit
Validation Flag Category:		Matrix	2	J	Flags	(0.23%)	for Matrix spike duplicate recovery criteria less than lower limit
Validation Flag Category:		Matrix	1	J	Flags	(0.11%)	for Post digestion spike failed

Note: The total number of validation flags may exceed the actual number of samples if multiple flags were applied to the same samples. Consequently, the percentage of total flags (flags applied/number of samples) may exceed 100 percent.

Qualifier Description:

J = detected result, estimated concentration

U = non-detected result

UJ = non-detected result, estimated concentration

* The most severe flag for each analyte becomes the final validation flag.

TABLE 4

Holding Times – Qualified Data

Method	Matrix	Sample ID	Analyte	Holding Time	Result	Holding Time Qualifier	Final Flag*
FGS-055	WATER	Program 7/Site 1/ GSL Water					
			Selenium	273 Days	0.857 ug/L	J	J
FGS-055	WATER	Program 8/Site 3/GSL Water					
			Selenium	245 Days	0.884 ug/L	J	J
FGS-055	WATER	Program 8/Site 9/GSL Water					
			Selenium	246 Days	0.655 ug/L	J	J
FGS-055	WATER	Program 9/Site 7/GSL Water					
			Selenium	240 Days	0.759 ug/L	J	J
FGS-055	WATER	Program3/Method Blank Begin					
			Selenium	181 Days	0.05 ug/L	UJ	UJ

Qualifier Description:

J = detected result, estimated concentration

UJ = non-detected result, estimated concentration

* The most severe flag for each analyte becomes the final validation flag.

Criteria:

HT>UCL = Holding time exceeded

HTp>UCL = Holding time exceeded

TABLE 5

Blank Spike – Qualified Data

Method	Matrix	Sample ID / QC Type	Analyte	Result	Qualifier*	LCS Recovery	Criteria
FGS-055	WATER		**Selenium**				
		FB_090706 FA / N		0.319 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		FB_090706 FA / N		0.319 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		FB_090706 RA / N		0.503 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		FB_090706 RA / N		0.503 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		GD_090506 FA / N		1.13 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		GD_090506 FA / N		1.13 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		GD_090506 RA / N		1.16 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		GD_090506 RA / N		1.16 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		GD_090506A FA / N		1.07 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		GD_090506A FA / N		1.07 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		GD_090506A RA / N		1.17 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		GD_090506A RA / N		1.17 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		KCUU_091206 FA / N		26.8 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		KCUU_091206 FA / N		26.8 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		KCUU_091206 RA / N		26.8 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		KCUU_091206 RA / N		26.8 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		LC_090506 FA / N		0.552 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		LC_090506 FA / N		0.552 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		LC_090506 RA / N		1.51 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		LC_090506 RA / N		1.51 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		SALT CANAL_090706 RA / N		1.08 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		SALT CANAL_090706 RA / N		1.08 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		WR_090706 FA / N		0.168 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		WR_090706 FA / N		0.168 ug/L	J	RPD = 60.9 Limit =20	LCSRPD
		WR_090706 RA / N		0.205 ug/L	J	%R = 53 LCL=80 UCL=120	LCS<LCL
		WR_090706 RA / N		0.205 ug/L	J	RPD = 60.9 Limit =20	LCSRPD

TABLE 5

Blank Spike – Qualified Data

Method	Matrix	Sample ID / QC Type	Analyte	Result	Qualifier*	LCS Recovery	Criteria

Note: Sample ID/QC Type = Field Sample Identifier and QAQC Type

Qualifier Description:

J = detected result, estimated concentration

* The most severe flag for each analyte becomes the final validation flag.

Criteria:

LCS<LCL = LCS recovery less than lower control limit

LCSRPD = LCSD RPD criteria exceeded

TABLE 6

Matrix Spike Precision/Accuracy – Qualified Data

Method	Matrix	Sample ID	Analyte	Result	MS/MSD Qualifier*	Criteria
FGS-055	WATER		**Selenium**			
		2565 6.5m FA-Dissolved		0.423 ug/L	J	MS<LCL
		2565 6.5m FA-Dissolved		0.423 ug/L	J	PDS
		2565 6.5m FA-Dissolved		0.423 ug/L	J	SD<LCL
		2565 6.5m RA-Total		0.587 ug/L	J	MS<LCL
		2565 6.5m RA-Total		0.587 ug/L	J	SD<LCL
		2565 7.5 M_120606 RA		0.283 ug/L	J	MS<LCL
		2565 7.5 M_120606 RA		0.283 ug/L	J	SD<LCL
		2565 7.5m_032007 FA		0.43 ug/L	J	MS<LCL
		2565 7.5m_032007 RA		0.961 ug/L	J	MS<LCL
		2565 8.0m_042607 Total		0.865 ug/L	J	MS<LCL
		2565 8.0m_042607 Total		0.865 ug/L	J	SD<LCL
		2565 8.0m_110106 FA		0.4 ug/L	J	MS<LCL
		2565 8.0m_110106 FA		0.4 ug/L	J	SD<LCL
		2565 8.0m_110106 RA		0.468 ug/L	J	MS<LCL
		2565 8.0m_110106 RA		0.468 ug/L	J	SD<LCL
		2767 0.2m RA-Total		0.46 ug/L	J	MS<LCL
		2767 0.2m RA-Total		0.46 ug/L	J	SD<LCL
		2767 0.2m_110306 RA		0.657 ug/L	J	MS<LCL
		2767 0.2m_110306 RA		0.657 ug/L	J	SD<LCL
		2767 3.0M 230506 1130 FA		0.364 ug/L	J	MS<LCL
		2767 3.0M 230506 1130 FA		0.364 ug/L	J	SD<LCL
		3510 0.2m_110306 RA		0.665 ug/L	J	MS<LCL
		3510 0.2m_110306 RA		0.665 ug/L	J	PDS
		3510 0.2m_110306 RA		0.665 ug/L	J	SD<LCL
		3510 8.0 M_120706 FA		0.261 ug/L	J	MS<LCL
		3510 8.0 M_120706 FA		0.261 ug/L	J	SD<LCL
		3510 8.0 M_120706 RA		0.49 ug/L	J	MS<LCL
		3510 8.0 M_120706 RA		0.49 ug/L	J	SD<LCL
		3510 8.0m_031907 FA		0.681 ug/L	J	MS<LCL
		3510 8.0m_031907 Kem RA		0.929 ug/L	J	MS<LCL
		3510 8.0m_031907 RA		0.812 ug/L	J	MS<LCL
		3510 8.5m_050107 Total		0.718 ug/L	J	MS<LCL
		3510 8.5m_050107 Total		0.718 ug/L	J	SD<LCL

TABLE 6

Matrix Spike Precision/Accuracy – Qualified Data

Method	Matrix	Sample ID	Analyte	Result	MS/MSD Qualifier*	Criteria
		Program 7/Site 1/ GSL Water		0.734 ug/L	J	MS<LCL
		Program 7/Site 1/ GSL Water		0.734 ug/L	J	PDS
		Program 7/Site 1/ GSL Water		0.734 ug/L	J	SD<LCL
		Program 8/Site 3/GSL Water		0.398 ug/L	J	MS<LCL
		Program 8/Site 3/GSL Water		0.398 ug/L	J	SD<LCL
		Program 8/Site 9/GSL Water		0.582 ug/L	J	MS<LCL
		Program 8/Site 9/GSL Water		0.582 ug/L	J	SD<LCL
		Program 9/Site 7/GSL Water		0.899 ug/L	J	MS<LCL
		Program 9/Site 7/GSL Water		0.759 ug/L	J	MS>UCL
		Program 9/Site 7/GSL Water		0.899 ug/L	J	SD<LCL
		Program12/Site 4/GSL Water		0.827 ug/L	J	MS<LCL
		Program12/Site 4/GSL Water		0.827 ug/L	J	SD<LCL
		Program5/Site2/GSL Water		0.559 ug/L	J	MS<LCL
		Program5/Site2/GSL Water		0.559 ug/L	J	PDS
		Program5/Site2/GSL Water		0.559 ug/L	J	SD<LCL
		WR 080806 0945 T		0.148 ug/L	J	PDS
		WR 080806 0950 T		0.153 ug/L	J	PDS

Qualifier Description:

J = detected result, estimated concentration

* The most severe flag for each analyte becomes the final validation flag.

Criteria:

MS<LCL = Matrix spike recovery less than lower limit

MS>UCL = Matrix spike recovery greater than upper limit

PDS = Post digestion spike failed

SD<LCL = Matrix spike duplicate recovery criteria less than lower limit

TABLE 7

Blank Contamination – Qualified Data

Method	Matrix	Analyte	Sample ID	Result	Blank Contamination Qualifier*	Criteria	Comments
FGS-055	WATER	**Selenium**					
			GSL1-2_040507 Total	0.292 ug/L	U	LB>RL	
			Program 8/Method Blank Begin/W	0.142 ug/L	U	FB>RL	
			Program 9/Method Blank Begin/W	0.057 ug/L	U	FB>RL	
			Program 9/Method Blank End/Wat	0.058 ug/L	U	FB>RL	
			Program5/Site1/GSL Water	0.456 ug/L	U	FB>RL	
			Program5/Site2/GSL Water	0.559 ug/L	U	FB>RL	
			Program5/Site3/GSL Water	0.411 ug/L	U	FB>RL	
			Program5/Site4/GSL Water	0.478 ug/L	U	FB>RL	
			Program5/Site4/GSL Water-Disso	0.372 ug/L	U	FB>RL	
			Program5/Site5/GSL Water	0.431 ug/L	U	FB>RL	
			Program5/Site5/GSL Water-Disso	0.444 ug/L	U	FB>RL	
			Program5/Site6/GSL Water	0.592 ug/L	U	FB>RL	
			Program5/Site6/GSL Water-Disso	0.468 ug/L	U	FB>RL	
			Program5/Site7/GSL Water	0.578 ug/L	U	FB>RL	
			Program5/Site8/GSL Water	0.44 ug/L	U	FB>RL	
			Program5/Site9/GSL Water	0.41 ug/L	U	FB>RL	

Qualifier Description:

U = non-detected result

* The most severe flag for each analyte becomes the final validation flag.

Criteria:

FB>RL = Field blank concentration greater than the RL

LB>RL = Laboratory blank contamination greater than the RL

TABLE 8

Site Completeness by Analyte – Qualified Data

			Number of Occurrences									
Method	**Analyte**	**Units**	**Analyses**	**Detects**	**Non-detects**	**Blank Flags**	**J Flags**	**M Flags**	**Contractor R Flags**	**Total R Flags**	**Contractor Percent Completeness**	**Overall Percent Completeness**
FGS-055	Selenium	ug/L	885	823	62		45				100	100
FGS-055	Selenium (IV)	ug/L	16	15	1						100	100
FGS-055	Selenium, dissolved	ug/L	63	59	4						100	100

Attachment 2
Laboratory and Environmental Testing, Inc.
Summary Tables

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06060006	Blood A-1	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-10	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-11	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-12	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-12	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-2	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-2	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-3	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-4	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-5	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-6	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-7	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-8	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood A-9	LET-HFAA	5/4/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-01	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-02	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-03	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-04	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-05	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-06	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-07	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-07	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-08	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-09	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-10	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood CG-11	LET-HFAA	5/2/2006	6/7/2006	7/27/2006	8/12/2006
		Blood H-1	LET-HFAA	5/9/2006	6/7/2006	6/27/2006	8/18/2006
		Blood H-10	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006
		Blood H-11	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006
		Blood H-12	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006
		Blood H-2	LET-HFAA	5/9/2006	6/7/2006	6/27/2006	8/18/2006
		Blood H-3	LET-HFAA	5/9/2006	6/7/2006	6/27/2006	8/12/2006
		Blood H-4	LET-HFAA	5/9/2006	6/7/2006	6/27/2006	8/12/2006
		Blood H-5	LET-HFAA	5/9/2006	6/7/2006	6/27/2006	8/12/2006
		Blood H-6	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06060006	Blood H-7	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006
		Blood H-7	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006
		Blood H-8	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006
		Blood H-9	LET-HFAA	5/9/2006	6/7/2006	7/27/2006	8/12/2006
		Egg A-1	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-10	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-11	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-11	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-12	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-2	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-3	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-3	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-4	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-5	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-6	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-7	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-8	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg A-9	LET-HFAA	5/23/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-1	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-10	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-11	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-12	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-2	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-3	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-4	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-5	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-6	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-7	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-7	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-8	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg H-9	LET-HFAA	5/25/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-1	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-10	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-11	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-12	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06060006	Egg M-2	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-3	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-4	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-5	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-6	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-7	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-8	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-8	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Egg M-9	LET-HFAA	5/15/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-1	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-10	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-11	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-12	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-2	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-3	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-4	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-5	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-5	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-6	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-7	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-8	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver A-9	LET-HFAA	5/4/2006	6/7/2006	7/24/2006	8/12/2006
		Liver CG-01	LET-HFAA	5/2/2006	6/7/2006	7/24/2006	8/12/2006
		Liver CG-01	LET-HFAA	5/2/2006	6/7/2006	7/24/2006	8/12/2006
		Liver CG-02	LET-HFAA	5/2/2006	6/7/2006	7/24/2006	8/12/2006
		Liver CG-03	LET-HFAA	5/2/2006	6/7/2006	7/24/2006	8/12/2006
		Liver CG-04	LET-HFAA	5/2/2006	6/7/2006	7/24/2006	8/12/2006
		Liver CG-05	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006
		Liver CG-06	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006
		Liver CG-07	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006
		Liver CG-08	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006
		Liver CG-08	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006
		Liver CG-09	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006
		Liver CG-10	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006
		Liver CG-11	LET-HFAA	5/2/2006	6/7/2006	6/27/2006	8/12/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06060006	Liver H-1	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-10	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-11	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-12	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-2	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-3	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-4	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-5	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-6	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-7	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-7	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-8	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Liver H-9	LET-HFAA	5/9/2006	6/7/2006	7/24/2006	8/12/2006
		Sediment A-1	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Sediment A-1	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Sediment H-1	LET-HFAA	5/9/2006	6/7/2006	7/26/2006	8/12/2006
		Sediment M-1	LET-HFAA	5/5/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp A-1	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp A-1	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp A-2	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp A-3	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp A-4	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp A-5	LET-HFAA	5/4/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp H-1	LET-HFAA	5/12/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp H-2	LET-HFAA	5/12/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp H-3	LET-HFAA	5/12/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp H-4	LET-HFAA	5/12/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp H-5	LET-HFAA	5/12/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp M-1	LET-HFAA	5/5/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp M-2	LET-HFAA	5/5/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp M-3	LET-HFAA	5/5/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp M-3	LET-HFAA	5/5/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp M-4	LET-HFAA	5/5/2006	6/7/2006	7/26/2006	8/12/2006
		Shrimp M-5	LET-HFAA	5/5/2006	6/7/2006	7/26/2006	8/12/2006
	L06060006-16	GS1 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06060006-16	GS-10 SURFACE	TOC	6/2/2006	6/9/2006		9/28/2006
		GS-11	TOC	2/2/2006	6/9/2006		9/28/2006
		GS11 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006
		GS11-ooze	TOC	6/27/2006	7/7/2006		9/28/2006
		GS12 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006
		GS12-ooze	TOC	6/27/2006	7/7/2006		9/28/2006
		GS-13 Comp.	TOC	6/2/2006	6/9/2006		9/28/2006
		GS14 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006
		GS14-ooze	TOC	6/27/2006	7/7/2006		9/28/2006
		GS15 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006
		GS-18	TOC	6/2/2006	6/9/2006		9/28/2006
		GS18 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006
		GS18-ooze	TOC	6/27/2006	7/7/2006		9/28/2006
		GS-19	TOC	6/2/2006	6/9/2006		9/28/2006
		GS1-ooze	TOC	6/26/2006	7/7/2006		9/28/2006
		GS-20	TOC	6/2/2006	6/9/2006		9/28/2006
		GS20 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006
		GS20-ooze	TOC	6/27/2006	7/7/2006		9/28/2006
		GS3 - mineral layer	TOC	6/26/2006	7/7/2006		9/28/2006
		GS-4	TOC	5/31/2006	6/9/2006		9/28/2006
		GS4 - mineral layer	TOC	6/27/2006	7/7/2006		9/28/2006
		GS4-ooze	TOC	6/27/2006	7/7/2006		9/28/2006
		GS5 - mineral layer	TOC	6/26/2006	7/7/2006		9/28/2006
		GS5-ooze	TOC	6/26/2006	7/7/2006		9/28/2006
		GS8 - mineral layer	TOC	6/26/2006	7/7/2006		9/28/2006
		GS8-ooze	TOC	6/26/2006	7/7/2006		9/28/2006
		GS-9	TOC	5/31/2006	6/9/2006		9/28/2006
		GS9 - mineral layer	TOC	6/26/2006	7/7/2006		9/28/2006
		GS9-ooze	TOC	6/26/2006	7/7/2006		9/28/2006
		Sediment A-1	TOC	5/4/2006	6/7/2006		9/28/2006
		Sediment H-1	TOC	5/9/2006	6/7/2006		9/28/2006
		Sediment M-1	TOC	5/5/2006	6/7/2006		9/28/2006
	L06060161	GS-10 SURFACE	LET-HFAA	6/2/2006	6/9/2006	6/27/2006	8/12/2006
		GS-11	LET-HFAA	6/2/2006	6/9/2006	6/27/2006	8/12/2006
		GS-13 Comp.	LET-HFAA	6/2/2006	6/9/2006	6/27/2006	8/12/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06060161	GS-18	LET-HFAA	6/2/2006	6/9/2006	6/27/2006	8/12/2006
		GS-19	LET-HFAA	6/2/2006	6/9/2006	6/27/2006	8/12/2006
		GS-19	LET-HFAA	6/2/2006	6/9/2006	6/27/2006	8/12/2006
		GS-20	LET-HFAA	6/2/2006	6/9/2006	6/27/2006	8/12/2006
		GS-4	LET-HFAA	5/31/2006	6/9/2006	6/27/2006	8/12/2006
		GS-9	LET-HFAA	5/31/2006	6/9/2006	6/27/2006	8/12/2006
	L06070233	GS1 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS11 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS11 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS11-ooze	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS11-ooze	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS12 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS12-ooze	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS14 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS14-ooze	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS15 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS18 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS18-ooze	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS1-ooze	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
		GS20 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS20-ooze	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS3 - mineral layer	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
		GS4 - mineral layer	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS4-ooze	LET-HFAA	6/27/2006	7/7/2006	8/7/2006	8/12/2006
		GS5 - mineral layer	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
		GS5-ooze	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
		GS8 - mineral layer	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
		GS8-ooze	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
		GS9 - mineral layer	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
		GS9-ooze	LET-HFAA	6/26/2006	7/7/2006	8/7/2006	8/12/2006
	L06080012	1	LET-HFAA	6/16/2006	8/2/2006	9/20/2006	9/27/2006
		10	LET-HFAA	6/15/2006	8/2/2006	9/20/2006	9/27/2006
		11	LET-HFAA	6/15/2006	8/2/2006	9/20/2006	9/27/2006
		12	LET-HFAA	6/14/2006	8/2/2006	9/21/2006	9/27/2006
		13	LET-HFAA	6/14/2006	8/2/2006	9/21/2006	9/27/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06080012	14	LET-HFAA	6/15/2006	8/2/2006	9/21/2006	9/27/2006
		15	LET-HFAA	6/15/2006	8/2/2006	9/21/2006	9/27/2006
		16	LET-HFAA	6/14/2006	8/2/2006	9/21/2006	9/27/2006
		17	LET-HFAA	6/14/2006	8/2/2006	9/21/2006	9/27/2006
		18	LET-HFAA	6/14/2006	8/2/2006	9/21/2006	9/27/2006
		18	LET-HFAA	6/14/2006	8/2/2006	9/21/2006	9/27/2006
		19	LET-HFAA	6/14/2006	8/2/2006	9/21/2006	9/27/2006
		2	LET-HFAA	6/16/2006	8/2/2006	9/20/2006	9/27/2006
		20	LET-HFAA	6/16/2006	8/2/2006	9/21/2006	9/27/2006
		21	LET-HFAA	6/16/2006	8/2/2006	9/21/2006	9/27/2006
		22	LET-HFAA	6/16/2006	8/2/2006	9/21/2006	9/27/2006
		23	LET-HFAA	6/16/2006	8/2/2006	9/21/2006	9/27/2006
		24	LET-HFAA	6/15/2006	8/2/2006	9/21/2006	9/27/2006
		3	LET-HFAA	6/28/2006	8/2/2006	9/20/2006	9/27/2006
		4	LET-HFAA	6/14/2006	8/2/2006	9/20/2006	9/27/2006
		5	LET-HFAA	6/14/2006	8/2/2006	9/20/2006	9/27/2006
		6	LET-HFAA	6/15/2006	8/2/2006	9/20/2006	9/27/2006
		6106-1-AML a	LET-HFAA	6/1/2006	8/2/2006	9/20/2006	9/27/2006
		6106-1-AML b	LET-HFAA	6/1/2006	8/2/2006	9/25/2006	10/6/2006
		6106-2-AML a	LET-HFAA	6/1/2006	8/2/2006	9/20/2006	9/27/2006
		6106-2-AML b	LET-HFAA	6/1/2006	8/2/2006	9/25/2006	10/6/2006
		6106-3-AML a	LET-HFAA	6/1/2006	8/2/2006	9/20/2006	9/27/2006
		6106-3-AML b	LET-HFAA	6/1/2006	8/2/2006	9/25/2006	10/6/2006
		6106-4-AML a	LET-HFAA	6/1/2006	8/2/2006	9/20/2006	9/27/2006
		6106-5-AML a	LET-HFAA	6/1/2006	8/2/2006	9/20/2006	9/27/2006
		6106-5-AML b	LET-HFAA	6/1/2006	8/2/2006	9/25/2006	10/6/2006
		6106-5-AML b	LET-HFAA	6/1/2006	8/2/2006	9/25/2006	10/6/2006
		61306-1-AML a	LET-HFAA	6/13/2006	8/2/2006	9/20/2006	9/27/2006
		61306-1-AML b	LET-HFAA	6/13/2006	8/2/2006	9/25/2006	9/27/2006
		61306-2-AML a	LET-HFAA	6/13/2006	8/2/2006	9/20/2006	9/27/2006
		61306-2-AML b	LET-HFAA	6/13/2006	8/2/2006	9/25/2006	9/27/2006
		61306-3-AML a	LET-HFAA	6/13/2006	8/2/2006	9/20/2006	9/27/2006
		61306-3-AML b	LET-HFAA	6/13/2006	8/2/2006	9/25/2006	9/27/2006
		6606-10-AML a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-10-AML a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06080012	6606-10-AML b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	9/27/2006
		6606-1-JFC a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-1-JFC b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	10/6/2006
		6606-2-JFC a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-2-JFC b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	10/6/2006
		6606-3-JFC a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-3-JFC b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	10/6/2006
		6606-4-JFC a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-4-JFC b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	10/6/2006
		6606-5-JFC a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-5-JFC a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-5-JFC b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	10/6/2006
		6606-6-AML a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-6-AML b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	9/27/2006
		6606-7-AML a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-7-AML b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	9/27/2006
		6606-7-AML b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	9/27/2006
		6606-8-AML a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-8-AML b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	9/27/2006
		6606-9-AML a	LET-HFAA	6/6/2006	8/2/2006	9/20/2006	9/27/2006
		6606-9-AML b	LET-HFAA	6/6/2006	8/2/2006	9/25/2006	9/27/2006
		6706-1-JFC a	LET-HFAA	6/7/2006	8/2/2006	9/20/2006	9/27/2006
		6706-1-JFC b	LET-HFAA	6/7/2006	8/2/2006	9/25/2006	9/27/2006
		6706-2-JFC a	LET-HFAA	6/7/2006	8/2/2006	9/20/2006	9/27/2006
		6706-2-JFC b	LET-HFAA	6/7/2006	8/2/2006	9/25/2006	9/27/2006
		7	LET-HFAA	6/15/2006	8/2/2006	9/20/2006	9/27/2006
		8	LET-HFAA	6/14/2006	8/2/2006	9/20/2006	9/27/2006
		8	LET-HFAA	6/14/2006	8/2/2006	9/20/2006	9/27/2006
		9	LET-HFAA	6/14/2006	8/2/2006	9/20/2006	9/27/2006
		AML-1-06	LET-HFAA	6/8/2006	8/2/2006	9/18/2006	10/6/2006
		AML-131-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		AML-2-06	LET-HFAA	6/8/2006	8/2/2006	9/18/2006	10/6/2006
		AML-2-06	LET-HFAA	6/8/2006	8/2/2006	9/18/2006	10/6/2006
		AML-3-06	LET-HFAA	6/12/2006	8/2/2006	9/18/2006	10/6/2006
		ANTI-1-I a	LET-HFAA	6/16/2006	8/2/2006	9/18/2006	10/6/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06080012	ANTI-1-I b	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	10/6/2006
		ANTI-1-I c	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	9/27/2006
		ANTI-1-S	LET-HFAA	6/16/2006	8/2/2006	9/21/2006	10/6/2006
		ANTI-1-S	LET-HFAA	6/16/2006	8/2/2006	9/21/2006	10/6/2006
		ANTI-1-S	TOC	6/16/2006	8/2/2006		10/26/2006
		ANTI-2-I a	LET-HFAA	6/16/2006	8/2/2006	9/20/2006	10/6/2006
		ANTI-2-I b	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	10/6/2006
		ANTI-2-I c	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	9/27/2006
		ANTI-2-I d	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	9/27/2006
		ANTI-2-S	LET-HFAA	7/3/2006	8/2/2006	9/21/2006	10/6/2006
		ANTI-2-S	TOC	7/3/2006	8/2/2006		10/26/2006
		ANTI-3-I a	LET-HFAA	6/16/2006	8/2/2006	9/20/2006	9/26/2006
		ANTI-3-I b	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	10/6/2006
		ANTI-3-I c	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	9/27/2006
		ANTI-3-I d	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	9/27/2006
		ANTI-3-I d	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	9/27/2006
		ANTI-3-I e	LET-HFAA	6/16/2006	8/2/2006	9/25/2006	9/27/2006
		ANTI-3-S	LET-HFAA	7/3/2006	8/2/2006	9/21/2006	9/27/2006
		ANTI-3-S	TOC	7/3/2006	8/2/2006		10/26/2006
		BJO-08-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		BJO-08-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		BJO-100-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		BJO-5-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		BJO-67-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		BJO-68-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		BJO-7-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		CNE-500-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		CNE-502-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-01-06	LET-HFAA	5/24/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-01-06	LET-HFAA	5/24/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-15-06	LET-HFAA	5/31/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-20-06	LET-HFAA	6/1/2006	8/2/2006	9/18/2006	10/6/2006
		JAC-21-06	LET-HFAA	6/1/2006	8/2/2006	9/18/2006	10/6/2006
		JAC-22-06	LET-HFAA	6/1/2006	8/2/2006	9/18/2006	10/6/2006
		JAC-30-06	LET-HFAA	6/5/2006	8/2/2006	9/18/2006	10/6/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06080012	JAC-3-06	LET-HFAA	5/29/2006	8/2/2006	9/18/2006	10/6/2006
		JAC-31-06	LET-HFAA	6/5/2006	8/2/2006	9/18/2006	10/6/2006
		JAC-32-06	LET-HFAA	6/5/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-33-06	LET-HFAA	6/5/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-34-06	LET-HFAA	6/5/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-4-06	LET-HFAA	5/29/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-5-06	LET-HFAA	5/29/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-51-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-60-06	LET-HFAA	6/15/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-6-06	LET-HFAA	5/29/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-61-06	LET-HFAA	6/15/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-61-06	LET-HFAA	6/15/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-62-06	LET-HFAA	6/15/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-7-06	LET-HFAA	5/29/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-8-06	LET-HFAA	5/29/2006	8/2/2006	9/18/2006	9/26/2006
		JAC-9-06	LET-HFAA	5/29/2006	8/2/2006	9/18/2006	9/26/2006
		JFC-06-06	LET-HFAA	5/26/2006	8/2/2006	9/18/2006	9/26/2006
		JFC-12-06	LET-HFAA	5/26/2006	8/2/2006	9/18/2006	9/26/2006
		JFC-37-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		JFC-9-06	LET-HFAA	5/26/2006	8/2/2006	9/18/2006	9/26/2006
		KEE-169-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		KEE-169-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		KEE-171-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		KEE-175-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		KEE-2-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		KEE-5-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		KEE-5-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		KT-1-06	LET-HFAA	5/17/2006	8/2/2006	9/18/2006	9/26/2006
		LJA-152-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		LJA-160-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	10/6/2006
		LJA-211-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/27/2006
		LJA-212-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		LJA-213-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		MEF-74-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		NS-06-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06080012	NS-100-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		NS-10-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	9/26/2006
		NS-8-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		NS-9-06	LET-HFAA	6/23/2006	8/2/2006	9/18/2006	10/6/2006
		OGBA-1-I a	LET-HFAA	6/23/2006	8/2/2006	9/20/2006	9/26/2006
		OGBA-1-I b	LET-HFAA	6/23/2006	8/2/2006	9/25/2006	10/6/2006
		OGBA-1-S	LET-HFAA	7/25/2006	8/2/2006	9/21/2006	9/27/2006
		OGBA-1-S	TOC	7/25/2006	8/2/2006		10/26/2006
		OGBA-2-I a	LET-HFAA	6/23/2006	8/2/2006	9/20/2006	9/26/2006
		OGBA-2-I b	LET-HFAA	6/23/2006	8/2/2006	9/25/2006	10/6/2006
		OGBA-2-I c	LET-HFAA	6/23/2006	8/2/2006	9/25/2006	9/27/2006
		OGBA-2-S	LET-HFAA	7/25/2006	8/2/2006	9/21/2006	9/27/2006
		OGBA-2-S	TOC	7/25/2006	8/2/2006		10/26/2006
		OGBA-3-I a	LET-HFAA	6/23/2006	8/2/2006	9/20/2006	9/26/2006
		OGBA-3-I a	LET-HFAA	6/23/2006	8/2/2006	9/20/2006	9/26/2006
		OGBA-3-I b	LET-HFAA	6/23/2006	8/2/2006	9/25/2006	10/6/2006
		OGBA-3-I c	LET-HFAA	6/23/2006	8/2/2006	9/25/2006	9/27/2006
		OGBA-3-I d	LET-HFAA	6/23/2006	8/2/2006	9/25/2006	9/27/2006
		OGBA-3-S	LET-HFAA	7/25/2006	8/2/2006	9/25/2006	9/27/2006
		OGBA-3-S	TOC	7/25/2006	8/2/2006		10/26/2006
		SALT-1-I a	LET-HFAA	6/21/2006	8/2/2006	9/20/2006	9/26/2006
		SALT-1-I b	LET-HFAA	6/21/2006	8/2/2006	9/25/2006	10/6/2006
		SALT-1-I b	LET-HFAA	6/21/2006	8/2/2006	9/25/2006	10/6/2006
		SALT-1-S	LET-HFAA	6/28/2006	8/2/2006	9/25/2006	9/27/2006
		SALT-1-S	TOC	6/28/2006	8/2/2006		10/26/2006
		SALT-2-I a	LET-HFAA	6/21/2006	8/2/2006	9/20/2006	9/26/2006
		SALT-2-I b	LET-HFAA	6/21/2006	8/2/2006	9/25/2006	10/6/2006
		SALT-2-S	LET-HFAA	6/28/2006	8/2/2006	9/25/2006	9/27/2006
		SALT-2-S	LET-HFAA	6/28/2006	8/2/2006	9/25/2006	9/27/2006
		SALT-2-S	TOC	6/28/2006	8/2/2006		10/26/2006
		SALT-3-I a	LET-HFAA	6/21/2006	8/2/2006	9/20/2006	9/26/2006
		SALT-3-I b	LET-HFAA	6/21/2006	8/2/2006	9/25/2006	10/6/2006
		SALT-3-S	LET-HFAA	6/28/2006	8/2/2006	9/25/2006	9/27/2006
		SALT-3-S	TOC	6/28/2006	8/2/2006		10/26/2006
		SAP-1-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06080012	SAP-2-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		SAP-4-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
		SAP-5-06	LET-HFAA	6/14/2006	8/2/2006	9/18/2006	9/26/2006
	L06080360	CNE-501-06	LET-HFAA	6/14/2006	8/16/2006	9/22/2006	9/27/2006
		JAC-50-06	LET-HFAA	6/14/2006	8/16/2006	9/22/2006	9/27/2006
		JFC-32-06	LET-HFAA	6/14/2006	8/16/2006	9/22/2006	9/27/2006
		JFC-33-06	LET-HFAA	6/14/2006	8/16/2006	9/25/2006	9/27/2006
		JFC-34-06	LET-HFAA	6/14/2006	8/16/2006	9/22/2006	9/27/2006
		JFC-35-06	LET-HFAA	6/14/2006	8/16/2006	9/25/2006	9/27/2006
		JFC-36-06	LET-HFAA	6/14/2006	8/16/2006	9/25/2006	9/27/2006
		LJA-151-06	LET-HFAA	6/14/2006	8/16/2006	9/25/2006	9/27/2006
		SAP-18-06	LET-HFAA	6/5/2006	8/16/2006	9/25/2006	9/27/2006
		SAP-18-06	LET-HFAA	6/5/2006	8/16/2006	9/25/2006	9/27/2006
		SAP-19-06	LET-HFAA	6/5/2006	8/16/2006	9/25/2006	9/27/2006
		SAP-19-06	LET-HFAA	6/5/2006	8/16/2006	9/22/2006	9/27/2006
		SAP-22-06	LET-HFAA	6/14/2006	8/16/2006	9/25/2006	9/27/2006
		SAP-25-06	LET-HFAA	6/14/2006	8/16/2006	9/25/2006	9/27/2006
	L06100259	CH2M Visit/Site 9/Seston	LET-HFAA	7/20/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 10/Site 1/Seston/Clog	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 10/Site 3/Seston Clog	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 10/Site 4/Seston Clog	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 10/Site 4/Seston Clog	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 10/Site 6/Seston Clog	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 10/Site 7/Seston Clog	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 10/Site 9/Seston Clog	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 11/Site 1/Seston Clog	LET-HFAA	10/14/2006	10/24/2006	11/6/2006	11/12/2006
		Pro 11/Site 3/Seston Clog	LET-HFAA	10/14/2006	10/24/2006	11/6/2006	11/12/2006
		Pro 11/Site 4/Seston Clog	LET-HFAA	10/14/2006	10/24/2006	11/6/2006	11/12/2006
		Pro 11/Site 6/Seston Clog	LET-HFAA	10/14/2006	10/24/2006	11/6/2006	11/12/2006
		Pro 11/Site 6/Seston Clog	LET-HFAA	10/14/2006	10/24/2006	11/6/2006	11/12/2006
		Pro 11/Site 7/Seston Clog	LET-HFAA	10/14/2006	10/24/2006	11/6/2006	11/12/2006
		Pro 11/Site 9/Seston Clog	LET-HFAA	10/14/2006	10/24/2006	11/6/2006	11/12/2006
		Pro 8/BLANK/Seston	LET-HFAA	7/13/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 8/Site 1/Seston Clog	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 8/Site 3/Seston Clog	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06100259	Pro 8/Site 4/Seston Clog	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 8/Site 7/Seston Clog	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 8B/Site 6/Seston	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 9/Site 1/Seston Clog	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 9/Site 1/Seston Clog	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 9/Site 3/Seston Clog	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 9/Site 4/Seston Clog	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 9/Site 6/Seston Clog	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 9/Site 7/Seston Clog	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
		Pro 9/Site 9/Seston Clog	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
		Program 10/BLANK/Seston	LET-HFAA	9/24/2006	10/24/2006	11/3/2006	11/12/2006
		Program 3/BLANK/Seston	LET-HFAA	5/25/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 1/Seston	LET-HFAA	5/24/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 2/Seston	LET-HFAA	5/24/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 3/Seston	LET-HFAA	5/25/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 4/Seston	LET-HFAA	5/25/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 5/Seston	LET-HFAA	5/25/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 5/Seston	LET-HFAA	5/25/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 6/Seston	LET-HFAA	5/25/2006	10/24/2006	11/6/2006	11/12/2006
		Program 3/Site 7/Seston	LET-HFAA	5/25/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 8/Seston	LET-HFAA	5/25/2006	10/24/2006	11/2/2006	11/12/2006
		Program 3/Site 9/Seston	LET-HFAA	5/25/2006	10/24/2006	11/6/2006	11/12/2006
		Program 5/BLANK/Seston	LET-HFAA	6/23/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 2/Seston	LET-HFAA	6/27/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 3/Seston	LET-HFAA	6/27/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 4/Seston	LET-HFAA	6/26/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 5/Seston	LET-HFAA	6/26/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 6/Seston	LET-HFAA	6/26/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 6/Seston	LET-HFAA	6/26/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 7/Seston	LET-HFAA	6/23/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 8/Seston	LET-HFAA	6/23/2006	10/24/2006	11/2/2006	11/12/2006
		Program 5/Site 9/Seston	LET-HFAA	6/23/2006	10/24/2006	11/2/2006	11/12/2006
		Program 6/BLANK/Seston	LET-HFAA	7/13/2006	10/24/2006	11/2/2006	11/12/2006
		Program 6/Site 1/Seston	LET-HFAA	7/13/2006	10/24/2006	11/2/2006	11/12/2006
		Program 6/Site 3/Seston	LET-HFAA	7/13/2006	10/24/2006	11/2/2006	11/12/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06100259	Program 6/Site 4/Seston	LET-HFAA	7/13/2006	10/24/2006	11/2/2006	11/12/2006
		Program 6/Site 6/Seston	LET-HFAA	7/13/2006	10/24/2006	11/2/2006	11/12/2006
		Program 6/Site 7/Seston	LET-HFAA	7/13/2006	10/24/2006	11/2/2006	11/12/2006
		Program 6/Site 9/Seston	LET-HFAA	7/13/2006	10/24/2006	11/2/2006	11/12/2006
		Program 7 Site 9/Seston	LET-HFAA	7/26/2006	10/24/2006	11/3/2006	11/12/2006
		Program 7/BLANK/Seston	LET-HFAA	7/13/2006	10/24/2006	11/3/2006	11/12/2006
		Program 7/Site 1/Seston	LET-HFAA	7/26/2006	10/24/2006	11/3/2006	11/12/2006
		Program 7/Site 3/Seston	LET-HFAA	7/26/2006	10/24/2006	11/3/2006	11/12/2006
		Program 7/Site 3/Seston	LET-HFAA	7/26/2006	10/24/2006	11/3/2006	11/12/2006
		Program 7/Site 4/Seston	LET-HFAA	7/27/2006	10/24/2006	11/3/2006	11/12/2006
		Program 7/Site 6/Seston	LET-HFAA	7/27/2006	10/24/2006	11/3/2006	11/12/2006
		Program 7/Site 7/Seston	LET-HFAA	7/26/2006	10/24/2006	11/3/2006	11/12/2006
		Program 8/Site 1/Seston	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Program 8/Site 3/Seston	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Program 8/Site 4/Seston	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Program 8/Site 4/Seston	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Program 8/Site 7/Seston	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Program 8/Site 9/Seston	LET-HFAA	8/23/2006	10/24/2006	11/3/2006	11/12/2006
		Program 9/BLANK/Seston	LET-HFAA	8/28/2006	10/24/2006	11/3/2006	11/12/2006
	L06100351	1-092806	LET-HFAA	9/28/2006	10/26/2006	12/7/2006	12/9/2006
		2-092806	LET-HFAA	9/28/2006	10/26/2006	12/7/2006	12/9/2006
		3 and 4-092806	LET-HFAA	9/28/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 1/Site 1/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 1/Site 2/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 1/Site 3/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 1/Site 4/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 1/Site 6/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 1/Site 7/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 1/Site 9/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 1/Site 9/Adult (850)	LET-HFAA	4/30/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 10B/Site 1/Adult (850	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 1/Juv (500)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 10B/Site 1/N-C (125)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 3/Adult (850	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 3/Juv (500)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06100351	Pro 10B/Site 3/N-C (125)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 4/Adult (850	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 4/Juv (500)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 4/N-C (125)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 4/N-C (125)	LET-HFAA	9/24/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 10B/Site 6/Adult (850	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 6/Juv (500)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 10B/Site 6/N-C (125)	LET-HFAA	9/24/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 10B/Site 7/N-C (125)	LET-HFAA	9/24/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 10B/Site 9/Adult (850	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 9/Adult (850	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 9/Juv (500)	LET-HFAA	9/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 10B/Site 9/N-C (125)	LET-HFAA	9/24/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 1/Adult (850)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 1/Juv (500)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 1/N-C (125)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 3/Adult (850)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 3/Juv (500)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 3/N-C (125)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 4/Adult (850)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 4/Juv (500)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 4/N-C (125)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 4/N-C (125)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 6/Adult (850)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 6/Juv (500)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 6/N-C (125)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 7/Adult (850)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 7/Juv (500)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 7/N-C (125)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 9/Adult (850)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 9/Adult (850)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 11/Site 9/N-C (125)	LET-HFAA	10/14/2006	10/26/2006	12/7/2006	12/9/2006
		Pro 2/Site 1/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2/Site 2/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2/Site 3/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06100351	Pro 2/Site 4/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2/Site 5/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2/Site 6/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2/Site 7/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2/Site 8/Adult (850)	LET-HFAA	5/4/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2B/Site 1/Adult (850)	LET-HFAA	5/12/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2B/Site 2/Adult (850)	LET-HFAA	5/12/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2B/Site 2/Adult (850)	LET-HFAA	5/12/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2B/Site 3/Adult (850)	LET-HFAA	5/12/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2B/Site 4/Adult (850)	LET-HFAA	5/12/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2B/Site 5/Adult (850)	LET-HFAA	5/12/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 2B/Site 6/Adult (850)	LET-HFAA	5/12/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 1/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 2/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 3/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 4/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 5/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 6/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 6/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 7/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	11/29/2006	12/9/2006
		Pro 3/Site 8/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 3/Site 9/Adult (850)	LET-HFAA	5/24/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 5/Site 1/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 5/Site 2/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 5/Site 3/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 5/Site 4/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 5/Site 5/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 5/Site 6/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 5/Site 6/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 5/Site 7/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 5/Site 8/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 5/Site 9/Adult (850)	LET-HFAA	6/22/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 6/Site 1/Adult (850)	LET-HFAA	7/10/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 6/Site 3/Adult (850)	LET-HFAA	7/10/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 6/Site 4/Adult (850)	LET-HFAA	7/10/2006	10/26/2006	12/4/2006	12/10/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06100351	Pro 6/Site 6/Adult (850)	LET-HFAA	7/10/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 6/Site 7/Adult (850)	LET-HFAA	7/10/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 6/Site 9/Adult (850)	LET-HFAA	7/10/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 7/Site 1/Adult (850)	LET-HFAA	7/27/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 7/Site 1/Adult (850)	LET-HFAA	7/27/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 7/Site 3/Adult (850)	LET-HFAA	7/27/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 7/Site 4/Adult (850)	LET-HFAA	7/27/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 7/Site 6/Adult (850)	LET-HFAA	7/27/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 7/Site 7/Adult (850)	LET-HFAA	7/27/2006	10/26/2006	12/4/2006	12/10/2006
		Pro 7/Site 9/Adult (850)	LET-HFAA	7/27/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 1/Adult (850)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 1/N-C (125)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 3/Adult (850)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 3/N-C (125)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 4/Adult (850)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 4/N-C (125)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 6/Adult (850)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 6/N-C (125)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 7/Adult (850)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 9/Adult (850)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 9/Adult (850)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 8/Site 9/N-C (125)	LET-HFAA	8/23/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 1/Adult (850)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 1/N-C (125)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 3/Adult (850)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 3/N-C (125)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 4/Adult (850)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 4/N-C (125)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 6/Adult (850	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 6/N-C (125)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 7/Adult (850)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 7/Adult (850)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 7/N-C (125)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 9/Adult (850)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/9/2006
		Pro 9/Site 9/N-C (125)	LET-HFAA	8/28/2006	10/26/2006	12/4/2006	12/10/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06110001	2267 5-26-06 #1	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267 5-26-06 #2	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267 6-19-06 composite	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267 7-28-06 #1	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267 7-28-06 #2	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 0-2 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 10-13 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 13-16 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 13-16 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 16-19 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 19-22 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 2-4 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 25-28 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 4-6 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 6-8 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2267-2 84-88 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565 5-26-06 deep #1	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565 5-26-06 deep #2	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565 5-26-06 deep #2	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 0-2 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 10-12 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 12-14 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 12-14 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 14-16 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 16-18 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 2-4 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 32-34 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 4-6 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 6-8 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		2565-3 8-10 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 7-27-06 deep #1	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 7-27-06 deep #2	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 0-1 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 1-2 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 2-3 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06110001	3510 Box 3-4 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 4-5 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 5-6 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 6-7 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 6-7 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 7-8 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 8-9 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
		3510 Box 9-10 cm	LET-HFAA	7/25/2006	11/2/2006	11/22/2006	12/8/2006
	L06120096	0.45 Cellulose Filter Blk	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/29/2007
		0.45 Micron Filter Blk	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		0.45 Polycarb Filter Blk	LET-HFAA	11/20/2006	12/19/2006	1/18/2007	1/29/2007
		0.8 Micron Filter Blk	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 1/0.45 Poly	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 1/Seston 0.45	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 1/Seston 0.8	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 3/0.45 Poly	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 3/Seston 0.45	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 3/Seston 0.8	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 4/0.45 Poly	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 4/Seston 0.45	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 4/Seston 0.8	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 6/0.45 Poly	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 6/0.45 PolyMS	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/26/2007
		Pro 12/Site 6/Seston 0.45	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 6/Seston 0.8	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 7/0.45 Poly	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 7/Seston 0.45	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 7/Seston 0.8	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 9/0.45 Poly	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 9/Seston 0.45	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 9/Seston 0.8	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/29/2007
		Pro 12/Site 9/Seston 0.8MS	LET-HFAA	11/20/2006	12/19/2006	1/22/2007	1/26/2007
		Pro 13/Site 1/0.45 Cell	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/29/2007
		Pro 13/Site 1/Adult(850)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/26/2007
		Pro 13/Site 1/Juv(500)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L06120096	Pro 13/Site 1/Na-Cy(125)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 3/0.45 Cell	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/29/2007
		Pro 13/Site 3/Adult(850)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 3/Juv(500)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 3/Na-Cy(125)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 4 Juv(500)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 4/0.45 Cell	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/29/2007
		Pro 13/Site 4/Adult(850)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/26/2007
		Pro 13/Site 4/Na-Cy(125)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 4/Na-Cy(125)MS	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/26/2007
		Pro 13/Site 6/0.45 Cell	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/29/2007
		Pro 13/Site 6/Adult(850)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/26/2007
		Pro 13/Site 6/Juv(500)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 6/Na-Cy(125)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 7/0.45 Cell	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/29/2007
		Pro 13/Site 7/0.45 CellMS	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/26/2007
		Pro 13/Site 7/Adult(850)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/26/2007
		Pro 13/Site 7/Juv(500)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 7/Na-Cy(125)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 9/0.45 Cell	LET-HFAA	12/2/2006	12/19/2006	1/18/2007	1/29/2007
		Pro 13/Site 9/Adult(850)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/26/2007
		Pro 13/Site 9/Adult(850)MS	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/26/2007
		Pro 13/Site 9/Juv(500)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
		Pro 13/Site 9/Na-Cy(125)	LET-HFAA	12/2/2006	12/19/2006	1/17/2007	1/29/2007
	L07030001	2267 #1 11-01-06	LET-HFAA	11/1/2006	2/28/2007	3/21/2007	3/27/2007
		2267 #1 12-07-06	LET-HFAA	12/7/2006	2/28/2007	3/21/2007	3/27/2007
		2267 #1 12-07-06MS	LET-HFAA	12/7/2006	2/28/2007	3/21/2007	3/27/2007
		2267 #1 8-29-06	LET-HFAA	8/29/2006	2/28/2007	3/21/2007	3/27/2007
		2267 #2 11-01-06	LET-HFAA	11/1/2006	2/28/2007	3/21/2007	3/27/2007
		2267 #2 12-07-06	LET-HFAA	12/7/2006	2/28/2007	3/21/2007	3/27/2007
		2267 #2 8-29-06	LET-HFAA	8/29/2006	2/28/2007	3/21/2007	3/27/2007
	L07030024	EG-A-1	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-10	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-11	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-12	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07030024	EG-A-13	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-14	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-15	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-2	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-3	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-4	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-5	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-51	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-52	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-52MS	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-53	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-54	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-55	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-56	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-57	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-58	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-59	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-6	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-60	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-61	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-62	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-62MS	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-63	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-64	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-65	LET-HFAA	11/10/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-7	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-7MS	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-8	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-A-9	LET-HFAA	9/11/2006	3/8/2007	3/20/2007	3/27/2007
		EG-Hat-1	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-10	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-11	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-12	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-13	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-14	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07030024	EG-Hat-16	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-2	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-3	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-4	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-5	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-6	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-7	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-71	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-72	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-72MS	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-73	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-74	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-75	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-76	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-77	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-78	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-79	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-7MS	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-8	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-80	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-81	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-82	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-83	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-83MS	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-84	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-85	LET-HFAA	11/22/2006	3/8/2007	3/19/2007	3/27/2007
		EG-Hat-9	LET-HFAA	9/13/2006	3/8/2007	3/19/2007	3/27/2007
	L07030096	Composite #2	LET-HFAA	9/11/2006	3/27/2007	4/10/2007	4/18/2007
		Composite #2	LET-HFAA	9/11/2006	3/27/2007	4/10/2007	4/18/2007
		Composite #2	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		Composite #2	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		Composite #3	LET-HFAA	9/11/2006	3/27/2007	4/10/2007	4/18/2007
		Composite #3	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		Composite #4	LET-HFAA	9/11/2006	3/27/2007	4/10/2007	4/18/2007
		Composite #4	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07030096	Composite #5	LET-HFAA	9/11/2006	3/27/2007	4/10/2007	4/18/2007
		Composite #5	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A1	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A1	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A10	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A10	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A11	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A11	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A12	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A12	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A2	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A2	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A3	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A3	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A4	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A4	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A5	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A5	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A51	LET-HFAA	11/10/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A51	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A52	LET-HFAA	11/10/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A52	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A53	LET-HFAA	11/10/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A53	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A54	LET-HFAA	11/10/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A54	LET-HFAA	11/10/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A54	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A54	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A55	LET-HFAA	11/10/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A55	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A56	LET-HFAA	11/10/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A56	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A6	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A6	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A60	LET-HFAA	11/10/2006	3/27/2007	4/9/2007	4/18/2007

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07030096	EG-A60	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A61	LET-HFAA	11/10/2006	3/27/2007	4/9/2007	4/18/2007
		EG-A61	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A63	LET-HFAA	11/10/2006	3/27/2007	4/9/2007	4/18/2007
		EG-A63	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A64	LET-HFAA	11/10/2006	3/27/2007	4/9/2007	4/18/2007
		EG-A64	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A66	LET-HFAA	11/10/2006	3/27/2007	4/9/2007	4/18/2007
		EG-A66	LetHG	11/10/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A7	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A7	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A7	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A7	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A8	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A8	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-A9	LET-HFAA	9/11/2006	3/27/2007	4/6/2007	4/18/2007
		EG-A9	LetHG	9/11/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat1	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat1	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat10	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat10	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat13	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat13	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat13	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat13	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat2	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat2	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat2	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat2	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat3	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat3	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat4	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat4	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat5	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat5	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07030096	EG-Hat6	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat6	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat7	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat7	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat71	LET-HFAA	11/22/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat71	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat72	LET-HFAA	11/22/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat72	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat73	LET-HFAA	11/22/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat73	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat74	LET-HFAA	11/22/2006	3/27/2007	4/10/2007	4/18/2007
		EG-Hat74	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat75	LET-HFAA	11/22/2006	3/27/2007	4/10/2007	4/18/2007
		EG-Hat75	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat76	LET-HFAA	11/22/2006	3/27/2007	4/10/2007	4/18/2007
		EG-Hat76	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat77	LET-HFAA	11/22/2006	3/27/2007	4/10/2007	4/18/2007
		EG-Hat77	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat78	LET-HFAA	11/22/2006	3/27/2007	4/10/2007	4/18/2007
		EG-Hat78	LetHG	11/22/2006	3/27/2007	4/11/2007	4/19/2007
		EG-Hat8	LET-HFAA	9/13/2006	3/27/2007	4/9/2007	4/18/2007
		EG-Hat8	LetHG	9/13/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat81	LET-HFAA	11/22/2006	3/27/2007	4/10/2007	4/18/2007
		EG-Hat81	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
		EG-Hat85	LET-HFAA	11/22/2006	3/27/2007	4/10/2007	4/18/2007
		EG-Hat85	LetHG	11/22/2006	3/27/2007	4/11/2007	4/18/2007
	L07040001	EG-Hat 1	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 10	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 13	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 16	LetHG	9/13/2006	4/5/2007	4/11/2007	4/19/2007
		EG-Hat 3	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 3	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 4	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 5	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 6	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07040001	EG-Hat 71	LetHG	11/22/2006	4/5/2007	4/11/2007	4/19/2007
		EG-Hat 72	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 72	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 73	LetHG	11/22/2006	4/5/2007	4/11/2007	4/19/2007
		EG-Hat 74	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 75	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 76	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 77	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 77	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 78	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 79	LetHG	11/22/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 8	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 8	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
		EG-Hat 80	LetHG	11/22/2006	4/5/2007	4/11/2007	4/19/2007
		EG-Hat 9	LetHG	9/13/2006	4/5/2007	4/11/2007	4/18/2007
	L07040097	GSL 1-1	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 1-2	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 1-3	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 1-4	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 1-5	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 2-1	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 2-1MS	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 2-2	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 2-3	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 2-4	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 2-5	LET-HFAA	3/7/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 3-1	LET-HFAA	3/9/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 3-2	LET-HFAA	3/9/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 3-2MS	LET-HFAA	3/9/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 3-3	LET-HFAA	3/9/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 3-4	LET-HFAA	3/9/2007	4/27/2007	5/4/2007	5/14/2007
		GSL 3-5	LET-HFAA	3/9/2007	4/27/2007	5/4/2007	5/14/2007
	L07050001	35	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		36	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		37	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07050001	38	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		39	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		40	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		40MS	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		41	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		42	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		43	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		44	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		45	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		46	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		46MS	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		47	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
		48	LET-HFAA	4/28/2007	5/4/2007	5/11/2007	5/14/2007
	L07060001	PG-12 / AAF / SITE #1	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AAF / SITE #3	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AAF / SITE #4	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AAF / SITE #6	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AAF / SITE #7	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AAF / SITE #9	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AJF / SITE #1	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AJF / SITE #1MS	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AJF / SITE #3	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AJF / SITE #4	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AJF / SITE #6	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AJF / SITE #7	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / AJF / SITE #9	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / ANF / SITE #1	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / ANF / SITE #3	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / ANF / SITE #4	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / ANF / SITE #6	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / ANF / SITE #7	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/29/2007
		PG-12 / ANF / SITE #7MS	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-12 / ANF / SITE #9	LET-HFAA	11/20/2006	6/7/2007	6/25/2007	6/27/2007
		PG-14 / ACF / SITE #1	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / ACF / SITE #3	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07060001	PG-14 / ACF / SITE #4	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / ACF / SITE #6	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / ACF / SITE #7	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / ACF / SITE #9	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / FILTER BLANK	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / SES / SITE #1	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / SES / SITE #3	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / SES / SITE #4	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / SES / SITE #6	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / SES / SITE #6MS	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / SES / SITE #7	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-14 / SES / SITE #9	LET-HFAA	1/26/2007	6/7/2007	6/25/2007	6/27/2007
		PG-15 / ACF / SITE #3	LET-HFAA	3/15/2007	6/7/2007	6/25/2007	6/27/2007
		PG-15 / ACF / SITE #6	LET-HFAA	3/15/2007	6/7/2007	6/25/2007	6/27/2007
		PG-15 / ACF / SITE #6MS	LET-HFAA	3/15/2007	6/7/2007	6/25/2007	6/27/2007
		PG-15 / ACF / SITE #9	LET-HFAA	3/15/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AAF / SITE #1	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AAF / SITE #3	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AAF / SITE #4	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AAF / SITE #6	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AAF / SITE #7	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AAF / SITE #9	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AJF / SITE #1	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AJF / SITE #3	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AJF / SITE #4	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AJF / SITE #4MS	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / AJF / SITE #6	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / AJF / SITE #7	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / AJF / SITE #9	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / ANF / SITE #1	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / ANF / SITE #3	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / ANF / SITE #4	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / ANF / SITE #6	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / ANF / SITE #9	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/29/2007
		PG-16 / SES / SITE #1	LET-HFAA	5/7/2007	6/7/2007	6/25/2007	6/27/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07060001	PG-16 / SES / SITE #3	LET-HFAA	5/7/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / SES / SITE #4	LET-HFAA	5/7/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / SES / SITE #6	LET-HFAA	5/7/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / SES / SITE #7	LET-HFAA	5/4/2007	6/7/2007	6/25/2007	6/27/2007
		PG-16 / SES / SITE #9	LET-HFAA	5/7/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / AAF / SITE #1	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AAF / SITE #3	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AAF / SITE #3MS	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AAF / SITE #4	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AAF / SITE #6	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AAF / SITE #7	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AJF / SITE #1	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AJF / SITE #3	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AJF / SITE #4	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-17 / AJF / SITE #6	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / AJF / SITE #7	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / AJF / SITE #9	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / AJF / SITE #9MS	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / ANF / SITE #1	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / ANF / SITE #3	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / ANF / SITE #4	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / ANF / SITE #6	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / ANF / SITE #7	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / ANF / SITE #9	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #1	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #3	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #3MS	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #4	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #6	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #7	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #9	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17 / SES / SITE #9MS	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/27/2007
		PG-17/ AAF / SITE #9	LET-HFAA	5/23/2007	6/7/2007	6/25/2007	6/29/2007
		PG-CS / AAF / #1	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAF / #2	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07060001	PG-CS / AAF / #3	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAF / #4	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAF / #5	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAF / #5MS	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAF / #6	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAU / #2	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAU / #3	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAU / #4	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAU / #5	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AAU / #6	LET-HFAA	5/8/2007	6/7/2007	6/29/2007	6/29/2007
		PG-CS / AAU / #6	LET-HFAA	5/8/2007	6/7/2007	6/29/2007	6/29/2007
		PG-CS / AJF / #1	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AJF / #2	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AJF / #3	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AJF / #4	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AJF / #5	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / AJF / #6	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / ANF / #1	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / ANF / #2	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / ANF / #3	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / ANF / #3MS	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / ANF / #4	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / ANF / #5	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
		PG-CS / ANF / #6	LET-HFAA	5/8/2007	6/7/2007	6/25/2007	6/27/2007
	L07060189	PG-18 / AAF / SITE #1	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AAF / SITE #3	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AAF / SITE #4	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AAF / SITE #6	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AAF / SITE #7	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ACF / SITE #1	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ACF / SITE #3	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ACF / SITE #4	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ACF / SITE #6	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ACF / SITE #7	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ACF / SITE #9	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07060189	PG-18 / AJF / SITE #1	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AJF / SITE #3	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AJF / SITE #6	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AJF / SITE #7	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AJF / SITE #7MS	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / AJF / SITE #9	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ANF / SITE #1	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ANF / SITE #3	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ANF / SITE #4	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ANF / SITE #6	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ANF / SITE #7	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / ANF / SITE #9	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / SES / SITE #4MS	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18 / SES / SITE #7MS	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
		PG-18/ AAF / SITE #9	LET-HFAA	6/9/2007	6/12/2007	6/25/2007	6/27/2007
	L07070001	CG432-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG432-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG432-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG432-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG433-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG433-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/6/2007
		CG433-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG433-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/6/2007
		CG437-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG437-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/6/2007
		CG437-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG437-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/6/2007
		CG438-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG438-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/6/2007
		CG438-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG438-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG439-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG439-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG439-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG439-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	CG440-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG440-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG440-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG440-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG445-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG445-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG445-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG445-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG446-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG446-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG446-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG446-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG450-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG450-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG450-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG450-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG456-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG456-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG456-BloodMS	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG456-BloodMS	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG456-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG456-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG456-LiverMS	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG456-LiverMS	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG469-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG469-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/7/2007
		CG469-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG469-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG493-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG493-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG493-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG493-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/6/2007
		CG494-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG494-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG494-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	CG494-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/6/2007
		CG495-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG495-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG495-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG495-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG497-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG497-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG497-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG497-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/6/2007
		CG513-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG513-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG513-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG513-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG514-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG514-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG514-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG514-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG515-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG515-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG515-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG515-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/6/2007
		CG516-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG516-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG516-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG516-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/6/2007
		CG517-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG517-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG517-BloodMS	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG517-BloodMS	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG517-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG517-Liver	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG517-LiverMS	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG517-LiverMS	LetHG	1/1/1950	7/11/2007	7/17/2007	8/7/2007
		CG523-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG523-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	CG523-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG523-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		CG545-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG545-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/7/2007
		CG545-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG545-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG555-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG555-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/7/2007
		CG555-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG555-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG565-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG565-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG565-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG565-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG566-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG566-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/7/2007
		CG566-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG566-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG587-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG587-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/7/2007
		CG587-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG587-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG594-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG594-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG594-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/15/2007
		CG594-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		CG596-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG596-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/7/2007
		CG596-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/13/2007
		CG596-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG600-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/15/2007
		CG600-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG600-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/13/2007
		CG600-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG601-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	CG601-Blood	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG601-BloodMS	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG601-BloodMS	LetHG	1/1/1950	7/11/2007	7/27/2007	8/6/2007
		CG601-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/13/2007
		CG601-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG601-LiverMS	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/13/2007
		CG601-LiverMS	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG606-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG606-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/6/2007
		CG606-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/13/2007
		CG606-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		CG616-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG616-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG616-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/13/2007
		CG616-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG617-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG617-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG617-Liver	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/13/2007
		CG617-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG621-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG621-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG621-Liver	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		CG621-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG622-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG622-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG622-Liver	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/15/2007
		CG622-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG626-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG626-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG626-Liver	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		CG626-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG627-Blood	LET-HFAA	1/1/1950	7/11/2007	7/27/2007	8/12/2007
		CG627-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG627-Liver	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		CG627-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	CG642-Blood	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG642-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG642-Liver	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		CG642-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG644-Blood	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG644-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/7/2007
		CG644-Liver	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		CG644-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/7/2007
		CG665-Blood	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG665-Blood	LetHG	1/1/1950	7/11/2007	7/25/2007	8/6/2007
		CG665-BloodMS	LET-HFAA	1/1/1950	7/11/2007	7/30/2007	8/12/2007
		CG665-BloodMS	LetHG	1/1/1950	7/11/2007	7/25/2007	8/6/2007
		CG665-Liver	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		CG665-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		CG665-LiverMS	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		CG665-LiverMS	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		GSLM01-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM01-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM01-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		GSLM01-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		GSLM01-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM01-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		GSLM02-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM02-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM02-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		GSLM02-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		GSLM02-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM02-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		GSLM03-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM03-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM03-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		GSLM03-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		GSLM03-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM03-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		GSLM04-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	GSLM04-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM04-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		GSLM04-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		GSLM04-Food- Subtracted	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		GSLM04-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM04-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		GSLM04-Liver- SubtractedMS	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		GSLM04-LiverMS	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM04-LiverMS	LetHG	1/1/1950	7/11/2007	7/18/2007	8/6/2007
		GSLM05-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM05-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM05-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		GSLM05-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		GSLM05-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM05-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		GSLM06-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM06-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM06-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM06-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		GSLM07-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM07-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM07-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		GSLM07-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		GSLM08-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM08-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM08-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/15/2007
		GSLM08-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		GSLM09-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM09-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM09-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/15/2007
		GSLM09-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		GSLM10-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/15/2007
		GSLM10-Blood	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007
		GSLM10-BloodMS	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/15/2007
		GSLM10-BloodMS	LetHG	1/1/1950	7/11/2007	7/24/2007	8/6/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	GSLM10-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/15/2007
		GSLM10-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		GSLM11-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM11-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		GSLM11-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/15/2007
		GSLM11-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		GSLM12-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		GSLM12-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		GSLM12-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/15/2007
		GSLM12-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		H01-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		H01-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H01-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H01-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H02-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		H02-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H02-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H02-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H03-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		H03-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H03-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H03-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H04-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		H04-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H04-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H04-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H05-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H05-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H05-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H05-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H06-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H06-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H06-BloodMS	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H06-BloodMS	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H06-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	H06-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H07-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H07-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		H07-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H07-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H08-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H08-Blood	LetHG	1/1/1950	7/11/2007	7/31/2007	8/6/2007
		H08-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H08-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H09-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H09-Blood	LetHG	1/1/1950	7/11/2007	7/31/2007	8/6/2007
		H09-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H09-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/6/2007
		H10-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H10-Blood	LetHG	1/1/1950	7/11/2007	7/31/2007	8/6/2007
		H10-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H10-Liver	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		H10-LiverMS	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H10-LiverMS	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		H11-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H11-Blood	LetHG	1/1/1950	7/11/2007	7/31/2007	8/6/2007
		H11-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H11-Liver	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		H12-Blood	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		H12-Blood	LetHG	1/1/1950	7/11/2007	7/31/2007	8/6/2007
		H12-Liver	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		H12-Liver	LetHG	1/1/1950	7/11/2007	7/23/2007	8/6/2007
		HATFOOD01-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		HATFOOD01-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/7/2007
		HATFOOD02-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		HATFOOD02-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/7/2007
		HATFOOD03-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		HATFOOD03-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/7/2007
		HATFOOD03-FoodMS	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		HATFOOD03-FoodMS	LetHG	1/1/1950	7/11/2007	7/23/2007	8/7/2007

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	HATFOOD04-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		HATFOOD04-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/10/2007
		HATFOOD05-Food	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		HATFOOD05-Food	LetHG	1/1/1950	7/11/2007	7/23/2007	8/10/2007
		NET01-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET01-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET01-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/15/2007
		NET01-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		NET02-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET02-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET02-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET02-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		NET02-LiverMS	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET02-LiverMS	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		NET03-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET03-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET03-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET03-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		NET04-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET04-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET04-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET04-Liver	LetHG	1/1/1950	7/11/2007	7/18/2007	8/10/2007
		NET05-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET05-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET05-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET05-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET06-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET06-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET06-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET06-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET07-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET07-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET07-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET07-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET08-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/15/2007

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	NET08-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET08-BloodMS	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/15/2007
		NET08-BloodMS	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET08-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET08-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET09-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET09-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET09-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET09-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET10-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET10-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET10-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET10-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET11-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET11-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET11-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET11-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET12-Blood	LET-HFAA	1/1/1950	7/11/2007	8/1/2007	8/13/2007
		NET12-Blood	LetHG	1/1/1950	7/11/2007	7/30/2007	8/6/2007
		NET12-Liver	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET12-Liver	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		NET12-LiverMS	LET-HFAA	1/1/1950	7/11/2007	8/3/2007	8/13/2007
		NET12-LiverMS	LetHG	1/1/1950	7/11/2007	7/19/2007	8/10/2007
		P01-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P01-Egg	LetHG	1/1/1950	7/11/2007	7/23/2007	8/10/2007
		P02-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P02-Egg	LetHG	1/1/1950	7/11/2007	7/23/2007	8/10/2007
		P03-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P03-Egg	LetHG	1/1/1950	7/11/2007	7/23/2007	8/10/2007
		P04-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P04-Egg	LetHG	1/1/1950	7/11/2007	7/23/2007	8/10/2007
		P04-EggMS	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P04-EggMS	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P05-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P05-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070001	P06-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P06-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P07-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P07-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P08-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P08-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P09-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P09-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P10-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P10-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P10-EggMS	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P10-EggMS	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P11-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P11-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
		P12-Egg	LET-HFAA	1/1/1950	7/11/2007	8/6/2007	8/13/2007
		P12-Egg	LetHG	1/1/1950	7/11/2007	7/24/2007	8/10/2007
	L07070211	KJS-1-07 a egg	LET-HFAA	5/19/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-1-07 a egg	LetHG	5/19/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-1-07 b egg	LET-HFAA	5/19/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-1-07 b egg	LetHG	5/19/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-1-07 c egg	LET-HFAA	5/19/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-1-07 c egg	LetHG	5/19/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-1-07 liver	LET-HFAA	5/19/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-1-07 liver	LetHG	5/19/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-1-07 oviduct egg	LET-HFAA	5/19/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-1-07 oviduct egg	LetHG	5/19/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-1-07 ventricular blood	LET-HFAA	5/19/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-1-07 ventricular blood	LetHG	5/19/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-2-07 a egg	LET-HFAA	6/2/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-2-07 a egg	LetHG	6/2/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-2-07 b egg	LET-HFAA	6/2/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-2-07 b egg	LetHG	6/2/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-2-07 jugular blood	LET-HFAA	6/2/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-2-07 jugular blood	LetHG	6/2/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-2-07 liver	LET-HFAA	6/2/2007	7/18/2007	8/6/2007	8/14/2007

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Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070211	KJS-2-07 liver	LetHG	6/2/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-2-07 oviduct egg	LET-HFAA	6/2/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-2-07 oviduct egg	LetHG	6/2/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-2-07 ventricular blood	LET-HFAA	6/2/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-2-07 ventricular blood	LetHG	6/2/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-3-07 a egg	LET-HFAA	6/8/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-3-07 a egg	LetHG	6/8/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-3-07 b egg	LET-HFAA	6/8/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-3-07 b egg	LetHG	6/8/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-3-07 c egg	LET-HFAA	6/8/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-3-07 c egg	LetHG	6/8/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-3-07 liver	LET-HFAA	6/8/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-3-07 liver	LetHG	6/8/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-3-07 liverMS	LET-HFAA	6/8/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-3-07 liverMS	LetHG	6/8/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-3-07 ventricular blood	LET-HFAA	6/8/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-3-07 ventricular blood	LetHG	6/8/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-4-07 a egg	LET-HFAA	6/18/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-4-07 a egg	LetHG	6/18/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-4-07 b egg	LET-HFAA	6/18/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-4-07 b egg	LetHG	6/18/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-4-07 b eggMS	LET-HFAA	6/18/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-4-07 b eggMS	LetHG	6/18/2007	7/18/2007	8/1/2007	8/7/2007
		KJS-4-07 c egg	LET-HFAA	6/18/2007	7/18/2007	8/6/2007	8/14/2007
		KJS-4-07 c egg	LetHG	6/18/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-4-07 liver	LET-HFAA	6/18/2007	7/18/2007	8/9/2007	8/14/2007
		KJS-4-07 liver	LetHG	6/18/2007	7/18/2007	8/2/2007	8/7/2007
		KJS-4-07 ventricular blood	LET-HFAA	6/18/2007	7/18/2007	8/9/2007	8/14/2007
		KJS-4-07 ventricular blood	LetHG	6/18/2007	7/18/2007	8/2/2007	8/7/2007
		OGBA-BRFL adults	LET-HFAA	6/22/2007	7/18/2007	8/9/2007	8/14/2007
		OGBA-BRFL adults	LetHG	6/22/2007	7/18/2007	8/2/2007	8/7/2007
		OGBA-BRFL adultsMS	LET-HFAA	6/22/2007	7/18/2007	8/9/2007	8/14/2007
		OGBA-BRFL adultsMS	LetHG	6/22/2007	7/18/2007	8/2/2007	8/7/2007
		OGBA-BRFL larvae	LET-HFAA	6/22/2007	7/18/2007	8/9/2007	8/14/2007
		OGBA-BRFL larvae	LetHG	6/22/2007	7/18/2007	8/2/2007	8/7/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070211	SALT-BRFL adults	LET-HFAA	6/11/2007	7/18/2007	8/9/2007	8/14/2007
		SALT-BRFL adults	LetHG	6/11/2007	7/18/2007	8/2/2007	8/7/2007
	L07070299	DD-B 0-1cm	LET-HFAA	6/4/2007	7/27/2007	8/16/2007	8/20/2007
		DD-B 4-5cm	LET-HFAA	6/4/2007	7/27/2007	8/16/2007	8/20/2007
		DD-C 0-1cm	LET-HFAA	6/4/2007	7/27/2007	8/16/2007	8/20/2007
		DD-C 4-5cm	LET-HFAA	6/4/2007	7/27/2007	8/16/2007	8/20/2007
		DD-E 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/17/2007	8/20/2007
		DD-E 1-3cm	LET-HFAA	5/30/2007	7/27/2007	8/17/2007	8/20/2007
		DD-F 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-F 4-5cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-G 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-H 0-1cm	LET-HFAA	6/4/2007	7/27/2007	8/16/2007	8/20/2007
		DD-H 0-1cmMS	LET-HFAA	6/4/2007	7/27/2007	8/16/2007	8/17/2007
		DD-H 4-5cm	LET-HFAA	6/4/2007	7/27/2007	8/16/2007	8/20/2007
		DD-I 0-1cm	LET-HFAA	5/29/2007	7/27/2007	8/16/2007	8/20/2007
		DD-I 0-1cmMS	LET-HFAA	5/29/2007	7/27/2007	8/16/2007	8/17/2007
		DD-I 4-5cm	LET-HFAA	5/29/2007	7/27/2007	8/16/2007	8/20/2007
		DD-J 0-1cm	LET-HFAA	5/29/2007	7/27/2007	8/16/2007	8/20/2007
		DD-J 4-5cm	LET-HFAA	5/29/2007	7/27/2007	8/16/2007	8/20/2007
		DD-K 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-L 0-1cm	LET-HFAA	5/29/2007	7/27/2007	8/17/2007	8/20/2007
		DD-L 0-1cmMS	LET-HFAA	5/29/2007	7/27/2007	8/17/2007	8/17/2007
		DD-L 4-5cm	LET-HFAA	5/29/2007	7/27/2007	8/17/2007	8/20/2007
		DD-M 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-M 4-5cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-N 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-N 4-5cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-O 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-P 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-P 4-5cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-Q 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-Q 0-1cmMS	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/17/2007
		DD-Q 4-5cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-R 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-R 4-5cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07070299	DD-S 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-S Bioherm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-T 0-1cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
		DD-T 4-5cm	LET-HFAA	5/30/2007	7/27/2007	8/16/2007	8/20/2007
	L07080001	PG-19 / AAF / SITE #1	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AAF / SITE #3	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AAF / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AAF / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AAF / SITE #7	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AAF / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AJF / SITE #1	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AJF / SITE #3	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AJF / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AJF / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AJF / SITE #6MS	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AJF / SITE #7	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / AJF / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / ANF / SITE #1	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / ANF / SITE #3	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / ANF / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / ANF / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / ANF / SITE #7	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / ANF / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / Filter Blank	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / SITE #1	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / SITE #3	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / SITE #3MS	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / SITE #7	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-19 / SES / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 SES / Filter Blank	LET-HFAA	7/27/2007	8/1/2007	8/15/2007	8/17/2007
		PG-20 / AAF / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / AAF / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / AAF / SITE #7	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07080001	PG-20 / AAF / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / AJF / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / AJF / SITE #4MS	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / AJF / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / AJF / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / ANF / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / ANF / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / ANF / SITE #7	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / ANF / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/13/2007	8/17/2007
		PG-20 / SES / SITE #4	LET-HFAA	7/27/2007	8/1/2007	8/15/2007	8/17/2007
		PG-20 / SES / SITE #6	LET-HFAA	7/27/2007	8/1/2007	8/15/2007	8/17/2007
		PG-20 / SES / SITE #7	LET-HFAA	7/27/2007	8/1/2007	8/15/2007	8/17/2007
		PG-20 / SES / SITE #9	LET-HFAA	7/27/2007	8/1/2007	8/15/2007	8/17/2007
		PG-20 / SES / SITE #9MS	LET-HFAA	7/27/2007	8/1/2007	8/15/2007	8/17/2007
	L07080051	Site # 6 -1	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
		Site # 6 -1MS	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
		Site # 6 -2	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
		Site #4 - Hat -1	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
		Site #4 - Hat -2	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
		Site #4 - Hat -3	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
		Site #4 - Hat -4	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
		Site #4 - Hat -5	LET-HFAA	5/8/2007	8/2/2007	8/17/2007	8/20/2007
	L07080171	Salt-BRFL larvae 090707	LET-HFAA	7/19/2007	8/9/2007	8/17/2007	8/20/2007
		Salt-BRFL larvae 090707MS	LET-HFAA	7/19/2007	8/9/2007	8/17/2007	8/20/2007
	L07080513	DD-C 3-4 cm	LET-HFAA	7/3/2007	8/20/2007	8/30/2007	9/5/2007
		DD-C 4-5 cm	LET-HFAA	7/3/2007	8/20/2007	8/30/2007	9/5/2007
		DD-C 5-6 cm	LET-HFAA	7/3/2007	8/20/2007	8/30/2007	9/5/2007
		DD-C 6-7 cm	LET-HFAA	7/3/2007	8/20/2007	8/30/2007	9/5/2007
		DD-C 7-8 cm	LET-HFAA	7/3/2007	8/20/2007	8/30/2007	9/5/2007
		DD-C 8-9 cm	LET-HFAA	7/3/2007	8/20/2007	8/30/2007	9/5/2007
		DD-C 9-10 cm	LET-HFAA	7/3/2007	8/20/2007	8/30/2007	9/5/2007
		DD-I 3-4 cm	LET-HFAA	7/4/2007	8/20/2007	8/30/2007	9/5/2007
		DD-I 4-5 cm	LET-HFAA	7/4/2007	8/20/2007	8/30/2007	9/5/2007
		DD-I 5-6 cm	LET-HFAA	7/4/2007	8/20/2007	8/31/2007	9/5/2007
		DD-I 5-6 cmMS	LET-HFAA	7/4/2007	8/20/2007	8/31/2007	9/5/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07080513	DD-I 6-7 cm	LET-HFAA	7/4/2007	8/20/2007	8/31/2007	9/5/2007
		DD-I 7-8 cm	LET-HFAA	7/4/2007	8/20/2007	8/31/2007	9/5/2007
		DD-I 8-9 cm	LET-HFAA	7/4/2007	8/20/2007	8/31/2007	9/5/2007
		DD-I 9-10 cm	LET-HFAA	7/4/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 3-4 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 4-5 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 5-6 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 6-7 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 7-8 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 8-9 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 8-9 cmMS	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-L 9-10 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 3-4 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 4-5 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 5-6 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 6-7 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 7-8 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 7-8 cmMS	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 8-9 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-Q 9-10 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 3-4 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 4-5 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 5-6 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 6-7 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 6-7 cmMS	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 7-8 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 8-9 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
		DD-R 9-10 cm	LET-HFAA	7/3/2007	8/20/2007	8/31/2007	9/5/2007
	L07080556	DD-C 0-1 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-C 1-2 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-C 2-3 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-I 0-1 cm	LET-HFAA	7/4/2007	8/29/2007	9/6/2007	9/6/2007
		DD-I 1-2 cm	LET-HFAA	7/4/2007	8/29/2007	9/6/2007	9/6/2007
		DD-I 2-3 cm	LET-HFAA	7/4/2007	8/29/2007	9/6/2007	9/6/2007
		DD-I 2-3 cmMS	LET-HFAA	7/4/2007	8/29/2007	9/6/2007	9/6/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07080556	DD-L 0-1 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-L 1-2 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-L 2-3 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-Q 0-1 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-Q 1-2 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-Q 2-3 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-Q 2-3 cmMS	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-R 0-1 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-R 1-2 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
		DD-R 2-3 cm	LET-HFAA	7/3/2007	8/29/2007	9/6/2007	9/6/2007
	L07080631	Blank Filter	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 1/Adult	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 1/Juvenile	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 1/N-C	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 1/Ses Clog	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 3/Adult	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 3/Juvenile	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 3/N-C	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 3/Ses Clog	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 3/Ses ClogMS	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 4/Adult	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 4/Juvenile	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 4/JuvenileMS	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 4/N-C	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 4/Ses Clog	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 6/Adult	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 6/Juvenile	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 6/N-C	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 6/Ses Clog	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 7/Adult	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 7/Juvenile	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 7/N-C	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 7/Ses Clog	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 9/Adult	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 9/N-C	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007

TABLE 1

Sample Chronology – Data Summary

Lab Name	Package Number	Sample ID	Method	Sample Date	Receive Date	Extract Date	Analysis Date
LET	L07080631	Pro 21/Site 9/Ses Clog	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
		Pro 21/Site 9/Ses ClogMS	LET-HFAA	8/21/2007	8/30/2007	9/7/2007	9/7/2007
	L07100001	CS-2 / F-1 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-1 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-2 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-2 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-3 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-3 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-4 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-4 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-5 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / F-5 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-1 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-1 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-2 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-2 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-3 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-3 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-3 / NaupliiMS	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-4 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-4 / AdultMS	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-4 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-5 / Adult	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-5 / Nauplii	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007
		CS-2 / NF-5 / NaupliiMS	LET-HFAA	8/31/2007	10/3/2007	10/12/2007	10/12/2007

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L06080012	16-Jun-06				
		SOLID			
			ANTI-1-S (N)	L06080012	LET
			ANTI-2-S (N)	L06080012	LET
			ANTI-3-S (N)	L06080012	LET
			OGBA-1-S (N)	L06080012	LET
			OGBA-2-S (N)	L06080012	LET
			OGBA-3-S (N)	L06080012	LET
			SALT-1-S (N)	L06080012	LET
			SALT-2-S (N)	L06080012	LET
			SALT-3-S (N)	L06080012	LET
L06120096	02-Dec-06				
		TISSUE			
			0.45 Cellulose Filter Blk (FB)	L06120096	LET
			0.45 Micron Filter Blk (FB)	L06120096	LET
			0.45 Polycarb Filter Blk (FB)	L06120096	LET
			0.8 Micron Filter Blk (FB)	L06120096	LET
			Pro 12/Site 1/0.45 Poly (N)	L06120096	LET
			Pro 12/Site 1/Seston 0.45 (N)	L06120096	LET
			Pro 12/Site 1/Seston 0.8 (N)	L06120096	LET
			Pro 12/Site 3/0.45 Poly (N)	L06120096	LET
			Pro 12/Site 3/Seston 0.45 (N)	L06120096	LET
			Pro 12/Site 3/Seston 0.8 (N)	L06120096	LET
			Pro 12/Site 4/0.45 Poly (N)	L06120096	LET
			Pro 12/Site 4/Seston 0.45 (N)	L06120096	LET
			Pro 12/Site 4/Seston 0.8 (N)	L06120096	LET
			Pro 12/Site 6/0.45 Poly (N)	L06120096	LET
			Pro 12/Site 6/Seston 0.45 (N)	L06120096	LET
			Pro 12/Site 6/Seston 0.8 (N)	L06120096	LET
			Pro 12/Site 7/0.45 Poly (N)	L06120096	LET
			Pro 12/Site 7/Seston 0.45 (N)	L06120096	LET
			Pro 12/Site 7/Seston 0.8 (N)	L06120096	LET
			Pro 12/Site 9/0.45 Poly (N)	L06120096	LET
			Pro 12/Site 9/Seston 0.45 (N)	L06120096	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L06120096	02-Dec-06				
		TISSUE			
			Pro 12/Site 9/Seston 0.8 (N)	L06120096	LET
			Pro 13/Site 1/0.45 Cell (N)	L06120096	LET
			Pro 13/Site 1/Adult(850) (N)	L06120096	LET
			Pro 13/Site 1/Juv(500) (N)	L06120096	LET
			Pro 13/Site 1/Na-Cy(125) (N)	L06120096	LET
			Pro 13/Site 3/0.45 Cell (N)	L06120096	LET
			Pro 13/Site 3/Adult(850) (N)	L06120096	LET
			Pro 13/Site 3/Juv(500) (N)	L06120096	LET
			Pro 13/Site 3/Na-Cy(125) (N)	L06120096	LET
			Pro 13/Site 4 Juv(500) (N)	L06120096	LET
			Pro 13/Site 4/0.45 Cell (N)	L06120096	LET
			Pro 13/Site 4/Adult(850) (N)	L06120096	LET
			Pro 13/Site 4/Na-Cy(125) (N)	L06120096	LET
			Pro 13/Site 6/0.45 Cell (N)	L06120096	LET
			Pro 13/Site 6/Adult(850) (N)	L06120096	LET
			Pro 13/Site 6/Juv(500) (N)	L06120096	LET
			Pro 13/Site 6/Na-Cy(125) (N)	L06120096	LET
			Pro 13/Site 7/0.45 Cell (N)	L06120096	LET
			Pro 13/Site 7/Adult(850) (N)	L06120096	LET
			Pro 13/Site 7/Juv(500) (N)	L06120096	LET
			Pro 13/Site 7/Na-Cy(125) (N)	L06120096	LET
			Pro 13/Site 9/0.45 Cell (N)	L06120096	LET
			Pro 13/Site 9/Adult(850) (N)	L06120096	LET
			Pro 13/Site 9/Juv(500) (N)	L06120096	LET
			Pro 13/Site 9/Na-Cy(125) (N)	L06120096	LET
L07030001	07-Dec-06				
		SEDIMENT			
			2267 #1 12-07-06MS (MS)	L07030001	LET
		SOLID			
			2267 #1 11-01-06 (N)	L07030001	LET
			2267 #1 12-07-06 (N)	L07030001	LET
			2267 #1 8-29-06 (N)	L07030001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07030001	07-Dec-06				
		SOLID			
			2267 #2 11-01-06 (N)	L07030001	LET
			2267 #2 12-07-06 (N)	L07030001	LET
			2267 #2 8-29-06 (N)	L07030001	LET
L07030024	11-Sep-06				
		TISSUE			
			EG-A-1 (N)	L07030024	LET
			EG-A-10 (N)	L07030024	LET
			EG-A-11 (N)	L07030024	LET
			EG-A-12 (N)	L07030024	LET
			EG-A-13 (N)	L07030024	LET
			EG-A-14 (N)	L07030024	LET
			EG-A-15 (N)	L07030024	LET
			EG-A-2 (N)	L07030024	LET
			EG-A-3 (N)	L07030024	LET
			EG-A-4 (N)	L07030024	LET
			EG-A-5 (N)	L07030024	LET
			EG-A-51 (N)	L07030024	LET
			EG-A-52 (N)	L07030024	LET
			EG-A-52MS (MS)	L07030024	LET
			EG-A-53 (N)	L07030024	LET
			EG-A-54 (N)	L07030024	LET
			EG-A-55 (N)	L07030024	LET
			EG-A-56 (N)	L07030024	LET
			EG-A-57 (N)	L07030024	LET
			EG-A-58 (N)	L07030024	LET
			EG-A-59 (N)	L07030024	LET
			EG-A-6 (N)	L07030024	LET
			EG-A-60 (N)	L07030024	LET
			EG-A-61 (N)	L07030024	LET
			EG-A-62 (N)	L07030024	LET
			EG-A-62MS (MS)	L07030024	LET
			EG-A-63 (N)	L07030024	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07030024	11-Sep-06				
		TISSUE			
			EG-A-64 (N)	L07030024	LET
			EG-A-65 (N)	L07030024	LET
			EG-A-7 (N)	L07030024	LET
			EG-A-7MS (MS)	L07030024	LET
			EG-A-8 (N)	L07030024	LET
			EG-A-9 (N)	L07030024	LET
			EG-Hat-1 (N)	L07030024	LET
			EG-Hat-10 (N)	L07030024	LET
			EG-Hat-11 (N)	L07030024	LET
			EG-Hat-12 (N)	L07030024	LET
			EG-Hat-13 (N)	L07030024	LET
			EG-Hat-14 (N)	L07030024	LET
			EG-Hat-16 (N)	L07030024	LET
			EG-Hat-2 (N)	L07030024	LET
			EG-Hat-3 (N)	L07030024	LET
			EG-Hat-4 (N)	L07030024	LET
			EG-Hat-5 (N)	L07030024	LET
			EG-Hat-6 (N)	L07030024	LET
			EG-Hat-7 (N)	L07030024	LET
			EG-Hat-71 (N)	L07030024	LET
			EG-Hat-72 (N)	L07030024	LET
			EG-Hat-72MS (MS)	L07030024	LET
			EG-Hat-73 (N)	L07030024	LET
			EG-Hat-74 (N)	L07030024	LET
			EG-Hat-75 (N)	L07030024	LET
			EG-Hat-76 (N)	L07030024	LET
			EG-Hat-77 (N)	L07030024	LET
			EG-Hat-78 (N)	L07030024	LET
			EG-Hat-79 (N)	L07030024	LET
			EG-Hat-7MS (MS)	L07030024	LET
			EG-Hat-8 (N)	L07030024	LET
			EG-Hat-80 (N)	L07030024	LET
			EG-Hat-81 (N)	L07030024	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07030024	11-Sep-06				
		TISSUE			
			EG-Hat-82 (N)	L07030024	LET
			EG-Hat-83 (N)	L07030024	LET
			EG-Hat-83MS (MS)	L07030024	LET
			EG-Hat-84 (N)	L07030024	LET
			EG-Hat-85 (N)	L07030024	LET
			EG-Hat-9 (N)	L07030024	LET
L07030096A	11-Sep-06				
		TISSUE			
			Composite #2 (MS)	L07030096	LET
			Composite #2 (N)	L07030096	LET
			Composite #3 (N)	L07030096	LET
			Composite #4 (N)	L07030096	LET
			Composite #5 (N)	L07030096	LET
			EG-A1 (N)	L07030096	LET
			EG-A10 (N)	L07030096	LET
			EG-A11 (N)	L07030096	LET
			EG-A12 (N)	L07030096	LET
			EG-A2 (N)	L07030096	LET
			EG-A3 (N)	L07030096	LET
			EG-A4 (N)	L07030096	LET
			EG-A5 (N)	L07030096	LET
			EG-A51 (N)	L07030096	LET
			EG-A52 (N)	L07030096	LET
			EG-A53 (N)	L07030096	LET
			EG-A54 (MS)	L07030096	LET
			EG-A54 (N)	L07030096	LET
			EG-A55 (N)	L07030096	LET
			EG-A56 (N)	L07030096	LET
			EG-A6 (N)	L07030096	LET
			EG-A60 (N)	L07030096	LET
			EG-A61 (N)	L07030096	LET
			EG-A63 (N)	L07030096	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07030096A	11-Sep-06				
		TISSUE			
			EG-A64 (N)	L07030096	LET
			EG-A66 (N)	L07030096	LET
			EG-A7 (N)	L07030096	LET
			EG-A8 (N)	L07030096	LET
			EG-A9 (N)	L07030096	LET
			EG-Hat1 (N)	L07030096	LET
			EG-Hat10 (N)	L07030096	LET
			EG-Hat13 (N)	L07030096	LET
			EG-Hat2 (N)	L07030096	LET
			EG-Hat3 (N)	L07030096	LET
			EG-Hat4 (N)	L07030096	LET
			EG-Hat5 (N)	L07030096	LET
			EG-Hat6 (N)	L07030096	LET
			EG-Hat7 (N)	L07030096	LET
			EG-Hat71 (N)	L07030096	LET
			EG-Hat72 (N)	L07030096	LET
			EG-Hat73 (N)	L07030096	LET
			EG-Hat74 (N)	L07030096	LET
			EG-Hat75 (N)	L07030096	LET
			EG-Hat76 (N)	L07030096	LET
			EG-Hat77 (N)	L07030096	LET
			EG-Hat78 (N)	L07030096	LET
			EG-Hat8 (N)	L07030096	LET
			EG-Hat81 (N)	L07030096	LET
			EG-Hat85 (N)	L07030096	LET
L07040001	13-Sep-06				
		TISSUE			
			EG-Hat 1 (N)	L07040001	LET
			EG-Hat 10 (N)	L07040001	LET
			EG-Hat 13 (N)	L07040001	LET
			EG-Hat 16 (N)	L07040001	LET
			EG-Hat 3 (N)	L07040001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07040001	13-Sep-06				
		TISSUE			
			EG-Hat 4 (N)	L07040001	LET
			EG-Hat 5 (N)	L07040001	LET
			EG-Hat 6 (N)	L07040001	LET
			EG-Hat 71 (N)	L07040001	LET
			EG-Hat 72 (N)	L07040001	LET
			EG-Hat 73 (N)	L07040001	LET
			EG-Hat 74 (N)	L07040001	LET
			EG-Hat 75 (N)	L07040001	LET
			EG-Hat 76 (N)	L07040001	LET
			EG-Hat 77 (N)	L07040001	LET
			EG-Hat 78 (N)	L07040001	LET
			EG-Hat 79 (N)	L07040001	LET
			EG-Hat 8 (N)	L07040001	LET
			EG-Hat 80 (N)	L07040001	LET
			EG-Hat 9 (N)	L07040001	LET
L07040097	07-Mar-07				
		SEDIMENT			
			GSL 2-1MS (MS)	L07040097	LET
			GSL 3-2MS (MS)	L07040097	LET
		SOLID			
			GSL 1-1 (N)	L07040097	LET
			GSL 1-2 (N)	L07040097	LET
			GSL 1-3 (N)	L07040097	LET
			GSL 1-4 (N)	L07040097	LET
			GSL 1-5 (N)	L07040097	LET
			GSL 2-1 (N)	L07040097	LET
			GSL 2-2 (N)	L07040097	LET
			GSL 2-3 (N)	L07040097	LET
			GSL 2-4 (N)	L07040097	LET
			GSL 2-5 (N)	L07040097	LET
			GSL 3-1 (N)	L07040097	LET
			GSL 3-2 (N)	L07040097	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07040097	07-Mar-07				
		SOLID			
			GSL 3-3 (N)	L07040097	LET
			GSL 3-4 (N)	L07040097	LET
			GSL 3-5 (N)	L07040097	LET
L07050001	28-Apr-07				
		SEDIMENT			
			40MS (MS)	L07050001	LET
			46MS (MS)	L07050001	LET
		SOLID			
			35 (N)	L07050001	LET
			36 (N)	L07050001	LET
			37 (N)	L07050001	LET
			38 (N)	L07050001	LET
			39 (N)	L07050001	LET
			40 (N)	L07050001	LET
			41 (N)	L07050001	LET
			42 (N)	L07050001	LET
			43 (N)	L07050001	LET
			44 (N)	L07050001	LET
			45 (N)	L07050001	LET
			46 (N)	L07050001	LET
			47 (N)	L07050001	LET
			48 (N)	L07050001	LET
L07060001	20-Nov-06				
		TISSUE			
			PG-12 / AAF / SITE #1 (N)	L07060001	LET
			PG-12 / AAF / SITE #3 (N)	L07060001	LET
			PG-12 / AAF / SITE #4 (N)	L07060001	LET
			PG-12 / AAF / SITE #6 (N)	L07060001	LET
			PG-12 / AAF / SITE #7 (N)	L07060001	LET
			PG-12 / AAF / SITE #9 (N)	L07060001	LET
			PG-12 / AJF / SITE #1 (N)	L07060001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07060001	20-Nov-06				
		TISSUE			
			PG-12 / AJF / SITE #1MS (MS)	L07060001	LET
			PG-12 / AJF / SITE #3 (N)	L07060001	LET
			PG-12 / AJF / SITE #4 (N)	L07060001	LET
			PG-12 / AJF / SITE #6 (N)	L07060001	LET
			PG-12 / AJF / SITE #7 (N)	L07060001	LET
			PG-12 / AJF / SITE #9 (N)	L07060001	LET
			PG-12 / ANF / SITE #1 (N)	L07060001	LET
			PG-12 / ANF / SITE #3 (N)	L07060001	LET
			PG-12 / ANF / SITE #4 (N)	L07060001	LET
			PG-12 / ANF / SITE #6 (N)	L07060001	LET
			PG-12 / ANF / SITE #7 (N)	L07060001	LET
			PG-12 / ANF / SITE #7MS (MS)	L07060001	LET
			PG-12 / ANF / SITE #9 (N)	L07060001	LET
			PG-14 / ACF / SITE #1 (N)	L07060001	LET
			PG-14 / ACF / SITE #3 (N)	L07060001	LET
			PG-14 / ACF / SITE #4 (N)	L07060001	LET
			PG-14 / ACF / SITE #6 (N)	L07060001	LET
			PG-14 / ACF / SITE #7 (N)	L07060001	LET
			PG-14 / ACF / SITE #9 (N)	L07060001	LET
			PG-14 / FILTER BLANK (FB)	L07060001	LET
			PG-14 / SES / SITE #1 (N)	L07060001	LET
			PG-14 / SES / SITE #3 (N)	L07060001	LET
			PG-14 / SES / SITE #4 (N)	L07060001	LET
			PG-14 / SES / SITE #6 (N)	L07060001	LET
			PG-14 / SES / SITE #6MS (MS)	L07060001	LET
			PG-14 / SES / SITE #7 (N)	L07060001	LET
			PG-14 / SES / SITE #9 (N)	L07060001	LET
			PG-15 / ACF / SITE #3 (N)	L07060001	LET
			PG-15 / ACF / SITE #6 (N)	L07060001	LET
			PG-15 / ACF / SITE #6MS (MS)	L07060001	LET
			PG-15 / ACF / SITE #9 (N)	L07060001	LET
			PG-16 / AAF / SITE #1 (N)	L07060001	LET
			PG-16 / AAF / SITE #3 (N)	L07060001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07060001	20-Nov-06				
		TISSUE			
			PG-16 / AAF / SITE #4 (N)	L07060001	LET
			PG-16 / AAF / SITE #6 (N)	L07060001	LET
			PG-16 / AAF / SITE #7 (N)	L07060001	LET
			PG-16 / AAF / SITE #9 (N)	L07060001	LET
			PG-16 / AJF / SITE #1 (N)	L07060001	LET
			PG-16 / AJF / SITE #3 (N)	L07060001	LET
			PG-16 / AJF / SITE #4 (N)	L07060001	LET
			PG-16 / AJF / SITE #4MS (MS)	L07060001	LET
			PG-16 / AJF / SITE #6 (N)	L07060001	LET
			PG-16 / AJF / SITE #7 (N)	L07060001	LET
			PG-16 / AJF / SITE #9 (N)	L07060001	LET
			PG-16 / ANF / SITE #1 (N)	L07060001	LET
			PG-16 / ANF / SITE #3 (N)	L07060001	LET
			PG-16 / ANF / SITE #4 (N)	L07060001	LET
			PG-16 / ANF / SITE #6 (N)	L07060001	LET
			PG-16 / ANF / SITE #9 (N)	L07060001	LET
			PG-16 / SES / SITE #1 (N)	L07060001	LET
			PG-16 / SES / SITE #3 (N)	L07060001	LET
			PG-16 / SES / SITE #4 (N)	L07060001	LET
			PG-16 / SES / SITE #6 (N)	L07060001	LET
			PG-16 / SES / SITE #7 (N)	L07060001	LET
			PG-16 / SES / SITE #9 (N)	L07060001	LET
			PG-17 / AAF / SITE #1 (N)	L07060001	LET
			PG-17 / AAF / SITE #3 (N)	L07060001	LET
			PG-17 / AAF / SITE #3MS (MS)	L07060001	LET
			PG-17 / AAF / SITE #4 (N)	L07060001	LET
			PG-17 / AAF / SITE #6 (N)	L07060001	LET
			PG-17 / AAF / SITE #7 (N)	L07060001	LET
			PG-17 / AJF / SITE #1 (N)	L07060001	LET
			PG-17 / AJF / SITE #3 (N)	L07060001	LET
			PG-17 / AJF / SITE #4 (N)	L07060001	LET
			PG-17 / AJF / SITE #6 (N)	L07060001	LET
			PG-17 / AJF / SITE #7 (N)	L07060001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07060001	20-Nov-06				
		TISSUE			
			PG-17 / AJF / SITE #9 (N)	L07060001	LET
			PG-17 / AJF / SITE #9MS (MS)	L07060001	LET
			PG-17 / ANF / SITE #1 (N)	L07060001	LET
			PG-17 / ANF / SITE #3 (N)	L07060001	LET
			PG-17 / ANF / SITE #4 (N)	L07060001	LET
			PG-17 / ANF / SITE #6 (N)	L07060001	LET
			PG-17 / ANF / SITE #7 (N)	L07060001	LET
			PG-17 / ANF / SITE #9 (N)	L07060001	LET
			PG-17 / SES / SITE #1 (N)	L07060001	LET
			PG-17 / SES / SITE #3 (N)	L07060001	LET
			PG-17 / SES / SITE #3MS (MS)	L07060001	LET
			PG-17 / SES / SITE #4 (N)	L07060001	LET
			PG-17 / SES / SITE #6 (N)	L07060001	LET
			PG-17 / SES / SITE #7 (N)	L07060001	LET
			PG-17 / SES / SITE #9 (N)	L07060001	LET
			PG-17 / SES / SITE #9MS (MS)	L07060001	LET
			PG-17/ AAF / SITE #9 (N)	L07060001	LET
			PG-CS / AAF / #1 (N)	L07060001	LET
			PG-CS / AAF / #2 (N)	L07060001	LET
			PG-CS / AAF / #3 (N)	L07060001	LET
			PG-CS / AAF / #4 (N)	L07060001	LET
			PG-CS / AAF / #5 (N)	L07060001	LET
			PG-CS / AAF / #5MS (MS)	L07060001	LET
			PG-CS / AAF / #6 (N)	L07060001	LET
			PG-CS / AAU / #2 (N)	L07060001	LET
			PG-CS / AAU / #3 (N)	L07060001	LET
			PG-CS / AAU / #4 (N)	L07060001	LET
			PG-CS / AAU / #5 (N)	L07060001	LET
			PG-CS / AAU / #6 (N)	L07060001	LET
			PG-CS / AJF / #1 (N)	L07060001	LET
			PG-CS / AJF / #2 (N)	L07060001	LET
			PG-CS / AJF / #3 (N)	L07060001	LET
			PG-CS / AJF / #4 (N)	L07060001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07060001	20-Nov-06				
		TISSUE			
			PG-CS / AJF / #5 (N)	L07060001	LET
			PG-CS / AJF / #6 (N)	L07060001	LET
			PG-CS / ANF / #1 (N)	L07060001	LET
			PG-CS / ANF / #2 (N)	L07060001	LET
			PG-CS / ANF / #3 (N)	L07060001	LET
			PG-CS / ANF / #3MS (MS)	L07060001	LET
			PG-CS / ANF / #4 (N)	L07060001	LET
			PG-CS / ANF / #5 (N)	L07060001	LET
			PG-CS / ANF / #6 (N)	L07060001	LET
L07060189	09-Jun-07				
		TISSUE			
			PG-18 / AAF / SITE #1 (N)	L07060189	LET
			PG-18 / AAF / SITE #3 (N)	L07060189	LET
			PG-18 / AAF / SITE #4 (N)	L07060189	LET
			PG-18 / AAF / SITE #6 (N)	L07060189	LET
			PG-18 / AAF / SITE #7 (N)	L07060189	LET
			PG-18 / ACF / SITE #1 (N)	L07060189	LET
			PG-18 / ACF / SITE #3 (N)	L07060189	LET
			PG-18 / ACF / SITE #4 (N)	L07060189	LET
			PG-18 / ACF / SITE #6 (N)	L07060189	LET
			PG-18 / ACF / SITE #7 (N)	L07060189	LET
			PG-18 / ACF / SITE #9 (N)	L07060189	LET
			PG-18 / AJF / SITE #1 (N)	L07060189	LET
			PG-18 / AJF / SITE #3 (N)	L07060189	LET
			PG-18 / AJF / SITE #6 (N)	L07060189	LET
			PG-18 / AJF / SITE #7 (N)	L07060189	LET
			PG-18 / AJF / SITE #7MS (MS)	L07060189	LET
			PG-18 / AJF / SITE #9 (N)	L07060189	LET
			PG-18 / ANF / SITE #1 (N)	L07060189	LET
			PG-18 / ANF / SITE #3 (N)	L07060189	LET
			PG-18 / ANF / SITE #4 (N)	L07060189	LET
			PG-18 / ANF / SITE #6 (N)	L07060189	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07060189	09-Jun-07				
		TISSUE			
			PG-18 / ANF / SITE #7 (N)	L07060189	LET
			PG-18 / ANF / SITE #9 (N)	L07060189	LET
			PG-18 / SES / SITE #4MS (MS)	L07060189	LET
			PG-18 / SES / SITE #7MS (MS)	L07060189	LET
			PG-18/ AAF / SITE #9 (N)	L07060189	LET
L07070001	01-Jan-50				
		TISSUE			
			CG432-Blood (N)	L07070001	LET
			CG432-Liver (N)	L07070001	LET
			CG433-Blood (N)	L07070001	LET
			CG433-Liver (N)	L07070001	LET
			CG437-Blood (N)	L07070001	LET
			CG437-Liver (N)	L07070001	LET
			CG438-Blood (N)	L07070001	LET
			CG438-Liver (N)	L07070001	LET
			CG439-Blood (N)	L07070001	LET
			CG439-Liver (N)	L07070001	LET
			CG440-Blood (N)	L07070001	LET
			CG440-Liver (N)	L07070001	LET
			CG445-Blood (N)	L07070001	LET
			CG445-Liver (N)	L07070001	LET
			CG446-Blood (N)	L07070001	LET
			CG446-Liver (N)	L07070001	LET
			CG450-Blood (N)	L07070001	LET
			CG450-Liver (N)	L07070001	LET
			CG456-Blood (N)	L07070001	LET
			CG456-BloodMS (MS)	L07070001	LET
			CG456-Liver (N)	L07070001	LET
			CG456-LiverMS (MS)	L07070001	LET
			CG469-Blood (N)	L07070001	LET
			CG469-Liver (N)	L07070001	LET
			CG493-Blood (N)	L07070001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070001	01-Jan-50				
		TISSUE			
			CG493-Liver (N)	L07070001	LET
			CG494-Blood (N)	L07070001	LET
			CG494-Liver (N)	L07070001	LET
			CG495-Blood (N)	L07070001	LET
			CG495-Liver (N)	L07070001	LET
			CG497-Blood (N)	L07070001	LET
			CG497-Liver (N)	L07070001	LET
			CG513-Blood (N)	L07070001	LET
			CG513-Liver (N)	L07070001	LET
			CG514-Blood (N)	L07070001	LET
			CG514-Liver (N)	L07070001	LET
			CG515-Blood (N)	L07070001	LET
			CG515-Liver (N)	L07070001	LET
			CG516-Blood (N)	L07070001	LET
			CG516-Liver (N)	L07070001	LET
			CG517-Blood (N)	L07070001	LET
			CG517-BloodMS (MS)	L07070001	LET
			CG517-Liver (N)	L07070001	LET
			CG517-LiverMS (MS)	L07070001	LET
			CG523-Blood (N)	L07070001	LET
			CG523-Liver (N)	L07070001	LET
			CG545-Blood (N)	L07070001	LET
			CG545-Liver (N)	L07070001	LET
			CG555-Blood (N)	L07070001	LET
			CG555-Liver (N)	L07070001	LET
			CG565-Blood (N)	L07070001	LET
			CG565-Liver (N)	L07070001	LET
			CG566-Blood (N)	L07070001	LET
			CG566-Liver (N)	L07070001	LET
			CG587-Blood (N)	L07070001	LET
			CG587-Liver (N)	L07070001	LET
			CG594-Blood (N)	L07070001	LET
			CG594-Liver (N)	L07070001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070001	01-Jan-50				
		TISSUE			
			CG596-Blood (N)	L07070001	LET
			CG596-Liver (N)	L07070001	LET
			CG600-Blood (N)	L07070001	LET
			CG600-Liver (N)	L07070001	LET
			CG601-Blood (N)	L07070001	LET
			CG601-BloodMS (MS)	L07070001	LET
			CG601-Liver (N)	L07070001	LET
			CG601-LiverMS (MS)	L07070001	LET
			CG606-Blood (N)	L07070001	LET
			CG606-Liver (N)	L07070001	LET
			CG616-Blood (N)	L07070001	LET
			CG616-Liver (N)	L07070001	LET
			CG617-Blood (N)	L07070001	LET
			CG617-Liver (N)	L07070001	LET
			CG621-Blood (N)	L07070001	LET
			CG621-Liver (N)	L07070001	LET
			CG622-Blood (N)	L07070001	LET
			CG622-Liver (N)	L07070001	LET
			CG626-Blood (N)	L07070001	LET
			CG626-Liver (N)	L07070001	LET
			CG627-Blood (N)	L07070001	LET
			CG627-Liver (N)	L07070001	LET
			CG642-Blood (N)	L07070001	LET
			CG642-Liver (N)	L07070001	LET
			CG644-Blood (N)	L07070001	LET
			CG644-Liver (N)	L07070001	LET
			CG665-Blood (N)	L07070001	LET
			CG665-BloodMS (MS)	L07070001	LET
			CG665-Liver (N)	L07070001	LET
			CG665-LiverMS (MS)	L07070001	LET
			GSLM01-Blood (N)	L07070001	LET
			GSLM01-Food (N)	L07070001	LET
			GSLM01-Liver (N)	L07070001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070001	01-Jan-50				
		TISSUE			
			GSLM02-Blood (N)	L07070001	LET
			GSLM02-Food (N)	L07070001	LET
			GSLM02-Liver (N)	L07070001	LET
			GSLM03-Blood (N)	L07070001	LET
			GSLM03-Food (N)	L07070001	LET
			GSLM03-Liver (N)	L07070001	LET
			GSLM04-Blood (N)	L07070001	LET
			GSLM04-Food (N)	L07070001	LET
			GSLM04-Food- Subtracted (N)	L07070001	LET
			GSLM04-Liver (N)	L07070001	LET
			GSLM04-Liver- SubtractedMS (MS)	L07070001	LET
			GSLM04-LiverMS (MS)	L07070001	LET
			GSLM05-Blood (N)	L07070001	LET
			GSLM05-Food (N)	L07070001	LET
			GSLM05-Liver (N)	L07070001	LET
			GSLM06-Blood (N)	L07070001	LET
			GSLM06-Liver (N)	L07070001	LET
			GSLM07-Blood (N)	L07070001	LET
			GSLM07-Liver (N)	L07070001	LET
			GSLM08-Blood (N)	L07070001	LET
			GSLM08-Liver (N)	L07070001	LET
			GSLM09-Blood (N)	L07070001	LET
			GSLM09-Liver (N)	L07070001	LET
			GSLM10-Blood (N)	L07070001	LET
			GSLM10-BloodMS (MS)	L07070001	LET
			GSLM10-Liver (N)	L07070001	LET
			GSLM11-Blood (N)	L07070001	LET
			GSLM11-Liver (N)	L07070001	LET
			GSLM12-Blood (N)	L07070001	LET
			GSLM12-Liver (N)	L07070001	LET
			H01-Blood (N)	L07070001	LET
			H01-Liver (N)	L07070001	LET
			H02-Blood (N)	L07070001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070001	01-Jan-50				
		TISSUE			
			H02-Liver (N)	L07070001	LET
			H03-Blood (N)	L07070001	LET
			H03-Liver (N)	L07070001	LET
			H04-Blood (N)	L07070001	LET
			H04-Liver (N)	L07070001	LET
			H05-Blood (N)	L07070001	LET
			H05-Liver (N)	L07070001	LET
			H06-Blood (N)	L07070001	LET
			H06-BloodMS (MS)	L07070001	LET
			H06-Liver (N)	L07070001	LET
			H07-Blood (N)	L07070001	LET
			H07-Liver (N)	L07070001	LET
			H08-Blood (N)	L07070001	LET
			H08-Liver (N)	L07070001	LET
			H09-Blood (N)	L07070001	LET
			H09-Liver (N)	L07070001	LET
			H10-Blood (N)	L07070001	LET
			H10-Liver (N)	L07070001	LET
			H10-LiverMS (MS)	L07070001	LET
			H11-Blood (N)	L07070001	LET
			H11-Liver (N)	L07070001	LET
			H12-Blood (N)	L07070001	LET
			H12-Liver (N)	L07070001	LET
			HATFOOD01-Food (N)	L07070001	LET
			HATFOOD02-Food (N)	L07070001	LET
			HATFOOD03-Food (N)	L07070001	LET
			HATFOOD03-FoodMS (MS)	L07070001	LET
			HATFOOD04-Food (N)	L07070001	LET
			HATFOOD05-Food (N)	L07070001	LET
			NET01-Blood (N)	L07070001	LET
			NET01-Liver (N)	L07070001	LET
			NET02-Blood (N)	L07070001	LET
			NET02-Liver (N)	L07070001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070001	01-Jan-50				
		TISSUE			
			NET02-LiverMS (MS)	L07070001	LET
			NET03-Blood (N)	L07070001	LET
			NET03-Liver (N)	L07070001	LET
			NET04-Blood (N)	L07070001	LET
			NET04-Liver (N)	L07070001	LET
			NET05-Blood (N)	L07070001	LET
			NET05-Liver (N)	L07070001	LET
			NET06-Blood (N)	L07070001	LET
			NET06-Liver (N)	L07070001	LET
			NET07-Blood (N)	L07070001	LET
			NET07-Liver (N)	L07070001	LET
			NET08-Blood (N)	L07070001	LET
			NET08-BloodMS (MS)	L07070001	LET
			NET08-Liver (N)	L07070001	LET
			NET09-Blood (N)	L07070001	LET
			NET09-Liver (N)	L07070001	LET
			NET10-Blood (N)	L07070001	LET
			NET10-Liver (N)	L07070001	LET
			NET11-Blood (N)	L07070001	LET
			NET11-Liver (N)	L07070001	LET
			NET12-Blood (N)	L07070001	LET
			NET12-Liver (N)	L07070001	LET
			NET12-LiverMS (MS)	L07070001	LET
			P01-Egg (N)	L07070001	LET
			P02-Egg (N)	L07070001	LET
			P03-Egg (N)	L07070001	LET
			P04-Egg (N)	L07070001	LET
			P04-EggMS (MS)	L07070001	LET
			P05-Egg (N)	L07070001	LET
			P06-Egg (N)	L07070001	LET
			P07-Egg (N)	L07070001	LET
			P08-Egg (N)	L07070001	LET
			P09-Egg (N)	L07070001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070001	01-Jan-50				
		TISSUE			
			P10-Egg (N)	L07070001	LET
			P10-EggMS (MS)	L07070001	LET
			P11-Egg (N)	L07070001	LET
			P12-Egg (N)	L07070001	LET
L07070211	19-May-07				
		TISSUE			
			KJS-1-07 a egg (N)	L07070211	LET
			KJS-1-07 b egg (N)	L07070211	LET
			KJS-1-07 c egg (N)	L07070211	LET
			KJS-1-07 liver (N)	L07070211	LET
			KJS-1-07 oviduct egg (N)	L07070211	LET
			KJS-1-07 ventricular blood (N)	L07070211	LET
			KJS-2-07 a egg (N)	L07070211	LET
			KJS-2-07 b egg (N)	L07070211	LET
			KJS-2-07 jugular blood (N)	L07070211	LET
			KJS-2-07 liver (N)	L07070211	LET
			KJS-2-07 oviduct egg (N)	L07070211	LET
			KJS-2-07 ventricular blood (N)	L07070211	LET
			KJS-3-07 a egg (N)	L07070211	LET
			KJS-3-07 b egg (N)	L07070211	LET
			KJS-3-07 c egg (N)	L07070211	LET
			KJS-3-07 liver (N)	L07070211	LET
			KJS-3-07 liverMS (MS)	L07070211	LET
			KJS-3-07 ventricular blood (N)	L07070211	LET
			KJS-4-07 a egg (N)	L07070211	LET
			KJS-4-07 b egg (N)	L07070211	LET
			KJS-4-07 b eggMS (MS)	L07070211	LET
			KJS-4-07 c egg (N)	L07070211	LET
			KJS-4-07 liver (N)	L07070211	LET
			KJS-4-07 ventricular blood (N)	L07070211	LET
			OGBA-BRFL adults (N)	L07070211	LET
			OGBA-BRFL adultsMS (MS)	L07070211	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070211	19-May-07				
		TISSUE			
			OGBA-BRFL larvae (N)	L07070211	LET
			SALT-BRFL adults (N)	L07070211	LET
L07070299	04-Jun-07				
		SEDIMENT			
			DD-H 0-1cmMS (MS)	L07070299	LET
			DD-I 0-1cmMS (MS)	L07070299	LET
			DD-L 0-1cmMS (MS)	L07070299	LET
			DD-Q 0-1cmMS (MS)	L07070299	LET
		SOLID			
			DD-B 0-1cm (N)	L07070299	LET
			DD-B 4-5cm (N)	L07070299	LET
			DD-C 0-1cm (N)	L07070299	LET
			DD-C 4-5cm (N)	L07070299	LET
			DD-E 0-1cm (N)	L07070299	LET
			DD-E 1-3cm (N)	L07070299	LET
			DD-F 0-1cm (N)	L07070299	LET
			DD-F 4-5cm (N)	L07070299	LET
			DD-G 0-1cm (N)	L07070299	LET
			DD-H 0-1cm (N)	L07070299	LET
			DD-H 4-5cm (N)	L07070299	LET
			DD-I 0-1cm (N)	L07070299	LET
			DD-I 4-5cm (N)	L07070299	LET
			DD-J 0-1cm (N)	L07070299	LET
			DD-J 4-5cm (N)	L07070299	LET
			DD-K 0-1cm (N)	L07070299	LET
			DD-L 0-1cm (N)	L07070299	LET
			DD-L 4-5cm (N)	L07070299	LET
			DD-M 0-1cm (N)	L07070299	LET
			DD-M 4-5cm (N)	L07070299	LET
			DD-N 0-1cm (N)	L07070299	LET
			DD-N 4-5cm (N)	L07070299	LET
			DD-O 0-1cm (N)	L07070299	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07070299	04-Jun-07				
		SOLID			
			DD-P 0-1cm (N)	L07070299	LET
			DD-P 4-5cm (N)	L07070299	LET
			DD-Q 0-1cm (N)	L07070299	LET
			DD-Q 4-5cm (N)	L07070299	LET
			DD-R 0-1cm (N)	L07070299	LET
			DD-R 4-5cm (N)	L07070299	LET
			DD-S 0-1cm (N)	L07070299	LET
			DD-S Bioherm (N)	L07070299	LET
			DD-T 0-1cm (N)	L07070299	LET
			DD-T 4-5cm (N)	L07070299	LET
L07080001	27-Jul-07				
		SOLID			
			PG-19 / SES / Filter Blank (N)	L07080001	LET
			PG-20 SES / Filter Blank (N)	L07080001	LET
		TISSUE			
			PG-19 / AAF / SITE #1 (N)	L07080001	LET
			PG-19 / AAF / SITE #3 (N)	L07080001	LET
			PG-19 / AAF / SITE #4 (N)	L07080001	LET
			PG-19 / AAF / SITE #6 (N)	L07080001	LET
			PG-19 / AAF / SITE #7 (N)	L07080001	LET
			PG-19 / AAF / SITE #9 (N)	L07080001	LET
			PG-19 / AJF / SITE #1 (N)	L07080001	LET
			PG-19 / AJF / SITE #3 (N)	L07080001	LET
			PG-19 / AJF / SITE #4 (N)	L07080001	LET
			PG-19 / AJF / SITE #6 (N)	L07080001	LET
			PG-19 / AJF / SITE #6MS (MS)	L07080001	LET
			PG-19 / AJF / SITE #7 (N)	L07080001	LET
			PG-19 / AJF / SITE #9 (N)	L07080001	LET
			PG-19 / ANF / SITE #1 (N)	L07080001	LET
			PG-19 / ANF / SITE #3 (N)	L07080001	LET
			PG-19 / ANF / SITE #4 (N)	L07080001	LET
			PG-19 / ANF / SITE #6 (N)	L07080001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07080001	27-Jul-07				
		TISSUE			
			PG-19 / ANF / SITE #7 (N)	L07080001	LET
			PG-19 / ANF / SITE #9 (N)	L07080001	LET
			PG-19 / SES / SITE #1 (N)	L07080001	LET
			PG-19 / SES / SITE #3 (N)	L07080001	LET
			PG-19 / SES / SITE #3MS (MS)	L07080001	LET
			PG-19 / SES / SITE #4 (N)	L07080001	LET
			PG-19 / SES / SITE #6 (N)	L07080001	LET
			PG-19 / SES / SITE #7 (N)	L07080001	LET
			PG-19 / SES / SITE #9 (N)	L07080001	LET
			PG-20 / AAF / SITE #4 (N)	L07080001	LET
			PG-20 / AAF / SITE #6 (N)	L07080001	LET
			PG-20 / AAF / SITE #7 (N)	L07080001	LET
			PG-20 / AAF / SITE #9 (N)	L07080001	LET
			PG-20 / AJF / SITE #4 (N)	L07080001	LET
			PG-20 / AJF / SITE #4MS (MS)	L07080001	LET
			PG-20 / AJF / SITE #6 (N)	L07080001	LET
			PG-20 / AJF / SITE #9 (N)	L07080001	LET
			PG-20 / ANF / SITE #4 (N)	L07080001	LET
			PG-20 / ANF / SITE #6 (N)	L07080001	LET
			PG-20 / ANF / SITE #7 (N)	L07080001	LET
			PG-20 / ANF / SITE #9 (N)	L07080001	LET
			PG-20 / SES / SITE #4 (N)	L07080001	LET
			PG-20 / SES / SITE #6 (N)	L07080001	LET
			PG-20 / SES / SITE #7 (N)	L07080001	LET
			PG-20 / SES / SITE #9 (N)	L07080001	LET
			PG-20 / SES / SITE #9MS (MS)	L07080001	LET
L07080051	08-May-07				
		TISSUE			
			Site # 6 -1 (N)	L07080051	LET
			Site # 6 -1MS (MS)	L07080051	LET
			Site # 6 -2 (N)	L07080051	LET
			Site #4 - Hat -1 (N)	L07080051	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07080051	08-May-07				
		TISSUE			
			Site #4 - Hat -2 (N)	L07080051	LET
			Site #4 - Hat -3 (N)	L07080051	LET
			Site #4 - Hat -4 (N)	L07080051	LET
			Site #4 - Hat -5 (N)	L07080051	LET
L07080171	19-Jul-07				
		TISSUE			
			Salt-BRFL larvae 090707 (N)	L07080171	LET
			Salt-BRFL larvae 090707MS (MS)	L07080171	LET
L07080513	04-Jul-07				
		SEDIMENT			
			DD-I 5-6 cmMS (MS)	L07080513	LET
			DD-L 8-9 cmMS (MS)	L07080513	LET
			DD-Q 7-8 cmMS (MS)	L07080513	LET
			DD-R 6-7 cmMS (MS)	L07080513	LET
		SOLID			
			DD-C 3-4 cm (N)	L07080513	LET
			DD-C 4-5 cm (N)	L07080513	LET
			DD-C 5-6 cm (N)	L07080513	LET
			DD-C 6-7 cm (N)	L07080513	LET
			DD-C 7-8 cm (N)	L07080513	LET
			DD-C 8-9 cm (N)	L07080513	LET
			DD-C 9-10 cm (N)	L07080513	LET
			DD-I 3-4 cm (N)	L07080513	LET
			DD-I 4-5 cm (N)	L07080513	LET
			DD-I 5-6 cm (N)	L07080513	LET
			DD-I 6-7 cm (N)	L07080513	LET
			DD-I 7-8 cm (N)	L07080513	LET
			DD-I 8-9 cm (N)	L07080513	LET
			DD-I 9-10 cm (N)	L07080513	LET
			DD-L 3-4 cm (N)	L07080513	LET
			DD-L 4-5 cm (N)	L07080513	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07080513	04-Jul-07				
		SOLID			
			DD-L 5-6 cm (N)	L07080513	LET
			DD-L 6-7 cm (N)	L07080513	LET
			DD-L 7-8 cm (N)	L07080513	LET
			DD-L 8-9 cm (N)	L07080513	LET
			DD-L 9-10 cm (N)	L07080513	LET
			DD-Q 3-4 cm (N)	L07080513	LET
			DD-Q 4-5 cm (N)	L07080513	LET
			DD-Q 5-6 cm (N)	L07080513	LET
			DD-Q 6-7 cm (N)	L07080513	LET
			DD-Q 7-8 cm (N)	L07080513	LET
			DD-Q 8-9 cm (N)	L07080513	LET
			DD-Q 9-10 cm (N)	L07080513	LET
			DD-R 3-4 cm (N)	L07080513	LET
			DD-R 4-5 cm (N)	L07080513	LET
			DD-R 5-6 cm (N)	L07080513	LET
			DD-R 6-7 cm (N)	L07080513	LET
			DD-R 7-8 cm (N)	L07080513	LET
			DD-R 8-9 cm (N)	L07080513	LET
			DD-R 9-10 cm (N)	L07080513	LET
L07080556	04-Jul-07				
		SEDIMENT			
			DD-I 2-3 cmMS (MS)	L07080556	LET
			DD-Q 2-3 cmMS (MS)	L07080556	LET
		SOLID			
			DD-C 0-1 cm (N)	L07080556	LET
			DD-C 1-2 cm (N)	L07080556	LET
			DD-C 2-3 cm (N)	L07080556	LET
			DD-I 0-1 cm (N)	L07080556	LET
			DD-I 1-2 cm (N)	L07080556	LET
			DD-I 2-3 cm (N)	L07080556	LET
			DD-L 0-1 cm (N)	L07080556	LET
			DD-L 1-2 cm (N)	L07080556	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07080556	04-Jul-07				
		SOLID			
			DD-L 2-3 cm (N)	L07080556	LET
			DD-Q 0-1 cm (N)	L07080556	LET
			DD-Q 1-2 cm (N)	L07080556	LET
			DD-Q 2-3 cm (N)	L07080556	LET
			DD-R 0-1 cm (N)	L07080556	LET
			DD-R 1-2 cm (N)	L07080556	LET
			DD-R 2-3 cm (N)	L07080556	LET
L07080631	21-Aug-07				
		TISSUE			
			Blank Filter (N)	L07080631	LET
			Pro 21/Site 1/Adult (N)	L07080631	LET
			Pro 21/Site 1/Juvenile (N)	L07080631	LET
			Pro 21/Site 1/N-C (N)	L07080631	LET
			Pro 21/Site 1/Ses Clog (N)	L07080631	LET
			Pro 21/Site 3/Adult (N)	L07080631	LET
			Pro 21/Site 3/Juvenile (N)	L07080631	LET
			Pro 21/Site 3/N-C (N)	L07080631	LET
			Pro 21/Site 3/Ses Clog (N)	L07080631	LET
			Pro 21/Site 3/Ses ClogMS (MS)	L07080631	LET
			Pro 21/Site 4/Adult (N)	L07080631	LET
			Pro 21/Site 4/Juvenile (N)	L07080631	LET
			Pro 21/Site 4/JuvenileMS (MS)	L07080631	LET
			Pro 21/Site 4/N-C (N)	L07080631	LET
			Pro 21/Site 4/Ses Clog (N)	L07080631	LET
			Pro 21/Site 6/Adult (N)	L07080631	LET
			Pro 21/Site 6/Juvenile (N)	L07080631	LET
			Pro 21/Site 6/N-C (N)	L07080631	LET
			Pro 21/Site 6/Ses Clog (N)	L07080631	LET
			Pro 21/Site 7/Adult (N)	L07080631	LET
			Pro 21/Site 7/Juvenile (N)	L07080631	LET
			Pro 21/Site 7/N-C (N)	L07080631	LET
			Pro 21/Site 7/Ses Clog (N)	L07080631	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
L07080631	21-Aug-07				
		TISSUE			
			Pro 21/Site 9/Adult (N)	L07080631	LET
			Pro 21/Site 9/N-C (N)	L07080631	LET
			Pro 21/Site 9/Ses Clog (N)	L07080631	LET
			Pro 21/Site 9/Ses ClogMS (MS)	L07080631	LET
L07100001	31-Aug-07				
		TISSUE			
			CS-2 / F-1 / Adult (N)	L07100001	LET
			CS-2 / F-1 / Nauplii (N)	L07100001	LET
			CS-2 / F-2 / Adult (N)	L07100001	LET
			CS-2 / F-2 / Nauplii (N)	L07100001	LET
			CS-2 / F-3 / Adult (N)	L07100001	LET
			CS-2 / F-3 / Nauplii (N)	L07100001	LET
			CS-2 / F-4 / Adult (N)	L07100001	LET
			CS-2 / F-4 / Nauplii (N)	L07100001	LET
			CS-2 / F-5 / Adult (N)	L07100001	LET
			CS-2 / F-5 / Nauplii (N)	L07100001	LET
			CS-2 / NF-1 / Adult (N)	L07100001	LET
			CS-2 / NF-1 / Nauplii (N)	L07100001	LET
			CS-2 / NF-2 / Adult (N)	L07100001	LET
			CS-2 / NF-2 / Nauplii (N)	L07100001	LET
			CS-2 / NF-3 / Adult (N)	L07100001	LET
			CS-2 / NF-3 / Nauplii (N)	L07100001	LET
			CS-2 / NF-3 / NaupliiMS (MS)	L07100001	LET
			CS-2 / NF-4 / Adult (N)	L07100001	LET
			CS-2 / NF-4 / AdultMS (MS)	L07100001	LET
			CS-2 / NF-4 / Nauplii (N)	L07100001	LET
			CS-2 / NF-5 / Adult (N)	L07100001	LET
			CS-2 / NF-5 / Nauplii (N)	L07100001	LET
			CS-2 / NF-5 / NaupliiMS (MS)	L07100001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-001	04-May-06				
		SOLID			
			Sediment A-1 (MS)	L06060006	LET
			Sediment A-1 (N)	L06060006	LET
			Sediment A-1 (N)	L06060006-161-233-TO	LET
			Sediment H-1 (N)	L06060006	LET
			Sediment H-1 (N)	L06060006-161-233-TO	LET
			Sediment M-1 (N)	L06060006	LET
			Sediment M-1 (N)	L06060006-161-233-TO	LET
		TISSUE			
			Blood A-1 (N)	L06060006	LET
			Blood A-10 (N)	L06060006	LET
			Blood A-11 (N)	L06060006	LET
			Blood A-12 (MS)	L06060006	LET
			Blood A-12 (N)	L06060006	LET
			Blood A-2 (MS)	L06060006	LET
			Blood A-2 (N)	L06060006	LET
			Blood A-3 (N)	L06060006	LET
			Blood A-4 (N)	L06060006	LET
			Blood A-5 (N)	L06060006	LET
			Blood A-6 (N)	L06060006	LET
			Blood A-7 (N)	L06060006	LET
			Blood A-8 (N)	L06060006	LET
			Blood A-9 (N)	L06060006	LET
			Blood CG-01 (N)	L06060006	LET
			Blood CG-02 (N)	L06060006	LET
			Blood CG-03 (N)	L06060006	LET
			Blood CG-04 (N)	L06060006	LET
			Blood CG-05 (N)	L06060006	LET
			Blood CG-06 (N)	L06060006	LET
			Blood CG-07 (MS)	L06060006	LET
			Blood CG-07 (N)	L06060006	LET
			Blood CG-08 (N)	L06060006	LET
			Blood CG-09 (N)	L06060006	LET
			Blood CG-10 (N)	L06060006	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-001	04-May-06				
		TISSUE			
			Blood CG-11 (N)	L06060006	LET
			Blood H-1 (N)	L06060006	LET
			Blood H-10 (N)	L06060006	LET
			Blood H-11 (N)	L06060006	LET
			Blood H-12 (N)	L06060006	LET
			Blood H-2 (N)	L06060006	LET
			Blood H-3 (N)	L06060006	LET
			Blood H-4 (N)	L06060006	LET
			Blood H-5 (N)	L06060006	LET
			Blood H-6 (N)	L06060006	LET
			Blood H-7 (MS)	L06060006	LET
			Blood H-7 (N)	L06060006	LET
			Blood H-8 (N)	L06060006	LET
			Blood H-9 (N)	L06060006	LET
			Egg A-1 (N)	L06060006	LET
			Egg A-10 (N)	L06060006	LET
			Egg A-11 (MS)	L06060006	LET
			Egg A-11 (N)	L06060006	LET
			Egg A-12 (N)	L06060006	LET
			Egg A-2 (N)	L06060006	LET
			Egg A-3 (MS)	L06060006	LET
			Egg A-3 (N)	L06060006	LET
			Egg A-4 (N)	L06060006	LET
			Egg A-5 (N)	L06060006	LET
			Egg A-6 (N)	L06060006	LET
			Egg A-7 (N)	L06060006	LET
			Egg A-8 (N)	L06060006	LET
			Egg A-9 (N)	L06060006	LET
			Egg H-1 (N)	L06060006	LET
			Egg H-10 (N)	L06060006	LET
			Egg H-11 (N)	L06060006	LET
			Egg H-12 (N)	L06060006	LET
			Egg H-2 (N)	L06060006	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-001	04-May-06				
		TISSUE			
			Egg H-3 (N)	L06060006	LET
			Egg H-4 (N)	L06060006	LET
			Egg H-5 (N)	L06060006	LET
			Egg H-6 (N)	L06060006	LET
			Egg H-7 (MS)	L06060006	LET
			Egg H-7 (N)	L06060006	LET
			Egg H-8 (N)	L06060006	LET
			Egg H-9 (N)	L06060006	LET
			Egg M-1 (N)	L06060006	LET
			Egg M-10 (N)	L06060006	LET
			Egg M-11 (N)	L06060006	LET
			Egg M-12 (N)	L06060006	LET
			Egg M-2 (N)	L06060006	LET
			Egg M-3 (N)	L06060006	LET
			Egg M-4 (N)	L06060006	LET
			Egg M-5 (N)	L06060006	LET
			Egg M-6 (N)	L06060006	LET
			Egg M-7 (N)	L06060006	LET
			Egg M-8 (MS)	L06060006	LET
			Egg M-8 (N)	L06060006	LET
			Egg M-9 (N)	L06060006	LET
			Liver A-1 (N)	L06060006	LET
			Liver A-10 (N)	L06060006	LET
			Liver A-11 (N)	L06060006	LET
			Liver A-12 (N)	L06060006	LET
			Liver A-2 (N)	L06060006	LET
			Liver A-3 (N)	L06060006	LET
			Liver A-4 (N)	L06060006	LET
			Liver A-5 (MS)	L06060006	LET
			Liver A-5 (N)	L06060006	LET
			Liver A-6 (N)	L06060006	LET
			Liver A-7 (N)	L06060006	LET
			Liver A-8 (N)	L06060006	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-001	04-May-06				
		TISSUE			
			Liver A-9 (N)	L06060006	LET
			Liver CG-01 (MS)	L06060006	LET
			Liver CG-01 (N)	L06060006	LET
			Liver CG-02 (N)	L06060006	LET
			Liver CG-03 (N)	L06060006	LET
			Liver CG-04 (N)	L06060006	LET
			Liver CG-05 (N)	L06060006	LET
			Liver CG-06 (N)	L06060006	LET
			Liver CG-07 (N)	L06060006	LET
			Liver CG-08 (MS)	L06060006	LET
			Liver CG-08 (N)	L06060006	LET
			Liver CG-09 (N)	L06060006	LET
			Liver CG-10 (N)	L06060006	LET
			Liver CG-11 (N)	L06060006	LET
			Liver H-1 (N)	L06060006	LET
			Liver H-10 (N)	L06060006	LET
			Liver H-11 (N)	L06060006	LET
			Liver H-12 (N)	L06060006	LET
			Liver H-2 (N)	L06060006	LET
			Liver H-3 (N)	L06060006	LET
			Liver H-4 (N)	L06060006	LET
			Liver H-5 (N)	L06060006	LET
			Liver H-6 (N)	L06060006	LET
			Liver H-7 (MS)	L06060006	LET
			Liver H-7 (N)	L06060006	LET
			Liver H-8 (N)	L06060006	LET
			Liver H-9 (N)	L06060006	LET
			Shrimp A-1 (MS)	L06060006	LET
			Shrimp A-1 (N)	L06060006	LET
			Shrimp A-2 (N)	L06060006	LET
			Shrimp A-3 (N)	L06060006	LET
			Shrimp A-4 (N)	L06060006	LET
			Shrimp A-5 (N)	L06060006	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-001	04-May-06				
		TISSUE			
			Shrimp H-1 (N)	L06060006	LET
			Shrimp H-2 (N)	L06060006	LET
			Shrimp H-3 (N)	L06060006	LET
			Shrimp H-4 (N)	L06060006	LET
			Shrimp H-5 (N)	L06060006	LET
			Shrimp M-1 (N)	L06060006	LET
			Shrimp M-2 (N)	L06060006	LET
			Shrimp M-3 (MS)	L06060006	LET
			Shrimp M-3 (N)	L06060006	LET
			Shrimp M-4 (N)	L06060006	LET
			Shrimp M-5 (N)	L06060006	LET
LET-002	02-Jun-06				
		SOLID			
			GS-10 SURFACE (N)	L06060006-161-233-TO	LET
			GS-10 SURFACE (N)	L06060161	LET
			GS-11 (N)	L06060006-161-233-TO	LET
			GS-11 (N)	L06060161	LET
			GS-13 Comp. (N)	L06060006-161-233-TO	LET
			GS-13 Comp. (N)	L06060161	LET
			GS-18 (N)	L06060006-161-233-TO	LET
			GS-18 (N)	L06060161	LET
			GS-19 (MS)	L06060161	LET
			GS-19 (N)	L06060006-161-233-TO	LET
			GS-19 (N)	L06060161	LET
			GS-20 (N)	L06060006-161-233-TO	LET
			GS-20 (N)	L06060161	LET
			GS-4 (N)	L06060006-161-233-TO	LET
			GS-4 (N)	L06060161	LET
			GS-9 (N)	L06060006-161-233-TO	LET
			GS-9 (N)	L06060161	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-003	16-Jun-06				
		SOLID			
			20 (N)	L06080012	LET
			22 (N)	L06080012	LET
			23 (N)	L06080012	LET
			ANTI-1-S (MS)	L06080012	LET
			ANTI-1-S (N)	L06080012	LET
			ANTI-2-S (N)	L06080012	LET
			ANTI-3-S (N)	L06080012	LET
			OGBA-1-S (N)	L06080012	LET
			OGBA-2-S (N)	L06080012	LET
			OGBA-3-S (N)	L06080012	LET
			SALT-1-S (N)	L06080012	LET
			SALT-2-S (MS)	L06080012	LET
			SALT-2-S (N)	L06080012	LET
			SALT-3-S (N)	L06080012	LET
		TISSUE			
			1 (N)	L06080012	LET
			10 (N)	L06080012	LET
			11 (N)	L06080012	LET
			12 (N)	L06080012	LET
			13 (N)	L06080012	LET
			14 (N)	L06080012	LET
			15 (N)	L06080012	LET
			16 (N)	L06080012	LET
			17 (N)	L06080012	LET
			18 (MS)	L06080012	LET
			18 (N)	L06080012	LET
			19 (N)	L06080012	LET
			2 (N)	L06080012	LET
			21 (N)	L06080012	LET
			24 (N)	L06080012	LET
			3 (N)	L06080012	LET
			4 (N)	L06080012	LET
			5 (N)	L06080012	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-003	16-Jun-06				
		TISSUE			
			6 (N)	L06080012	LET
			6106-1-AML a (N)	L06080012	LET
			6106-1-AML b (N)	L06080012	LET
			6106-2-AML a (N)	L06080012	LET
			6106-2-AML b (N)	L06080012	LET
			6106-3-AML a (N)	L06080012	LET
			6106-3-AML b (N)	L06080012	LET
			6106-4-AML a (N)	L06080012	LET
			6106-5-AML a (N)	L06080012	LET
			6106-5-AML b (MS)	L06080012	LET
			6106-5-AML b (N)	L06080012	LET
			61306-1-AML a (N)	L06080012	LET
			61306-1-AML b (N)	L06080012	LET
			61306-2-AML a (N)	L06080012	LET
			61306-2-AML b (N)	L06080012	LET
			61306-3-AML a (N)	L06080012	LET
			61306-3-AML b (N)	L06080012	LET
			6606-10-AML a (MS)	L06080012	LET
			6606-10-AML a (N)	L06080012	LET
			6606-10-AML b (N)	L06080012	LET
			6606-1-JFC a (N)	L06080012	LET
			6606-1-JFC b (N)	L06080012	LET
			6606-2-JFC a (N)	L06080012	LET
			6606-2-JFC b (N)	L06080012	LET
			6606-3-JFC a (N)	L06080012	LET
			6606-3-JFC b (N)	L06080012	LET
			6606-4-JFC a (N)	L06080012	LET
			6606-4-JFC b (N)	L06080012	LET
			6606-5-JFC a (MS)	L06080012	LET
			6606-5-JFC a (N)	L06080012	LET
			6606-5-JFC b (N)	L06080012	LET
			6606-6-AML a (N)	L06080012	LET
			6606-6-AML b (N)	L06080012	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-003	16-Jun-06				
		TISSUE			
			6606-7-AML a (N)	L06080012	LET
			6606-7-AML b (MS)	L06080012	LET
			6606-7-AML b (N)	L06080012	LET
			6606-8-AML a (N)	L06080012	LET
			6606-8-AML b (N)	L06080012	LET
			6606-9-AML a (N)	L06080012	LET
			6606-9-AML b (N)	L06080012	LET
			6706-1-JFC a (N)	L06080012	LET
			6706-1-JFC b (N)	L06080012	LET
			6706-2-JFC a (N)	L06080012	LET
			6706-2-JFC b (N)	L06080012	LET
			7 (N)	L06080012	LET
			8 (MS)	L06080012	LET
			8 (N)	L06080012	LET
			9 (N)	L06080012	LET
			AML-1-06 (N)	L06080012	LET
			AML-131-06 (N)	L06080012	LET
			AML-2-06 (MS)	L06080012	LET
			AML-2-06 (N)	L06080012	LET
			AML-3-06 (N)	L06080012	LET
			ANTI-1-I a (N)	L06080012	LET
			ANTI-1-I b (N)	L06080012	LET
			ANTI-1-I c (N)	L06080012	LET
			ANTI-2-I a (N)	L06080012	LET
			ANTI-2-I b (N)	L06080012	LET
			ANTI-2-I c (N)	L06080012	LET
			ANTI-2-I d (N)	L06080012	LET
			ANTI-3-I a (N)	L06080012	LET
			ANTI-3-I b (N)	L06080012	LET
			ANTI-3-I c (N)	L06080012	LET
			ANTI-3-I d (MS)	L06080012	LET
			ANTI-3-I d (N)	L06080012	LET
			ANTI-3-I e (N)	L06080012	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-003	16-Jun-06				
		TISSUE			
			BJO-08-06 (MS)	L06080012	LET
			BJO-08-06 (N)	L06080012	LET
			BJO-100-06 (N)	L06080012	LET
			BJO-5-06 (N)	L06080012	LET
			BJO-67-06 (N)	L06080012	LET
			BJO-68-06 (N)	L06080012	LET
			BJO-7-06 (N)	L06080012	LET
			CNE-500-06 (N)	L06080012	LET
			CNE-502-06 (N)	L06080012	LET
			JAC-01-06 (MS)	L06080012	LET
			JAC-01-06 (N)	L06080012	LET
			JAC-15-06 (N)	L06080012	LET
			JAC-20-06 (N)	L06080012	LET
			JAC-21-06 (N)	L06080012	LET
			JAC-22-06 (N)	L06080012	LET
			JAC-30-06 (N)	L06080012	LET
			JAC-3-06 (N)	L06080012	LET
			JAC-31-06 (N)	L06080012	LET
			JAC-32-06 (N)	L06080012	LET
			JAC-33-06 (N)	L06080012	LET
			JAC-34-06 (N)	L06080012	LET
			JAC-4-06 (N)	L06080012	LET
			JAC-5-06 (N)	L06080012	LET
			JAC-51-06 (N)	L06080012	LET
			JAC-60-06 (N)	L06080012	LET
			JAC-6-06 (N)	L06080012	LET
			JAC-61-06 (MS)	L06080012	LET
			JAC-61-06 (N)	L06080012	LET
			JAC-62-06 (N)	L06080012	LET
			JAC-7-06 (N)	L06080012	LET
			JAC-8-06 (N)	L06080012	LET
			JAC-9-06 (N)	L06080012	LET
			JFC-06-06 (N)	L06080012	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-003	16-Jun-06				
		TISSUE			
			JFC-12-06 (N)	L06080012	LET
			JFC-37-06 (N)	L06080012	LET
			JFC-9-06 (N)	L06080012	LET
			KEE-169-06 (MS)	L06080012	LET
			KEE-169-06 (N)	L06080012	LET
			KEE-171-06 (N)	L06080012	LET
			KEE-175-06 (N)	L06080012	LET
			KEE-2-06 (N)	L06080012	LET
			KEE-5-06 (MS)	L06080012	LET
			KEE-5-06 (N)	L06080012	LET
			KT-1-06 (N)	L06080012	LET
			LJA-152-06 (N)	L06080012	LET
			LJA-160-06 (N)	L06080012	LET
			LJA-211-06 (N)	L06080012	LET
			LJA-212-06 (N)	L06080012	LET
			LJA-213-06 (N)	L06080012	LET
			MEF-74-06 (N)	L06080012	LET
			NS-06-06 (N)	L06080012	LET
			NS-100-06 (N)	L06080012	LET
			NS-10-06 (N)	L06080012	LET
			NS-8-06 (N)	L06080012	LET
			NS-9-06 (N)	L06080012	LET
			OGBA-1-I a (N)	L06080012	LET
			OGBA-1-I b (N)	L06080012	LET
			OGBA-2-I a (N)	L06080012	LET
			OGBA-2-I b (N)	L06080012	LET
			OGBA-2-I c (N)	L06080012	LET
			OGBA-3-I a (MS)	L06080012	LET
			OGBA-3-I a (N)	L06080012	LET
			OGBA-3-I b (N)	L06080012	LET
			OGBA-3-I c (N)	L06080012	LET
			OGBA-3-I d (N)	L06080012	LET
			SALT-1-I a (N)	L06080012	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-003	16-Jun-06				
		TISSUE			
			SALT-1-I b (MS)	L06080012	LET
			SALT-1-I b (N)	L06080012	LET
			SALT-2-I a (N)	L06080012	LET
			SALT-2-I b (N)	L06080012	LET
			SALT-3-I a (N)	L06080012	LET
			SALT-3-I b (N)	L06080012	LET
			SAP-1-06 (N)	L06080012	LET
			SAP-2-06 (N)	L06080012	LET
			SAP-4-06 (N)	L06080012	LET
			SAP-5-06 (N)	L06080012	LET
LET-004	14-Jun-06				
		TISSUE			
			CNE-501-06 (N)	L06080360	LET
			JAC-50-06 (N)	L06080360	LET
			JFC-32-06 (N)	L06080360	LET
			JFC-33-06 (N)	L06080360	LET
			JFC-34-06 (N)	L06080360	LET
			JFC-35-06 (N)	L06080360	LET
			JFC-36-06 (N)	L06080360	LET
			LJA-151-06 (N)	L06080360	LET
			SAP-18-06 (MS)	L06080360	LET
			SAP-18-06 (N)	L06080360	LET
			SAP-19-06 (MS)	L06080360	LET
			SAP-19-06 (N)	L06080360	LET
			SAP-22-06 (N)	L06080360	LET
			SAP-25-06 (N)	L06080360	LET
LET-005	27-Jun-06				
		SOLID			
			GS1 - mineral layer (N)	L06060006-161-233-TO	LET
			GS1 - mineral layer (N)	L06070233	LET
			GS11 - mineral layer (MS)	L06070233	LET

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Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-005	27-Jun-06				
		SOLID			
			GS11 - mineral layer (N)	L06060006-161-233-TO	LET
			GS11 - mineral layer (N)	L06070233	LET
			GS11-ooze (MS)	L06070233	LET
			GS11-ooze (N)	L06060006-161-233-TO	LET
			GS11-ooze (N)	L06070233	LET
			GS12 - mineral layer (N)	L06060006-161-233-TO	LET
			GS12 - mineral layer (N)	L06070233	LET
			GS12-ooze (N)	L06060006-161-233-TO	LET
			GS12-ooze (N)	L06070233	LET
			GS14 - mineral layer (N)	L06060006-161-233-TO	LET
			GS14 - mineral layer (N)	L06070233	LET
			GS14-ooze (N)	L06060006-161-233-TO	LET
			GS14-ooze (N)	L06070233	LET
			GS15 - mineral layer (N)	L06060006-161-233-TO	LET
			GS15 - mineral layer (N)	L06070233	LET
			GS18 - mineral layer (N)	L06060006-161-233-TO	LET
			GS18 - mineral layer (N)	L06070233	LET
			GS18-ooze (N)	L06060006-161-233-TO	LET
			GS18-ooze (N)	L06070233	LET
			GS1-ooze (N)	L06060006-161-233-TO	LET
			GS1-ooze (N)	L06070233	LET
			GS20 - mineral layer (N)	L06060006-161-233-TO	LET
			GS20 - mineral layer (N)	L06070233	LET
			GS20-ooze (N)	L06060006-161-233-TO	LET
			GS20-ooze (N)	L06070233	LET
			GS3 - mineral layer (N)	L06060006-161-233-TO	LET
			GS3 - mineral layer (N)	L06070233	LET
			GS4 - mineral layer (N)	L06060006-161-233-TO	LET
			GS4 - mineral layer (N)	L06070233	LET
			GS4-ooze (N)	L06060006-161-233-TO	LET
			GS4-ooze (N)	L06070233	LET
			GS5 - mineral layer (N)	L06060006-161-233-TO	LET
			GS5 - mineral layer (N)	L06070233	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-005	27-Jun-06				
		SOLID			
			GS5-ooze (N)	L06060006-161-233-TO	LET
			GS5-ooze (N)	L06070233	LET
			GS8 - mineral layer (N)	L06060006-161-233-TO	LET
			GS8 - mineral layer (N)	L06070233	LET
			GS8-ooze (N)	L06060006-161-233-TO	LET
			GS8-ooze (N)	L06070233	LET
			GS9 - mineral layer (N)	L06060006-161-233-TO	LET
			GS9 - mineral layer (N)	L06070233	LET
			GS9-ooze (N)	L06060006-161-233-TO	LET
			GS9-ooze (N)	L06070233	LET
LET-010307	28-Sep-06				
		TISSUE			
			1-092806 (N)	L06100351	LET
			2-092806 (N)	L06100351	LET
			3 and 4-092806 (N)	L06100351	LET
			Pro 1/Site 1/Adult (850) (N)	L06100351	LET
			Pro 1/Site 2/Adult (850) (N)	L06100351	LET
			Pro 1/Site 3/Adult (850) (N)	L06100351	LET
			Pro 1/Site 4/Adult (850) (N)	L06100351	LET
			Pro 1/Site 6/Adult (850) (N)	L06100351	LET
			Pro 1/Site 7/Adult (850) (N)	L06100351	LET
			Pro 1/Site 9/Adult (850) (MS)	L06100351	LET
			Pro 1/Site 9/Adult (850) (N)	L06100351	LET
			Pro 10B/Site 1/Adult (850 (N)	L06100351	LET
			Pro 10B/Site 1/Juv (500) (N)	L06100351	LET
			Pro 10B/Site 1/N-C (125) (N)	L06100351	LET
			Pro 10B/Site 3/Adult (850 (N)	L06100351	LET
			Pro 10B/Site 3/Juv (500) (N)	L06100351	LET
			Pro 10B/Site 3/N-C (125) (N)	L06100351	LET
			Pro 10B/Site 4/Adult (850 (N)	L06100351	LET
			Pro 10B/Site 4/Juv (500) (N)	L06100351	LET
			Pro 10B/Site 4/N-C (125) (MS)	L06100351	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-010307	28-Sep-06				
		TISSUE			
			Pro 10B/Site 4/N-C (125) (N)	L06100351	LET
			Pro 10B/Site 6/Adult (850 (N)	L06100351	LET
			Pro 10B/Site 6/Juv (500) (N)	L06100351	LET
			Pro 10B/Site 6/N-C (125) (N)	L06100351	LET
			Pro 10B/Site 7/N-C (125) (N)	L06100351	LET
			Pro 10B/Site 9/Adult (850 (MS)	L06100351	LET
			Pro 10B/Site 9/Adult (850 (N)	L06100351	LET
			Pro 10B/Site 9/Juv (500) (N)	L06100351	LET
			Pro 10B/Site 9/N-C (125) (N)	L06100351	LET
			Pro 11/Site 1/Adult (850) (N)	L06100351	LET
			Pro 11/Site 1/Juv (500) (N)	L06100351	LET
			Pro 11/Site 1/N-C (125) (N)	L06100351	LET
			Pro 11/Site 3/Adult (850) (N)	L06100351	LET
			Pro 11/Site 3/Juv (500) (N)	L06100351	LET
			Pro 11/Site 3/N-C (125) (N)	L06100351	LET
			Pro 11/Site 4/Adult (850) (N)	L06100351	LET
			Pro 11/Site 4/Juv (500) (N)	L06100351	LET
			Pro 11/Site 4/N-C (125) (MS)	L06100351	LET
			Pro 11/Site 4/N-C (125) (N)	L06100351	LET
			Pro 11/Site 6/Adult (850) (N)	L06100351	LET
			Pro 11/Site 6/Juv (500) (N)	L06100351	LET
			Pro 11/Site 6/N-C (125) (N)	L06100351	LET
			Pro 11/Site 7/Adult (850) (N)	L06100351	LET
			Pro 11/Site 7/Juv (500) (N)	L06100351	LET
			Pro 11/Site 7/N-C (125) (N)	L06100351	LET
			Pro 11/Site 9/Adult (850) (MS)	L06100351	LET
			Pro 11/Site 9/Adult (850) (N)	L06100351	LET
			Pro 11/Site 9/N-C (125) (N)	L06100351	LET
			Pro 2/Site 1/Adult (850) (N)	L06100351	LET
			Pro 2/Site 2/Adult (850) (N)	L06100351	LET
			Pro 2/Site 3/Adult (850) (N)	L06100351	LET
			Pro 2/Site 4/Adult (850) (N)	L06100351	LET
			Pro 2/Site 5/Adult (850) (N)	L06100351	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-010307	28-Sep-06				
		TISSUE			
			Pro 2/Site 6/Adult (850) (N)	L06100351	LET
			Pro 2/Site 7/Adult (850) (N)	L06100351	LET
			Pro 2/Site 8/Adult (850) (N)	L06100351	LET
			Pro 2B/Site 1/Adult (850) (N)	L06100351	LET
			Pro 2B/Site 2/Adult (850) (MS)	L06100351	LET
			Pro 2B/Site 2/Adult (850) (N)	L06100351	LET
			Pro 2B/Site 3/Adult (850) (N)	L06100351	LET
			Pro 2B/Site 4/Adult (850) (N)	L06100351	LET
			Pro 2B/Site 5/Adult (850) (N)	L06100351	LET
			Pro 2B/Site 6/Adult (850) (N)	L06100351	LET
			Pro 3/Site 1/Adult (850) (N)	L06100351	LET
			Pro 3/Site 2/Adult (850) (N)	L06100351	LET
			Pro 3/Site 3/Adult (850) (N)	L06100351	LET
			Pro 3/Site 4/Adult (850) (N)	L06100351	LET
			Pro 3/Site 5/Adult (850) (N)	L06100351	LET
			Pro 3/Site 6/Adult (850) (MS)	L06100351	LET
			Pro 3/Site 6/Adult (850) (N)	L06100351	LET
			Pro 3/Site 7/Adult (850) (N)	L06100351	LET
			Pro 3/Site 8/Adult (850) (N)	L06100351	LET
			Pro 3/Site 9/Adult (850) (N)	L06100351	LET
			Pro 5/Site 1/Adult (850) (N)	L06100351	LET
			Pro 5/Site 2/Adult (850) (N)	L06100351	LET
			Pro 5/Site 3/Adult (850) (N)	L06100351	LET
			Pro 5/Site 4/Adult (850) (N)	L06100351	LET
			Pro 5/Site 5/Adult (850) (N)	L06100351	LET
			Pro 5/Site 6/Adult (850) (MS)	L06100351	LET
			Pro 5/Site 6/Adult (850) (N)	L06100351	LET
			Pro 5/Site 7/Adult (850) (N)	L06100351	LET
			Pro 5/Site 8/Adult (850) (N)	L06100351	LET
			Pro 5/Site 9/Adult (850) (N)	L06100351	LET
			Pro 6/Site 1/Adult (850) (N)	L06100351	LET
			Pro 6/Site 3/Adult (850) (N)	L06100351	LET
			Pro 6/Site 4/Adult (850) (N)	L06100351	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-010307	28-Sep-06				
		TISSUE			
			Pro 6/Site 6/Adult (850) (N)	L06100351	LET
			Pro 6/Site 7/Adult (850) (N)	L06100351	LET
			Pro 6/Site 9/Adult (850) (N)	L06100351	LET
			Pro 7/Site 1/Adult (850) (MS)	L06100351	LET
			Pro 7/Site 1/Adult (850) (N)	L06100351	LET
			Pro 7/Site 3/Adult (850) (N)	L06100351	LET
			Pro 7/Site 4/Adult (850) (N)	L06100351	LET
			Pro 7/Site 6/Adult (850) (N)	L06100351	LET
			Pro 7/Site 7/Adult (850) (N)	L06100351	LET
			Pro 7/Site 9/Adult (850) (N)	L06100351	LET
			Pro 8/Site 1/Adult (850) (N)	L06100351	LET
			Pro 8/Site 1/N-C (125) (N)	L06100351	LET
			Pro 8/Site 3/Adult (850) (N)	L06100351	LET
			Pro 8/Site 3/N-C (125) (N)	L06100351	LET
			Pro 8/Site 4/Adult (850) (N)	L06100351	LET
			Pro 8/Site 4/N-C (125) (N)	L06100351	LET
			Pro 8/Site 6/Adult (850) (N)	L06100351	LET
			Pro 8/Site 6/N-C (125) (N)	L06100351	LET
			Pro 8/Site 7/Adult (850) (N)	L06100351	LET
			Pro 8/Site 9/Adult (850) (MS)	L06100351	LET
			Pro 8/Site 9/Adult (850) (N)	L06100351	LET
			Pro 8/Site 9/N-C (125) (N)	L06100351	LET
			Pro 9/Site 1/Adult (850) (N)	L06100351	LET
			Pro 9/Site 1/N-C (125) (N)	L06100351	LET
			Pro 9/Site 3/Adult (850) (N)	L06100351	LET
			Pro 9/Site 3/N-C (125) (N)	L06100351	LET
			Pro 9/Site 4/Adult (850) (N)	L06100351	LET
			Pro 9/Site 4/N-C (125) (N)	L06100351	LET
			Pro 9/Site 6/Adult (850 (N)	L06100351	LET
			Pro 9/Site 6/N-C (125) (N)	L06100351	LET
			Pro 9/Site 7/Adult (850) (MS)	L06100351	LET
			Pro 9/Site 7/Adult (850) (N)	L06100351	LET
			Pro 9/Site 7/N-C (125) (N)	L06100351	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-010307	28-Sep-06				
		TISSUE			
			Pro 9/Site 9/Adult (850) (N)	L06100351	LET
			Pro 9/Site 9/N-C (125) (N)	L06100351	LET
LET-010307A	25-Jul-06				
		SOLID			
			2267 5-26-06 #1 (N)	L06110001	LET
			2267 5-26-06 #2 (N)	L06110001	LET
			2267 6-19-06 composite (N)	L06110001	LET
			2267 7-28-06 #1 (N)	L06110001	LET
			2267 7-28-06 #2 (N)	L06110001	LET
			2267-2 0-2 cm (N)	L06110001	LET
			2267-2 10-13 cm (N)	L06110001	LET
			2267-2 13-16 cm (MS)	L06110001	LET
			2267-2 13-16 cm (N)	L06110001	LET
			2267-2 16-19 cm (N)	L06110001	LET
			2267-2 19-22 cm (N)	L06110001	LET
			2267-2 2-4 cm (N)	L06110001	LET
			2267-2 25-28 cm (N)	L06110001	LET
			2267-2 4-6 cm (N)	L06110001	LET
			2267-2 6-8 cm (N)	L06110001	LET
			2267-2 84-88 cm (N)	L06110001	LET
			2565 5-26-06 deep #1 (N)	L06110001	LET
			2565 5-26-06 deep #2 (MS)	L06110001	LET
			2565 5-26-06 deep #2 (N)	L06110001	LET
			2565-3 0-2 cm (N)	L06110001	LET
			2565-3 10-12 cm (N)	L06110001	LET
			2565-3 12-14 cm (MS)	L06110001	LET
			2565-3 12-14 cm (N)	L06110001	LET
			2565-3 14-16 cm (N)	L06110001	LET
			2565-3 16-18 cm (N)	L06110001	LET
			2565-3 2-4 cm (N)	L06110001	LET
			2565-3 32-34 cm (N)	L06110001	LET
			2565-3 4-6 cm (N)	L06110001	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-010307A	25-Jul-06				
		SOLID			
			2565-3 6-8 cm (N)	L06110001	LET
			2565-3 8-10 cm (N)	L06110001	LET
			3510 7-27-06 deep #1 (N)	L06110001	LET
			3510 7-27-06 deep #2 (N)	L06110001	LET
			3510 Box 0-1 cm (N)	L06110001	LET
			3510 Box 1-2 cm (N)	L06110001	LET
			3510 Box 2-3 cm (N)	L06110001	LET
			3510 Box 3-4 cm (N)	L06110001	LET
			3510 Box 4-5 cm (N)	L06110001	LET
			3510 Box 5-6 cm (N)	L06110001	LET
			3510 Box 6-7 cm (MS)	L06110001	LET
			3510 Box 6-7 cm (N)	L06110001	LET
			3510 Box 7-8 cm (N)	L06110001	LET
			3510 Box 8-9 cm (N)	L06110001	LET
			3510 Box 9-10 cm (N)	L06110001	LET
LET-111906	13-Jul-06				
		FILTER			
			Pro 8/BLANK/Seston (FB)	L06100259	LET
			Program 10/BLANK/Seston (FB)	L06100259	LET
			Program 3/BLANK/Seston (FB)	L06100259	LET
			Program 5/BLANK/Seston (FB)	L06100259	LET
			Program 6/BLANK/Seston (FB)	L06100259	LET
			Program 7/BLANK/Seston (FB)	L06100259	LET
			Program 9/BLANK/Seston (FB)	L06100259	LET
		TISSUE			
			CH2M Visit/Site 9/Seston (N)	L06100259	LET
			Pro 10/Site 1/Seston/Clog (N)	L06100259	LET
			Pro 10/Site 3/Seston Clog (N)	L06100259	LET
			Pro 10/Site 4/Seston Clog (MS)	L06100259	LET
			Pro 10/Site 4/Seston Clog (N)	L06100259	LET
			Pro 10/Site 6/Seston Clog (N)	L06100259	LET
			Pro 10/Site 7/Seston Clog (N)	L06100259	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-111906	13-Jul-06				
		TISSUE			
			Pro 10/Site 9/Seston Clog (N)	L06100259	LET
			Pro 11/Site 1/Seston Clog (N)	L06100259	LET
			Pro 11/Site 3/Seston Clog (N)	L06100259	LET
			Pro 11/Site 4/Seston Clog (N)	L06100259	LET
			Pro 11/Site 6/Seston Clog (MS)	L06100259	LET
			Pro 11/Site 6/Seston Clog (N)	L06100259	LET
			Pro 11/Site 7/Seston Clog (N)	L06100259	LET
			Pro 11/Site 9/Seston Clog (N)	L06100259	LET
			Pro 8/Site 1/Seston Clog (N)	L06100259	LET
			Pro 8/Site 3/Seston Clog (N)	L06100259	LET
			Pro 8/Site 4/Seston Clog (N)	L06100259	LET
			Pro 8/Site 7/Seston Clog (N)	L06100259	LET
			Pro 8B/Site 6/Seston (N)	L06100259	LET
			Pro 9/Site 1/Seston Clog (MS)	L06100259	LET
			Pro 9/Site 1/Seston Clog (N)	L06100259	LET
			Pro 9/Site 3/Seston Clog (N)	L06100259	LET
			Pro 9/Site 4/Seston Clog (N)	L06100259	LET
			Pro 9/Site 6/Seston Clog (N)	L06100259	LET
			Pro 9/Site 7/Seston Clog (N)	L06100259	LET
			Pro 9/Site 9/Seston Clog (N)	L06100259	LET
			Program 3/Site 1/Seston (N)	L06100259	LET
			Program 3/Site 2/Seston (N)	L06100259	LET
			Program 3/Site 3/Seston (N)	L06100259	LET
			Program 3/Site 4/Seston (N)	L06100259	LET
			Program 3/Site 5/Seston (MS)	L06100259	LET
			Program 3/Site 5/Seston (N)	L06100259	LET
			Program 3/Site 6/Seston (N)	L06100259	LET
			Program 3/Site 7/Seston (N)	L06100259	LET
			Program 3/Site 8/Seston (N)	L06100259	LET
			Program 3/Site 9/Seston (N)	L06100259	LET
			Program 5/Site 2/Seston (N)	L06100259	LET
			Program 5/Site 3/Seston (N)	L06100259	LET
			Program 5/Site 4/Seston (N)	L06100259	LET

TABLE 2

Sample Summary by Chain of Custody – Data Summary

COC Number	Sample Date	Matrix	Sample ID (Type)	SDG	Laboratory
LET-111906	13-Jul-06				
		TISSUE			
			Program 5/Site 5/Seston (N)	L06100259	LET
			Program 5/Site 6/Seston (MS)	L06100259	LET
			Program 5/Site 6/Seston (N)	L06100259	LET
			Program 5/Site 7/Seston (N)	L06100259	LET
			Program 5/Site 8/Seston (N)	L06100259	LET
			Program 5/Site 9/Seston (N)	L06100259	LET
			Program 6/Site 1/Seston (N)	L06100259	LET
			Program 6/Site 3/Seston (N)	L06100259	LET
			Program 6/Site 4/Seston (N)	L06100259	LET
			Program 6/Site 6/Seston (N)	L06100259	LET
			Program 6/Site 7/Seston (N)	L06100259	LET
			Program 6/Site 9/Seston (N)	L06100259	LET
			Program 7 Site 9/Seston (N)	L06100259	LET
			Program 7/Site 1/Seston (N)	L06100259	LET
			Program 7/Site 3/Seston (MS)	L06100259	LET
			Program 7/Site 3/Seston (N)	L06100259	LET
			Program 7/Site 4/Seston (N)	L06100259	LET
			Program 7/Site 6/Seston (N)	L06100259	LET
			Program 7/Site 7/Seston (N)	L06100259	LET
			Program 8/Site 1/Seston (N)	L06100259	LET
			Program 8/Site 3/Seston (N)	L06100259	LET
			Program 8/Site 4/Seston (MS)	L06100259	LET
			Program 8/Site 4/Seston (N)	L06100259	LET
			Program 8/Site 7/Seston (N)	L06100259	LET
			Program 8/Site 9/Seston (N)	L06100259	LET

TABLE 3

Site Completeness by Analyte – Qualified Data

Method	Analyte	Units	Number of Occurrences								Contractor Percent Completeness	Overall Percent Completeness
			Analyses	Detects	Non-detects	Blank Flags	J Flags	M Flags	Contractor R Flags	Total R Flags		
LET-HFAA	Selenium	ug	1		1						100	100
LET-HFAA	Selenium	ug	2		2						100	100
LET-HFAA	Selenium	ug/g	1011	1002	9		12				100	100
LET-HFAA	Selenium	ug/g	202	179	23						100	100
LetHG	Mercury	ug/g	266	263	3						100	100

Attachment 3
Evaluation of Sample Preparation and Spiking for Analysis of Selenium in Great Salt Lake Water Sample

Evaluation of Sample Preparation and Spiking for Analysis of Selenium in Great Salt Lake Water Samples

PREPARED FOR: Great Salt Lake Science Panel, Utah Division of Water Quality

PREPARED BY: Project Team

DATE: October 31, 2007

Background

Frontier Geosciences Inc. (FGS) has been performing selenium analyses of water samples for the Great Salt Lake selenium project per protocol included in the project Quality Assurance Project Plan (QAPP). Both raw acidified and filtered acidified samples have been analyzed by the Hydride Generation-Atomic Fluorescence Spectrometry (HGAFS) method developed by FGS. This is the same methodology that was used in the round robin event that was used to select the analytical method by the Science Panel for the Great Salt Lake water quality studies.

At the November 30-31, 2006 Science Panel meeting, project team members expressed concern that no deep brine water samples had been spiked to date. CH2M HILL investigated and requested FGS to spike a deep brine water sample in early December. Results received in January indicated low recoveries in matrix spike/matrix spike duplicate analyses (MS/MSDs). This resulted in analyses of further MS/MSDs and the analyses described below to ascertain why low recoveries were observed and how deep brine analytical results should be interpreted. Summary information of the original deep brine MS/MSD recoveries received through January 2007 is presented in Table 1 below. Results from follow-on MS/MSD analyses are presented in subsequent sections. A separate Microsoft Excel workbook, titled "Analytical_Matrix_Spike_Recoveries", is included that provides the "raw" data that were used to create the summary tables and graphs for this memorandum.

Sample QC

FGS follows their internal standard operating procedures for sample preparation and analysis as included in the QAPP. FGS selected samples randomly for MS/MSD analyses in the absence of directions on the chain-of-custody. FGS followed the QAPP Method Quality Objectives when matrix spike recoveries did not meet criteria, reviewing other data quality indicators such as Laboratory Control Sample recoveries and investigating the cause and/or performing additional QC analyses as

necessary. Additional details are provided in the following sections. ***Information that has been updated since the previous version of this memorandum is italicized***.

TABLE 1
Original Deep Brine Layer MS/MSD Recoveries (December 2006 – February 2007)

Native ID	Recovery (%)
2565 7.5 M_120606 RAMS	72
2565 7.5 M_120606 RASD	52
2565 6.5M FA - Dissolved	20
2565 6.5M FA - Dissolved	11
2565 6.5 M RA- Total	18
2565 6.5 M RA- Total	31
2565 8.0 M_110106 FA	14
2565 8.0 M_110106 FA	22
2565 8.0 M_110106 RA	12
2565 8.0 M_110106 RA	10
3510 8.0M_120706 FA	22
3510 8.0M_120706 FA	22
3510 8.0M_120706 RA	5.0
3510 8.0M_120706 RA	16

Notes:
Native ID identifies location, depth, date and other sample specifics.
RA – Raw analysis
FA – Field filtered analysis
RAMS – Raw analysis, matrix spike
RASD – Raw analysis, matrix spike duplicate

Sample Preparation and Analysis

Frontier Geosciences (FGS) developed the following sample preparation processes for the determination of selenium by HGAFS. This preparation process has been used for all water samples collected from the Great Salt Lake to date. FGS will modify the procedure once they receive permission to do so.

1) Samples are collected and stored in capped high-density polyethylene bottles.
2) Upon sample receipt, the laboratory verifies the field preservation to a pH of 2.

3) The samples remain capped in the original sample bottle until an aliquot is removed. The bottle is shaken and then the aliquot is transferred to a 50-ml centrifuge tube. Each sample aliquot is capped and oven-digested by heating overnight at 85° Celsius. (Note that the heating process often loosens the cap until the cooling process is complete.) FGS performs the oven digestion to aid in the digestion of organic matter and mineral precipitates.

4) The samples are then digested by adding a predetermined amount of 40% hydrochloric acid and potassium persulfate solution (persulfate digestion). This step is performed to reduce all inorganic and organic selenium to selenium (IV). The sample aliquot used for the persulfate digestion is not shaken, to prevent undigested solid material from entering the instrument during analysis.

5) Because the oven-digested sample must be cool prior to beginning the persulfate step, this step can be performed several days earlier. However, once the persulfate digestion is performed, the sample is analyzed the same day to ensure selenium remains in a reduced state.

6) The persulfate-digested samples are reacted with sodium borohydride and analyzed by an atomic fluorescence detector to obtain the selenium concentration.

Instrument Calibration and Verification

The instrument's initial calibration standards (ICALs) and the continuing calibration standards (CCVs) are prepared using selenium (IV). The ICAL ranges from 50 ng to 3000 ng with an instrument blank the first point in the ICAL. The ICAL is calculated using a linear regression with a correlation coefficient greater than 0.995. These ICAL and CCV standards are not oven-digested or persulfate-digested, because these standards are made from selenium (IV). However, the ICALs, CCVs and continuing calibration blanks have potassium persulfate added to them prior to analysis to matrix-match the samples and standards.

Two secondary source standards prepared from selenomethionine sources are persulfate-digested and analyzed. These standards are prepared at the mid-level of the calibration range and have consistently yielded recoveries between 90 and 100+%.

Laboratory Control Sample QC Analyses

Laboratory control sample/laboratory control sample duplicates (LCS/LCSDs) are prepared from a National Institute of Standards and Technology (NIST) 1640 source of selenium (IV). The LCS/LCSDs undergo oven digestion and persulfate digestion

and yield recoveries within the QAPP recovery limits of 80-120%. The LCS/LCSD is spiked at approximately 20 ug/L.

Matrix Spike and Matrix Spike Duplicate, and Analytical Spike and Analytical Spike Duplicate Analyses

MS/MSDs are randomly selected and spiked near the midpoint of the initial calibration (approximately 1.8 ug/L) with selenium (IV) prior to oven digestion and persulfate digestion. The average recovery of all MS/MSDs, including both shallow and deep brine layers, through January 2007 is approximately 76%. The overall range of recoveries (including shallow brine) was *0% to 124%*. The average, minimum, and maximum recoveries for MS/MSDs in the deep brine through January 2007 are approximately 23%, 5%, 72% respectively.

MS/MSD samples analyzed from Brad Marden's sampling program demonstrated an average recovery of only 66%. *Frontier reprepared and analyzed the matrix spikes and associated samples with the lowest recoveries. These "new" matrix spikes demonstrated acceptable recoveries. It is believed that the previous low recoveries were due to analyst error. Frontier has been asked to reprepare and analyze all samples in the batches with those samples. A brief memorandum will be prepared when the analyses are completed to present these new data.*The exact sample locations and depths are still being correlated with Brad, but these samples are not believed to contain deep brine layer material. Attachment 1 includes a more detailed summary of the MS/MSD spike recoveries along with a chart indicating the recoveries from the earliest to latest analysis dates as you move from left to right in the chart.

Analytical spike/analytical spike duplicates (AS/ASDs) are spiked with selenomethionine without oven digestion and before persulfate digestion. Selenomethionine is used for the AS/ASD and the second source standards to ensure the persulfate digestion is properly reducing the organic form of selenium to inorganic selenium. The average recovery of the AS/ASDs is 92%. The minimum recovery was 61% and the maximum recovery was 121%.The deep brine and samples from Brad Marden's program have average recoveries of 96% and 92%, respectively. Attachment 2 at the end of the memorandum includes a summary of the AS/ASDs and associated spike recoveries along with a chart indicating the recoveries from the earliest to latest analysis dates as you move from left to right in the chart.

Additional Evaluation of the Sampling and Analytical Procedures for the Deep Brine Samples

Several tasks were identified during a conference call with the project team on March 14 as a first step to further investigate low recoveries identified in MS/MSDs. New information resulting from the additional analyses is summarized below.

There was insufficient sample remaining to perform additional MS/MSD analyses from prior samples collected in the deep brine. The following analytical study was performed on two samples collected in mid-March from the deep brine layer to assess the impact of oven digestion on three forms of selenium:

- *Selenite spike added to sample prior to oven digestion, persulfate digestion and analysis*
- *Selenate spike added to sample prior to oven digestion, persulfate digestion and analysis*
- *Selenomethionine spike added to sample prior to oven digestion, persulfate digestion and analysis*
- *Selenite spike added to sample prior to persulfate digestion and analysis – oven preparation step was removed from procedure*
- *Selenate spike added to sample prior to persulfate digestion and analysis – oven preparation step was removed from procedure*
- *Selenomethionine spike added to sample prior to persulfate digestion and analysis – oven preparation step was removed from procedure*

The study data (Tables 2, 3 and 4) indicate that the oven digestion procedure is responsible for the low recoveries of selenite in spiked deep brine samples to date. This was verified by poor selenite recoveries using the oven digestion procedure. It is noteworthy that the selenate and selenomethionine were not affected by the oven preparation procedure.

Ultimately, the study data indicate that the ideal sample preparation procedure for the deep brine samples is the elimination of the oven digestion procedure entirely. All three selenium species were recovered at greater than 90% of the spiked amount when the oven digestion procedure was omitted.

During the March sampling event, two deep brine samples were collected using a Kemmerer sampler along with filtered and unfiltered samples as collected in prior events. The samples collected using the Kemmerer sampler were used to aid in evaluating if the standard sample collection procedures were introducing a bias to the sample data. Results of MS analyses with those samples are presented in Table 4. These data indicate that the sampling collection procedure does not appear to introduce a bias to the sample data if oven digestion is not used.

TABLE 2
Deep Brine MS/MSD Recoveries from Recent Analysis Evaluating Prep/Sampling Methods

Native ID	Recovery (%)
2565 7.5m_032007 RASITMS	0
2565 7.5m_032007 RASATMS	77
2565 7.5m_032007 RASMNMS	93
2565 7.5m_032007 RANOSITMS	97
2565 7.5m_032007 RANOSATMS	92
2565 7.5m_032007 RANOSMNMS	95
2565 7.5m_032007 FASITMS	27
2565 7.5m_032007 FASATMS	98
2565 7.5m_032007 FASMNMS	92
2565 7.5m_032007 FANOSITMS	97
2565 7.5m_032007 FANOSATMS	96
2565 7.5m_032007 FANOSMNMS	93
3510 8.0m_031907 RASITMS	4.7
3510 8.0m_031907 RASATMS	88
3510 8.0m_031907 RASMNMS	101
3510 8.0m_031907 RANOSITMS	98
3510 8.0m_031907 RANOSATMS	94
3510 8.0m_031907 RANOSMNMS	95
3510 8.0m_031907 FASITMS	4.8
3510 8.0m_031907 FASATMS	86
3510 8.0m_031907 FASMNMS	88
3510 8.0m_031907 FANOSITMS	100
3510 8.0m_031907 FANOSATMS	97
3510 8.0m_031907 FANOSMNMS	93
3510 8.0m_031907 Kem RASITMS	20
3510 8.0m_031907 Kem RASATMS	84
3510 8.0m_031907 Kem RASMNMS	116

TABLE 2
Deep Brine MS/MSD Recoveries from Recent Analysis Evaluating Prep/Sampling Methods

Native ID	Recovery (%)
3510 8.0m_031907 Kem RANOSITMS	103
3510 8.0m_031907 Kem RANOSATMS	96
3510 8.0m_031907 Kem RANOSMNMS	94

Notes:
Native ID identifies location, depth, date and other sample specifics.
Kem –Sample collected with Kemmerer sampler
RASMNMS – Raw analysis, selenomethionine matrix spike
RASATMS – Raw analysis, selenate matrix spike
RASITMS – Raw analysis, selenite matrix spike
RANOSMNMS – Raw analysis, no oven digestion, selenomethionine matrix spike
RANOSATMS – Field filtered analysis, no oven digestion, selenate matrix spike
RANOSITMS – Field filtered analysis, no oven digestion, selenite matrix spike
FASMNMS – Field filtered analysis, selenomethionine matrix spike
FASATMS – Field filtered analysis, selenate matrix spike
FASITMS – Field filtered analysis, selenite matrix spike
FANOSMNMS – Field filtered analysis, no oven digestion, selenomethionine matrix spike
FANOSATMS – Field filtered analysis, no oven digestion, selenate matrix spike
FANOSITMS – Field filtered analysis, no oven digestion, selenite matrix spike

TABLE 3
Average, Minimum, and Maximum Recovery for MS/MSDs in Deep Brine Samples from Recent Analysis Evaluating Prep/Sampling Methods

Selenium Species	Average Percent Recovery	Min Percent Recovery	Max Percent recovery
Selenite (oven)	11	0	27
Selenate (oven)	87	77	98
Selenomethionine(oven)	98	92	116
Selenite (no oven)	99	97	103
Selenate (no oven)	95	92	97
Selenomethionine (no oven)	94	93	95

TABLE 4
Comparison of MS Recovery Results (%) by Sample Collection Method and Spiked with Selenite, Selenate, or Selenomethionine

Location	*Method & Results (%)*		
	KemRASITMS	*RASITMS*	*FASITMS*
2565	*-*	*0*	*27*
3510	*20*	*4.7*	*4.8*
	KemRASATMS	*RASATMS*	*FASATMS*
2565	*-*	*77*	*98*
3510	*84*	*88*	*86*
	KemRASMNMS	*RASMNMS*	*FASMNMS*
2565	*-*	*93*	*92*
3510	*116*	*101*	*88*
	KemRANOSITMS	*RANOSITMS*	*FANOSITMS*
2565	*-*	*97*	*97*
3510	*103*	*98*	*100*
	KemRANOSATMS	*RANOSATMS*	*FANOSATMS*
2565	*-*	*92*	*96*
3510	*96*	*94*	*97*
	KemRANOSMNMS	*RANOSMNMS*	*FANOSMNMS*
2565	*-*	*95*	*93*
3510	*94*	*95*	*93*

Note:
Native ID identifies location, depth, date and other sample specifics.
Kem –Sample collected with Kemmerer sampler
RASITMS – Raw analysis, selenite matrix spike
RASATMS – Raw analysis, selenate matrix spike
RASMNMS – Raw analysis, selenomethionine matrix spike
RANOSITMS – Field filtered analysis, no oven digestion, selenite matrix spike
RANOSATMS – Field filtered analysis, no oven digestion, selenate matrix spike
RANOSMNMS – Raw analysis, no oven digestion, selenomethionine matrix spike
FASITMS – Field filtered analysis, selenite matrix spike
FASATMS – Field filtered analysis, selenate matrix spike
FASMNMS – Field filtered analysis, selenomethionine matrix spike
FANOSITMS – Field filtered analysis, no oven digestion, selenite matrix spike
FANOSATMS – Field filtered analysis, no oven digestion, selenate matrix spike
FANOSMNMS – Field filtered analysis, no oven digestion, selenomethionine matrix spike

The selenium concentrations for unspiked (native) deep brine samples are presented in Table 5. For both filtered and unfiltered samples, there is little difference between the results with and without use of the oven. The differences are small and inconsistent about whether the oven-digested sample results are lower. Considering the combination of results from the MS

samples (Tables 2, 3 and 4) and the unspiked samples (Table 5), the study data indicate that the effect of (or concern about) the very poor selenite MS recoveries may not be as serious as originally thought.

TABLE 5

Comparison of Results for Analysis of Unspiked Deep Brine Samples with and without use of Oven Digestion

NativeID	Final Result	Final Validation Flag	Comments
2565 7.5m_032007 FA	0.43	J*	
2565 7.5m_032007 FANO	0.507		Not oven digested
2565 7.5m_032007 RA	0.961	J*	
2565 7.5m_032007 RANO	0.892		Not oven digested
3510 8.0m_031907 FA	0.681	J*	
3510 8.0m_031907 FANO	0.621		Not oven digested
3510 8.0m_031907 Kem RA	0.929	J*	
3510 8.0m_031907 Kem RANO	1.05		Not oven digested
3510 8.0m_031907 RA	0.812	J*	
3510 8.0m_031907 RANO	1.07		Not oven digested

Note:
FA – Filtered analysis
FANO – Filtered analysis, no oven digestion
Kem - Kemmerer
RA - Raw analysis
RANO – Raw analysis, no oven digestion
* - "J" qualifier applied to the data due to the low MS recoveries

The additional samples of deep brine collected in March will also be used to determine if selenium is being lost due to volatilization during the sample filtration process. The trapped filtered solids collected during sampling are being analyzed for total selenium at the University of Utah. The total selenium concentration of the solid material collected during the filtration process will be added to the result from the

filtrate and then compared to the "raw" sample result. During data evaluation, if the sum of the solids and the filtrate is within *20%* of the raw result then the loss of selenium through volatilization will not be considered significant. *The data from this study are not available because the filters used in the field did not allow the sample material to be separted from the filter. Th ese data were not expected to change the conclusion of which preparation or analyses procedures should be implemented for future sampling events and therefore, additional studies were not performed.*

We had originally planned to have Tom May of the USGS Columbia Environmental Research Center analyze split samples from the March sampling event. However, split samples will not be sent to Tom May because 1) the study data indicate that the cause of the low MS recoveries in the deep brine samples has been identified and 2) the USGS graphite furnance is being replaced and will not be operational for about another month.

Path Forward

Discussions with FGS and the project team indicate that one or more of the following factors may be a cause of the low recoveries *from spiked samples of* the deep brine layer:

- Selenite spiked into the deep brine layer MS/MSDs is lost through precipitation
- *Spiked selenite* is lost through volatilization
- Sampling Method/Laboratory anomaly

While the exact reason for the loss of the spiked selenite added to the deep brine layer MS/MSDs was not determined through the study we performed, we did determine which preparation procedure produces good recoveries for all three of the selenium species evaluated. In addition, the concentrations of selenium measured in unspiked field samples from the deep brine layer were comparable, with no consistent difference between samples that were oven-digested and those that were not. The elimination of the oven digestion procedure should yield data of the quality required, and it will not be necessary to flag the results due to the low MS recoveries. We suggest that FGS be directed to eliminate the oven digestion procedure from future analyses for this project.

The study data suggest that the past data collected using the oven digestion procedure are still usablefor field-collected (unspiked) samples and that the selenite contribution to the total selenium concentrations reported is not significant. We suggest that the Science Panel evaluate the use of past deep brine data without qualification or adjustment.

Attachment 1 – MS/MSD Recoveries

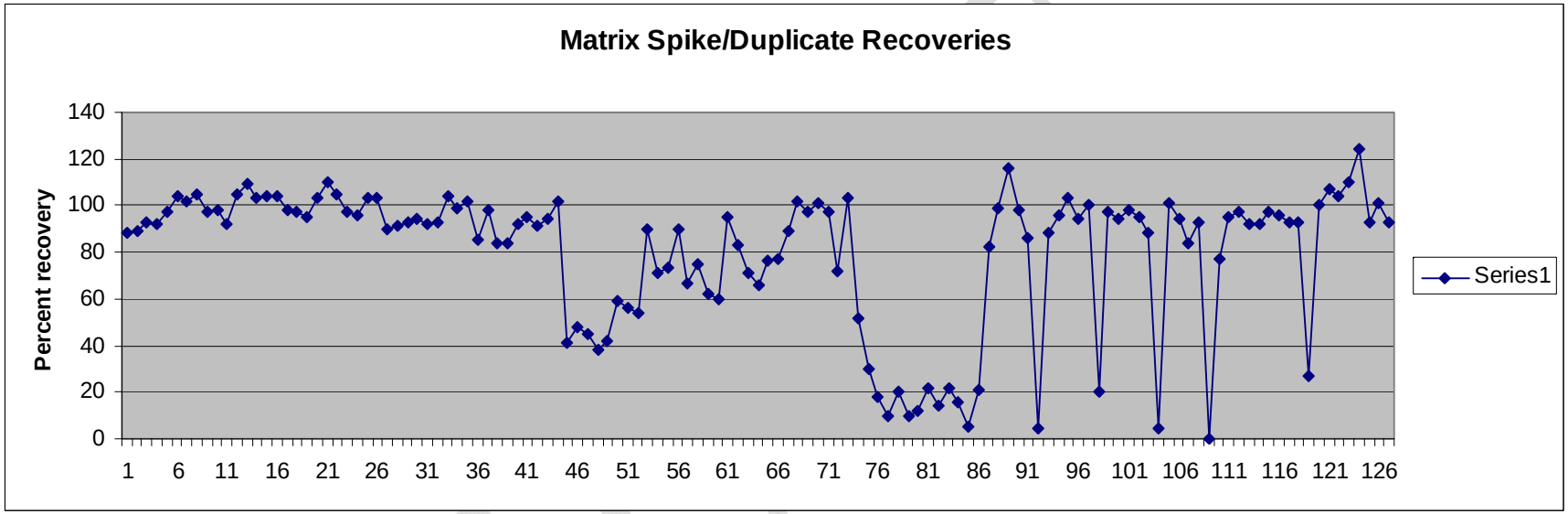
NativeID	Matrix	QAQC Type	Sample Date	Sample Time	Recovery
LEE CREEK 120506 1017 FASD	Water	SD	5/12/2006	10:15:00 AM	88
LEE CREEK 120506 1017 FAMS	Water	MS	5/12/2006	10:15:00 AM	89
BR1-250506 1430 FASD	Water	SD	5/25/2006	2:30:00 PM	93
BR1-250506 1430 FAMS	Water	MS	5/25/2006	2:30:00 PM	92
GOGGIN DRAIN_060606-RA TOTALMS	Water	MS	6/6/2006	1:30:00 PM	97
WR 170506 1325 RASD	Water	SD	5/17/2006	1:25:00 PM	104
WR 170506 1325 RAMS	Water	MS	5/17/2006	1:25:00 PM	102
GOGGIN DRAIN_060606-RA TOTALSD	Water	SD	6/6/2006	1:30:00 PM	105
GOGGIN DRAIN- RA TOTALMS	Water	MS	5/17/2006	10:45:00 AM	97
3510 0.2M 230506 1230 RASD	Water	SD	5/23/2006	12:30:00 PM	98
3510 0.2M 230506 1230 RAMS	Water	MS	5/23/2006	12:30:00 PM	92
GOGGIN DRAIN- RA TOTALSD	Water	SD	5/17/2006	10:45:00 AM	105
3510 0.2m_062006- RA TOTALMS	Water	MS	6/20/2006	11:30:00 AM	109
2767 3.0M 230506 1130 RASD	Water	SD	5/23/2006	11:30:00 AM	103
OGBA-3-WSD	Water	SD	6/23/2006	10:50:00 AM	104
3510 0.2m_062006- RA TOTALSD	Water	SD	6/20/2006	11:30:00 AM	104
OGBA-3-WMS	Water	MS	6/23/2006	10:50:00 AM	98
2267 4.0m_061906- RA TOTALSD	Water	SD	6/19/2006	3:50:00 PM	97
2267 4.0m_061906- RA TOTALMS	Water	MS	6/19/2006	3:50:00 PM	95
GD99 170506 0940 FASD	Water	SD	5/17/2006	9:40:00 AM	103
GD99 170506 0940 FAMS	Water	MS	5/17/2006	9:40:00 AM	110
2767 3.0M 230506 1130 RAMS	Water	MS	5/23/2006	11:30:00 AM	105
2767 3.0M FAMS	Water	MS	7/27/2006	3:00:00 PM	97
2767 3.0M FASD	Water	SD	7/27/2006	3:00:00 PM	96
LC RAMS	Water	MS	7/12/2006	1:30:00 PM	103
LC RASD	Water	SD	7/12/2006	1:30:00 PM	103
WR 080806 0950 TSD	WATER	SD	8/8/2006	9:50:00 AM	90
WR 080806 0950 TMS	WATER	MS	8/8/2006	9:50:00 AM	91
WR_090706 FAMS	WATER	MS	9/7/2006	10:51:00 AM	93
WR_090706 RASD	WATER	SD	9/7/2006	10:51:00 AM	94

NativeID	Matrix	QAQC Type	Sample Date	Sample Time	Recovery
WR_090706 RAMS	WATER	MS	9/7/2006	10:51:00 AM	92
WR_090706 FASD	WATER	SD	9/7/2006	10:51:00 AM	93
2767 2.7M-RASD	WATER	SD	6/3/2006	12:27:00 PM	104
2767 2.7M-RAMS	WATER	MS	6/3/2006	12:27:00 PM	99
3510 0.2M-RASD	WATER	SD	6/3/2006	12:29:00 PM	102
10010020_092606-RASD	WATER	SD	9/26/2006	12:30:00 PM	85
3510 0.2M-RAMS	WATER	MS	6/3/2006	12:29:00 PM	98
10010020_092606-RAMS	WATER	MS	9/26/2006	12:30:00 PM	84
2565 0.2m_092806 RASD	WATER	SD	9/26/2006	12:46:00 PM	84
2565 0.2m_092806 RAMS	WATER	MS	9/26/2006	12:46:00 PM	92
2267 3.5m_092706 RAMS	WATER	MS	9/26/2006	11:35:00 AM	95
BR1 10/10/06 1515 RASD	WATER	SD	10/10/2006	11:43:00 AM	91
2267 3.5m_092706 RASD	WATER	SD	9/26/2006	11:35:00 AM	94
BR1 10/10/06 1515 RAMS	WATER	MS	10/10/2006	11:43:00 AM	102
Program 7/Site 1/ GSL WaterSD	WATER	SD	7/26/2006	8:52:00 AM	41
Program 9/Site 7/GSL WaterMS	WATER	MS	7/26/2006	8:54:00 AM	48
Program 9/Site 7/GSL WaterSD	WATER	SD	7/26/2006	8:54:00 AM	45
Program 7/Site 1/ GSL WaterMS	WATER	MS	7/26/2006	8:52:00 AM	38
Program 8/Site 3/GSL WaterSD	WATER	SD	7/26/2006	8:54:00 AM	42
Program 8/Site 9/GSL WaterMS	WATER	MS	8/22/2006	12:00:00 AM	59
Program 8/Site 9/GSL WaterSD	WATER	SD	8/22/2006	12:00:00 AM	56
Program 8/Site 3/GSL WaterMS	WATER	MS	7/26/2006	8:54:00 AM	54
Program6/Site7/GSL WaterMS	WATER	MS	5/24/2006	12:00:00 AM	90
Program5/Site2/GSL WaterMS	WATER	MS	5/24/2006	12:00:00 AM	71
Program5/Site2/GSL WaterSD	WATER	SD	5/24/2006	12:00:00 AM	73
Program6/Site7/GSL WaterSD	WATER	SD	5/24/2006	12:00:00 AM	90
2767 0.2m_110306 RASD	WATER	SD	11/1/2006	2:00:00 PM	67
2767 0.2m_110306 RAMS	WATER	MS	11/1/2006	2:00:00 PM	75
3510 0.2m_110306 RAMS	WATER	MS	11/1/2006	2:00:00 PM	62
3510 0.2m_110306 RASD	WATER	SD	11/1/2006	2:00:00 PM	60
GD_110906 FAMS	WATER	MS	11/1/2006	2:00:00 PM	95
GD_110906 FASD	WATER	SD	11/1/2006	2:00:00 PM	83

NativeID	Matrix	QAQC Type	Sample Date	Sample Time	Recovery
2767 0.2m RA-TotalMS	WATER	MS	11/20/2006	2:00:00 PM	71
2767 0.2m RA-TotalSD	WATER	SD	11/20/2006	2:00:00 PM	66
Program12/Site 4/GSL WaterSD	WATER	SD	11/20/2006	12:00:00 AM	76
Program12/Site 4/GSL WaterMS	WATER	MS	11/20/2006	12:00:00 AM	77
Program13/Site 7/GSL WaterMS	WATER	MS	12/2/2006	12:00:00 AM	89
Program13/Site 7/GSL WaterSD	WATER	SD	12/2/2006	12:00:00 AM	102
LC_122106 RAMS	WATER	MS	12/7/2006	12:15:00 PM	97
LC_122106 RASD	WATER	SD	12/7/2006	12:15:00 PM	101
GD_013107 1440 RASD	WATER	SD	1/31/2007	2:40:00 PM	97
2565 7.5 M_120606 RAMS	WATER	MS	12/6/2006	11:25:00 AM	72
GD_013107 1440 RAMS	WATER	MS	1/31/2007	2:40:00 PM	103
2565 7.5 M_120606 RASD	WATER	SD	12/6/2006	11:25:00 AM	52
2565 6.5m RA-TotalSD	WATER	SD	11/21/2006	12:25:00 PM	30
2565 6.5m RA-TotalMS	WATER	MS	11/21/2006	12:25:00 PM	18
2565 6.5m FA-DissolvedSD	WATER	SD	11/21/2006	12:25:00 PM	10
2565 6.5m FA-DissolvedMS	WATER	MS	11/21/2006	12:25:00 PM	20
2565 8.0m_110106 RASD	WATER	SD	11/1/2006	12:00:00 PM	10
2565 8.0m_110106 RAMS	WATER	MS	11/1/2006	12:00:00 PM	12
2565 8.0m_110106 FASD	WATER	SD	11/1/2006	12:00:00 PM	22
2565 8.0m_110106 FAMS	WATER	MS	11/1/2006	12:00:00 PM	14
3510 8.0 M_120706 FASD	WATER	SD	12/7/2006	11:25:00 AM	22
3510 8.0 M_120706 RASD	WATER	SD	12/7/2006	11:25:00 AM	16
3510 8.0 M_120706 RAMS	WATER	MS	12/7/2006	11:25:00 AM	5
3510 8.0 M_120706 FAMS	WATER	MS	12/7/2006	11:25:00 AM	21
2267 4.0m_032007 RASD	WATER	SD	3/20/2007	1:20:00 PM	82
2267 4.0m_032007 RAMS	WATER	MS	3/20/2007	1:20:00 PM	99
3510 8.0m_031907 Kem RASMNMS	WATER	MS	3/19/2007	1:20:00 PM	116
2565 7.5m_032007 FASATMS	WATER	MS	3/20/2007	11:10:00 AM	98
3510 8.0m_031907 FASATMS	WATER	MS	3/19/2007	12:15:00 PM	86
3510 8.0m_031907 FASITMS	WATER	MS	3/19/2007	12:15:00 PM	4.8
3510 8.0m_031907 FASMNMS	WATER	MS	3/19/2007	12:15:00 PM	88
3510 8.0m_031907 Kem RANOSATMS	WATER	MS	3/19/2007	1:20:00 PM	96

NativeID	Matrix	QAQC Type	Sample Date	Sample Time	Recovery
3510 8.0m_031907 Kem RANOSITMS	WATER	MS	3/19/2007	1:20:00 PM	103
3510 8.0m_031907 Kem RANOSMNMS	WATER	MS	3/19/2007	1:20:00 PM	94
3510 8.0m_031907 FANOSITMS	WATER	MS	3/19/2007	12:15:00 PM	100
3510 8.0m_031907 Kem RASITMS	WATER	MS	3/19/2007	1:20:00 PM	20
3510 8.0m_031907 FANOSATMS	WATER	MS	3/19/2007	12:15:00 PM	97
3510 8.0m_031907 RANOSATMS	WATER	MS	3/19/2007	12:15:00 PM	94
3510 8.0m_031907 RANOSITMS	WATER	MS	3/19/2007	12:15:00 PM	98
3510 8.0m_031907 RANOSMNMS	WATER	MS	3/19/2007	12:15:00 PM	95
3510 8.0m_031907 RASATMS	WATER	MS	3/19/2007	12:15:00 PM	88
3510 8.0m_031907 RASITMS	WATER	MS	3/19/2007	12:15:00 PM	4.7
3510 8.0m_031907 RASMNMS	WATER	MS	3/19/2007	12:15:00 PM	101
Breech10010020_031907 RAMS	WATER	MS	3/19/2007	11:50:00 AM	94
3510 8.0m_031907 Kem RASATMS	WATER	MS	3/19/2007	1:20:00 PM	84
2565 7.5m_032007 RASMNMS	WATER	MS	3/20/2007	11:10:00 AM	93
2565 7.5m_032007 RASITMS	WATER	MS	3/20/2007	11:10:00 AM	0
2565 7.5m_032007 RASATMS	WATER	MS	3/20/2007	11:10:00 AM	77
2565 7.5m_032007 RANOSMNMS	WATER	MS	3/20/2007	11:10:00 AM	95
2565 7.5m_032007 RANOSITMS	WATER	MS	3/20/2007	11:10:00 AM	97
2565 7.5m_032007 RANOSATMS	WATER	MS	3/20/2007	11:10:00 AM	92
2565 7.5m_032007 FASMNMS	WATER	MS	3/20/2007	11:10:00 AM	92
2565 7.5m_032007 FANOSITMS	WATER	MS	3/20/2007	11:10:00 AM	97
2565 7.5m_032007 FANOSATMS	WATER	MS	3/20/2007	11:10:00 AM	96
2565 7.5m_032007 FANOSMNMS	WATER	MS	3/20/2007	11:10:00 AM	93
3510 8.0m_031907 FANOSMNMS	WATER	MS	3/19/2007	12:15:00 PM	93
2565 7.5m_032007 FASITMS	WATER	MS	3/20/2007	11:10:00 AM	27
Breech10010020_031907 RASD	WATER	SD	3/19/2007	11:50:00 AM	100
Program 8/Site 9/GSL WaterMS	WATER	MS	8/22/2006	12:00:00 AM	107
Program 7/Site 1/ GSL WaterMS	WATER	MS	7/26/2006	12:00:00 AM	104
Program 9/Site 7/GSL WaterMS	WATER	MS	8/28/2006	12:00:00 AM	110
Program 9/Site 7/GSL WaterSD	WATER	SD	8/28/2006	12:00:00 AM	124
Program 8/Site 3/GSL WaterSD	WATER	SD	8/23/2006	12:00:00 AM	93
Program 8/Site 9/GSL WaterSD	WATER	SD	8/22/2006	12:00:00 AM	101

NativeID	Matrix	QAQC Type	Sample Date	Sample Time	Recovery
Program 8/Site 3/GSL WaterMS	WATER	MS	8/23/2006	12:00:00 AM	93



Average Recovery	80	%		
Min recovery	0	%		
max recovery	124	%		
avg recovery deep brine				
- Selenite (oven)	11	%	min = 0%	Max = 27%
- Selenate (oven)	87	%	min = 77%	Max = 98%
- Selenomethionine(oven)	98	%	min = 92%	Max = 116%
- Selenite (no-oven)	99	%	min = 97%	Max = 103%
- Selenate (no-oven)	95	%	min = 92%	Max = 97%
- Selenomethionine(no-oven)	94	%	min = 93%	Max = 95%
avg recovery shallow brine	90	%	min = 60%	Max = 109%
avg recovery brad sites	78	%	min = 38%	Max = 124%

Please note that the following samples were removed from the table/chart because Frontier specified that these samples were not spiked:

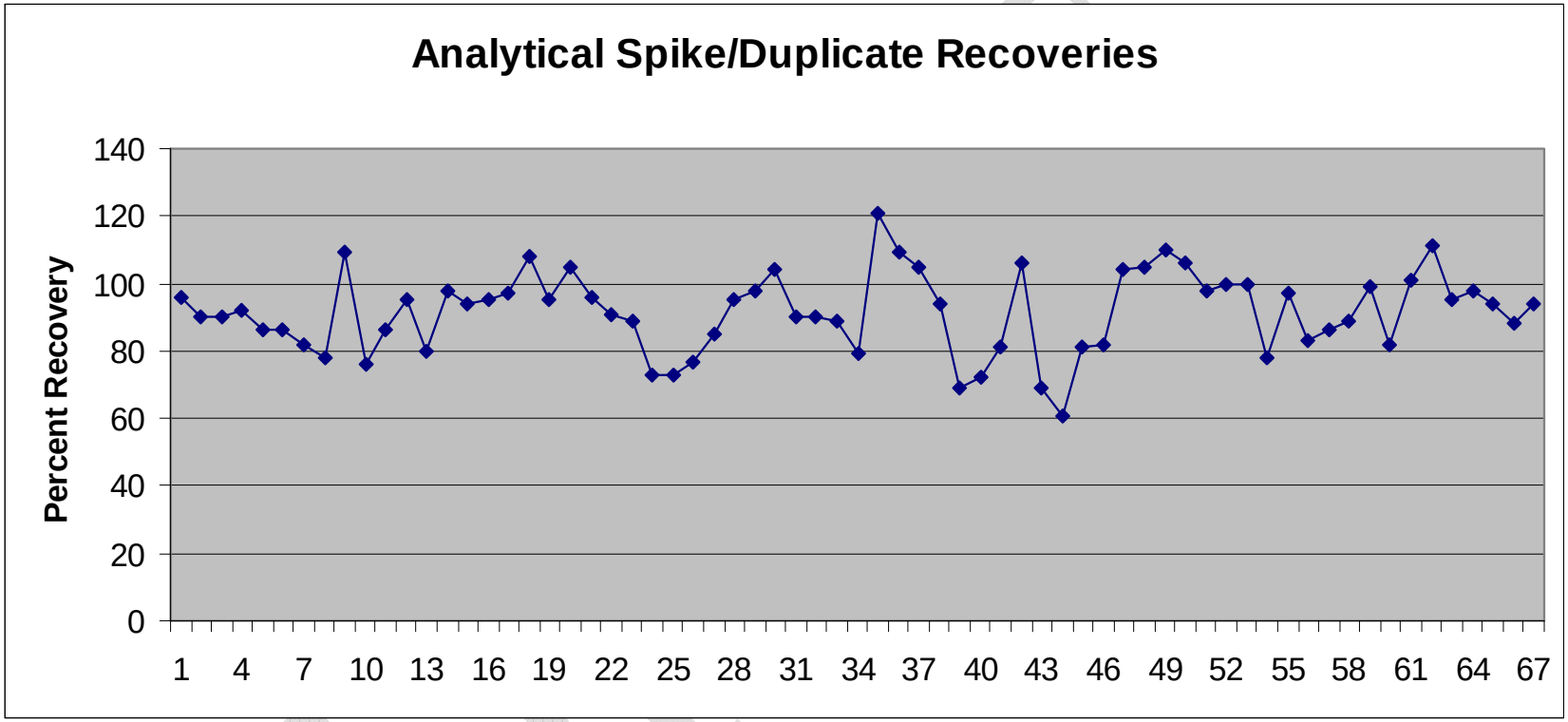
FGS	2565 7.5 M_120606 RAMS	WATER	MS	12/7/2006	11:25	8.6

FGS	2565 7.5 M_120606 RASD	WATER	SD	12/7/2006	11:25	6.2

Attachment 2– AS/ASD Recoveries

NativeID	Matrix	QAQC Type	Sample Date	Sample Time	Recovery
WATER -GSLM COLONYAS	Water	AS	8/8/2006	11:23:00 AM	96
BR1-250506 1430 RAAD	Water	AD	5/25/2006	2:30:00 PM	90
BR1-250506 1430 RAAS	Water	AS	5/25/2006	2:30:00 PM	90
WATER -GSLM COLONYAD	Water	AD	8/8/2006	11:23:00 AM	92
BR1_062106- FA DISSAS	Water	AS	6/21/2006	1:45:00 PM	86
BR1 030506 1425 RAAD	Water	AD	5/3/2006	2:25:00 PM	86
BR1 030506 1425 RAAS	Water	AS	5/3/2006	2:25:00 PM	82
2767 3.0M 230506 1130 FAAS	Water	AS	5/23/2006	11:30:00 AM	78
ANTI-1-WAS	Water	AS	6/16/2006	9:15:00 AM	109
2767 3.0M 230506 1130 FAAD	Water	AD	5/23/2006	11:30:00 AM	76
BR1_062106- RA TOTALAD	Water	AD	6/21/2006	1:45:00 PM	86
BR1_062106- RA TOTALAS	Water	AS	6/21/2006	1:45:00 PM	95
BR1_062106- FA DISSAD	Water	AD	6/21/2006	1:45:00 PM	80
2267 4.0m_061906- FA DISSAD	Water	AD	6/19/2006	3:50:00 PM	98
2267 4.0m_061906- FA DISSAS	Water	AS	6/19/2006	3:50:00 PM	94
2267 0.2m_061906- RA TOTALAD	Water	AD	6/19/2006	3:35:00 PM	95
2267 0.2m_061906- RA TOTALAS	Water	AS	6/19/2006	3:35:00 PM	97
ANTI-1-WAD	Water	AD	6/16/2006	9:15:00 AM	108
FB RAAS	Water	AS	7/18/2006	11:00:00 AM	95
FB RAAD	Water	AD	7/18/2006	11:00:00 AM	105
WR RAAS	Water	AS	7/12/2006	9:30:00 AM	96
WR RAAD	Water	AD	7/12/2006	9:30:00 AM	91
WR 080806 0950 TAD	WATER	AD	8/8/2006	9:50:00 AM	89
WR 080806 0950 TAS	WATER	AS	8/8/2006	9:50:00 AM	73
WR 080806 0945 TAD	WATER	AD	8/8/2006	9:45:00 AM	73
WR 080806 0945 TAS	WATER	AS	8/8/2006	9:45:00 AM	77
WR_090706 FAAD	WATER	AD	9/7/2006	10:51:00 AM	85
WR_090706 FAAS	WATER	AS	9/7/2006	10:51:00 AM	95
BR1 10/10/06 1515 RAAD	WATER	AD	10/10/2006	11:43:00 AM	98
BR1 10/10/06 1515 RAAS	WATER	AS	10/10/2006	11:43:00 AM	104
Program 9/Site 7/GSL WaterAS	WATER	AS	7/26/2006	8:54:00 AM	90
Program 7/Site 1/ GSL WaterAS	WATER	AS	7/26/2006	8:52:00 AM	90
Program 9/Site 7/GSL WaterAD	WATER	AD	7/26/2006	8:54:00 AM	89
Program 7/Site 1/ GSL WaterAD	WATER	AD	7/26/2006	8:52:00 AM	79
Program 8/Site 9/GSL WaterAS	WATER	AS	7/26/2006	8:55:00 AM	121
Program 8/Site 9/GSL WaterAD	WATER	AD	7/26/2006	8:55:00 AM	109
Program 8/Site 3/GSL WaterAS	WATER	AS	7/26/2006	8:54:00 AM	105
Program 8/Site 3/GSL WaterAD	WATER	AD	7/26/2006	8:54:00 AM	94
Program5/Site2/GSL WaterAD	WATER	AD	5/24/2006	12:00:00 AM	69

NativeID	Matrix	QAQC Type	Sample Date	Sample Time	Recovery
Program5/Site2/GSL WaterAS	WATER	AS	5/24/2006	12:00:00 AM	72
2767 0.2m_110306 RAAD	WATER	AD	11/1/2006	2:00:00 PM	81
2767 0.2m_110306 RAAS	WATER	AS	11/1/2006	2:00:00 PM	106
3510 0.2m_110306 RAAD	WATER	AD	11/1/2006	2:00:00 PM	69
3510 0.2m_110306 RAAS	WATER	AS	11/1/2006	2:00:00 PM	61
2767 0.2m RA-TotalAD	WATER	AD	11/20/2006	2:00:00 PM	81
2767 0.2m RA-TotalAS	WATER	AS	11/20/2006	2:00:00 PM	82
GSL-3AS	WATER	AS	12/4/2006	12:00:00 AM	104
GSL-3AD	WATER	AD	12/4/2006	12:00:00 AM	105
2565 7.5 M_120606 RAAS	WATER	AS	12/7/2006	11:25:00 AM	110
2565 7.5 M_120606 RAAD	WATER	AD	12/7/2006	11:25:00 AM	106
2565 7.5 M_120606 RAAS	WATER	AS	12/6/2006	11:25:00 AM	98
2565 7.5 M_120606 RAAD	WATER	AD	12/6/2006	11:25:00 AM	100
2565 7.5 M_120606 RAAD	WATER	AD	12/6/2006	11:25:00 AM	100
2565 6.5m FA-DissolvedAD	WATER	AD	11/21/2006	12:25:00 PM	78
2565 6.5m RA-TotalAD	WATER	AD	11/21/2006	12:25:00 PM	97
2565 6.5m FA-DissolvedAS	WATER	AS	11/21/2006	12:25:00 PM	83
2565 8.0m_110106 RAAD	WATER	AD	11/1/2006	12:00:00 PM	86
2565 8.0m_110106 FAAS	WATER	AS	11/1/2006	12:00:00 PM	89
2565 8.0m_110106 FAAD	WATER	AD	11/1/2006	12:00:00 PM	99
2565 8.0m_110106 RAAS	WATER	AS	11/1/2006	12:00:00 PM	82
2565 6.5m RA-TotalAS	WATER	AS	11/21/2006	12:25:00 PM	101
3510 8.0 M_120706 FAAD	WATER	AD	12/7/2006	11:25:00 AM	111
3510 8.0 M_120706 FAAS	WATER	AS	12/7/2006	11:25:00 AM	95
3510 8.0 M_120706 RAAS	WATER	AS	12/7/2006	11:25:00 AM	98
3510 8.0 M_120706 RAAD	WATER	AD	12/7/2006	11:25:00 AM	94
2267 0.2m_032007 RAAD	WATER	AD	3/20/2007	1:00:00 PM	88
2267 0.2m_032007 RAAS	WATER	AS	3/20/2007	1:00:00 PM	94



Average Recovery	92	%		
Min recovery	61	%		
max recovery	121	%		
avg recovery deep brine	96	%	Min= 78%	Max = 111%
avg recovery shallow brine	86	%	Min = 61%	Max = 106%
avg recovery brad	92		Min = 69%	Max = 121%

Attachment 4
Laboratory Comparison of Composite Eared Grebe Blood Samples for Se and Hg

Laboratory Comparison of Composite Eared Grebe Blood Samples for Se and Hg

PREPARED FOR: Great Salt Lake Science Panel

PREPARED BY: Gary Santolo

COPIES: Harry Ohlendorf
Jeff DenBleyker
Earl Byron
Dan Moore
Principal Investigators

DATE: August 28, 2007

PROJECT NUMBER: 341055.07.05

Analyses described in this technical memorandum were undertaken to address questions about the high selenium (Se) concentrations measured in gull and shorebird blood in 2006. The general approach for these analyses was described in a previous technical memorandum dated March 15, 2007 (Subject: "Avian Blood Sample Analysis")

Blood samples collected from eared grebes in September and November 2006 were frozen and a subsample was freeze-dried and split at the USGS laboratory for analysis by USGS Columbia Environmental Research Center in Columbia, MO and LET. Splitting the samples after freeze-drying and homogenizing them provided homogeneity of the split samples for comparison between labs.

The quantity of grebe blood in each sample was small but adequate for the Se analyses that the project was designed to undertake. The quantity of grebe blood in each sample was not adequate, however, to facilitate an inter-lab comparison and other potential analyses (e.g., for mercury [Hg]) of the blood. Compositing of some of the blood samples was required to enable those comparisons and additional analyses.

In addition to the 10 grebes collected during the early and late time period from each of the two locations (Hat Island and Antelope Island), blood (and liver) samples were available from 4 extra grebes collected from the vicinity of Hat Island in the early collection period, 4 extra grebes from Hat Island in the late collection, and 5 extra grebes from Antelope Island in the late collection. The approach for compositing and splitting the samples for inter-lab comparison was as follows:

- Gary Santolo and Mike Conover determined which extra grebe blood samples were to be used to make the composite samples (using "spare" samples other than those to be analyzed individually and we provided that list of samples to LET and to Tom May at the USGS laboratory, who did analyses for inter-lab comparison.

- LET then provided the identified blood samples to Tom May, who created 3 freeze-dried composites with 5 blood samples combined in each. Tom then split the 3 composites and provided half of each freeze-dried, homogenized sample to LET.

Inter-laboratory Comparison of Se Analyses

Tom May and LET each used part of each of the 3 composited samples to do duplicate analyses for Se using hydride generation AA (the same method used by LET for the gull and shorebird samples previously). In addition, they also did duplicate analyses of the samples for both Se + Hg, with LET using the approach described below.

The main advantage of using the composited samples for the interlaboratory comparison was that more mass was available for each lab to work with (1 to 1.5 grams of dried blood in each of the 3 samples. Although this was still pretty small, it was adequate and much preferred over trying to split individual bird blood samples). Inter-laboratory comparison was completed for both the Se analyses and the Se + Hg analyses on the same 3 samples.

Comparability of the samples between the laboratories is a qualitative indicator of the confidence with which one data set can be compared to another. Standard techniques and procedures were used for collecting, splitting, and analyzing the representative samples.

Precision, the measure of variability between duplicate analyses, was calculated for LET and USGS duplicates. Precision was evaluated by comparing the relative percent difference (RPD) of LET and USGS duplicate samples with RPD objectives stated in the QAPP. The RPD is also a measure of the sample heterogeneity or matrix variability.

Standard reference materials were analyzed for Se and Hg by each of the labs.

Composite Blood Sample Methods (USGS)

Composite Preparation:

Each grebe blood sample was received in a syringe container. Blood samples were grouped together in three polyethylene bags, labeled #2, #3, and #4. After receiving instructions regarding which blood samples to composite, a composite was formed by expelling as much blood as possible from each syringe into a common vial using the syringe plunger. The plungers were then pulled out of the syringes, with each plunger being rinsed off with deionized water into its corresponding syringe barrel and the syringe contents then being allowed to elute into the common collection vial. Because of this addition of water to retrieve as much blood as possible from each syringe, percent moistures on the blood could not be determined. Contents of each composite sample vial were then frozen in preparation for lyophilization.

Lyophilization and Homogenization:

Composite blood samples were lyophilized in the collection vial. After lyophilization, dried blood samples were mechanically ground and mixed with a glass rod to a fine powder. Each dried and ground composite was then split into two containers, with one container going to LET Inc. All dried samples were stored in a desiccator until time of chemical preparation.

Results

SRM Results

Standard reference materials (SRM) from ClinChek® Control, Seronorm™ Trace Elements Whole Blood, and Certified Reference Material, A-13 (International Atomic Energy Agency [IAEA]) were analyzed by LET and the USGS laboratory to determine the analytical and method precision. Both laboratories reported that the quality control results for the study and all concentrations reported were within acceptable limits. The results of the reference sample analyses are presented in Appendix A and B.

Inter-lab Comparison Results

Blood

Split composite blood samples were analyzed by both laboratories for Se and Hg concentrations. There was less than 8 percent RPD between laboratories for all blood Se samples. The winter (November) and fall (September) samples from the Antelope Island and Hat Island gull locations had similar Se concentrations and the composite blood Se sample from the Hat Island winter grebes was over 3.2 times higher than the fall samples (Table 1).

There was less than 13 percent RPD between laboratories for all blood Hg samples. Similar to the Se results, the from winter samples Antelope Island and fall samples Hat Island gull colonies had similar Hg concentrations and composite blood samples from the Hat Island winter samples were over 2.7 times higher than the fall samples. The QAPP does not address precision requirements for primary and split samples, but the precision demonstrated meets the requirements for a single laboratory, and therefore confirms that the split data are comparable. Ultimately, this brief study confirms that LET's analytical method is performing as expected and meets the data quality objectives defined by the program.

A quick review of the early grebe Se and Hg blood liver results shows a similar pattern of Hat Island winter concentrations being about 2 to 3 times higher than fall Hat Island samples or fall and winter Antelope Island samples.

Table 1. Results of Inter-lab Comparison between the USGS Laboratory and LET for Eared Grebe Split Composite Blood Samples Analyzed for Selenium and Mercury Concentrations and the Relative Percent Difference between Laboratory Results.

		Selenium			Mercury		
Location	Time Period	USGS µg Se/g	LET µg Se/g	Se Relative Percent Difference $\frac{(((X_1-X_2)\times 100)}{(X_1+X_2)/2))}$	USGS µg Hg/g	LET µg Hg/g	Hg Relative Percent Difference $\frac{(((X_1-X_2)\times 100)}{(X_1+X_2)/2))}$
Hat Island	Fall	11.8	11.4	3.45	4.82	4.7	2.52
Hat Island	Winter	39.5	36.6	7.62	14.6	12.9	12.36
Antelope Island	Winter	14.7	14.3	2.76	4.72	4.8	-1.68

Quality LET Service
Laboratory and Environmental Testing, Inc.

L.E.T., Inc.
3501 Berrywood Dr.
Columbia, MO 65201
573-874-2481
573-443-1202 Fax

February 16, 2007

LET Sample Report

Units: mcg/g Dry Weight **Batch Number:** L07010094
Analyte: Se

LET I.D.	Submitter I.D.	Concentration	D.L.	Matrix
L07010095	IAEA A-13	0.2	0.2	Animal Tissue
L07010096	8841 ClinChek Blood 3	0.90	0.2	Animal Tissue
L07010097	SERO 201705 Blood 3	1.0	0.2	Animal Tissue

LET Duplicate Report

Units: mcg/g Dry Weight **Batch Number:** L07010094
Analyte: Se

LET I.D.	Submitter I.D.	Sample	D.L.	Duplicate	% Deviation
L07010095	IAEA A-13	0.2	0.2	0.2	0.0
L07010096	8841 ClinChek Blood 3	0.90	0.2	1.1	20.0
L07010097	SERO 201705 Blood 3	1.0	0.2	1.0	0.0

LET Spike Report

Units: mcg/g Dry Weight **Batch Number:** L07010094
Analyte: Se

LET I.D.	Submitter I.D.	Sample	D.L.	Spiked Sample	% Recovery
L07010097	SERO 201705 Blood 3	1.0	0.2	27	112

* Spike was analytical.

LET Blank Report

Units: mcg/g Dry Weight **Batch Number:** L07010094

Analyte: Se

LET I.D.	Submitter I.D.	Sample Equivalent Concentration	Detection Limit
L07010094	Blank-1	<0.2	0.2

LET Reference Sample Report

Units: mcg/g **Batch Number:** L07010094

Analyte Se

LET I.D.	SRM I.D.	LET Concentration	Detection Limit	Certified Mean ± s.d.
L07010098	NIST 1566b	2.0	0.1	2.06 ± 0.15

CCB & CCS Report for Se - Batch L07010094

ERA QC023500 Certified Value for Se - 596 PPB Acceptable Range (530 – 658)

Sample Run on 1/100 Dilution for Analysis

#	Se	% of Certified
1	608.	102.
2	621.	104.
3	612.	103.
4	611.	103.
Mean +/- s.d.	613. +/- 5.6	103. +/- 0.8

All CCB’s less than Reporting Detection Limit

Table 1. Measured concentrations (µg/g dry weight) of selenium and mercury in composite Grebe blood samples.

CERC #	Field ID	Se	Hg
38879	#2: EG-A57,EG-A58,EG-A59,EG-A62,EG-A65	14.7	4.72
38880	#3: EG-Hat9,EG-Hat11,EG-Hat12,EG-Hat14	11.8	4.82
38881	#4: EG-Hat79,EG-Hat80,EG-Hat82,EG-Hat84	39.5	14.6

Table 2. Performance of reference tissues and solutions used for instrument calibration verification during analysis of composite Grebe blood samples.

BID[a]	Ele.	Run Date	Reference Solution	Actual Conc	Meas Conc 1	Meas Conc 2	% Error 1	% Error 2	ISOP[b]	Oper Init.
05/02/07	Hg	05/02/07	QC112[c]	0.2	0.2	0.2	2.1	5.5	P.581	VDM
05/02/07	Hg	05/02/07	QC116[d]	3.4	3.4	3.6	2.0	7.6	P.581	VDM
04/18/07	Se	07/26/07	Spex[e]	3.0	3.0	2.9	-0.1	-3.0	P.207	MJW

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]ISOP = instrumental standard operating procedure.

[c]QC112 = International Atomic Energy Agency Reference Material 407: Trace Elements and Methylmercury in fish tiss

[d]QC116 = National Research Council Canada SRM DOLT-3: dogfish liver.

[e]Spex Claritas PPT, Cat No. CLSe2-2Y; Spex CertiPrep, Metuchen, NJ.

Table 3. Measured concentrations of Se and Hg in reference materials (µg/g dry weight) prepared and analyzed with the composite Grebe blood samples.

BID[a]	Ele.	QC #	Meas. Conc.	Reference Material	Matrix	Upper Limit	Lower Limit	% Rec[b]	Prep SOP	Prep Init.	ISOP[c]	Oper. Init.
04/18/07	Se	43	0.25	IAEA A-13[d]	blood	0.32	0.16	100.	P.256a	VDM	P.207	MJW
04/18/07	Se	113	1.06	SeroNorm 201705[e]	blood	1.05	0.92	101.	P.256a	VDM	P.207	MJW
04/18/07	Se	114	1.12	ClinChek 8841[f]	blood	1.14	0.76	100.	P.256a	VDM	P.207	MJW
05/02/07	Hg	113	0.085	SeroNorm 201705	blood	0.087	0.073	100.	---	---	P.581	VDM
05/02/07	Hg	114	0.087	ClinChek 8841	blood	0.10	0.067	100.	---	---	P.581	VDM
05/02/07	Hg	107b	0.14	NIST 966[g]	blood	0.16	0.14	100.	---	---	P.581	VDM
05/02/07	Hg	112	0.23	IAEA 407[h]	whole-body fish	0.23	0.22	100.	---	---	P.581	VDM
05/02/07	Hg	116	3.63	NRCC DOLT-3[i]	dogfish liver	3.51	3.23	103.	---	---	P.581	VDM

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]recovery within certified range is considered as 100%, otherwise calculation of recovery is performed relative to upper or lower limit of certified range.

[c]ISOP = instrumental standard operating procedure.

[d]IAEA A-13 = International Atomic Energy Agency CRM A-13: Animal Blood.

[e]Seronorm 201705 Trace Elements, Whole Blood, Level 3.

[f]ClinChek 8841 Whole Blood, Control Level 2.

[g]NIST 966 = National Institute of Standards and Technology SRM 966: Bovine Blood.

[h]International Atomic Energy Agency Reference Material 407: Whole-body Fish.

[i]NRCC DOLT-3 = National Research Council Canada DOLT-3 CRM: Dogfish Liver.

Table 4. Instrumental precision within an analytical "run" for selenium determined by flow injection atomic absorption conducted for the composite Grebe blood samples.

BID[a]	Ele.	Run Date	Std. Conc.[b]	Vol[c] (µL)	Initial Abs/Read	Mean Read[d]	# of checks	SD[e]	%RSD[f]	ISOP	Oper. Init.
04/18/07	Se	07/26/07	3	500	0.11	0.11	5	0.002	2.0	P.207	MJW

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]Std. Conc. = units in ppb unless otherwise noted.

[c]Vol (µL) = sample loop size for the FIAS 400 in microliters.

[d]Mean Read = units are absorbance.

[e]SD = standard deviation.

[f]%RSD = percent relative standard deviation.

Table 5. Relative percent difference for the duplicate analysis of a blood sample digestate.

BID[a]	Element	Matrix	Analytical Units	Dup 1	Dup 2	Diff[b]	Mean	RPD[c]	ISOP[d]	Oper. Init.
04/18/07	Se	blood	µg/g	4.12	4.24	0.12	4.18	2.9	P.241	MJW/TWM

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]Diff = Dup 1 - Dup 2.

[c]RPD = relative percent difference, calculated as Diff/Mean X 100; acceptance criteria +/- 10%.

[d]ISOP = standard operating procedure used for instrumental analysis of sample.

Table 6. Percent relative standard deviations from the triplicate prep and analysis of composite Grebe blood samples for mercury and selenium.

BID[a]	Ele.	Matrix	Sample	Rep 1	Rep 2	Rep 3	Mean	Units	SD[b]	%RSD[c]	PSOP[d]	Prep. Init.	ISOP[e]	Oper. Init.
04/18/07	Se	blood	38880	11.8	12.4	11.3	11.8	µg/g	0.51	4.4	P.256a	VDM	P.207	MJW
05/02/07	Hg	blood	38879	4.66	4.70	4.81	4.72	µg/g	0.078	1.6	---	---	P.581	VDM
05/02/07	Hg	blood	38880	4.82	4.75	4.88	4.82	µg/g	0.064	1.3	---	---	P.581	VDM
05/02/07	Hg	blood	38881	14.5	14.7	14.7	14.6	µg/g	0.16	1.1	---	---	P.581	VDM

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]SD = standard deviation.

[c]%RSD = percent relative standard deviation.

[d]PSOP = standard operating procedure used for chemical preparation of sample.

[e]ISOP = standard operating procedure used for instrumental analysis of sample.

Table 7. Percent recoveries of mercury and selenium from pre-combustion/digestion spikes of composite Grebe blood samples.

BID[a]	Ele.	Spike Form	Amt.[b] µg	Matrix	Spiked µg[c] Meas.	Unspiked[d] µg	Spk/Unspiked[e] Ratio	Spk/Unspiked SD[f]	% REC[g]	PSOP	Prep. Init.	ISOP	Oper. Init.
04/18/07	Se	selenomethionine	1.00	blood	2.25	1.21	0.8	19.	104.	P.256a	VDM	P.207	MJW
04/18/07	Se	Se^{+6}	10.0	blood	11.5	1.39	7.2	165.	101.	P.256a	VDM	P.207	MJW
05/02/07	Hg	CH_3HgOH	0.025	blood	0.030	0.0009	28.2	1870.	117.	---	---	P.581	VDM
05/02/07	Hg	CH_3HgOH	0.05	blood	0.053	0.0008	62.8	4180.	104.	---	---	P.581	VDM

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]Amt µg = the absolute µg amount of the spike in the form listed in column 3 which was added to a sample.

[c]Spiked µg Meas. = the micrograms (µg) of the analyte in the sample spike measured by the instrument (spike + unspiked).

[d]Unspiked (µg) = amt (µg) of the analyte in the unspiked sample.

[e]Spk/Unspiked Ratio = the ratio of the spike amount added (column 4) divided by the mean unspiked sample concentration (column 7).

[f]Spk/Unspiked SD = the ratio of the spike amount added (column 4) divided by the standard deviation of the unspiked sample concentration.

[g]%REC = Spiked µg Meas. (column 6) - Unspiked sample µg (column 7) divided by the Amt. µg (column 4) X 100.

Table 8. Percent recoveries of Se in post-digestion (analysis) spikes of composite Grebe blood digestates.

BID[a]	Ele.	Matrix	Units	Spk Amt[b]	Vol.	Effec. Conc[c]	Unspiked Conc	Spiked[d] Conc	% REC[e]	PSOP	Prep. Init.	ISOP	Oper. Init.
04/18/07	Se	blood	ng/mL	0.04	10.	4.0	3.33	7.44	103.	P.256a	VDM	P.207	MJW
04/18/07	Se	blood	ng/mL	0.04	10.	4.0	2.29	6.37	102.	P.256a	VDM	P.207	MJW
04/18/07	Se	blood	ng/mL	0.04	10.	4.0	4.12	8.14	101.	P.256a	VDM	P.207	MJW

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]Spk Amt = the absolute µg amount of the spike added to a sample .

[c]Effec Conc = Spk Amt in ng divided by the volume (mL); units ng/mL.

[d]Spiked Conc = ng/mL of the analyte in the sample spike measured by the instrument (spike + unspiked).

[e]%REC = Spiked Conc - Unspiked Conc divided by the Effec. Conc X 100.

Table 9. Blank equivalent concentrations (BECs) for blanks analyzed with composite Grebe blood sample.

BID[a]	Ele.	Matrix	Units	Blk Conc 1	Blk Conc 2	Blk Conc 3	Dil Vol (mL)	Mean	Wgt (g)[b]	Mean BEC µg/g	BEC SD	PSOP	Prep Init.	ISOP[c]	Analyst
04/18/07	Se	blood	ng/mL	0.008	0.003	-0.0004	25.	0.004	0.10	0.001	0.001	P.256a	VDM	P.207	MJW
05/02/07	Hg	blood	ng	0.18	0.040	0.080	---	0.10	0.05	0.002	0.001	---	---	P.581	VDM

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]dry weight used to compute BECs.

[c]ISOP = standard operating procedure used for instrumental analysis of sample.

Table 10. Instrument detection limits for mercury and selenium.

BID	Run Date[a]	Ele.	Std. Conc.[b]	Std SD 1[c]	Std SD 2	Std SD 3	IDL[d]	Units	SOP	Oper. Init.
04/18/07	07/02/07	Se	0.20	0.007	0.007	0.006	0.020	ng/mL	E.059	MJW
05/02/07	10/03/06	Hg	0.005	0.001	0.0005	0.001	0.003	ng	P.581	VDM

[a]date of 3rd consecutive day analysis, following which IDL was computed.

[b]Se: concentration of low level standard used in analysis, in ng/mL; Hg: mass of low level standard, in ng.

[c]standard deviation from analysis of standard 7 consecutive times in one day, on three non-consecutive days (SD1, SD2, SD3).

[d]IDL = instrument detection limit, computed as the sum of the three non-consecutive standard deviations.

Table 11. Method detection and quantitation limits for mercury and selenium.

BID[a]	Element	Matrix	W/D/L[b]	Blank SD	Sample SD	MDL[c]	MQL[d]	PSOP	Prep. Init.	ISOP	Inst. Init.	Units
04/18/07	Se	blood	D	0.016	0.0011	0.048	0.16	P.256a	VDM	P.207	MJW	µg/g
05/02/07	Hg	blood	D	0.013	0.0014	0.039	0.13	---	---	P.581	VDM	µg/g

[a]BID = Block Initiation Date: a date assigned to each member of a group of samples that will identify the sample as a member of the group or "block."

[b]W/D/L = state of starting sample: wet (W), dry (D), or liquid (L).

[c]MDL = method limit of detection, computed as $3 \times (SD_b^2 + SD_s^2)^{1/2}$ where SD_b = standard deviation of a blank and SD_s = standard deviation of a low level sample or spiked sample (n = 3).

[d]MQL = method quantitation limit (ng/mL), computed as 3.3 X the MDL.

Selenium in Marine Birds

PREPARED FOR: Great Salt Lake Science Panel

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DATE: May 1, 2007

PROJECT NUMBER: 341055.P7.02

During the Science Panel meeting on March 21-22, 2007, the Panel asked CH2M HILL to create summary tables of selenium concentrations in livers, blood and eggs of marine-type birds from the literature to compare against what has been observed at the Great Salt Lake. Table 1 provides a summary of the data from our sampling in the Great Salt Lake (GSL) in 2006, along with information we have compiled for selenium (and also for mercury when results were reported in the same papers). The results are reported in the table as given in the reference (i.e., either arithmetic or geometric mean); however, when individual values were given, we calculated a geometric mean. When results were reported on wet-weight (ww) basis, we converted them to dry-weight (dw) basis using the study-specific percent moisture if it was provided in the reference. For conversion of plasma samples from µg Se/L ww to µg Se/g dw the percent moisture used was 92 percent. For conversion of whole blood selenium where percent moisture was not provided, 80 percent moisture was used. The text below provides a brief summary of some of the more relevant findings.

Selenium in Blood

We found only five studies that provided blood selenium concentrations in marine birds. Goede (1993a, b) reported selenium concentrations separately for plasma and red blood cells (RBCs), and Goede and Wolterbeek (1994) reported concentrations in RBCs. Grand et al. (2002) and Wayland et al. (2001) reported concentrations in blood as wet weight and did not give percent moisture for the samples.

The range of means found for selenium in blood of marine birds was 3.5 µg Se/g in oystercatchers (plasma conversion; Goede 1993b) to 96.3 µg Se/g in spectacled eiders from the Yukon-Kuskokwim Delta, AK (Grand et al. 2002). Geometric mean selenium in blood samples from the birds collected from GSL ranged from 12.6 to 34.1 µg Se/g, which fall within the range found in the marine bird studies.

Selenium in Livers

Mean selenium concentrations in livers ranged from 3.2 to 133 µg Se/g in the studies that we found (Elliott et al. 1992; Renzoni et al. 1986). This encompasses the range of geometric means from the birds collected from GSL (7.5 to 22.5 µg Se/g). Only two studies provided both liver and blood selenium concentrations. In oystercatchers (Goede 1993a), RBC concentrations (23 µg Se/g dw) were slightly higher and less variable (21-25 µg Se/g dw)

than liver concentrations (19 µg Se/g dw; 15-21 µg Se/g dw). In common eiders (Wayland et al. 2001), blood and liver selenium concentrations also were similar to each other; in 1997 the values were 17.6 µg Se/g dw in blood and 20.1 µg Se/g dw in livers, and in 1998 they were 23.0 µg Se/g dw in blood and 18.5 µg Se/g dw in livers. For both blood and livers in both years, selenium concentrations in the eiders were more variable than those found in the oystercatchers mentioned above.

Selenium in Eggs

Mean concentrations in eggs ranged from 0.121 to 6.07 µg Se/g in the studies that we found (Burger and Gochfeld 1995; Ohlendorf and Harrison 1986). This encompasses the range of geometric means for the birds collected from GSL (1.93 to 4.73 µg Se/g). In female spectacled eiders, mean blood selenium (64 µg Se/g dw) was over 80 times the mean egg concentration (0.78 µg Se/g dw; Grand et al. [2001]). Henny et al. (1995) predicted egg concentrations (21.3 or 29.2 µg Se/g dw, based on different regressions) from liver concentrations in white-winged scoters (mean of 54 µg Se/g dw for combined males and females; concentration not given separately for females) based on established fresh water liver-egg relationships. However, they found that selenium concentrations in eggs were only about 10 percent of the predicted concentrations. In the study by Renzoni et al. (1986), mean selenium concentrations in livers of Corey's shearwaters were from 10 to over 22 times those found in eggs.

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TABLE 1
Selenium and Mercury Concentrations (µg/g dry weight) in Livers, Blood, and Eggs from the Great Salt Lake and Marine Birds from Elsewhere

Species	Location	Selenium						Mercury						Reference
		Liver		Blood		Egg		Liver		Blood		Egg		
		Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	
Great Salt Lake Birds														
American avocet	Antelope Island	11.9	5; 8.3-16	19.5	4; 16-23	2.22	21; 1.6-2.9							GSL Database
American avocet	Ogden Bay	16.2	5; 11-28	32.1	5; 21-60	1.93	19; 1.2-3.2							GSL Database
American avocet	Saltaire	22.5	5; 15-38	22.1	5; 12-35	4.73	7; 2.9-8.2							GSL Database
American avocet	West Carrington					2.5	1; NA							GSL Database
Black-necked stilt	Ogden Bay	22.0	5; 11-40	34.1	5; 20-68	2.47	21; 1.3-3.6							GSL Database
California gull	Antelope Island	6.98	12; 4-13	12.6	12; 6.4-25	2.75	12; 2.1-4.1							GSL Database
California gull	Hat Island	7.51	13; 5.6-13	14.8	11; 6.3-29	2.76	11; 2.0-3.4							GSL Database
California gull	Great Salt Lake Minerals	8.75	11; 3.9-13	21.0	12; 5.0-37	3.33	12; 2.6-4.3							GSL Database
Marine Birds														
Black guillemot	Canadian Arctic, Green I, Digges Sound	9.07	10; NA					3.75	10; NA					Braune, unpublished[e]
Black guillemot	Canadian Arctic, Prince Leopold I	10.8	5; NA					3.97	5; NA					Braune, unpublished[e]
Fulmar	Canadian Arctic, Prince Leopold I	34.4	10; NA					8.12	10; NA					Braune, unpublished[e]
Glaucous gull	Canadian Arctic, Coats I	9.2	2; NA					6.78	2; NA					Braune, unpublished[e]
Kittiwake	Canadian Arctic, Prince Leopold I	36.2	10; NA					3.05	10; NA					Braune, unpublished[e]
Herring gull (1989)	Long Island, NY					1.92	20; NA					0.172	20; NA	Burger and Gochfeld 1995
Herring gull (1991)	Long Island, NY					2.13	20; NA					0.370	20; NA	Burger and Gochfeld 1995
Herring gull (1992)	Long Island, NY					1.74	20; NA					0.121	20; NA	Burger and Gochfeld 1995
Herring gull (1993)	Long Island, NY					1.41	20; NA					0.248	20; NA	Burger and Gochfeld 1995
Herring gull (1994)	Long Island, NY					1.01	20; NA					0.458	20; NA	Burger and Gochfeld 1995
Puffin	Canadian Atlantic, Gull I	11.7	6; NA					2.6	6; NA					Elliott et al. 1992[e]
Puffin	Canadian Atlantic, Ille St Marie	8.29	6; NA					1.4	6; NA					Elliott et al. 1992[e]
Herring gull	Canadian Atlantic, Gull I	3.21	6; NA					1.7	6; NA					Elliott et al. 1992[e]
Herring gull	Canadian Atlantic, Kent I	3.36	6; NA					1.5	6; NA					Elliott et al. 1992[d]
Herring gull	Canadian Atlantic, Manawagonish I	3.2	6; NA					0.69	6; NA					Elliott et al. 1992[e]
Great skua	North Atlantic	17.7	13; 6.7-35					7.7	13; 3.2-30					Furness and Hutton 1979
Oystercatcher (Plasma conversion)	Frisian coast Dutch Wadden Sea, Paesenser Polder			5.1	5; 4.2-6.5									Goede 1993a
Oystercatcher	Frisian coast Dutch Wadden Sea, Paesenser Polder	19	5; 15.3-21.2	23	5; 21-25									Goede 1993a

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		Selenium						Mercury						
		Liver		Blood		Egg		Liver		Blood		Egg		
Species	Location	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Reference
Oystercatcher (Plasma)	Dutch Wadden Sea, Coast			4.2	38; NA									Goede 1993b
Oystercatcher (Plasma)	Dutch Wadden Sea, Inland			3.5	23; NA									Goede 1993b
Oystercatcher (Plasma)	Norway, Coast			5.2	10; NA									Goede 1993b
Oystercatcher (Plasma)	Norway, Inland			4.0	10; NA									Goede 1993b
Oystercatcher (RBC)	Dutch Wadden Sea, Coast			20.5	37; NA	2.3	54; NA							Goede 1993b
Oystercatcher (RBC)	Dutch Wadden Sea, Inland			6.4	22; NA	2.2	29; NA							Goede 1993b
Oystercatcher (RBC)	Norway, Coast			28.5	15; NA									Goede 1993b
Oystercatcher (RBC)	Norway, Inland			8.4	10; NA									Goede 1993b
Oystercatcher (F; RBC)	Dutch Wadden Sea, Coast			22.1	20; NA					1.9	20; NA			Goede and Wolterbeek 1994
Oystercatcher (M; RBC)	Dutch Wadden Sea, Coast			18.8	17; NA					2.5	17; NA			Goede and Wolterbeek 1994
Oystercatcher (F; RBC)	Dutch Wadden Sea, Inland									1.4	11; NA			Goede and Wolterbeek 1994
Oystercatcher (M; RBC)	Dutch Wadden Sea, Inland									2.0	11; NA			Goede and Wolterbeek 1994
Spectacled eider (M; Incubating)	Yukon-Kuskokwim Delta, Alaska			96.3	10; NA									Grand et al. 2002
Spectacled eider (F; Incubating)	Yukon-Kuskokwim Delta, Alaska			64	46; NA									Grand et al. 2002
Spectacled eider (1995 viable eggs)	Yukon-Kuskokwim Delta, Alaska					0.76	8; NA					0.21	8; NA	Grand et al. 2002[f]
Spectacled eider (1995 inviable eggs)	Yukon-Kuskokwim Delta, Alaska					0.74	10; NA					0.21	10; NA	Grand et al. 2002[f]
Spectacled eider (1996 viable eggs)	Yukon-Kuskokwim Delta, Alaska			67	38; NA	4.2	19; NA			0.70	38; NA	0.18	15; NA	Grand et al. 2002
Spectacled eider (1996 inviable eggs)	Yukon-Kuskokwim Delta, Alaska			52	8; NA	3.5	31; NA			0.50	8; NA	0.18	26; NA	Grand et al. 2002
Common eider (F; Hatch)	Yukon-Kuskokwim Delta, Alaska			36.5	11; NA					1.9	11; NA			Grand et al. 2002
Spectacled eider (F; Hatch)	Yukon-Kuskokwim Delta, Alaska			45.1	29; NA					1.7	29; NA			Grand et al. 2002
Spectacled eider (F; Brood rearing)	Yukon-Kuskokwim Delta, Alaska			21.6	4; NA					1.9	4; NA			Grand et al. 2002
Spectacled eider (Duckling)	Yukon-Kuskokwim Delta, Alaska			9.8	10; NA					1.9	10; NA			Grand et al. 2002
Double-crested cormorant (WA)	NW Washington, San Juan Islands	19.4	3; 17-21					38	3; 29-60					Henny et al. 1989
Double-crested cormorant	Colville Island					1.6						1.4		Henny et al. 1989
Double-crested cormorant	Protection Island NWR					1.4						1.3		Henny et al. 1989
Scoter (white-winged, black, surf)	Cape Yakataga, AK 1991	24.4	5; 14-45					3.5	5; 2.3-7.2					Henny et al. 1995
White-winged Scoter	Cape Suckling, AK 1991	22.8	5; 12-39					2.5	5; 1.2-12					Henny et al. 1995
White-winged Scoter	Cape Yakataga, AK 1992	18.7	4; 12-53					2.4	4; 1.6-4.9					Henny et al. 1995
Spectacled eider	St. Lawrence I, AK	23.8	3; 5-77					0.6	3; 0.4-1.1					Henny et al. 1995

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		Selenium						Mercury						
		Liver		Blood		Egg		Liver		Blood		Egg		
Species	Location	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Reference
Steller's eider	Togiak NWR, AK	14	1; NA					1.1	1; NA					Henny et al. 1995
White-winged Scoter	Yukon Flats NWR, AK	54	37; 24-85				6; 2.7-4.7[b]	0.99	37; 0.28-4.02					Henny et al. 1995
Spectacled eider	Yukon Delta, AK 1992					3.3	19; 1.8-5.3					0.07	19; <0.03-0.41	Henny et al. 1995
Oystercatcher	Burry Inlet, Dyfed, Isle of May, Fife							0.73	9; 0.42-0.86					Hutton 1981
Herring gull	Burry Inlet, Dyfed, Isle of May, Fife							4.08	23; 0.52-11.1					Hutton 1981
Great skua	Burry Inlet, Dyfed, Isle of May, Fife							10.4	12; 3.2-30.4					Hutton 1981
Black-footed albatross	Northern Pacific	113	18; 39.0-311					25.5	18; 10.6-70.8					Kim et al. 1996
Northern fulmar	Northern Pacific	32	18; 12.2-56.7					2.83	18; 0.24-6.21					Kim et al. 1996
Brown booby	SW Ryukyu Islands	13.4	14; 4.54-26.6					3.66	14; 0.5-21.1					Kim et al. 1996
Grey petrel	Southern Indian Ocean	100	5; 49.0-194					7.42	5; 5.14-9.68					Kim et al. 1996
Light-mantled sooty albatross	Southern Indian Ocean	74.2	4; 47.9-94.9					12.2	4; 5.44-17.4					Kim et al. 1996
Northern giant petrel	Southern Indian Ocean	76.5	6; 35.6-154					14.5	6; 2.29-23.2					Kim et al. 1996
White-capped albatross	Southern Indian Ocean	41	3; 30.6-56.4					14.5	3; 13.4-15.9					Kim et al. 1996
Yellow-nosed albatross	Southern Indian Ocean	44.4	4; 26.0-61.6					4.24	4; 2.94-5.19					Kim et al. 1996
Royal albatross	Southern Indian Ocean	16.8	3; 14.8-18.5					8.94	3; 4.40-15.1					Kim et al. 1996
White-chinned petrel	Southern Indian Ocean	47.7	3; 28.0-85.5					8.83	3; 7.60-10.6					Kim et al. 1996
Alcids (guillemot [murre] & razorbill)	Dutch Coast	3.4	4; 2.4-4.6					2.1	4; 1.8-2.4					Koeman et al. 1975
Little auk	Greenland	19.7	13; NA					1.61	13; NA					Nielsen and Dietz 1989[e]
Black guillemot	Greenland	8.72	42; NA					2.2	42; NA					Nielsen and Dietz 1989[e]
Brünnich's guillemot	Greenland	7.58	20; NA					2.63	20; NA					Nielsen and Dietz 1989[e]
Common eider	Greenland	27.4	21; NA					3.09	21; NA					Nielsen and Dietz 1989[e]
King eider	Greenland	27.1	21; NA					2.07	21; NA					Nielsen and Dietz 1989[e]
Fulmar	Greenland	28.7	17; NA					0.92	17; NA					Nielsen and Dietz 1989[e]
Glaucous gull	Greenland	16.4	15; NA					8.72	15: NA					Nielsen and Dietz 1989[e]
Kittiwake	Greenland	32	15; NA					2.1	15; NA					Nielsen and Dietz 1989[e]
Brünnich's guillemot	Nordenskiöld Land, Svalbard	27.6	9; 3.7-8.74					2.02	9; 1.01-3.02					Norheim 1987[e]
Common eider	Nordenskiöld Land, Svalbard	29.9	9; 11.4-84					3.36	6; 1.68-5.71					Norheim 1987[e]
Fulmar	Nordenskiöld Land, Svalbard	10.1	10; 4.70-21.5					7.06	10; 2.02-14.1					Norheim 1987[e]
Glaucous gull	Nordenskiöld Land, Svalbard	7.39	11; 4.37-12.1					5.38	11; 2.69-7.73					Norheim 1987[e]
Little auk	Nordenskiöld Land, Svalbard	8.74	9; 5.04-15.1					1.68	9; 1.34-2.35					Norheim 1987[e]

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		Selenium						Mercury						
		Liver		Blood		Egg		Liver		Blood		Egg		
Species	Location	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Reference
Wedge-tailed shearwater	Oahu, HI					5.33	6; NA					0.837	6; NA	Ohlendorf and Harrison 1986
Red-fooetd booby	Oahu, HI					6.07	6; NA					1.2	6; NA	Ohlendorf and Harrison 1986
Sooty tern	Oahu, HI					4.74	4; NA					0.507	4; NA	Ohlendorf and Harrison 1986
Wedge-tailed shearwater	French Frigate Shoals, HI					4.42	7; NA					0.557	7; NA	Ohlendorf and Harrison 1986
Red-footed booby	French Frigate Shoals, HI					5.02	7; NA					1.3	7; NA	Ohlendorf and Harrison 1986
Sooty tern	French Frigate Shoals, HI					4.81	7; NA					0.474	7; NA	Ohlendorf and Harrison 1986
Wedge-tailed shearwater	Laysan, HI					4.46	6; NA					0.482	6; NA	Ohlendorf and Harrison 1986
Red-footed booby	Laysan, HI					5.36	6; NA					1.56	6; NA	Ohlendorf and Harrison 1986
Sooty tern	Laysan, HI					5.15	6; NA					0.634	6; NA	Ohlendorf and Harrison 1986
Wedge-tailed shearwater	Midway, HI					5.14	6; NA					0.553	6; NA	Ohlendorf and Harrison 1986
Red-footed booby	Midway, HI					5.97	6; NA					2.36	6; NA	Ohlendorf and Harrison 1986
Sooty tern	Midway, HI					4.07	6; NA					0.642	6; NA	Ohlendorf and Harrison 1986
Corey's shearwater (Station 1)	Atlantic and Mediterranean Islands	33.6	3; NA			3.4	20; NA	4.6	3; NA			2.1	20; NA	Renzoni et al. 1986
Corey's shearwater (Station 2)	Atlantic and Mediterranean Islands	81.9	5; NA			5.5	10; NA	14.9	5; NA			7.3	10; NA	Renzoni et al. 1986
Corey's shearwater (Station 3)	Atlantic and Mediterranean Islands	132.7	5;NA			5.9	11; NA	17.8	5;NA			5.9	11; NA	Renzoni et al. 1986
Corey's shearwater (Station 4)	Atlantic and Mediterranean Islands	32.9	5; NA			3.3	1; NA	18.9	5; NA			4.8	1; NA	Renzoni et al. 1986
Audouin's gull (1 of 2) [c]	Chafarinas Islands, SW Mediterranean					3.76	4; NA					5.69	4; NA	Sanpera et al. 2000
Audouin's gull (2 of 2) [c]	Chafarinas Islands, SW Mediterranean					3.82	4; NA					4.66	4; NA	Sanpera et al. 2000
Audouin's gull (1 of 3) [d]	Chafarinas Islands, SW Mediterranean					2.82	10; NA					6.57	10; NA	Sanpera et al. 2000
Audouin's gull (2 of 3) [d]	Chafarinas Islands, SW Mediterranean					2.57	10; NA					5.88	10; NA	Sanpera et al. 2000
Audouin's gull (3 of 3) [d]	Chafarinas Islands, SW Mediterranean					2.71	9; NA					5.5	9; NA	Sanpera et al. 2000
Puffin	Barents Sea	>10<15	17; NA					>1<2	17; NA					Savinov et al. 2003
Black guillemot	Barents Sea	>5<10	13; NA					<1	13; NA					Savinov et al. 2003
Glaucous gull	Barents Sea	>5<10	15; NA					>1<2	15; NA					Savinov et al. 2003
Little auk	Barents Sea	<5	25; NA					<1	25; NA					Savinov et al. 2003
Common eider	Barents Sea	>10<15	3; NA					~1	3; NA					Savinov et al. 2003
King eider	Barents Sea	>10<15	9; NA					<1	9; NA					Savinov et al. 2003
Herring gull	Barents Sea	>5<10	5; NA					~1	5; NA					Savinov et al. 2003
Black-legged kittiwake	Barents Sea	>10<15	46; NA					<1	46; NA					Savinov et al. 2003
Northern fulmar	Barents Sea	>15	15; NA					>3<4	15; NA					Savinov et al. 2003

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Species	Location	Selenium						Mercury						Reference
		Liver		Blood		Egg		Liver		Blood		Egg		
		Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	Mean[a]	n; Range	
Arctic tern	Barents Sea	>5<10	5; NA					>1<2	5; NA					Savinov et al. 2003
Brunnich's guillemot	Barents Sea	>5<10	5; NA					<1	5; NA					Savinov et al. 2003
Razorbill	Barents Sea	>15	5; NA					>1<2	5; NA					Savinov et al. 2003
Common eider (1997)	Canadian Arctic	20.1	12; 11-32	17.6	12; 4.9-39			1.8	11; 1.1-3.7	1.1	11; 0.8-1.4			Wayland et al. 2001
Common eider (1998)	Canadian Arctic	18.5	15; 11-47	23	15; 13-44			3.9	15; 2.5-5.8	1.1	15; 0.7-1.9			Wayland et al. 2001
Common eider (F)	Canadian Arctic	16.2	21; 6.5-47					3.3	21; 1.5-9.8					Wayland et al. 2003
Brünnich's guillemot	Barents Sea, Hormøya	7.05	14; NA					1.11	14; NA					Wenzel and Gabrielsen 1995[e]
Common guillemot	Barents Sea, Hormøya	17.6	10; NA					1.88	10; NA					Wenzel and Gabrielsen 1995[e]
Kittiwake	Barents Sea, Hormøya	16.9	22; NA					2.85	22; NA					Wenzel and Gabrielsen 1995[e]

[a] As reported in references (arithmetic or geometric mean), or calculated from individual values when available (geometric mean).

[b] Eggs from oviducts (2.7 and 3.0 μg/g dw) or less well-developed (2.8, 3.0, 3.4, 4.7 μg/g dw) in females shot. Predicted 21.3 or 29.2 μg/g dw in eggs based on livers and other species/area.

[c] Eggs from two-egg clutches

[d] Eggs from three-egg clutches

[e] As reported in Savinov et al. 2003

[f.] As reported in Grand et al 2002, 66% moisture used for egg wet weight to dry weight conversion

F = Females

M = Males

RBC = Red Blood Cells

Avian Blood Sample Analysis

PREPARED FOR: Utah Department of Environmental Quality, Division of Water Quality; Great Salt Lake Science Panel; Dr. John Cavitt; and Dr. Mike Conover

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DATE: March 15, 2007

Background

The concensus of the Science Panel at their November 30-31, 2006 meeting was that the reported selenium (Se) concentrations in blood from nesting birds were higher than expected given the concentrations found in eggs. CH2M HILL reviewed the datasets and analytical methods and reported findings to the Science Panel during their January 4, 2007 conference call. CH2M HILL, the PIs, and Science Panel have since discussed the issue extensively.

Purpose

The purpose of this memorandum is to address a number of questions raised at the Science Panel's conference call on January 4, 2007, pertaining to methods used in analyzing blood samples collected from the Great Salt Lake and present the recommended plan for further analysis of available blood samples developed since that conference call.

Why was avian blood analyzed as freeze-dried samples vs. direct analysis of whole blood?

Chemists from the California Animal Food Health Service Laboratory at UC Davis (who have analyzed samples for us on some of our other projects) stated that they had run spiked blood samples that had been dried and that they would not expect freeze-drying to affect the Se results. Only volatile forms would be lost if there was any loss, and freeze-drying the blood would minimize that loss. Ed Hinderberger (at LET) does not believe that the freeze-drying process will have a discernable impact on the Se results in blood and this premise is supported by the acceptable data quality indicator results. Ed mentioned that several years ago LET evaluated several sample digestion procedures and found that the current sample preparation process (see LET sample preparation SOP in the Quality Assurance Project Plan) generated the most accurate sample data.

Although all of the laboratory chemists that we spoke to from UC Davis, LET, and USFWS indicated that freeze-drying the samples is appropriate, the most relevant remarks were from Brenda Bischoff, who is the Analytical Control Facility Branch Chief for the U.S. Fish and Wildlife Service. The Analytical Control Facility (http://www.fws.gov/chemistry/) does analyses of samples for the USFWS and also handles contracting of analytical services

by other labs for the USFWS. Brenda said that if they were analyzing blood in their own lab, they would freeze-dry the samples for analysis, and both of the labs they have under contract (LET, and the Trace Element Research Laboratory at Texas A&M University) also freeze-dry blood samples for analysis. She also said that Ed Hinderberger's (LET) Se analyses are top-quality, which agrees with our experience over many years of our having used his lab.

Is bias introduced?

Chemists at UC Davis did not think that there would be a bias from freeze-drying. However, if there was a bias it would be a negative bias through loss of volatile forms.

Why were blood sample results reported as dry-weight values vs. wet-weight values?

CH2M HILL directed LET to analyze avian blood and report on dry-weight basis plus percent moisture based upon prior experience, the prevailing reporting found in the literature, as well as consistency with the QAPP. Most of the literature on blood Se in wildlife expresses Se as either µg Se/g or ppm on a wet- or dry-weight basis (El-Begearmi et al. 1977, Moksnes and Norheim 1986, Heinz et al. 1990, Heinz and Fitzgerald 1993, Goede and Wolterbeek 1994, Hoffman and Heinz 1998, NIWQP 1998, Yamamoto et al. 1998, Caldwell et al. 1999, Santolo and Yamamoto 1999, Santolo et al. 1999, Osofsky et al. 2001, Franson et al. 2002, Grand et al. 2002, Henny et al. 2002, Hopkins et al. 2005, Weech et al. 2006). Diagnostic values for Se in poultry blood also are given as ppm values (e.g., Puls 1988). Occasionally (e.g., Wayland et al. 2001), blood Se concentrations in birds are reported as µg Se/dl of blood, but this is not a common practice.

Under uniform conditions of sampling blood, the moisture content of blood is fairly uniform, but under field conditions the moisture content can vary substantially. For example, when mallard blood was sampled over a period of about 3 months by exsanguination in a laboratory study, the dry-weight content of blood averaged 21.70$\pm$0.21 percent (mean $\pm$ SE) (Scanlon 1982). In a laboratory study with kestrels (Yamamoto et al. 1998, Santolo et al. 1999), the dry-weight content of blood averaged 21.40$\pm$0.11 percent (mean $\pm$ SE) with a range from 14 to 25 percent. However, when kestrels and other raptors were sampled in the field (Santolo and Yamamoto 1999), the dry-weight content of blood averaged 19.30$\pm$0.14 percent (mean $\pm$ SE) with a range from 9 to 32 percent. In both the laboratory and field studies of kestrels (and other raptors), blood samples were taken in a consistent manner from the birds by the same investigators. However, there was much greater variability in moisture content of birds collected in the field (Variance = 8.3) and than in the lab (Variance = 2.2).

For the birds sampled at the Great Salt Lake, it was not possible to take blood from a vein in the same manner as blood is collected in most studies (because those birds had been shot). Instead, blood was collected from the thoracic cavity of the birds soon after they were shot. Although the collection method may have resulted in more variablity in moisture content of the sample collected, the range and average moisture content does not seem remarkably different than found in the sampling of raptor blood under field conditions (Santolo and Yamamoto 1999), though we did not compare those statistically. It is unlikely that the

moisture content of the blood samples would change much after collection because they were stored in air-tight containers.

For the reasons given above, and discussed in the December 21, 2006, technical memorandum, "Evaluation of Avian Blood Sample Data from Great Salt Lake, 2006," we believe that it is more appropriate to use dry-weight concentrations because those values generally reduce the variability among blood samples and also normalize the Se concentrations among various tissues and the dietary concentration (i.e., all are on the same dry-weight basis). If it is desirable to estimate wet-weight concentrations (other than using the reported values provided by the lab), that is probably done best by using "normal" moisture content of about 80 percent and dividing the dry-weight concentrations by 5 to get an approximate wet-weight concentration.

What are the results for analyses of reference materials, spiked samples, etc. that are associated with Great Salt Lake avian blood samples?

The Science Panel requested that reference samples, spike values, and other QC data be provided for review. Attached to the memorandum is a table (Attachment A) including the blood and liver data reported as dry-weight and wet-weight concentrations including the standard reference material measurements, reference spikes, and the laboratory duplicate data.

Can blood samples be split to allow for comparison with a different lab? If so, how should that be done?

There is no available material from gull, avocet, or stilt blood samples collected from the Great Salt Lake in 2006.

Blood samples collected from eared grebes in September and November 2006 were frozen and have not been freeze-dried or split. Although it is theoretically possible to split those samples for analysis at two different labs, there is concern that thawing and splitting the samples before freeze-drying them would raise many issues about the lack of comparability (homogeneity) of the split samples (i.e., the previously-frozen blood can't be split with certainty that the samples are comparable) for comparison between labs. Thus, the grebe samples should be freeze-dried for analysis of Se because that is now standard practice and would increase our chances of getting homogeneous samples to split.

The quantity of grebe blood in each sample is small but adequate for the Se analyses the project was designed for. The quantity of grebe blood in each sample is not adequate, however, to facilitate an inter-lab comparison and other potential analyses (e.g., for mercury [Hg]) of the blood. Compositing of some of the blood samples will be required to enable those comparisons and additional analyses.

In addition to the 10 grebes collected during the early and late time period from each of the two locations (Hat Island and Antelope Island), blood (and liver) samples are available from 5 extra grebes collected from the vicinity of Hat Island in the early collection period, 5 extra grebes from Hat Island in the late collection, and 5 extra grebes from Antelope Island in the late collection. The proposed approach for compositing and splitting the samples for inter-lab comparison is as follows:

- Gary Santolo and Mike Conover will determine which extra grebe blood samples will be used to make the composite samples (using "spare" samples other than those that would give us the most representative sample using the remaining grebes) and we provide that list of samples to LET and to Tom May at the USGS Columbia Environmental Research Center in Columbia, MO, who would do analyses for inter-lab comparison.
- LET will then provide the identified blood samples to Tom May, who will create 3 freeze-dried composites with 5 blood samples combined in each. Tom will split the 3 composites and provide half of each freeze-dried, homogenized sample to LET.

How will the inter-laboratory comparison of Se analyses be completed?

Tom May and LET will each use part of each of the three composited samples to do duplicate analyses for Se using hydride generation AA (the same method used by LET for the gull and shorebird samples previously). In addition, they will also do duplicate analyses of the samples for both Se + Hg, with LET using the proposed approach described below.

The main advantage of using the composited samples for the interlaboratory comparison is that more mass would be available for each lab to work with (1 to 1.5 grams of dried blood in each of the 3 samples – still pretty small, but should be adequate and much preferred over trying to split individual bird blood samples). In addition, we can get inter-lab comparison for both the Se analyses and the Se + Hg analyses on the same 3 samples.

Standard reference materials will be analyzed for Se and Hg by each of the labs.

Why and how will bird livers and blood be analyzed for Hg?

The technical memorandum submitted to the Science Panel on December 21, 2006, raised the hypothesis that elevated Se in avian blood may be in part a result of elevated Hg exposure of the sampled birds. A total of 56 eared grebes were collected by Mike Conover in 2006; 40 livers and 40 blood samples were originally planned for Se analyses, and some of them also will be analyzed for both Se and Hg. The remaining livers will be kept in storage, whereas most of the extra blood samples will be used for compositing and inter-lab confirmation of analytical results. The benefit of analyzing livers and blood of those grebes for Hg is that the results should help the project team understand how Se concentrations in liver and blood change with period of residence of the grebes on the lake and also the possible influence of Hg on the Se concentrations in blood, if any.

The Science Panel decided at its conference call on February 22, 2007 to complete Se + Hg analyses of blood and liver for the following:

- 10 eared grebes from early season and 10 of those grebes from late season (total of 20 birds from one location [Mike Conover has suggested using birds from near Hat Island]);
- 10 goldeneyes from the late season (with caveat that these birds may be feeding off-lake); and
- An undetermined number of nesting birds from the Great Salt Lake in May/June 2007 (the number and species to be determined at the March 21-23, 2007 Science Panel meeting).

The analyses of liver samples are under way, and blood analyses will be done once the method for Se + Hg analyses has been subjected to inter-laboratory comparison. Tom May and LET will complete duplicate analyses of the composited blood samples (described above) for both Se + Hg, with LET using the proposed approach described below. Tom's method for Hg is somewhat different, but the expectation is that results should be comparable. Instead of the microwave digestion of a liquid sample, he uses 10-50 mg of the freeze-dried sample that is then thermally combusted in pure oxygen at high temperature, and Hg is then captured in a gold trap, with concentration determined in an AA cell using a mercury autoanalyzer (a DMA 80).

For LET to do the Se + Hg analyses of blood samples (which require different analytical methods), the lab has suggested a change in the procedure for preparation of those samples. Two preparation procedures are summarized below, including the one used previously and the proposed approach (the only real difference is the microwave digestion step) that will facilitate completion of the additional Hg analyses. LET has used this method of sample preparation on other samples and reports good results.

Blood sample preparation used for California gulls and shorebirds:

1) Freeze-dry the samples

2) Perform dry-ash digestion for Se analysis

Proposed procedure for preparation of blood from eared grebes and ducks to be analyzed for Se + Hg:

1) Freeze-dry the samples

2) Perform microwave digestion using a nitric/peroxide solution

3) Split digestate - 25 ml for Hg analysis and 25 ml for Se analysis

4) Perform dry-ash digestion for Se analysis

After the inter-laboratory comparison of analyses of blood for Se and for Se + Hg is completed (with satisfactory results), LET will analyze 20 grebe blood samples (not identified for Se + Hg analysis) for Se using the same methods as for gulls and shorebirds and the other 20 grebe blood samples for Se + Hg using the proposed preparation procedure.

Where to from here?

CH2M HILL will coordinate the above analyses upon approval by the Science Panel.

The following items will be on the agenda for the March 21-23, 2007 Science Panel meeting:

1. Identify the number and species of nesting birds to be sampled for Se + Hg analyses in May/June 2007.
2. Determine path forward given different potential results from laboratories, i.e., If we confirm high Se and Hg, what then?; If high Se and low Hg, what then?; If we show low Se, what then? A decision should be made as to how to proceed with available data. Funding may not be available for further study.
3. Discuss approval of bird reports for publication.

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Attachment A – Validated Data with Laboratory Data Quality Indicator Data

Location	NativeID	Species	QA/QC Type	Sample Date	Sample Time	Matrix	Analyte	Dry Weight Result	Final Validation Flag	RL	Wet Weight Result	Wet Weight RL	Units	Dry Weight Expected Value	Dry Weight Recovery	Comments	LCL	UCL
Antelope Island	Blood A-10	CA Gull	N	4-May-06	10:00	Blood	Selenium	8.8		0.2	1.7	0	ug/g					
Antelope Island	Blood A-11	CA Gull	N	4-May-06	10:00	Blood	Selenium	10		0.3	2.1	0.1	ug/g					
Antelope Island	Blood A-12	CA Gull	MS	4-May-06	10:00	Blood	Selenium	34		1	5.6	0.2	ug/g	33.3	103	wet recovery =101	80	120
Antelope Island	Blood A-12	CA Gull	N	4-May-06	10:00	Blood	Selenium	6.4		0.3	1.1	0.1	ug/g					
Antelope Island	Blood A-1	CA Gull	N	4-May-06	10:00	Blood	Selenium	7.7		0.2	1.9	0.1	ug/g					
Antelope Island	Blood A-2	CA Gull	N	4-May-06	10:00	Blood	Selenium	20		0.6	4.7	0.1	ug/g					
Antelope Island	Blood A-3	CA Gull	N	4-May-06	10:00	Blood	Selenium	19		0.6	4.3	0.1	ug/g					
Antelope Island	Blood A-4	CA Gull	N	4-May-06	10:00	Blood	Selenium	22		0.4	3	0.1	ug/g					
Antelope Island	Blood A-5	CA Gull	N	4-May-06	10:00	Blood	Selenium	14		0.3	2.7	0.1	ug/g					
Antelope Island	Blood A-6	CA Gull	N	4-May-06	10:00	Blood	Selenium	25		0.8	6.7	0.2	ug/g					
Antelope Island	Blood A-7	CA Gull	N	4-May-06	10:00	Blood	Selenium	13		0.3	3.1	0.1	ug/g					
Antelope Island	Blood A-8	CA Gull	LR			Blood	Selenium	14		0.5	3.2	0.1	ug/g	13				
Antelope Island	Blood A-9	CA Gull	N	4-May-06	10:00	Blood	Selenium	7.7		0.2	1.5	0	ug/g					
Antelope Island	6106-1-AML a	AMAV	N	1-Jun-06	7:45	Liver	Selenium	14		0.2	4.4	0.1	ug/g					
Antelope Island	6106-1-AML b	AMAV	N	1-Jun-06	7:45	Blood	Selenium	23		0.2	5.6	0.1	ug/g					
Antelope Island	6106-2-AML a	AMAV	N	1-Jun-06	7:45	Liver	Selenium	16		0.2	5	0.1	ug/g					
Antelope Island	6106-2-AML b	AMAV	N	1-Jun-06	7:45	Blood	Selenium	23		0.3	6	0.1	ug/g					
Antelope Island	6106-3-AML a	AMAV	N	1-Jun-06	7:45	Liver	Selenium	8.3		0.2	2.8	0.1	ug/g					
Antelope Island	6106-3-AML b	AMAV	N	1-Jun-06	7:45	Blood	Selenium	17		1	4.7	0.3	ug/g					
Antelope Island	6106-4-AML a	AMAV	N	1-Jun-06	8:00	Liver	Selenium	10		0.2	3	0.1	ug/g					
Antelope Island	6106-5-AML a	AMAV	N	1-Jun-06	8:10	Liver	Selenium	13		0.2	4.1	0.1	ug/g					
Antelope Island	6106-5-AML b	AMAV	MS	1-Jun-06	8:10	Liver	Selenium	32		0.3	8.1	0.1	ug/g	30.8		Not Calculated	80	120
Antelope Island	6106-5-AML b	AMAV	N	1-Jun-06	8:10	Blood	Selenium	16		0.2	4.1	0.1	ug/g					
Antelope Island	Liver A-10	CA Gull	N	4-May-06	10:00	Liver	Selenium	6.5		0.2	1.8	0.1	ug/g					
Antelope Island	Liver A-11	CA Gull	N	4-May-06	10:00	Liver	Selenium	6.9		0.2	2	0.1	ug/g					
Antelope Island	Liver A-12	CA Gull	N	4-May-06	10:00	Liver	Selenium	6.8		0.2	2	0.1	ug/g					
Antelope Island	Liver A-1	CA Gull	N	4-May-06	10:00	Liver	Selenium	5.3		0.2	1.5	0.1	ug/g					

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Location	NativeID	Species	QA/QC Type	Sample Date	Sample Time	Matrix	Analyte	Dry Weight Result	Final Validation Flag	RL	Wet Weight Result	Wet Weight RL	Units	Dry Weight Expected Value	Dry Weight Recovery	Comments	LCL	UCL
Antelope Island	Liver A-2	CA Gull	N	4-May-06	10:00	Liver	Selenium	6.9		0.2	2.1	0.1	ug/g					
Antelope Island	Liver A-2	CA Gull	LR			Liver	Selenium	6.9		0.2	2.1	0.1	ug/g	6.9				
Antelope Island	Liver A-3	CA Gull	N	4-May-06	10:00	Liver	Selenium	9.5		0.2	2.3	0.1	ug/g					
Antelope Island	Liver A-4	CA Gull	N	4-May-06	10:00	Liver	Selenium	13		0.4	3.3	0.1	ug/g					
Antelope Island	Liver A-5	CA Gull	MS	4-May-06	10:00	Liver	Selenium	16		0.4	4.3	0.1	ug/g	15.9	101	wet recovery =104	80	120
Antelope Island	Liver A-5	CA Gull	N	4-May-06	10:00	Liver	Selenium	6.1		0.2	1.6	0.1	ug/g					
Antelope Island	Liver A-6	CA Gull	N	4-May-06	10:00	Liver	Selenium	9.9		0.4	2.8	0.1	ug/g					
Antelope Island	Liver A-7	CA Gull	N	4-May-06	10:00	Liver	Selenium	6		0.2	1.8	0.1	ug/g					
Antelope Island	Liver A-8	CA Gull	N	4-May-06	10:00	Liver	Selenium	6.7		0.2	1.8	0.1	ug/g					
Antelope Island	Liver A-8	CA Gull	LR			Liver	Selenium	6.8		0.2	1.8	0.1	ug/g	6.7				
Antelope Island	Liver A-9	CA Gull	N	4-May-06	10:00	Liver	Selenium	4		0.2	1.2	0.1	ug/g					
GSL Mineral Colony	Blood CG-01	CA Gull	N	2-May-06	10:00	Blood	Selenium	17		0.4	4.6	0.1	ug/g					
GSL Mineral Colony	Blood CG-02	CA Gull	N	2-May-06	10:00	Blood	Selenium	28		0.5	6	0.1	ug/g					
GSL Mineral Colony	Blood CG-03	CA Gull	N	2-May-06	10:00	Blood	Selenium	32		0.8	6.5	0.2	ug/g					
GSL Mineral Colony	Blood CG-03	CA Gull	LR			Blood	Selenium	32		0.8	6.6	0.2	ug/g	32				
GSL Mineral Colony	Blood CG-04	CA Gull	N	2-May-06	10:00	Blood	Selenium	37		1	10	0.3	ug/g					
GSL Mineral Colony	Blood CG-05	CA Gull	N	2-May-06	10:00	Blood	Selenium	13		0.4	2.3	0.1	ug/g					
GSL Mineral Colony	Blood CG-06	CA Gull	N	2-May-06	10:00	Blood	Selenium	18		0.6	3.7	0.1	ug/g					
GSL Mineral Colony	Blood CG-07	CA Gull	MS	2-May-06	10:00	Blood	Selenium	13		0.3	2.8	0.1	ug/g	12.4	107	wet recovery =107	80	120
GSL Mineral Colony	Blood CG-07	CA Gull	N	2-May-06	10:00	Blood	Selenium	5		0.2	1.1	0	ug/g					
GSL Mineral Colony	Blood CG-08	CA Gull	N	2-May-06	10:00	Blood	Selenium	33		0.7	7.4	0.2	ug/g					
GSL Mineral Colony	Blood CG-09	CA Gull	N	2-May-06	10:00	Blood	Selenium	31		1	6.2	0.2	ug/g					
GSL Mineral Colony	Blood CG-10	CA Gull	N	2-May-06	10:00	Blood	Selenium	25		0.8	5.3	0.2	ug/g					
GSL Mineral Colony	Blood CG-11	CA Gull	N	2-May-06	10:00	Blood	Selenium	37		1	8.7	0.2	ug/g					
GSL Mineral Colony	Liver CG-01	CA Gull	MS	2-May-06	10:00	Liver	Selenium	18		0.4	5.2	0.1	ug/g	16.6	115	wet recovery =110	80	120
GSL Mineral Colony	Liver CG-01	CA Gull	N	2-May-06	10:00	Liver	Selenium	6.7		0.2	2	0.1	ug/g					
GSL Mineral Colony	Liver CG-02	CA Gull	N	2-May-06	10:00	Liver	Selenium	12		0.4	3.5	0.1	ug/g					
GSL Mineral Colony	Liver CG-03	CA Gull	N	2-May-06	10:00	Liver	Selenium	9.9		0.4	3.1	0.1	ug/g					

Attachment A – Validated Data with Laboratory Data Quality Indicator Data

Location	NativeID	Species	QA/QC Type	Sample Date	Sample Time	Matrix	Analyte	Dry Weight Result	Final Validation Flag	RL	Wet Weight Result	Wet Weight RL	Units	Dry Weight Expected Value	Dry Weight Recovery	Comments	LCL	UCL
GSL Mineral Colony	Liver CG-04	CA Gull	N	2-May-06	10:00	Liver	Selenium	13		0.4	3.7	0.1	ug/g					
GSL Mineral Colony	Liver CG-04	CA Gull	LR			Liver	Selenium	13		0.4	3.7	0.1	ug/g	13				
GSL Mineral Colony	Liver CG-05	CA Gull	N	2-May-06	10:00	Liver	Selenium	6.1		0.2	1.9	0.1	ug/g					
GSL Mineral Colony	Liver CG-06	CA Gull	N	2-May-06	10:00	Liver	Selenium	7.5		0.2	2.1	0.1	ug/g					
GSL Mineral Colony	Liver CG-07	CA Gull	N	2-May-06	10:00	Liver	Selenium	3.9		0.2	1	0.1	ug/g					
GSL Mineral Colony	Liver CG-08	CA Gull	MS	2-May-06	10:00	Liver	Selenium	21		0.4	6	0.1	ug/g	20.9		Not Calculated	80	120
GSL Mineral Colony	Liver CG-08	CA Gull	N	2-May-06	10:00	Liver	Selenium	11		0.4	3.1	0.1	ug/g					
GSL Mineral Colony	Liver CG-09	CA Gull	N	2-May-06	10:00	Liver	Selenium	11		0.4	2.9	0.1	ug/g					
GSL Mineral Colony	Liver CG-10	CA Gull	N	2-May-06	10:00	Liver	Selenium	8.6		0.2	2.4	0.1	ug/g					
GSL Mineral Colony	Liver CG-11	CA Gull	N	2-May-06	10:00	Liver	Selenium	12		0.4	3.6	0.1	ug/g					
Hat Island Colony	Blood H-10	CA Gull	N	9-May-06	10:00	Blood	Selenium	25		0.6	5.7	0.1	ug/g					
Hat Island Colony	Blood H-11	CA Gull	N	9-May-06	10:00	Blood	Selenium	8.1		0.2	1.3	0	ug/g					
Hat Island Colony	Blood H-11	CA Gull	LR			Blood	Selenium	8.1		0.2	1.3	0	ug/g	8.1				
Hat Island Colony	Blood H-12	CA Gull	N	9-May-06	10:00	Blood	Selenium	6.3		0.2	1.3	0	ug/g					
Hat Island Colony	Blood H-1	CA Gull	N	9-May-06	10:00	Blood	Selenium	12		0.2	1.6	0	ug/g					
Hat Island Colony	Blood H-2	CA Gull	N	9-May-06	10:00	Blood	Selenium	29		0.5	5.3	0.1	ug/g					
Hat Island Colony	Blood H-2	CA Gull	LR			Blood	Selenium	29		0.5	5.3	0.1	ug/g	29				
Hat Island Colony	Blood H-3	CA Gull	N	9-May-06	10:00	Blood	Selenium	8.5		0.6	2.1	0.1	ug/g					
Hat Island Colony	Blood H-4	CA Gull	N	9-May-06	10:00	Blood	Selenium	15		0.3	2.3	0.1	ug/g					
Hat Island Colony	Blood H-5	CA Gull	N	9-May-06	10:00	Blood	Selenium	15		0.4	3.9	0.1	ug/g					
Hat Island Colony	Blood H-6	CA Gull	N	9-May-06	10:00	Blood	Selenium	17		0.4	5.4	0.1	ug/g					
Hat Island Colony	Blood H-7	CA Gull	MS	9-May-06	10:00	Blood	Selenium	32		0.7	3.8	0.1	ug/g	32.6	96.4	wet recovery =89.7	80	120
Hat Island Colony	Blood H-7	CA Gull	N	9-May-06	10:00	Blood	Selenium	16		0.7	2	0.1	ug/g					
Hat Island Colony	Blood H-8	CA Gull	N	9-May-06	10:00	Blood	Selenium	22		1	6.6	0.3	ug/g					
Hat Island Colony	Blood H-9	CA Gull	N	9-May-06	10:00	Blood	Selenium	18		0.5	2.5	0.1	ug/g					
Hat Island Colony	Liver H-9	CA Gull	N	9-May-06	10:00	Liver	Selenium	8.6		0.4	2.5	0.1	ug/g					
Hat Island Colony	Liver H-10	CA Gull	N	9-May-06	10:00	Liver	Selenium	9.3		0.4	2.7	0.1	ug/g					
Hat Island Colony	Liver H-11	CA Gull	N	9-May-06	10:00	Liver	Selenium	5.7		0.2	1.6	0.1	ug/g					

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Location	NativeID	Species	QA/QC Type	Sample Date	Sample Time	Matrix	Analyte	Dry Weight Result	Final Validation Flag	RL	Wet Weight Result	Wet Weight RL	Units	Dry Weight Expected Value	Dry Weight Recovery	Comments	LCL	UCL
Hat Island Colony	Liver H-12	CA Gull	N	9-May-06	10:00	Liver	Selenium	5.6		0.2	1.8	0.1	ug/g					
Hat Island Colony	Liver H-1	CA Gull	N	9-May-06	10:00	Liver	Selenium	6.3		0.2	1.8	0.1	ug/g					
Hat Island Colony	Liver H-2	CA Gull	N	9-May-06	10:00	Liver	Selenium	13		0.4	2.8	0.1	ug/g					
Hat Island Colony	Liver H-2	CA Gull	LR			Liver	Selenium	13		0.4	2.7	0.1	ug/g	13				
Hat Island Colony	Liver H-3	CA Gull	N	9-May-06	10:00	Liver	Selenium	5.9		0.2	1.8	0.1	ug/g					
Hat Island Colony	Liver H-4	CA Gull	N	9-May-06	10:00	Liver	Selenium	6.8		0.2	2.1	0.1	ug/g					
Hat Island Colony	Liver H-5	CA Gull	N	9-May-06	10:00	Liver	Selenium	6.1		0.2	1.8	0.1	ug/g					
Hat Island Colony	Liver H-6	CA Gull	N	9-May-06	10:00	Liver	Selenium	8.4		0.4	2.5	0.1	ug/g					
Hat Island Colony	Liver H-7	CA Gull	MS	9-May-06	10:00	Liver	Selenium	19		0.4	5.5	0.1	ug/g	19.2	98.2	wet recovery =99.0	80	120
Hat Island Colony	Liver H-7	CA Gull	N	9-May-06	10:00	Liver	Selenium	9.3		0.4	2.7	0.1	ug/g					
Hat Island Colony	Liver H-8	CA Gull	N	9-May-06	10:00	Liver	Selenium	8.6		0.4	2.6	0.1	ug/g					
LET QC	ANTI-DOLT-3	LET QC	SRM				Selenium	6.8		0.2	6.8	0.2	ug/g	7.06		NRCC DOLT-3	6.6	7.5
LET QC	BJO-DOLT-03	LET QC	SRM				Selenium	7		0.2	7	0.2	ug/g	7.06		NRCC DOLT-3	6.6	7.5
LET QC	Blood A-13	LET QC	SRM				Selenium	6.7		0.4	6.7	0.4	ug/g	7.06		NRCC DOLT-3	6.6	7.5
LET QC	Blood H-13	LET QC	SRM				Selenium	5.6		0.4	5.6	0.4	ug/g	5.63		NRCC TORT-2	5	6.3
LET QC	JFC-TORT-02	LET QC	SRM				Selenium	5.1		0.2	5.1	0.2	ug/g	5.63		NRCC TORT-2	5	6.3
LET QC	Liver H-13	LET QC	SRM				Selenium	7		0.4	7	0.4	ug/g	7.06		NRCC DOLT-3	6.6	7.5
LET QC	RefSpk-1	LET QC	BS				Selenium	5		0.2	5	0.2	ug	5	100			
LET QC	RefSpk-1	LET QC	BS				Selenium	5.1		0.2	5.1	0.2	ug	5	102			
LET QC	RefSpk-2	LET QC	BS				Selenium	5.1		0.1	5.1	0.1	ug	5	102			
LET QC	RefSpk-2	LET QC	BS				Selenium	5.2		0.2	5.2	0.2	ug	5	104			
LET QC	RefSpk-3	LET QC	BS				Selenium	5		0.1	5	0.1	ug	5	100			
LET QC	RefSpk-3	LET QC	BS				Selenium	5.2		0.2	5.2	0.2	ug	5	104			
LET QC	RefSpk-4	LET QC	BS				Selenium	5.1		0.2	5.1	0.2	ug	5	102			
LET QC	RefSpk-4	LET QC	BS				Selenium	5.3		0.2	5.3	0.2	ug	5	106			
LET QC	RefSpk-5	LET QC	BS				Selenium	4.9		0.2	4.9	0.2	ug	5	98			
LET QC	RefSpk-6	LET QC	BS				Selenium	5.5		0.2	5.5	0.2	ug	5	110			
LET QC	RefSpk-6	LET QC	BS				Selenium	18		0.2	18	0.2	ug	20	90			

Attachment A – Validated Data with Laboratory Data Quality Indicator Data

Location	NativeID	Species	QA/QC Type	Sample Date	Sample Time	Matrix	Analyte	Dry Weight Result	Final Validation Flag	RL	Wet Weight Result	Wet Weight RL	Units	Dry Weight Expected Value	Dry Weight Recovery	Comments	LCL	UCL
LET QC	RefSpk-7	LET QC	BS				Selenium	5.1		0.2	5.1	0.2	ug	5	102			
LET QC	RefSpk-8	LET QC	BS				Selenium	5.1		0.1	5.1	0.1	ug	5	102			
LET QC	RefSpk-8	LET QC	BS				Selenium	17		0.5	17	0.5	ug	20	85			
LET QC	RefSpk-9	LET QC	BS				Selenium	5.1		0.1	5.1	0.1	ug	5	102			
LET QC	RefStd-1	LET QC	BS				Selenium	5.1		0.2	5.1	0.2	ug	5	102			
LET QC	RefStd-2	LET QC	BS				Selenium	5.1		0.1	5.1	0.1	ug	5	102			
LET QC	RefStd-2	LET QC	BS				Selenium	5.1		0.2	5.1	0.2	ug	5	102			
LET QC	RefStd-3	LET QC	BS				Selenium	5.1		0.1	5.1	0.1	ug	5	102			
LET QC	RefStd-3	LET QC	BS				Selenium	5.2		0.2	5.2	0.2	ug	5	104			
LET QC	RefStd-4	LET QC	BS				Selenium	3.8		0.2	3.8	0.2	ug	5	76			
LET QC	RefStd-4	LET QC	BS				Selenium	4.8		0.2	4.8	0.2	ug	5	96			
LET QC	RefStd-5	LET QC	BS				Selenium	5		0.2	5	0.2	ug	5	100			
LET QC	RefStd-6	LET QC	BS				Selenium	0.2	U	0.2	0.2	0.2	ug	5		Not spiked – Sample spikes ok-		
LET QC	RefStd-6	LET QC	BS				Selenium	21		0.2	21	0.2	ug	20	102			
LET QC	RefStd-7	LET QC	BS				Selenium	5.1		0.2	5.1	0.2	ug	5	102			
LET QC	RefStd-7	LET QC	BS				Selenium	19		0.5	19	0.5	ug	20	95			
LET QC	RefStd-8	LET QC	BS				Selenium	5.2		0.1	5.2	0.1	ug	5	104			
LET QC	RefStd-8	LET QC	BS				Selenium	16		0.5	16	0.5	ug	20	80			
LET QC	RefStd-9	LET QC	BS				Selenium	5.1		0.1	5.1	0.1	ug	5	102			
Ogden Bay	61306-1-AML a	BNST	N	13-Jun-06	7:30	Liver	Selenium	16		0.2	5.3	0.1	ug/g					
Ogden Bay	61306-1-AML b	BNST	N	13-Jun-06	7:30	Blood	Selenium	23		0.6	9.3	0.2	ug/g					
Ogden Bay	61306-2-AML a	BNST	N	13-Jun-06	7:30	Liver	Selenium	11		0.2	3.1	0.1	ug/g					
Ogden Bay	61306-2-AML b	BNST	N	13-Jun-06	7:30	Blood	Selenium	20		0.3	5.3	0.1	ug/g					
Ogden Bay	61306-3-AML a	BNST	N	13-Jun-06	7:30	Liver	Selenium	29		0.5	8.4	0.1	ug/g					
Ogden Bay	61306-3-AML b	BNST	N	13-Jun-06	7:30	Blood	Selenium	40		0.5	11	0.1	ug/g					
Ogden Bay	6606-1-JFC a	AMAV	N	6-Jun-06	7:30	Liver	Selenium	28		0.5	8.4	0.1	ug/g					
Ogden Bay	6606-1-JFC b	AMAV	N	6-Jun-06	7:30	Blood	Selenium	60		0.5	21	0.2	ug/g					
Ogden Bay	6606-2-JFC a	AMAV	N	6-Jun-06	7:30	Liver	Selenium	17		0.2	5.3	0.1	ug/g					

Attachment A – Validated Data with Laboratory Data Quality Indicator Data

Location	NativeID	Species	QA/QC Type	Sample Date	Sample Time	Matrix	Analyte	Dry Weight Result	Final Validation Flag	RL	Wet Weight Result	Wet Weight RL	Units	Dry Weight Expected Value	Dry Weight Recovery	Comments	LCL	UCL
Ogden Bay	6606-2-JFC b	AMAV	N	6-Jun-06	7:30	Blood	Selenium	33		2	12	0.7	ug/g					
Ogden Bay	6606-3-JFC a	AMAV	N	6-Jun-06	7:45	Liver	Selenium	15		0.2	4.5	0.1	ug/g					
Ogden Bay	6606-3-JFC b	AMAV	N	6-Jun-06	7:45	Blood	Selenium	34		0.5	12	0.2	ug/g					
Ogden Bay	6606-4-JFC a	AMAV	N	6-Jun-06	7:45	Liver	Selenium	14		0.2	4.1	0.1	ug/g					
Ogden Bay	6606-4-JFC b	AMAV	N	6-Jun-06	7:45	Blood	Selenium	21		4	7.2	1	ug/g					
Ogden Bay	6606-5-JFC a	AMAV	MS	6-Jun-06	7:45		Selenium	21		0.4	6	0.1	ug/g	21		Not Calculated	80	120
Ogden Bay	6606-5-JFC a	AMAV	N	6-Jun-06	7:45	Liver	Selenium	11		0.2	3.3	0.1	ug/g					
Ogden Bay	6606-5-JFC b	AMAV	N	6-Jun-06	7:45	Blood	Selenium	24		0.6	13	0.3	ug/g					
Ogden Bay	6706-1-JFC a	BNST	N	7-Jun-06	7:30	Liver	Selenium	40		1	13	0.3	ug/g					
Ogden Bay	6706-1-JFC b	BNST	N	7-Jun-06	7:30	Blood	Selenium	68		1	26	0.4	ug/g					
Ogden Bay	6706-2-JFC a	BNST	N	7-Jun-06	7:30	Liver	Selenium	25		0.5	7.7	0.2	ug/g					
Ogden Bay	6706-2-JFC b	BNST	N	7-Jun-06	7:30	Blood	Selenium	37		0.9	12	0.3	ug/g					
Saltaire	6606-10-AML a	AMAV	MS	6-Jun-06	8:45	Liver	Selenium	31		0.5	9.8	0.2	ug/g	29.0		Not Calculated	80	120
Saltaire	6606-10-AML a	AMAV	N	6-Jun-06	8:45	Liver	Selenium	19		0.5	6	0.2	ug/g					
Saltaire	6606-10-AML b	AMAV	N	6-Jun-06	8:45	Blood	Selenium	28		0.3	6.2	0.1	ug/g					
Saltaire	6606-6-AML a	AMAV	N	6-Jun-06	8:45	Liver	Selenium	15		0.2	4	0.1	ug/g					
Saltaire	6606-6-AML b	AMAV	N	6-Jun-06	8:45	Blood	Selenium	18		0.3	4.1	0.1	ug/g					
Saltaire	6606-7-AML a	AMAV	N	6-Jun-06	8:45	Liver	Selenium	24		0.5	6.8	0.1	ug/g					
Saltaire	6606-7-AML b	AMAV	MS	6-Jun-06	8:45	Liver	Selenium	66		0.6	22	0.2	ug/g	65.6		Not Calculated	80	120
Saltaire	6606-7-AML b	AMAV	N	6-Jun-06	8:45	Blood	Selenium	35		0.3	12	0.1	ug/g					
Saltaire	6606-8-AML a	AMAV	N	6-Jun-06	8:45	Liver	Selenium	22		0.5	6.2	0.1	ug/g					
Saltaire	6606-8-AML b	AMAV	N	6-Jun-06	8:45	Blood	Selenium	12		0.3	2.6	0.1	ug/g					
Saltaire	6606-9-AML a	AMAV	N	6-Jun-06	8:45	Liver	Selenium	38		1	11	0.3	ug/g					
Saltaire	6606-9-AML b	AMAV	N	6-Jun-06	8:45	Blood	Selenium	25		0.4	7.4	0.1	ug/g					
LET QC	IAEA A-13	LET QC	SRM				Selenium	0.2		0.2	0.2	0.2	ug/g	0.24			0.16	0.32
LET QC	IAEA A-13-D	LET QC	SRM				Selenium	0.2		0.2	0.2	0.2	ug/g	0.24			0.16	0.32
LET QC	8841 ClinChek Blood 3	LET QC	SRM				Selenium	0.9		0.2	0.9	0.2	ug/g	0.952			0.7626	1.14
LET QC	8841 ClinChek Blood 3D	LET QC	SRM				Selenium	1.1		0.2	1.1	0.2	ug/g	0.952			0.7626	1.14

Attachment A – Validated Data with Laboratory Data Quality Indicator Data

Location	NativeID	Species	QA/QC Type	Sample Date	Sample Time	Matrix	Analyte	Dry Weight Result	Final Validation Flag	RL	Wet Weight Result	Wet Weight RL	Units	Dry Weight Expected Value	Dry Weight Recovery	Comments	LCL	UCL
LET QC	SERO 201705 Blood 3	LET QC	SRM				Selenium	1		0.2	1	0.2	ug/g	0.985			0.924	1.05
LET QC	SERO 201705 Blood 3D	LET QC	SRM				Selenium	1		0.2	1	0.2	ug/g	0.985			0.924	1.05
LET QC	SERO 201705 Blood 3	LET QC	MS				Selenium	27		0.5	27	0.5	ug/g	24.3	112		80	120
LET QC	NIST Oyster	LET QC	SRM				Selenium	2		0.1	2	0.1	ug/g	2.06			1.91	2.21

Notes:
QC types – N = Normal Investigative Sample, LR = Laboratory replicate sample, MS = Matrix Spike, BS= Laboratory Blank Spike, SRM = Standard Reference Material
Not Calculated – Spike concentration is not calculated when the sample result is greater than the spike concentration.
The dry weight expected value for sample with a QA/QC type of “LR” represents the Normal Investigative Sample concentration.
To calculate the MS percent recovery, divide the dry weight sample concentration by the dry weight expected value and multiply by 100.

Evaluation of Mercury Concentrations in Birds Collected from Great Salt Lake

PREPARED FOR: Utah Department of Environmental Quality, Division of Water Quality, & Great Salt Lake Science Panel

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COPIES: Mike Conover
John Cavitt

DATE: April 7, 2008

Higher-than-expected selenium concentrations were found in blood of American avocets, black-necked stilts, and California gulls collected from the Great Salt Lake (GSL) during 2006, in comparison to selenium results for concurrently collected food-chain, liver, and egg samples. While the Science Panel agreed that the critical endpoints for selenium are diet and eggs, they also agreed that the question of high selenium concentrations in blood samples should be further evaluated.

It was expected that selenium concentrations in blood would be similar to those in the birds' diet during the 4 to 8 weeks before their collection. This assumption was based on feeding studies of mallards (Heinz and Fitzgerald 1993) where blood concentrations plateaued after 8 weeks at 84 percent of the 10 micrograms per gram (µg/g) and 70 percent of the 20 µg/g dietary concentration and of American kestrels (Yamamoto et al. 1998) where blood plateaued after 77 days at 100percent of the 5 µg/g and 98 percent of the 9 µg/g dietary concentration. In a study in which selenium accumulation in the liver was studied (Heinz et al. 1990), liver selenium reached a peak concentration of 95 percent of the dietary concentration in 8 days and plateaued.

Blood selenium concentrations were also unexpectedly high when compared to egg concentrations in GSL birds. In kestrels fed 6 or 12 µg/g selenium, egg concentrations were about twice the diet and blood concentrations (Santolo et al. 1999). In contrast, gull and avocet blood collected from GSL birds was 5.5 and 10 times the concentrations observed in eggs (in gulls the geometric mean in blood was 16 and in eggs it was 2.9 µg/g; in avocets the geometric mean in blood was 24 and in eggs it was 2.4 µg/g).

In a technical memorandum, Santolo and Ohlendorf (2007) suggested that the high selenium concentrations may have been due in part to elevated mercury. An inter-lab comparison was conducted to validate the laboratory results by having USGS and the project lab (LET) each analyze split samples of composite eared grebe blood for selenium and mercury (Santolo 2007). The results of the interlab comparison showed that the laboratory (i.e., LET) met the data quality objectives defined by the program. There was only an 8 percent relative percent difference (RPD) for selenium and a 13 percent RPD for mercury.

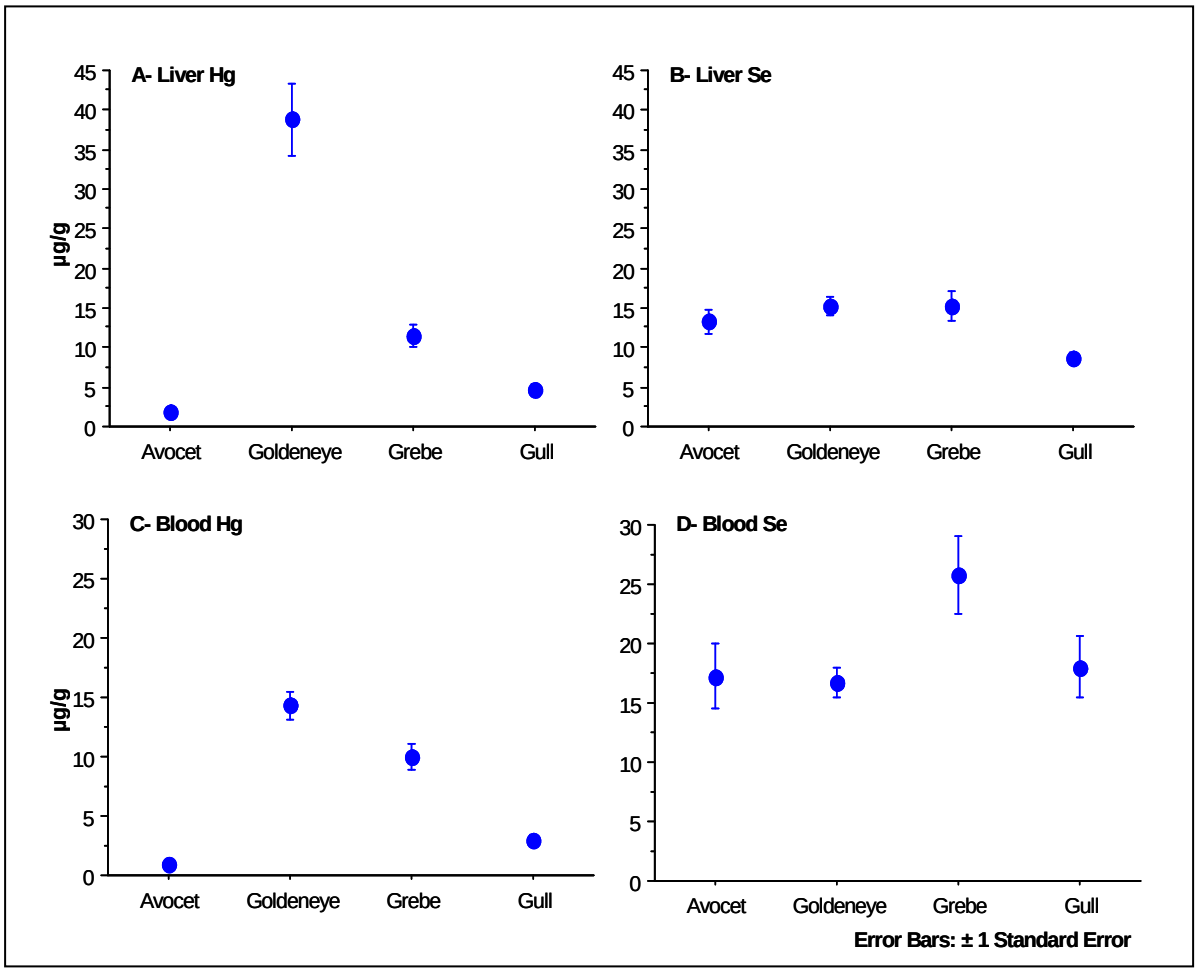
Results of sampling of avian blood, livers, and eggs for mercury and selenium have been reported by Conover et al. (2007a,b,c) and Cavitt (2007) for California gulls, common goldeneyes, eared grebes, and American avocets. For example, results of the selenium and mercury analyses of blood and liver from grebes collected near Hat Island and near Antelope Island showed a pattern of increasing mercury and selenium from fall to winter at Hat Island and higher concentrations at Hat Island than at Antelope Island (Conover 2007b). Similarly, mercury and selenium concentrations in liver and blood from common goldeneyes increased from arrival in fall through winter (Conover et al. 2007c).

This technical memorandum provides a summary and interpretation of those results from the avian mercury and selenium sampling.

Results

There are apparent species differences in mercury and selenium concentrations in liver and blood (Figure 1A-D). Mercury concentrations in livers were highest in common goldeneyes (39 µg/g dw), followed by eared grebes (13 µg/g), and lowest in California gulls (4.6 µg/g) and American avocets (1.9 µg/g; Figure 1A). However, liver selenium concentrations were similar among avocets, grebes, and ducks but lower in gulls (Figure 1B). Blood mercury concentrations were higher in wintering ducks and grebes than in breeding avocets and gulls (Figure 1C) and blood selenium was higher in grebes than other species (Figure 1D). Mercury was significantly higher in grebes sampled in November than in grebes sampled in September (t_{18} = -3.3, P = 0.004).

Figure 1. Mercury and selenium concentrations (µg/g dw) in livers and blood of American avocets, eared grebes, common goldeneyes, and California gulls sampled from Great Salt Lake.



Mercury and selenium molar ratios provide the most reliable and comprehensive criteria for evaluating risks associated with exposure, so these interactions are expressed on a molar basis. There was a near 1:1 ratio in liver but not blood when mercury and selenium results from all birds (ducks, grebes, gulls, and avocets) were combined, but there were notable differences among species (Table 1, Figure 2).

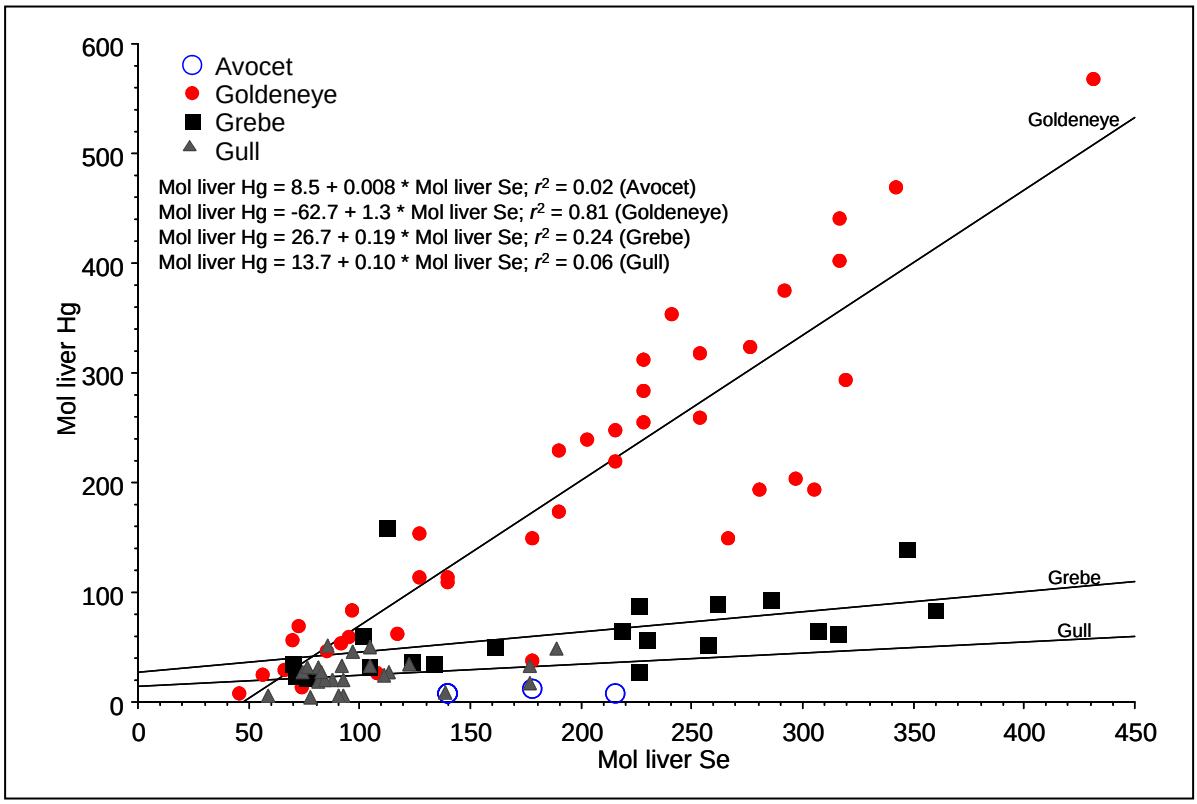
The intraspecies molar relationship between mercury and selenium in liver was most significant in common goldeneyes ($r^2 = 0.81$, $F_{1,40} = 162$, $P < 0.001$), and there was slightly higher than a 1:1 ratio. Eared grebes had a low slope value with a significant relationship and a low correlation coefficient (Table 1). However, by removing a single outlier sample (i.e., likely a newly arrived juvenile with a low liver selenium and high mercury concentration), the slope value was increased to 0.24 and the significance of the relationship was increased ($r^2 = 0.61$, $F_{1,20} = 28$, $P < 0.001$). The molar relationship of mercury and selenium in gull livers from the GSL was not significant ($r^2 = 0.06$, $F_{1,24} = 1.4$, $P = 0.25$).

Table 1. Relationship between selenium (x) and mercury (y) concentrations (µg/g dw) in liver and blood of birds from Great Salt Lake collected in 2007.

Species	***n***	**Regression equation**	**Correlation coefficient (r^2)**	***F***	***P* value**	**Hg Increment[1]**
Liver						
All birds	89	y = - 12.1 + 2.53x	0.52	94	< 0.001	0.99
Common goldeneye	40	y = - 12.58 + 3.36x	0.81	162	< 0.001	1.3
Eared grebe	21	y = 5.35 + 0.47x	0.24	6.1	0.02	0.19
California gull	24	y = 2.75 + 0.26x	0.06	1.4	0.24	0.10
American avocet	4	y = 1.69 + 0.02x	0.016	0.03	0.87	0.008
Blood						
All birds	89	y = - 9.79 + 0.53x	0.05	4.8	0.03	0.098
Common goldeneye	40	y = - 6.51 + 1.9x	0.28	15.1	<0.001	0.22
Eared grebe	21	y = 3.47 + 0.31x	0.49	14.3	0.002	0.096
California gull	24	y = 1.46 + 0.12x	0.18	7.5	0.009	0.026
American avocet	4	y = 0.99 + 0.06x	0.43	1.52	0.34	-0.003

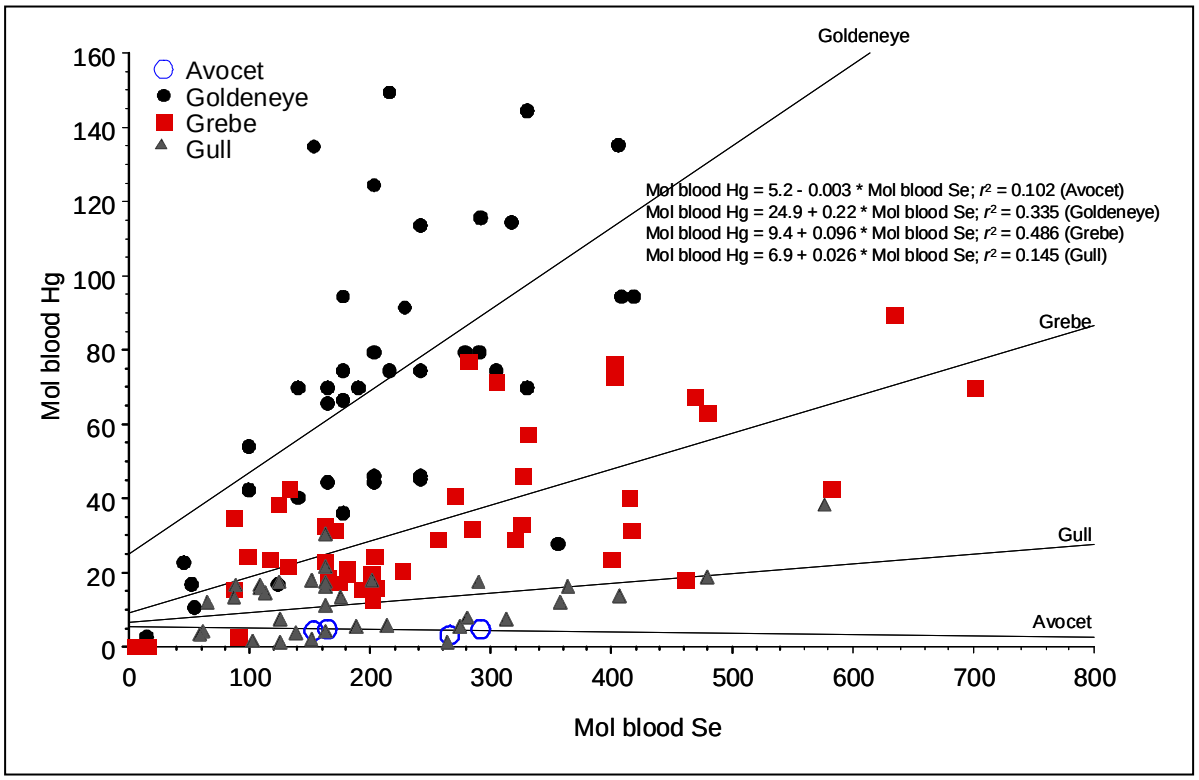
[1] Increment on an atomic basis (atomic weight ratio Hg/Se = 2.54).

Figure 2. Molar relationship between mercury and selenium concentrations in livers of birds sampled from Great Salt Lake.



The intraspecies molar relationship between mercury and selenium in blood was most significant in eared grebes (r^2 = 0.49, $F_{1,17}$ = 38.8, P < 0.001) and common goldeneyes (r^2 = 0.34, $F_{1,40}$ = 19.1, P < 0.001), but with a low slope and correlation coefficient for both (Table 1, Figure 3). The molar relationship of mercury and selenium in gull blood also was significant, but with a lower r^2 and slope (r^2 = 0.15, $F_{1,36}$ = 5.8, P = 0.02). The relationship of blood mercury and selenium on molar basis was not significant in American avocets (r^2 = 0.10, $F_{1,4}$ = 0.23, P = 0.68); however, the sample size for avocets was small.

Figure 3. Molar relationship between mercury and selenium concentrations in blood of birds sampled from Great Salt Lake.



On molar basis, mercury in liver was significantly related (r^2 = 0.83, $F_{1,68}$ = 331, P < 0.001) to that in blood in all birds sampled, and the ratio of liver to blood mercury was nearly 3:1 (slope = 3.1). Selenium concentrations in liver and blood also were significantly related (r^2 = 0.37, $F_{1,110}$ = 65, P < 0.001) and the ratio was about 1:1 (slope = 0.95). Moles of liver selenium were significantly related to moles of mercury in the blood (r^2 = 0.59, $F_{1,68}$ = 98, P < 0.001) with a high slope value (slope = 0.36). Although the relationship between mercury and selenium in blood was significant, it explained only about 16 percent of the variability in the results (r^2 = 0.12, $F_{1,68}$ = 8.8, P = 0.004) with a low slope value (slope = 0.13).

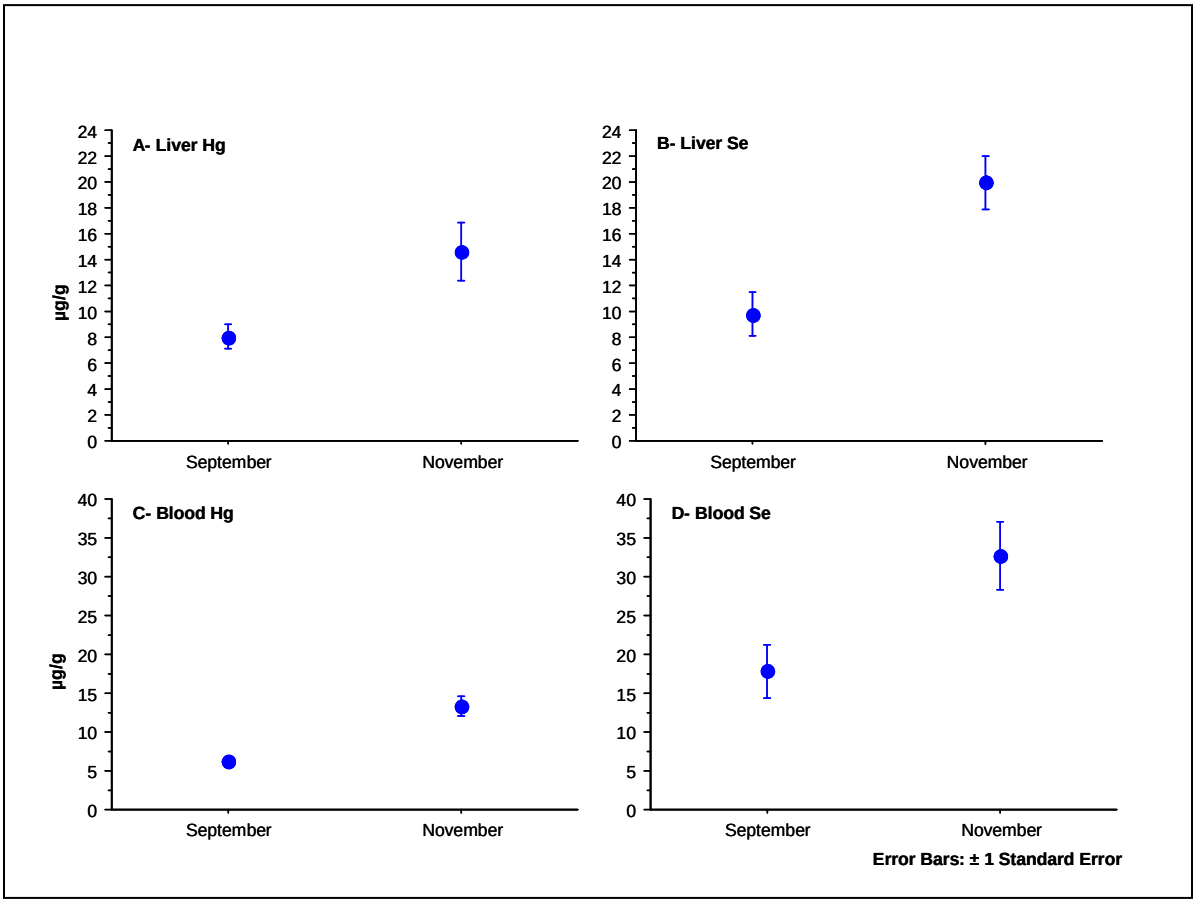
Grebes were the only species for which distinct arrival (September) and later (November) periods were sampled. In grebes, mercury and selenium concentrations in livers significantly increased from September to November (Table 2, Figure 4). Shortly after arrival, the relationship between mercury and selenium in livers was not significant (r^2 = 0.37, $F_{1,9}$ = 4.1, P = 0.08) and there was a low slope value (0.14); in contrast, there was a significant relationship between mercury and selenium (r^2 = 0.42, $F_{1,11}$ = 6.6, P = 0.03) and a higher slope value (0.28) in November grebes.

Table 2. Mercury and selenium (µg/g dw) in livers and blood from fall resident eared grebes in September and in November at Great Salt Lake.

Sample Period (Month)	Liver		Blood	
	GM Hg[1] (*n*) Range	GM Se[1] (*n*) Range	GM Hg[1] (*n*) Range	GM Se (*n*) Range
Early (September)	7.2B (9) 4.5 – 12	8.8B (29) 5.0 - 20	4.4A (22) 0.09 – 8.6	14A (22) 0.3 – 46
Late (November)	14A (11) 5.9 – 28	13A (29) 6.4 - 28	5.7A (21) 0.05 - 18	19A (21) 1.1 – 55

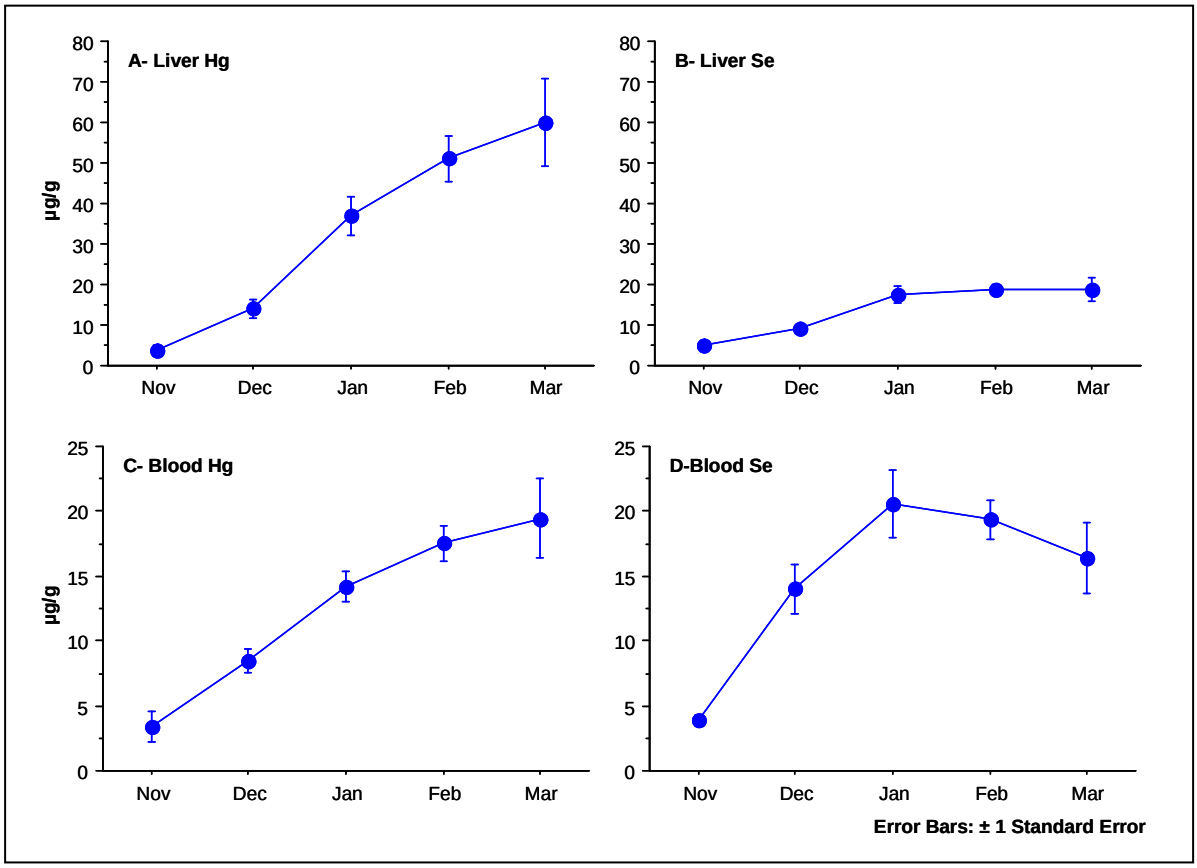
[1] Geometric means with different uppercase letters within columns are significantly different from each other (Unpaired *t*-test ά = 0.05).

Figure 4. Liver mercury (A) and selenium (B) and blood mercury (C) and selenium (D) concentrations (µg/g dw) in eared grebes collected from Great Salt Lake in September and November.



Similar but more pronounced increases in mercury and selenium in livers and blood were observed in goldeneyes collected from November 2005 through March 2006 (Figure 5A-D). For example, mercury increased in common goldeneye livers from a mean of 3.9 µg/g dw, when they first arrived in November, to 14 µg/g in December, 37 µg/g in January, 51 µg/g in February, and 60 µg/g in March (Figure 4A). Selenium concentration in livers increased from November (GM = 5.1 µg/g) to 16 µg/g dw in March but reached a plateau in January (Figure 5B). Mercury concentrations in blood continued to increase from November (in parallel with livers), whereas selenium concentrations in blood decreased after January (when they had plateaued in livers). The initial increase of selenium concentration in blood was much faster than in liver, and it was faster than the increase for mercury in blood (Figures 5C and 5D).

Figure 5. Liver mercury (A) and selenium (B) and blood mercury (C) and selenium (D) concentrations (µg/g dry weight) in common goldeneyes collected from Great Salt Lake in November through March.



Mercury concentrations were lower in livers and blood of gulls and avocets than in ducks and grebes but the sample size for avocets was small (Table 3) and gulls and avocets were collected within a short period during their spring breeding season. No significant relationship was found between mercury and selenium in gulls ($F_{1,24}$ = 1.4, P = 0.25) or avocets ($F_{1,4}$ = 0.03, P = 0.87).

Table 3. Mercury and selenium (µg/g dw) in livers and blood from common goldeneyes, eared grebes, California gulls, and American avocets collected from Great Salt Lake.

	Liver		Blood	
Species	GM Hg[1] (*n*) Range	GM Se[1] (*n*) Range	GM Hg[1] (*n*) Range	GM Se (*n*) Range
Common goldeneye	26A (40) 1.6 – 114	13A (40) 3.6 - 34	12A (40) 0.6 - 30	14A (40) 1.1 – 33
Eared grebe	11B (21) 4.5 – 32	11AB (59) 5.0 – 28	4.9B (43) 0.05 - 18	16A (43) 0.3 – 55
California gull	2.6C (24) 0.3 – 9.9	7.9B (24) 4.7 – 15	2.5C (24) 0.6 – 7.6	14A (24) 4.8 – 46
American avocet	1.9C (4) 1.7 – 2.7	13AB (4) 11 – 17	0.89C (4) 0.7 – 1.0	17A (4) 12 – 23

[1] Geometric means with different uppercase letters within columns are significantly different from each other (Tukey-Kramer ά = 0.05).

California Gull Mercury and Selenium

Gulls collected from Neponset Reservoir had significantly lower mercury concentrations in liver than gulls from Hat Island and lower blood concentrations than gulls from Great Salt Lake Minerals (GSLM) and Hat Island. However, selenium concentrations in liver and blood were similar to those observed in gulls from both Great Salt Lake sites (Table 4).

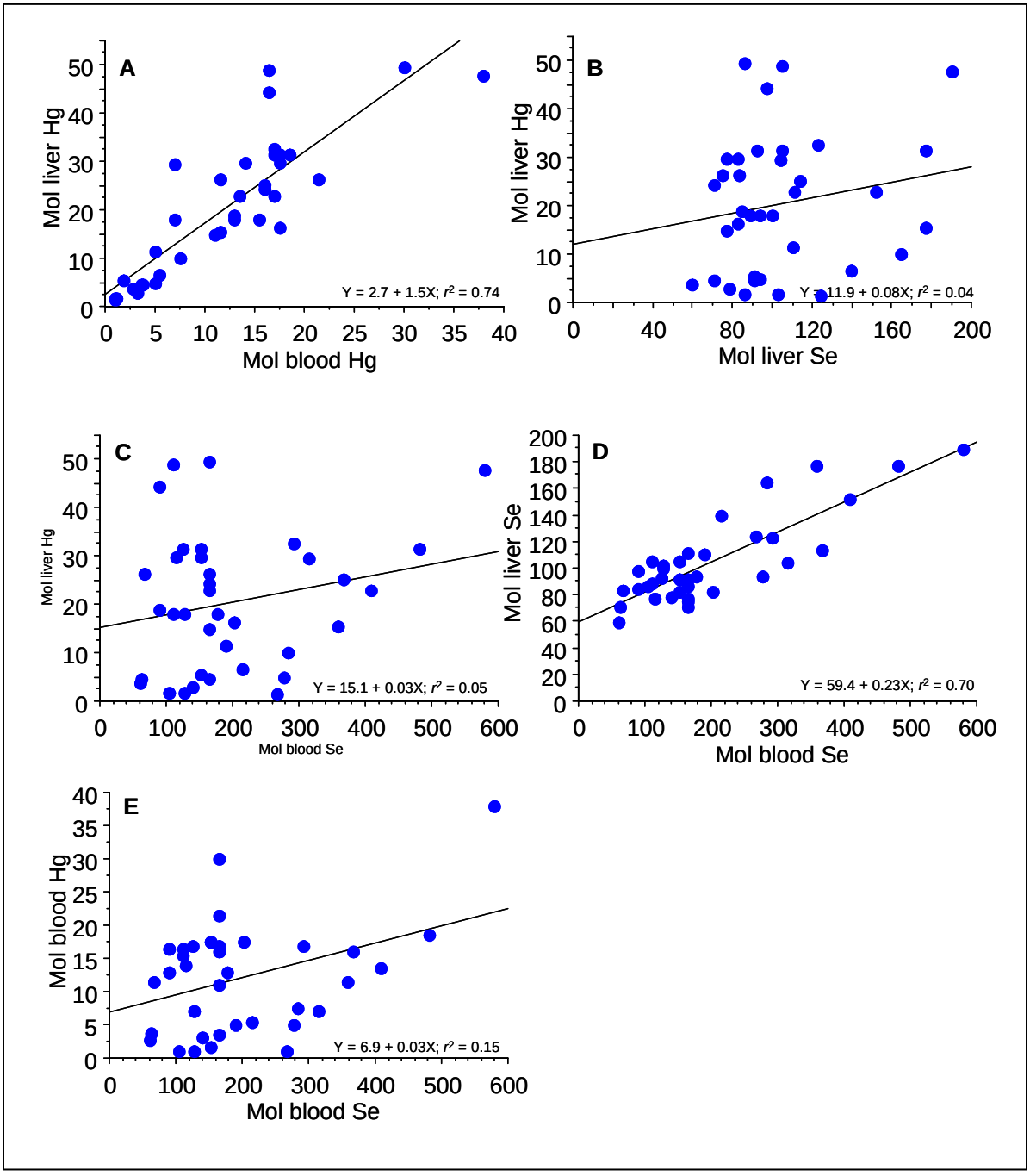
Table 4. Mercury and selenium (µg/g dw) in livers and blood from California gulls collected from Great Salt Lake and Neponset Reservoir.

	Liver		Blood	
Location	GM Hg[1] (*n*) Range	GM Se[1] (*n*) Range	GM Hg[1] (*n*) Range	GM Se (*n*) Range
GSLM	2.9AB (12) 0.6 – 9.9	8.8A (12) 6.2 - 15	2.3A (12) 0.6 – 7.6	18A (12) 8.7 – 463
Hat Island	4.9A (12) 0.8 – 9.8	7.1A (12) 4.7 – 9.7	2.7A (12) 0.6 – 4.3	9.8B (12) 4.8 – 23
Neponset	1.6B (12) 0.3 – 5.9	7.9A (12) 5.6 – 13	0.8B (12) 0.2 – 3.2	14AB (12) 5.0 – 32

[1] Geometric means with different uppercase letters within columns are significantly different from each other (Tukey-Kramer ά = 0.05).

On a molar basis, gulls showed a significant positive relationship ($P < 0.001$) between mercury in liver and blood with a slope of 1.5 (Figure 6A) but did not show a significant relationships between mercury and selenium in livers ($P = 0.25$; Figure 6B) or mercury in liver versus selenium in blood ($P = 0.41$). There was a significant molar relationship ($P < 0.001$) between selenium in liver and blood with a slope of 0.23 (Figure 6D) and mercury and selenium in blood ($P = 0.02$; Figure 6E).

Figure 6. Molar relationship between mercury concentrations in liver and blood (A), liver mercury and selenium (B), liver mercury and blood selenium (C), liver and blood selenium (D), and blood mercury and selenium(E) of California gulls sampled from Great Salt Lake and Neponset Reservoir.



Discussion

We believe the most likely explanation for the higher-than-expected blood selenium concentrations is exposure to elevated mercury concentrations in GSL, as previously suggested (Santolo and Ohlendorf 2007).

Despite their common occurrence, biological effects of metal contaminant mixtures are poorly understood and difficult to predict. However, selenium and mercury are known to interact, and selenium is thought to have a protective effect against mercury by forming a stable and nontoxic complex. The interaction between these elements may also increase the retention and accumulation of mercury (Furness and Rainbow 1990) and perhaps selenium. Differences in the relationship between blood and liver selenium concentrations may be attributed to more rapid elimination from liver than blood and to binding of selenium to inorganic mercury forming an inert Hg-Se protein with a long half-life (Wayland et al. 2001). Alternatively, high mercury may cause a rapid increase in blood selenium, and faster than in liver as shown by the goldeneyes.

Studies by Henny et al. (2002) and Spalding et al. (2000) have shown high correlations of selenium with inorganic mercury on a molar basis in livers of fish-eating birds. Those authors suggested that selenium may contribute to the sequestration of inorganic mercury, thereby reducing its toxicity. This conclusion would be consistent with the results of a selenium-mercury interaction study with mallards by Heinz and Hoffman (1998) in which adults were fed 10 µg Se/g, 10 µg Hg/g, or 10 µg Se + 10 µg Hg/g (Heinz and Hoffman 1998). Female mallards fed the combination diet (10 µg Se + 10 µg Hg/g) had about 1.5 times higher liver selenium concentrations than those fed the selenium-only diet, and the male mallards fed the combination diet had almost 12 times the selenium concentration of those fed the selenium-only diet. Selenium provided a protective effect that reduced the toxicity of mercury to adult male ducks. However, when the diet contained 10 µg Se/g plus 10 µg Hg/g, the effects on reproduction were worse than for either selenium or mercury alone. The number of young produced per female and frequency of teratogenic effects were significantly affected by the combination of mercury and selenium in the diet. Selenium in eggs from mallards fed the combination diet, converted from wet weight to dry weight, were 47 µg/g, which was higher than control eggs (1.8 µg/g) and eggs from mallards fed 10 µg Se/g (38 µg/g) or 10 µg Hg/g (1.9 µg/g). Although in the GSL studies breeding gulls and avocets showed higher selenium concentrations than would be expected from dietary selenium alone, no reproductive effects were observed.

Japanese quail fed increasing concentrations of mercury with a constant concentration of selenium as selenite (i.e., 0 Hg + 6 µg Se/g, 2.5 ppm Hg + 6 µg Se/g, 5 µg Hg/g + 6 µg Se/g, 10 µg Hg/g + 6 µg Se/g, or 15 µg Hg/g + 6 µg Se/g) (nominal dw concentrations) for 20 weeks had blood selenium concentrations that increased with increasing mercury (El-Begearmi et al. 1977). This is similar to what we observed in common goldeneyes wintering at GSL.

In a field study, common eiders from the Arctic were sampled over a 2-year period (Wayland et al. 2001). From the first to second year, liver mercury concentrations more than doubled (from 1.8 to 3.9 µg Hg/g dw) but blood mercury concentrations did not change (0.23 µg Hg/dl). From the first to second year, liver selenium concentrations went from

20.1 to 18.5 µg Se/g dw but blood selenium increased from 3.5 µg Se/dl to 4.7 µg Se/dl. This suggests that with the higher mercury levels (i.e., in year 2), there was some proportion of selenium bound to mercury. Similarly, grebe liver mercury and selenium increased from September to November but blood mercury and selenium did not (Table 2).

In marine wading birds, selenium and mercury showed a strongly positive relationship in blood; however, this relationship was not observed in liver or kidney (Goede and Wolterbeek 1994). This suggests that the selenium concentrations observed in the blood were higher than in the diet and were caused by the higher mercury concentrations and is similar to what was observed at GSL.

Birds feeding at different sampling locations had diets that varied from saline to fresh water according to locations. Shorebirds from Ogden Bay and Saltair had at least partially freshwater diets. Gulls from Neponset Reservoir and possibly also Antelope Island and GSLM had at least partially freshwater diets. Shorebirds from Antelope Island and gulls from Hat Island likely had 100 percent diets from saline water. This may have affected exposure to mercury and selenium in individual shorebirds and gulls.

Selenium concentration in avocet blood was higher but avocets did not have a correspondingly elevated mercury concentration. However, the avocets were sampled at one point in time whereas grebes and ducks were sampled over a period of months. Avocets appear to take up selenium quickly and different species may have differences in how they process and retain selenium and mercury. For example, grebes feed only on the lake, and goldeneyes feed in marshes where more methylation of mercury occurs. Avocets eat corixids from freshwater sources (such as the KUCC outfall ditch and Ogden Bay site), as do some goldeneyes and gulls; however, grebes forage exclusively in the saline open waters.

As an essential nutrient, normal selenium concentrations in blood of birds should be about 1 µg/g, but there should normally not be any mercury in birds. Selenium and mercury in grebes almost doubled between September and November while they resided on GSL. Results of a recent study by Nathan Darnall/USGS et al. (personal communication) found a similar increase, with mercury increasing in December to almost 30 µg/g. This increase could be due to factors such as seasonal differences, stress, varying inflows, and temperatures.

There was more selenium than mercury in avocets and grebes. Although mercury undoubtedly contributes to the bioaccumulation of selenium, the elevated selenium levels may not be entirely due to mercury. In birds, uptake of selenium is faster than that of mercury, and the collected samples represent only a snapshot in time so they may not tell the entire story. Further study evaluating selenium and mercury concentrations in birds when they first arrive and then measuring those levels over time would be needed to definitively answer the question.

Generally, blood selenium concentrations were higher than liver concentrations in all birds collected at GSL. There was no significant difference among nesting colonies for selenium in livers of California gulls. However, blood selenium concentrations were significantly higher in gulls from the GSLM colony than the Antelope Island ($P = 0.007$) and Hat Island colonies ($P = 0.039$).

Laboratory analyses in samples collected during 2007 included mercury. Knowing mercury concentrations in bird samples provides us with information that can be used to identify possible reasons for the higher-than-expected blood selenium concentrations that were found. Dietary selenium influences mercury toxicity and can be directly related to mercury:selenium ratios (Kim et al. 1996, Henny et al. 2002, Nicholas et al. 2007).

The toxic effects of mercury in birds can include weight loss due to reduced food intake, weakness in wings and legs leading to difficulty flying and standing, and loss of coordination (Scheuhammer 1987). The toxic effects of selenium in adult and juvenile birds include reduced reproductive success, emaciation, and loss of feathers (Ohlendorf 2003). Mercury and selenium toxic effects were not observed in birds from GSL even though some concentrations were in the range where they would be expected. Correlation between mercury and selenium is not well established in birds, and there seem to be highly variable relationships that depend on species and concentrations. The mercury and selenium relationship may be influenced by the relative rates of accumulation (Ohlendorf 1993), the nonessential nature of mercury and essential nature of selenium, the excretion of MeHg (Kim et al. 1996), whether mercury is in the inorganic or methylated form (Henny et al. 2002), or other factors.

When there is a low concentration of mercury, a lower molar ratio is observed; however, at high mercury and selenium concentrations in the liver, most selenium binds mercury resulting in a mercury-to-selenium ratio greater than 1.0 (Kim et al. 1996). Common goldeneyes had significantly higher liver selenium concentrations than the other birds and also had a mercury increment of 1.3. This suggests that selenium plays a role in mercury detoxification for individuals with high mercury levels. However, molting and species-specific demethylation also influence the relationship.

In conclusion, both grebes and ducks showed a temporal increase of mercury and selenium in liver and blood and there was a strong molar relationship, especially in livers, between mercury and selenium for goldeneyes and grebes. In gulls, mercury concentrations were lower overall (especially in Neponset Reservoir birds) and the molar relationship for mercury and selenium was not evident. The blood selenium concentrations especially did not reflect the dietary or egg concentrations observed. A rapid increase in blood selenium appears to be associated with mercury exposure. The initial large increase in blood selenium, faster than in the liver, observed in the goldeneyes and grebes may explain the high blood selenium observed in shorebirds and gulls during 2006. Residence time for shorebirds and gulls before collection in 2006 is not known, but presumably they were in this "early exposure" phase. The grebe and duck mercury and selenium results support the hypothesis that the high selenium concentrations observed in gulls and shorebirds may have been due to the initial increase in blood selenium due to their exposure to mercury. Both dietary and egg concentrations of selenium were below levels of concern in that they were well below the EC_{10} for effects derived in the laboratory with mallards. Dietary selenium concentrations may be too low or the exposure time too short for egg selenium concentrations to be greatly affected by the mercury-selenium interactions at GSL.

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DERVING A SELENIUM STANDARD FOR THE GREAT SALT LAKE FOR THE PROTECTION OF AQUATIC WILDLIFE

Prepared by:

William J. Adams, Ph.D.

Summary

1. In recognition of the insensitivity of indigenous aquatic species, it is recommended that avian thresholds are used for the assessment of selenium the Great Salt Lake (GSL).
2. I support the use of the bird egg EC10 threshold (12.5 mg/kg) and I also support the use of the dietary threshold, 4.87 mg/kg. This later value must be adjusted for trophic transfer from diet to bird eggs to be used as a monitoring for brine shrimp in the GSL.
3. I do not support the use of values other than the EC10, such as EC05 or EC03 or the lower bounds on the EC10 values as they add conservatism where it is not needed. The EC10 for mallard duck hatchability as used in the modelling approach provides a conservative estimate of effects threshold for birds using the GSL. Other conservative measure were also sadded into the over GLS assessment made by the Science Panel.
4. I do not support the development of a water-based selenium standard at this time in light of the uncertainty between water concentrations and tissue concentrations. I recommend that the best way forward is to institute a tissue-based standard with a tissue-based monitoring program incorporated into UPDES permits.

Introduction

In this short paper I cover four key topics of interest relative to establishing a selenium standard for the protection of aquatic wildlife for the GSL:

1. Relevant background information on selenium
2. Effects thresholds for aquatic wildlife; diet and egg
3. Need for conservancy in setting the standard
4. Proposed approach going forward for a selenium standard

Deriving a Selenium Standard

1. Relevant background information on selenium

Selenium is a metalloid that is known to be both essential and toxic at elevated levels above background. It is well established that the primary route of exposure for wildlife is through the diet. It is also well established in the scientific literature that aquatic invertebrates and algae are less sensitive than fish or avian species. Since the GSL does not contain fish (except in small freshwater zones), the primary focus is on setting a standard that is protective of avian wildlife. Recognizing that the use of the GSL by birds is unique in terms of its habitat, number of birds using the Lake and the importance of the food source, it is important to protect the resource.

Acute and chronic studies performed with aquatic species inhabiting the Lake (brine shrimp, brine flies and algae) have shown that these species are relatively insensitive to

selenium and should a water quality standard be set in accordance with USEPA guidelines used for other water bodies, the selenium standard would be quite high (>200 ug/L). In recognition of the insensitivity of indigenous aquatic species, Brix et al. (2004) recommended the use of avian thresholds for the assessment of selenium in the GSL.

2. Effects thresholds for aquatic wildlife; diet and egg

The Science Panel recommended the following selenium toxicity thresholds, which are based on the EC10 values (10% effect concentrations) derived in Ohlendorf (2003):

- **Dietary threshold:** 4.87 mg/kg dry wt. (95% confidence interval = 3.56-5.74)
- **Egg threshold:** 12.5 mg/kg dry wt. (95% confidence interval = 6.4-16.5)

Ohlendorf (2003) derived the above EC10 values based on the relationships between dietary/egg selenium concentrations and egg hatchability in mallard ducks. EC10 values were estimated, which represent the selenium concentration in the mallard diet or egg that is associated with a 10% reduction in hatching success relative to the control. This value of approximately 12 mg/kg was confirmed by Adams et al. (2003) who, in a separate publication using a different statistical approach, also showed that the EC10 could be higher depending upon the statistical approach selected and that the EC10 could range from 12-15 mg/kg (each with an associated confidence interval). The Adams et al. (2003) analysis also included chick survival following hatching. As a means to being conservative, my co-authors and I have used an EC10 of 12.5 mg/kg in performing risk assessments. **I continue to support the use of the bird egg EC10** (12.5 mg/kg) as a protective and conservative value when it is applied to the most sensitive species and most sensitive endpoint as the case for the selenium assessment for the mallard duck for the GSL**.** The EC10 value has been universally adopted in recent months in Europe as the preferred approach to setting toxicity thresholds for risk assessments and has undergone extensive peer review by scientists and 25 member countries. **I also support the use of the dietary threshold**, 4.87 mg/kg dry wt. as an appropriate level that is protective for birds consuming organisms from the GSL. However, for this value to be used as a monitoring tool for the GSL, it must be adjusted to reflect site-specific transfer of selenium from diet to egg, which would increase the concentration in brine shrimp not to be exceeded to approximately 6-7 mg/kg.

3. Need for conservancy in setting the standard

There are several issues that can be considered in evaluating whether the dietary and egg selenium values of 4.87 (3.56-5.74) mg/kg and 12.5 (6.4-16.5) mg/kg, respectively, are sufficiently conservative. One issue, discussed above, is the relative sensitivity of the species used to derive the values. The mallard, as we have seen, appears to be very sensitive to selenium, so we leave that issue. Another issue is the sensitivity of the endpoint. The selenium toxicity data available for mallards are based on long-term reproductive studies, in which endpoints such as fertility, hatchability, teratogenesis, and hatchling survival were evaluated. Of these, hatchability clearly appears to be a very sensitive endpoint. The following evaluates the EC10 values further to demonstrate that they are appropriately conservative and highlights some of the uncertainties in trying to estimate even lower effect concentrations (e.g., EC01, EC03) from existing data sets.

It is important to understand that EC10 values are specific to the data on which the values are based and it cannot be assumed that they are directly translatable to a 10% decline in bird reproductive output at the GSL. Nor can the assumption be made that a reduction in reproduction due to a chemical will translate into an equal reduction in population numbers. A small loss in

reproduction may not translate to any loss in the population. The intent is to set the protection level sufficiently low such that the recruitment to the population is sufficient to maintain population numbers. The use of EC10 values has gained widespread use in the literature over the past decade as an acceptable protective level (exception being Threaten and Endangered Species). Because it becomes more difficult to precisely measure biological effects at very low doses, it is difficult to develop thresholds based on lower levels of effects, such as EC01, EC03, EC05 values, since the confidence intervals are very large and indicate a large degree of uncertainty in the effect level. **It is important to point out that that an EC10 of 12 mg/kg is lower than the lowest concentrations that have been shown to be statistically significant relative to controls** and is therefore conservative. Estimation techniques used to derive concentrations below the EC10 are of questionable value and reflect estimates of possible effects.

The modeling approach used to evaluate a standard for the GSL has included several conservative steps, these include the following: (1) use of the most sensitive bird species tested to date, mallard duck, which rarely inhabits the GSL; (2) selection of the most sensitive endpoint (reproductive success); (3) use of the dietary species with the greatest ability to accumulate selenium (brine shrimp) and (4) an assumption that the birds feed exclusively on diet from Lake. These four factors bring a large degree of conservatism into the risk-based approach to setting a standard for the Lake. **On this basis, I cannot support the use of additional conservatism** such as the use of an EC05 or EC03 or the lower bounds on the EC10. Such values reflect unnecessary degrees of conservatism.

4. Proposed approach going forward

Brix et al (2004) evaluated the potential for selenium to accumulate in brine shrimp and be consumed by sensitive birds. This analysis was based upon measured concentrations of selenium in brine shrimp that were exposed to selenium (as selenate) being discharged to the GSL from the tailings impoundment. Concentrations ranged from 1-121 ug/L with tissue concentrations in brine shrimp ranging from 2.8-15.5 mg/kg (ppm). This resulted in a concentration of 27 ug/L being associated with a tissue concentration greater than 5 ppm in the diet of birds (see data below). The 5 ppm value was determined to be the approximate EC10 for dietary effects for mallard ducks and recently reaffirmed by the Science Panel (4.86 mg/kg).

Table 1. Summary of co-located selenium concentrations in water and brine shrimp in the vicinity of the Kennecott discharge.

Sample date	Station	Total Se (µg/L)	Dissolved Se (µg/L)	Tissue Se (mg/kg dry wt)	BAF[a]
6/21/98	1	120	121	15.5	129
6/21/98	2	117	116	15.4	132
6/21/98	3	85	81	7.82	92
6/21/98	4	30	30	3.36	112
6/21/98	5	2	2	2.75	1,375
6/21/98	6	2	2	2.86	1,430
6/21/98	7	2	2	3.14	1,570
8/27/98	7	1	1	3.38	3,380

[a] BAF = bioaccumulation factor.

In a subsequent study performed in 2004, I collected corixids (water boatmen) from the discharge zone of the Kennecott 012 outfall to the GSL. The corixids were collected along a one mile stretch of the discharge stream leading to the Lake. At the time of the sampling the concentration of selenium in the effluent was 27 ug/L and had remained in the range of 25-28 ug/L for more than 30 days. This provided a unique opportunity to revaluate the tissue levels of aquatic invertebrates. The results of this survey revealed that the average concentration in the corixids was 5.5 mg/kg (ppm). Hence, the original prediction that 27 ug/l will result in 5 mg/Kg in brine shrimp tissue was confirmed by this assessment where the exposure to these organisms occurred in a natural setting and exposure was constant.

Subsequent extensive studies performed by Dr. Marjorie Brooks at the University of Laramie, have indicated that selenate has a low potential for accumulation by brine shrimp and algae. Dr. Brooks conducted long term bioaccumulation studies with brine shrimp that exceeded 20 days and with algae that were 60 days in length using GSL water and selenate and selenite. The studies of Dr Brooks and the published results of Brix et al. (2004), as well as the 2004 survey of corixids in the Kennecott effluent, indicate that levels substantially above those in the GSL (0.5-0.7 ug/L) are required to achieve organism tissue levels greater than 4.86 mg/kg.

In contrast, the study performed by Dr. Grosell was designed to evaluate the uptake kinetics of selenate by algae and brine shrimp from water and diet following short-tem exposures. These biokinetic studies suggest a much more extensive accumulation of selenium than observed by Brix et al. and/or Brooks. A review of the accumulation of selenium by brine shrimp in the Hailstone Reservoir appears to be intermediate to those of Brix et al (2004) and Grosell. The evaluation of the data for Mono Lake also indicates that a liner model for assessing selenium above concentrations that are currently in the Lake is questionable.

In light of the inconsistency in the above mentioned studies and considering that there is a lack of data on the form of selenium in the Lake, the precise relationship between water and organism tissue selenium levels, I see no way to propose a water-based selenium standard for the GSL. Laboratory data are conflicting (Brooks versus Grosell) and site-specific field data indicate reduced uptake of selenate (Brix et al. 2004, Adams 2004, Hailstone) in GSL water. Data from other sites in the US indicate "selenium" is more accumulative in some ecosystems than others. At present, there is no scientific consensus on how to model selenium accumulation and there is no definitive data to establish the water to brine shrimp relationship for the GSL. Therefore, **I do not support the development of water-based selenium standard at this time.**

I recommend that the best way forward is to **institute a tissue-based selenium standard** with a tissue-based monitoring program incorporated into UPDES permits. Monitoring of water and brine shrimp should be instituted for each permit containing a selenium requirement. Further, monitoring in the vicinity of the effluent (edge of mixing zone) and the off-shore vicinity of the discharge should be required. Monitoring should occur in the months of April, May and June while the birds are nesting. Brine shrimp and water

concentrations of selenium should be monitored and criteria for assessing the trends as well as trigger for further action identified if the concentrations are determined to be harmful. Numbers of samples and sampling techniques need to be standardized as well as the method of analysis. I suggest all of this is done with full public participation.

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Adams, W. J., K. V. Brix, M. Edwards, L. M. Tear, D.K. DeForest, and A. Fairbrother. 2003. Analysis of field and laboratory data to derive selenium toxicity, thresholds for birds. Environ. Tox. And Chem. Vol. 22, No. 9, 2020-2029.

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Justification for selection of a water quality standard

Anne Fairbrother, D.V.M., Ph.D.
Parametrix, Inc.

I recommend setting the standard based on selenium concentration in bird eggs. The standard should be 12.5 mg/kg (dry wet) total selenium in eggs.

Justification

The stated intent of development of a site-specific water quality standard for the Great Salt Lake is protection of birds whose diets include substantial amounts of brine shrimp and brine flies from the open waters of the lake. For substances such as selenium that accumulate to high levels in the food chain, there may not be a direct linear relationship between the water concentration and effects in the bird species of concern. This is because the transfer rates from water to food items to the birds are complicated by water chemistry and the biology of the organisms involved. It is best, therefore, to set the standard on an attribute of the birds that would be most sensitive to change as a result of exposure to selenium. This will reduce the uncertainty in what value the standard should take, because there is no need for estimates or assumptions about trophic relationships. Of course, in order to write discharge permits, it will be necessary to calculate what the water concentration is likely to be when the adverse effects to the birds occur, but a declaration of "impaired" (i.e., exceeding the standard) would not be based on this less reliable endpoint. Instead, water concentrations could be used to trigger more intensive analysis of whether birds are being impacted.

That said, we know that selenium is a reproductive toxicant, so we need to protect birds from impairment of their ability to hatch out chicks. Ideally, the standard would be set at a level where reproductive output (as measured by the percentage of eggs that hatch) is known to be impaired by selenium. This would mean monitoring hatchability in the bird populations and when the hatch rate is lowered by 10% as a result of selenium exposure, then impairment would be declared. However, this is not very practical as it is difficult to attribute reduced reproductive success solely to one stressor. There are many factors (e.g., weather, other toxicants, predators, genetics) that contribute to large variability in hatching rates among birds, between colonies, or across years. Therefore, another attribute is needed that is a more direct association between hatch rate and selenium exposure.

Laboratory studies with many species of birds and fish have shown that the amount of selenium in the eggs is related to embryo survival (and, ultimately, hatching). Embryos can tolerate a certain amount of extra selenium in the egg, but as selenium levels increase more and more of the embryos are deformed, weakened, and die. Laboratory studies with birds have shown that mallards are the most sensitive among the species

that have been tested so far. Combining the data from all mallard studies allows us to estimate that at 12.5 mg/kg (dry wet) of selenium in the egg, hatchability is decreased 10% from what we would expect to see in unexposed, laboratory-housed birds. As indicated in our Fact Sheet, there is uncertainty about this value, but it is most likely that this is the selenium concentration associated with a 10% reduced hatch.

While it might seem counter intuitive to say that we would allow up to a 10% reduced hatch before declaring the system to be selenium-impaired, this number really will be protective of the birds on the open waters of the Great Salt Lake. As I mentioned above, there are many, many factors that influence the hatching rate of birds, such as weather and predation. Selenium effects on the embryo are not entirely additive to these other factors as some are occurring in the same eggs that get eaten or that get drowned by a sudden rain, or fail to hatch for some other reason. So the realized reduction in hatchability due to selenium will be much less than 10%, even when the average selenium concentration is at 12.5 mg/kg. In addition, in self-sustaining populations (such as for the species of birds that are at the lake), there generally is an excess of young that hatch as not all the young-of-the-year will survive to reproduce the following year. Again, there are compensatory mechanisms that will reduce the overall impact of a selenium induced reduction in hatchability on the continuing survival of the population (i.e., the numbers and density of birds). Obviously, there is a limit to how much extra selenium related effects the populations can tolerate. Without building and running a true population model that balances the birth and death rates, we cannot say what this threshold is for each of the different species. Based on prior experience of many ecotoxicologists, it is likely that this threshold is above the 10% reduced hatch level, and probably is closer to 20% (the upper limit of the range of values presented in the Fact Sheet). Thus, setting the standard at 12.5 mg/kg, which is based on a very selenium-sensitive species, should still provide a margin of safety for the birds on the lake even when the lake is declared "impaired."

While we have spent considerable time and expense developing a model to calculate what water concentration is associated with 12.5 mg/kg selenium in gull or shorebird eggs, I believe there remains great uncertainty in this model, particularly in the transfer rates (water to brine shrimp/flies and diet to eggs for each bird species). Therefore, I recommend the state adopt the adaptive management approach and use the monitoring scheme under development by CH2M Hill (as reviewed by the science panel). It may be that the water value associated with the recommended egg-based standard will be adjusted as the transfer factors become more accurate. Furthermore, I recommend that the state conduct studies either in the laboratory or field to verify that the egg concentration upon which the standard is based actually is associated with a measurable reduction in hatchability for the species of concern. It may be that the standard will need to be adjusted to become more site- and species-specific as a result.

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Université des Acadiens

MEMO

April 30, 2008

TO: W. Moellmer, Utah DWQ

FROM: D. Hayes, Director, Institute for Coastal Ecology and Engineering

RE: Proposed Se Standard for Open Waters of Great Salt Lake

This memo presents my thoughts on the proposed open water Selenium Water Quality Standard for the Great Salt Lake. It represents my thoughts as of this date. Of course, my opinions may change with additional information or a better understanding of important technical aspects.

Before going further, I would like to thank you for this opportunity to participate on the Great Salt Lake Science Panel. I have enjoyed getting to know the other panel members and am very impressed with the depth and breadth of their knowledge. I have learned an enormous amount during this process. And, I have always thought that the Great Salt Lake did not receive the recognition that it deserves as a great natural treasure. I am hoping that this will begin a renewed interest in this natural resource.

Se Balance in the GSL

A significant portion of this effort went to quantifying selenium loads into and out of the GSL. These efforts were crucial to our understanding of the lake and the potential for making decisions that may later prove to be irreversible. I see this selenium balance as the foundation for any water quality standard. We must recognize that there are substantial gaps and uncertainties in this mass balance. Our estimate of incoming selenium loads are about 1300 kg/yr for a normal flow year and about 3500 kg/yr of selenium losses. While it is essential that the State continue its effort to understand selenium (and other constituent) loads into and out of the GSL, the current data are sufficient upon which to base some conclusions.

Given that the GSL has received selenium loads for hundreds of years, the current lake concentration of about 0.6 ppb total Se is probably near a steady-state concentration. There is some evidence of recent increases in sediment selenium concentrations that may reflect the rise in anthropogenic selenium discharges over the past century. Given the available data, I conclude that temporary increases in water column selenium concentration may occur, but are likely offset over time through

slightly higher particulate concentrations (that eventually become bottom sediments) and increased volatilization. .

GSL selenium loads estimates of 1300 to 3500 kg/yr, give me a lot of comfort that the the proposed new discharge of less than 50 kg/yr will be likely assimilated by the GSL with no noticeable change in lake selenium concentrations. Since our studies, consistent with existing scientific literature for selenium concentrations in this range, have not uncovered any ecological impact due to current concentrations, it is unlikely that the new discharge poses any significant ecological concerns for the GSL or the GSL ecosystem.

Establishing a basis for the standard

The Science Panel's hypothesis is that shorebirds and gulls are the most sensitive GSL species to selenium and, thus, are the primary targets of protection for the water quality standard. Although the first signs of impairment would be reduced hatchability success rates, these are difficult to measure. Prior studies have shown a relationship between egg and diet selenium concentrations and hatchability success. Thus, our GSL-specific studies focused on selenium concentrations in bird eggs and diet. These studies provide a scientific basis upon which to develop trophic transfer models of selenium from the water column-to-diet selenium concentrations and water column-to-egg selenium concentrations.

For this approach, an appropriate protective standard requires an understanding of hatchability success as a function of egg selenium concentrations or diet selenium concentrations. Unfortunately, those data are not available for the most sensitive GSL bird species and we had to use data for the impact of selenium concentrations on hatchability information for Mallards – considered to be significantly conservative. The panel has generally accepted the EC10 range of selenium concentrations of 6.4 ppm to 17 ppm to represent the most likely range of selenium concentrations for a standard; the most probably EC10 selenium concentration is 13 ppm.

Although an EC3 is sometimes taken as a No- Effects Concentration (NOEC) for chronic and acute toxicity evaluations. However, my understanding is that most biological populations can withstand a 10% decrease in hatchability without a population effect. Further, I am concerned about the accuracy of the toxicity models below an EC10. Adopting the 95% lower confidence limit of the EC10 provides reasonable assurance that there would not be a 10% decrease in hatchability. Given that the available hatchability data are for a conservative species, I believe this would build in excessive conservatism. Thus, I recommend using the most probable EC10 value of 13 ppm.

Determining measurable surrogate for the standard

The recommended value should be translated into a water quality concentration for compliance monitoring. It also seems prudent to use Brine Shrimp as an indicator species. Exceedence of guidance values for either should raise concerns about long-term trajectories. Based upon model

runs for shorebirds using 2006-07 data, the following table gives corresponding water column

Egg Selenium Concentration (ppm)	Water Column-Diet Model	Diet-to-Egg Model	Water Column Selenium Concentration (ppb)	Brine Shrimp Selenium Conc (ppm)
13	MSTF	Shorebird	2.9	19
13	BAF	Shorebird	2.8	19
13	Grossell	Shorebird	2.5	19

selenium concentrations. It should be pointed out that these water column concentrations are likely very conservative since linear trophic transfer models are used when they are likely have an asymptotic shape. However, it would also be useful to evaluate the impact during other flow years.

Implementing the standard

A tiered approach to implementation will be important to identify potential impacts well before the GSL becomes impaired. Increased monitoring requirements (spatial and temporal frequency as well as additional species) must be combined with intensive analyses to understand the entire available body of information. I perceive 4 tiers of the standard:

1. Normal – data shows no reason for concern; data collection is minimal for compliance and long-term system knowledge.
2. Concern – data shows some increase from baseline; data collection is minimal for compliance, but long-term system data collection increases in intensity.
3. At Risk – data shows significant, sustained increases above baseline; data collection expanded for both compliance and long-term system knowledge. Some management actions should be considered to avoid further degradation.
4. Impairment – data exceeds the standard; management actions required to

Importance of Future Data Collection and Analysis

I cannot stress enough how crucial it is that the State continue to monitor and gather information about the GSL. These efforts need not focus exclusively on selenium, but should be comprehensive in scope. The GSL is a unique resource. I would hope that the State would develop and implement some effort aimed exclusively at understand the complexities of the GSL system and its long-term protection.

Recommended Selenium Standard for the Open Water of Great Salt Lake

Theron Miller

Numeric Standard:

12 mg Se/ kg dry weight

Rational:

1. This number represents the geometric mean of EC10 values for the mallard duck in controlled laboratory experiments.
2. Compared to with a much more limited data set available for the American avocet, mallard ducks are nearly three times more sensitive than American avocets. Yet, the American avocet is the only obvious waterbird that nest immediately adjacent to GSL open water. Although other birds incidentally have been observed to nest in adjacent emergent wetlands, we have a relatively strong understanding that these birds are not feeding upon GSL food resources, i.e. brine shrimp or brine flies. Therefore, I believe that an egg tissue number based upon mallards represents a reasonable safety factor.
3. As compared to other effective concentration values (e.g. EC 3 or EC 20), I believe that an EC10 is the lowest value that can be scientifically (statistically) detected above natural background egg mortality. Therefore, this represents a scientifically defensible value.

Implementation:

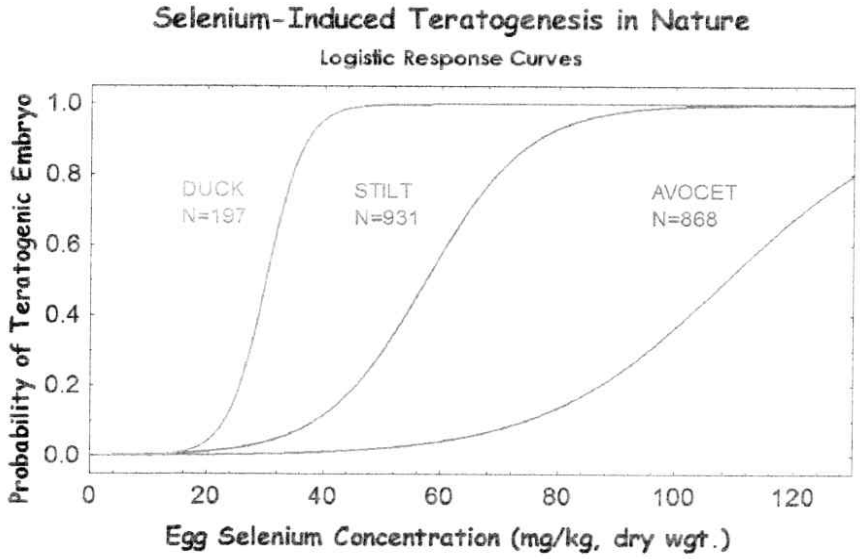
1. Our modeling indicates that water concentration associated with the EC10 value will be approximately 1.4 ug/L. This is 2 – 3X current Se concentrations. However, because of many unknowns associated with Se dynamics, I suggest a tiered approach to monitoring and implementing protective measures.
2. This approach will include increased levels of monitoring from water, to diet to egg concentrations.
3. Also, rather than prepare a TMDL, if and when egg Se concentrations reach 12 mg/kg, this implementation plan should include provisions, (associated with Antidegradation rules) that will make every effort to prevent GSL Se concentrations from reaching the modeling-based water value.
4. Associated with (3) above, I recommend a Watershed Management Plan be implemented in order to address the potential elevated concentrations in Se. This WMP will address appropriate watershed sources (i.e. nonpoint sources as well as point sources) and identify restoration efforts for these nonpoint sources. This WMP should be implemented when the water Se concentration reaches (e.g.)1 – 1.2 ug/L and associated diet and egg concentrations are shown to increase in the same proportion.

Science Panel Member Recommendation for a Tissue Based Standard for the Open Water of the Great Salt Lake: William O. Moellmer, Ph.D.

The Science Panel *(Recommended Guidelines for a Water Quality Standard for Selenium in Great Salt Lake)* has determined that selenium-related impairment for the open waters of GSL should be defined by hatching success of "birds that feed primarily on open waters of GS." Toxicological studies have shown that a 10% reduction (called an "EC_{10}") in egg hatchability of the mallard duck occurs when the egg contains selenium concentrations between 6.4 and 16 mg/kg. This range of selenium concentrations in the eggs and associated reductions in egg hatchability are shown in the table below. The statistical analysis indicates the greatest probability of a 10% hatchability reduction is associated with 12 mg/kg in the egg. There is only a very small chance that the low or high values in the ranges provided are the true concentration where a 10% effect occurs. The relationship between egg Se concentration and hatchability is given below in Table 1:

Egg Selenium (mg/kg)	Reduction in Hatchability
6.4	2%
12	10%
16	21%

The most complete selenium toxicological information for aquatic birds is on the mallard duck. It is also known that they do not feed on food sources in GSL. Therefore a more "site specific" species could be considered -- in this case, the black-necked stilet. The following figure demonstrates the difference in sensitivity of selenium between the mallard and the stilt. As can be seen, there is an approximate 1.8 fold higher tolerance to selenium by the black-necked stilt (@ 0.1 PTE). The and avocets and gulls have even more.



It is therefore possible to compare the relative sensitivity of the mallard to the stilt. The above table was adjusted by a factor of 1.8 to give the following as indicated in Table 2:

Egg Selenium (mg/kg)	Reduction in Hatchability
11.65	2%
21.84	10%
29.12	21%

This adjusted statistical relationship of the *"EC10"* for stilts shows that perhaps the most probable number for the egg is 22 mg/kg with the "tails of the curve" at the 5% and 95% confidence intervals to be at 12 and 29 mg/kg.

To maintain a conservative posture and to err on the side of the environment, it seems an argument could be made by taking an average egg value between 12 mg/kg (Table 1) for the mallard and 22 mg/kg (Table 2) for the stilt to give 17 mg/kg.

However, personal values come into play and I choose to: (1) be more conservative; (2) take into greater consideration the clear uncertainty involved in these studies; and (3) to be in concert with the general recommendation of the Science Panel that the standard be within the range of 6.4 mg/kg and 16 mg/kg. Therefore, my personal recommendation is that the egg be used as a tissue based water quality standard for the open waters of Great Salt Lake at a value of 12.5 mg/kg.

Hence, impairment of the beneficial use (an exceedence of the standard) would be declared when this standard of 12.5 mg/kg for the egg would be exceeded based upon an appropriate averaging period and power analysis yet to be determined.

It is important to keep ahead of the possibility of impairment by a rigorous monitoring/action program. A monitoring implementation program should be designed to evaluate any upward movement in the water column and tissue concentrations in brine shrimp toward implementation/action targets yet to be determined. Upon Se concentration increases, triggers for action would be initiated similar to TMDL requirements. Therefore possible signs leading to impairment are detected and acted upon prior to listing.

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Site-specific Model Development for the Great Salt Lake

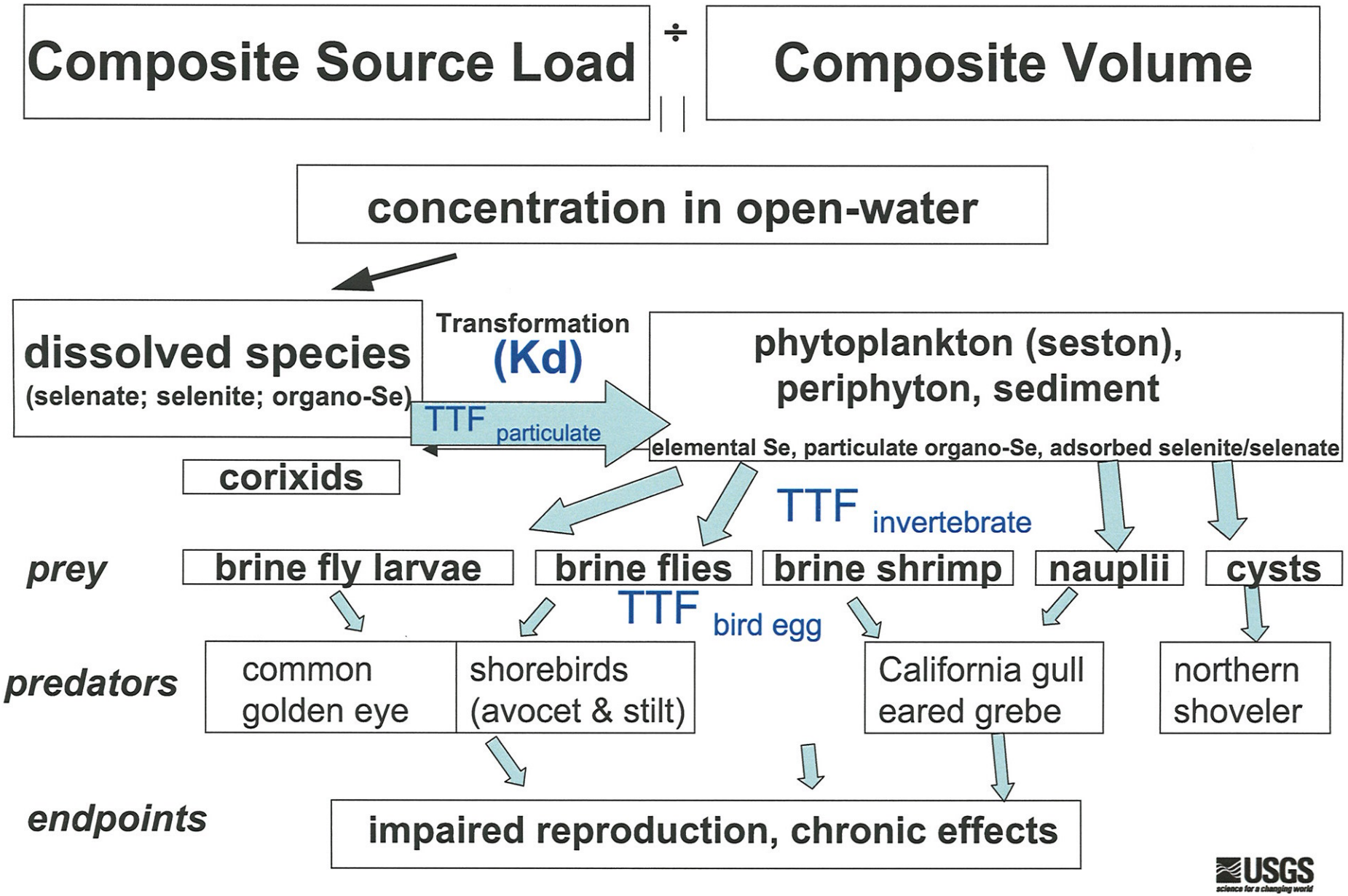
Forecasting Selenium Concentrations: Foodweb Specific Modeling

Theresa S. Presser
U.S. Geological Survey
Menlo Park, California

Joseph P. Skorupa
U.S. Fish and Wildlife Service
Arlington, Virginia

Presentation to Science Panel
and Steering Committee
May 2, 2008

Great Salt Lake Selenium Model



Site-Specific Trophic Transfer Factors

Measured concentrations		TTFs	
Water-column =	0.64 ppb total		
	0.54 ppb dissolved	Water to Seston=	1484 from total
			1760 from diss
Seston=	0.95 ppm		
Brine Shrimp =	3.97 ppm	Seston to Shrimp = 4.2	
Nauplius=	2.44 ppm	Seston to Nauplius =2.6	
Cysts =	2.1 ppm	Seston to Cysts = 2.2	
Brine fly adults =	1.7 ppm	Periphyton to Brine fly adult = 1.8	
Brine fly larvae =	1.4 ppm	Periphyton to Brine fly larvae = 1.5	
Corixid =	2.4 ppm	Seston to Corixid = 2.5	
Midge =	2.0 ppm	Seston to midge = 2.1	

Diet to egg = 2.0 (1.8-2.55)

all dry weight, except water column

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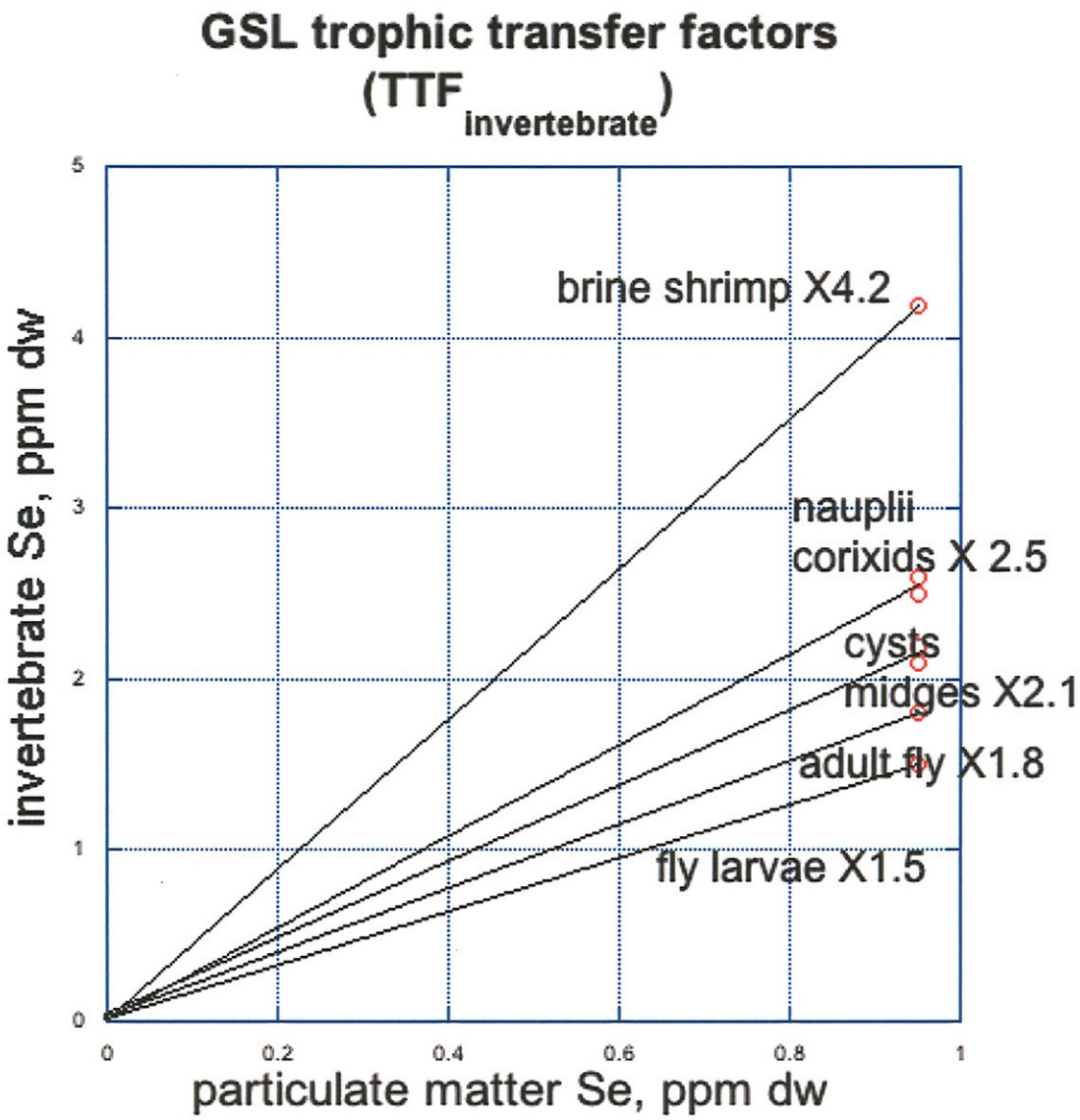

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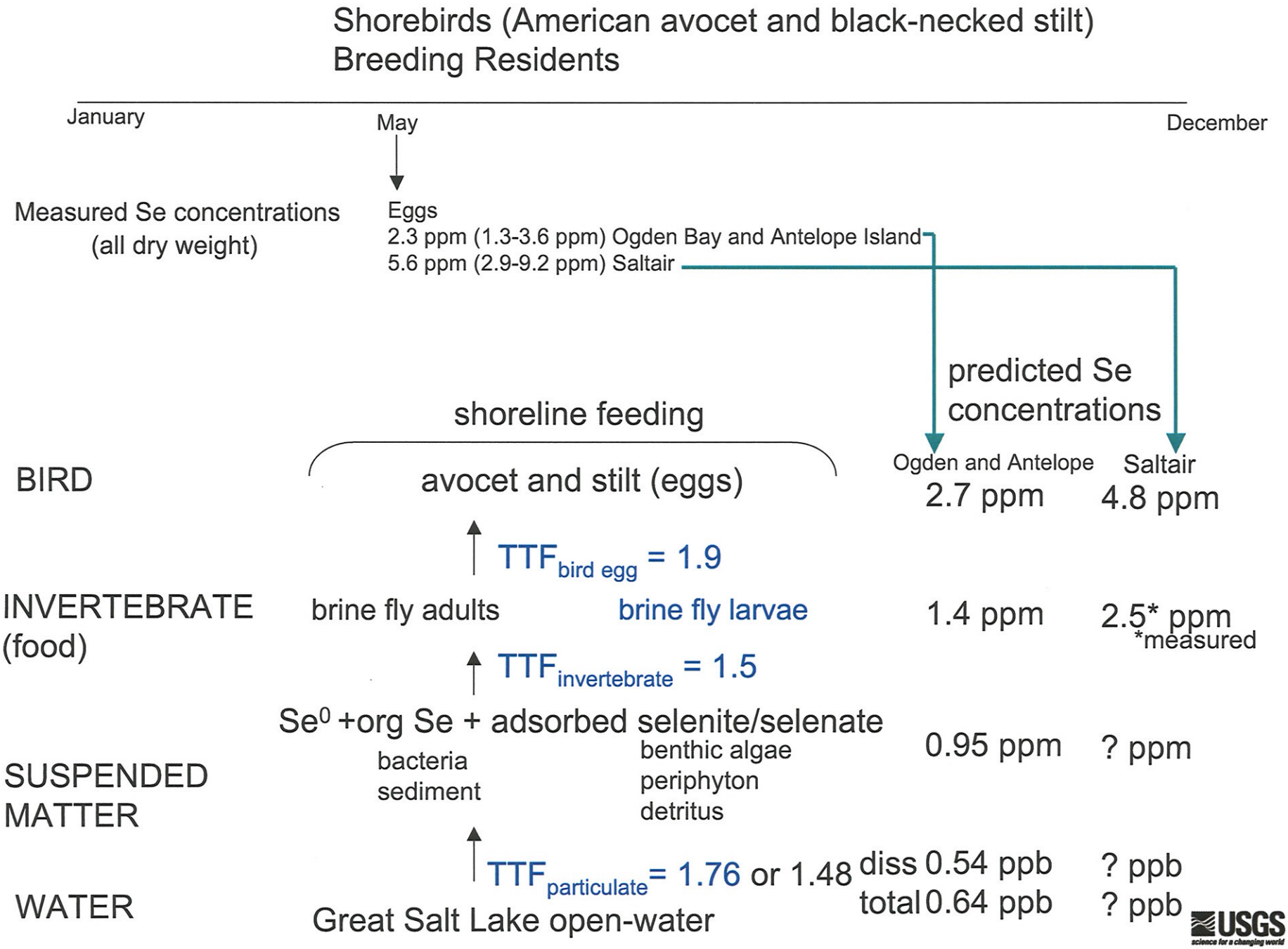
Shorebirds (American avocet and black-necked stilt)
Breeding Residents
January
May
December
Measured Se concentrations
(all dry weight)
Eggs
2.3 ppm (1.3-3.6 ppm) Ogden Bay and Antelope Island
5.6 ppm (2.9-9.2 ppm) Saltair
predicted Se
concentrations
shoreline feeding
BIRD
avocet and stilt (eggs)
Ogden and Antelope
Saltair
2.7 ppm
4.8 ppm
TTF bird egg = 1.9
INVERTEBRATE
(food)
brine fly adults
brine fly larvae
1.4 ppm
2.5* ppm
*measured
TTF invertebrate = 1.5
Se0 +org Se + adsorbed selenite/selenate
bacteria
sediment
benthic algae
periphyton
detritus
0.95 ppm
? ppm
SUSPENDED
MATTER
TTF particulate = 1.76 or 1.48
diss 0.54 ppb
? ppb
WATER
total 0.64 ppb
? ppb
Great Salt Lake open-water
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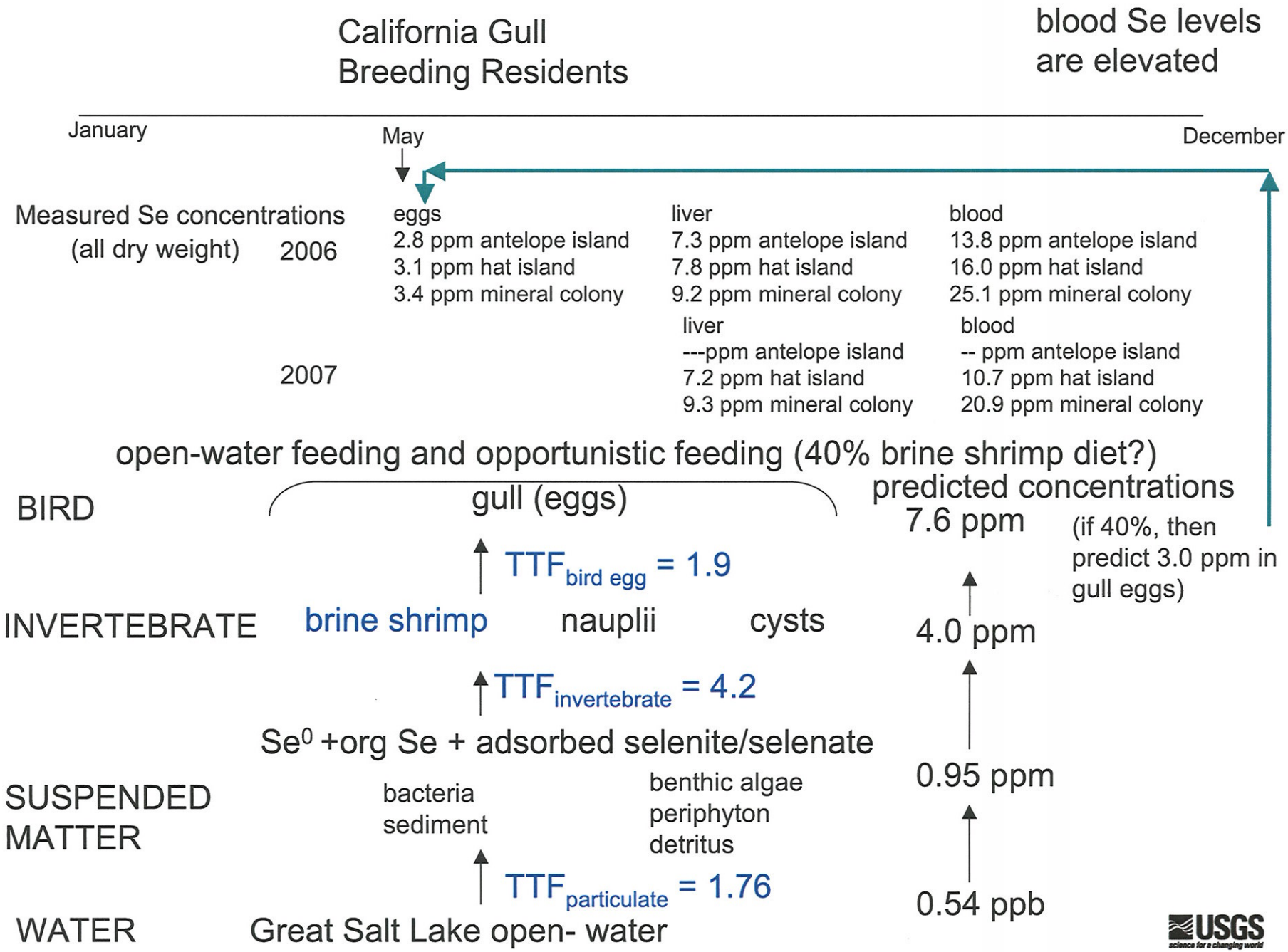
California Gull
Breeding Residents
blood Se levels
are elevated
January
May
December
Measured Se concentrations
(all dry weight)
2006
eggs
2.8 ppm antelope island
3.1 ppm hat island
3.4 ppm mineral colony
liver
7.3 ppm antelope island
7.8 ppm hat island
9.2 ppm mineral colony
blood
13.8 ppm antelope island
16.0 ppm hat island
25.1 ppm mineral colony
2007
liver
---ppm antelope island
7.2 ppm hat island
9.3 ppm mineral colony
blood
-- ppm antelope island
10.7 ppm hat island
20.9 ppm mineral colony
open-water feeding and opportunistic feeding (40% brine shrimp diet?)
predicted concentrations
BIRD
gull (eggs)
7.6 ppm
(if 40%, then predict 3.0 ppm in gull eggs)
TTF bird egg = 1.9
INVERTEBRATE
brine shrimp
nauplii
cysts
4.0 ppm
TTF invertebrate = 4.2
Se0 +org Se + adsorbed selenite/selenate
SUSPENDED MATTER
bacteria
sediment
benthic algae
periphyton
detritus
0.95 ppm
TTF particulate = 1.76
WATER
Great Salt Lake open- water
0.54 ppb
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Eared Grebe
Migratory (staging)

blood Se levels
are elevated

2006 2006

January — September — November — December

Measured Se concentrations
(all dry weight)

Locational		Age	
liver	8.6 ppm Antelope Island	juvenile liver 8.5 ppm	
	15.2 ppm Stansbury Island	adult liver 15.8 ppm	
blood	16.8 ppm Antelope Island	juvenile blood 15 ppm	
	25.4 ppm Stansbury Island	adult blood 27 ppm	

September
liver 9.4 ppm
blood 18.5 ppm

November
liver 14.5 ppm
blood 23.3 ppm

October
liver 13.4 ppm

December
Dec 4 liver 25.4 ppm
Dec 20 liver 23.2 ppm

open-water feeding

BIRD — grebe

$TTF_{bird\ egg} = 1.9$

INVERTEBRATE — brine shrimp

$TTF_{invert} = 4.2$

Se^0 +org Se + adsorbed selenite/selenate

SUSPENDED MATTER
bacteria
sediment
benthic algae
periphyton
detritus

$TTF_p = 1.76$

WATER — Great Salt Lake open- water

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Common goldeneye
Northern shoveler
Migratory (over-wintering)

blood Se levels
are elevated

January → December

Measured Se concentrations
(all dry weight)

Locational

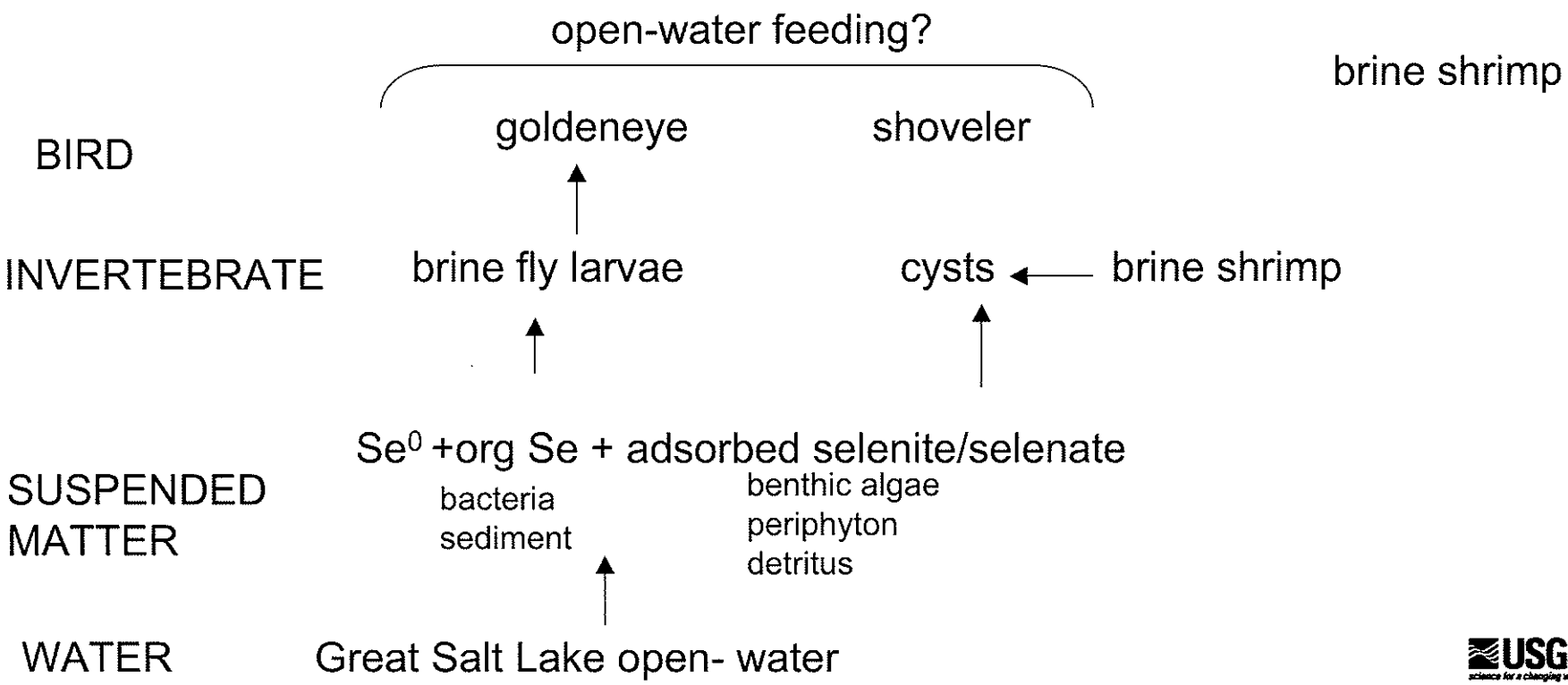
liver 12.6 ppm Fremont Island
18.0 ppm Stansbury Island
blood 16.3 ppm Fremont Island
17.1 ppm Stansbury Isand

Age

juvenile liver 12.7 ppm
adult liver 17.2 ppm
juvenile blood 14.8 ppm
adult blood 18.1 ppm

Nov 2005-Jan 2006

early	late
liver 12.2 ppm	18.7 ppm
blood 15.9 ppm	17.6 ppm



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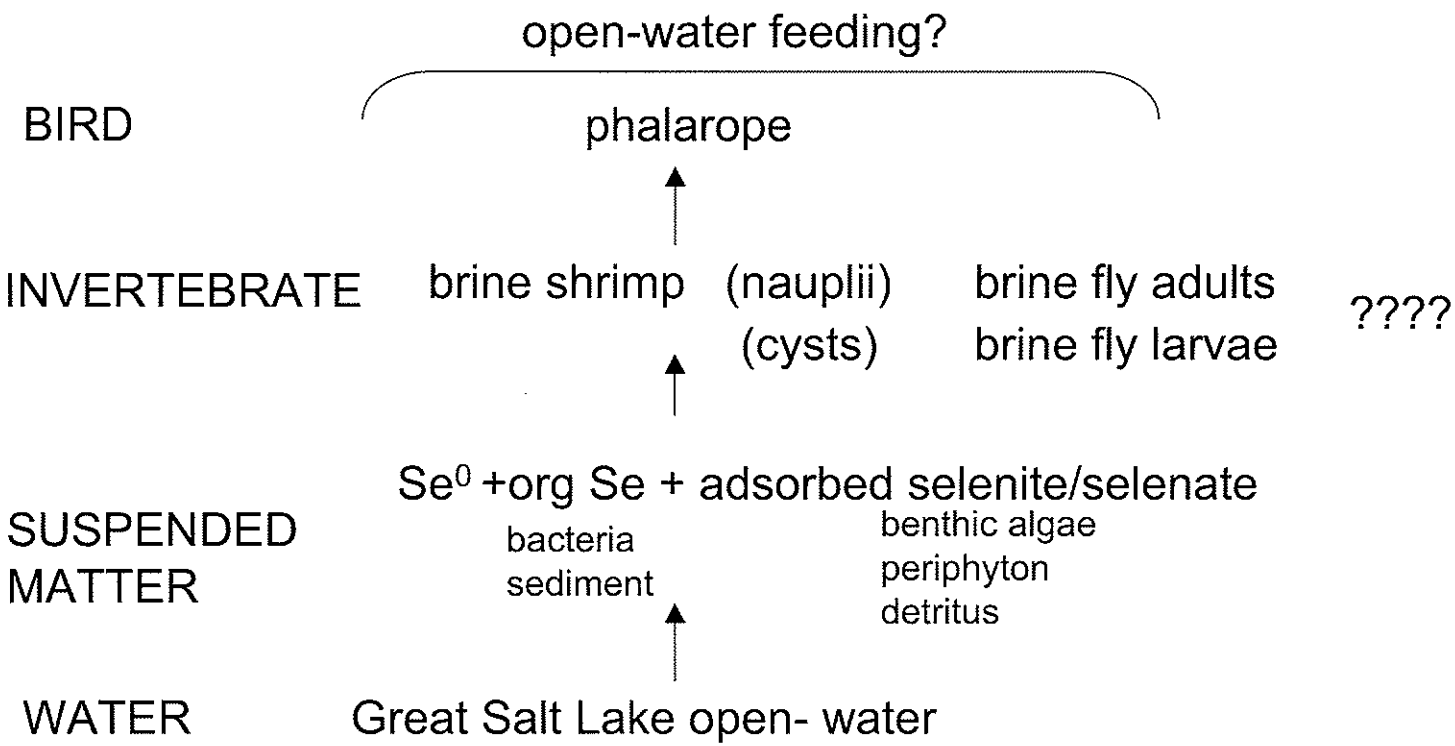
Wilson's phalarope
Red-necked phalarope
Migratory

Need body weight adjustment ?

January — June — August — December

staging?



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Levels of Protection Based on Diet or Egg Selenium Concentration)

Table 1 95 % confidence interval for reduced hatchability in mallard eggs—laboratory derived

Se diet, ppm dw	Best case	Maximum likelihood	Worst case
3.6	EC <1	EC 3	EC 10
4.9	EC 4	EC 10	EC 24
5.7	EC 10	EC 18	EC 32
Se egg, ppm dw			
6.4	EC <1	EC 1.5	EC 10
12	EC 3.5	EC 10	EC 26
16	EC 10	EC 21	EC 38

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Scenario Table: Forecasting Water-Column Selenium Concentrations

Scenario Level of protection?	bird egg ppm	TTF_{bird} factor	invertebrate ppm	TTF_{invert} factor	seston ppm	TTF_{seston} (Kd) factor	Water-column ppb
→ **brine shrimp (adults)**							
	6.4	1.8	3.6	4.2	0.86	1.76	0.49
	12.5	2.55	**4.9**	4.2	1.17	1.76	0.66
	16.5	2.9	5.7	4.2	1.36	1.76	0.77
→ **brine shrimp (nauplii)**							
	6.4	1.8	3.6	2.6	1.4	1.76	0.80
	12.5	2.55	**4.9**	2.6	1.9	1.76	1.1
	16.5	2.9	5.7	2.6	2.2	1.76	1.25
→ **brine fly adult**							
	6.4	1.8	3.6	1.8	2.0	1.76	1.1
	12.5	2.55	**4.9**	1.8	2.7	1.76	1.5
	16.5	2.9	5.7	1.8	3.2	1.76	1.8
→ **brine fly larvae**							
	6.4	1.8	3.6	1.5	2.4	1.76	1.4
	12.5	2.55	**4.9**	1.5	3.3	1.76	1.9
	16.5	2.9	5.7	1.5	3.8	1.76	2.2

(all dry weight, except water-column)

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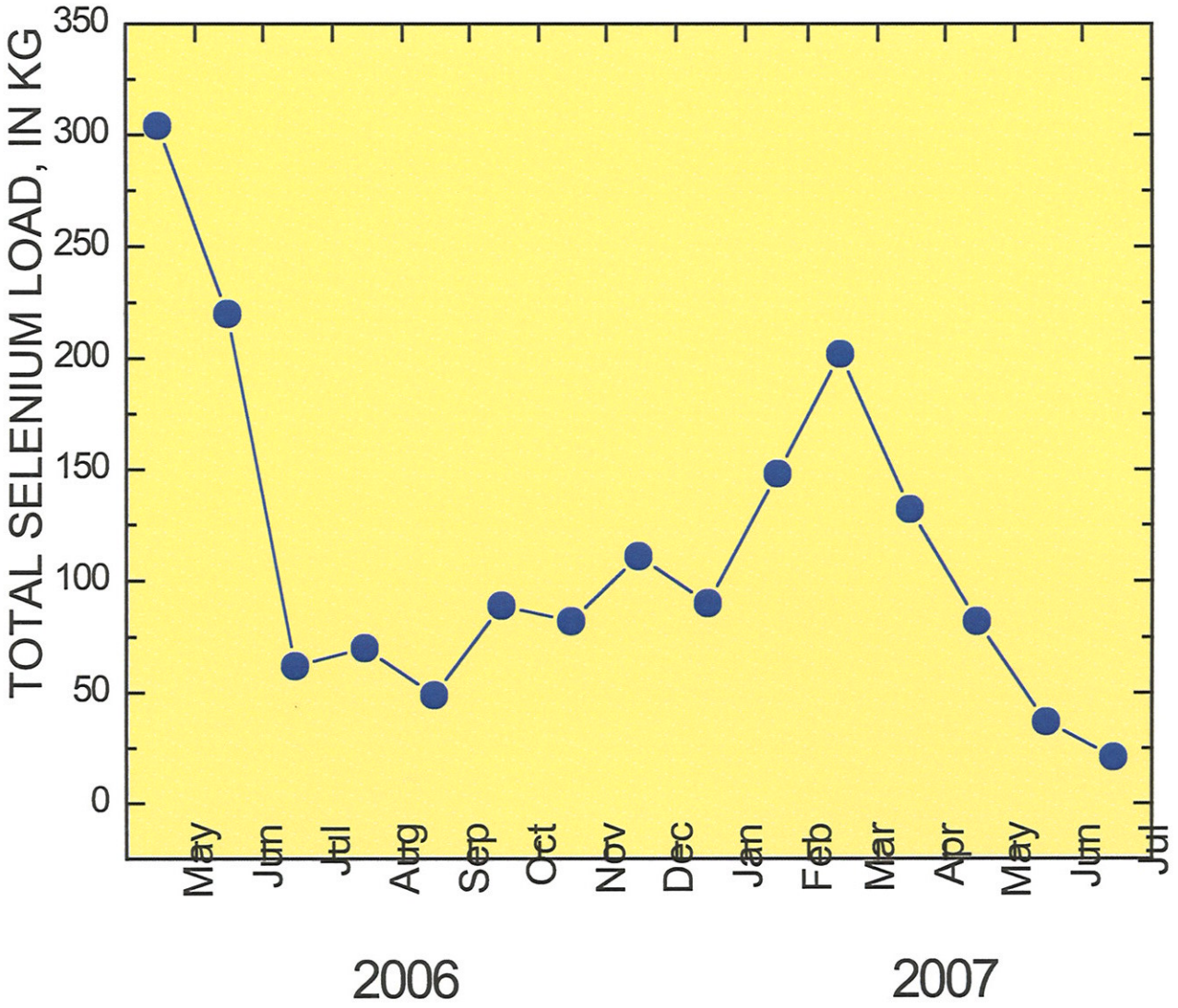
Variability in measured Se concentrations

	Brine shrimp (adult) ppm dw Se	Seston ppm dw Se	Water-column ppb dissolved	Water-column ppb total
2006	2.3 - 6.8 (Apr-Dec)	0.44 - 3.1	0.39 - 0.61	---
2007	3.4 - 5.2 (May-Aug)	0.57 - 1.9	0.50 - 0.58	0.59 - 0.68

MONTHLY LOAD TRENDS



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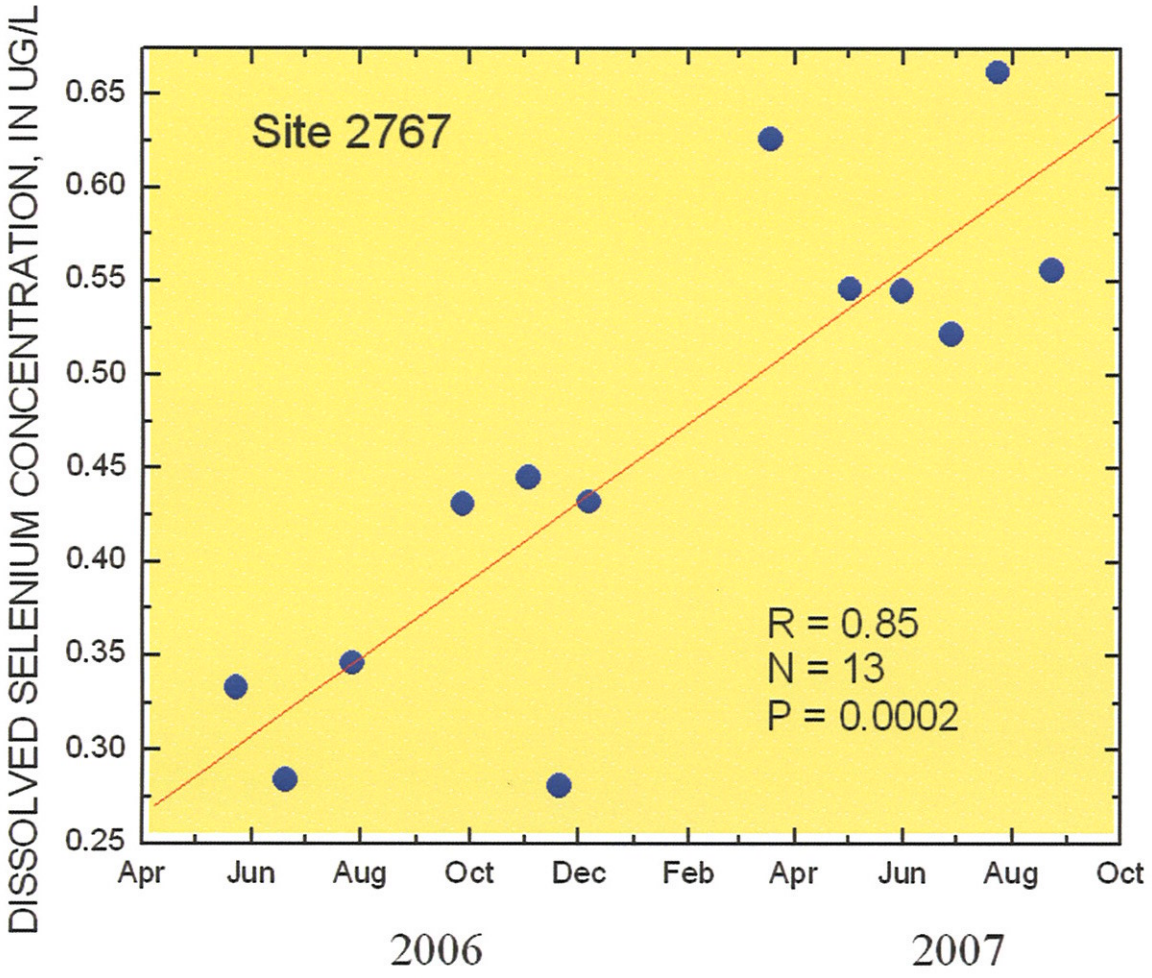
Se INCREASE IN OPEN WATER



Mann-Kendall
Trend analysis

Site identification	Occurrence of upward trend in concentration at 90 percent confidence level
2267	Yes
2767	Yes
3510	Yes
2565	Yes

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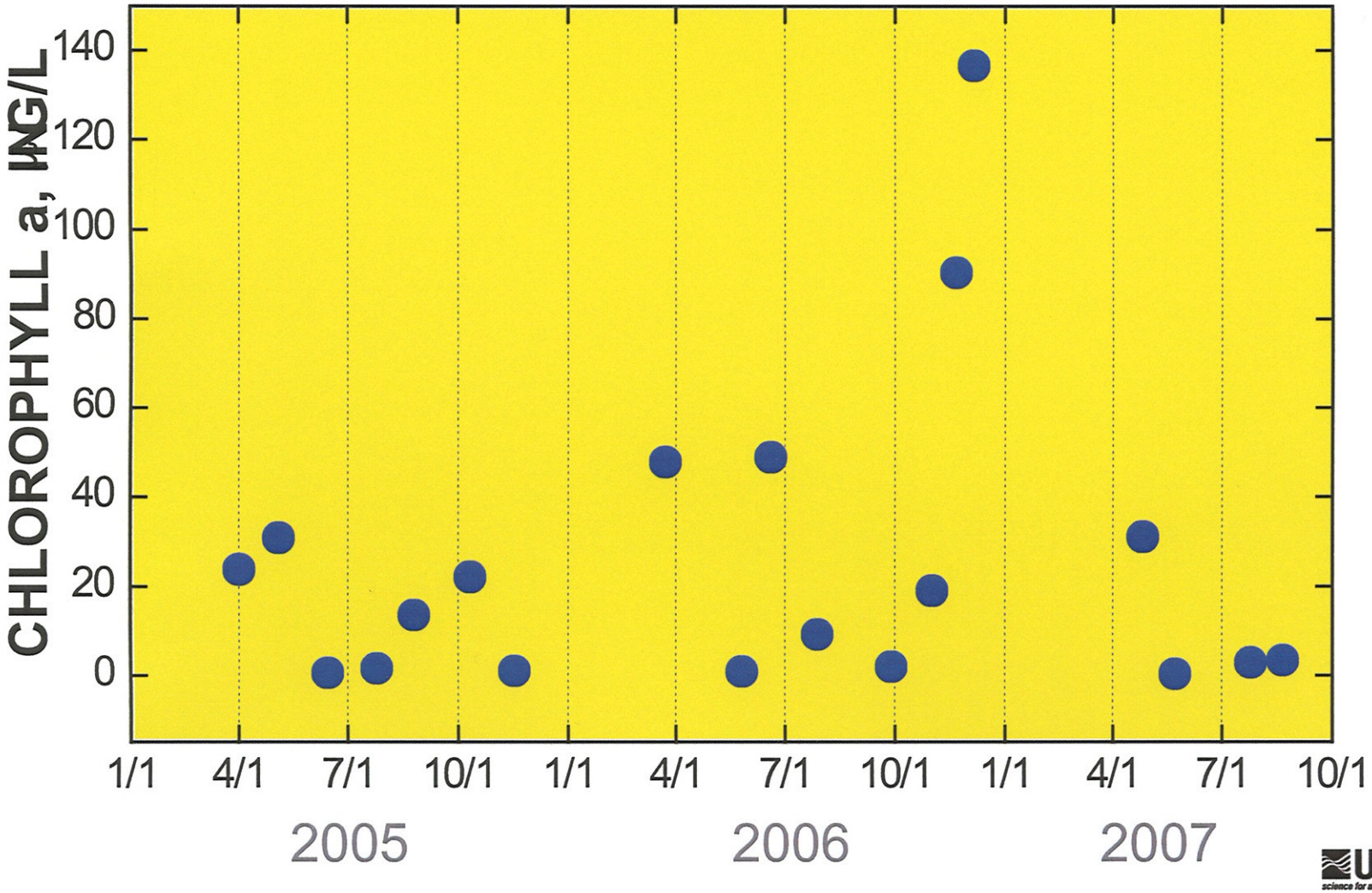
CHLOROPHYLL a (2565)

(as a representation of monthly changes in seston abundance)



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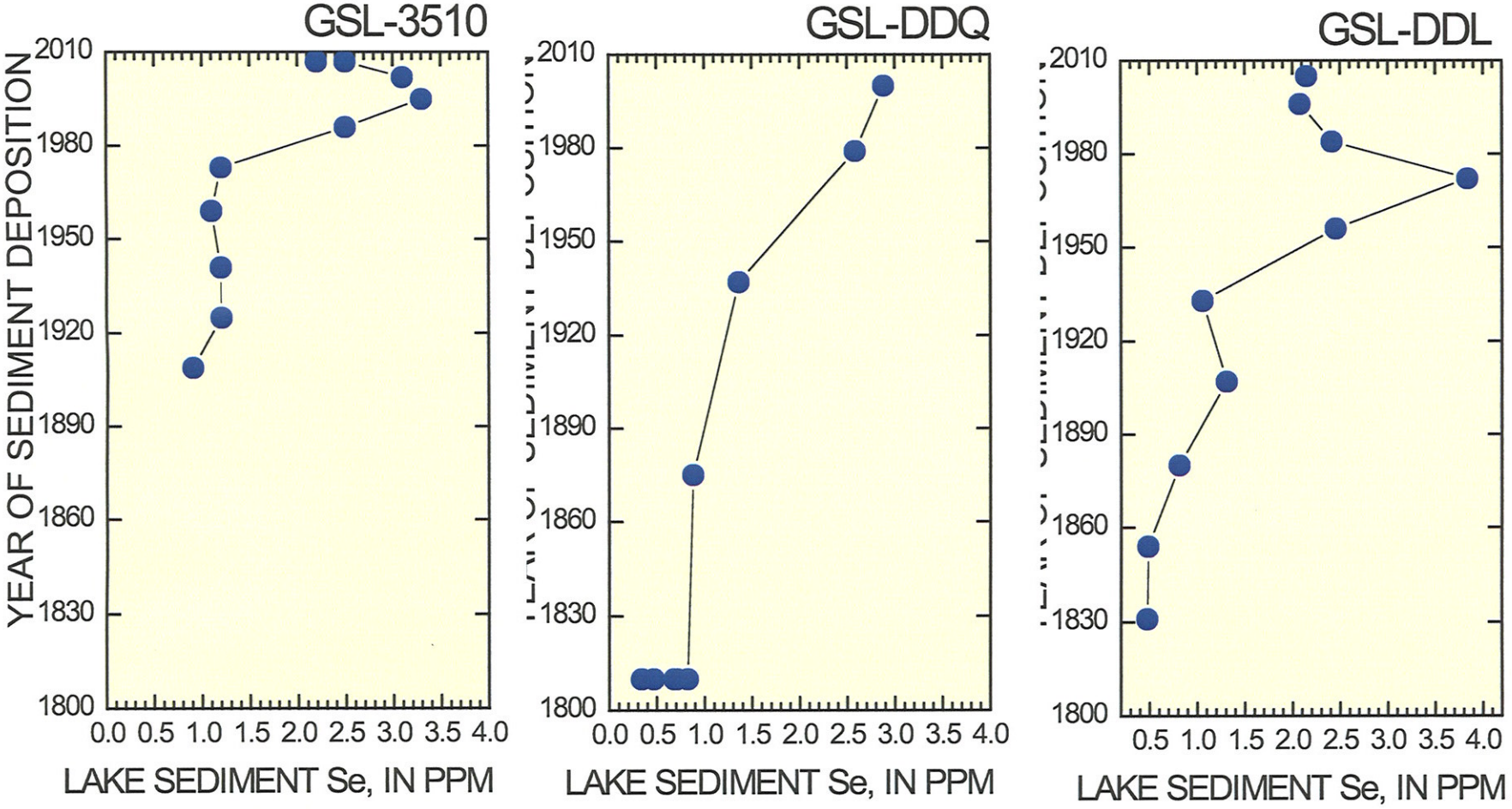
Se INCREASE IN SEDIMENT CORES



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Great Salt Lake Selenium Standard

Written Recommendation to the Steering Committee
Joseph Skorupa, U.S. Fish & Wildlife Service

I. The Great Salt Lake's Unique Values Warrant a Highly Precautionary Approach

As summarized by Aldrich and Paul (2002):

The Great Salt Lake ecosystem is widely recognized to be unique and to have very high environmental and commercial value. Great Salt Lake is recognized regionally, nationally, and hemispherically for its extensive wetlands, and its tremendous and often unparalleled values to migratory birds. These values are derived from the lake's unique physical features, including its immense size, dynamic water levels, diversity in aquatic environments, extensive wetlands and geographic position in avian migration corridors. These features create a mosaic of habitat types that are attractive to literally millions of migratory birds that use the lake extensively for breeding, staging, and in some cases, a wintering destination. Great Salt Lake also has a rich history of wildlife management activities that were initiated in the late 1890's by private hunting clubs, but were followed by substantial state, federal, and private investments in conservation programs. [emphasis added]

Additionally, the Great Salt Lake produces a significant proportion of the world's supply of brine shrimp cysts and the commercial harvest has become internationally renowned for its high quality (CH2M HILL 2008). Mineral extraction represents yet another substantive commercial value associated with the Great Salt Lake ecosystem (CH2M HILL 2008).

II. Tolerably Toxic as Opposed to Nontoxic is Too Reckless an Approach for Such a High Value System With Such Substantive Remaining Uncertainties

High environmental and commercial value ecosystems such as the Great Salt Lake warrant full protection, not partial protection. Full protection, does not equate to zero discharge, it equates to setting standards based on a reasonable expectation that the resulting standard will be nontoxic. That reasonable expectation is derived from *a designed intent for the standard to be at or below the no-effect concentration,* called the NEC. Based on data from another western U.S. saline-sink lake, Abert Lake in Oregon, with a water selenium concentration of < 0.2 ug/L, the normal baseline for selenium in brine shrimp is probably about 1.5 ug/g dry weight (Westcot et al. 1990; California Department of Water Resources file data). Brine shrimp in the Great Salt Lake are currently estimated to be at about 4 ug/g Se dry weight (Marden 2008), or about 2.5-times above presumptive baseline indicating that substantive amounts of selenium have already been assimilated by the Great Salt Lake ecosystem without exceeding the NEC, at least for those endpoints that have been examined such as the eggs of California Gulls, American Avocets, and Black-necked Stilts (Cavitt 2008; Conover et al. 2008).

Setting the standard based on the EC10 for toxicity amounts to *a designed intent for a" tolerably toxic" objective*. The critical risk associated with this approach is in making an estimate of what level of poisoning is "tolerable". When entire categories of potential adverse effects, such as avian nonbreeding effects, are currently devoid of any useful assessment endpoint data for the Great Salt Lake (Science Panel Discussions), and when less than a handful of species among the full spectrum of breeding birds that occur at GSL have been examined, the uncertainties associated with assessing what is "tolerable" are very substantive. Overshooting what is truly

tolerable is unlikely to be an error that would be easily corrected. Previous studies at Kesterson Reservoir, Belews Lake, Martin Reservoir (reviewed in Skorupa 1998), and in the Sierra Nevada (Maier et al. 1998) have shown that selenium is very efficiently recycled within aquatic ecosystems and that relaxation of selenium levels, even following complete cessation of discharge, can be a very long-term process. In short, while it is easy to raise the levels of environmental selenium it is not nearly as easy to lower them once a certain level has been allowed.

III. No Observed Effect Concentration (NOEC) is not the Same as a No Effect Concentration (NEC)

NOEC's are actually statistically based constructs that are highly dependent on the statistical power of the test that produced a particular NOEC. Such tests typically have very low power. For example, the mallard reproductive toxicity test for selenium published by Heinz et al. (1989) and associated with a dietary NOEC of 4 ug/g Se dry weight did not have the statistical power to detect anything lower than about a 40% difference between the response of the controls and the response of any treatment group (J. Skorupa, pers. obs.). Accordingly, the dietary NOEC of 4 ug/g indicates nothing more than that the toxic effects, compared to controls, at that diet were less than 40%. They could have been 39% or they could have been 0%, or anything between. Because of the interpretive drawbacks of NOEC's they are now widely avoided as a basis for setting standards and criteria whenever possible (and in our case it is possible to avoid relying on NOEC's). For example, there was an ISO resolution (ISO TC147/SC5/WG10 Antalya 3) as well as an OECD (Organisation for Economic Co-operation and Development) workshop recommendation (OECD, 1998) that the NOEC should be phased out from international standards (OECD 2006:14). Environment Canada (2005) notes, that there is a growing literature which points out many deficiencies of the NOEC approach (Suter et al. 1987; Miller et al. 1993; Pack 1993; Noppert et al. 1994; Chapman 1996; Chapman et al. 1996; Pack 1998; Suter 1996; Moore and Caux 1997; Bailer and Oris 1999; Andersen et al. 2000; Crane and Newman 2000; Crane and Godolphin 2000). Moore and Caux (1997) reported that 76.9% of NOEC's exceeded the estimated EC10 level of toxic effects. However, as illustrated above for the Heinz et al. (1989) mallard study, the toxicity equivalent of a particular NOEC is highly specific to the study that generated it and may range over quite a broad range of possibilities.

IV. Ultimately the Standard Should Be Linked to an Estimate of the NEC for Avian Eggs

Avian reproductive impairment is the most sensitive endpoint that can currently be assessed and monitored at the Great Salt Lake, and may in fact eventually be demonstrated as the most sensitive endpoint overall. The ***potential*** for avian reproductive impairment can be assessed from food web (diet) and/or water selenium concentrations, but it is the concentration of selenium in the eggs that directly determines the ***realized*** avian reproductive impairment, if any (Skorupa and Ohlendorf 1991). Thus, back-calculating a water standard from an adopted "not-to-exceed" objective for avian egg selenium is the approach that would be most directly linked to the controlling endpoint. Therefore, the remainder of this write-up will focus on a recommendation regarding a "not-to-exceed" objective for avian egg selenium based on the goal of providing a best estimate of the NEC for avian eggs. In the course of getting there, I will also offer a professional opinion on the best estimate of an EC10 value for avian eggs because there seems to be considerable interest in that value and because it represents the upper limit of what EPA may be willing to approve.

V. Best Estimate of EC10 for Mallard Egg Hatchability

Controlled feeding studies of captive mallards exposed to known dietary concentrations of selenium provide the best available set of data for estimating a generic avian egg hatchability EC10 (Heinz et al. 1987, 1989; Heinz and Hoffman 1996, 1998; Stanley et al. 1994,1996). It should be noted, however, that although mallards are believed to be a fairly sensitive species of bird to selenium toxicity, comparative toxicity profiles are available for very few bird species and of the handful of species that we do have data for at least two species, American coot (Ohlendorf et al. 1986) and chickens (reviewed in Detwiler 2002) are already known to be more sensitive to selenium than mallards. Based on my own 20+ years of experience monitoring reproductive performance of selenium-exposed waterbird populations and on data collected throughout the western U.S. for the National Irrigation Water Quality Program (Seiler et al. 2003) I expect that redhead ducks and Canada geese are also more sensitive than mallards. My current professional opinion (hypothesis) is that mallards are more likely to be closer to the upper 75th percentile of sensitivity than to the 90th percentile. If my hypothesis is valid, a given level of protection for mallards would also be equally, or more, protective of most other bird species, but less protective for perhaps the most sensitive upper quartile.

At least three different statistical approaches to estimating a mallard EC10 from the results of the controlled feeding studies cited above have been pursued in recent years. Ohlendorf (2003) conducted logistic regression on a set of pooled results from different studies, the pooling of data being made possible by converting all results to a control-adjusted basis. Ohlendorf's maximum likelihood estimate of the EC10 is 12.5 ug/g (all results cited on a dry-weight basis), with estimated 95% confidence limits of 6.4 to 16.5 ug/g. An issue of concern related to Ohlendorf's analysis is the use of control-adjusted data. Selenium is a hormetic chemical, meaning that adverse effects can be caused by deficient dietary exposure as well as by excessive dietary exposure. Consequently, the classic concept of a control group as a zero (or nearly zero) exposure group is inappropriate for evaluating results of selenium toxicity tests. For a hormetic chemical, ignoring the potential effects of hormesis will always lead to potentially overestimating particular effects points such as the EC10 (Beckon et al. 2008). Potentially, at least some of the data points used in Ohlendorf's analysis may have been adjusted to an inappropriately estimated control, in turn raising the potential of upward-bias in the estimated EC-10. Even if selenium were not a hormetic chemical and the classic concept of a control group was fully applicable, the use of "control-adjusted" data is statistically improper unless the control values used for making adjustments were themselves estimated by model-fitting. For example, in the OECD (2006:31) document titled, "*Current Approaches in the Statistical Analysis of Ecotoxicity Data: A Guidance to Application*", the following guidance is presented:

A current habit in analyzing continuous data is to divide the observed response by the (mean) observed response in the controls. These corrected observations then reflect the percent change compared to the controls, which is usually the entity of interest. <u>However, such a pre-treatment of the data is improper</u>: Among other problems it assumes that the (mean) response in the controls is known without error, which is not the case. Therefore, this should be avoided, and instead the background response should be estimated from the data by fitting the model to the untreated* [**i.e., unadjusted**] *data. Thus, the estimation error in the controls is treated in the same way as the estimation errors in the other concentration groups. (see e.g. chapter 6.2.2 and 6.3.2). [emphasis added]

It is not clear to me what magnitude or direction of bias might be introduced by such improper pre-treatment of the data, or whether the bias would systematically be in only one direction, or even whether the bias would affect the maximum likelihood estimate of an EC10 at all, as

opposed to only affecting the variance characteristics (confidence limits) of the analytical results. What does seem clear, is that results from analyses that don't rely on simple control-adjusted data, in general, and for a hormetic chemical in particular, are preferable to those that do.

An analysis of the mallard toxicity data based on the statistical method of hockey stick regression was also provided to the Science Panel courtesy of Dr. William Adams, as documented by CH2M HILL (2007). Adams' maximum likelihood estimate of the mallard EC10 is 11.5 ug/g, with estimated 95% confidence limits of 9.7 to 13.6 ug/g. In common with Ohlendorf's analysis, Adams' analysis does not formally take into account the possibility of hormesis effects in the data and improperly (OECD 2006) relies on simple control-adjusted data as the input for statistical analysis. A cursory examination of Figure 4 (hockey stick regression) in CH2M HILL's "Thresholds Values" final technical memorandum (February 28, 2007) clearly shows that use of control-adjusted data artificially removes all variance in the response variable for low exposure data points (more than one-third of the total data set). As explicitly noted in CH2M HILL's final technical memorandum, hockey stick regression is sensitive to the scatter, i.e., estimation error characteristics, of the response variable. Another concern with this analysis is that it is based on duckling mortality rather than on egg hatchability. Egg hatchability is a strictly comparable response metric between the different mallard studies in question, while duckling mortality is not. Some of the experiments fed the ducklings the same selenium-treated diet that the hens producing the ducklings had been fed (which would mimic nature), while some studies did not. Some of the studies used different age cutoffs for assessing duckling survival. Because of these toxicologically critical differences between the studies, it is not valid to pool their results for statistical analysis as if they were all measuring comparable exposure and response metrics (Skorupa 1999). A final concern is that the hockey stick regression method was designed specifically to estimate the location of a threshold response (9.8 ug/g in Adams' analysis) not to estimate ECxx values. For example, see the discussion of hockey stick regression by Environment Canada (2005) in their publication titled, "*Guidance Document on Statistical Methods for Environmental Toxicity Tests*". Estimates of the EC10 from a hockey stick regression approach are probably not very appropriate unless the estimate of the location of the threshold response is very precise (which it usually isn't) because it is that estimate that determines which data points will be included and excluded from the response part of the hockey stick. Adams did not report the 95% confidence interval for his estimated 9.8 ug/g threshold point (which itself is improperly [OECD 2006] based on simple control-adjusted input data and therefore may be erroneous).

Recently, a subset of the mallard toxicity data (the data points from Heinz et al. 1989) were analyzed using a generalized biphasic response model that collapses down to a logistic model in the absence of a biphasic response (Beckon et al. 2008). This method of analysis differs from both Ohlendorf and Adams in that it explicitly accommodates hormetic effects in the data via a model that is mechanistically specific to the phenomenon being analyzed and his analysis did not rely on using control-adjusted input data. In both those respects, the analysis by Beckon et al. is statistically more valid and more relevant to known selenium biochemistry. Beckon et al.'s estimate of the mallard EC10 is 7.7 ug/g, however no 95% confidence interval was reported. Beckon et al. also demonstrated the substantive potential for upward bias in EC10 estimates when hormetic data is forced into a standard logistic regression model. The drawbacks of Beckon et al.'s analysis include that it doesn't report an estimated confidence interval and that it is based on fewer data points than the analyses of Ohlendorf and Adams. However, Ohlendorf and Adams gain their larger sample size only by improperly (OECD 2006) using simple control-adjusted input data, which is what makes it possible to pool data from different studies. As tempting as it is to improperly pre-treat the data in order to increase the sample size by pooling results from multiple studies, or to ignore fundamental experimental incompatibilities between studies (in the

case of duckling mortality) also to increase the sample size, the reality is that we are limited to the Heinz et al. (1989) study for drawing inferences that are fully technically valid.

Therefore my recommendation regarding the best estimate of an EC10 for mallard egg hatchability is 7.7 ug/g Se on a dry-weight, whole egg basis, as per the biphasic model of Beckon et al. (2008).

VI. Estimating the No Effects Concentration (NEC) for Avian Eggs

As stated above, and for the reasons stated above, such as the high environmental and commercial value of the Great Salt Lake ecosystem, the great uncertainties still unresolved regarding selenium biogeochemistry in the Great Salt Lake and regarding what the most sensitive species and endpoints might be, my professional recommendation is for an egg standard that is more protective than an EC10. My professional recommendation is that the State of Utah be prudently precautionary by aiming to set the egg standard at a no effect concentration (NEC). Various methods of estimating the NEC have been proposed. In a human health context, EPA has proposed that the lower 95% confidence limit of the EC10 be used as an estimator of the NEC (EPA. 2000) and at least one text book, "*Statistics in Ecotoxicology*" also recommends such an approach more generally than just in a human risk management context (Sparks 2000). Consequently, the estimates of the NEC for avian eggs that would be associated with Ohlendorf's and Adams' analyses of the mallard EC10 are 6.4 and 9.7 ug/g respectively. The hockey stick regression method of data analysis was actually designed to estimate the NEC directly. Based on Adams' hockey stick regression results, that direct estimate would be 9.8 ug/g. Of course those three estimates for the NEC are made ignoring the concerns presented above regarding potential technical deficiencies in the underlying analyses that produced the confidence intervals, etc. Furthermore, two of these three estimates for the NEC are above what I consider to be the most technically valid estimate of the EC10, i.e., above 7.7 ug/g. With regard to hockey stick regression it has been recommended in a human risk management context that the lower confidence boundary on the threshold estimate be considered the NEC (e.g., Yanagimoto and Yamamoto 1979). However, Adams did not report a confidence interval for his threshold point of 9.8 ug/g.

Skorupa and Ohlendorf (1991) reported that normal background means for selenium in avian eggs extended up to about 3 ug/g. Therefore, my best professional estimate is that the mallard NEC for egg selenium lies somewhere between 3 and 7.7 ug/g. There simply does not exist a well-founded basis for picking a particular number within that range. EPA often deals with such irreducible bounded zones of interest by settling on the geometric mean of the boundary values (see Clean Water Act water criteria derivation methodologies). In this case the geometric mean of our boundary values is 4.8 ug/g.

Therefore my recommendation regarding the best estimate of a No Effect Concentration (NEC) for avian eggs (measured as a sample mean) is 5 ug/g and I would expect this value to be precautionary enough to account for the fact that mallards are not the most sensitive species of bird to selenium toxicity.

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MEMORANDUM

SUBJECT: Recommended Numeric Selenium Standard for the Great Salt Lake

FROM: Bill Wuerthele

TO: Bill Moellmer, Utah Division of Water Quality
Jeff DenBleyker, CH2MHill

As requested, here is my recommendation and rationale for a selenium criterion (numeric selenium standard) applicable to the open waters of the Great Salt Lake. The recommendation is for a tissue-based standard with an implementation procedure containing four general elements. At a minimum, I believe a tissue-based standard would have to include/reference part (a) of the implementation procedure below, i.e., a method for translating the tissue-based standard to a water column value which would form the basis for controlling selenium discharges to the open waters of the GSL.

Recommended Numeric Selenium Standard for the Open Waters of the Great Salt Lake

The geometric mean of the selenium concentration in the eggs of aquatic-dependent birds using the open waters of the Great Salt Lake shall not exceed 12 mg Se/kg dry weight. The open waters of the Great Salt Lake are defined as …..(need to define)

Recommended Implementation Procedure (reference in the water quality standards rule)

The tissue-based selenium standard for the open waters of the Great Salt Lake (GSL) will be applied using the Department's implementation procedure entitled …. which includes the following elements:

a) Identification of the specific Bioaccumulation Model transfer factors to be used in deriving a dissolved selenium water column concentration from diet and egg tissue concentrations; Identification of the averaging period and return interval for the derived water column concentration; Notice that this derived water column concentration will form the basis for controlling the discharge of selenium to the open waters of the GSL;

b) A protocol to be used in translating the derived water column concentration into effluent limits for regulated discharges of selenium that are likely to reach the open waters of the GSL, with consideration given to the fate/transport of discharged selenium, mixing zones, antidegradation and other elements of the water quality standards as appropriate;

c) An assessment protocol to be used in monitoring selenium concentrations and trends in water, diet and, as appropriate, bird eggs and to be used in identifying management options where key trigger values are exceeded; Explanation that the protocol, as well, will use new data to evaluate model relationships, address uncertainty, and identify adjustments which would improve the Bioaccumualtion Model; and

d) *A public notice and comment protocol to be applied where the Department contemplates making significant revisions to the implementation procedure (e.g., revisions to the transfer factors).*

Rationale

Water quality standard

A water quality standard consists of a designated use or uses for a waterbody and criteria necessary to protect that use or those uses. The criteria are to be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. Where a waterbody is assigned multiple use designations, the criteria are to protect the most sensitive use.

The GSL is a Class 5 waterbody which includes protection of the following designated uses: primary and secondary contact recreation; waterfowl, shorebirds and other water-oriented wildlife including the necessary aquatic organisms in their food chain, and mineral extraction.

For selenium, based on the scientific literature and available information specific to the GSL, protection of aquatic-dependent birds is the most sensitive use assigned to the GSL, and reproductive success (egg hatchability) is the critical endpoint to be used in defining the selenium criterion (numeric standard) that would be protective of that designated use.

I am recommending that a selenium concentration in bird eggs, an indicator of reproductive success which can be readily monitored, be used as a tissue-based numeric standard for the GSL.

Selenium concentrations in eggs

The Science Panel determined that extensive laboratory studies with mallards provide the best available data to evaluate avian exposure to and effects from selenium.

The mallard is an appropriate and conservative surrogate for birds nesting at the GSL because:

- It is more sensitive to the effects of selenium than typical shorebirds found at the GSL;
- Ducks, generally, are more sensitive than other aquatic-dependent birds that commonly nest at the GSL;
- Birds that typically inhabit saline habitats are less sensitive to selenium than related counterparts that more commonly use freshwater habitats;
- In the laboratory studies, the selenium in the mallards' diet was in the form of selenomethionine, which is more readily taken up by birds than other forms of selenium.

Based on the mallard data, the Science Panel identified a range of egg selenium concentrations associated with the EC_{10}[1] for egg hatchability (a range based on the mean and its 95% confidence interval).

[1] The EC_{10} for egg hatchability is the concentration at which 10% of the eggs that are incubated to full term do not hatch due to selenium exposure.

The range of egg selenium values based on the 95% confidence interval is: 6.4 mg Se/kg to 16 mg Se/kg, with a mean of 12 mg Se/kg

Tissue-based standard for selenium

Ideally, a site-specific numeric selenium standard for the GSL would be a water column concentration that is predictive of an acceptable level of reproductive success for aquatic-dependent birds using the open waters of the GSL. A water column concentration is preferred because it would be specific to the selenium entering the open waters of the GSL, and it is the form of a numeric standard that is most readily translated into control requirements for pollutant discharges.

For selenium, however, there are a number of variables that can affect the extrapolation of a water column concentration to selenium levels in bird eggs and a prediction of reproductive success. And, for the GSL, the predictive uncertainty introduced by these variables is compounded by the limited site-specific data currently available.

It seems reasonable at present, therefore, to base the numeric selenium standard for the GSL on an egg selenium concentration, given:

- The current limited site-specific data and the resulting uncertainty in extrapolating a water column concentration to an acceptable selenium level in bird eggs (or, the reverse) with a high level of confidence;
- The conservatism in the mallard egg threshold value, providing a fairly high level of confidence that a numeric standard based on that value will be protective of the designated use;
- The more direct measure of use protection provided by the egg threshold value; and
- The possible Section 303(d) impairment implications if a water column value, based on an uncertain extrapolation from the egg threshold value, were to be the standard.

Nevertheless, there are several drawbacks to such a tissue-based standard. First, it will be difficult to ascribe the source of all selenium measured in the birds' eggs to selenium from the open waters of the GSL. And, second, it still will be necessary to translate the tissue-based value to a water column value that can serve as the basis for controlling the discharge of selenium to the open waters of the GSL.

Adoption of a tissue-based selenium standard, therefore, should include a commitment to continued monitoring and assessment of selenium concentrations in water, diet and, as appropriate, bird eggs. And, the State should commit to using these new data to evaluate model relationships, address uncertainty, and identify adjustments that would improve the numeric standard and its implementation.

Level of protection

The most sensitive designated use for the GSL and the critical endpoint for that use are: 1) protection of aquatic-dependent birds using the open waters of the GSL and 2) reproductive success for those birds. As such, the numeric selenium standard under consideration for the GSL is a wildlife criterion (numeric standard).

The Environmental Protection Agency (EPA) has no national guidance for deriving wildlife criteria, and therefore, the Agency has not formally addressed the level of protection question for wildlife criteria, at least at a national level.

The only place where the Agency has taken a position on the level of protection question for wildlife criteria is in the Great Lakes Initiative (GLI). There, the Agency used the no observed effect concentration (NOEC)[2] as the appropriate level of protection in deriving wildlife criteria applicable to the Great Lakes (a NOEC and an EC_{10} often occur at similar concentrations and provide a similar level of protection). Although use of a NOEC (EC_{10}) in the GLI provides some insight into the Agency's thinking on this matter and sets something of a precedent, the approach taken applies only to the Great Lakes and does not establish a formal, Agency-wide position on the use of a NOEC (EC_{10}) in wildlife criteria derivation.

Similarly, the Agency's use of an EC_{20} in publishing its draft tissue-based aquatic life criterion for selenium does not establish an Agency-wide position on the use of an EC_{20} in criteria derivation. It should be noted that the draft selenium criterion: 1) is an aquatic life criterion, not a wildlife criterion; 2) is a draft, and therefore use of an EC_{20} here is not a final Agency decision; and 3) the Agency is still considering comments on the draft. Nevertheless, although publication of the draft does not establish an Agency-wide position, it does indicate that the Agency might consider a level of protection as high as an EC_{20} to be acceptable.

The Agency has, however, established a national position that protective criteria need not be set at the "no effect" level (EC_0). For example, EPA's 1985 guideline for deriving aquatic life criteria uses a threshold set at protecting 95% of the genera in the dataset. The aquatic life criteria guideline, therefore, accepts that an aquatic community can sustain some low level of effect and still be considered fully protected. And, as a result, EPA's national criteria recommendations are not set at "no effect" levels.

From the above, it appears that an acceptable level of protection lies somewhere between an EC_0 and an EC_{20}, and without national guidance on this matter, the Science Panel, the Steering Committee and the Board all have a certain level of flexibility in selecting what each views to be an appropriate level of protection.

It is my personal view that selection of an appropriate level of protection and a final numeric standard for the open waters of the GSL should incorporate a reasonable level of risk, an appropriate level of caution, and consideration of the environmental value of the Great Salt Lake. Based on this and considering the conservatism built into the mallard egg threshold value, I believe an EC_{10} based on the mallard data will provide an appropriate level of protection for aquatic-dependent birds using the open waters of the GSL.

An EC_{10} is, I believe, consistent with the criteria development position taken by EPA which acknowledges a criterion can incorporate some level of effect and still be considered fully protective. And, in terms of ensuring protection of the GSL resource, an EC_{10} is not

[2] NOEC is the highest concentration of a toxicant in a toxicity test at which no statistically significant adverse effects to test organisms are observed relative to the control.

inconsistent with EPA's position taken in either the GLI or the draft selenium criterion for aquatic life, being as protective as the GLI approach and more protective (more conservative) than the draft selenium criterion.

The Science Panel has provided a range of egg selenium values centered on the concentration that would cause a 10% reduction in reproductive success (EC_{10} for egg hatchability). Most likely, the actual EC_{10} is associated with the midpoint of the range, the 12 mg Se/kg value. My recommendation for the tissue-based standard, therefore, is that midpoint value, i.e., 12 mg Se/kg as dry-weight.

Recommended numeric selenium standard for the open waters of the GSL:

The geometric mean of the selenium concentration in the eggs of aquatic-dependent birds using the open waters of the Great Salt Lake shall not exceed 12 mg Se/kg dry weight.