Great Salt Lake Water Quality Studies

Selenium Program Update

May 2, 2008
Agenda

1. Program Update
   - Program Objective
   - Status of Investigations
   - Status of Model
   - Status of Report

2. Key Observations

3. Science Panel Recommendations
Program Objective

*Define a site-specific, numeric water quality standard for selenium (Se) that prevents impairment of the beneficial uses of the open waters of the Great Salt Lake*
Status of Investigations

• **Project 1 – Birds**
  - Reports complete, 3 final reports on website, 2 in the next week
  - Further analysis of grebe organs did not show relationship between body condition and selenium

• **Project 2A – Benthic Zone**
  - Report complete, found on website

• **Project 2B – Pelagic Zone**
  - Awaiting final report, data complete
Project 2B – Pelagic Zone

• Completed comparison of “bulk sampling method” for brine shrimp and separation by age classes
• Adult brine shrimp Se was generally twice that of nauplii
• Developed corrections for 2006 data, decided to use only 2007 data
• Decided to use adult brine shrimp values to represent bird diet
Status of Investigations

- **Project 3 – Se Loads**
  - Report complete, found on website

- **Project 4 – Se Flux**
  - Report complete, found on website

- **Project 5 – Brine Shrimp Kinetics**
  - Final experiment: look at brine shrimp uptake directly from water at lower concentrations
  - Final experiments are complete, waiting for final analytical data
  - Final report to be updated with new data, new “Grosell Model” incorporated into Bioaccumulation Model
Status of the Model

- Some additional refinements were identified this week, should be final next week
Status of the Report

- Final Draft is provided to the Steering Committee on CD
- Report will be updated with information from the Science Panel meeting and finalized
- Sections will be posted to website as they are finalized
- Sections 1-5 should be on website
Key Observations
Program Questions

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?
Key Observations – Question 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)?
Key Observations – Question 1

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 associated with the open waters of Great Salt Lake.
Key Observations – Question 1

- Geometric means for eggs in gulls was 2.89 mg/kg and shorebirds 2.72 mg/kg; below the 85 percentile of background levels.

- 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% confidence limit (6.4 µg Se/g) but below the median (12 µg Se/g) of the mallard EC_{10} for egg hatchability.
Key Observations – Question 1

Have any adverse effects been observed in non-reproductive endpoints (e.g., 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.
Key Observations – Question 1

The Science Panel believes that, based upon available information, the reproductive endpoint (i.e., egg hatchability) is the most sensitive endpoint for selenium on Great Salt Lake. Non-reproductive endpoints will require additional research before they can be used in assessing the water quality standard.
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)?

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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?
Key Observations – Question 2

2. What is the relative importance (based on selenium concentrations and their availability) of various food-chain exposure pathways for aquatic wildlife?
Started with Conceptual Model (Johnson et al., 2006)

Simplified conceptual model (November 2006)

Developed into a quantitative model
Pathways of Bioaccumulation Model

**ABIOTIC MODULE**

Food Concentration
- Choose Brine Shrimp Model
  - > Grosell
  - > Bioaccumulation Factor
  - > Multi-Step Transfer Factor

Brine Shrimp, Shrimp Cysts, Brine Fly Adult, Brine Fly Larvae, Corixid, Midge

Select Diet & Sediment Proportions

Select Offsite Diet Proportion & Concentration

**BIRD MODULE**

Diet Concentration

Select Evaluation Model

CSL Shorebird Model, Mallard Model, GSL Gull Model

Egg Concentration

Model Predicts Water Concentration that Yields Diet and Egg Concentration Limits Specified by User

KEY

- Input
- Output

Egg Hatchability (EC Curve)

Predicted reduction in egg hatchability based on modeled diet or egg concentrations

Insufficient data at this time.
Key Observations – Question 2

- Data were collected to document food exposure pathways for gulls, avocets and stilts. For birds associated only with open waters of GSL, gulls were feeding mainly upon brine shrimp and shorebirds were feeding mainly upon brine fly larvae.

- For modeling purposes, the following assumptions are made for bird diets:
  - Shorebirds – 95% brine fly larvae, 5% sediment
  - Gulls – 100% brine shrimp
**Bioaccumulation Model**

**Water to Diet**

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### Water Column Concentration (µg Se/L)

- Water column concentrations have been observed to vary historically between 0.40 and 0.86 µg Se/L.
- Please specify the water column concentration to estimate diet/egg conc. 0.60

### Diet Limits

- Solve for Shorebird
- Solve for Gull

### Egg Limits

- Solve for Shorebird
- Solve for Gull

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### Resulting Tissue Concentrations of Diet Options (µg Se/g dw)

<table>
<thead>
<tr>
<th>Diet Options</th>
<th>Concentration</th>
<th>Shorebird</th>
<th>Gull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brine shrimp (adults)</td>
<td>3.90</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Brine shrimp cysts</td>
<td>2.15</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Brine fly adults</td>
<td>1.68</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Brine fly larva</td>
<td>1.25</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Corixid</td>
<td>2.33</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Midge</td>
<td>2.00</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

- **Total Before Sediment**: 1.28
- **Total Onsite Diet Concentration**: 3.90

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### Offsite

- **Total Offsite Diet Concentration**: 1.90

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### Resulting Egg Concentrations and Indices for Each Species (µg Se/g dw)

| Limits and Modeled Diet Concentrations for Each Species (µg Se/g dw) |
|-------------------------------------------------------------|-------------------------------------------------|
| Limits for Diet Concentration                             | Modeled Diet Concentration                     |
| 4.80                                                       | 1.28                                           |
| 5.70                                                       | 3.90                                           |

---

### Modeled Egg Concentrations

<table>
<thead>
<tr>
<th>Limits for Egg Concentration</th>
<th>Modeled Egg Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.50</td>
<td>12.50</td>
</tr>
<tr>
<td>12.50</td>
<td>2.53</td>
</tr>
<tr>
<td>5.70</td>
<td>8.03</td>
</tr>
</tbody>
</table>
Key Observations – Question 3

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?
Bioaccumulation Model
Water to Diet

Bioaccumulation Model (Version 4.2)
Selenium Cycling in the Open Waters of the Great Salt Lake
April 25, 2008

Water Column Concentration (µg Se/L)

Water column concentrations have been observed to vary historically between 0.40 and 0.86 µg Se/L.

Choose brine shrimp model:
- Grosec Model
- BAF
- MS-TF

Resulting Tissue Concentrations of Diet Options (µg Se/g dw)

Please specify concentrations of diet options for each species.

<table>
<thead>
<tr>
<th>Diet Options</th>
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<td>1.25</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Corixid</td>
<td>2.33</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Midge</td>
<td>2.00</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Total Before Sediment:

- 100% for both Shorebird and Gull

Total Onsite Diet Concentration:

- 1.28 for Shorebird
- 3.90 for Gull

Please specify offsite diet ratio and concentration:

- 1.90 for Offsite

Limits and Modeled Diet Concentrations for Each Species (µg Se/g dw):

- Limits for Diet Concentration: 4.80 for Shorebird, 5.70 for Gull
- Modeled Diet Concentration: 1.28 for Shorebird, 3.90 for Gull

Resulting Egg Concentrations and Indices for Each Species (µg Se/g dw):

Please specify limits and which model to use to estimate Egg Concentration.

- Shorebird Model
- Malard Model

- Limits for Egg Concentration: 12.50 for Shorebird, 12.50 for Gull
- Modeled egg concentrations: 2.53 for Shorebird, 8.03 for Gull

Use buttons to display detailed worksheets of inputs for Estimated Mass Balance scenario.

Displays detailed models and other information.

Displays assumed actual and modeled diet and tissue concentrations (including blood, liver, and egg) for Shorebirds and Gulls.
Bioaccumulation Model
Water to Diet

Three Brine Shrimp Models

1. **Grosecell Model**
   - Equation relating Se in water/algae to brine shrimp

2. **Bioaccumulation Factor (BAF) Model**
   - BAF relating Tot-Se in water to brine shrimp, based on GSL data

3. **Multi-step Transfer Factor (MSTF)**
   - Relates Tot-Se to dissolved Se in water to seston to brine shrimp, based on GSL data
Comparison of 3 Brine Shrimp Models

Figure 7-1. Comparison of Three Brine Shrimp Models

- Diamond: Grosell Model
- Purple: Bioaccumulation Factor (BAF)
- Yellow: Multi-Step Transfer Factor (MSTF)
- Red: 2007 Brine Shrimp Data
Water to Diet

• Consensus Items
  – BAF and MSTF models developed from water range of 0.4 - 0.8 µg Se/L
  – Grosell Model range 0 – 2.5 µg Se/L but estimates high
  – **Selected MSTF model for use**
  – Valid range for model is only 0 – 2.5 µg Se/L in water
  – Models may over-predict Se in diet above 0.8 µg Se/L, must use caution above this concentration
Transfer Factors in Bioaccumulation Model

**ABIOTIC MODULE**

- **Food Concentration**
  - Choose Brine Shrimp Model
  - > Groell
  - > Bioaccumulation Factor
  - > Multi-Step Transfer Factor

**Select Diet & Sediment Proportions**

**Select Offsite Diet Proportion & Concentration**

**BIRD MODULE**

- **Select Evaluation Model**
  - CSL Shorebird Model
  - Mallard Model
  - Gull Transfer Factor
  - GSL Gull Model

**Model Predicts Water Concentration that Yields Diet and Egg Concentration Limits Specified by User**

**Input by user or back-calculated from diet or egg concentration limits specified by user**

**Egg Hatchability (EC Curve)**

Predicted reduction in egg hatchability based on modeled diet or egg concentrations
Bioaccumulation Model
Diet to Egg

Water Column Concentration (µg Se/L)

Diet Limits
- Solve for Shorebird
- Solve for Gull

Egg Limits
- Solve for Shorebird
- Solve for Gull

Use these buttons to display detailed calculation modules and other information:
- Displays detailed worksheets of inputs for Estimated Mass Balance scenario
- Shows modeled water column and biota tissue concentrations
- Shows Abiotic Model
- Hides Abiotic Model
- Shows Abiotic Model
- Hides Abiotic Model

Resulting Tissue Concentrations of Diet Options (µg Se/g dw)

<table>
<thead>
<tr>
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</tr>
<tr>
<td>Brine fly larvae</td>
<td>1.25</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Copepod</td>
<td>2.33</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Midge</td>
<td>2.00</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Total Before Sediment:
- Sediment: 0.65 (6%)
- Phytoplankton: 0.89 (0%)

Total Onsite Diet Concentration: 1.28 µg Se/g dw

Please specify offsite diet ratio and
concentration: 1.90 µg Se/g dw

Limits and Modeled Diet Concentrations for Each Species (µg Se/g dw)

Resulting Egg Concentrations and Indices for Each Species (µg Se/g dw)

- Modeled Diet Concentration: 1.28 µg Se/g dw
- Modeled Egg Concentration:
  - Shorebird: 12.50 µg Se/g dw
  - Gulf: 12.50 µg Se/g dw
- Limits for Egg Concentration:
  - Shorebird: 2.53 µg Se/g dw
  - Gulf: 8.03 µg Se/g dw
Comparison of 3 Models Evaluated for Shorebirds

- Shorebird Regression Model
- Mallard Regression Model
- Shorebird Transfer Factor
- Measured Geometric Mean for Shorebird Eggs
Comparison of 3 Models Evaluated for Gulls

- Shorebird Regression Model
- Mallard Regression Model
- Gull Transfer Factor
- Measured Geometric Mean for Gull Eggs

Comparison of Gull Egg Selenium Concentration (mg Se/kg) vs. Water Selenium Concentration (μg Se/L)
Key Observations – Question 3

- Relationships for shorebirds are site-specific and are the best understood from information we have. For implementation of the standard, we will use shorebirds with the Shorebird Regression to derive egg to diet Se concentrations and the MSTF relationship to derive diet to water Se concentrations.
Key Observations – Question 4

4. What are the most important processes that affect the partitioning, cycling, and removal of selenium in the Great Salt Lake open waters?
Key Observations – Question 4

• **Primary processes for loss of Se from GSL:**
  – Volatilization (2,108 kg/yr [820 - 5,240])
  – Flow to North Arm (880 kg/yr [0 -1,600])
  – Permanent Sedimentation (520 kg/yr [45 - 990])
  – Brine Shrimp Cyst Harvest (29 kg/yr [10 - 48])

• **Most Se in dissolved phase**

• **Long term cycling not addressed**
# Mass Balance Model

## Mass Balance Calculator

Sensitivity of Water Column Concentration to Changes in Mass Balance Assumptions

*Based on July 2006 through June 2007 data*

### Annual Mass Balance

<table>
<thead>
<tr>
<th>Water Column Selenium Inputs (kg)</th>
<th>Estimated Values</th>
<th>Hypothetical Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tributaries</td>
<td>1,281</td>
<td>-</td>
</tr>
<tr>
<td>Atmospheric Deposition</td>
<td>596</td>
<td>-</td>
</tr>
<tr>
<td>Particle Dissolution &amp; Sediment Remineralization</td>
<td>(137)</td>
<td>-</td>
</tr>
<tr>
<td>Deep Brine Layer Contribution</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>Shoreline Rewetting</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>Unknown Source</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total kg</strong></td>
<td><strong>1,776</strong></td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Column Selenium Outputs (kg)</th>
<th>Estimated Values</th>
<th>Hypothetical Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss to North Arm</td>
<td>880</td>
<td>-</td>
</tr>
<tr>
<td>Permanent Sediment Burial</td>
<td>520</td>
<td>-</td>
</tr>
<tr>
<td>Volatilization</td>
<td>2,108</td>
<td>-</td>
</tr>
<tr>
<td>Brine Shrimp Cyst Harvest</td>
<td>29</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total kg</strong></td>
<td><strong>3,537</strong></td>
<td>-</td>
</tr>
</tbody>
</table>

| Lake Selenium Inputs Exceed Outputs by X kg: | (1,761) |

<table>
<thead>
<tr>
<th>Water Column Concentration</th>
<th>Predicted Water Concentration (Total μg Se/L)</th>
<th>Water Column Se Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.60</td>
<td>5,724</td>
</tr>
</tbody>
</table>

### 12 Month Tributary Input (Kg)

<table>
<thead>
<tr>
<th>Loading Source</th>
<th>2006-07</th>
<th>Dry Year</th>
<th>Wet Year</th>
<th>INPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bear River</td>
<td>321</td>
<td>161</td>
<td>1,799</td>
<td>-</td>
</tr>
<tr>
<td>Farmington Bay</td>
<td>137</td>
<td>82</td>
<td>587</td>
<td>-</td>
</tr>
<tr>
<td>Goggin Drain</td>
<td>337</td>
<td>202</td>
<td>1,450</td>
<td>-</td>
</tr>
<tr>
<td>KUCC Outfall</td>
<td>337</td>
<td>337</td>
<td>1,096</td>
<td>-</td>
</tr>
<tr>
<td>Lee Creek</td>
<td>96</td>
<td>96</td>
<td>313</td>
<td>-</td>
</tr>
<tr>
<td>Weber River</td>
<td>52</td>
<td>31</td>
<td>336</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL Kg</strong></td>
<td><strong>1,281</strong></td>
<td><strong>910</strong></td>
<td><strong>5,581</strong></td>
<td>-</td>
</tr>
</tbody>
</table>

### Atmospheric Deposition Rate

<table>
<thead>
<tr>
<th>Source</th>
<th>Dry Flux Rate kg/km2/yr</th>
<th>Wet Flux Rate kg/km2/yr</th>
<th>Assumed Rate (dry + wet flux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ches Bay 1991</td>
<td>0.259</td>
<td>0.130</td>
<td>0.389</td>
</tr>
<tr>
<td>Great Salt Lake</td>
<td>0.259</td>
<td>0.065</td>
<td>0.324</td>
</tr>
</tbody>
</table>

### Volatilization Output (kg)

<table>
<thead>
<tr>
<th>95th % con. inter.</th>
<th>Geomean</th>
<th>68th % con. inter.</th>
<th>User Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>820 - 5,420</td>
<td>2,108</td>
<td>1,380 - 3,210</td>
<td>-</td>
</tr>
</tbody>
</table>

*Display detailed worksheets of inputs for Estimated Mass Balance scenario*
Mass Balance Model

- Only one year of data
- Lots of variability in values but represents best available data
- Requires more work before we can accurately predict future water Se concentrations
Key Observations – Question 5

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

• Tributary loads
  – (1,540 kg over 15 months)
Key Observations – Question 5

- **Possible unmeasured loads**
  - Groundwater
  - Atmospheric Deposition
  - Unmeasured Surface Flows
  - Lake Sediment pore water diffusion

- **Observed anomalies in mass balance**
  - Mass Balance indicates greater loss than load
  - Waterborne Se in lake observed to increase during the study period
  - Lake level/volume decreased in study period
Results of Research Program

- Vastly improved our understanding of Great Salt Lake cycling of Se
- Developed quantitative model based on one year of data
- Most confident in diet to egg relationships, believe water to diet relationships over-predict (e.g., conservative) estimate of Se in diet for water Se > 0.8 µg Se/L
- Provided a tool DWQ can use to relate water/diet/egg Se concentrations for implementation