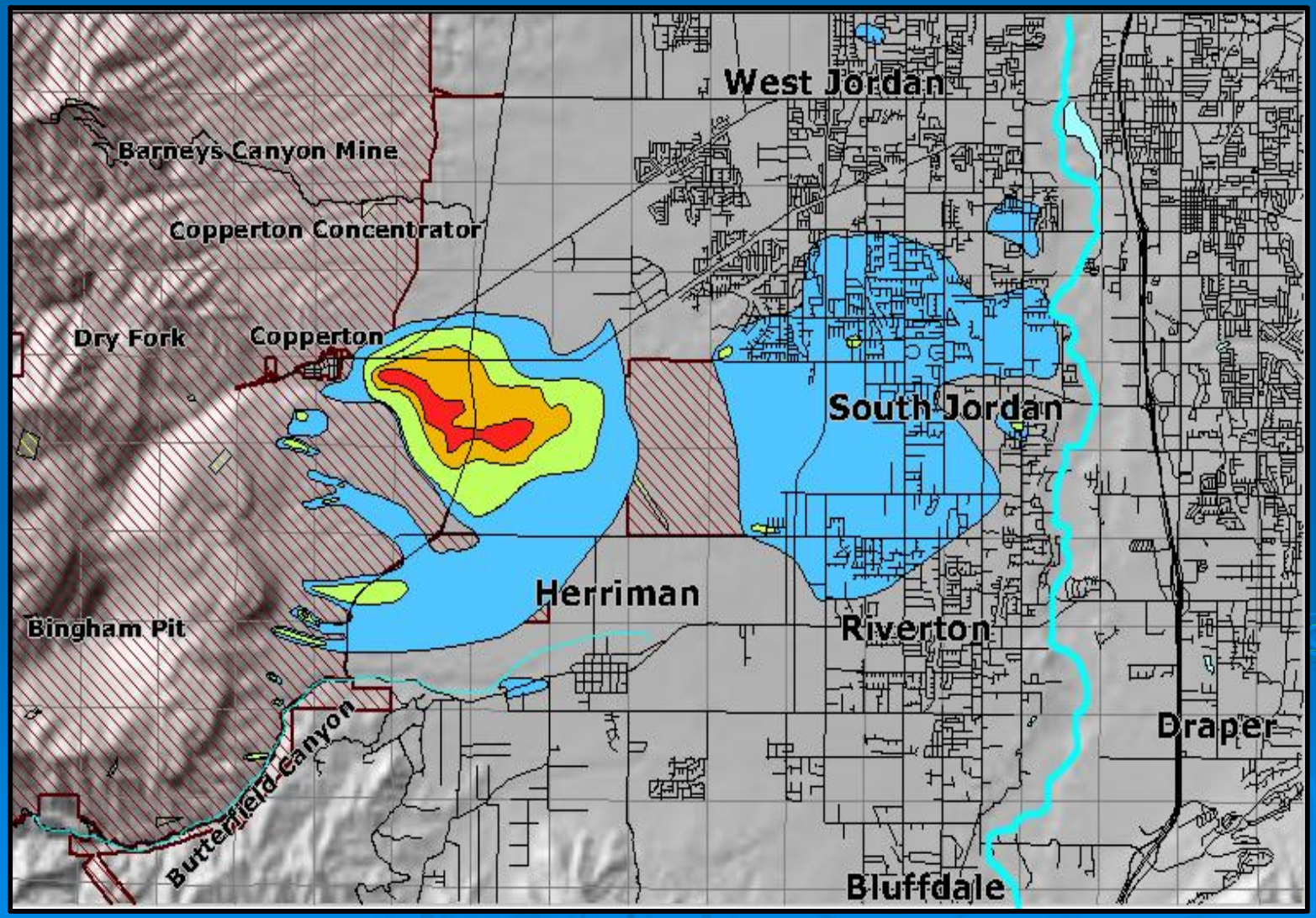
Great Salt Lake Water Quality Initiative

Addressing Selenium Issues and Developing a Selenium Standard for the Open Waters of the Great Salt Lake

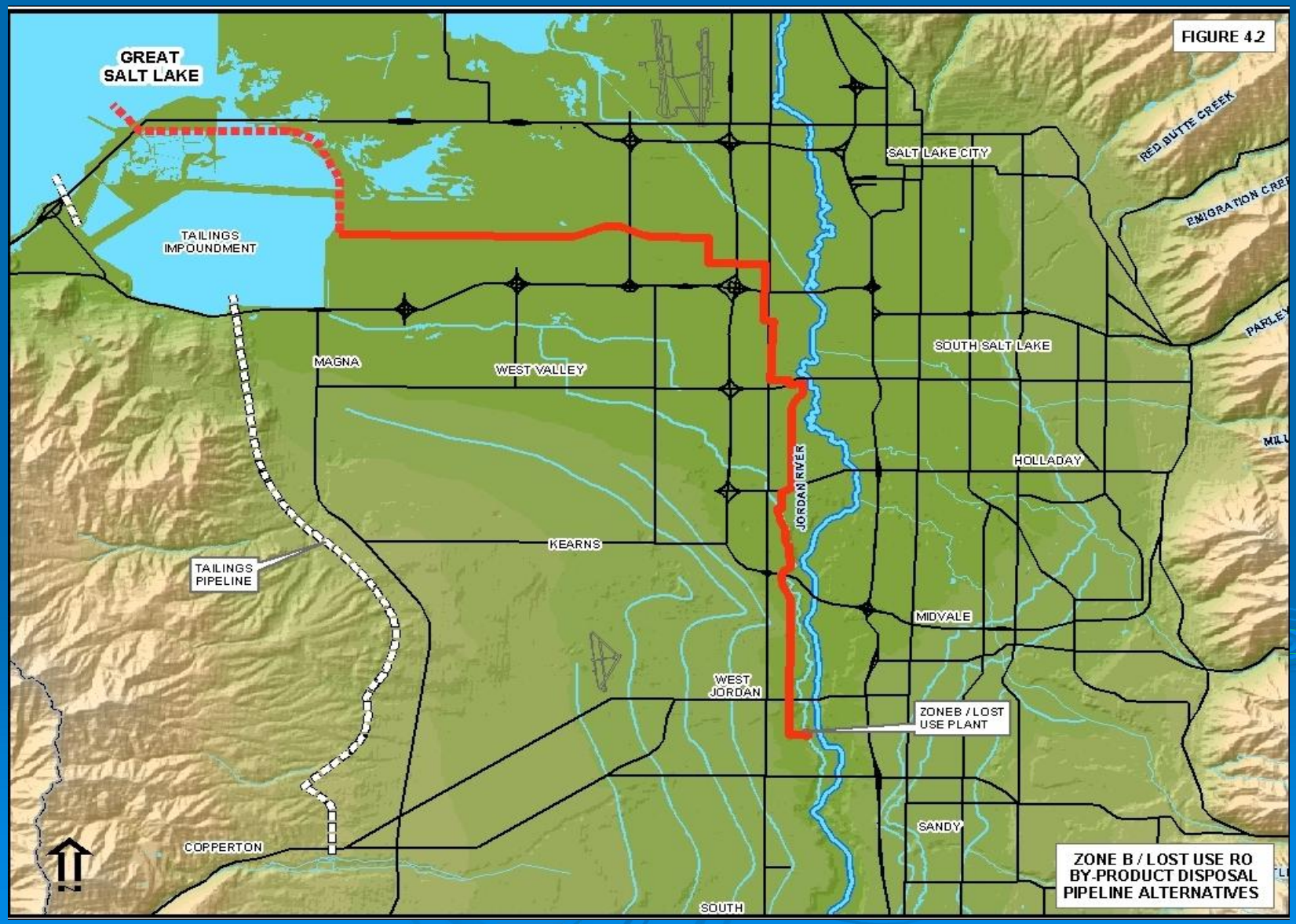
William O. Moellmer, Ph.D.
Utah Division of Water Quality
Salt Lake City, Utah

Bingham Copper Mine

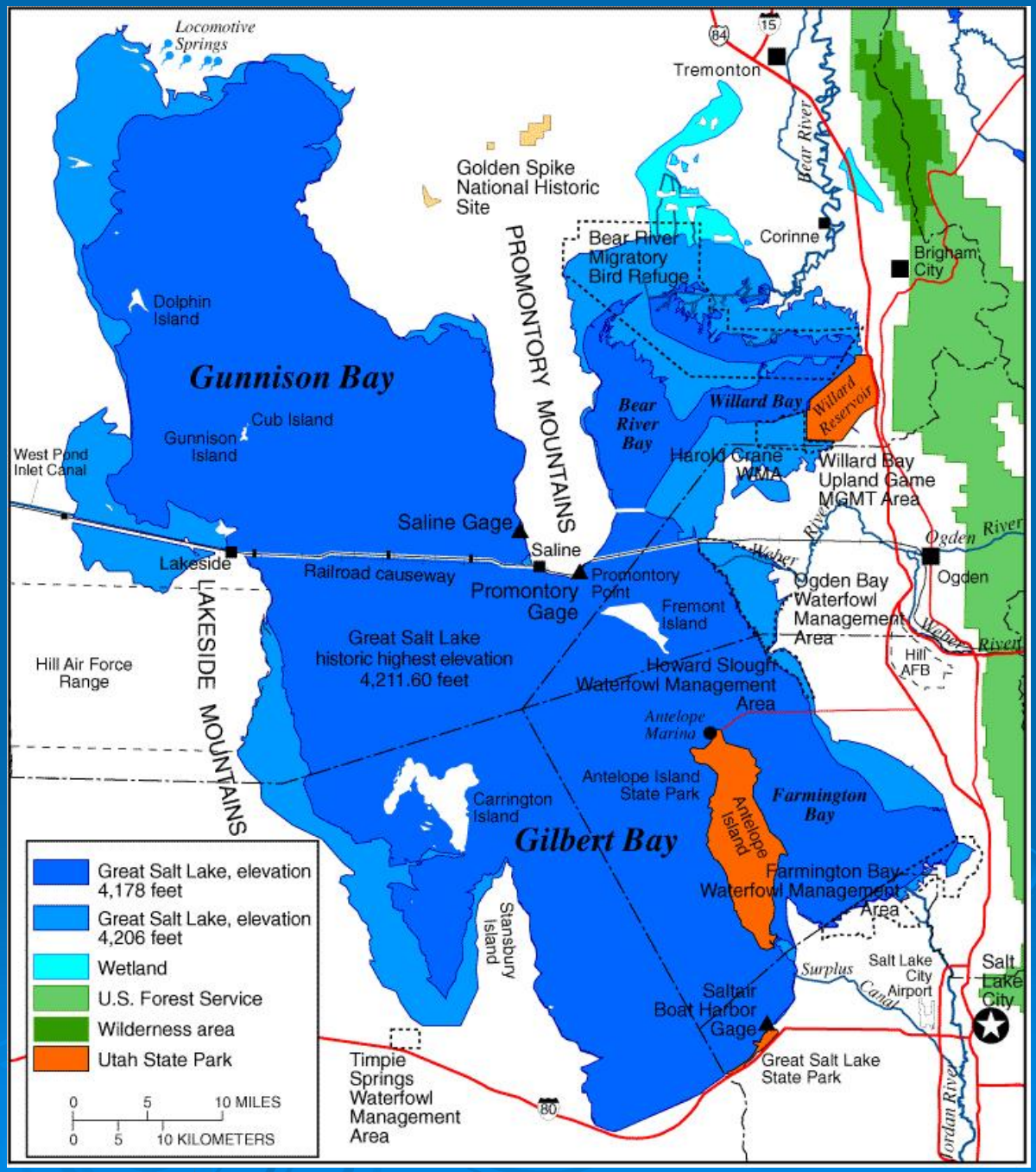
Sulfate Plumes



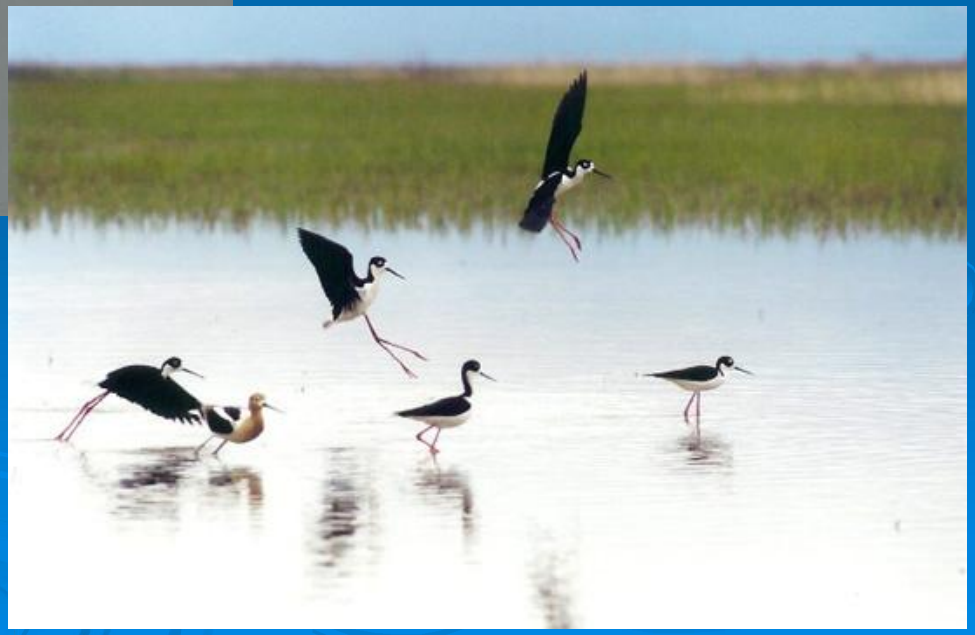
Brines Pipeline



The Great Salt Lake - Utah



Eared Grebe



Black-Necked Stilts

Wildlife Selenium Problem

Kesterson Reservoir California – 1980's

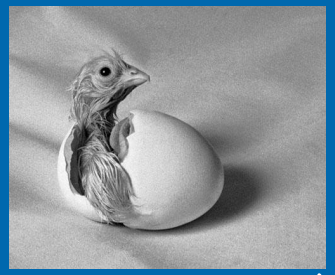
- Subsurface agricultural drainage water was used for marsh management in Merced County, CA.
- Inflow Avg. ~300 μg/L selenium.
- All fish except mosquitofish disappeared.
- Selenium-induced effects, including dead or deformed embryos or chicks, were found in 39% of the nests.
- Many dead birds were found.

Biomagnification up the GSL Food Chain

[Might this be happening here?]

Brine Flies & Brine Shrimp

Birds



Chicks

Stunted Growth

Teratogenesis

Selenium Growth Effects

13 and 14 day-old Avocet chicks from clean and seleniferous environments prior to hatching with same diet after hatching.

Examples of Teratogenic Effects

(from Seiler et al. 2003)

Gadwall (Kesterson Reservoir, California) with arrested development of lower bill, spoonbill narrowing of upper bill, and missing eyes

Examples of Teratogenic Effects (from Seiler et al. 2003)

Black-necked stilt (Kesterson Reservoir, California) with missing eyes, malformed bill, limb deformities.

Examples of Teratogenic Effects
(from USFWS)

Deformed Ca. Clapper rail with reduced wings and extra toes found in 1998 near marsh downstream of discharge from oil refinery (Martinez, CA).

Examples of Teratogenic Effects (from Seiler et al. 2003)

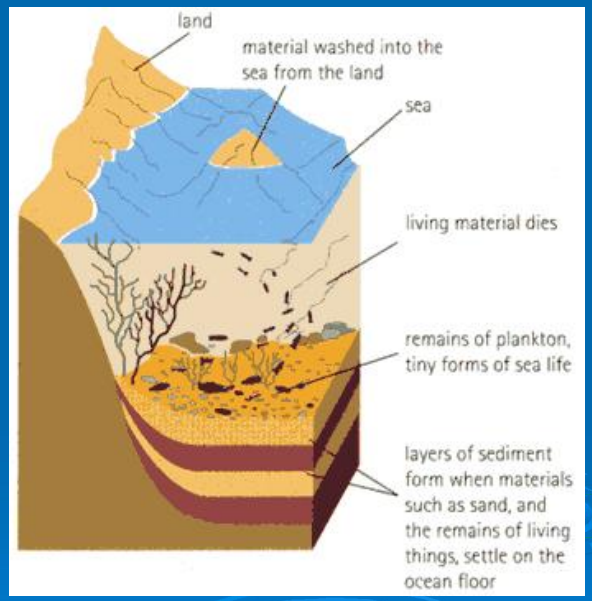
Redhead (middle Green River Basin, Utah) with spoonbill narrowing of upper bill

Fate and Transport

- Water
  - Selenate salts predominate.
  - Selenates are highly mobile due to their high solubility and low adsorption onto soil particles.
  - Selenites are less soluble in water than the corresponding selenates.
  - Organic selenium is typically less abundant than inorganic selenium (selenate and selenite) but toxicologically important.

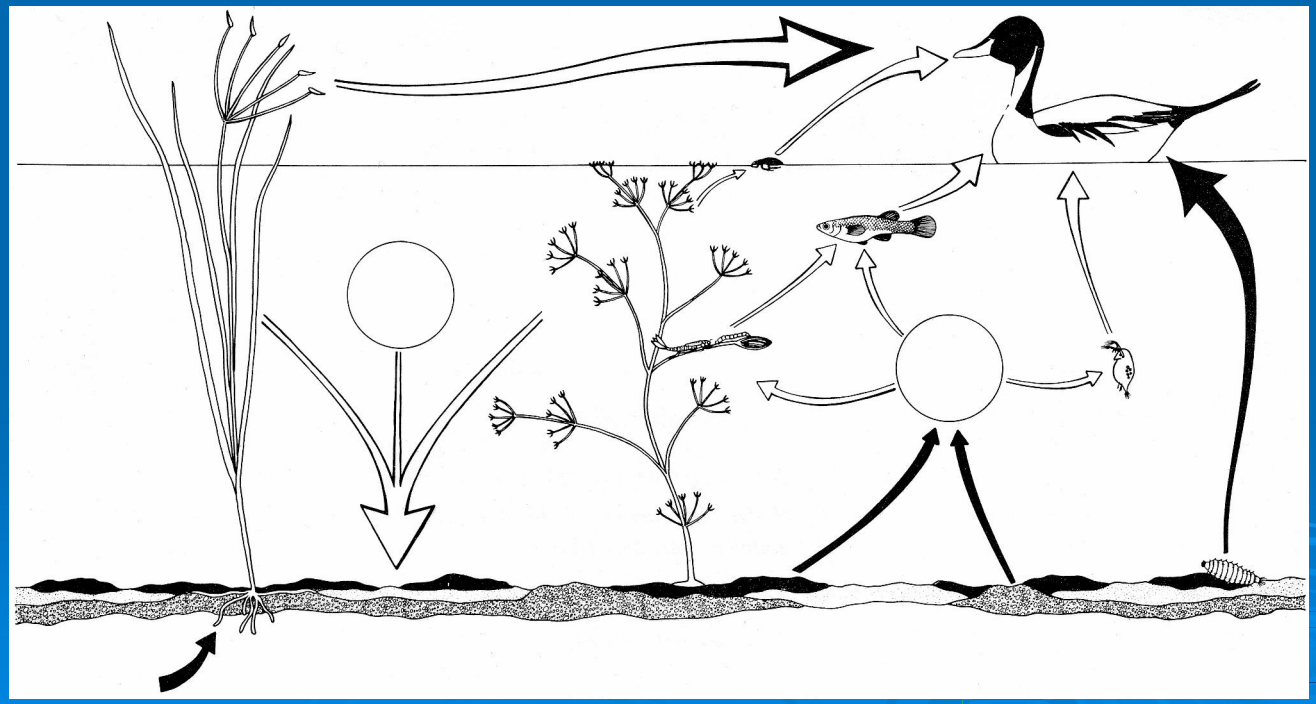
Fate and Transport (cont.)

- Aquatic systems
  - Selenium is generally associated with sediments (acting as a sink and reservoir) for plants and animals.
  - Relatively small amounts are found dissolved in water.
  - In bottom sediments, metal and organic selenides are most common.
  - Organic forms can volatilize into the atmosphere.



Fate and Transport (cont.)

Selenium Cycling in Aquatic Systems (from Lemly & Smith 1987)



Bioaccumulation

- Selenium bioaccumulates in both aquatic and terrestrial food chains
  - Water to aquatic plants (algae) or invertebrates (brine shrimp) often 1000X waterborne concentration.
  - Ingestion is the main uptake pathway.

Bird - Chronic and Acute Toxicity

- At higher values than normal dietary levels, selenium replaces sulfur in some metabolic pathways (proteins).
- Chronic selenium toxicosis causes reproductive problems (embryo mortality and teratogenesis) in birds.
- Early life stages of birds are most sensitive.

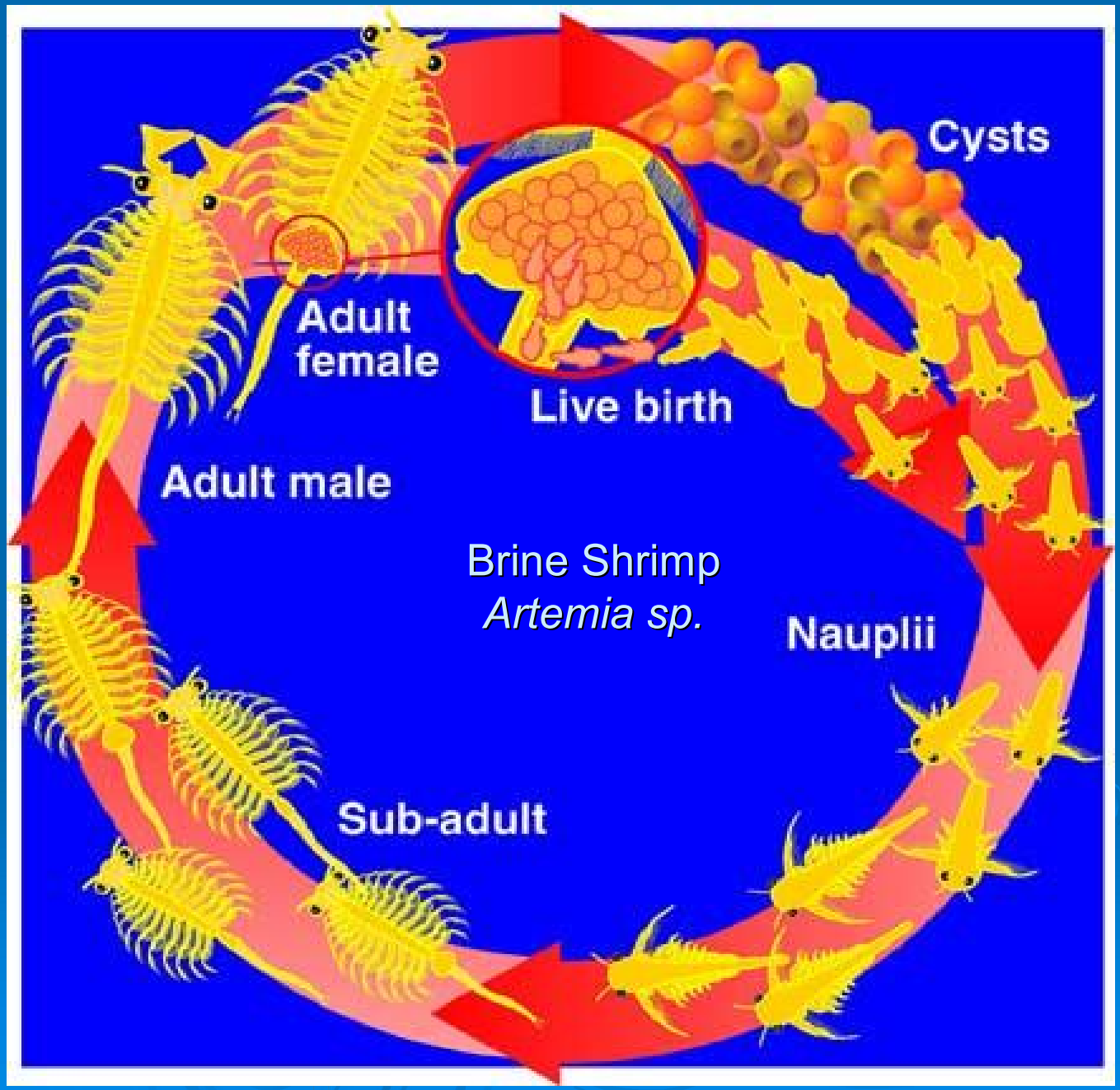
Bird - Selenium Relationships

- Risk of reproductive effects can be estimated from selenium in:
  - Hatchability Success
  - Eggs (yolk), Liver, Blood?
  - Diet
  - Water
  - Sediment (worst predictor)

Utah Division of Water Quality

Water Quality Standards

Protection of "aquatic oriented wildlife including their necessary aquatic organisms in their food chain…



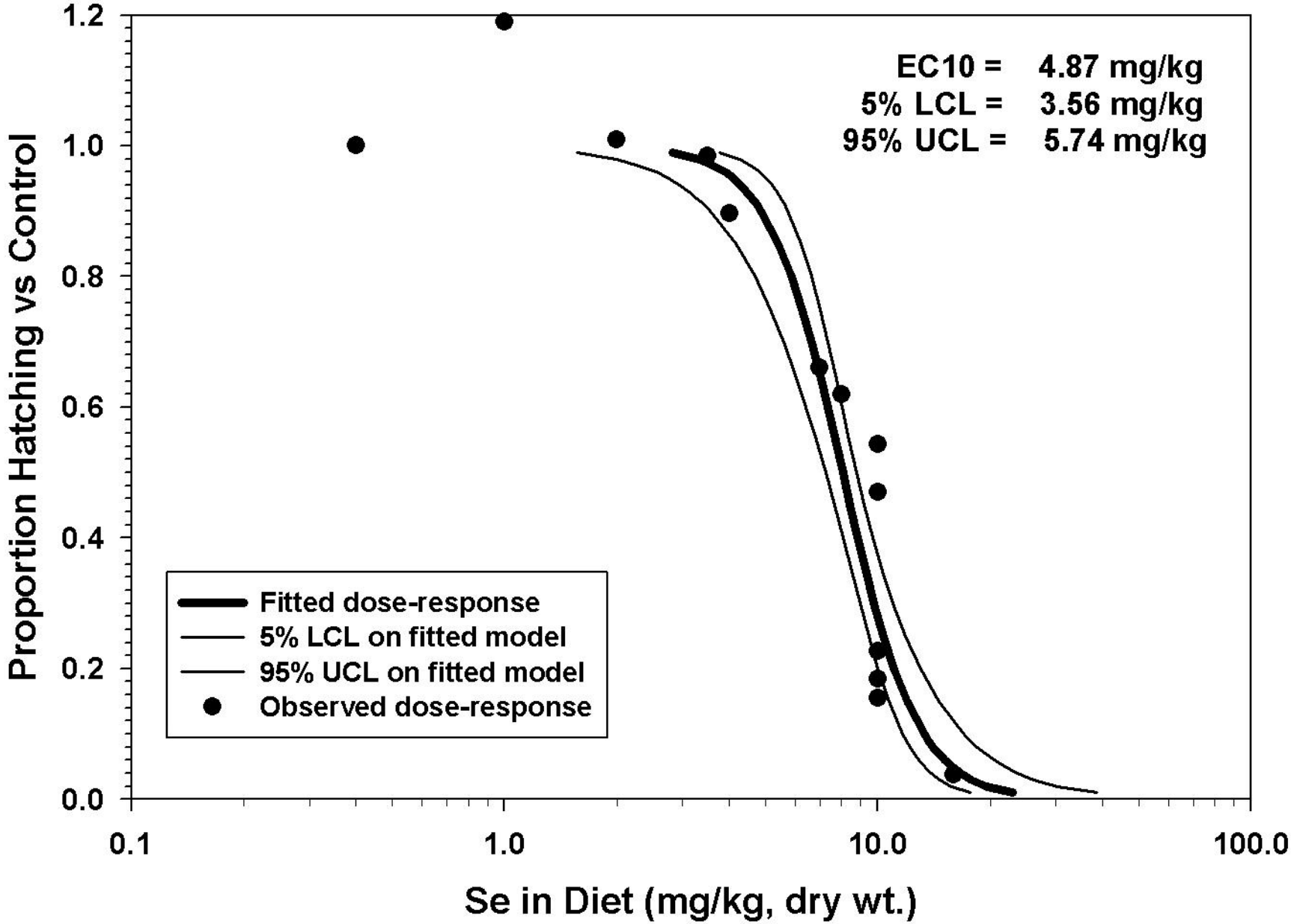


Figure 1. Mallard egg hatchability vs control as a function of selenium concentration in diet.

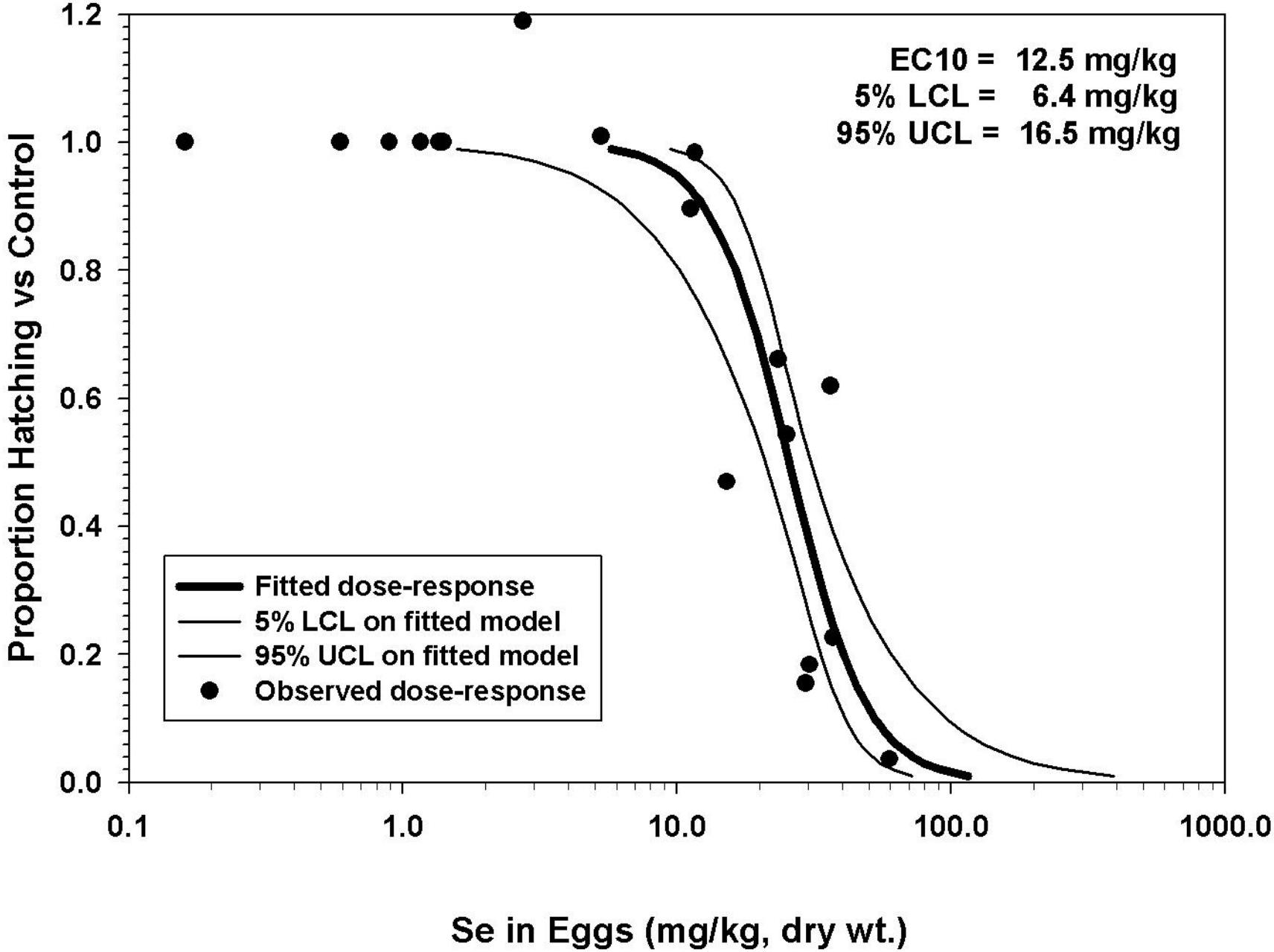
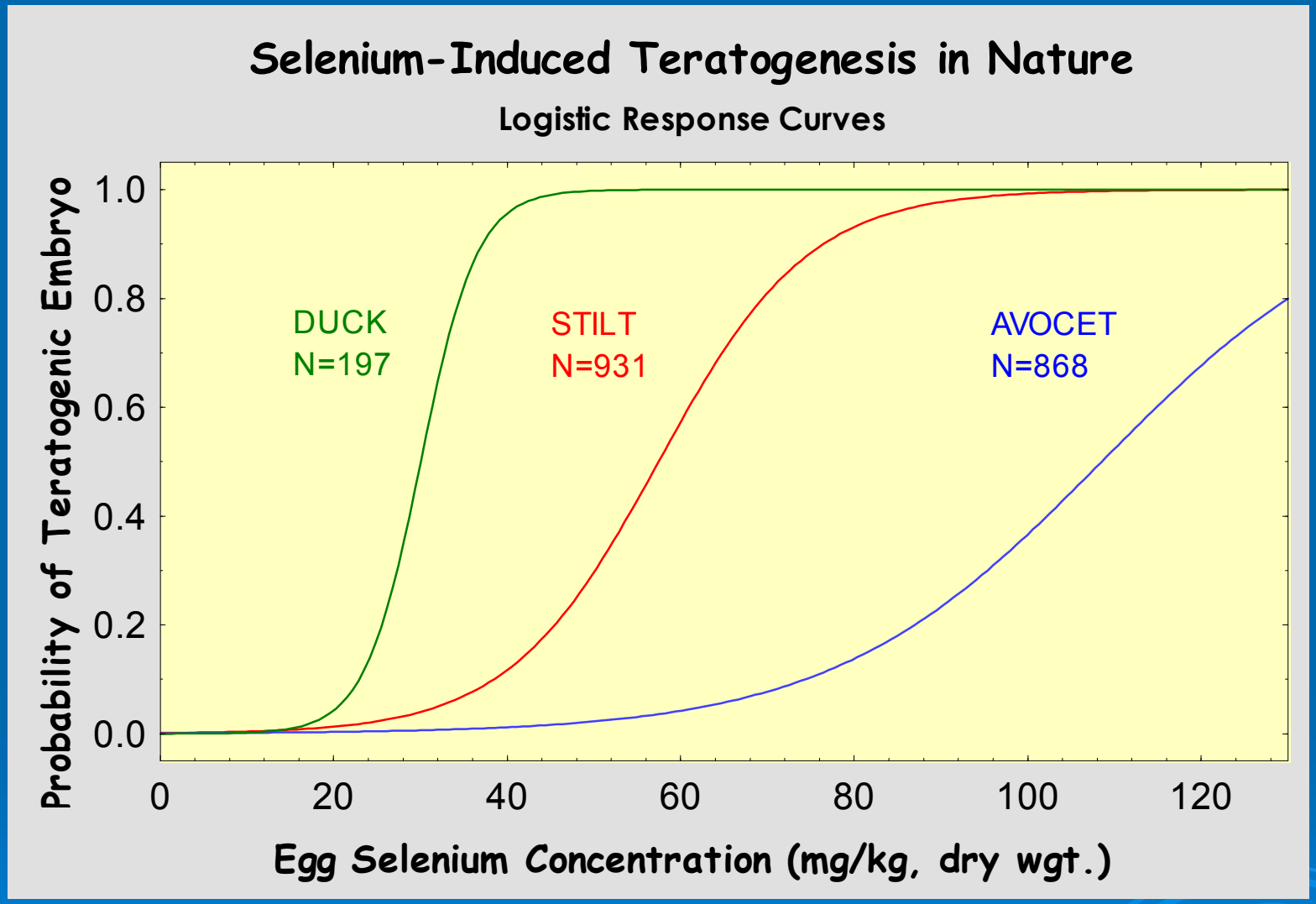


Figure 2. Mallard egg hatchability vs control as a function of selenium concentration in eggs.



Logistic response curves for selenium-induced teratogenesis among black-necked stilt, American avocet, and duck eggs exposed to agricultural drainage water.

TASK 1: Methodology and Background Concentration in Great Salt Lake

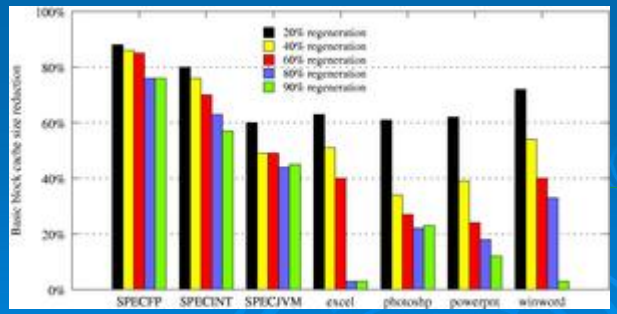
- Determine a Detection Limit for Measuring Selenium for samples taken from the open water of the Great Salt Lake.
- Determine the Concentration of Selenium in the Great Salt Lake

Sunset over the Great Salt Lake

Observable chemocline between the Surface & the Deep Brine Layers of the Great Salt Lake

Laboratory Round Robin Statistical Design

- Two Sample Locations
  - 1 Meter and 7 meters
- Filter in the Field (0.45 micron)
- Triplicate Samples from each depth
- Four Spike levels for each sample
  - 0.1 – 1.0;
  - 1.0 – 5.0;
  - 10-50;
  - 50-100 ug/l Se
- Blanks
- Great Salt Lake Water (1 and 7 meters)



Sample Collection

20 Liter Carboy

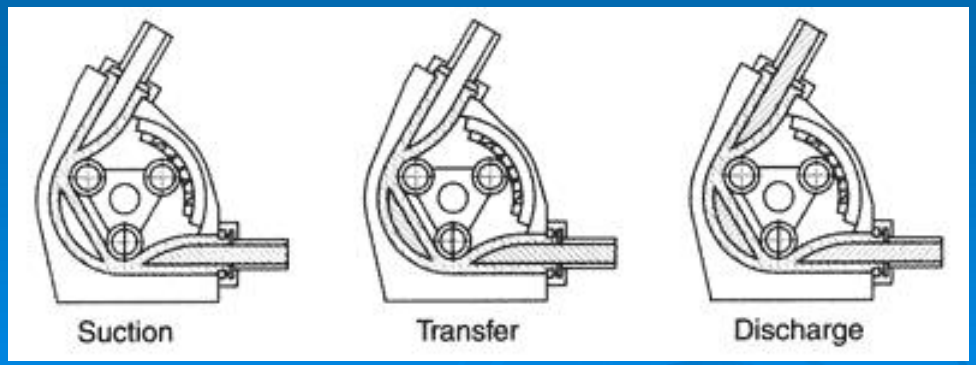
2 from 1 meter

2 from 7 meters

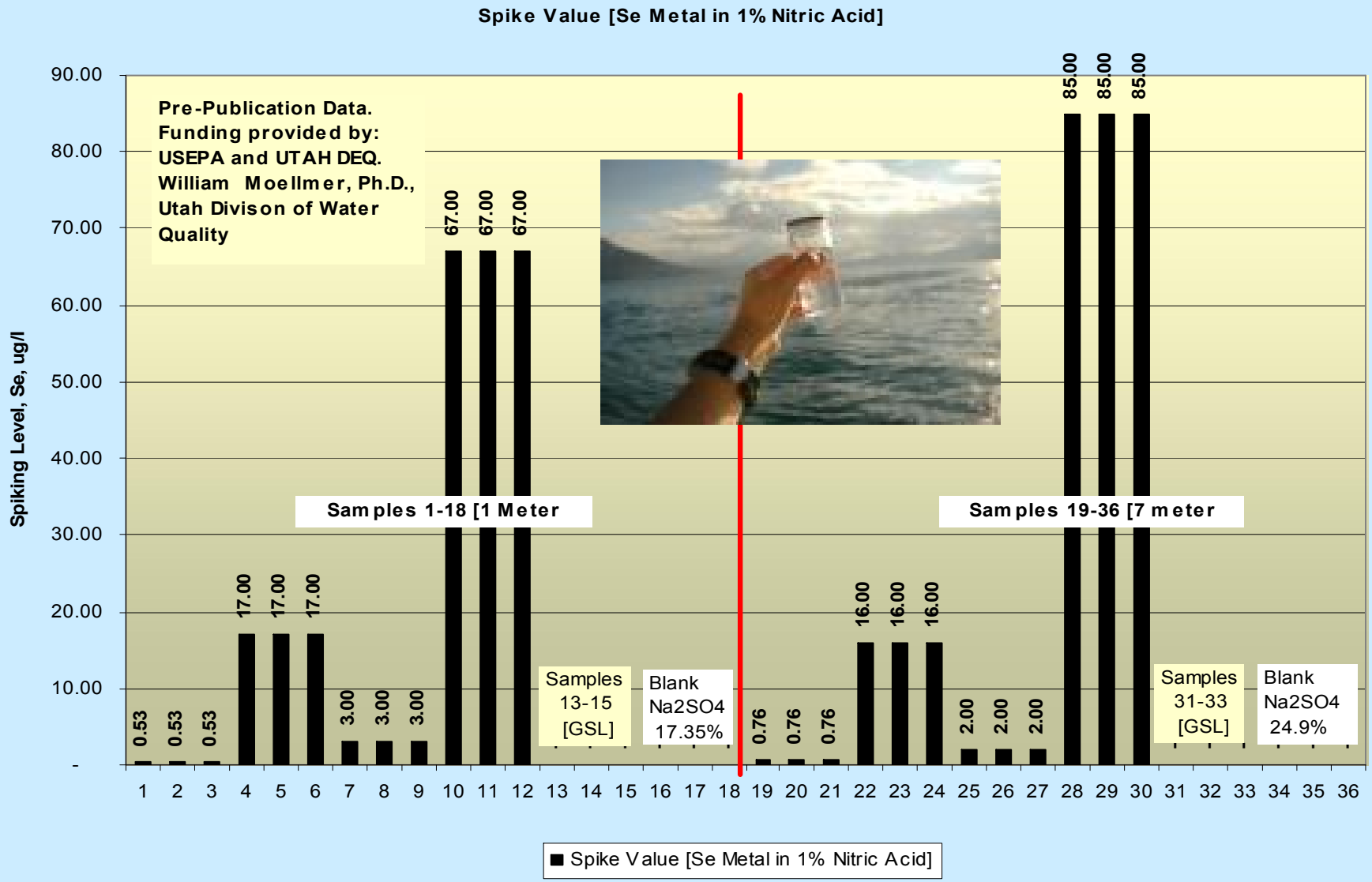
Pumping the “deep brine”.

Tygon Tubing and

Peristaltic Pump



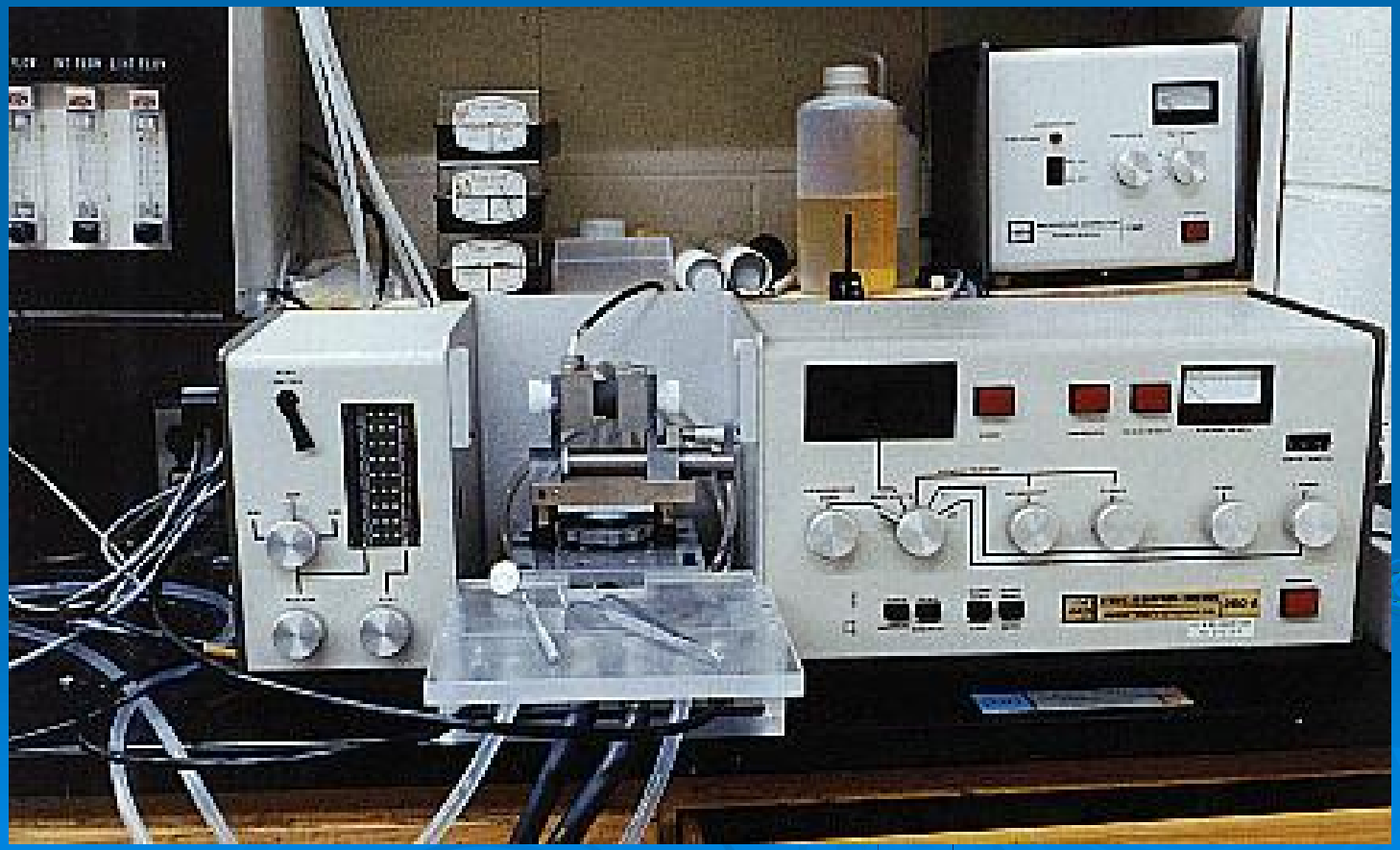
Round Robin Spiking Levels



Laboratories

Laboratories Participating in Round Robin Study	ICPMS	ICPMS with Dynamic Reaction Cell	Hydride Gener-ation	GFAA	ICPMS with Collision Cell
American West (SLC)	X	X		X	
Frontier Geosciences (Seattle)			X		
USGS			X	X	X
Kennecott (SLC)		X	X		
ACZ (Steamboat Spr.)			X		
Agilent Tech. (Seattle)					X
P&E (Los Angeles)		X			

GFAA – Graphite Furnace Atomic Adsorption



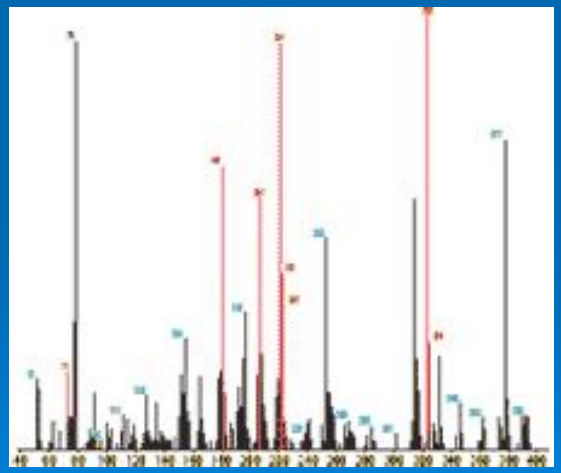
Hydride Generation

ICP-MS

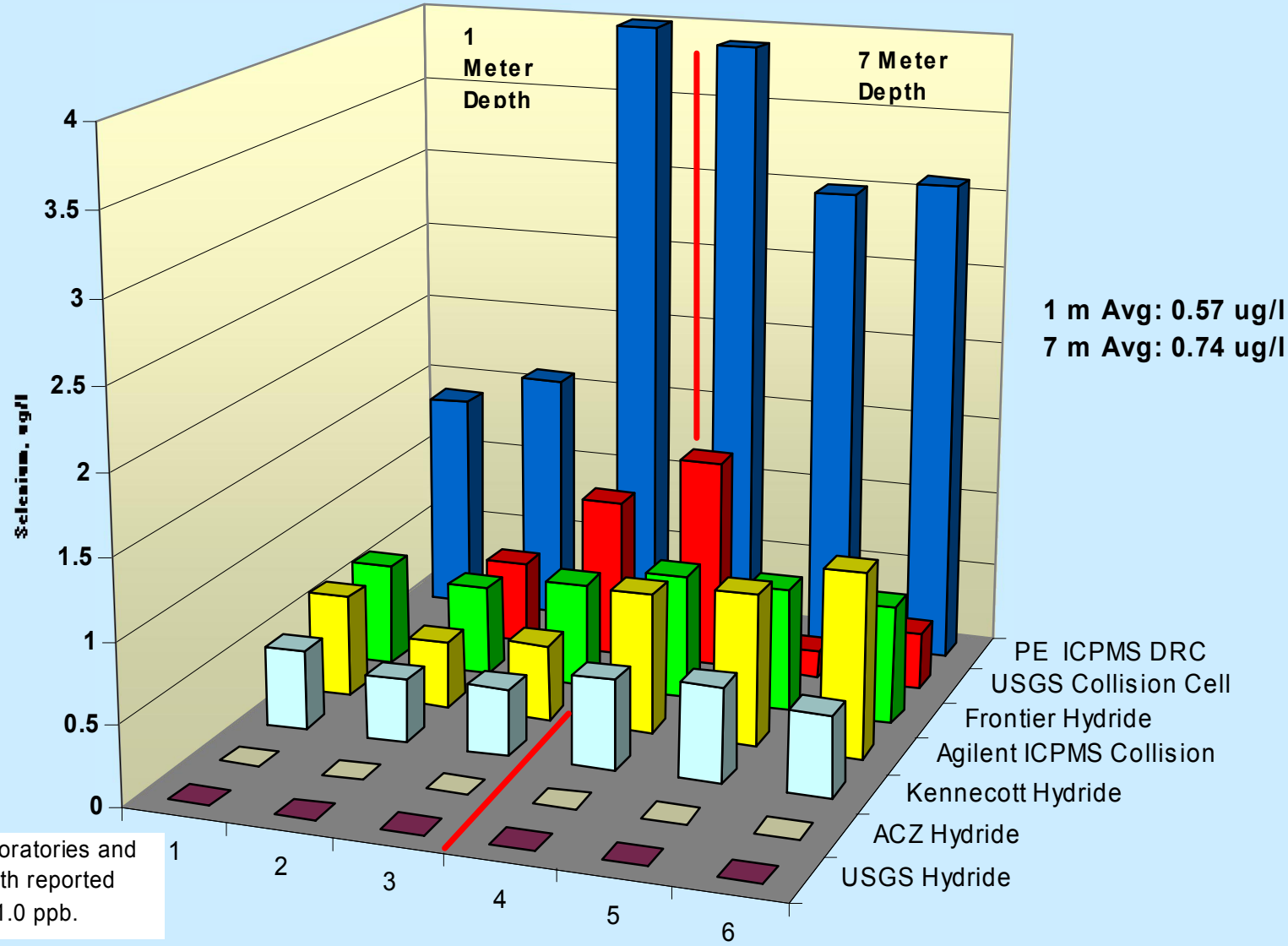
Inductively Coupled Plasma Mass Spectrometer

ICP-MS with Dynamic Reaction Cell (DRC) [P&E]

ICP-MS with Collision Cell [Agilent Technologies]



Concentration of Se in Gilbert Bay @ USGS Site



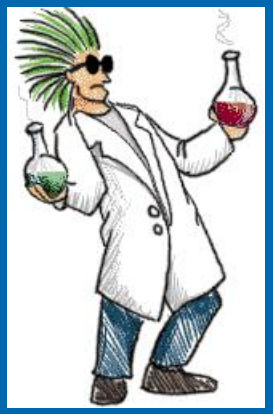
ACZ Laboratories and USGS both reported values <1.0 ppb.

USGS Hydride | ACZ Hydride | Kennecott Hydride | Agilent ICPMS Collision
Frontier Hydride | USGS Collision Cell | PE ICPMS DRC

Steering Committee

- Governmental Representatives
  - Federal
  - State
- Environmental Organizations
- General Public

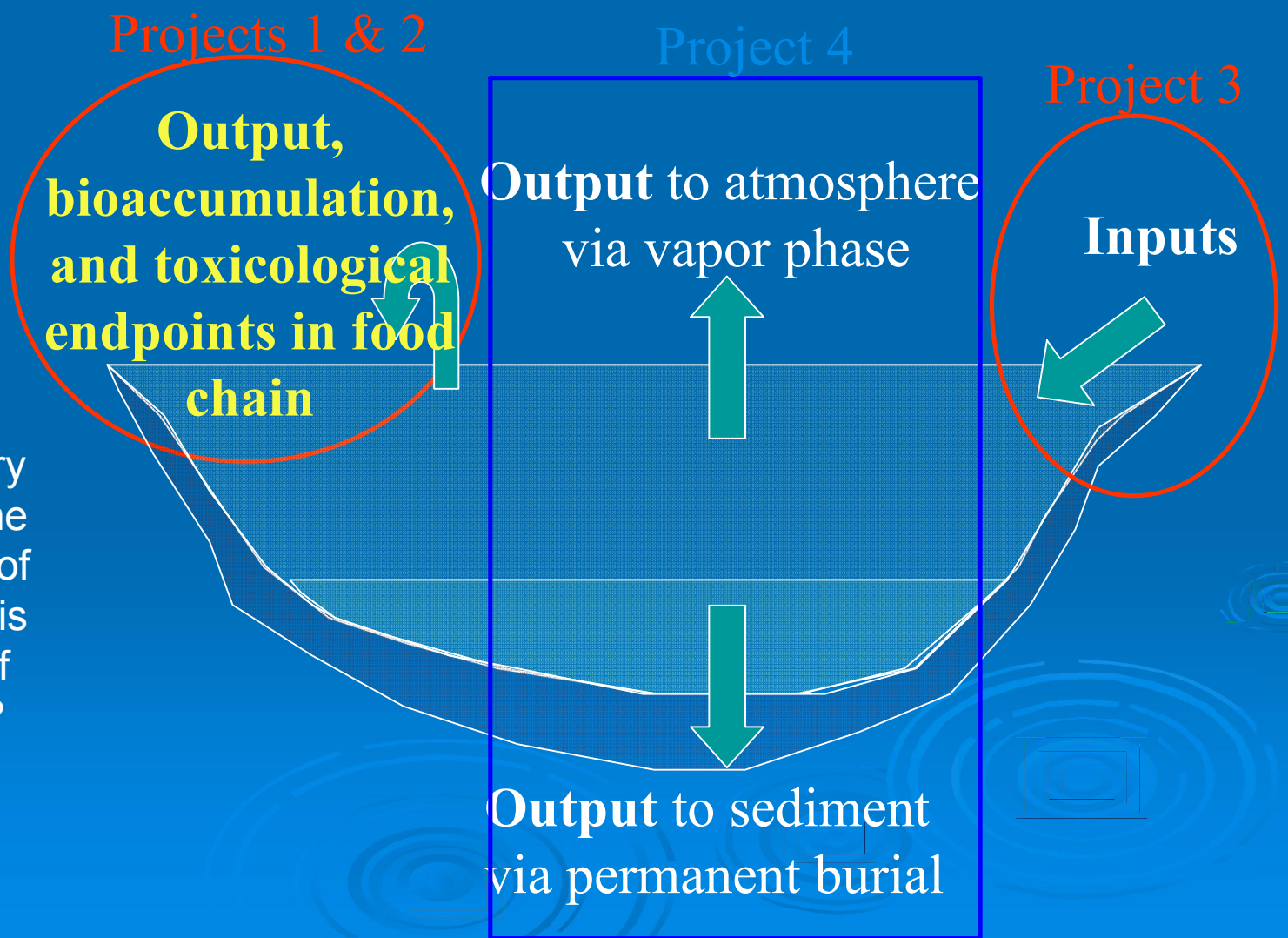
Science Panel



- William Adams, Ph.D., Rio Tinto, Inc.
- Anne Fairbrother, Ph.D., EPA
- Theresa Presser, Ph.D., USGS
- Harry Ohlendorf, Ph.D., CH2M-Hill (Contractor)
- Joseph Skorupa, Ph.D., USFWS
- William Moellmer, Ph.D., Utah DWQ, Chair
- Theron Miller, Ph.D., Utah DWA, Co-Chair
- William Wurethele, EPA Region 8 (Standards Development)
- Brad Marden, Artemia Association (Brine Shrimp Expert)
- Don Hayes, Ph.D., University of Louisiana, Lafayette

Underlined: Nationally known selenium experts.

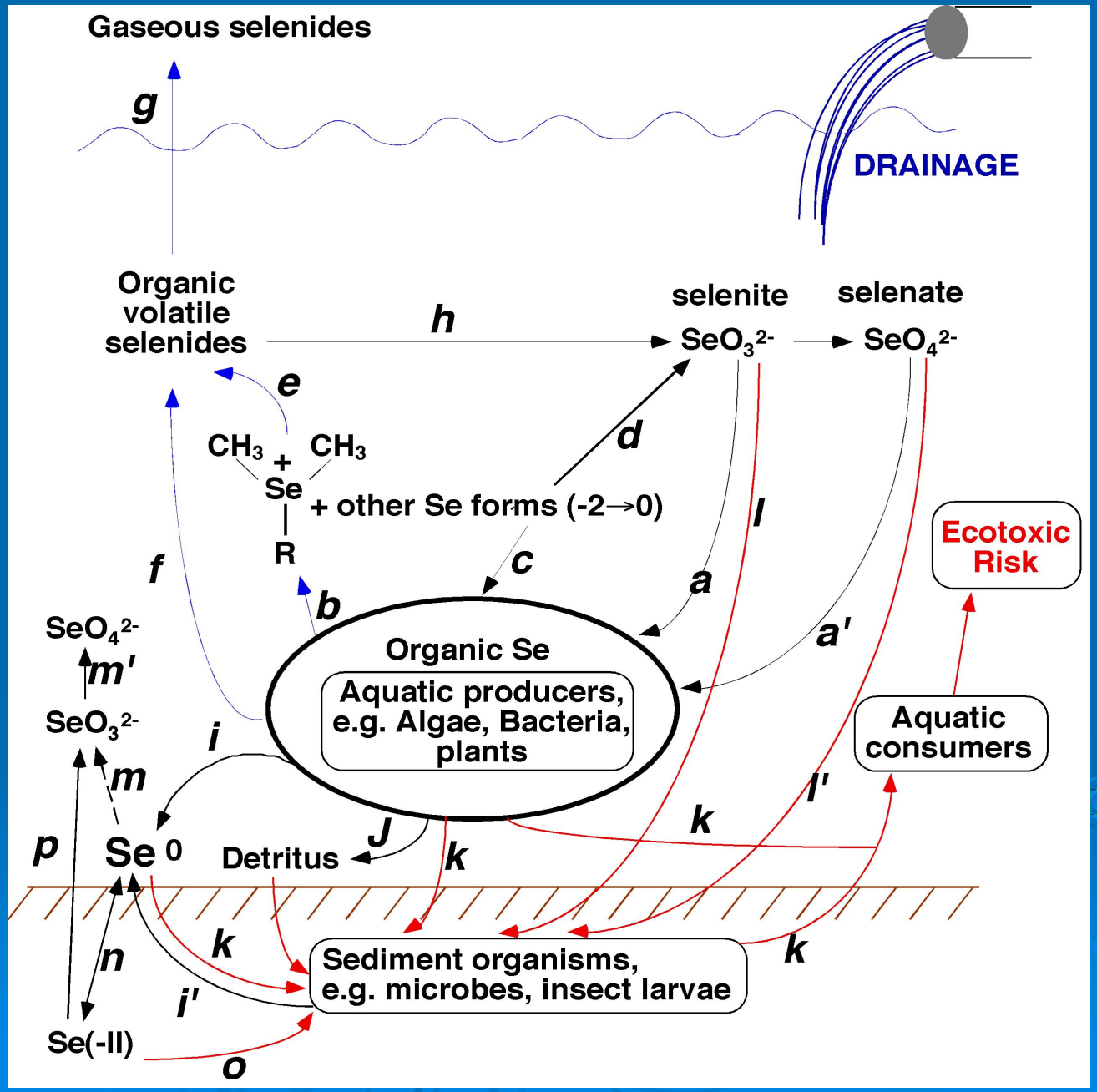
Science Panel Identified Four Projects to Meet Objective



Is the chemistry such as that the concentration of Se in the lake is independent of input sources?

TASK 2: Conceptual Model

Dr. William Johnson



Project 1 – Avian Ecology

Project Objective

- Determine Se flux from bird diet to critical end points by determining ambient selenium concentrations in water, brine shrimp, brine flies, other food items, birds and bird eggs.
- Determine potential selenium effects on critical end points
  - biomagnification
  - reproductive effects
  - tissue burdens & survival

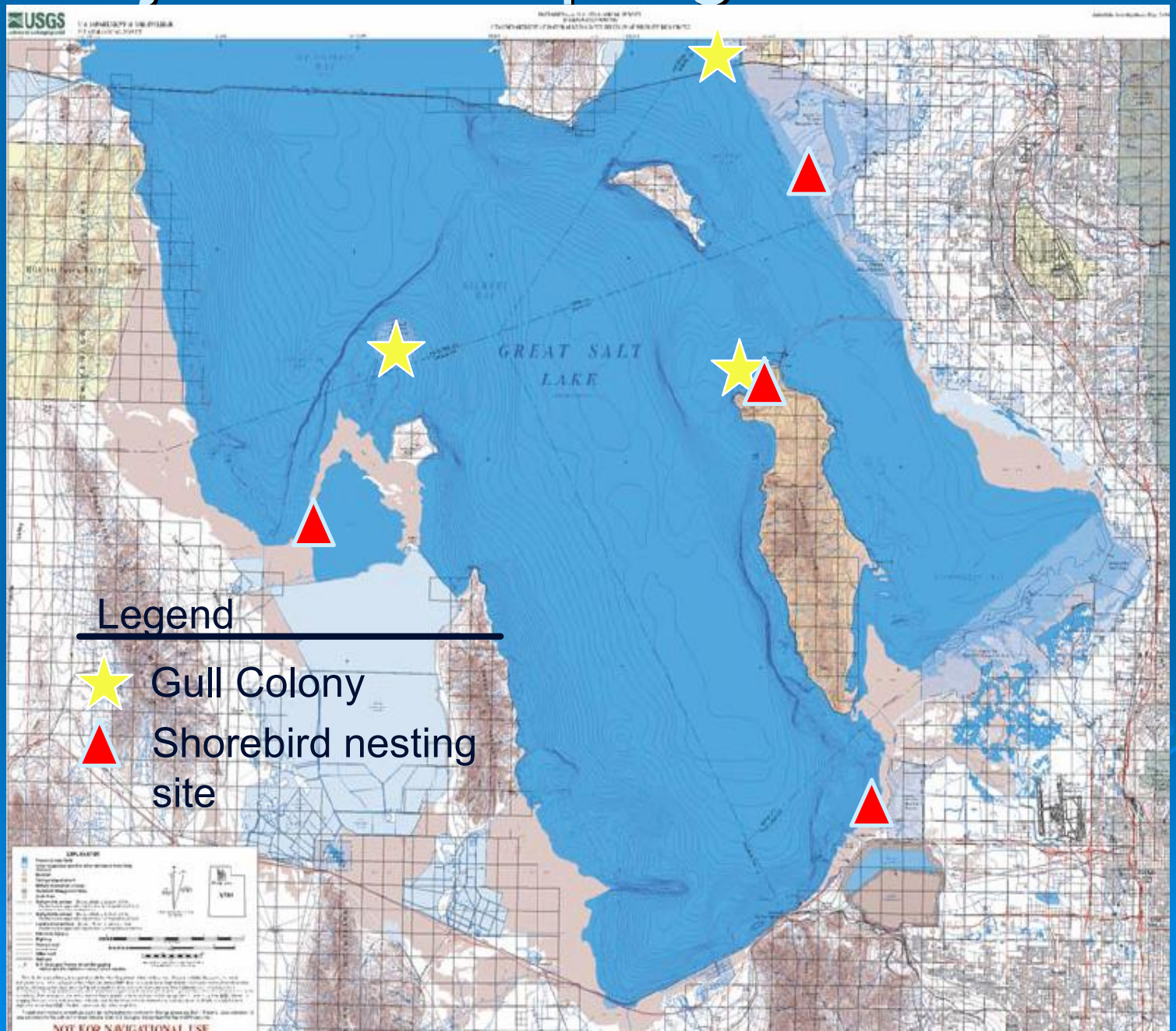
UtahState UNIVERSITY

Michael Conover, PhD [USU]

WEBER STATE UNIVERSITY

John Cavitt, PhD [Weber State]

Project 1: Sampling Locations



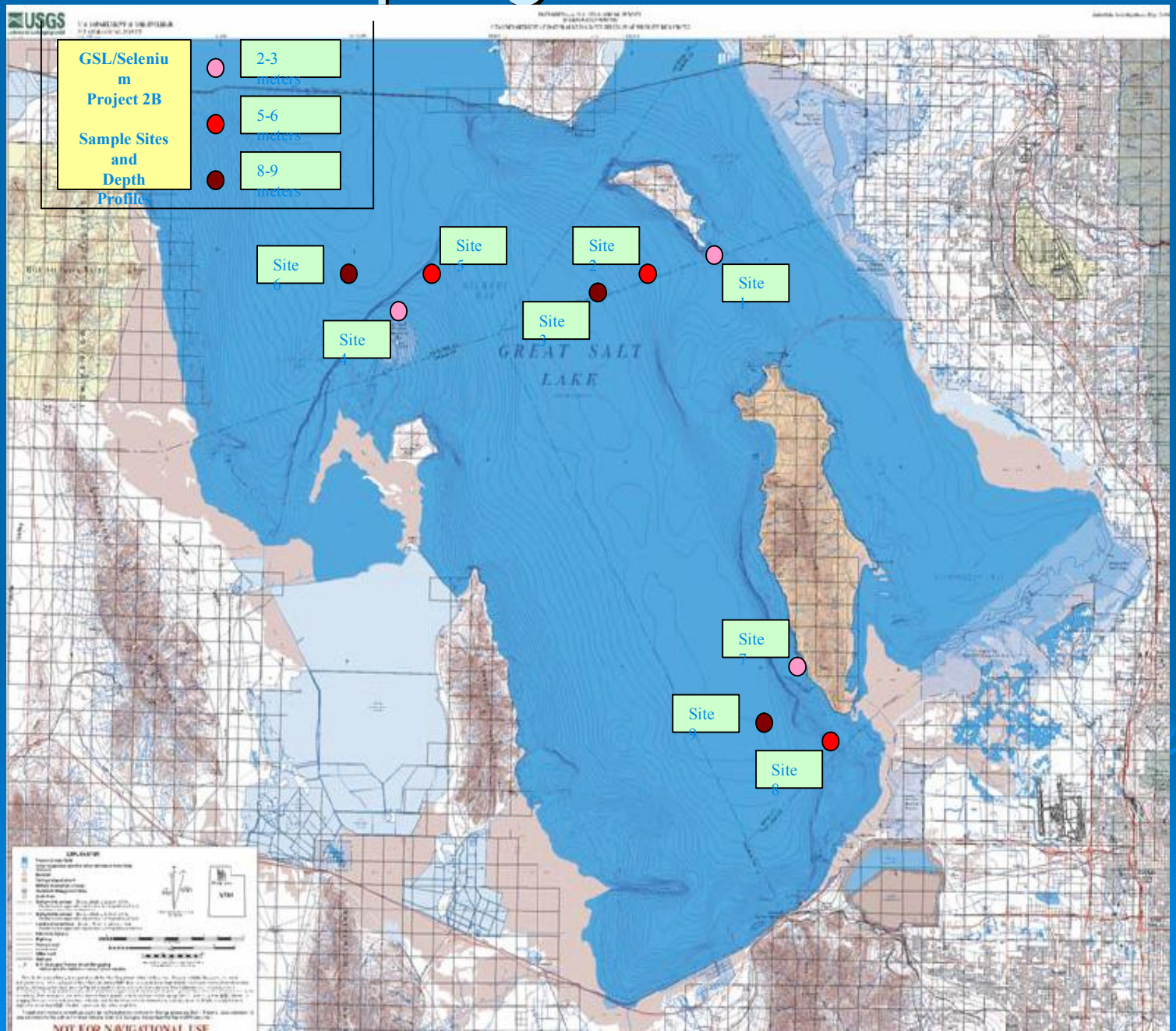
Project 2: Design and Conduct Selenium Concentrations Synoptic Surveys in the Great Salt Lake

- Survey of Se in Periphyton and Brine Shrimp from the Benthic Zone
- Survey of Selenium in Water, Seston (plankton, organic detritus and inorganic particles such as silt) , and *Artemia*
- Determine importance of brine fly & larvae

UtahState UNIVERSITY

Wayne Wurtsbaugh, PhD [USU]
Brad Marden [Parliament Fisheries]

Sampling Locations



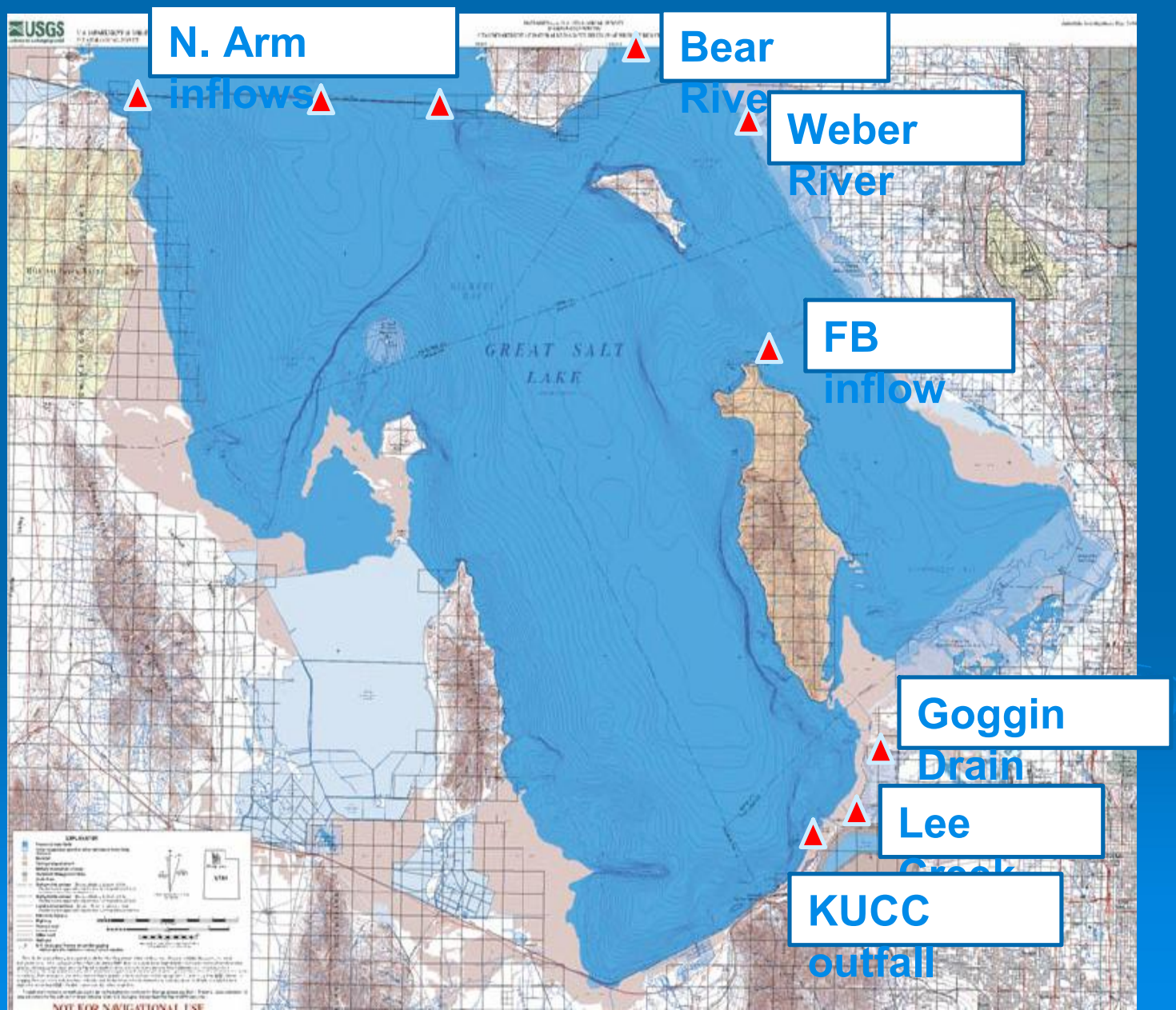
Project 3 – Selenium Inputs

Project Objective

- Measure discharge and Se loads from various sources to open waters of the Great Salt Lake
- Understand inputs to the ecosystem.

Dave Naftz, PhD
[USGS]
Bill Johnson, PhD
[UofU]

Gage Locations



Project 4 – Study of Selenium Flux

Project Objective

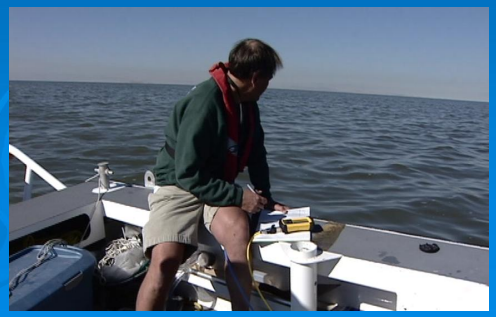
- Are volatilization and ebullition (bubbling) significant release mechanisms for Se from the GSL?
- Is Se stored in sediment and do mixing events re-mobilize the Se?
- Does changing water elevation/lake area re-introduce Se into the water column?

THE UNIVERSITY OF UTAH

Bill Johnson, PhD [UofU]

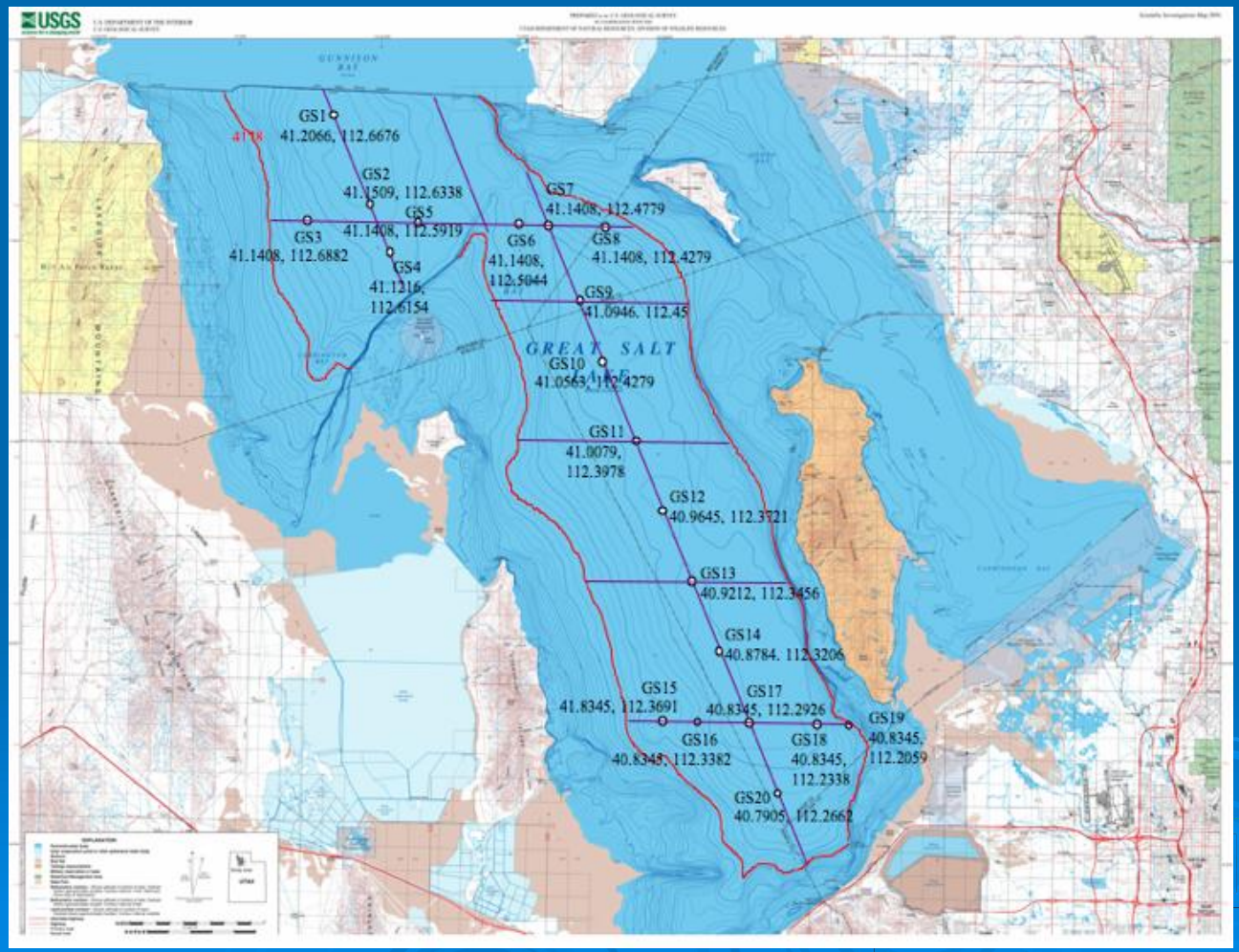
USGS science for a changing world

•Dave Naftz, PhD [USGS]



Project 4 – Se in Vapor/Sediment

Total Dissolved Gas sampling locations



Two Grand Questions

In the grand scheme of things, is the water column concentration of selenium in the Great Salt Lake (~0.7 ug/L) in equilibrium?

Is the selenium concentration in the Great Salt Lake independent of its input sources?

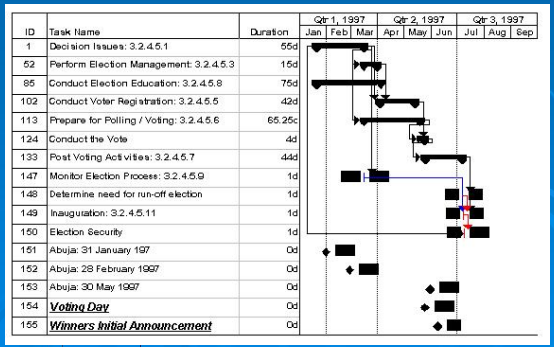
Program Support Task

Project Tasks

1. Planning and Design
2. Coordination/Management
3. Technical Oversight
4. Establish Data Quality Objectives
5. Quality Assurance/Data Management

Project Schedule

- Project 1: 4/2006 - 5/2007
- Project 2: 4/2006 – 11/2006
- Project 3: 3/2006 – 5/2008
- Project 4: 6/2006 – 5/2007
- **Water Quality Standard Recommendation December 2007**



ID	Task Name	Duration
1	Decision Issues: 3.2.4.5.1	55d
52	Perform Election Management: 3.2.4.5.3	15d
85	Conduct Election Education: 3.2.4.5.8	75d
102	Conduct Voter Registration: 3.2.4.5.5	42d
113	Prepare for Polling / Voting: 3.2.4.5.6	65.25c
124	Conduct the Vote	4d
133	Post Voting Activities: 3.2.4.5.7	44d
147	Monitor Election Process: 3.2.4.5.9	1d
148	Determine need for run-off election	1d
149	Inauguration: 3.2.4.5.11	1d
150	Election Security	1d
151	Abuja: 31 January 197	0d
152	Abuja: 28 February 1997	0d
153	Abuja: 30 May 1997	0d
154	***Voting Day***	0d
155	***Winners Initial Announcement***	0d

Project Costs

Studies and Project Management	**$1,633,000**
USGS Matching Funds	***$124,000***
Total Cost	**$1,757,000**

Great Salt Lake Water Quality Studies Science Panel

Conference Call: May 22, 2007
Science Panel Meeting: July 30-31, 2007
Division of Water Quality Offices

Questions?