Running Head: Site-Specific Water Quality Standard for Selenium

Author to whom copyright and page proofs should be sent:

Kevin V. Brix
EcoTox
2001 NW Nye Street
Newport, Oregon 97365
Tel: (541) 574-9623
Fax (541) 574-9490
E-mail: Ecotox@aol.com

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DERIVATION OF A SITE-SPECIFIC WATER QUALITY STANDARD FOR SELENIUM IN THE GREAT SALT LAKE, UTAH

Kevin V. Brix,† David K. DeForest, ‡ Rick D. Cardwell, § William J. Adams, ‖

†EcoTox, 2001 NW Nye Street, Newport, Oregon 97365

‡Parametrix, Inc., 5808 Lake Washington Blvd. NE, Suite 200, Kirkland, Washington 98033

§Parametrix, Inc., 1600 SW Western Blvd., Suite 165, Corvallis, Oregon, 97333

‖Kennecott Utah Copper, 8315 West 3595 South, P.O. Box 6001, Magna, Utah 84044

22 Corresponding Author: Ecotox@aol.com

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ABSTRACT

The purpose of this study was to develop a site-specific water quality standard for selenium in the Great Salt Lake, Utah. The study examined the direct bioavailabilty and toxicity of selenium, as selenate, to biota resident to the Great Salt Lake and the potential for dietary selenium exposure to aquatic dependent birds that might consume resident biota. Because of its high salinity, the lake has limited biological diversity with bacteria, algae, diatoms, brine shrimp and brine flies being the only organisms present in the main (hypersaline) portions of the Lake. To evaluate their sensitivity to selenium, a series of acute and chronic toxicity studies were conducted on brine shrimp, *Artemia franciscana*, brine fly, *Ephydra cinerea*, and a hypersaline alga, *Dunaliella viridis*. The resulting acute and chronic toxicity values indicated that resident species are more selenium tolerant than many freshwater species. This is thought to result in part to the lake's high ambient sulfate concentrations (>5,800 mg/L), as sulfate is known to reduce selenate bioavailability. The acute and chronic test results were compared to selenium concentrations expected to occur in a mining effluent discharge located at the south end of the lake. Based on these comparisons, no appreciable risks to resident aquatic biota were projected. Field and laboratory data collected on selenium bioaccumulation in brine shrimp demonstrated a linear relationship between water and tissue selenium concentrations. Applying a dietary selenium threshold of 5 mg/kg dw for aquatic birds to this relationship resulted in an estimate of 27 µg/L Se in water as a safe concentration for this exposure pathway and an appropriate site-specific water quality standard.

Key Words: Selenium Site Specific Water Quality Standard Great Salt Lake

INTRODUCTION

The Great Salt Lake (GSL) is the fourth largest terminal lake in the world [1] and the largest hypersaline lake in North America [2]. In 1957, the Southern Pacific Railroad Company constructed a rock-filled causeway across the lake, dividing it into two arms. Although culverts link the two arms, they are insufficient to maintain mixing between them. Consequently, the GSL essentially consists of two lakes, each with varying salinity and dominant organisms. Approximately 92 percent of freshwater inputs enter the southern arm [3], resulting in the northern arm being more saline (approximate salinity 330 g/L) than the southern arm (approximate salinity 100 g/L).

The food web of the southern arm of the GSL is relatively simple because few organisms can tolerate its high salinity and low oxygen solubility [4, 5]. The aquatic food web consists of at least four species of bacteria (mainly *Halobacterium* and *Halococcus*), up to 20 species of algae (mainly *Dunaliella viridis* and *D. salina*), at least 17 diatom species, brine shrimp (*Artemia franciscana*), and seven species of brine flies (*Ephydra* spp.). Additionally, in areas near significant freshwater inputs where the salinity is less than <75 g/L, corixids (*Trichocorixa verticalis*), rotifers (*Brachionus* sp.) and two species of copepods (*Cletocampus albuquerquensis* and *Diaptomus connexus*) have been observed [2, 5-8]. The abundance of these taxa fluctuates with season and salinity [1].

Because of the high salinity, no fish occur in the lake except in freshwater estuaries near the Bear, Jordan and Weber Rivers. This lack of aquatic predators, in turn, can lead to extraordinarily high densities of brine shrimp and brine flies, which are an important food source for resident and migratory birds. The lake and its surrounding

wetlands is an important stop-over point for migratory shorebirds and waterfowl. Greater than 75% of the West's population of tundra swans (*Cygnus columbianus*), 50% of the continent's Wilson's phalaropes (*Phalaropus tricolor*), 25% of the continent's northern pintails (*Anas acuta*), the world's largest nesting population of California gulls (*Larus californicus*), and millions of other waterfowl use the lake during their annual migration periods.

The eastern and southeastern shorelines of the lake's southern arm are bordered by the Salt Lake City metropolitan area. Among the industries bordering the lake are the smelting and refining facilities for a copper mine. The major constituent of this facility's wastewater discharge is selenium, with concentrations as high as 300 µg/L Se having been measured historically. Current selenium discharge levels are approximately 20-50 µg/L before dilution. The majority (>95%) of this Se is in the form of selenate and unless otherwise noted, all discussion of Se in this paper is referring to selenate. The effluent is considerably less saline (5 g/L) than the lake creating creating a small estuarine zone in the immediate area of the discharge.

The outfall discharge has cut a channel 2-4 feet deep in the lake sediments immediately offshore. Water depth surrounding the channeled area averages approximately 8-18 inches. Lake sediments consist of well-compacted silty, sandy clays. Sediments in the channeled area are less compacted and composed of finer material. Dense stands of *Phragmites* sp. have established along the banks of the channel, stabilizing it. Over time, deposition of fine sediments and organic material and continued colonization by *Phragmites* has effectively extended the channel approximately 1,500 feet out into the lake (Figure 1). The water depth and velocity, along with the dense

Phragmites, effectively limits shorebird use in the channel proper, but they are routinely observed to feed along the shorelines on either side of the channel.

Because of its unique water quality characteristics and biota, generic water quality criteria do not apply to the GSL [9], and historically very little toxicity data has been generated for the lake's resident species. Hence, the appropriate water quality standard for Se in the GSL is unclear. Additionally, unlike most other metals and metalloids, the diet typically represents the most important exposure pathway for Se, with top trophic level consumers (e.g., fish and aquatic-dependent birds) being the most sensitive environmental receptors in an aquatic system [10, 11]. Consequently, any site-specific water quality standard for selenium must consider exposure via both water and dietary pathways. This study was designed to evaluate potential exposure and effects from Se discharges to the lake via both pathways through a series of laboratory and field studies on resident species. Study results were then used to develop an appropriate site-specific water quality discharge limit.

METHODS AND MATERIALS

Given that Se may cause either direct effects on aquatic biota resident to the lake or the resident biota may accumulate Se to deleterious levels for organisms that consume them, both pathways needed evaluation in order to propose an appropriate site-specific water quality standard (Figure 2).

To evaluate the potential for direct effects on resident aquatic biota, we conducted toxicity tests on brine shrimp, larvae of the brine fly, *Ephydra cinerea*, and the most

common alga in the southern arm of the lake, *Dunaliella viridis*. This species is a principal food source for brine shrimp. Acute testing was conducted using brine shimp and brine fly larvae and chronic testing was conducted using *Dunaliella viridis* and brine shrimp. The chronic sensitivity of brine flies was not investigated because of their extreme insensitivity when tested acutely.

To evaluate the potential for avian toxicity arising from the dietary pathway, Se concentrations in brine shrimp were measured in specimens collected within and adjacent to the mine discharge, as well as at background Se concentrations in the lake. These data were then compared to appropriate dietary thresholds for aquatic dependent birds.

Toxicity Testing

Acute Testing

The methods used for conducting the acute tests were consistent with those described in U.S. EPA [12], although parameters such as dilution water and test volume were modified to meet species-specific requirements. Tests were static non-renewal studies conducted at 25 ± 1 °C with five test concentrations and a control. Dilution water for the acute tests was GSL water collected from the shoreline on the north side of Antelope Island, a location well removed from anthropogenic inputs to the lake. Conventional water quality parameters were measured in the dilution water prior to testing (Table 1).

Reagent grade sodium selenate (CAS #13410-01-0) obtained from Sigma Chemical Company, St. Louis, Missouri was used to create stock solutions. For the brine shrimp study, a 10 g/L stock solution was prepared by adding 23.9 g of sodium selenate to 1 L of deionized water. The extreme insensitivity of brine fly larvae prevented preparation of a single stock solution. Instead, the sodium selenate was added directly to 5 L batches of dilution water in order to achieve the desired nominal test concentrations.

The brine shrimp test was initiated with nauplii <24 hours old that were hatched overnight at 25 °C in 25 g/L artificial seawater. Nauplii were not acclimated to the dilution water salinity (82 g/L) prior to testing. This treatment reflects natural conditions where cysts hatch in the relatively low salinity lens of water on the lake surface and then drop down in the more saline water column. Nauplii were randomly introduced to exposure chambers (600 mL beakers with 400 mL of test solution) for each of the five treatments and control. Four replicates were conducted with each treatment. Preliminary testing indicated brine shrimp required daily feeding to achieve acceptable control survival and so were fed daily 2 mL of a 500,000 cells/mL stock of the marine algae *Platymonas* sp.

Brine fly larvae were collected for testing from White Rock Bay on the north shore of Antelope Island. Larvae were identified to species by Chadwick and Associates in Littleton, Colorado. Test organisms were held in GSL water in 40 L aquaria at 12 °C for eight weeks prior to testing. During holding 40 mL of 3.5 x 10^6 cells/mL solution of *Dunaliella viridis* were added weekly to the aquaria. Forty-eight hours prior to testing, larvae were acclimated to the test temperature of 25 °C. Four replicate 1 L beakers with

800 mL of test solution were tested at each Se concentration. Test organisms were not fed during testing.

Chronic Testing

The methods for conducting the chronic brine shrimp life-cycle test were previously described in Brix et al. [13]. Briefly, this 28-day test measured survival, growth and reproduction of the parental generation, and survival and growth of the F_1 generation. The test was conducted under intermittent flow-through conditions beginning with brine shrimp nauplii <24 hours old. After 11 days, brine shrimp matured sexually and began pairing for mating. At this time, they were thinned by collecting and weighing (dry) a random subsample from each test concentration. Six adult pairs for each test concentration were then monitored for reproduction until day 28 when surviving shrimp were measured for dry weight. For each test concentration, randomly selected nauplii (F_1 generation) from the pairs were subjected to the same conditions as the parental generation for 11 days, with survival and dry weight being monitored for comparison with the parental generation.

The experimental design for the algae toxicity test followed U.S. EPA [14] and EU [15], except for the dilution media, which was GSL water passed through a 1 µm filter. In this test, 1×10^4 cells of *D. viridis* from a culture in log-phase growth were inoculated into 125 mL test flasks with 50 mL of test solution. Test flasks were placed on a shaker table rotated at 100 cpm. Each test concentration consisted of 16 replicates and every 24 hours, four of the replicates were terminated, whereupon water quality was

monitored and cell densities measured using a Hach 300 spectrophotometer. The spectrophotometer was calibrated against known cell density stocks of *D. viridis*.

Analytical Chemistry

For all tests, water quality parameters (temperature, salinity, pH and dissolved oxygen) were measured daily in one replicate of each treatment and control. Samples from each concentration were collected for Se analysis at test initiation and termination using the hydride generation method of Cutter [16]. The exception to this sampling regime was the chronic brine shrimp study where samples were collected on a weekly basis.

Data Analysis

For the acute brine fly and brine shrimp tests, statistical analyses were conducted using the statistical computer package Toxis® [17] to estimate the LC50 and its 95% confidence interval, as well as the no observed effect concentration (NOEC) and lowest observed effect concentration (LOEC). The NOEC and LOEC were determined by Steel's many-one rank test and the LC50 was estimated by probit analysis.

The statistical evaluation of the chronic brine shrimp results included testing for differences between the treatments and controls at reproductive pairing (Day 11), Day 21 and Day 28 by parametric or non-parametric methods depending on whether data met normality and homogeneity assumptions. If the data met the assumptions of normality

and homogeneity, an ANOVA was computed to determine whether any differences existed among levels (concentrations or generations). If either of the assumptions could not be met, the non-parametric Kruskal-Wallis test was used to test for differences. The statistics were calculated using Statgraphics [18].

For the chronic algae tests, statistical analyses for the NOEC and LOEC were conducted using SPSS [19] in accordance with procedures described in EU [15]. Specific growth rate and cumulative area under the curve were calculated for each replicate, as were summary statistics for each time period. The statistical computer package Toxis® [17] was used to estimate the EC50 value and the 95% confidence interval based on results from specific growth rate and cumulative area under the growth curve calculations.

Field Bioaccumulation Study

In order to evaluate the potential for Se in the mining effluent to bioaccumulate in aquatic organisms that might be fed upon by migratory shorebirds, a field program was implemented to sample water and co-located brine shrimp at various locations relative to the mining effluent discharge (Figure 1). Two sampling events (June and August) were undertaken to characterize Se concentrations in water and biota. However, because brine shrimp were not found at most stations in the discharge channel during the August sampling event, only results for the June sampling event and a single sampling station (station 7) with brine shrimp present during the August sampling event are presented.

Surface samples were collected because preliminary sampling efforts indicated the majority of brine shrimp occurred in the upper water column. Water depth along the

sampling transect varied from 0.5 to 1.5 meters. Water samples were collected using a battery-powered peristaltic pump using methods consistent with U.S. EPA [20]. Samples were collected within the channel midway between the banks wherever possible.

When present, brine shrimp were collected at the same time and place as water samples to evaluate the relationship between water and tissue Se concentrations. Brine shrimp were collected using a dip net with a 15 x 30 cm basket constructed of 500 μm Nitex™ screen. The dip net was slowly trawled through the water column approximately 15 cm below the water surface until the net contained sufficient specimens (5 g wet weight) for analysis.

Total recoverable and dissolved Se were measured in water samples at the Kennecott Environmental Laboratory using the hydride generation method of Cutter [16] with an analytical detection limit of 2 μg/L Se. Total selenium was determined on the tissue digestate by hydride generation – atomic fluorescence spectrometry. A total reduction/oxidation digestion, converting all forms to selenium (IV) was accomplished by boiling the digested sample in 4M HCl with potassium persulfate. The analytical detection limit in tissues was 0.5 mg/kg dw.

RESULTS

Toxicity Testing

Well defined concentration-response relationships were observed for all of the studies. For the acute brine fly study, an LC50 of 495 mg/L Se was estimated. The brine

252 shrimp LC50 of 78 mg/L indicated it was substantially more sensitive than the brine fly
253 (Table 3). In the chronic *D. viridis* study, EC50s of 45 and 32 mg/L were observed for
254 the specific growth and area under the curve endpoints (Table 4). The NOEC was 11
255 mg/L for both endpoints. A number of different endpoints were evaluated in the chronic
256 brine shrimp study. Day 11 growth of the parental generation and Day 21 reproduction
257 were comparable and the most sensitive endpoints evaluated. For both, the NOEC was 3
258 mg/L Se and the LOEC 8 mg/L Se (Table 5). Overall, these two endpoints for the brine
259 shrimp were also the most sensitive of any endpoint and species evaluated.

260 Water quality parameters were within expected ranges for all studies (Table1).
261 Measured dissolved oxygen concentrations (1.8-6.0) mg/L require a brief discussion, as
262 the values are lower than what is typically considered acceptable in toxicity tests. The
263 low dissolved oxygen values measured during testing are a result of the hypersalinity of
264 the test solutions, which limits oxygen solubility. Dissolved oxygen saturation at these
265 salinities ranges from 3.6 to 5.0 mg/L depending on salinity and test temperature
266 (supersaturated values were measured in the study with *D. viridis* as will typically occur
267 in algal assays). Hence, the measured values in the tests were typically >60% saturation,
268 as is customary for toxicity tests. For comparison, the southern arm of the GSL has a
269 dissolved oxygen saturation of 2.0 mg/L, which is lower than noted above because the
270 lake is at an elevation of 4,200 feet [8], whereas the tests were performed in a laboratory
271 at sea level. Hence, the dissolved oxygen concentrations in these tests are characteristic
272 of what these organisms normally encounter in the environment. Selenium test
273 concentrations stayed relatively constant for all tests with coefficients of variation in test
274 concentrations ≤20% for all treatments in all studies.

Field Bioaccumulation Study

In the June sampling event, surface water Se concentrations generally decreased with distance from the outfall. Near the mouth of the outfall (Station 1) concentrations were as high as 120 μg/L Se, but declined relatively rapidly to background concentrations (2 μg/L Se) at Station 5 and beyond. Total recoverable and dissolved Se were essentially equivalent at all stations. This is expected for Se discharges in the form of selenate, as it does not readily adsorb to suspended solids [21, 22].

Consistent with water concentrations, Se in brine shrimp from the June sampling event was highest near the outfall mouth, with concentrations as high as 15 mg/kg dw (Table 6). Also consistent with waterborne Se data, brine shrimp tissue concentrations dropped relatively rapidly to background (2-3 mg/kg dw) beginning at Station 4. The single station (station 7) sampled in August also resulted in background Se concentrations in brine shrimp tissue.

DISCUSSION

Toxicity Studies

The current U.S. EPA acute and chronic water quality criteria for Se in freshwater systems are 20 and 5 μg/L [23]. However, U.S. EPA has recently proposed a revised criterion in which the acute criterion for selenate is 185 μg/L and the chronic criterion is

298 based on a tissue residue concentration in fish [24]. In comparison, the lowest acute and
299 chronic toxicity values measured for biota resident to the GSL were one to two orders of
300 magnitude higher than the proposed acute criterion. However, as discussed below, a
301 close examination of the data indicates resident biota are actually average in sensitivity
302 relative to other freshwater species that have been tested. We make these comparisons
303 not as an argument that the freshwater water quality criteria is appropriate for the GSL,
304 but simply to understand why biota resident to the GSL may appear to be relatively
305 insensitive to Se.

306 The primary factor causing GSL biota to appear relatively insensitive is the effect
307 of ambient sulfate concentrations on selenate bioavailability. It is well recognized that
308 sulfate reduces selenate bioavailability to a variety of organisms, including algae,
309 bacteria, midges, daphnids and brine shrimp [25-30]. Brix et al. [31] quantified this
310 relationship by summarizing available data and conducting additional studies with
311 amphipods, daphnids and fish. They then developed a log-linear relationship similar to
312 that derived for hardness and divalent cationic metals to normalize for selenate
313 bioavailability as a function of ambient sulfate concentrations. This relationship is
314 important when evaluating the toxicity data in this study because the ambient sulfate
315 concentration in the GSL is 5,800 mg/L, high enough to significantly reduce selenate
316 bioavailability.

317 When the high ambient sulfate concentration of the GSL is considered, the
318 relative acute sensitivity of brine shrimp and brine flies is comparable to many freshwater
319 species. When the acute data from this study are plotted with available acute data and all
320 data normalized for ambient sulfate concentrations, brine shrimp and brine flies rank at

the 29th and 63rd percentiles of the species sensitivity distribution (Figure 3). The acute brine shrimp data derived in this study are largely consistent with a previous study by Forsythe et al. [25], who estimated 96hour LC50s of 1.4 and 82 mg/L Se at ambient sulfate concentrations of 50 and 14,000 mg/L, respectively.

Similar to results for the acute studies, the effect levels from the chronic *D. viridis* study are considerably higher than observed for other algal species that have been tested with selenate, although the amount of data available are relatively limited. For example, selenate chronic values for the freshwater green algae *Selenastrum capricornutum* and *Scenedesmus obliquus* are in the range of 0.1-0.3 mg/L Se [32], compared with 14 mg/L Se obtained for *D. viridis* in this study. While selenate toxicity to algae is also sulfate dependent [30], the *D. viridis* study was conducted in an artificial media with a sulfate concentration of only 195 mg/L. Normalizing this value to 50 mg/L sulfate (generally comparable to standard freshwater algal test media) only lowers the estimated chronic value for *D. viridis* to 6.3 mg/L. Hence, *D. viridis* appears to be substantially less sensitive than freshwater green algae that have been previously tested.

In the chronic brine shrimp study, growth of the parental generation on Day 11 and reproduction on Day 21 were the two most sensitive endpoints, with both endpoints having a NOEC of 3 mg/L and LOEC of 8 mg/L Se. Hence, the chronic value for this study is the geometric mean of the NOEC and LOEC, 5 mg/L. Published data on the chronic sensitivity of other invertebrate species to selenate are limited to an LOEC of >0.7 mg/L for the amphipod *Hyalella azteca* [33].

Overall, the sensitivity of resident biota was relatively well characterized by the studies performed. One shortcoming was the lack of testing of the corixid, *Trichocorixa*

344 *verticalis*, which has sporadically been observed in the discharge channel perimeter.
345 Although no standard toxicity testing with this species has been conducted, Thomas et al.
346 [34] did assess the short-term (48 hours) bioaccumulation of Se in *T. verticalis* by
347 exposing organisms to Se concentrations as high as 1 mg/L with no effect on survival.
348 Hence, the 48-hour LC50 for this species is >1 mg/L Se.

349 An overall assessment of the selenium toxicity data generated in this study
350 indicates brine shrimp is the GSL's most sensitive species resident, with a chronic value
351 of 5 mg/L Se. In comparison, selenium concentrations in the mine effluent typically
352 range from 20-50 µg/L Se, approximately two orders of magnitude lower than those
353 predicted to cause chronic effects. Accordingly, the direct effects of Se on resident biota
354 are not the critical exposure pathway in deriving a site-specific water quality discharge
355 limit for the GSL.

356

357 **Bioaccumulation Study**

358

359 When tissue Se in brine shrimp is plotted as a function of co-located waterborne
360 Se concentrations, a relatively strong relationship is observed (r^2 = 0.92) (Figure 4).
361 These data demonstrate an inverse relationship between waterborne exposure
362 concentration and corresponding bioaccumulation factor that is frequently observed for
363 metals [35, 36]. Using this relationship, the site-specific waterborne Se concentration
364 that results in the dietary threshold for aquatic dependent birds can be estimated. For this
365 assessment, we used a conservative avian dietary Se threshold of 5 mg/kg dw [37, 38]. A
366 dietary threshold for birds was used because they are considered to be more sensitive that

other wildlife species. Using the equation for the linear regression model in Figure 3, the water Se concentration resulting in a brine shrimp selenium concentration of 5 mg/kg dw can be back-calculated using the following equation:

$$\text{Site - Specific Water Quality Standard} = \frac{\text{Dietary Threshold - Intercept}}{\text{Slope}} \quad (3)$$

Where: Dietary Threshold = 5 mg/kg dw

Intercept = 2.2802

Slope = 0.1002

Using this equation, a waterborne Se concentration of 27 µg/L is the maximum concentration that will not result in brine shrimp Se concentrations equal to or greater than the avian dietary threshold of 5 mg/kg dw. Given that this value is more than two orders of magnitude lower than the lowest effect level observed for direct Se toxicity to resident aquatic biota, Se bioaccumulation in brine shrimp and subsequent dietary toxicity to aquatic birds clearly represents the most critical exposure pathway. Consequently, a site-specific water quality discharge limit of 27 µg/L Se appears protective for aquatic species and sensitive wildlife for this site.

CONCLUSION

The GSL is a unique ecosystem in the United States for which there are no water quality criteria and existing freshwater or marine national water quality criteria are inappropriate due to the unique water quality characteristics and biota of the Lake. Using a risk-based approach, we evaluated critical exposure pathways for Se released into this environment with the objective of setting a site-specific water quality discharge limit.

Resident aquatic biota were found to be comparable in sensitivity to other species that have been tested, but naturally high ambient sulfate concentrations significantly reduce Se bioavailability in this environment. Field bioaccumulation data collected from the study site indicate that waterborne Se concentrations as high as 27 μg/L will not result in an exceedance of the Se dietary threshold for aquatic birds that feed on resident biota. Therefore, 27 μg/L Se appears to be an appropriate site-specific water quality discharge limit for the protection of all exposure pathways at this site.

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534 selenium exposure of biota associated with nonmarine aquatic habitats. 1996, U.S.
535 Fish and Wildlife Service, National Irrigation Water Quality Program:
536 Sacramento, California. p. 74 pp.
537

538 **Table 1. Dilution water quality during the acute and chronic toxicity tests.**

Parameter	Range
Temperature (°C)	25 ±1
pH	7.9 – 8.4
Dissolved Oxygen (mg/L)	1.8 – 6.0
Salinity (g/L)	80 – 102
Total Organic Carbon (mg/L)	35 – 49
Dissolved Organic Carbon (mg/L)	34.8 – 40
Total Suspended Solids (mg/L)	5-18
Sulfate (mg/L)	5,800

539

Table 2. Composition of artificial water used for testing *Dunaliella viridis*.

Salt	Concentration (mg/L)
NaCl	100,000
$MgCl_2$ 6 H_2O	1,500
$MgSO_4$ 7 H_2O	500
KCl	200
$CaCl_2$ 2 H_2O	400
KNO_3	1,000
$NaHCO_3$	43
H_3BO_3	2.86
$MnCl_2$ 4 H_2O	1.81
$ZnSO_4$ 7 H_2O	0.222
Na_2MoO_4 2 H_2O	0.39
$CuSO_4$ 5 H_2O	0.079
$Co(NO_3)_2$ 6 H_2O	0.049
$FeCl_3$ 6 H_2O	2.44
KH_2PO_4	35

Table 3. Summary of acute toxicity test results (all values are mg/L Se).

Species	Se Form	LC50 (95% C.L.)	NOEC	LOEC
Artemia franciscana	Selenate	78 (71-86)	51	71
Ephydra cinerea	Selenate	490 (445-542)	369	691

545 **Table 4. Summary of chronic *Dunaliella viridis* toxicity test (all values are mg/L Se).**

Evaluation	Specific Growth	Cumulative Area Under Growth Curve
EC50 (95% C.I.)	45 (36-71)	32 (28-36)
NOEC	11	11
LOEC	18	18
Chronic Value	14	14

546

547 **Table 5. Summary of chronic *A. franciscana* toxicity test results.**

Endpoint	Evaluation	mg/L Se
Survival – parental Day 11	NOEC	38
	LOEC	74
Survival – parental Day 21	NOEC	74
	LOEC	>74
Survival – parental Day 28	NOEC	74
	LOEC	>74
Growth – parental Day 11	NOEC	3
	LOEC	8
Growth – parental Day 28	NOEC	15
	LOEC	38
Reproduction - parental Day 21	NOEC	3
	LOEC	8
Reproduction - parental Day 28	NOEC	15
	LOEC	38
Survival - F_1	NOEC	15
	LOEC	38
Growth - F_1	NOEC	15
	LOEC	38
Final Chronic Value		5

548

549 **Table 6. Summary of Co-located Selenium Data in Surface Water and Brine Shrimp.**

Sample Date	Station	Total Se (µg/L)	Dissolved Se (µg/L)	Tissue Se (mg/kg dw)	BAF
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	1375
6/21/98	6	2	2	2.86	1430
6/21/98	7	2	2	3.14	1570
8/27/98	7	1	1	3.38	3380

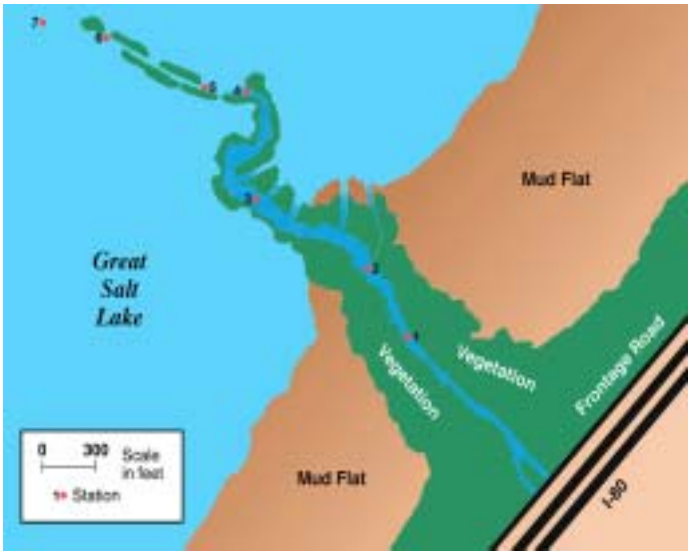
550

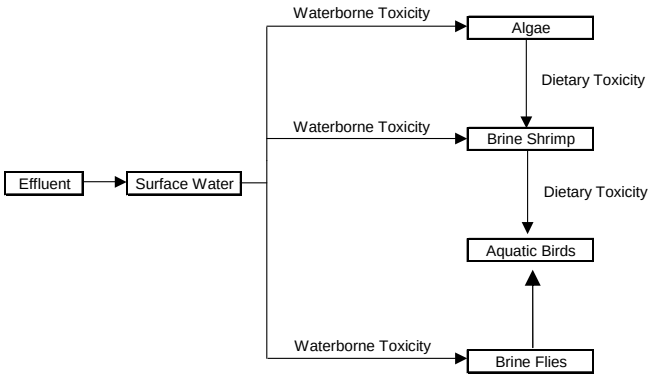
Figure 1 - Map of Study Area and Sampling Locations.

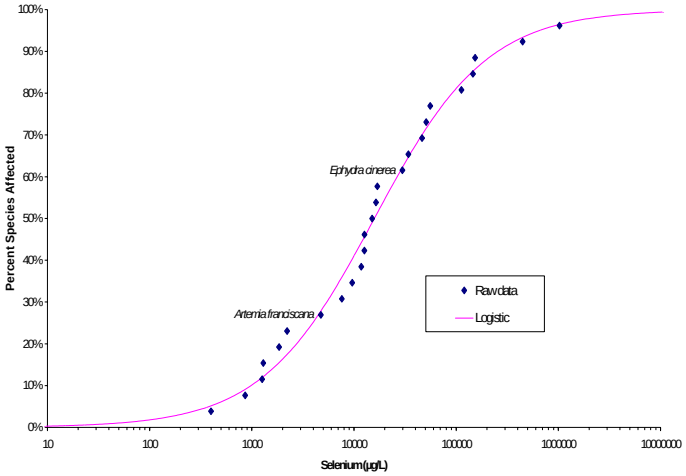
Figure 2 – Conceptual Model.

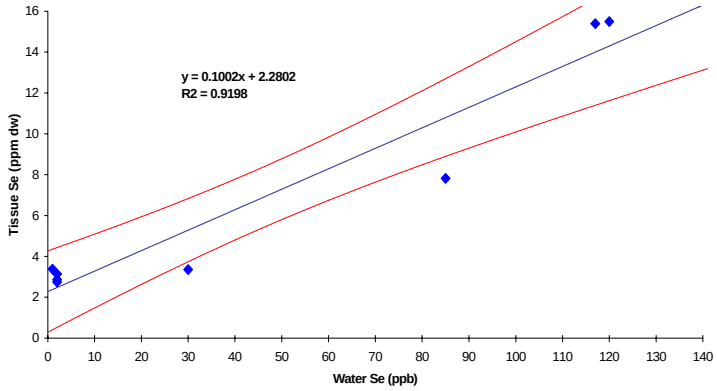
Figure 3 - Species Sensitivity Distribution for Selenate (Sulfate-Normalized).

Figure 4 - Relationship Between Water and Brine Shrimp Selenium Concentrations.


Great
Salt
Lake
Mud Flat
Vegetation
Vegetation
Frontage Road
I-80
Mud Flat
0
300
Scale
in feet
Station


Waterborne Toxicity
Algae
Dietary Toxicity
Waterborne Toxicity
Brine Shrimp
Effluent
Surface Water
Dietary Toxicity
Aquatic Birds
Waterborne Toxicity
Brine Flies


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Species Affected
10
100
1000
10000
100000
1000000
10000000
Selenium(µg/L)
Ephydra cinerea
Artemia franciscana
Raw data
Logistic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R2 = 0.9198
Tissue Se (ppm dw)
Water Se (ppb)
0
2
4
6
8
10
12
14
16
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140