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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Ohlendorf, H.M. 2003. Ecotoxicology of selenium. Pages 466-500 in Handbook of Ecotoxicology. D.J. Hoffman, B.A. Rattner, G.A. Burton, Jr., and J. Cairns, Jr., eds. Lewis Publishers, Boca Raton, FL.

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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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:

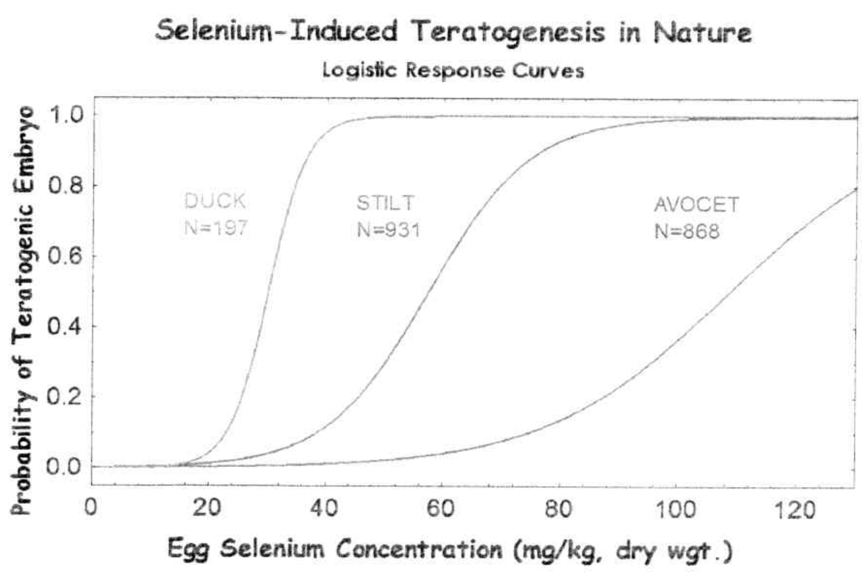
1. Our modeling indicates that water concentration associated with the EC10 value will be approximately 1.4 ug/L. This is 2 – 3X current Se concentrations. However, because of many unknowns associated with Se dynamics, I suggest a tiered approach to monitoring and implementing protective measures.
2. 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.

science for a changing world

Site-specific Model Development for the Great Salt Lake

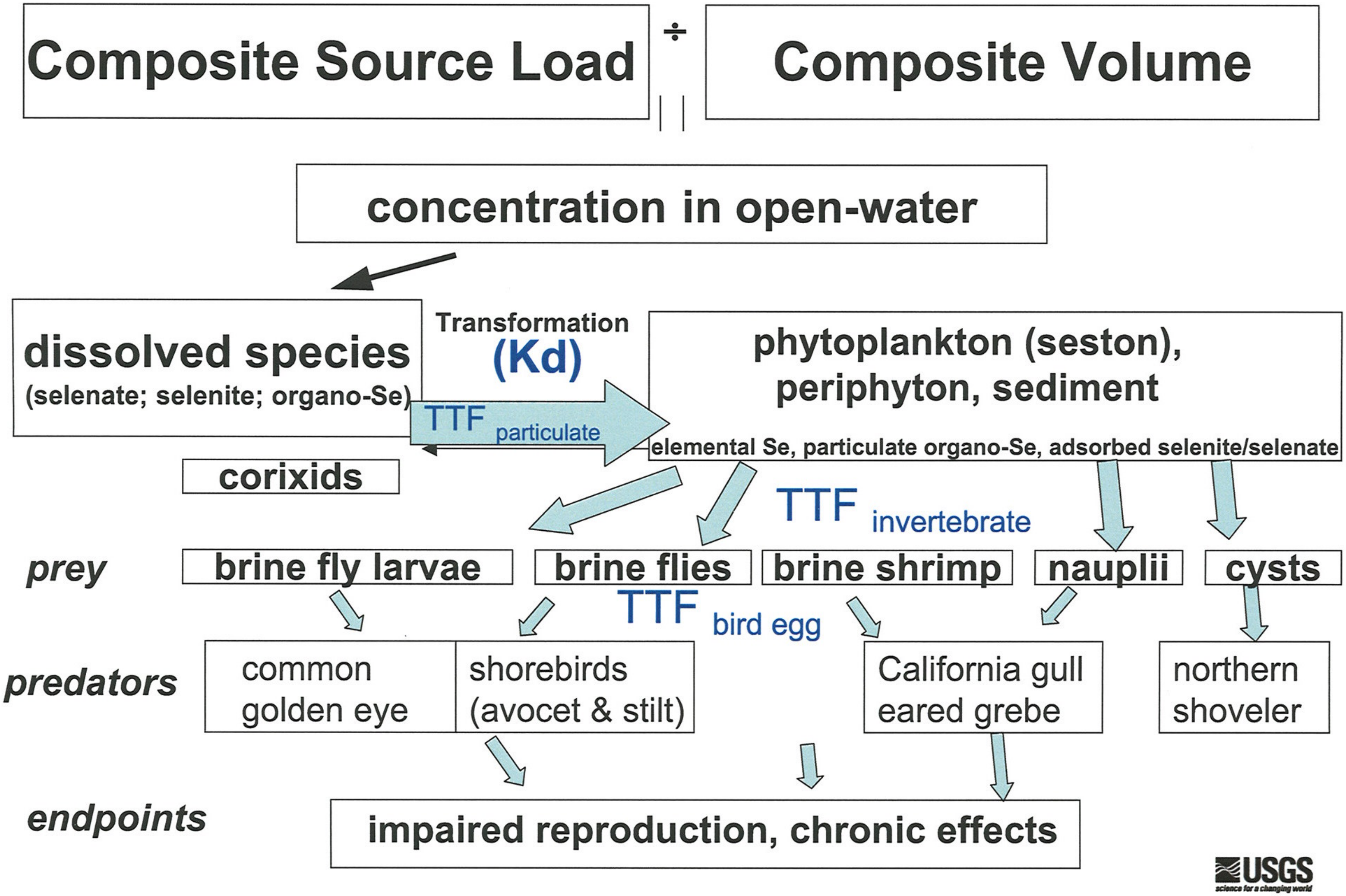
Forecasting Selenium Concentrations: Foodweb Specific Modeling

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

Water-column =	0.64 ppb total
	0.54 ppb dissolved
Seston=	0.95 ppm
Brine Shrimp =	3.97 ppm
Nauplius=	2.44 ppm
Cysts =	2.1 ppm
Brine fly adults =	1.7 ppm
Brine fly larvae =	1.4 ppm
Corixid =	2.4 ppm
Midge =	2.0 ppm

TTFs

Water to Seston= 1484 from total
1760 from diss

Seston to Shrimp = 4.2

Seston to Nauplius =2.6

Seston to Cysts = 2.2

Periphyton to Brine fly adult = 1.8

Periphyton to Brine fly larvae = 1.5

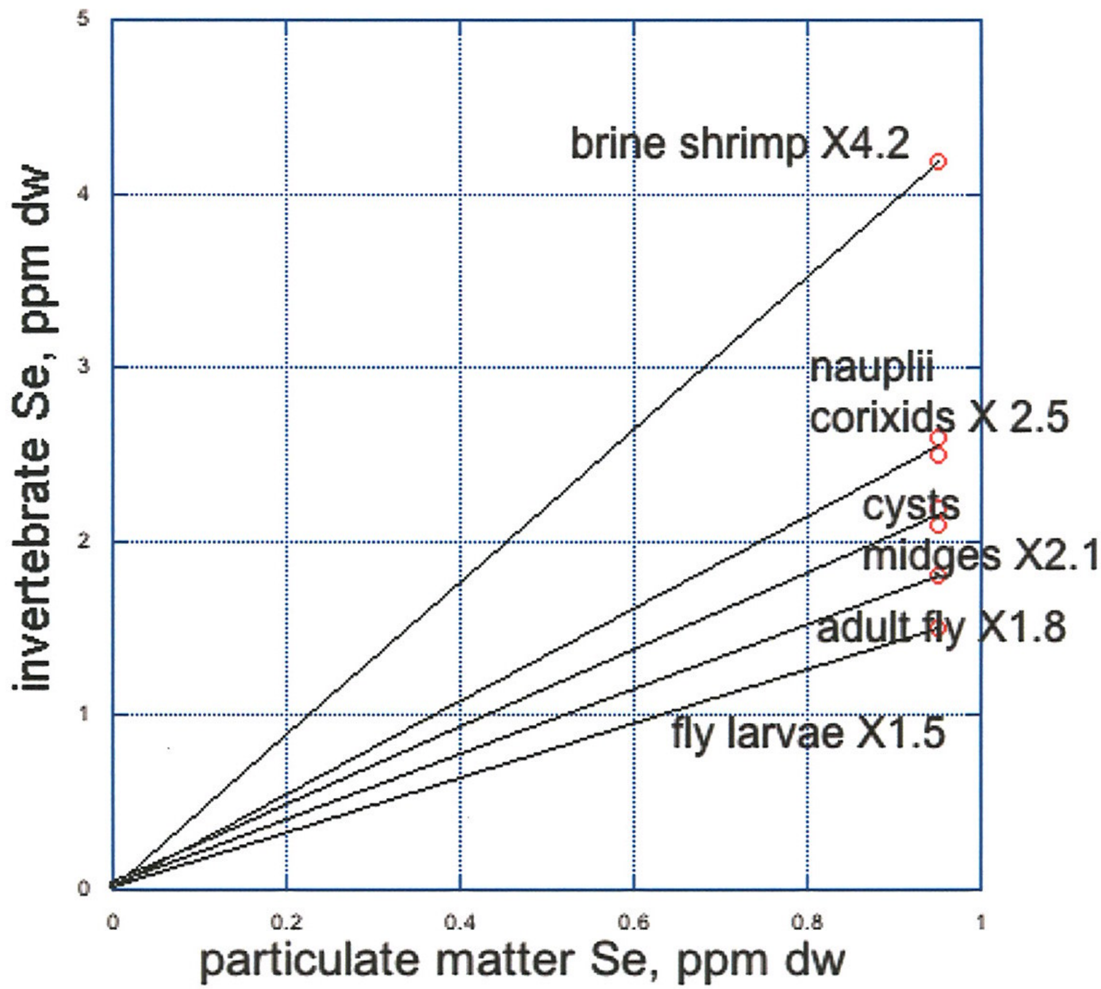
Seston to Corixid = 2.5

Seston to midge = 2.1

Diet to egg = 2.0 (1.8-2.55)

all dry weight, except water column

GSL trophic transfer factors ($TTF_{invertebrate}$)



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Shorebirds (American avocet and black-necked stilt) Breeding Residents

January — May — December

Measured Se concentrations (all dry weight)

May: 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

		Ogden and Antelope	Saltair
BIRD	avocet and stilt (eggs)	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
	↑ $TTF_{invertebrate} = 1.5$		
SUSPENDED MATTER	Se^0 +org Se + adsorbed selenite/selenate (bacteria, sediment; benthic algae, periphyton, detritus)	0.95 ppm	? ppm
	↑ $TTF_{particulate}$ = 1.76 or 1.48		
WATER	Great Salt Lake open-water	diss 0.54 ppb	? ppb
		total 0.64 ppb	? ppb

*measured

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California Gull
Breeding Residents

blood Se levels
are elevated

January — May — December

Measured Se concentrations
(all dry weight)

2006

eggs	liver	blood
2.8 ppm antelope island	7.3 ppm antelope island	13.8 ppm antelope island
3.1 ppm hat island	7.8 ppm hat island	16.0 ppm hat island
3.4 ppm mineral colony	9.2 ppm mineral colony	25.1 ppm mineral colony

2007

liver	blood
---ppm antelope island	-- ppm antelope island
7.2 ppm hat island	10.7 ppm hat island
9.3 ppm mineral colony	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

$TTF_{invertebrate} = 4.2$

Se^0 +org Se + adsorbed selenite/selenate — 0.95 ppm

SUSPENDED MATTER — bacteria, sediment — benthic algae, periphyton, detritus

$TTF_{particulate} = 1.76$

WATER — Great Salt Lake open- water — 0.54 ppb

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Eared Grebe
Migratory (staging)

January — September 2006 — November 2006 — December

blood Se levels are elevated (September to November 2006)

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

October
liver 13.4 ppm

November
liver 14.5 ppm
blood 23.3 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

↑ $TTF_{invert} = 4.2$

SUSPENDED MATTER: Se^0 +org Se + adsorbed selenite/selenate
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

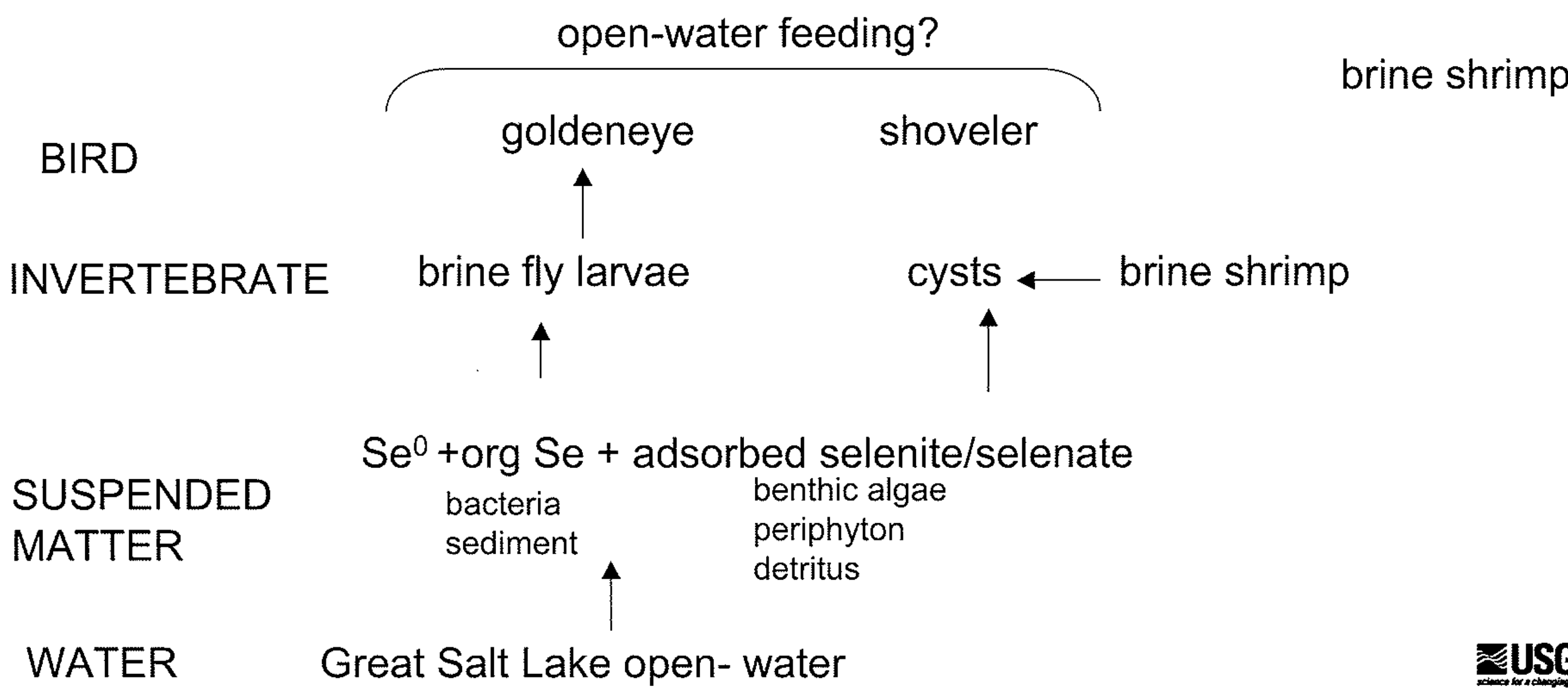
January → December

Measured Se concentrations
(all dry weight)

Locational			Age	
liver	12.6 ppm	Fremont Island	juvenile liver	12.7 ppm
	18.0 ppm	Stansbury Island	adult liver	17.2 ppm
blood	16.3 ppm	Fremont Island	juvenile blood	14.8 ppm
	17.1 ppm	Stansbury Isand	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?

open-water feeding?

BIRD phalarope

INVERTEBRATE brine shrimp (nauplii) (cysts) brine fly adults brine fly larvae ????

SUSPENDED MATTER

Se^0 +org Se + adsorbed selenite/selenate

bacteria
sediment

benthic algae
periphyton
detritus

WATER Great Salt Lake open- water

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

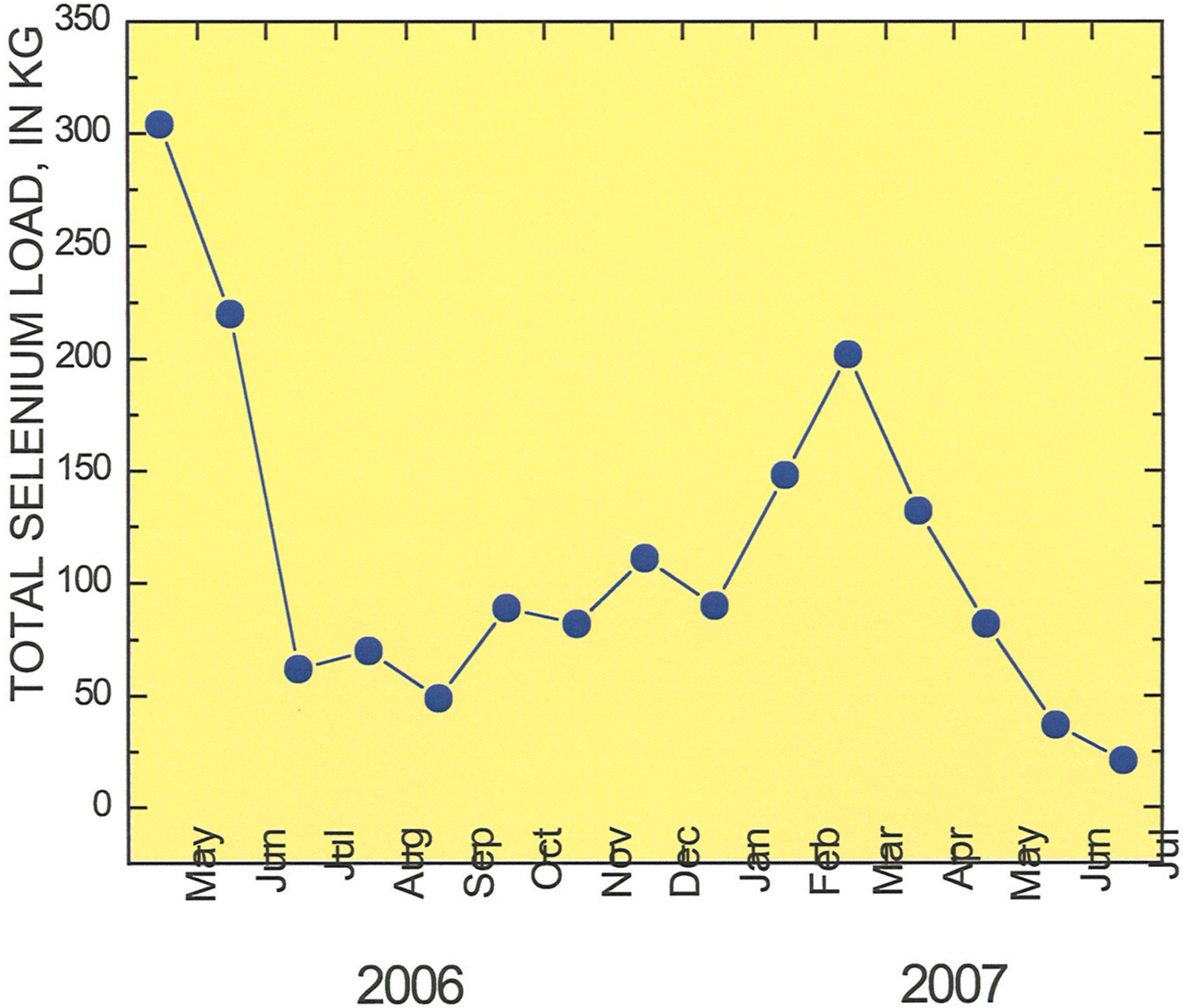
Scenario Level of protection?	bird egg ppm	TTF_{bird} factor	invertebrate ppm	TTF_{invert} factor	seston ppm	TTF_{seston} (Kd) factor	Water-column ppb
brine shrimp (adults)							
	6.4	1.8	3.6	4.2	0.86	1.76	0.49
	12.5	2.55	**4.9**	4.2	1.17	1.76	0.66
	16.5	2.9	5.7	4.2	1.36	1.76	0.77
brine shrimp (nauplii)							
	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)

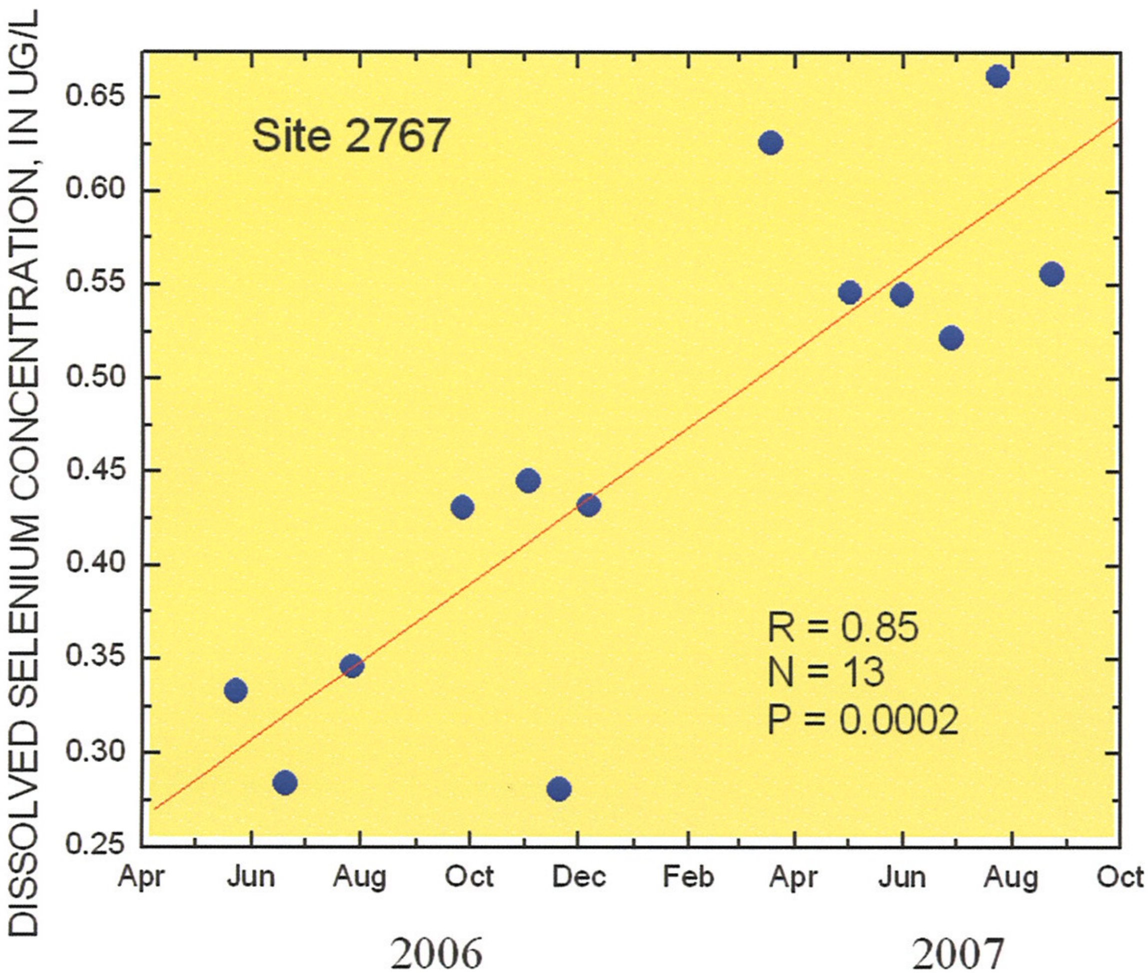
Variability in measured Se concentrations

	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



Se INCREASE IN OPEN WATER



Mann-Kendall
Trend analysis

Site identi-fication	Occurrence of upward trend in concentra-tion at 90 percent confidence level
2267	Yes
2767	Yes
3510	Yes
2565	Yes

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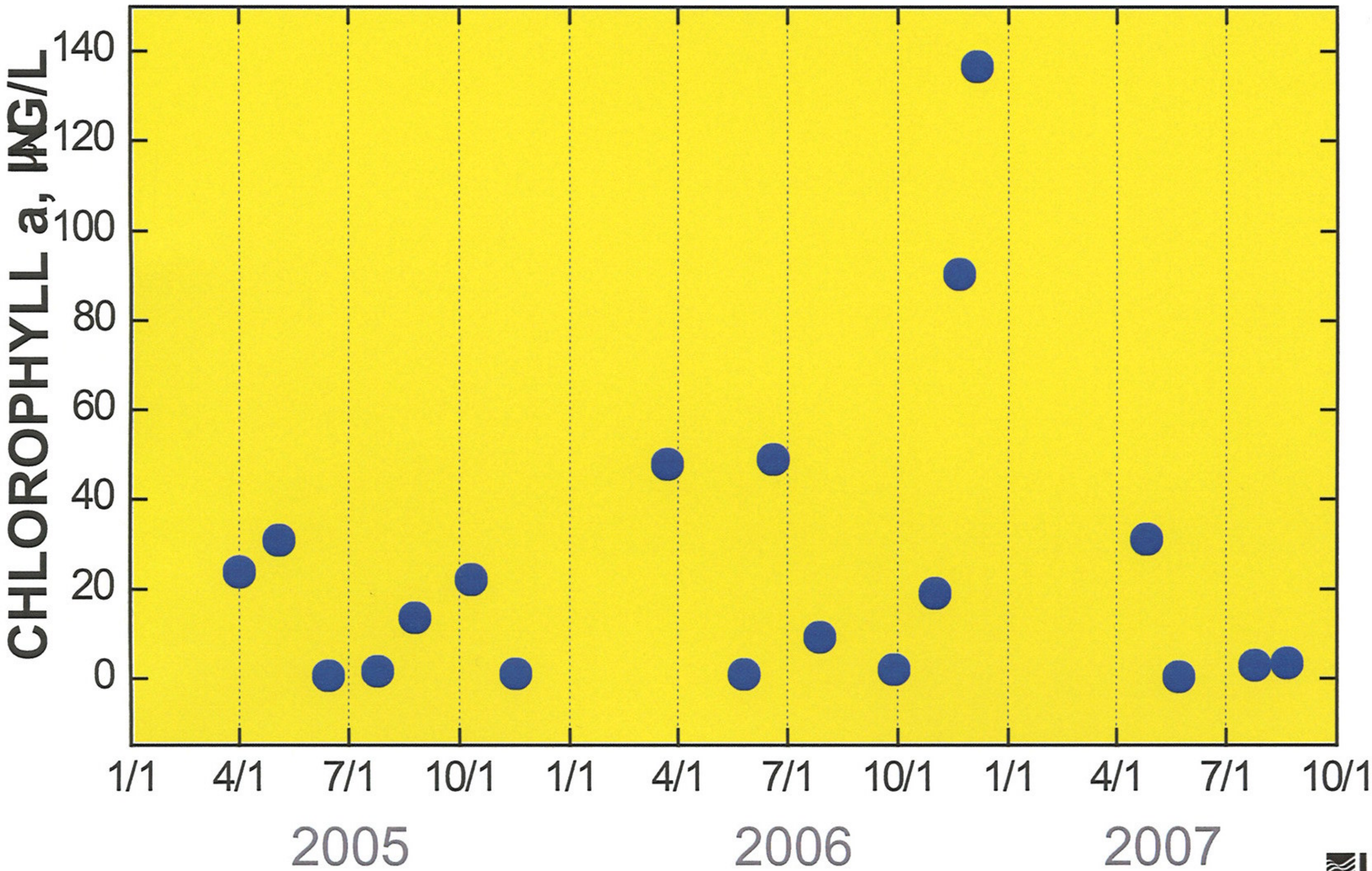
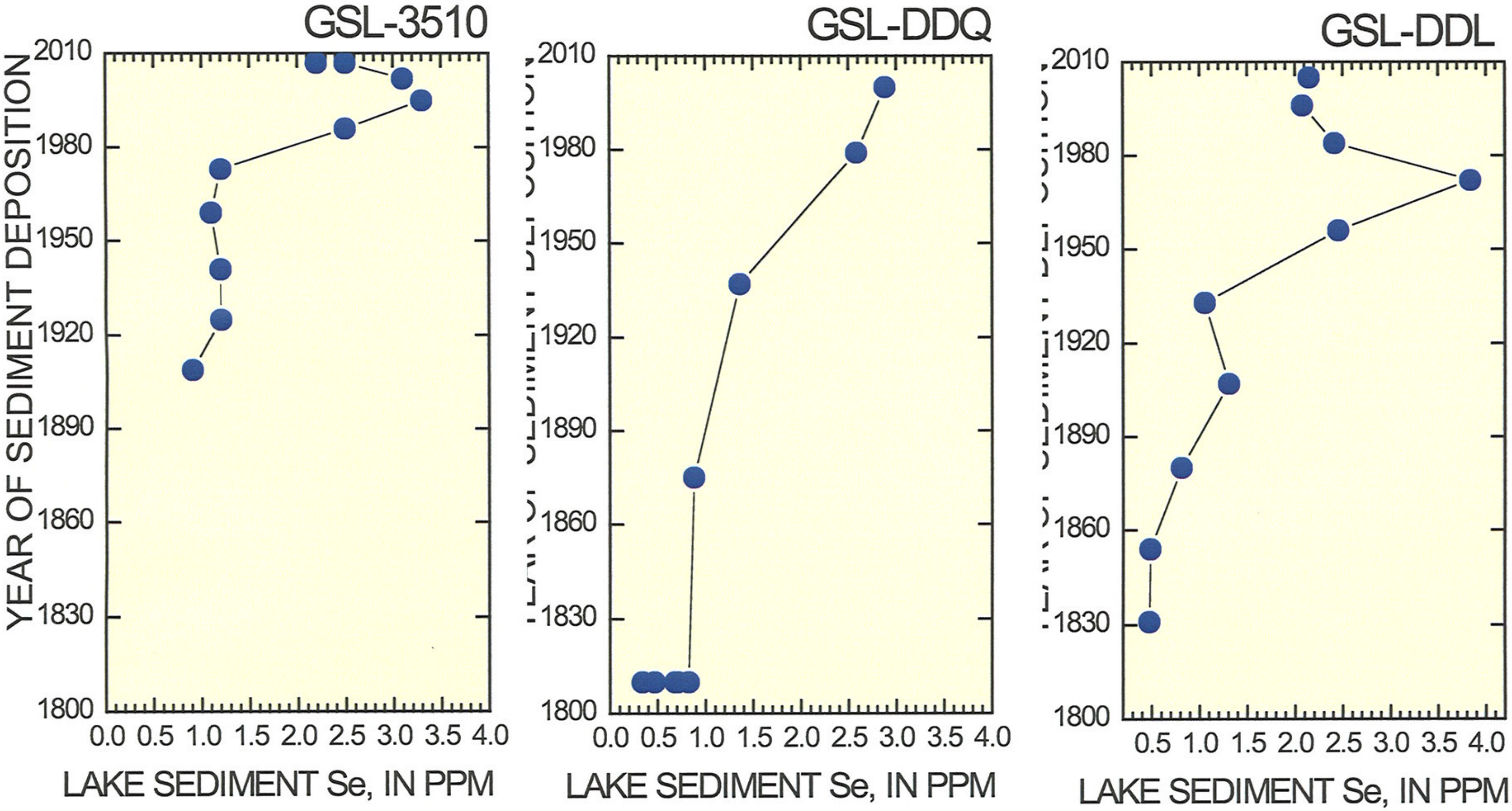
CHLOROPHYLL a (2565)

(as a representation of monthly changes in seston abundance)



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 <u>all variance</u> 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.