Implications of Selenium in Proposed Wastewater Discharges to Great Salt Lake

prepared by

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Maximum Acceptable Selenium in Waters of Great Salt Lake

Among aquatic ecosystems, those that are shallow and slow moving or static (lentic) are most likely to accumulate selenium and experience toxic impacts in fish and wildlife (Lemly

2002a). The Great Salt Lake (GSL) fits into this category of ecosystems and thus carries a relatively high risk of selenium poisoning. It is therefore crucial to set environmentally sound limits on waterborne selenium for GSL, based on real-world case examples of selenium poisoning, in order to keep accumulation below levels that threaten aquatic life.

The traditional approach to establish limits on waterborne selenium has been to simply adopt the USEPA national freshwater criterion (5 _g/L, parts-per-billion). The environmental basis for this number comes from Belews Lake, NC, where fish populations in areas of the lake with waterborne selenium >5 _g/L suffered major toxic impacts (Lemly 1985, USEPA 1987). At the time this criterion value was established (mid-1980's), little data were available from other aquatic systems to evaluate how broadly applicable the criterion actually was. Since that time, a growing body of scientific information has emerged, including additional information from Belews Lake, which indicates that toxic impacts to aquatic life can occur when selenium levels approach 2 _g/L (Frankenberger and Engberg 1998, Skorupa 1998a, Lemly 1997, Hamilton and Lemly 1999; references by Skorupa and Hamilton included as attachments). This lower toxic threshold is especially likely if waterborne selenium is predominantly in the selenite form or has been biologically processed (i.e., selenate incorporated into the food chain, deposited as detritus, recycled into water), or if the contaminated water enters a river backwater, wetland, pond, lake, reservoir, or other impoundment (Lemly 2002a). Because of these findings, a value of 2 _g /L has been recommended by several selenium experts as the concentration limit necessary to protect fish and wildlife (Peterson and Nebeker 1992, Maier and Knight 1994, Skorupa 1998b, Hamilton and Lemly 1999, Lemly 2002a, Hamilton 2004), and USEPA has begun a review/revision process for their national freshwater criterion (USEPA 1998, Hamilton 2003). Moreover, based on broad experience dealing with a variety of selenium contamination issues, the U.S. Fish and Wildlife Service and a number of state water quality agencies have adopted a value of 2 _g/L or less as their management or regulatory standard (see Engberg et al. 1998, Skorupa 1998b, Hamilton and Lemly 1999, USFWS 2003). An especially pertinent case example to draw upon for guidance is the Salton Sea, CA (a saline ecosystem quite similar to GSL), where only 1.5 _g/L waterborne selenium accumulated to toxic concentrations in the aquatic food chain (Skorupa 1998a). I recommend that 2 _g /L be adopted as the maximum acceptable concentration of selenium in ambient waters of GSL, and that this value be designated as a site-specific standard applicable to GSL and adjoining wetlands, irrespective of standards that may be in place for other surface waters of the state (e.g., 5 _g/L). Further, I recommend that this same concentration limit be imposed on all wastewater and drainage discharge entering GSL, with no provision that mixing/dilution be allowed in order to meet the 2 _g/L standard in ambient waters.

Guidance for Implementing a 2 _g/L Selenium Limit

USEPA provides states the option of developing site-specific standards and regulations governing their implementation if adequate justification is given. Establishing standards that are sensitive to selenium's local variations in aquatic cycling and toxic effects should be the goal of

Utah's regulatory agencies regarding GSL. Evidence now available for selenium bioaccumulation and impacts in western wetlands and saline lakes similar to GSL indicates that setting 2 _g/L as the standard would be a prudent step to take. However, in addition to "setting a number" it is also important to consider how standards will be implemented and enforced — i.e., will there be provisions for averaging concentrations over several days in order to meet standards, will periodic exceedance of standards be allowed, and will mixing zones be used to dilute selenium inputs and achieve standard limits. The state may seek to follow the example set by USEPA (e.g., Stephan et al. 1985, USEPA 1985, USEPA 1987), which allows averaging, exceedances, and mixing zones to factor into the implementation of standards. However, the guidance provided by USEPA is generic, and it would greatly reduce the effectiveness of a site-specific selenium standard for GSL. There are several important precautions that should be taken by water quality regulators if they intend to rely on USEPA guidance documents to implement site-specific selenium standards.

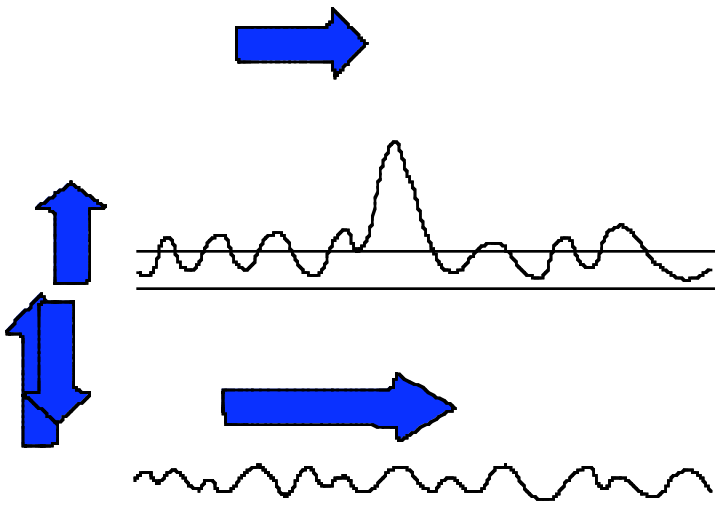
USEPA guidelines allow the national criterion for chronic exposure to be exceeded periodically (once every three years, on average) as long as the four-day average concentration is 5 _g Se/L or less (USEPA 1987). During exceedances, the permissible ambient (ecosystem-wide) waterborne concentration can be as high as 20 _g Se/L (Figure 1). Stephan et al. (1985) gives the rationale for this approach: "the averaging period of four days was selected by the USEPA on the basis of data concerning how rapidly some aquatic species react to increases in the concentrations of some pollutants, and three years is the Agency's best scientific judgement of the average amount of time aquatic ecosystems should be provided between excursions". The wording of the statement reveals that this is a generic model for contaminant exposure-response and associated derivation of criteria–i.e., the words "some aquatic species" and "some pollutants". The model was developed in the early 1980's when there was relatively little field data on selenium cycling and bioaccumulation in aquatic systems, and no attempt has been made by USEPA to test it's assumptions using selenium data that have become available since that time.

Figure 1. Contrasts between the existing USEPA national water quality criterion for selenium (chronic exposure, A) and the process recommended for setting a site-specific standard for GSL (B). A principal difference is that in implementing USA national criteria, USEPA guidelines allow four-day averages and exceedances up to the Criterion Maximum Concentration (CMC, 20 _g Se/L). This can offset the protection to aquatic life that is afforded by the Criterion Continuous Concentration (CCC, 5 _g Se/L). To provide full protection, the site-specific standard for GSL should be set using a biologically-based concentration limit (2 _g/L) as the CMC, and not allow averages, exceedances, or mixing zones.

There are 4 specific flaws that invalidate the USEPA model when it is applied to selenium:

(1) The USEPA guidance document clearly indicates that the process for USA national criteria is molded to fit publicly owned wastewater treatment facilities (POTWs) that discharge a point source into a flowing receiving water (Stephan et al. 1985, pp. 11-12). However, the most widespread threats of selenium poisoning in aquatic habitats are in lentic systems (reservoirs, wetlands, and off-channel bays and impoundments), and are due to power plant discharges, agricultural irrigation, and other sources, not POTWs. The environmental dynamics of selenium in lentic ecosystems is quite different than the riverine conditions used for the USEPA model.

(2) The four-day average is based on organism responses to



waterborne exposure alone. However, food chain bioaccumulation and dietary intake are more important in causing chronic selenium toxicity to aquatic life (Lemly 1985, Lemly 1997). This component of selenium cycling is overlooked in the USEPA model. Moreover, exposure-bioaccumulation-response times for selenium in fish and aquatic birds (waterborne or dietary intake) are on the order of weeks or months rather than four days (e.g., Lemly 1982, Heinz, Hoffman and Gold 1988, Coyle et al. 1993, Heinz and Fitzgerald 1993)–the USEPA model assumptions are not correct.

(3) The concentrations of waterborne selenium allowed by USEPA during exceedances (up to 20 _g Se/L) are not environmentally acceptable for lentic systems or lotic systems that will deliver selenium into off-channel bays, wetlands, lakes, reservoirs, or other down-gradient lentic systems. Studies such as those by Cumbie and Van Horn (1978), Bryson et al. (1984), Lemly (1985), Gillespie and Baumann (1986), and Hamilton et al. (1996) show that concentrations of 10-20 _g Se/L can quickly reach dietary levels that are toxic to fish and aquatic birds. Consider, for example, a scenario in which an exceedance causes waterborne selenium in a lake or wetland to reach 15 _g Se/L–an acceptable concentration in the USEPA model (Figure 1). By the time ambient locations reach this level, the entire "bioaccumulation engine" of the ecosystem will have been fueled by the influx of new selenium, which substantially escalates the toxic threat to aquatic life (Lemly 1985). (4) The three year period between excursions (exceedances), although perhaps reflecting the best scientific judgement available for *some* pollutants in the early 1980's, is not appropriate for selenium given today's knowledge of the environmental dynamics and cycling of this trace element. Once an aquatic ecosystem has captured the selenium dose delivered by an exceedance, it can continue to cycle it tightly within the system for many years. For example, studies show that the recovery period for reservoirs contaminated by 10 _g Se/L selenium could be >10 years, perhaps several decades, due to recycling of selenium from sediments into benthic-detrital food chains and associated dietary and reproductive toxicity to fish (Garrett and Inmann 1984, Lemly 1997).

Similar problems are evident with the use of dilution or mixing zones, which are areas exempt from ambient standards. This concept was developed for application to flowing waters (Stephan et al. 1985). It has no credible basis for application to selenium in lentic/wetland systems because the "dilution zone" may constitute the entire body of open water (Lemly 1985, 1997). Even in riverine habitats, the notion of mixing zones is a totally artificial process because USEPA has not referenced data verifying that a mixing zone can effectively dilute a selenium-laden effluent and also be environmentally compatible with fish and wildlife habitat uses, which it must be under federal statutes in the USA, such as the Migratory Bird Treaty Act and the Endangered Species Act (Margolin 1979). Selenium strongly bioaccumulates in food organisms and makes the dilution zone an area of extremely high exposure for fish and wildlife. Several case studies show that using mixing zones to dilute seleniferous water creates more biological hazards than it resolves (e.g., Skorupa 1998). The apparent benefits gained by achieving target concentrations in a mixing zone may be more than offset by detrimental effects that are caused by other aspects of the selenium cycle. The threat of toxic impacts overrides the need to attempt "dilution as a solution", particularly in shallow, saline habitats such as GSL.

Given these flaws, it is important to closely examine the rationale for, and distinction between, national criteria and site-specific standards. USEPA criteria are intended to provide protection for most aquatic species most of the time, not everything all of the time (Stephan et al. 1985). Because of this basic caveat, as well as the fact that there are differences in ecosystem and aquatic species sensitivity to selenium, there may be a plausible argument for allowing some leeway in meeting the national criterion–i.e., a *reasonable* averaging of concentrations over time if

monitoring indicates that there are no biological effects (but not 20 _g Se/L exceedances). However, at a local level, the national criterion's intent to protect "most species" still leaves large gaps that could lead to substantial inconsistencies (toxic effects at or below the criterion level, lack of effects above the criterion). Site-specific water quality criteria, i.e., the standard for GSL, should reflect the sensitivity of local biota and close the gaps. If full protection of aquatic life is desired, then there should be no provision for averages, exceedances, or mixing/dilution zones in the implementation of standards.

Concentration versus Loading Considerations

Because of selenium's propensity to accumulate in sediments and recycle into the aquatic food chain, actions to regulate this pollutant must take loading into account (the total mass of selenium) as well as the waterborne concentration (amount per unit volume). Thus, in addition to the recommended 2 _g/L waterborne standard, a limit should be set on the loading of selenium to GSL. The key factor in setting a proper loading limit, or Total Maximum Daily Load (TMDL) is to determine the ability of the ecosystem in question to take up waterborne selenium and hold it in biota or detritus/sediments. This is known as the system's retention capacity (RC). The more that selenium is held in the system, the higher the RC. It is necessary to know the RC in order to develop an environmentally sound TMDL because the higher the RC, the lower the TMDL has to be to prevent toxic threats to fish and wildlife. A published procedure is available for determining RC based on primary productivity, water flow regime, and sediment type (Lemly 2002b; reference provided as attachment). Applying this procedure to GSL is a simple process. Without TMDLs, seemingly harmless waterborne concentrations of selenium (i.e., those that meet regulatory standards) may build up in sediments, recycle into aquatic food chains, and cause unforseen toxic impacts (Lemly 2002c).

Regardless of what the waterborne standard and TMDL are, it is important to monitor selenium concentrations to make sure these regulatory steps are keeping selenium concentrations below levels of concern in fish and wildlife. Monitoring provides a critical feedback loop that is needed for on-going assessment of the health of the GSL ecosystem. The following concentration limits are suggested as guidelines for interpreting the monitoring data (Lemly 2002a).

Table 1. Toxic effect thresholds[a] for selenium in aquatic ecosystems.

Selenium source	Selenium concentration[b]	Effect
Water		
Inorganic selenium	2 _g/L	Food-chain bioaccumulation and reproductive failure in fish and aquatic birds

Organic selenium	< 1 _g/L	Food-chain bioaccumulation and reproductive failure in fish and aquatic birds
Sediments	2 _g/g	Food-chain bioaccumulation and reproductive failure in fish and aquatic birds
Food-chain organisms	3 _g/g	Reproductive failure in fish and aquatic birds
Fish tissues		
Whole-body	4 _g/g	Mortality of juveniles and reproductive failure
Skeletal muscle (skinless fillets)	8 _g/g	Reproductive failure
Liver	12 _g/g	Reproductive failure
Ovary and eggs	10 _g/g	Reproductive failure
Aquatic Birds		
Liver	10 _g/g	Reproductive failure
Eggs	3 _g/g	Reproductive failure

[a] These are levels at which toxic effects begin to occur in sensitive species of fish and aquatic birds. They are not levels that signify the point at which all species die from selenium poisoning.

[b] Selenium concentrations in parts per billion for water; parts per million on a dry weight basis for sediments, food-chain organisms, and fish and bird tissues.

Implications for Wastewater Proposed for Discharge into GSL

The reverse osmosis wastewater produced by treating contaminated groundwater from Kennecott Utah Copper Corporation activities constitutes a highly hazardous waste with regard to its selenium content. The concentrations of selenium expected in discharges (7-48 _g/L; State of Utah, 2003), in combination with the volume of discharge (19.2 MGD), will be a major source of selenium pollution to GSL. Without question, the discharge will create an area of highly contaminated water, sediments, and associated aquatic life that will expand over time. The extent of this expansion will depend on: (1) how long selenium-laden wastewater is discharged, and (2) limnological factors in GSL such as primary and secondary productivity, wind circulation and mixing, and biological activity in sediments. Hydrological connections with the main body of GSL

could lead to contamination of associated wetlands that are managed for waterfowl or other fish and wildlife uses. Hydrological mapping would provide clues as to where selenium movement may occur and allow other habitats that are at risk to be identified (Lemly 2002a).

Discharging the proposed amounts of selenium into GSL carries great environmental risk. Applying an EPA or state standard of 5 _g/L to GSL is a mistake. The number is badly outdated and the implementation guidance that is available from EPA is fatally flawed. Evidence from similar ecosystems in the West shows that as little as 1.5 _g/L can cause problems. Using GSL as a dilution chamber will create areas of high selenium exposure to fish and wildlife. It is crucial to understand that when selenium contamination begins, a cascade of bioaccumulation events is set into motion which makes meaningful intervention nearly impossible — once the threshold is crossed, toxic impacts will occur. However, this cascade of events need not happen in GSL if adequate foresight and planning are exercised. Regulatory authorities in Utah have the opportunity to exercise this foresight, which includes consideration of other disposal options (e.g., alternative discharge locations such as Kennecott Utah property). Prudent risk management based on environmentally sound hazard assessment and water quality goals can prevent biological impacts. If other options are not chosen and GSL is used as the discharge location, it is essential that: (1) a 2 _g/L standard be imposed on selenium in the discharge itself, (2) a TMDL for total selenium entering GSL be derived, and (3) biological monitoring be conducted to make sure selenium concentrations remain below levels of concern for fish and wildlife.

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