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COMMENTARY

Water-Sediment Controversy in Setting Environmental Standards for Selenium

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A substantial amount of laboratory and field research on selenium effects to biota has been accomplished since the national water quality criterion was published for selenium in 1987. Many articles have documented adverse effects on biota at concentrations below the current chronic criterion of 5 µg/L. This commentary will present information to support a national water quality criterion for selenium of 2 µg/L, based on a wide array of support from federal, state, university, and international sources. Recently, two articles have argued for a sediment-based criterion and presented a model for deriving site-specific criteria. In one example, they calculate a criterion of 31 µg/L foi a stream with a low sediment selenium toxicity threshold and low site-specific sediment total organic carbon cotitent, which is substantially higher than the national criterion of 5 µg/L. Their basic premise for proposing a sediment-based method has been critically reviewed and problems in their approach are discussed.

1. INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) is currently reevaluating the national water quality chronic criterion for selenium (USEPA, 1998), which was set at 5 µg/L in 1987 (USEPA, 1987). There is a growing body of literature that supports a lower chronic selenium criterion. Beginning in late 1982, investigations of contamination at Kesterson Reservoir in the central valley of California were initiated, which revealed that selenium from agricultural irrigation sources was elevated and causing adverse effects in fish and wildlife (Ohlendorf *et* al., 1986; Saiki, 1986). The National Irrigation Water Quality Program (NIWQP) was initiated in 1985 to determine the concentrations of potentially toxic constituents, especially selenium, in water, bottom sediment, and biota at 20 sites in 18 western states (Engberg and Sylvester, 1993), then expanded to include six additional areas (Feltz and Engberg, 1994). The NIWQP investigations in the Green (Stephens *et al.,* 1988, 1992, Peltz and Waddell, 1991), Colorado and Gunnison (Butler *et al.,* 1989, 1991, 1994, 1996), and San Juan (Blanchard *et al.,* 1993; Butler et *al.,* 1995; Thomas *et al., 1997)* rivers suggested that selenium and other elements are sufficiently elevated in water, bottom sediments, or biota to adversely affect aquatic organisms in those rivers. Research undertaken in western rivers to assess the hazard of selenium and other elements from irrigation drainwater sources on endangered fish has provided additional information to suggest that selenium is adversely affecting endangered fish.

Despite the mounting evidence of toxic effects below 5 µg/L, there is a controversy over whether the current national criterion is too high or too low. The basis for this disagreement stems from different views of whether a water-based or sediment-based method for deriving criteria is more valid in light of the field evidence for bioaccumulation and toxicity to fish and wildlife (USEPA, 1998). Below, is provided information that supports a water-based chronic criterion for selenium of 2 µg/L. Also included is a discussion of problems in two recent articles (Canton and Van Derveer, 1997; Van Derveer and Canton, 1997) that propose a sediment-based approach that could result in substantially elevated selenium concentrations in water above the current USEPA criterion. Because the sediment-based approach was proposed primarily for western rivers, information is presented from the NIWQP investigations and research with endangered fish from western rivers.

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2. SUPPORT FOR 2 μg/L WATER-BASED CRITERION

The current standard of 5 μg/L was established based almost solely on information from Belews Lake, North Carolina. USEPA (1987) states "The freshwater Criterion Continuous Concentration (CCC) should be between 10 μg/L and the concentrations in the unaffected portion of Belews Lake, which is near or below 5 μg/L. Therefore, the CCC will be set at 5 μg/L." Since that time, investigations have found that there were adverse effects in the "unaffected" arm, the portion of the lake south of Highway 158. Holland (1979) reported that selenium concentrations were biomagnified substantially up the food chain in this arm of Belews Lake. He found about 2 μg/L in water, 23-25 μg/g in plankton, 26-31 μg/g in benthic invertebrates, and 18-47 μg/g in three fish species. Sorensen et al. (1984) reported adverse effects in fish from this arm of the lake, which had 4 μg/L in water in 1976- 1977 and 3 μg/L in 1980- 198 1, i.e., elevated selenium residues in muscle and liver, higher condition factor, lower hematocrit, and adverse histopathological changes in liver, kidney, and ovary compared to reference fish. The findings of Holland (1979) and Sorensen et al. (1984), from research at the same site used by the USEPA to establish the 1987 criterion, support the need for a national water quality criterion below 5 μg/L.

Engberg et al. (1998) summarized federal and state perspectives on regulation and remediation of irrigation-induced selenium problems and concluded that the current USEPA criterion for selenium of 5 μg/L was underprotective. Recently, Skorupa (1998) reviewed the findings of 12 "real-world" examples of selenium poisoning and concluded that a national water-based criterion of <5 μg/L was broadly justified. He reviewed information from selenium-contaminated sites at Belews Lake, North Carolina, Kesterson Reservoir, California, Hyco Reservoir, North Carolina, Martin Reservoir, Texas, Richmond (Chevron marsh), California, Tulare Basin, California, Salton Sea, California, Kendrick Reclamation Project, Wyoming, Red Rock Ranch (agroforestry), California, Ouray National Wildlife Refuge (NWR), Utah, and Sweitzer Lake, Colorado, which included cooling reservoirs at coal-fired power plants, wetlands for treating petroleum wastes, and argicultural irrigation sources.

Moreover, several comprehensive reports from state and university technical review committees as well as research scientists have also recommended ≤2 μg/L for the protection of aquatic birds and mammals (SWRCBC, 1987; UCC, 1988; DuBowy, 1989: Skorupa and Ohlendorf, 1991; CEPA, 1992; Peterson and Nebeker 1992), thus indicating wide support for this criterion concentration. In-depth reviews by Maier and Knight (1994) and Lemly (1993a, 1996) recommended 2 μg/L as a probable safe water concentration based on a convergence of concentrations of concern, derived in several laboratory and field studies, for the protection of fish and wildlife from selenium toxicity. The states of Arizona (1992) and New Mexico (1995) have established a water quality standard for selenium for the protection of aquatic life at 2 μg/L. Thus, there seems to be substantial support for a national water-based criterion of 2 μg/L. All of these recommendations are based on the bioaccumulation of selenium from water into the food chain and the subsequent effects of dietary exposure to higher trophic levels.

2.1. International Support

From an international perspective. there is additional support for a U.S. water quality criterion of 2 μg L. The water quality standard for selenium in Canada is 1 μg L (CCREM, 1987). This document has recently been revised and the Canadian water quality standard for selenium has remained at 1 μg/L (N. Nagpal, Inland Waters Directorate, personal communication, 1998). A study of lakes in Sweden that were treated with selenite to mitigate high concentrations of mercury in fish concluded that waterborne concentrations of selenium needed to be kept below 2 μg/L to avoid undesirable bioaccumulation of selenium in fish and unintentional side effects such as the complete die-off of perch observed in several lakes (Paulsson and Lundbergh, 1991, 1994). On behalf of the Directorate General for Environmental Protection, The Netherlands. Emans *et* al. (1993) evaluated several extrapolation methods using multiple species (MS) toxicity data to predict the no observed adverse effect concentration (NOEC) of various environmental contaminants on ecosystems and then validated the extrapolation method with results from field studies. For selenium, they calculated extrapolation values for the MS NOEC of 2.2 and 2.5 μg/L.

3. FOOD CHAIN TOXICITY THRESHOLD

The critical link in the recommendation of 2 μg/L as the potentially safe waterborne selenium concentration for the protection of fish and wildlife resources is bioaccumulation and biomagnification into the food chain. Maier and Knight (1994) and Lemly (1993a, 1996) recommended 3 μg/g dry weight as the dietary threshold for selenium toxicity to fish and wildlife. This concentration in the food chain is often achieved at low waterborne selenium concentrations over a long period of time or by rapid loading of an aquatic ecosystem over a short period of time.

For example, Lemly (1997) reported developmental deformities in young fish from Belews Lake 10 years after selenium inputs to the lake were stopped in 1986. He found in 1996 that waterborne selenium concentrations were < 1 μg/L, and even though sediment concentrations of selenium were 65-75% lower than in 1986, they still were sufficiently elevated (l-4 μg/g) to contaminate benthic invertebrates to 2-5 μg/g. Based on a protocool for aquatic hazard assessment of selenium in five ecosystem components (water, sediments, invertebrates, fish eggs, and bird eggs; Lemly, 1995), there was still a moderate hazard at Belews Lake in 1996 due to ecosystem loading prior to 1986. This moderate hazard is due to the recycling of selenium in the aquatic food chain. The selenium contamination event at Belews Lake can also be considered a pulse event, in that adverse effects have been documented 10 years after selenium input had ceased (Lemly, 1993b, 1997). Because of the long-term effects of pulse events from selenium exposure in aquatic ecosystems, site-specific water quality criteria must consider the effects of pulse events (Lemly, 1998).

Another example of aquatic ecosystem loading of selenium is given by Maier et *al.* (1998). They reported that application of seleniferous fertilizer to a deer forage range in California resulted in a pulse of selenium entering a stream and briefly raising the water concentrations from < 1 μg/L to 10.9 μg/L at 3 h post-application. Selenium concentrations in aquatic invertebrates in the stream increased from 1.67 μg/g before application to 4.74 μg/g 3 h after application and remained elevated after 2 (4.02 μg/g), 4 (4.99 μg/g), 6 (4.21 μg/g), 8 (4.30 μg/g), and 11 (4.54 μg/g) months post-application. This is the first study to determine that a short pulse event can load an aquatic environment quickly and that the selenium can be conserved in the ecosystem. These concentrations of selenium in the food chain are a potential ecotoxic problem based on the results of laboratory and field studies (Maier and Knight, 1994; Lemly, 1993a, 1996).

4. CRITIQUE OF A SEDIMENT-BASED SELENIUM CRITERION

Recent articles by Canton and Van Derveer (1997) and Van Derveer and Canton (1997) concluded that the chronic water quality criteria for the protection of fish and wildlife from the bioaccumulative effects of selenium should be expressed on a particulate basis, such as sediment selenium concentration or a measure of the organic content of sediment where selenium would be expected to accumulate. In an example in their second article, they present a sediment selenium model and use it to derive a site-specific chronic dissolved selenium standard of 31 μg/L, using a sediment selenium toxicity threshold of 2.5 μg/g and a site-specific mean sediment total organic carbon of 0.5%. This site-specific standard contrasts sharply with the current USEPA criterion of 5 μg/L.

4.1. Belews Lake, North Carolina

First, in criticizing the use of waterborne criteria, Canton and Van Derveer (1997) state that recent "recommendations of 2 μg/L or less . . . are based primarily on data from two sites . : Belews Lake and Kesterson." There are several field studies from other locations, which suggest that a recommendation of 2 μg/L is appropriate. The field locations are Martin Lake. Texas (Lemly, 1985a; Sorensen, 1988). Hyco Reservoir, North Carolina (Lemly, 1985a; Gillespie and Baumann, 1986; Woock and Summers, 1984). and Chevron marsh (Richmond), California, Salton Sea, California, and Swedish lakes (reviewed by Skorupa, 1998).

Second, in reviewing the justification for the current USEPA national water quality criterion, the literature review of Canton and Van Derveer (1997) did not include several important publications, which influenced their conclusions. For example, they state " . . . Belews Lake . . . impacts to fish populations . . . *seemingly* ***resulted*** from elevated dietary Se." They also state, " . . . waterborne concentrations that *reportedly* eliminated many of the fish species of Belews Lake." In point of fact. there is a substantial literature base to indicate that selenium caused the observed adverse effects at Belews Lake (Cumbie and Van Horn, 1978; Duke Power Company, 1980; Finley, 1985; Lemly. 1985a, b, 1993b; Couglan and Velte. 1989). Later. the authors state "This resulted in elevated Se in ***sediments*** and subsequently in the food chain, although water column concentrations were ***relatively*** low, in the range of 10 μg/L." This statement does not take into account a substantial amount of literature reporting that waterborne uptake of selenium by primary producers and zooplankton occurs, thus loading the water-column food chain with selenium (reviewed by Ihnat, 1989; Maier and Knight, 1994). Planktonic food chains in Belews Lake contained toxic concentrations of selenium derived from waterborne uptake (Cumbie and Van Horn, 1978; Lemly, 1985a, b). Further, from a biological standpoint, 10 μg/L is not "relatively low" because reviews of several field studies have found adverse effects in aquatic organisms at water concentrations ranging from 2 to 5 μg/L (Maier and Knight, 1994; Lemly, 1996; Skorupa, 1998).

Canton and Van Derveer (1997) also stated concerning Belews Lake that "An arm of the lake [Highway 158 arm] that did not receive coal fly-ash effluent did not appear to have any discernible toxic effects on fish." To the contrary, Sorensen et al. (1984) reported adverse effects in fish from this arm of the lake, and Holland (1979) reported selenium concentrations in plankton, benthic invertebrates, and fish from this arm of the lake that were above toxic thresholds.

4.2. Gunnison River, Colorado

Canton and Van Derveer (1997) list two citations (Butler et *al.*, 1991, 1994) to indicate that high selenium concentrations were found in the Gunnison River in water, sediment, and tissues where they state that no evidence of biological impacts was observed. These two studies by Butler et *al.* (1991, 1994) were contaminant surveys conducted as part of the NIWQP in the Gunnison River basin-Grand Valley project area. These investigations were not designed to evaluate biological effects from exposure to contaminants. The NIWQP mission does not include identifying or quantifying biological effects (Feltz and Engberg, 1994), and by themselves, cannot be used to evaluate biological effects associated with selenium or other trace elements. However, comparing concentrations of contaminants measured in NIWQP studies with concentrations associated with adverse effects derived in laboratory and field studies designed to measure biological effects is a legitimate way of determining whether adverse effects might be expected. One critical flaw in Canton and Van Derveer (1997) is that they interpreted the two NIWQP studies as exposure-response studies instead of exposure surveys.

Moreover, Canton and Van Derveer (1997) cited Lemly et al. (1993) to indicate that biological effects were not observed in the Gunnison River studies, yet Lemly *et* al. (1993) did not discuss or cite specific results from Gunnison River reports. To the contrary, Lemly et al. (1993) contains a figure that identifies the Gunnison River as a site where subsurface drainage from federal irrigation projects may be causing toxicity to fish and wildlife, based on a comparison to biological effects studies, and a table identifies the Gunnison River as a study area where toxicity is also predicted on the basis of concentrations of selenium found in fish and bird tissues. Furthermore, a recent review of NIWQP studies for land susceptible to selenium contamination predicted that a selenium problem was likely in the Gunnison River Basin-Grand Valley Project area (Seiler, 1998). This prediction was validated by the fact that the Gunnison-Grand Valley study area was one of only four NIWQP study areas where Kesterson-type deformities of bird embryos were found (Seiler, 1998).

4.3. Effects in Western Streams

Canton and Van Derveer (1997) state that "Despite these elevated [selenium] concentrations [in streams in southeastern Colorado], no biological impacts, such as reduced fish diversity or abundance, has been observed." This assertion is the foundation of their agrument for sediment-based criteria, yet none of the empirical data essential for discerning biological effects were given to substantiate the statement, i.e., dietary studies; growth, survival, and reproductive viability studies; teratogenic deformity assessment. Canton and Van Derveer (1997) base their argument on the presence of fish species and conclude that water-based selenium criteria were weak, based on a small dataset from a single watershed in southeastern Colorado. Apparently no research or literature search was done to determine whether sensitive species were present historically in southeastern Colorado streams.

Fauna1 surveys, in the absence of historical information, are not sufficient to detect contaminant impacts, or lack thereof, in an open river system. Adverse effects on a portion of a demographically open fish population in a section of the river with contaminant impacts would be very difficult to detect and must be confirmed with detailed biological studies because of immigration of individuals from the portion of the population in nonaffected river reaches or tributary streams. The review by Skorupa (1998) addresses this concern succinctly and states "It is common for instream studies to report the counterintuitive combination of abnormally elevated levels of selenium in fish tissue associated with what is viewed as a normally abundant and diverse fish fauna." The end result is that Canton and Van Derveer (1997) erroneously conclude that the toxic thresholds for selenium derived from laboratory and field studies in closed basins, i.e., demographically closed populations, do not apply to stream studies. Effects of selenium on species or populations of fish in the lake and reservoir studies cited by Canton and Van Derveer (1997) were substantiated with appropriate biological tests, whereas the stream, river investigation by Van Derveer and Canton (1997) was not.

Canton and Van Derveer (1997) and Van Derveer and Canton (1997) repeatedly use this incorrect reasoning that the presence of fish in Colorado streams with elevated selenium concentrations indicates the absence of impacts. Their claim of no biological effects in Colorado streams cannot be confirmed from information given or referenced in their papers. On the contrary, monitoring of fish populations in rivers is an insensitive measure of contaminant effects unless substantial effort is made to assess the health of the fish community. This assertion was addressed by the USEPA in their guidelines for deriving water quality criteria. Stephan et al. (1984) stated that "The insensitivity of most monitoring programs [for number of taxa or individuals] greatly limits their usefulness for studying the validity of [water quality] criteria because unacceptable changes can occur and not be detected. Therefore, although limited field studies can sometimes demonstrate that criteria are under protective, only high quality field studies can reliably demonstrate that criteria are not under protective [i.e., overprotective]." No high quality field studies directly examining the relationship between selenium exposure and a primary response variable, such as egg viability or body condition, were cited by Canton and Van Derveer (1997) to support their conclusion of no adverse effects in Colorado streams. Based on the authors' measure of response, the selenium poisoning of western mosquitofish (*Gambusia affinis)* at Kesterson Reservoir (Saiki and Ogle, 1995) would have been a no-response case.

Fausch et al. (1990) reviewed the most common approaches to assessment of environmental degradation using fish communities in lotic systems, which included (1) indicator taxa or guilds; (2) indices of species richness. diversity, and evenness; (3) multivariate methods: and (4) the index of biotic integrity (IBI). Each of the approaches had specific caveats necessary to addressing disadvantages with the approach. Fausch *et* al. (1990) repeated for each of the approaches the necessity of appropriate reference sites, and for the more data intensive methods (the IBI consists of 12 community attributes), the setting of a priori values, such as the expected fish community for a relatively unperturbed stream in specific ecoregion, by a competent fish ecologist/biologist/ichthyologist. They acknowledge that most of the methods have been developed in the Midwest, and problems with the methods were encountered when applied to other ecoregions. The Ohio Environmental Protection Agency has expended substantial effort in applying the IBI method to water quality monitoring of that state (OEPA, 1988). Canton and Van Derveer (1997) and Van Derveer and Canton (1997) did not use any of these methods to substantiate that healthy fish communities occurred in streams in southeastern Colorado.

Furthermore, their claim of no biological effects in Colorado streams cannot be confirmed from the information given or referenced in their articles. Their statement seemed to have fallen into the null fallacy trap: (1) There is no evidence for adverse effects, versus (2) There is evidence for no adverse effects (J. Skorupa, USFWS, personal communication, 1995). The null fallacy occurs when statement 1 (a null finding) is given equal weight as statement 2 (a positive finding). What often is overlooked is that a null finding usually implies a lack of positive evidence in both directions-for effects or for absence of effects.

Contrary to the claim of Canton and Van Derveer (1997) that there are no biological effects, there is evidence that fish populations in several Colorado, Utah, and New Mexico streams with elevated selenium concentrations are not healthy. Findings in several NIWQP investigations indicate that selenium concentrations are elevated sufficiently in water, bottom sediment, and biota in the middle Green, upper Colorado, Gunnison, Mancos, and San Juan rivers to cause adverse effects in fish and wildlife (Butler et al., 1989, 1991, 1994, 1995; Stephens et al. 1988, 1992; Peltz and Waddell, 1991; Blanchard et al., 1993; Thomas *et al.,* 1997). These rivers have several endangered fish including Colorado squawfish *(Ptychocheilus lucius)*, razorback sucker (*Xyrauchen texanus*), bonytail (*Gila elegans*), and humpback chub (*Gila cypha*). Toxic effects from selenium and other inorganics are important factors in the decline of these species and inhibition of their recovery (Hamilton, 1995, 1998; Buhl and Hamilton, 1993; Hamilton and Waddell, 1994; Waddell and May, 1995; Buhl, 1997; Hamilton and Buhl, 1997a, b; Hamilton *et* al., 1996; 2000; Stephens and Waddell, 1998). Moreover, the Recovery Program for the Endangered Fish Species of the Upper Colorado River Basin dropped one proposed floodplain restoration site for endangered fish because elevated selenium concentrations were present in water and biota, put six sites on temporary hold pending outcome of ongoing selenium research with endangered fish, and have three other sites on temporary hold due to concerns about other inorganic contaminants (P. Nelson, USFWS, written communication, 1997; Holley and Weston, 1995; Stephens *et* al., 1995; Archuleta and Holley, 1996).

4.4. Water/Diet Versus Sediment Uptake

Canton and Van Derveer (1997) state that "The chronic toxicity threat posed by Se is primarily from dietary uptake, which is a result of its propensity to cycle through the sediment, where it enters the benthic-detrital food web and ultimately causes reproductive impairment in fish and wildlife through dietary uptake." The authors of this commentary agree that the detrital pathway is one of the most important pathways by which selenium is recycled. However, waterborne uptake is responsible for the entry of selenium into the aquatic food web (Lemly and Smith, 1987). This critical point is not mentioned by Canton and Van Derveer (1997). Uptake of selenium by bacteria, algae, and aquatic invertebrates rapidly removes selenium from the water column and concomitantly reduces water concentrations, which can give a false impression of low waterborne selenium concentrations precluding adverse effects. For example, Besser et al. (1993) reported that the bioconcentration factor for algal accumulation of selenium from water in absence of sediment was 5300- 15,700 for selenomethionine, 1440-1600 for selenite, and 428 for selenate, and for daphnids these bioconcentration factors were 30,300-229,000, 570-3600, and 293, respectively. Canton and Van Derveer (1997) have presented an incomplete discussion that does not address the importance of waterborne selenium in food web residue dynamics, and do not present data to support their underlying assumption that selenium bioaccumulation and toxicity are more strongly linked to the sediment pathway than the aqueous pathway.

Canton and Van Derveer (1997) further state that "Particulate Se, typically measured as either sediment, detrital, or suspended particulate Se, has been recently identified as a better predictor of adverse biological effects." However, one of the key references they cited in support of this statement (Presser *et* al., 1994) does not promote sediment. detrital, or suspended particulate selenium as the best predictor, but rather stresses the importance of defining selenium contamination based on an ecosystem level evaluation that includes the collection of a variety of food chain organisms (T. Presser, USGS, personal communication, 1997). Presser and Piper (1998) have further illustrated this point in a recent publication in which they apply a mass balance approach to data available for systems impacted by selenium in California. Their definition of mass balance has been expanded beyond that documented in water-quality loads because of the nonconservative behavior of selenium. and consequently they recommend including a biotic component. This new approach to mass balance recognizes the cumulative loading in water, sediment, and biota.

Furthermore, a well-matched dataset of simultaneous measures of selenium in water, sediment, and a relevant biological response variable is needed to derive a predictor of adverse effects. The authors are aware of only one well-matched dataset that meets this criterion. In a study of evaporation ponds in the Tulare Lake basin, California, selenium in water was a better predictor of selenium in eggs of black-necked stilt (*Himantopus mexicanus*) (r^2 = 0.81; Ohlendorf et al., 1993) than was selenium in sediment (r^2 = 0.60; Skorupa et *al.,* 1996). Van Derveer and Canton (1997) concluded the opposite without citing any matched sets of data that support such a conclusion.

Morevoer, the use of Hill's criteria (Hill, 1965) by Canton and Van Derveer (1997) to support their conclusion that sediment selenium is better for predicting adverse biological effects than waterborne selenium is inaccurate and lacks adequate development. Canton and Van Derveer (1997) do not adequately present the support data from the references they cite. It is unclear how they can make conclusions about how sediment organic carbon can be used to predict the bioavailability and toxicity of selenium to biota because they did not present, and apparently did not measure, selenium bioaccumulation at the study sites. Their analysis of linkages between sediment selenium and biological effects (Table 3 in Canton and Van Derveer, 1997) is not supported for several reasons: (1) almost half the sediment selenium concentrations are reported as less than values (below limit of detection), yet these data were apparently used to estimate thresholds; (2) data for sites where effects were predicted by other authors, yet they do not assess the basis or accuracy of those predictions; and (3) their toxicity thresholds were based on the 10th percentiles of observed effects concentrations from a dataset of only seven values.

4.5. In-Stream Considerations

The unsupported logic used to justify the sediment-based water quality criteria presented in Canton and Van Derveer (1997) is cited at least seven times as support in Van Derveer and Canton (1997). Based on the model to calculate a site-specific chronic dissolved selenium stream standard, they calculated an instream standard of 31 μg/L. However, two stream studies with 10 μg/L selenium and fathead minnow and bluegill *(Lepomis macrochirus)* demonstrated adverse biological effects on adults and progeny (Schultz and Hermanutz, 1990; Hermanutz, 1992; Hermanutz et al., 1992). These studies do not support the conclusion by Van Derveer and Canton (1997) that higher water quality standards for selenium are justified in streams.

The error in proposing an instream standard 31 μg/L is not considering the consequence to offstream waters, such as backwaters, oxbows, and reservoirs. There may be no readily observed impacts from selenium in lotic systems. due to relatively low productivity compared to lentic systems that would potentially lower the bioaccumulation of selenium in the lotic environment. However. high in-stream selenium concentrations in an offstream environment, such as a backwater or reservoir, would undoubtedly result in substantial selenium bioaccumulation in the food web and potentially severe effects on fish and wildlife populations. Lemly (1999) addressed this concern by proposing a hydrological unit approach for setting selenium criteria. This method recognizes that all of the hydrologically connected parts of a watershed basin must be considered together and given the same criterion in order to protect against toxic impacts at sites where bioaccumulation is greatest. Skorupa (1998) has also addressed this concern and uses the example of California's Salton Sea. which already exhibits selenium threshold toxicity. He notes that a seemingly trivial increase of l-2 μg/L in Colorado River water, as a result of implementing site-specific selenium criteria within the Colorado River and its tributaries, would double the selenium load delivered to the Salton Sea, which in turn could put millions of fish and birds in serious jeopardy.

Proposing high instream selenium standards must be balanced by considering offstream consequences. Selenium will move throughout the length of the channel of the affected stream or river, and with its terminal destination the ocean. Sedimentaion does not remove selenium entirely from lotic ecosystems. For example, the major finding of the NIWQP investigation of the lower Colorado River between Davis Dam and the U.S.-Mexico border was that consistently higher selenium concentrations occurred in backwaters and oxbows that received water from the Colorado River than in canals returning irrigation water to the river (Radtke *et* al., 1988). The investigation concluded that selenium concentration in the lower Colorado River was not from local agricultural sources, but rather from upstream sources, i.e., the upper Colorado River basin. even though river water had to pass through Lakes Powell, Mead. and Havasu. About 82% of the selenium entering Lake Powell from the Colorado and San Juan rivers passes through to the lower basin downstream of Lake Powell (Engberg. 1999).

Selenium contamination has also been documented in the lower end of the upper Colorado River basin in fish from Lake Powell (Waddell and Wiens, 1993) and in fish from the 24-km river reach between Glen Canyon Dam and Lee's Ferry on the Colorado River (A. Ayres, AZ Dep. Game & Fish, personal communication, 1997). The basis for Skorupa's concern for the Salton Sea is sound (Skorupa. 1998). Prior to selenium arriving at the ocean or terminal destination of a river, protection of offstream effects from selenium toxicity must be the paramount decision point for deriving instream selenium standards. especially for a system like the Colorado River because its entire Bow is diverted offstream under normal condition; i.e., none reaches the ocean (McDowell et al., 1997). However, when the Colorado River did flow to the Gulf of California. river water at Yuma, Arizona, contained 4 μg/L selenium in November 1936 (Byers *et* al., 1938), and water in the Gulf 30 and 70 miles southeast of the mouth of the Colorado River contained 3 μg/L (Lakin and Byers, 1941), which indicates selenium in river water was carried considerable distances into the Gulf.

5. CONCLUSIONS

There is a growing body of literature that continues to document the extensive contamination of aquatic environments with selenium, and the adverse effects in aquatic organisms. The majority of this literature demonstrates the need for a national water quality criterion below the current value of 5 μg/L. Several extensive reviews of the literature have concluded that a criterion of 2 μg/L is justified. Two recent articles that proposed a sediment-based approach to establishing a selenium criterion for streams, especially those in Colorado (Canton and Van Derveer, 1997; Van Derveer and Canton, 1997), failed to find that no biological effects occur in fish populations in Colorado streams with elevated selenium in water or demonstrate that sensitive fish species have not disappeared. They have incorrectly interpreted exposure survey reports as being exposure-response studies, ignored the importance of waterborne entry of selenium in aquatic food webs, overlooked key studies from the extensive body of selenium literature, and failed to consider the offstream consequences of proposing high instream selenium standards. Consequently, Canton and Van Derveer (1997) and Van Derveer and Canton (1997) fail to provide an adequate argument for changing the selenium chronic criterion from a water basis to a particulate or sediment basis. On the other hand, evidence is continuing to increase that a water-based criterion of 2 μg/L is justfied.

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