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Environmental Hazard of Selenium in the Animas La Plata Wate Development Project

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A hazard assessment of selenium was conducted for the Animas La Plata Project, a multiple-use water development proposed for Colorado and New Mexico by the United States Bureau of Reclamation. A published protocol for aquatic hazard assessment of selenium was applied to environmental monitoring data to assess current threats to biota in the water supply rivers (Animas, La Plata, and Mancos Rivers). Hazard evaluations were also made for two proposed reservoirs (Ridges Basin and Southern Ute Reservoirs) based on estimated concentrations of selenium. The assessment protocol indicated moderate hazard in the Animas and La Plata Rivers, and high hazard in the Mancos River and both of the proposed reservoirs. These ratings indicate that the risk of selenium poisoning in fish and aquatic birds is substantial. Moreover, the geology and climate of this site make it prone to irrigation-induced selenium contamination of water and biota. The water supplies already contain dangerously high concentrations of selenium that may increase further due to agricultural irrigation drainage. The stage is set for significant environmental problems unless a development scenario can be devised that will effectively reduce ecological risks.

INTRODUCTION

The Animas La Plata Projedt (Project) has been proposed by the U.S. Bureau of Reclamation (Bureau) as a water resource development that would divert and impound flows of the Animas and La Plata Rivers for agricultural irrigation as well as industrial and municipal uses. The Project would be located in La Plata and Montezuma Counties in Colorado, and San Juan County in New Mexico. Water would be pumped or diverted from the rivers and stored in Ridges Basin Reservoir and Southern Ute Reservoir, both of which would be constructed in the Project. Irrigation water would be pumped or released from the reservoirs into canal systems built to serve local agricultural fields. Both the La Plata and Mancos rivers would receive irrigation drainage water, which would ultimately discharge into the San Juan River. The Project has been in the planning stage since the early 1970s. A complete prospectus a description are given in the 1979 Definite Plan Repo 1980 Final Environmental Statement (FES), and the Supplement to the FES (SFES; USBR, 1979, 1980, 19

Concerns have been raised about the potential fo threats to fish and wildlife because of contaminants (e lenium, mercury, and arsenic) in Project water supplies, as the possibility that irrigation drainage would further d water quality (Finger, 1995; State of New Mexico, There is a longstanding precedent for these concerns b of severe environmental impacts that have occurred a Bureau water development projects; for example, the 1 son National Wildlife Refuge episode in California, *a* "Kesterson Effect" at several other locations in the v U.S. (Lemly, 1994; Lemly *et al.,* 1993; Presser, 1994; 1 et *al.,* 1994). The track record established over the p years indicates that accurate contaminant assessment is requisite for developing environmentally sound agricult rigation in arid western states. Inadequate evaluation o ronmental risks has been a major shortcoming of pr Bureau water development projects (Zahm, 1986; Moore 1990). Construction and implementation of the Anim Plata Project raises important environmental safety iss lated to water quality. Selenium contamination is one most recognized and potentially serious threats to fis wildlife. Fortunately, it is possible to prudently evalu severity of this threat because of the extensive toxicity da on selenium that has developed over the past 10–15 year paper presents the results of a selenium hazard evalua the Animas La Plata Project. It was conducted using the available assessment methodology in order to provide date information for decision makers involved with the F

MATERIALS AND METHODS

Hazard Assessment Method

A recently published technique known as the Pr method (Lemly, 1995) was used to evaluate existing a tential selenium contamination in the Project. Concent of selenium (measured or estimated) were compared to profiles given in the Protocol. A separate hazard ratin

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derived for five ecosystem components (water, sediments, benthic macroinvertebrates, fish, and aquatic birds) based on where the highest selenium concentrations fell on the corresponding hazard profile. Numerical scores were assigned according to the following hazard ratings: none, 1; minimal, 2; low, 3; moderate, 4; high, 5. A final ecosystem-level hazard assessment was determined by adding the scores for each ecosystem component and comparing the total to the following evaluation criteria: no hazard, 5; minimal hazard, 6-8; low hazard, 9-11; moderate hazard, 12-15; high hazard, 16-25.

These criteria can be modified for use when data for one ecosystem component are missing (Lemly, 1996). Modified criteria were necessary to evaluate the rivers in the Project because no data were available for aquatic bird eggs. Modified criteria are the following: no hazard, 4; minimal hazard, 5-7; low hazard, 8–10; moderate hazard, 1 I-14; high hazard, 15-20.

Field validation studies indicate that regardless of whether four or five components are used, hazard estimates generated by the Protocol are more accurate and reliable than those resulting from the U.S. Environmental Protection Agency's hazard quotient method of analysis (Lemly, 1996). Thus, the Protocol has proven to be a good technique for assessing selenium hazards to fish and aquatic birds.

Sources of Data

Selenium data originated from environmental monitoring studies conducted for the Project by the Bureau from December 1992 through April 1994 (Finger, 1995). Selenium concentrations for fish were converted to equivalent egg concentrations (whole-body values x 3.3; given in parentheses) according to Lemly (1995) for use in the Protocol method.

Assessments were made for the proposed reservoirs (Ridges Basin Reservoir and Southern Ute Reservoir) using estimated concentrations of selenium and estimated ecological/hydrological conditions (trophic status, retention time/loading-flushing rates, and primary wildlife management values, i.e., characteristics of the proposed fishery and/or aquatic bird habitat/usage designations). Estimated waterborne concentrations of selenium were based on those given in Finger (1995), which were approximately the same as the average annual dissolved concentration for the water supply rivers (Animas River in the case of Ridges Basin Reservoir; La Plata River in the case of Southern Ute Reservoir) measured during 1992-1994. However, for the current assessment the upper value of the expected range of concentrations was used (50% of the maximum for the rivers) instead of an average concentration in order to more accurately predict the potential for impacts associated with brief high-flow, high-selenium events. Such events can provide a pulse of selenium that results in bioaccumulation and toxicity sufficient to overshadow the effect of lower "mean" or "average" concentrations in impoundments (Lemly, 1996). Moreover, the Protocol specifies the use of maximum waterborne concentrations in order to accurately estimate hazard from bio accumulation (Lemly, 1995).

RESULTS

Concentrations of selenium measured in the water suppl rivers for the Project ranged from 1 to 29 μg/liter (Table 1 Concentrations in sediments and biota ranged from 0.1 to 2. and 1.1 to 46.2 μg/g, respectively. These concentrations are a substantially higher than would be expected in the absence c natural or anthropogenic sources of selenium enrichmet (Lemly, 1985, 1993a).

The estimated concentrations of selenium in biota of th

TABLE 1
Hazard Assessment for Selenium in the Animas La Plata Project

Site and environmental component	Selenium concentration[a]	Evaluation by component		Totals for the si	
		Hazard	Score	Score	Hazar
Animas Rive?					
Water	1-20	High	5		
Sediments	0. I-2.3	Low	3	14	Modera
Invertebrates	1.8-2.9	Minimal	2		
Fish eggs	3.0-15.8	Moderate	4		
Score total:			14		
La Plata Rive?					
Water	1-12	High	5		
Sediments	0.1–0.95	None	1	13	Modera
Invertebrates	1.1-2.2	Minimal	2		
Fish eggs	2.6-39.6	High	5		
Score total:			13		
Mancos River[b]					
Water'	2-29	High	5		
Sediments	0.2–0.8	None	1	16	High
Invertebrates	1.8-l 1.2	High	5		
Fish eggs	5.6–46.2	High	5		
Score total:			16		
Ridges Basin Reservoir[d]					
Water	1-10	High	5		
Sediments	1-8	High	5	25	High
Invertebrates	5–75	High	5		
Fish eggs	5–100	High	5		
Bird eggs	5-100	High	5		
Score total:			25		
Southern Ute Reservoir[d]					
Water	1-6	High	5		
Sediments	1-5	High	5	25	High
Invertebrates	5-50	High	5		
Fish eggs	5-80	High	5		
Bird eggs	5-80	High	5		
Score total:			25		

[a] Concentrations in kg/liter (parts per billion) for water, μg/g (parts p million) dry weight for sediments and biota.
[b] Based on measured concentrations of selenium.
[c] Unfiltered samples.
[d] Based on estimated concentrations of selenium.

proposed reservoirs were obtained by formulating and examining the aquatic cycling and bioaccumulation scenario likely to occur once the reservoirs are impounded, given the estimated waterborne selenium. These predictions were based on a synthesis of environmental data for impoundments with selenium inputs and ecological conditions similar to those expected for the proposed Project reservoirs (e.g., Birkner, 1978; Garrett and Inmann, 1984; Woock and Summers, 1984; Lemly 198.5, 1993c, 1997b; Gillespie and Baumann, 1986; TUGCO, 1986; Stephens *et al.,* 1992; Hallock and Hallock, 1993; Butler *et al.,* 1994). Estimated waterborne concentrations of selenium in the reservoirs ranged from I to 10 μg/liter. Estimated concentrations in sediments and biota ranged from 1 to 8 and 5 to 100 μg/g, respectively (Table 1). As was the case for the rivers, projected concentrations of selenium in the reservoirs are substantially elevated and equal or exceed toxicity thresholds for sensitive species of fish and aquatic birds (Lemly, 1993a).

The following hazard estimates resulted when the Protocol method was applied to these data sets (Table 1): Animas River, moderate hazard (score, 14; four components); La Plata River, moderate hazard (score, 13; four components); Mancos River, high hazard (score, 16; four components); Ridges Basin Reservoir, high hazard (score, 25; five components); Southern Ute Reservoir, high hazard (score, 25; five components).

All of the sites scored a hazard rating of "moderate" or "high." A hazard rating of "moderate" indicates a persistent toxic threat of sufficient magnitude to substantially impair but not eliminate reproductive success; some species will be severely affected while others will be relatively unaffected. A "high" hazard rating denotes an imminent, persistent toxic threat sufficient to cause complete reproductive failure in most species of fish and aquatic birds (Lemly, 1995).

DISCUSSION

Evidence of Ecological Risk

The results of this hazard assessment indicate that the Animas La Plata Project carries high environmental risk with regard to selenium contamination and associated threats to fish and wildlife. According to the Protocol, moderate hazard exists in the Animas and La Plata Rivers and high hazard exists in the Mancos River. High hazard ratings were indicated for both of the proposed impoundments (Table 1). High and moderate hazard denote that complete or partial reproductive impairment may occur in sensitive species of fish and aquatic birds (Lemly, 1995). The question facing decision makers is whether the existing and potential future hazard constitutes an acceptable or unacceptable risk. It is possible to provide some interpretive guidance that may be useful in further delineating this ecological risk.

Risk Factor 1

There is a risk of current and future selenium poisoning in the rivers based on recent conditions at the Project site (1992-1994). Selenium concentrations were 1–20 μg/liter in the mas River, and 1-12 μg/liter in the La Plata River. Co trations in whole fish were l-5 and 1-12 μg/g, respect which converts to approximately 3-16 and 3–40 μg/g in At these tissue concentrations, it would be expected that togenic deformities would occur in some of the devel embryos of sensitive fish species (Woock *et al.,* 1987; Co *al.,* 1993; Lemly, 1993a,c, 1997). Selenium is passed parents to offspring in the eggs, where it is absorbed c early development and can cause a variety of morphol deformities (Gillespie and Baumann, 1986; Lemly, IS Similar effects would also be expected to occur in aquatic if they feed and nest at the Project site (Ohlendorf *et al.,* 1988). Developmental abnormalities in association wi evated tissue concentrations of selenium are a reliabl primary bioindicator of selenium toxicosis (Skorupa Ohlendorf, 1991; Lemly, 1993c; Skorupa *et al.,* 1996). simply necessary to examine embryonic or newly hatche and birds to make the assessment. However, no such st have been conducted at the Project site to determine wh these diagnostic symptoms of selenium poisoning are pr This information would be very useful in evaluating cu conditions and confirming whether there are existing prob that would argue against developing the Project from a fis wildlife health perspective.

Risk Factor 2

There is a risk of selenium toxicosis in the reservoirs if are impounded. Retention times will be long (in excess year, based on projected inflows minus evaporative loss irrigation usage), and consequently, flushing rates will be This creates a scenario in which the potential for seleniu bioaccumulate in aquatic food chains, be efficiently depo and recycled from sediments, and cause ill effects in fish wildlife is maximized. The scientific literature contain ever-expanding record of case histories of such scenarios across the U.S., including sites similar to those under co eration in the Animas La Plata Project (e.g., Garrett an mann, 1984; Woock and Summers, 1984; Lemly, 1985, 19 1997; Gillespie and Baumann, 1986; TUGCO, 1986; Step *et al.,* 1992; Hallock and Hallock, 1993; Butler *et al.,* 1 This environmental data base indicates that the expected centrations of selenium in Project impoundments (up t μg/liter) are capable of causing substantial reproductive pacts to fish and aquatic birds. Recent information indi that even 5 μg/liter is too high to protect sensitive species reproductive toxicity and the effects of Winter Stress drome (Lemly, 1993a,b; Skorupa and Ohlendorf, 1991 order to protect fish and wildlife reproduction, water sup to wetlands and impoundments where bioaccumulatic maximized should contain no more than l-2 μg/liter disso selenium (e.g., Lemly, 1993a,c; Skorupa and Ohlendot-f, 1 Peterson and Nebeker, 1992; Skorupa *et al.,* 1996). On basis, it would appear unwise to proceed with constructio

these impoundments if their intended uses include fish and wildlife habitat and associated recreation.

The credibility of the predictions for impoundments depends on accurately estimating waterborne concentrations. This is particularly difficult given the lack of information on how irrigation drainage may affect selenium loading. For this assessment, 50% of the current (1992–1994) maximum selenium concentration for the water supply river was used as a maximum for the future concentration expected in the reservoir. The rationale for this is as follows.. Once river water enters a reservoir, a portion of the selenium would be removed from solution due to a combination of biological uptake and chemical/physical processes (Lemly and Smith, 1987). Thus, the river water and the impoundments would not be in a simple 1: 1 equilibrium relationship. The amount, removed and the equilibrium concentration reached would depend on several hydrological and biological conditions that can only be estimated, including the contribution of agricultural irrigation return flows to the annual water/selenium budget. However, it is not unusual for selenium concentrations in reservoirs or off-channel wetlands and impoundments to periodically reach 75% or more of the incoming concentration during periods of high flow, rapid recharge following irrigation drawdown, or reduced uptake rates by biota (e.g., Ohlendorf *et al.,* 1987; Allen, 1991; Stephens *et al.,* 1992; Hallock and Hallock, 1993; Butler *et al.,* 1994). The 50% number used in this assessment seems to be environmentally realistic, reasonably conservative (which is necessary given the uncertainties of irrigation drainage), and should produce credible hazard estimates for the Ridges Basin and Southern Ute Reservoirs.

It can be seen from Table 1 that concentrations of selenium in biota are expected to be much greater in the impoundments than the rivers even though the maximum waterborne concentrations are only 50% as high. The reason is because selenium tends to bioaccumulate to a greater extent in lentic systems (Lemly and Smith, 1987; Allen, 1991). The benthic food pathway in wetlands and reservoirs typically plays a much greater role in sequestering selenium in sediments, and remobilizing it into aquatic food chains, than in stream or riverine systems. Thus, for the waterborne concentrations of selenium considered in this study (l-29 μg/liter), the potential for bioaccumulation and associated dietary and reproductive toxicity to fish and wildlife is likely to be substantially greater in the impoundments.

Risk Factor 3

There is risk due to uncertainties about the impact of agricultural irrigation on selenium transport and loading. Selenium levels currently present at the Project site reflect weathering of natural geologic sources and hydrologic transport to the rivers. A rough equilibrium or balance is probably in place. Agricultural irrigation could substantially and rapidly change this balance. Selenium can be highly concentrated (>200 μg/liter) in irrigation drainwater that originates on soils derived from Cretaceous shale formations (seleniferous soils; Presser, 1994; Presser *et al.,* 1994). Most of this project area consists of just such soils. Recent evaluations by the U.S. Geological Survey recognize this fact and indicate that the Animas La Plata site lies in a high-hazard area prone to irrigation-induced selenium contamination of water and biota (Seiler and Skorupa, 1995: Seiler *et al.,* 1997). Selenium in irrigation return flows could markedly affect water quality in the rivers and impoundments of the Project. Consequently, it is necessary to fully account for this portion of selenium loading in any hydrological or toxicity model that is developed. Neither the FES nor the SFES for the Project contain adequate information on future irrigation drainwater scenarios. Thus, it is not possible to formulate toxicity scenarios that are based on realistic drainwater conditions. However, it is essential to do this in order to characterize possible effects of irrigation and, thereby, delineate the influence of agriculture on water quality and selenium threats to fish and wildlife.

CONCLUSIONS

Hazard assessment indicated that selenium poses a significant toxic threat to aquatic biota in the Animas La Plata Project. Several lines of evidence indicate that ecological risk is high with regard to the health of fish and wildlife:

(1) Selenium is elevated in the water supplies for the Project. and residues of selenium in invertebrates and fish are already at or near toxic levels in the La Plata and Mancos Rivers. Consequently, the rivers have essentially no capacity to assimilate additional selenium, which may result from agricultural irrigation.

(2) Projected concentrations of selenium in the waters of Ridges Basin and Southern Ute Reservoirs (up to 10 μg/liter) are unacceptable for wetlands and aquatic habitats intended to support fish and wildlife reproduction. Aquatic food chains in impounded waters from the Animas, La Plata, or Mancos Rivers would likely experience bioaccumulation sufficient to cause reproductive impairment in fish and aquatic birds.

(3) Important environmental safety issues remain unresolved; for example, the question of current selenium teratogenesis in fish and birds, and uncertainties about the quantity and selenium content of agricultural irrigation return flows.

(4) The current selenium status of the Project site reflects a delicate balance between selenium sources (natural geologically derived selenium) and local hydrology driven by an arid climate. Historical evidence suggests that overlaying irrigated agriculture is likely to upset this balance and set the stage for significant environmental problems.

(5) Alternative land and water management scenarios will be necessary to effectively reduce the ecological risks associated with the Project.

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