A Technical Framework for Implementing Aquatic Ecosystem Loading Limits (TMDLs) to Reduce Selenium Pollution From Phosphate Mining Wastes on Caribou National Forest, Idaho

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BACKGROUND

Beginning in 1996, selenium associated with phosphate mining on Caribou National Forest (CNF) was implicated as the cause of death to horses and sheep grazing on private land adjacent to the national forest. In response to these concerns, the Forest Service began a monitoring study to determine selenium concentrations in and around the mine sites. By 1998, the study revealed that elevated concentrations of selenium were present in water, sediment, and biota at many locations. In late 1998, CNF staff contacted me and asked if I would interpret the selenium levels and evaluate the toxic threat to fish and wildlife resources. I reviewed the monitoring data, traveled to CNF and conducted an on-site inspection of the mining operations, and prepared a risk assessment report (Lemly, 1999a). The report concluded that there were significant threats to major populations of Yellowstone cutthroat trout and other species that have high management priority with the State of Idaho and the U.S. Fish and Wildlife Service (e.g., rainbow trout, elk, migratory waterfowl, whooping crane, etc.). Concurrent with my involvement, the U.S. Geological Survey began studies to assess the location and geological nature of the selenium sources. By late 1999, it was clear that selenium leaching from phosphate mine wastes on CNF was indeed responsible for the livestock poisonings, and had also contaminated a large part of the Blackfoot River Watershed. The level of contamination in some mine-spoils was great enough to be designated hazardous waste, and caused the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Justice (DOJ) to begin taking action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as Superfund). The USFWS has taken an active role in the Caribou problem because of risks to migratory waterfowl and whooping crane, which invokes their management responsibilities under the Migratory Bird Treaty Act and the Endangered Species Act. Also, the State of Idaho (State) is designating the Blackfoot River and Blackfoot Reservoir as “impaired water bodies”, which triggers federal regulatory actions for remediating water pollution under Section 303(d) of the Clean Water Act. Thus, by 2000, what was initially viewed by some to be a local environmental problem for Region 4 of the Forest Service had escalated into a national, interagency issue, and was identified as one of the most important emerging selenium contamination issues in the USA (Lemly, 1999b).

NEED FOR TMDLs

With the scope and ecological risks of the Caribou issue now fairly well defined, attention is shifting to cleanup, remediation, and control of selenium pollution. The next step in resolving the environmental aspect of the problem is for the Forest Service to develop a contaminant management plan that meets regulatory requirements and also protects fish and wildlife resources. This plan will need to address concerns of the State and EPA under Section 303(d) of the Clean Water Act — i.e., the designation of impaired water bodies — and also satisfy the concerns of DOJ under CERCLA. Within EPA’s current regulatory framework, this is done by setting Total Maximum Daily Load limits (TMDLs). The objective of TMDLs is to identify all pollution sources and then allocate/regulate discharges to meet the water quality needs of aquatic life within the basin. The TMDL process will be necessary to determine the ecological capacity of the Blackfoot Watershed for selenium, and set limits on how much selenium can be safely discharged from CNF into the Blackfoot River and Blackfoot Reservoir. As the responsible party (i.e., the trustee of the land from which the pollution emanates), the Forest Service is liable for implementing pollution control strategies to meet TMDL limits, and conducting effectiveness monitoring. Because of selenium's unique biogeochemical cycle, it's propensity to bioaccumulate and cause teratogenic deformities and reproductive failure in wildlife, and it's long-term persistence in the environment (Lemly, 1985, 1993a, 1997; Lemly and Smith, 1987), special procedures are required to set environmentally safe TMDLs for this contaminant. Neither the State nor EPA have such procedures. Although the EPA has published an overview document that explains principles underlying the development and implementation of TMDLs (USEPA, 1999), no selenium-specific guidance is given. This leaves biologists and environmental contaminant specialists without the assessment framework necessary to effectively address the TMDL issue for selenium. It is critical to have a technically sound approach for evaluating selenium because it is considered a priority contaminant by natural resource managers and EPA. Moreover, proposing TMDLs for this trace element is likely to generate attention by groups with widely divergent interests, who could challenge the validity of the techniques used. This report provides the necessary guidance by laying out an assessment method that links the basic components of EPA's TMDL process to the contaminant-specific information required for selenium. The hazard assessment procedures and interpretive guidelines used in the method have all been published in the peer-reviewed literature. This methodology can be used as a technical framework by DOJ as it moves forward with the CNF selenium contamination issue. The resulting TMDLs will be environmentally safe, meet state and federal regulatory requirements, and afford protection to fish and wildlife resources.

PROCEDURE

The method presented here is structured to answer two basic questions:

(1) Is selenium impairing the water body based on biological criteria, and

(2) If so, what amount of selenium load reduction is necessary to correct the problem.

A 7-step procedure can be used to answer these questions and develop environmentally safe TMDLs for selenium. The basic premise in this approach is that selenium concentrations be kept below levels that threaten the reproduction of fish and aquatic birds.

Step 1): Delineate and characterize the hydrological unit (HU) of concern.

TMDLs for selenium should be based on an assessment of the degree of toxicological hazard to fish and wildlife, which is influenced by the hydrology of the site under consideration. The physical area from which measurements are taken to evaluate selenium concentrations and biological threats/effects, i.e., the database for setting TMDLs, must encompass more than an isolated segment of a river, a tributary stream, etc. Because of hydrological connections between the various aquatic habitats that may be present in a watershed basin – wetlands, rivers, streams, lakes, and impoundments – the toxic threat from selenium contamination is also connected. For example, a TMDL that is set for a stream or river where low bioaccumulation occurs may result in *seemingly* harmless concentrations becoming a problem in downstream impoundments or in off-channel bays and wetlands where bioaccumulation is greater.

The hydrologically connected parts of a basin that are downgradient of a selenium input (natural or anthropogenic selenium source), extending to the point at which new sources of low-selenium water dominate the hydrology and lower concentrations below levels of concern (e.g., confluence with a larger tributary or river, spring or groundwater inflow), should be the area evaluated and given a specific TMDL, not isolated parts (Figure 1). Thus, a hydrological unit (HU) should be identified and used as the "site" for the purpose of setting TMDLs. Importantly, TMDLs derived is this manner will reflect the transport and bioaccumulation of selenium within the entire HU rather than simply focusing on a small, artificially designated segment of the system. Failure to use a HU approach can set the stage for significant biological problems and undermine the intended outcome of the TMDL process. Consult Lemly (1999c) for more information on the rationale and justification for using HU's.

Substitute HU for the term "water body" used by states and EPA in their TMDL documentation, and use the entire HU as a "mixing zone" for the purpose of evaluating potential selenium transport and bioaccumulation. Characterize and map the aquatic system of the HU using available information in combination with field reconnaissance to identify/verify hydrological connections. Identify all aquatic habitats within the HU: wetlands, streams, rivers, off-channel bays, lakes, reservoirs, other impoundments; map their spatial and gradient/hydrological relationships, i.e., know what flows where, and into/out of what. Obtain information on trophic status, prevailing sediment type (organic, inorganic, mixed), and volume replacement times or flushing rates for lakes, reservoirs and other impoundments, bays off main-stem rivers, and wetlands; describe general level of primary productivity (low-oligotrophic, moderate-mesotrophic, high-eutrophic), predominant flow regime (slow, moderate, swift), and dominant sediment characteristics (depositional, erosional, particle size, organic, inorganic, mixed) of flowing-water habitats. Large rivers merit special attention in order to identify, map, and describe the variety of habitats that may be present, e.g., main-stem, off-channel bays, seepage or floodplain wetlands, etc. Characterize fish and wildlife uses (feeding, spawning, nesting, migration, etc.) and identify biota of special concern, i.e., endangered or threatened species, management priorities, and selenium-sensitive species (e.g., centrarchid fishes, *Lepomis* sp., *Micropterus* sp.; waterbirds such as stilts, *Recurvirostra* sp.; and ducks, *Anas* sp.). Also, identify habitats where bioaccumulation would likely be greatest (e.g., wetlands, lakes, reservoirs and other impoundments, and off-channel backwater areas of rivers).

Step 2): Determine if selenium is present at hazardous levels in the HU.

Gather information on selenium concentrations. If there is no recent monitoring data (within the past 3 years), or if the data do not satisfy the following requirements, then it will be necessary to collect and analyze new samples. Selenium concentrations are needed for 5 ecosystem components: water, sediments, benthic macroinvertebrates, fish eggs, and aquatic bird eggs (use fish/bird tissue to egg conversion factor of 3.3 if no eggs are available; i.e., tissue concentration X 3.3 = approximate egg concentration; Lemly and Smith, 1987). If bird eggs **OR** fish eggs cannot be obtained (but not both missing), a 4-component assessment can be done. Collect a minimum of 10 samples of each component in each major habitat type present in the HU (stream, river, off-channel bay, wetland, lake, reservoir, other impoundment). Make sure to designate sampling sites throughout the HU to provide adequate spatial coverage. Maintain high quality assurance/quality control in all sampling and analysis; document QA/QC procedures for future reference. Evaluate selenium concentrations with hazard assessment protocol (Lemly, 1995 for 5-component datasets; Lemly, 1996 for 4-component datasets) to determine the hazard rating. A rating of low, moderate, or high hazard indicates that the TMDL process should continue. A rating of either minimal or no hazard indicates that TMDL calculations are not necessary, but the HU should be monitored by applying the assessment protocol to selenium measurements made on a 3-year interval. If monitoring reveals that hazard has increased above the minimal level, TMDL reductions are needed.

Step 3): Determine selenium sources, concentrations, and discharge volumes.

Identify all possible sources of selenium (agricultural, industrial, petrochemical, mining, etc.) and map them in the HU, noting their proximity/discharge to specific habitat types, i.e., wetlands, streams, rivers, reservoirs, etc. Determine/verify selenium concentrations from each source using existing data or by analyzing new samples; determine/estimate average discharge volume from each source. Calculate total existing selenium loading rate to the HU (kg/day).

Step 4): Estimate the retention capacity of the HU for selenium.

A key part of the TMDL process for selenium is to estimate retention capacity (RC). This will determine the sensitivity of the HU to selenium and, thereby, serve as an indicator of how much selenium the system can tolerate. For the purposes of this paper, RC is defined as the propensity of a system to accumulate and conserve selenium. Components of RC include bioaccumulation, detrital retention, physical and chemical sequestration, and recycling within the HU. The more that selenium is held within a HU – whether incorporated in biota, deposited in sediments, etc., – the higher the RC. It is necessary to know 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.

To a large extent, RC depends on the degree of bioaccumulation and internal recycling in the HU, which is reflected in (1) primary productivity, (2) water flow regime, and (3) sediment type. From the characterization of HU done in Step 1 (above), information on these three factors should be available for each aquatic habitat. Use the matrix in Table 1 to assign each of these factors a separate RC rating; low, medium, or high. A rating should be done for each distinct habitat in the HU, i.e., each main-stem river, off-channel bay, stream, wetland, lake, reservoir, and other impoundment.

An overall RC rating for each habitat is determined by combining the three factor ratings as follows:

3 low ratings = low RC

2 low and 1 medium = low RC

2 low and 1 high = medium RC

2 medium and 1 low = medium RC

2 medium and 1 high = medium RC

3 medium ratings = medium RC

2 high and 1 low = medium RC

2 high and 1 medium = high RC

3 high ratings = high RC

The final RC rating for the HU should be set equal to the highest individual habitat rating. For example, if there are two habitats with low RC and one with medium RC, the final RC rating for the HU is medium.

Step 5): Calculate the total allowable selenium load.

Begin by plugging the hazard rating from Step 2, and the RC from Step 4, into the matrix in Table 2. The table indicates the appropriate amount of load reduction needed: small, medium, or large. The total existing selenium load should be reduced by 10% if the amount designated is small, 25% if it is medium, and 50% if it is large. Subtract the indicated amount from the total existing selenium loading rate (kg/day) calculated in Step 3. This will yield the total allowable selenium load for the HU.

Step 6): Allocate total allowable selenium load among discharge sources.

Designate allowable discharges making sure to keep habitat type and sensitive species in mind. For example, it would be inappropriate to allow the largest loading to occur in habitats occupied by priority species (threatened or endangered, or management priority), selenium-sensitive species (e.g., centrarchid fishes, *Lepomis* sp., *Micropterus* sp.; waterbirds such as stilts, *Recurvirostra* sp.; and ducks, *Anas* sp.), or where bioaccumulation would likely be greatest (e.g., in a wetland, lake, reservoir, or off-channel backwater area of a river).

Step 7): Monitor to determine effectiveness of selenium load reduction in meeting environmental quality goals.

The objective of the TMDL process is to keep selenium concentrations below levels that are toxic to biota. Therefore, it is important to use environmental quality goals as a guide in follow-up effectiveness monitoring. For this purpose, I recommend that the following guidelines be used as maximum allowable selenium concentrations (Lemly, 1993b, 1995):

Water = 2 µg/l, filtered samples (0.45 µm)

Sediment = 2 µg/g dry weight

Benthic invertebrates = 3 µg/g dry weight

Fish tissues: whole body = 4 µg/g dry weight

skeletal muscle (skinless fillets) = 8 µg/g dry weight

liver = 12 µg/g dry weight

ovary and eggs = 10 µg/g dry weight

Aquatic bird tissues: liver = 10 µg/g dry weight

eggs = 3 µg/g dry weight

These guideline values represent concentrations that are protective of fish and wildlife reproduction. Monitor selenium residues annually, and apply hazard assessment protocols (same as for Step 2) to determine if hazard is reduced to either the minimal or no hazard level. If it is, then no further load reductions are necessary – conduct environmental monitoring every 3 years. If it isn't, repeat Step 5 to determine the additional amount of selenium load reduction necessary, implement load reduction, and monitor annually. The entire TMDL process is summarized in Figure 2.

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Table 1. Retention capacity (RC) ratings for selenium in aquatic systems based on habitat type and general biological/physical characteristics.

	Habitat Type		
	Stream, Main-Stem River	Lake, Reservoir, Off-Channel Bay, Impoundment	Wetland
Productivity			
High (eutrophic)	High	High	High
Moderate (mesotrophic)	Medium	Medium	Medium
Low (oligotrophic)	Low	Low	Low
Flow			
Swift	Low	Low	Low
Moderate	Medium	Medium	Medium
Slow	High	High	High
Sediment			
Inorganic	Low	Low	Low
Mixed	Medium	Medium	Medium
Organic	High	High	High

Table 2. Amount of selenium load reduction necessary for a hydrological unit (HU) based on hazard rating and retention capacity (RC).

	Hazard Rating		
	Low	Moderate	High
RC of HU			
Low	Small	Medium	Large
Medium	Medium	Medium	Large
High	Medium	Large	Large

Figure 1. Illustration of the "hydrological unit" concept. Arrows indicate the relative concentrations of selenium. The interconnected parts of a unit may include several types of aquatic habitats; for example, a main-stem river, an off-channel wetland, and a reservoir. The hydrological connections transport selenium throughout the unit and thus greatly influence its bioaccumulation potential. Because of this, the entire hydrological unit should be the "water body" that is used to develop a TMDL for selenium.

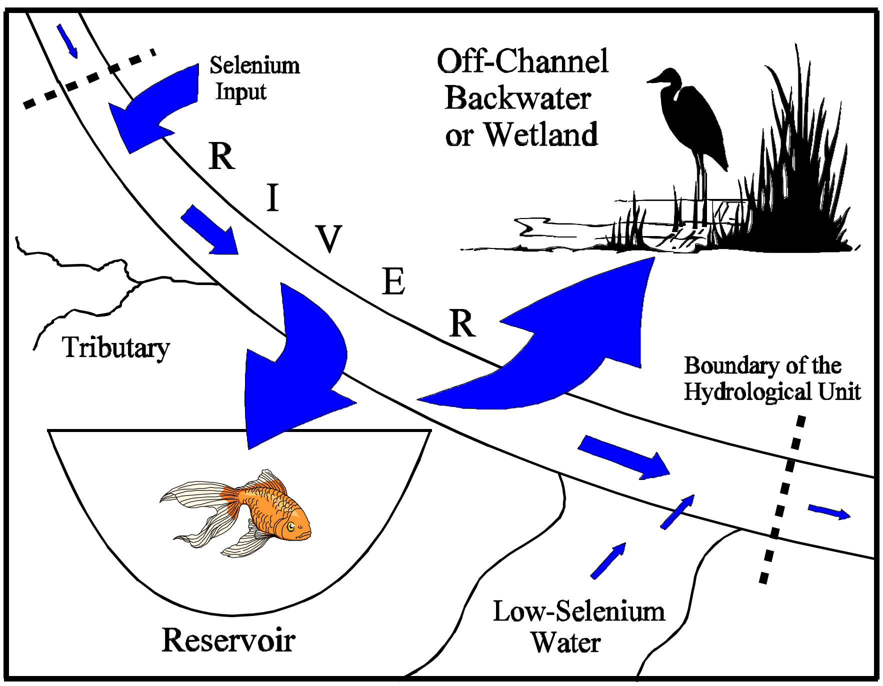

Figure 2. Steps in the TMDL process for selenium.