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A Procedure for Setting Environmentally Safe Total Maximum Daily Loads (TMDLs) for Selenium

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This article presents a seven-step procedure for developing environmentally safe total maximum daily loads (TMDLs) for selenium. The need for this information stems from recent actions taken by the U.S. Environmental Protection Agency (EPA) that may require TMDLs for selenium and other contaminants that are impairing water bodies. However, there is no technical guidance from EPA or elsewhere that deals exclusively with selenium. This leaves biologists and environmental contaminant specialists without the tools needed to effectively address the TMDL issue for selenium. This article provides 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 underlying principle in this process is that selenium concentrations be kept below levels that threaten reproduction of fish and aquatic birds. The steps are: (1) Delineate and characterize the hydrological unit (HU, i.e., water body) of interest. (2) Determine selenium concentrations and assess biological hazard. (3) Determine sources, concentrations, and volumes of selenium discharges; calculate existing selenium load. (4) Estimate retention capacity of HU for selenium. (5) Calculate the total allowable selenium load and specify reductions needed to meet the target loading. (6) Allocate selenium load among discharge sources. (7) Monitor to determine effectiveness of selenium load reduction in meeting environmental quality goals. Proper application of this procedure will ensure compliance with EPA regulatory requirements and also protect fish and wildlife resources.

INTRODUCTION

This article was prepared to provide field biologists, environmental contaminant specialists, and natural resource managers with a step-by-step procedure for developing total maximum daily loads (TMDLs) for selenium. The need for this information stems from recent actions taken by the U.S. Environmental Protection Agency (EPA) that may require TMDLs on impaired water bodies. For many years, water quality regulations in the United States have been implemented through point-source control programs such as the National Pollution Discharge Elimination System (NPDES) permit system. Recently, the USEPA has placed more emphasis on characterizing and reducing nonpoint sources of pollution to provide watershed-level improvement of water quality. This approach, know as total maximum daily loads, sets a limit on the total aggregate amount of a contaminant allowed in an aquatic system. 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 a watershed. The states are required to identify impaired water bodies to comply with Section 303(d) of the Clean Water Act. The USEPA is working with states and implementing the TMDL process as a way to gauge point and nonpoint sources of pollution, control/reduce discharges, and improve overall water quality pursuant to the requirements of Section 303(d). The EPA has requested that state and federal biologists provide input in this process for substances ranging from nutrients and sediments to pesticides and trace elements such as selenium. Every substance identified as a priority must be given a separate TMDL assessment, and this must be done independently for each impaired water body. The biologist's role may range from a simple review and recommendation based on available information to coordination/conduct of field work to assess contaminant cycling and fate, fish and wildlife exposure, toxicity, etc., involving considerable time and resources.

The magnitude of this effort becomes apparent when one considers that each state may have dozens to hundreds of impaired water bodies that will need TMDLs, many of which could involve selenium because of its widespread concern as a water quality issue (Lemly et *al*., 1993; Lemly, 1999a). Although USEPA has published an overview document that explains principles underlying the development and implementation of TMDLs (USEPA, 1999), no procedures specific to selenium are given. This leaves biologists and environmental contaminant specialists without the assessment framework necessary to effectively address the TMDL issue for selenium. Due to selenium's propensity to

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bioaccumulate and cause reproductive impairment in fish and wildlife, and persist in the environment, selenium-specific methods are needed. It is critical to have a technically sound approach for evaluating selenium because it is considered a priority contaminant by natural resource managers and USEPA. 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 article provides guidance by laying out an assessment method that links the basic components of EPA's TMDL process to the contaminant-specific information necessary for selenium. The hazard assessment procedures and interpretive guidelines used in the method have all been published in the peer-reviewed literature.

PROCEDURE

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

1. Is selenium impairing the water body based on biological criteria,
2. If so, what amount of selenium load reduction is necessary to correct the problem?

A seven-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

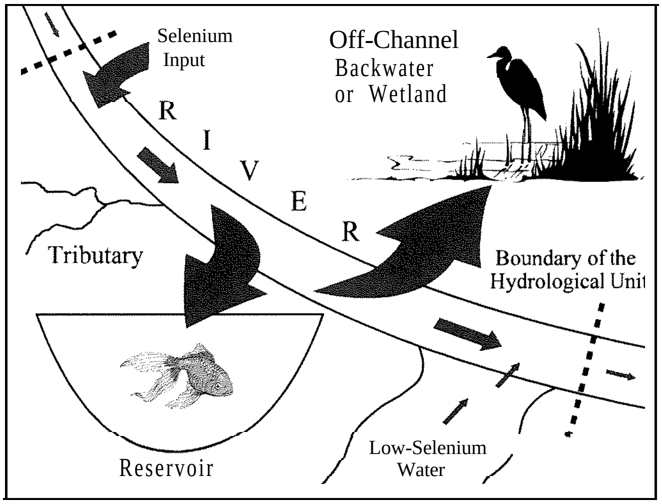

FIG. 1. Illustration of the "hydrological unit" principle. Arrows indicate the relative concentrations of selenium **The** interconnected parts of a unit may include several types of aquatic habitats, for example, a main-stem river, an off-channel wetland, and a reservoir. The hydrological connections 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.

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 (Fig. 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 (1999b) for more information on the rationale and justification for using HUs.

Substitute HU for the term "water body" used by states and USEPA 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 oft' 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 to identify, map, and describe the variety of habitats that may be present, e.g., main-stem, off-channel bays, seepage or floodplain wetlands. 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 are 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 five 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 four-component assessment can be done. Collect a minimum of IO 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 five-component datasets; Lemly, 1996, for four-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 bc 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. 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).

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

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, KC 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 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 Row 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

TABLE 2

Amount of Selenium Load Reduction Necessary for a Hydrological Unit (HU) Based on Hazard Rating and Retention Capacity (RC)[a]

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

[a]Necessary load reductions = 10% for small, 25% for medium, 50% for large.

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 I 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, *Anus* sp.), or where bioaccumulation would likely be greatest (e.g., in a wetland, lake, reservoir, or off-channel backwater area of a river).

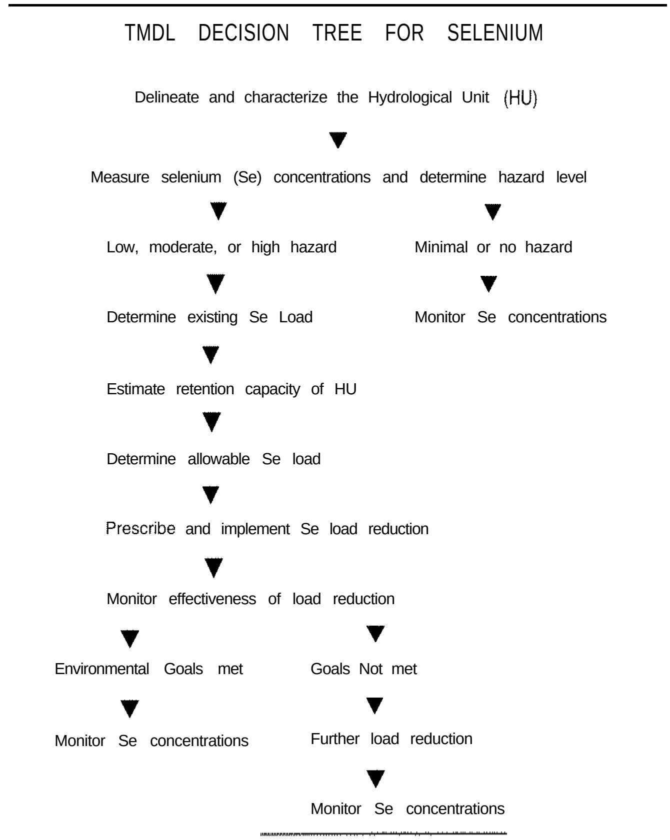

FIG. 2. Steps in the TMDL process for selenium.

Step 7: Monitor to Deter-mine Effectiveness of Selenium Loud 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, 1993, 1995):

Water = 2 μg/L, filtered samples (0.45 μm)
Sediment = 2 μg/g dry wt
Benthic invertebrates = 3 μg/g dry wt
Fish tissues: whole body = 4 μg/g dry wt
skeletal muscle (skinless fillets) = 8 μg/g dry wt

liver = 12 μg/g dry wt
ovary and eggs = 10 μg/g dry wt
Aquatic bird tissues: liver = 10 μg/g dry wt
eggs = 7 μg/g dry wt

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 is not, 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 Fig. 2.

CONCLUSIONS

On the surface, the TMDL process may seem to be a formidable EPA regulatory requirement that generates uncertainty and apprehension, and is not easily addressed. Without adequate technical guidance, this may be true in many cases. However, the straightforward, seven-step procedure given in this article takes away the uncertainty and allows environmentally safe TMDLs to be set for selenium. It is important to use this specific method because it is tailored to account for selenium's ability to bioaccumulate and cause reproductive toxicity to fish and wildlife. A key part of the method is the identification and use of a hydrological unit (HU) as the basis for evaluation. The HU approach provides the contaminant-specific site characterization that is necessary for selenium. Proper application of this TMDL technique will ensure compliance with EPA regulatory requirements and also protect fish and wildlife resources.

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