DRAFT RSET ISSUE PAPER #18 – Development Of Tissue Trigger Levels For Aquatic-Dependent Wildlife

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QUESTION/ISSUE: How should tissue levels be developed to protect higher trophic level wildlife from exposure to contaminants that bioaccumulate?

DISCUSSION:

<u>Background</u>: Aquatic organisms in both freshwater and marine environments can be exposed to bioaccumulative contaminants as a result of dredging or disposal of dredged materials. During the dredging or disposal process, sediment is re-suspended into the water column and resettles in or downstream from the dredge cut or disposal site. At the site of the dredge cut, a new sediment surface layer is exposed and new materials can slough into the dredge cut area during side-slope adjustment. If sediment at these sites contains bioaccumulative contaminants at any concentration, aquatic organisms can be exposed to the contaminants through contact with re-suspended materials during dredging or disposal, re-colonization of areas where contaminated sediment has been exposed in the dredge cut, or through resettlement of contaminated suspended materials on surface areas in or near the dredge or disposal site. The degree of contaminant exposure in aquatic organisms would be determined by the duration of time an organism is exposed to contaminated materials, the bioavailability of the contaminant to specific organisms, and the ability of organisms to metabolize, eliminate, and accumulate a contaminant. These variables make quantifying an organism's exposure during the relatively short dredging timeframe difficult, and insufficient data exists to support a relationship between concentrations of bioaccumulative contaminants in sediment and their absolute bioavailability to aquatic organisms (i.e., it is difficult to predict if bioaccumulation will occur based on sediment concentrations alone).

Because aquatic organisms such as sediment-dwelling invertebrates and fish can be exposed to bioaccumulative contaminants during dredging and disposal operations, it is important to understand how the accumulation of contaminants into the tissues of these organisms can adversely affect higher trophic animals, such as birds and mammals, when consumed. In this paper, we describe a process to use "tissue trigger levels" in wildlife prey items as a first step in developing sediment cleanup levels that are protective of higher trophic species exposed to bioaccumulative contaminants at sediment dredge and disposal sites. These tissue trigger levels are appropriate for both freshwater and marine dredge and disposal sites.

This paper provides a general set of concepts that should be considered in developing tissue trigger levels for contaminants that bioaccumulate[1] and biomagnify[2] in food chains. A tissue trigger level is defined as the concentration or target level of a bioaccumulative contaminant in a prey item that is considered protective of aquatic-dependent wildlife (birds and mammals that prey on aquatic species). Thus, contaminants present in prey items at or below the trigger level will not harm the most sensitive life stage of bird or mammal predators. Because it can be difficult and costly to directly measure tissue concentrations in higher order receptors, we consider prey items as sentinels, which can be monitored on a site-specific basis to determine if action is warranted to protect aquatic-dependent wildlife from bioaccumulative chemicals in a watershed. Though sediment ingestion is another pathway by which chemicals can enter aquatic dependant wildlife, the dietary pathway tends to be the dominant source for bioaccumulative chemicals (Bridges et al. 1996).

It is important to note that tissue trigger levels are not toxicity reference values (TRVs) and therefore may not be protective of the prey species themselves. Rather, tissue trigger levels are derived based on TRVs previously established and reported for the protection of sensitive life stages of higher trophic level species. Therefore, TRVs for the receptors identified in a watershed must be available prior to identifying a trigger level. Although contaminants can bioaccumulate and harm species lower in the food chain such as invertebrates and fish, the focus of this paper is solely on protecting avian and mammalian species. Companion papers from other RSET subcommittees will address the protection of lower trophic level aquatic species such as fish and invertebrates.

The tissue trigger levels outlined in this paper can be used with chemical-specific biota-sediment accumulation factors (BSAFs) to develop Sediment Quality Values (SQVs) protective of higher trophic level dietary exposure pathways. The process and conditions that may warrant development of sediment-based protective values is addressed in other companion RSET papers.

Chemicals of Concern to Aquatic-dependent Wildlife:

Organic and inorganic chemicals commonly taken up in aquatic food chains can be accumulated or magnified over time to concentrations that are potentially harmful to higher trophic level species even when these concentrations may not be harmful to their prey organisms (U.S. Environmental Protection Agency (EPA) 1998). Researchers have a reasonably good handle on the types of chemicals that are typically of concern to aquatic dependant wildlife through dietary bioaccumulation (Bridges et al. 1996; Froese et al. 1998; EPA 2003). The first step in understanding the potential risk to aquatic-dependent wildlife

[1] Bioaccumulation is a process reflecting the net accumulation of a chemical by an organism as a result of uptake from all environmental sources. A bioaccumulative chemical accumulates in an organism faster that can be eliminated, resulting in higher concentrations in the organism compared to the organism's surroundings.

[2] Biomagnification is the process by which a chemical is transferred through the foodchain (i.e., trophic transfer) and concentrates in higher order receptors at levels that are many times higher than in receptors at lower trophic levels. The concentrations that reside in predators such as fish-eating birds and mammals can be high enough to affect reproduction or result in other chronic toxic effects, even though the concentrations in their prey items at lower trophic levels may be below threshold effect levels.

from trophic transfer is to conduct a site-specific review of the chemicals occurring in the sediment and/or tissue in the watershed of interest, or refer to companion RSET papers identifying bioaccumulative chemicals of concern (BCOCs). If no BCOCs occur in site sediment (or tissue) based on a review of sufficient data with adequate detection limits, then a further evaluation of the potential for trophic transfer (bioaccumulation into wildlife) would not be required.

Defining Aquatic-dependent Wildlife Receptors

Recognizing the difficulties on developing tissue trigger levels on a site-specific basis, guidance is provided in this paper to developing tissue trigger levels in wildlife prey items that are more broadly applicable to a wide range of sites. If the wildlife sentinel species discussed herein are for some reason less appropriate for a particular site, then the same general approach may be used to develop other tissue trigger concentrations in the prey items of additional wildlife species. However, it is likely that the concepts presented in this paper will be applicable to most if not all sites where BCOCs are present that could impact higher trophic wildlife.

Certain avian and mammalian receptors are frequently considered as “representative” or sentinel wildlife receptors as shown in Table 1. These include the great blue heron, belted kingfisher, osprey and bald eagle, which consume large amounts of fish in their diets. Most of these receptors are found in both freshwater and marine environments. Depending on the type of water body under consideration, shorebirds (such as the stilt, avocet or sandpiper) may also serve as representative receptors since these birds typically consume aquatic invertebrates including insects and crustaceans, which may bioaccumulate metals/metalloids to a higher degree than fish consumed by predominantly fish-eating birds. Mammals that commonly feed on crustaceans and fish in watersheds include river otter, sea otter and mink.

The following sentinel wildlife species are representative for wildlife occurring in many freshwater and marine environments.

Table 1. Common Aquatic-dependent Wildlife Receptors in Freshwater and Marine Systems

Candidate Wildlife Receptors	Scientific Name	Present in RSET Region?	Dominant Food Items
Birds			
Great Blue Heron	*Ardea herodias*	Yes	Fish, crustaceans, small mammals
Belted Kingfisher	*Ceryle alcyon*	Yes	Fish and crayfish

Black-Necked Stilt	*Himantopus mexicanus*	Yes (summer)	Aquatic (including emergent) insects, small fish
American Avocet	*Recurvirostra Americana*	Yes (summer)	Mostly crustaceans and insects (including emergent)
Spotted Sandpiper or Western Sandpiper	*Actitis macularia or Calidris mauri*	Yes	Aquatic insects, mollusks, worms, crustaceans
Bald Eagle	*Haliaeetus leucocephalus*	Yes	Fish, fish-eating and non-fish eating birds, some mammals
Osprey	*Pandion haliaetus*	Yes	Fish
Mammals			
North American River Otter**	*Lutra canadensis*	Yes	Fish predominantly. Also crustaceans (crayfish)
Northern Sea Otter*	*Enhydra lutris lutris*	Yes	Marine fish, shellfish and invertebrates
American Mink**	*Mustela vision*	Yes	Crustaceans (crayfish), fish

* Predominantly a marine species
** Predominantly a freshwater species

Development of Tissue Trigger Levels

Tissue trigger values should be derived after selecting the receptor species used to represent a site and identifying TRVs from the literature that are protective of the receptors. The TRVs selected from the literature should address information about the likelihood of biological effects to aquatic-dependent wildlife (for example, reduced survival, growth, and reproduction) and address what level of bioaccumulation constitutes an “unacceptable adverse effect.” Once the TRV is selected, empirical data collected from the watershed or data from literature reviews can be used to derive a tissue trigger. Key parameters identified for use in modeling should come from the literature and be based on studies specific to the receptor. Additional site-specific parameters can be added at any time to fine-tune the model and potentially adjust the tissue trigger level in an area if warranted.

TRVs from the scientific literature or other noted data sources will be the primary focus when developing the generic prey tissue trigger levels for RSET. Tissue trigger levels are developed based on toxicity studies for wildlife species as closely related to the species of

[3] Gavage studies can be considered if well-conducted dietary studies are not available for a BCOC. Gavage

interest at a site as possible. Two types of TRV studies are of greatest relevance to setting wildlife prey item tissue trigger levels: dietary TRV and egg-based TRV studies. The approach for establishing tissue trigger levels using each type of TRV study is presented below.

Establishing Prey Tissue Trigger Levels Using Dietary TRV Studies

The most straightforward way to determine if concentrations of BCOCs are of concern in wildlife prey items is to compare concentrations measured in these organisms at a site to the dietary test concentrations from a well-conducted TRV study for the wildlife species of interest. The TRV ideally should represent a no-observed-adverse effect level (NOAEL). Where a NOAEL is not available, a low-observed-adverse effect level (LOAEL) can be considered, although LOAELs may not be protective of listed species and safety factors may need to be incorporated in the assessment. The use of dietary studies for establishing TRVs makes the implicit assumption that the dietary exposure pathway is of greater importance than other exposure pathways such as incidental sediment ingestion. This is generally the case for most receptors, although the sediment ingestion pathway can be of high importance for receptors such as shorebirds.

TRV studies should be based on sensitive toxicity endpoints such as reproduction as a matter of priority. Also, the dietary TRV selected should be protective of the most sensitive life stage of a receptor for a particular test chemical (i.e., if a test chemical exerts toxicity at lower concentrations to developing embryos or juveniles compared to adults, then a TRV protecting these more sensitive life stages should be used in the assessment). TRV studies with toxicity endpoints relative to impacts on growth and survival may also be considered when more sensitive reproductive endpoint TRV studies are not available. The studies should be dietary to have maximum relevance to establishing tissue trigger levels for use at dredging and disposal sites. For the dietary approach, injection or other non-dietary based studies have less relevance in establishing tissue trigger levels since the goal in establishing tissue trigger levels is to determine *what levels in wildlife food* could cause them harm and be easily monitored[3]. Fortunately, many dietary studies are available for BCOCs in the scientific literature and can be used for establishing tissue trigger levels for wildlife protection.

Commonly used databases containing wildlife TRV studies include EPA's Soil Screening Levels (EPA 2003), Oak Ridge National Laboratories (ORNL), EPA's ECOTOX database (ECOTOX 2003), and the Environmental Residue-Effects Database (ERED) 2003. The scientific literature should be consulted in cases where TRV studies are not available from these sources.

The tissue trigger level is established using the NOAEL (or LOAEL with adjustment) dietary test concentration from a well-conducted TRV study. As an example, the selenium

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represents forced oral administration to the stomach using oil, water or capsule. Resulting tissue trigger levels established from this type of study should be interpreted with greater caution. As a matter of priority well-conducted dietary studies are always the preferred type of TRV study.

[4] Compounds that demonstrate "dioxin-like" effects include dioxins, furans and some PCB congeners (EPA 2003).

NOAEL for mallards is 4 mg/kg in the diet (Heinz et al. 1989). Therefore, if selenium concentrations greater than 4 mg/kg in aquatic invertebrates or fish at a given site are measured it could be concluded that there is a potential risk to aquatic-dependent birds feeding on these organisms. Ideally, an adjustment for the difference in food ingestion rate to bodyweight ratios between the test wildlife species in the TRV study and the species of interest at the site should be made. This adjustment is made as follows:

$$\textbf{Tissue Trigger Level} = \mathbf{C_{tissue}} \cdot \frac{\mathbf{FIR_{test}}}{\mathbf{BW_{test}}} \cdot \frac{\mathbf{BW_{site}}}{\mathbf{FIR_{site}}}$$

Where:

Tis. Trig. Level	=	Allowable prey concentration for wildlife (mg/kg)
C_{tissue}	=	Chemical concentration in TRV test diet (food item)
FIR_{test}	=	Food ingestion rate of TRV test species (kg/day)
BW_{test}	=	Body weight of TRV test species (kg)
BW_{site}	=	Body weight of site species (kg)
FIR_{site}	=	Food ingestion rate of site species (kg/day)

Food ingestion rates and bodyweights of site-specific wildlife species of interest can be determined from many literature sources including EPA’s Wildlife Exposure Factor Handbook (EPA 1993). Site-specific species with a higher food ingestion rate to body weight ratio than that of the test species would have a lower tissue-based guideline and vice versa.

Establishing Prey Tissue Trigger Levels Using Egg-Based TRV Studies

The dietary model above can be used for establishing tissue trigger concentrations protective of wildlife for many organic and inorganic compounds. However, some types of chemicals such as DDE, polychlorinated biphenyls (PCBs), “dioxin-like[4]” compounds (EPA 2003) and selenium (Fairbrother et al. 1999; Adams et al. 2003) have demonstrated effects on avian development at the level of the egg. In these cases, developing tissue trigger levels based on eggs is more appropriate than the dietary pathway because the reproductive effects and corresponding TRVs are based on concentrations in bird eggs rather than in the diet, as the dietary pathway model above may not result in tissue levels that are sufficiently protective.

Estimated egg-based TRVs (NOAELs or LOAELs) are available for fish-eating birds for PCBs (calculated as total PCBs) and DDE (Custer et al. 1999, Elliott et al. 1994, Wiemeyer et. al 1984; 1988; 1994, Yamashita et. al 1993), and an egg-based approach would be the preferred method for assessing these particular chemicals. Examples and explanations of using the egg-based approach can be found in EPA (2003) and other references (Giesy et al 1995, U.S. Fish and Wildlife Service (USFWS) 1994).

A simple egg-based model for developing tissue trigger levels follows below.

$$\textbf{Tissue Trigger Level} = \mathbf{TRVegg / BMF_{egg}}$$

Where:

Tissue Trigger Level (mg/kg) = Tissue concentration in prey protective of avian predators
TRV_{egg} = Egg-based Toxicity Reference Value (mg/kg)
BMF_{egg} = Biomagnification factor from prey to egg (unitless)

The BMF_{egg} value can be derived from site-specific data (if available) or from the literature. Examples of site-specific derivation of BMFs can be found in Henny et al. (2003), USFWS (2004), and Braune and Norstrom (1989). Other methods to estimate BMFs can be found in USFWS (1994).

Conclusion

Trigger levels can be useful to screen measured fish and invertebrate tissue data for their potential to result in bioaccumulative effects in upper trophic avian and mammalian wildlife or used to establish general sediment quality values to guide cleanup (i.e., at sites where sediment contamination is understood to be the dominant contaminant source for uptake into biological tissue). Trigger levels should be developed based on data specific to a watershed, or based on literature values when site-specific data is unavailable. Exceedance of tissue trigger levels would not automatically constitute a requirement for cleanup but would indicate a need for further evaluation of the bioaccumulation pathway for fish- and invertebrate eating birds at a given location, or require actions to minimize exposure of aquatic-dependent wildlife to contaminants at the site. Minimizing exposure could include such actions as installing silt fences to minimize re-suspended sediment from leaving the site during dredging and disposal, and using close-lipped clamshell bucket to reduce disturbance of sediment while dredging.

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