Establishing Selenium Standards for Lake Koocanusa and Kootenai River that Protect Aquatic Life

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What are water quality standards?

• A measure of defining how clean we want our water.

• Clean enough for what?
  • Aquatic life to propagate
  • Recreation or swimming
  • Drinking
  • Agriculture or industry purposes

Selenium standards for Lake Koocanusa and the Kootenai River are being set to protect our aquatic life – which means the standard represents the LIMIT (or cap) of selenium concentration – below which we have confidence that aquatic life is protected.
### Addressing Selenium: Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
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</table>
| 2010 | MOUC – Flathead Valley
Coordinated efforts began between BC & MT to address transboundary water quality |
| 2012 | Koocanusa Listed for Se |
| 2013 | BC Ministerial Order
Remediate water quality effects of past mining activities and guide environmental management of future mining activities in the Elk Valley, including Lake Koocanusa |
| 2015 | LKMRWG
Bi-national working group established |
| 2016 | EPA updates national Se criteria recommendations |
| 2015-2020 | MT & BC Se standard development |
A Multi-National Transboundary Effort

- Six years of coordination with BC-ENV co-leading this effort
- Participation of an engaged Working group consisting of broad ranging entities (state, tribal, federal, industry, etc.)
- Involvement and dedication from top selenium experts in the US, Canada, and the world guiding the development of this standard
- Coordinated transboundary data sharing and data collection
- Co-managed public website housing all data, meeting summaries, sampling and analysis plans, technical reports and literature
- Public meetings held in Montana beginning in 2015
- BC-ENV currently working through their standard setting process the goal of which is a aligned transboundary water column Se standard
Lake Koocanusa Monitoring and Research Working Group

- Formed in 2015 to address transboundary water quality issues
- Semi annual meetings
- Selenium was determined to be the first priority
- Formation of a Selenium Technical Subcommittee
  - Guide data collection and determination of a protective water column standard
Overview of proposed standards

To reflect biological uptake through diet, the predominant pathway for selenium toxicity, DEQ is proposing the following standards

**Lake Koocanusa**
Fish Tissue (mg/kg dry weight (dw))
- Egg ovary - 15.1
- Muscle - 11.3
- Whole body - 8.5

Water column - 0.8 µg/L
(site-specific)

**Kootenai River**
Fish Tissue (mg/kg dry weight (dw))
- Egg ovary - 15.1
- Muscle -11.3
- Whole body - 8.5

Water column – 3.1 µg/L
Why Now

• Multi-year data collection effort
• Peer-reviewed modeling report complete
• SeTSC recommendations received
• BC & DEQ co-developed and agreed upon scenarios for a protective water column Se

• Standards necessary to prevent impacts to aquatic life
• No adverse economic impacts to Montana
Kootenai/Kootenay River
• Originates in SE British Columbia (B.C.)

Lake Koocanusa
• Reservoir created by Libby Dam
• Located in Montana and B.C.
95% of the selenium entering the lake is from the Elk River
Selenium Source

• Selenium (Se) is from historic and current coal mining in the Elk Valley, B.C.

• 4 mines in operation.
  • 4 new mines in the environmental assessment (EA) process
Reservoirs and rivers process selenium differently requiring lakes/reservoirs to have a lower Se standard than rivers.
Toxicological effects of selenium

- Reduced production of viable eggs
- Reduced growth
- Mortality or deformity
- Altered liver enzyme function
- Winter Stress Syndrome

Adapted from Presser and Skorupa, 2019
Selenium levels in fish tissue at current water Se concentrations

Source: EPA Region 8
Average selenium levels are currently ~ 1.0 µg/L

Source EPA Region 8
Data collection

- Water chemistry
- Dissolved Se
- Se speciation
- Particulate (SPM) Se
- Sediment Se
- Periphyton tissue Se
- Invertebrate tissue Se
- Zooplankton tissue Se
- Fish muscle tissue Se
- Fish whole body tissue Se
- Fish egg/ovary Se
- Fish food habits
- Bird egg Se
### Fish identified by SeTSC for modeling

<table>
<thead>
<tr>
<th>species (common name)</th>
<th>species (scientific name)</th>
<th>family</th>
<th>origin and utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Koocanusa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bull trout</td>
<td><em>Salvelinus confluentus</em></td>
<td>salmonid</td>
<td>native, game</td>
</tr>
<tr>
<td>burbot</td>
<td><em>Lota lota</em></td>
<td>lotid</td>
<td>native, game</td>
</tr>
<tr>
<td>kokanee</td>
<td><em>Oncorhynchus nerka</em></td>
<td>salmonid</td>
<td>non-native, game</td>
</tr>
<tr>
<td>longnose sucker</td>
<td><em>Catostomus catostomus</em></td>
<td>catastomus</td>
<td>native, non-game</td>
</tr>
<tr>
<td>largescale sucker</td>
<td><em>Catostomus macrocheilus</em></td>
<td>catastomus</td>
<td>native, non-game</td>
</tr>
<tr>
<td>mountain whitefish</td>
<td><em>Prosopium williamsoni</em></td>
<td>salmonid</td>
<td>native, game</td>
</tr>
<tr>
<td>Northern pikeminnow</td>
<td><em>Ptychocheilus oregonensis</em></td>
<td>cyprinid</td>
<td>native, non-game</td>
</tr>
<tr>
<td>peamouth chub</td>
<td><em>Mylodelepis caurinus</em></td>
<td>cyprinid</td>
<td>native, non-game</td>
</tr>
<tr>
<td>rainbow trout (wild strain); not claimed in BC</td>
<td><em>Oncorhynchus mykiss</em></td>
<td>salmonid</td>
<td>native, game</td>
</tr>
<tr>
<td>rainbow trout X cutthroat (stocked hybrid)</td>
<td><em>Gerrard strain</em></td>
<td>salmonid</td>
<td>hatchery strains</td>
</tr>
<tr>
<td>redside shiner</td>
<td><em>Richardsonius balteatus</em></td>
<td>cyprinid</td>
<td>native, non-game</td>
</tr>
<tr>
<td>Westslope cutthroat trout</td>
<td><em>Oncorhynchus clarki lewisi</em></td>
<td>salmonid</td>
<td>native, game</td>
</tr>
</tbody>
</table>
Selenium modeling by

**Model Inputs:**
- Fish-tissue Se target (mg/kg d.w.)
- Food Web
- TTF & bioavailability
- Kd (Suspended Se/dissolved Se)

**Peer-reviewed MODEL**
Presser & Luoma (2010)

**Protective Candidate Criteria**
(µg/L)

\[
C_{\text{target}} = \frac{C_{\text{tissue criterion element}}}{TTF_{\text{composite}} \times K_d}
\]

**ABSTRACT**

The main route of exposure for selenium (Se) to breeding, forage, and forage-limbed biota is based on the trophic levels of risk. We propose here an ecosystem-scale model that conceptualizes and quantifies the various steps that determine how Se is processed from water through diet to predators. This approach uses biophysiological and physiological factors from laboratory and field studies and considers loading, speciation transfer to particulate material, bioavailability, bioaccumulation in invertebrates, and trophic transfer to predators. Validation of the model is through data sets from 25 historic and recent field case studies of lake exposed sites. The model links Se concentrations at aquatic media (vegetation, particulate, tissue, and food web specific). It can be used to forecast toxicity under different management or regulatory proposals or as a methodology for translating a threshold (or other predictor based Se concentration guideline) to a dissolved Se concentration. The model illustrates some critical aspects of implementing a tissue criterion. The choice of fish species determines the food web through which Se should be modeled, 3) the choice of food web critical because the particulate material to prey limits of bioaccumulation differs widely among invertebrates, 4) the characteristic of the fate and phase of particulate material is important for quantifying Se exposure to prey through the base of the food web, and 4) the metric different descriptors between particulate material and dissolved Se concentrations allows determination of a specific dissolved Se concentration that would be responsible for third fish body burden in specific environments. The linked approach notes that environmental Se dissolved Se concentrations will differ among ecosystems depending on the ecological pathways and biophenological conditions in that system. Uncertainties and model limitations can be directly illustrated by exposing scenarios based on specific criteria. The model can also be used to facilitate specific regulation and to present specific criteria to facilitate dilution exposure by ecosystem setting and in situ. Appleby, the model provides a tool for framing a specific ecological problem or occurrence of exposure, quantify exposure within the ecosystem, and many new uncertainties about how to prevent it by understanding the pathophysiology of the underlying system ecology, biophysics, and hydrology. 

**Keywords:** Selenium Food web Bioaccumulation Site-specific ecological exposure

**INTRODUCTION**

Effects of Se toxicity have been proven drastic because of concentrations (i.e., local restrictions) of fish populations and occurrence of death of aquatic birds in impacted habitats (Sharpea 1998; Chapman et al. 2010). The large geologic extent of the source is connected to the environment by anthropogenic activities that include power generation, oil refining, mining, and irrigation drainage (Presser, Pyper, et al. 2004). Toxicity arises when dissolved Se is transformed to organic Se after uptake by bacteria, algae, fungi, and plants (i.e., synthesis of Se-containing amino acids) and then passed through food webs. Biochemical pathways, unable to distinguish Se from Se, substitute enzymes to into proteins and after their structure and function (Stahman 1974). The impact of these reactions is recorded most importantly during hatching of eggs or development of young life stages. Thus, the reproductive consequences of material transfer are the most direct and sensitive indicators of the effects of Se (Hynes 1974). Each step in this sequence of processes is relatively well known, but the integrating approaches for quantifying the linkage between Se concentrations in the environment and effects on animals are very limited in magnitude of understanding. Conventional methodologies relate dissolved or water-soluble Se concentration and tissue Se concentrations through simple ratios (i.e., bioconcentration factor, BCF) bioaccumulation factor (BAF), reproduction or probability distribution functions (Dulaway 1989; Peterson and Neller 1992; McGree et al. 2000; Tall et al. 2000; Braze et al. 2000; Dufour et al. 2000). None of these approaches adequately accounts for each of the important processes that connect Se concentrations in water to the bioavailability, bioaccumulation, and toxicity of Se. In this paper, we present an ecosystem-scale methodology that reduces uncertainty by systematically quantifying each of the influential processes that link source inputs of Se to toxicity. In particular, we emphasize a methodology for relaxing dissolved Se to bioaccumulated Se. The methodology allows us to: 1) model Se exposures with greater certainty than previously achieved through traditional approaches that skip steps, 2) explain or predict Se toxicity (or lack of mortality) in site-specific circumstance, and 3) translate proposed Se guidelines among media under different management or regulatory scenarios. Important components of the methodology are: 1) empirically determined environmental partitioning factors between water and particulate material that quantify the effects of dissolved speciation and phase transformation, 2) concentration of Se in living and resolving particular partition at the base
Invertebrate to fish (IFM) model

- IFM model applies for all species consuming only invertebrates or zooplankton

Trophic level fish (TFM) model

- TFM model applies to all predator fish species
- It adds one more step in the food web

Particulate $\rightarrow$ Aquatic Insects $\rightarrow$ Zooplankton $\rightarrow$ fish $\rightarrow$ Predator fish

Particulate $\rightarrow$ Aquatic Insects $\rightarrow$ fish $\rightarrow$ fish $\rightarrow$ Predator fish
Implication: All $K_d$ values considered as independent scenarios
USGS Modeling Results, Conclusions

• USGS modeling was based on EPA national guideline (8.5 mg/kg w. body).

• Values other than 8.5 could be input. Modeling choices and assumptions were guided by goals in the report and previously defined by the SeTSC.

• USGS (Presser and Naftz, 2020) peer-reviewed report provided the foundation from which DEQ was able to develop a protective water column Se standard in collaboration with BC.

• Summary of Goals:
  • Consideration of ecologically significant species and those important to stakeholders
  • Protection of ecosystem during max dietary exposure (feeding in a benthic food web)
  • 100% protection of the fish species in the reservoir assuming a reproductive end point from reproductively mature females feeding in a lentic ecosystem
  • Long-term protection for fish in all parts of the reservoir during all phases of reservoir operation, all Se loading profiles, and all water years
Post Report: DEQ & BC-ENV collaborative analysis

LKMRWG Steering Committee (DEQ & BC-ENV) solicited recommendations from the SeTSC on model inputs and final criteria recommendations

SeTSC members provided recommendations during half day teleconference & written recommendations

DEQ & BC-ENV considered recommendations from SeTSC to develop three additional scenarios

DEQ identified a Se standard protective of the aquatic life beneficial use
SeTSC recommendations

• Whole body tissue:
  • 5/7 members recommended a whole-body tissue value lower than 8.5 mg/kg dw
    • Ranged from 4.6 to 7.0 mg/kg
    • 2/7 members recommended 8.5 mg/kg dw

• Food Webs, TTFs, bioavailability:
  • 3/7 members specifically recommended the TFM TL3 at 100% aquatic insect diet; no recommendations for any other food web were presented
  • General agreement that the 60% bioavailability at literature TTFs may be over predictive
    • Recommendations ranged from using 60% at literature TTFs
    • Calculating site specific TTFs – recommendations ranged from 1.1 -1.2 (Aq.Ins) to 0.58-0.85 (zoo)
    • Combining USGS TTFs with EPA TTFs to create a larger database to recalculate

• Kd selection:
  • General agreement that the median (50th percentile) would be appropriate if a lower whole body tissue value is selected, and a more conservative percentile should be selected if 8.5 whole body tissue value is applied.

• Final criteria:
  • 4/7 members provided recommendations on a final water column value
    • One member recommended 1.5 ug/L based on EPA 304(a) criteria
    • Three members recommended criteria ranging between 0.6 ug/L and 0.8 ug/L
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Whole body tissue threshold (mg/kg dw)</th>
<th>Food Web</th>
<th>diet</th>
<th>TTF Aquatic Insect</th>
<th>TTF Zooplankton</th>
<th>Bioavailability</th>
<th>Kd percentile</th>
<th>Predicted dissolved water column Se (ug/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.6</td>
<td>IFM</td>
<td>100% Aquatic Insects</td>
<td>2.8</td>
<td>45%</td>
<td>50th (median)</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5.6</td>
<td>TFM TL3</td>
<td>75% Aquatic Insects/ 25% Zooplankton</td>
<td>2.8</td>
<td>1.5</td>
<td>45%</td>
<td>50th (median)</td>
<td>0.91</td>
</tr>
<tr>
<td>3</td>
<td>5.6</td>
<td>TFM TL3</td>
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**DEQ & BC-ENV co-developed**

**DEQ developed - EPA fish tissue criteria**
Proposed Se standards for Lake Koocanusa

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<td>Dissolved selenium (µg/L)</td>
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</tr>
<tr>
<td>Egg/Ovary (mg/kg dw)</td>
<td>15.1</td>
</tr>
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<td>Muscle (mg/kg dw)</td>
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Proposed Se standards for Kootenai River

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