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

Beneficial Uses

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

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Addressing Selenium: Timeline

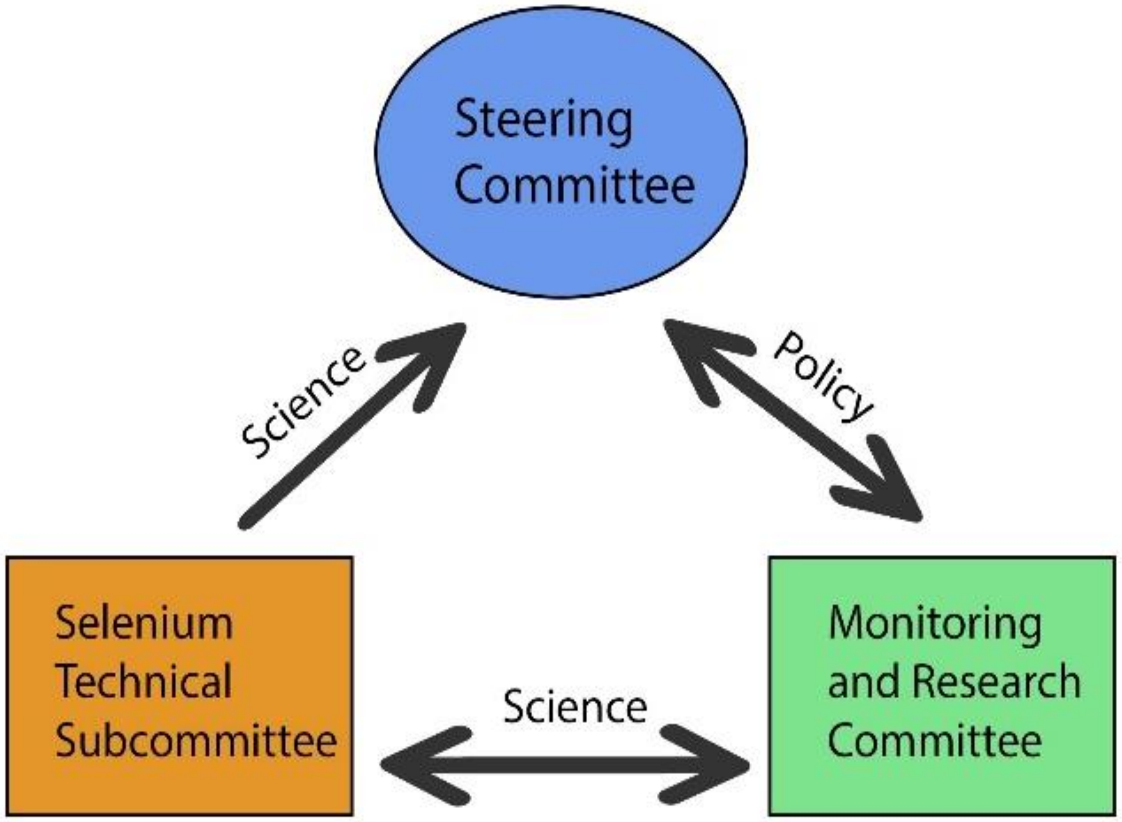
2010	2012	2013	2015	2016	2015-2020
MOUC – Flathead Valley *Coordinated efforts began between BC & MT to address transboundary water quality*	**Koocanusa Listed for Se**	**BC Ministerial Order** *Remediate water quality effects of past mining activities and guide environmental management of future mining activities in the Elk Valley, including Lake Koocanusa*	**LKMRWG** *Bi-national working group established*	**EPA updates national Se criteria recommendations**	**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



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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

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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

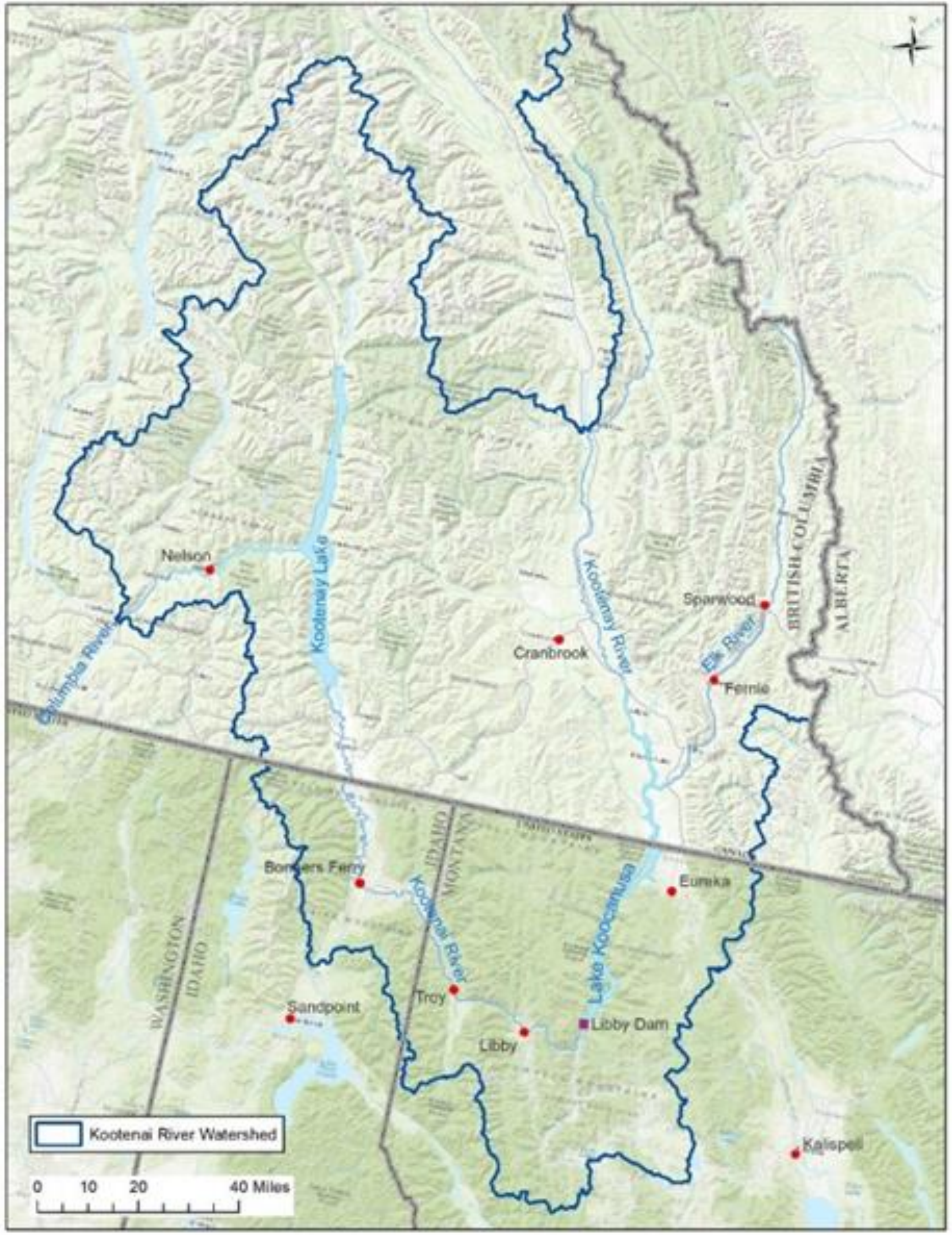
Kootenai Watershed

Kootenai/Kootenay River

- Originates in SE British Columbia (B.C.)

Lake Koocanusa

- Reservoir created by Libby Dam
- Located in Montana and B.C.



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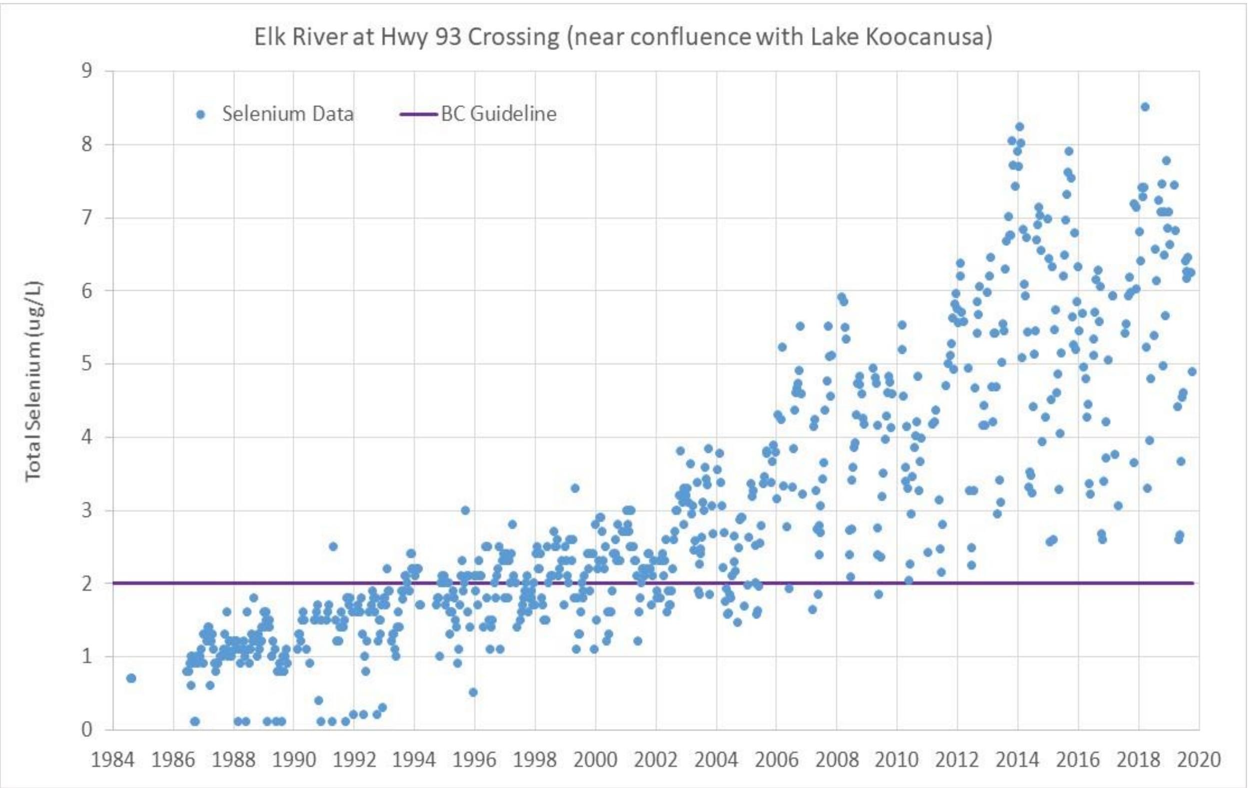
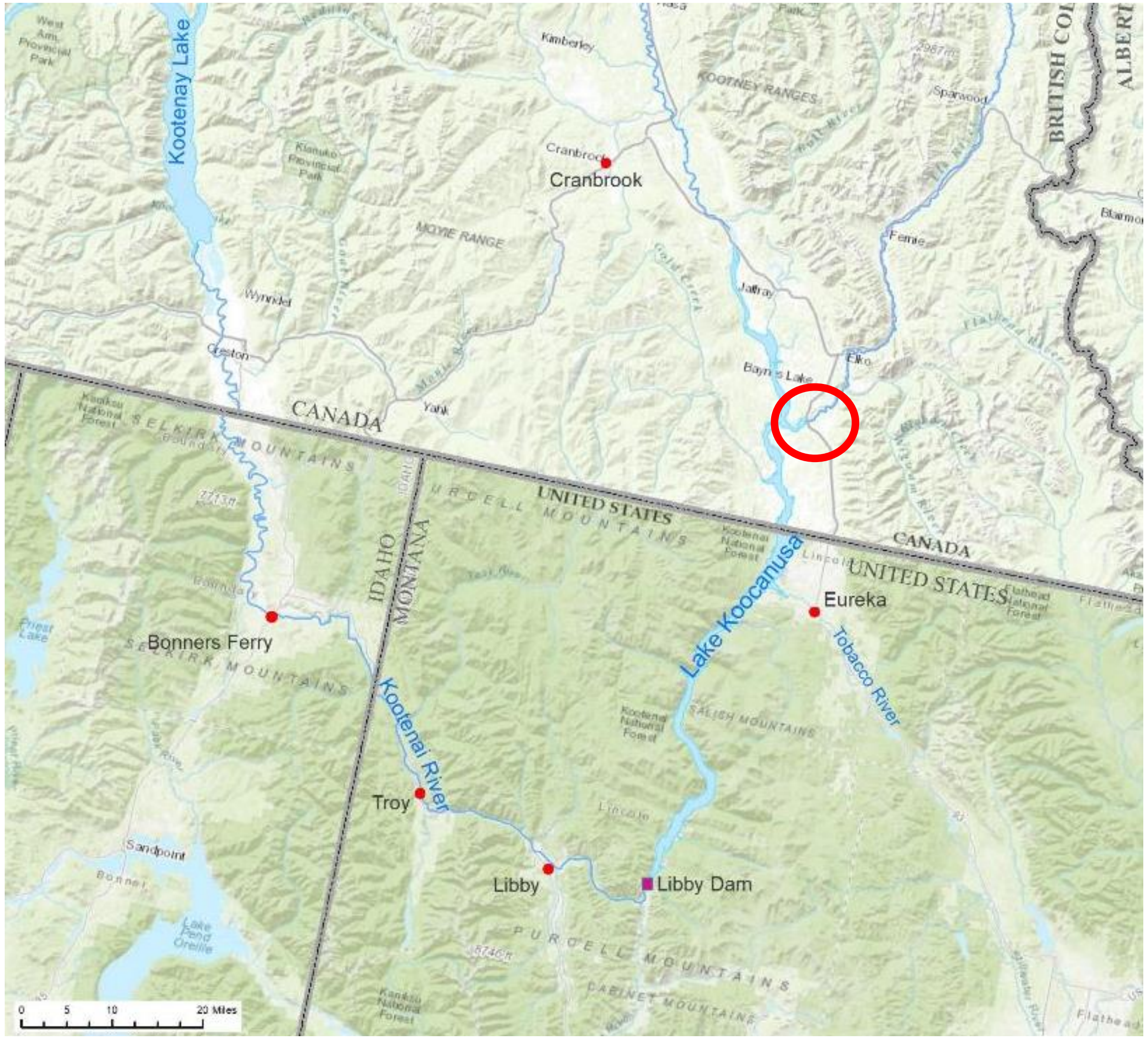
Selenium increase over time: Elk River, Canada





95% of the selenium entering the lake is from the Elk River

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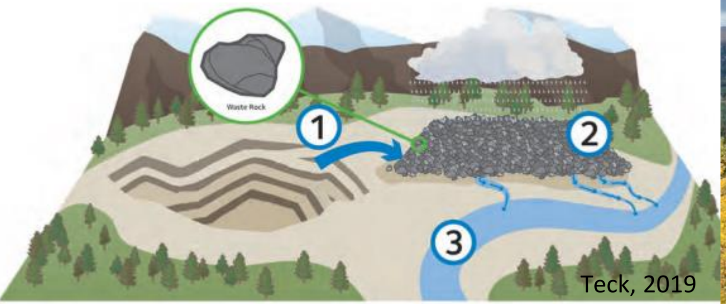
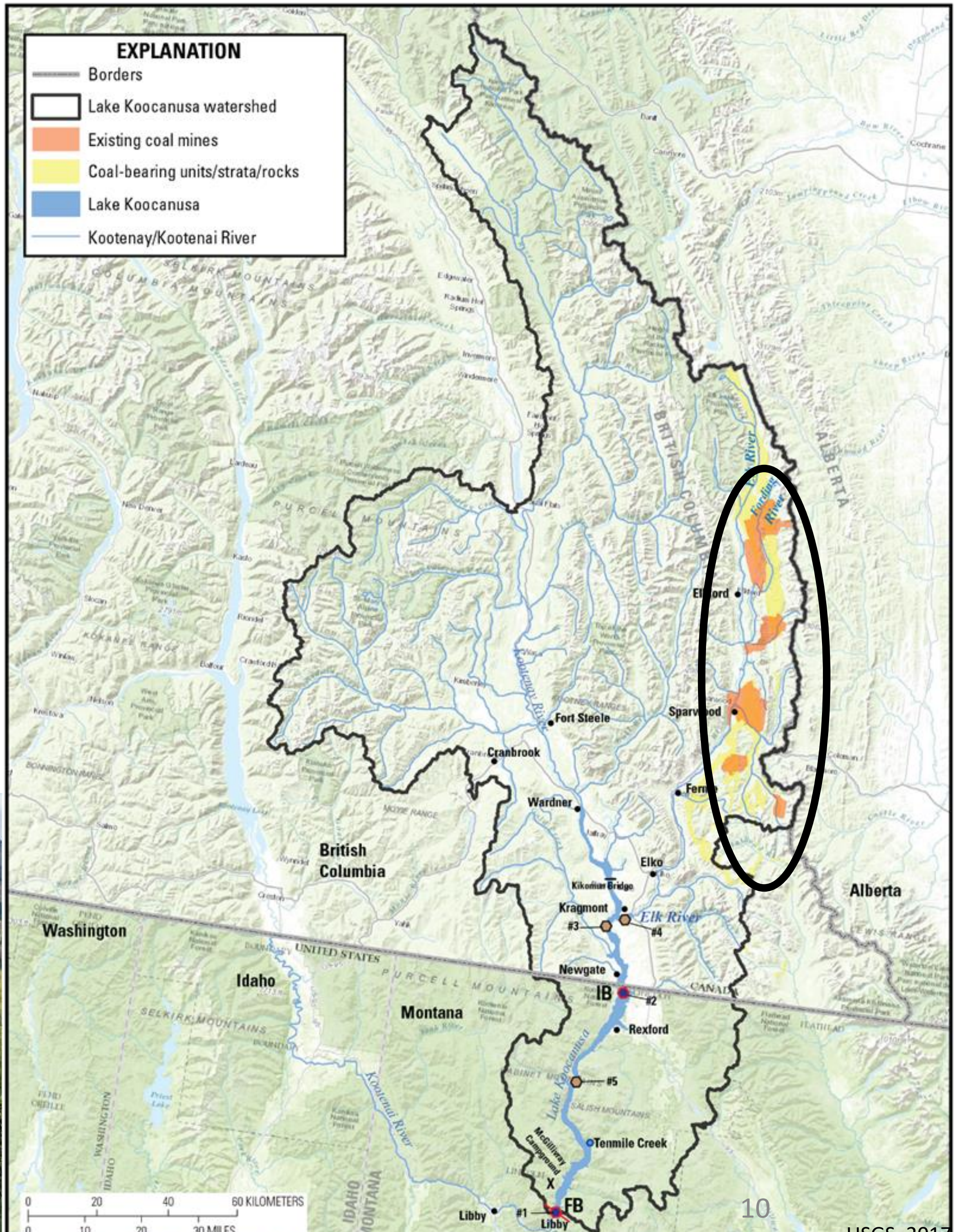
Selenium Source

- 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



Teck, 2019



USGS, 2017

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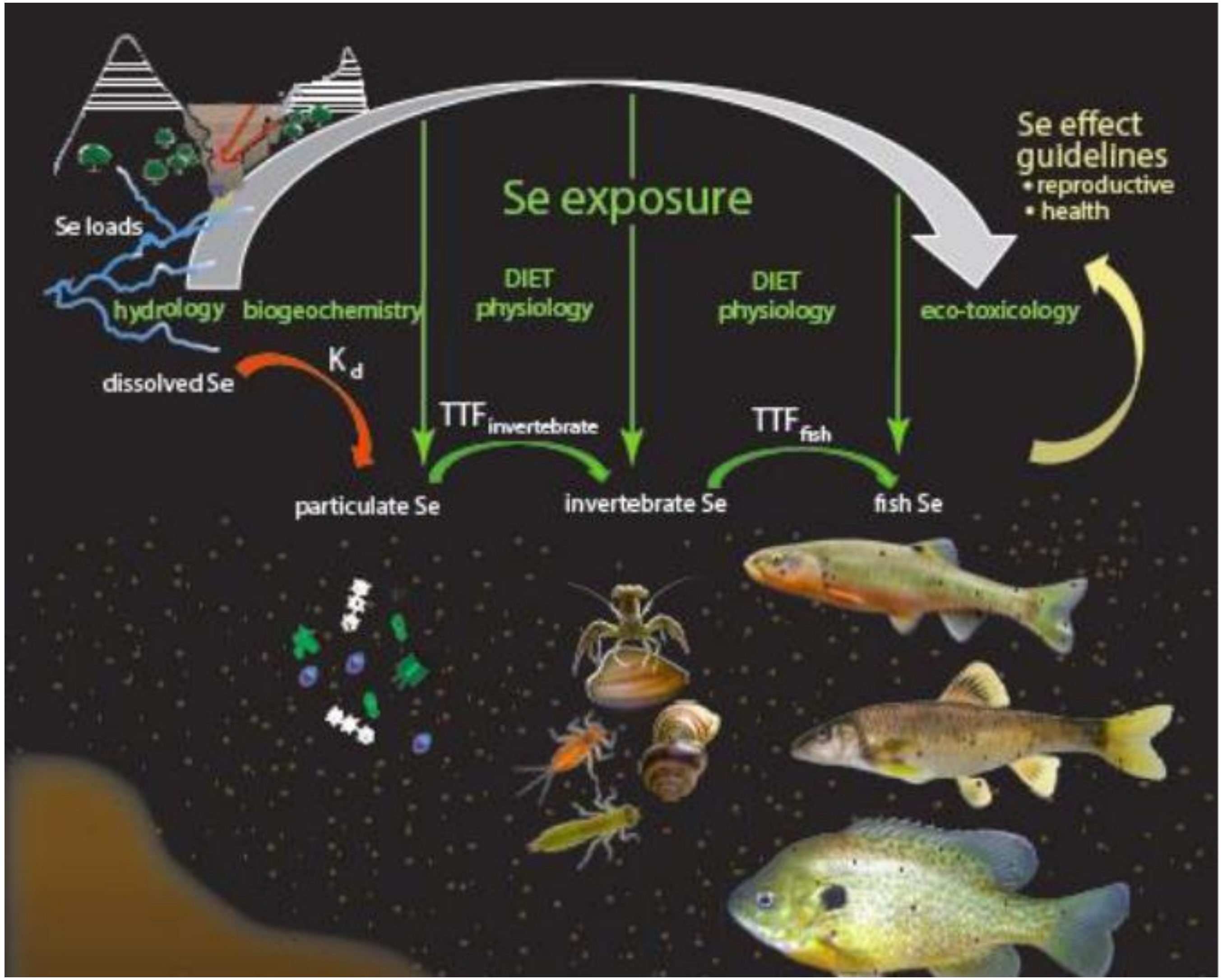
Selenium dietary exposure pathway

Reservoirs and rivers process selenium differently requiring lakes/reservoirs to have a lower Se standard than rivers



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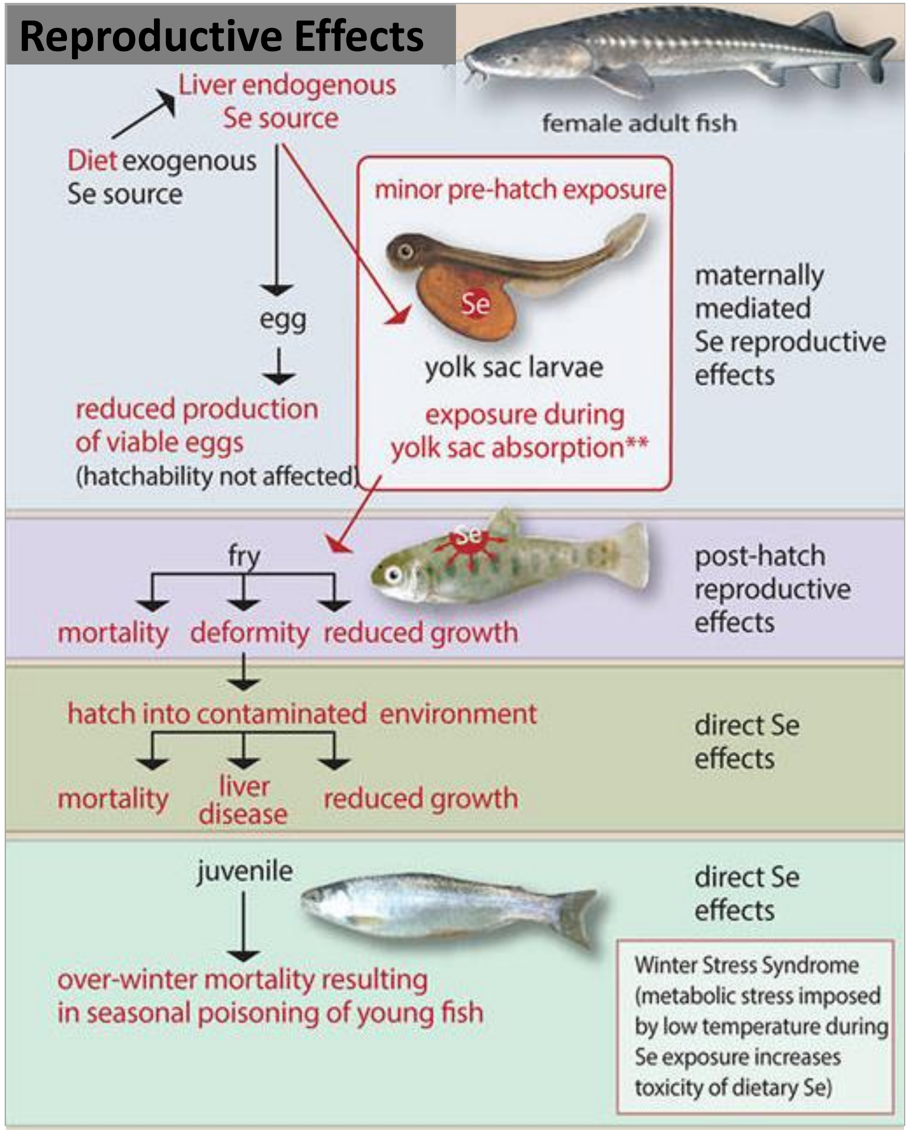
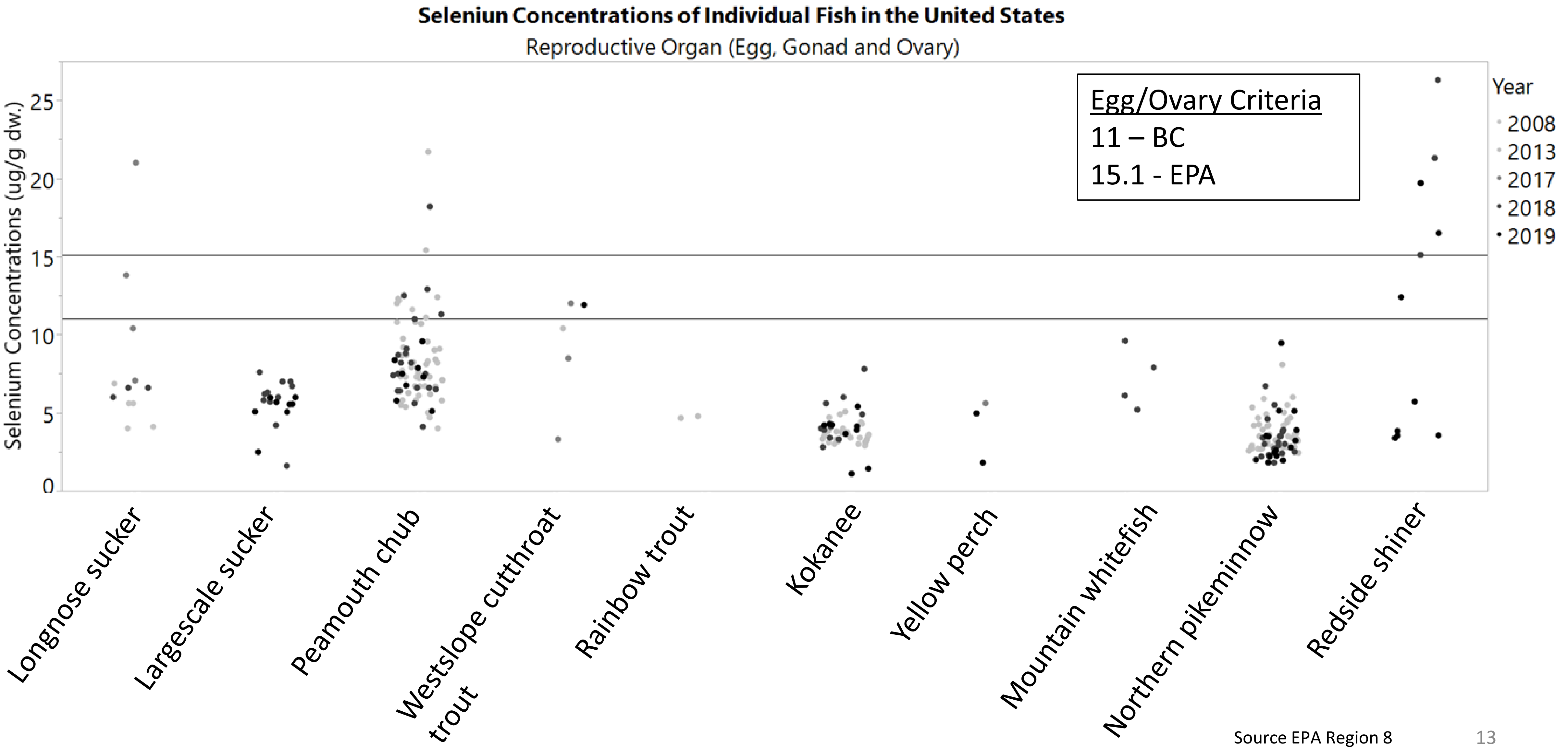
Toxicological effects of selenium

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



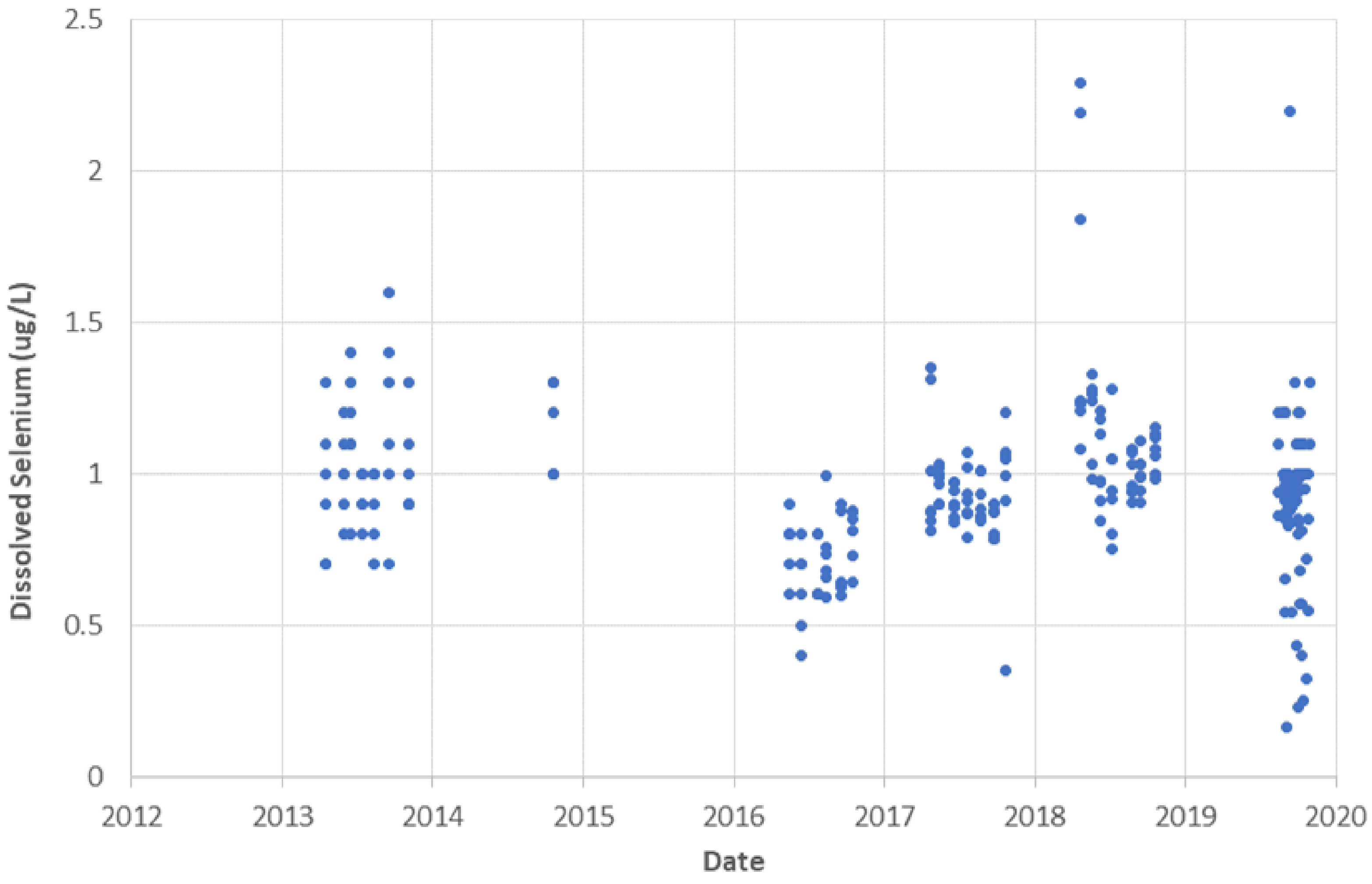
Adapted from Presser and Skorupa, 2019

Selenium levels in fish tissue at current water Se concentrations



Source EPA Region 8

Average selenium levels are currently ~ 1.0 μg/L

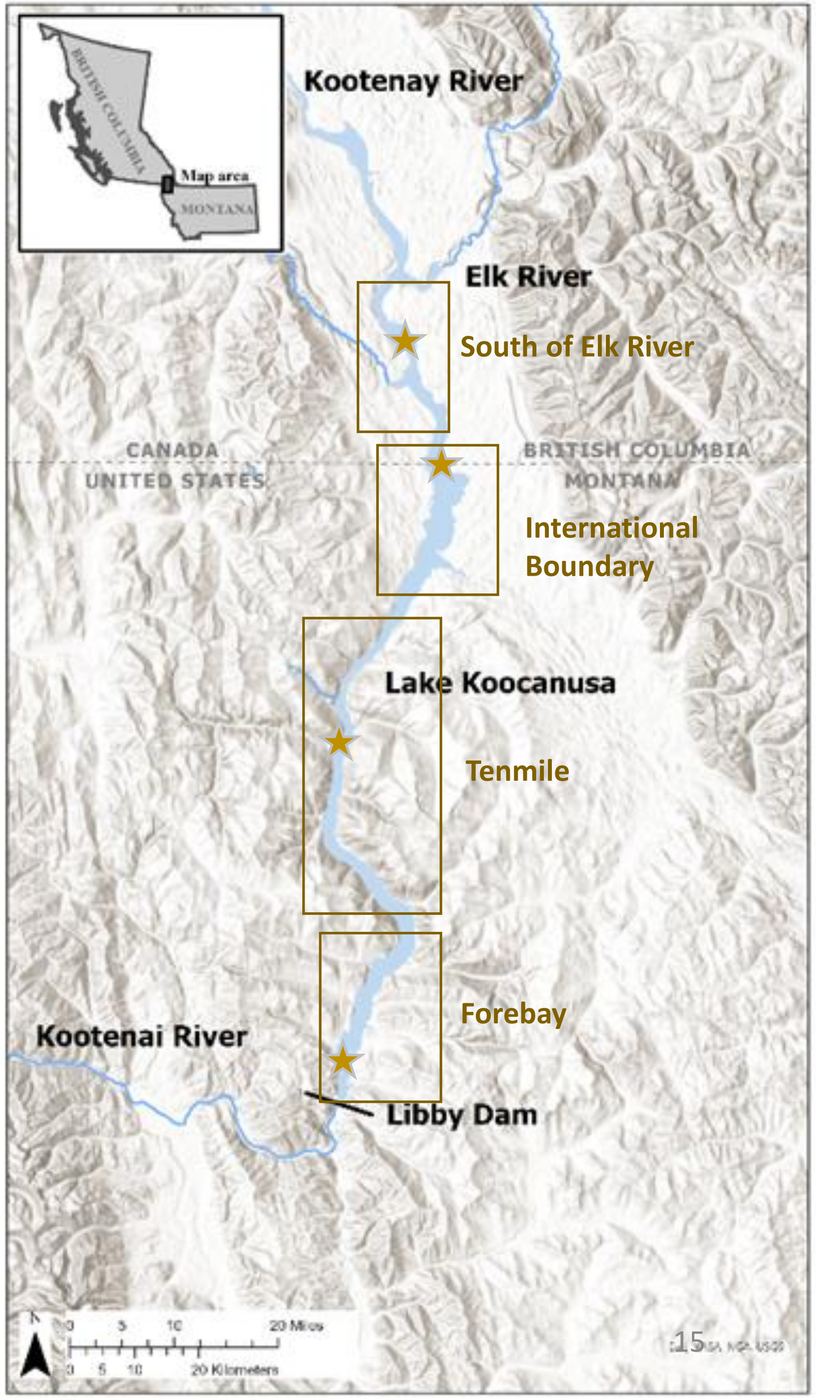


Source EPA Region 8

Data collection

MT FWP	**MT DEQ**	**USACE**	**USGS**	**USFWS**	**BC-ENV**	**Teck**

- 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



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Fish identified by SeTSC for modeling

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

Selenium modeling by USGS

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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)

$$C_{target} = \frac{C_{tissue\ \ criterion\ \ element}}{TTF^{composite}\ X\ K_d}$$

A Methodology for Ecosystem-Scale Modeling of Selenium

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(Submitted 18 August 2009; Returned for Revision 12 February 2010; Accepted 26 May 2010)

Original Research

ABSTRACT

The main route of exposure for selenium (Se) is dietary, yet regulations lack biologically based protocols for evaluations of risk. We propose here an ecosystem-scale model that conceptualizes and quantifies the variables that determine how Se is processed from water through diet to predators. This approach uses biogeochemical and physiological factors from laboratory and field studies and considers loading, speciation, transformation to particulate material, bioavailability, bioaccumulation in invertebrates, and trophic transfer to predators. Validation of the model is through data sets from 29 historic and recent field case studies of Se-exposed sites. The model links Se concentrations across media (water, particulate, tissue of different food web species). It can be used to forecast toxicity under different management or regulatory proposals or as a methodology for translating a fish-tissue (or other predator tissue) Se concentration guideline to a dissolved Se concentration. The model illustrates some critical aspects of implementing a tissue criterion: 1) the choice of fish species determines the food web through which Se should be modeled, 2) the choice of food web is critical because the particulate material to prey kinetics of bioaccumulation differs widely among invertebrates, 3) the characterization of the type and phase of particulate material is important to quantifying Se exposure to prey through the base of the food web, and 4) the metric describing partitioning between particulate material and dissolved Se concentrations allows determination of a site-specific dissolved Se concentration that would be responsible for that fish body burden in the specific environment. The linked approach illustrates that environmentally safe dissolved Se concentrations will differ among ecosystems depending on the ecological pathways and biogeochemical conditions in that system. Uncertainties and model sensitivities can be directly illustrated by varying exposure scenarios based on site-specific knowledge. The model can also be used to facilitate site-specific regulation and to present generic comparisons to illustrate limitations imposed by ecosystem setting and inhabitants. Used optimally, the model provides a tool for framing a site-specific ecological problem or occurrence of Se exposure, quantify exposure within that ecosystem, and narrow uncertainties about how to protect it by understanding the specifics of the underlying system ecology, biogeochemistry, and hydrology. Integr Environ Assess Manag 2010;6:685–710. © 2010 SETAC

Keywords: Selenium Food web Bioaccumulation Site-specific ecological exposure Ecosystem-scale

INTRODUCTION

Effects from Se toxicity have proven dramatic because of extirpations (i.e., local extinctions) of fish populations and occurrences of deformities of aquatic birds in impacted habitats (Skorupa 1998; Chapman et al. 2010). The large geologic extent of Se sources is connected to the environment by anthropogenic activities that include power generation, oil refining, mining, and irrigation drainage (Presser, Piper, 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 de novo) and then passed through food webs. Biochemical pathways, unable to distinguish Se from S, substitute excess Se into proteins and alter their structure and function (Stadtman 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 maternal transfer are the most direct and sensitive predictors of the effects of Se (Heinz 1996).

Each step in this sequence of processes is relatively well known, but the existing protocols for quantifying the linkage between Se concentrations in the environment and effects on animals have orders of magnitude of uncertainties. Conventional methodologies relate dissolved or water-column Se concentrations and tissue Se concentrations through simple ratios (i.e., bioconcentration factor, BCF; bioaccumulation factor, BAF), regressions, or probability distribution functions (DuBowy 1989; Peterson and Nebeker 1992; McGeer et al. 2003; Toll et al. 2005; Brix et al. 2005; DeForest et al. 2007). 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 links source inputs of Se to toxicity. In particular, we emphasize a methodology for relating dissolved Se to bioaccumulated Se. The methodology allows us to 1) model Se exposure with greater certainty than previously achieved through traditional approaches that skip steps, 2) explain or predict Se toxicity (or lack of toxicity) in site-specific circumstances, 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) concentrations of Se in living and nonliving particulates at the base

All Supplemental Data may be found in the online version of this article.
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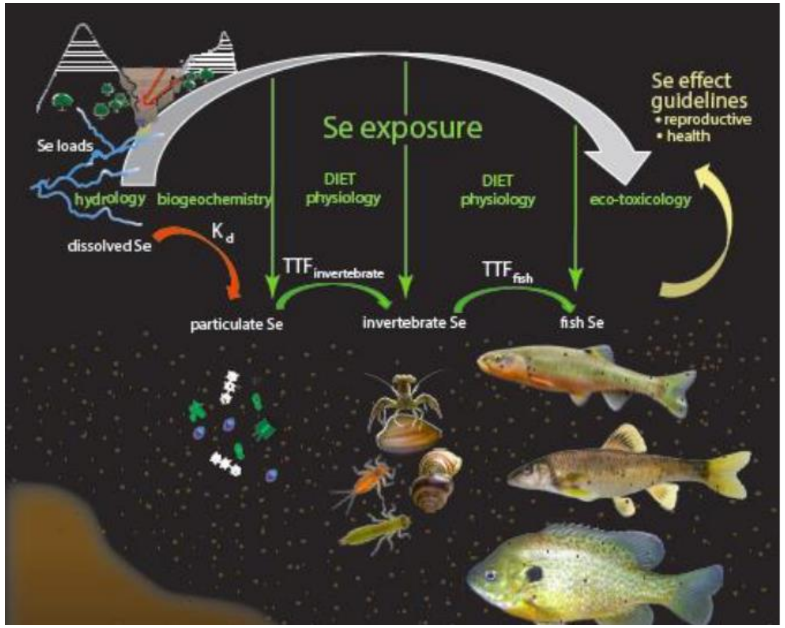
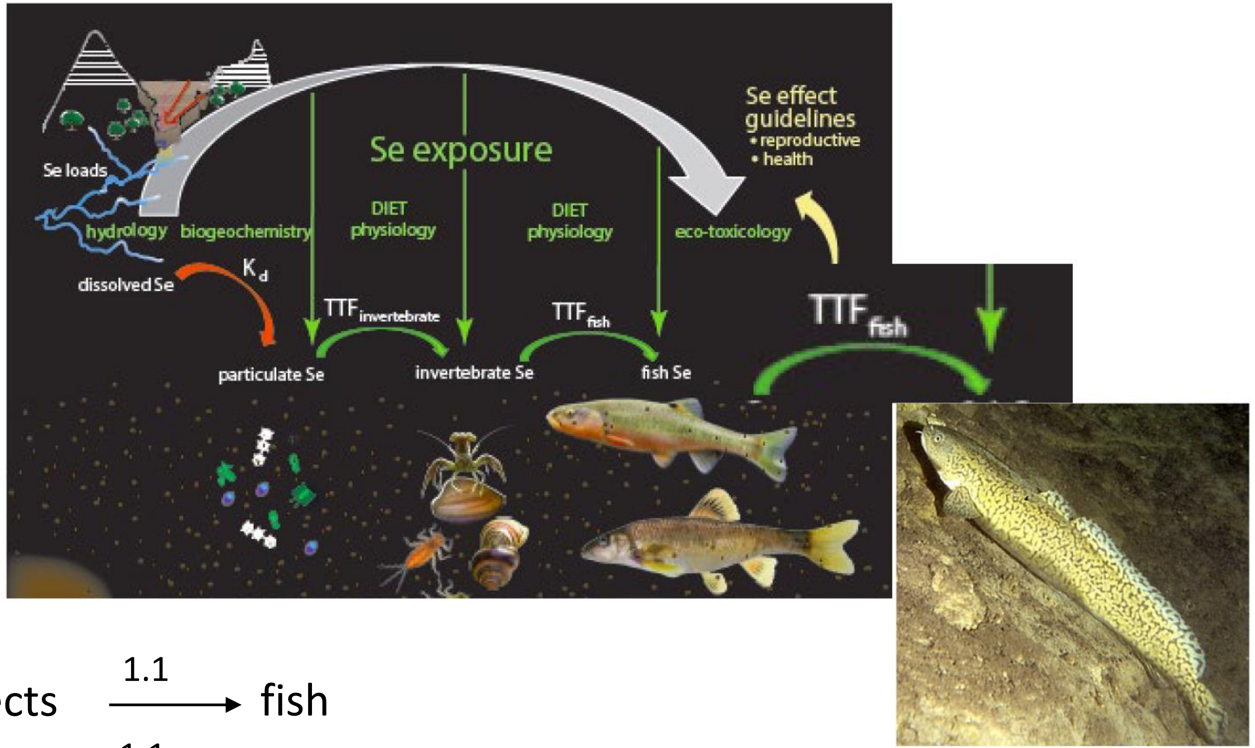
Invertebrate to fish (IFM) model

- 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

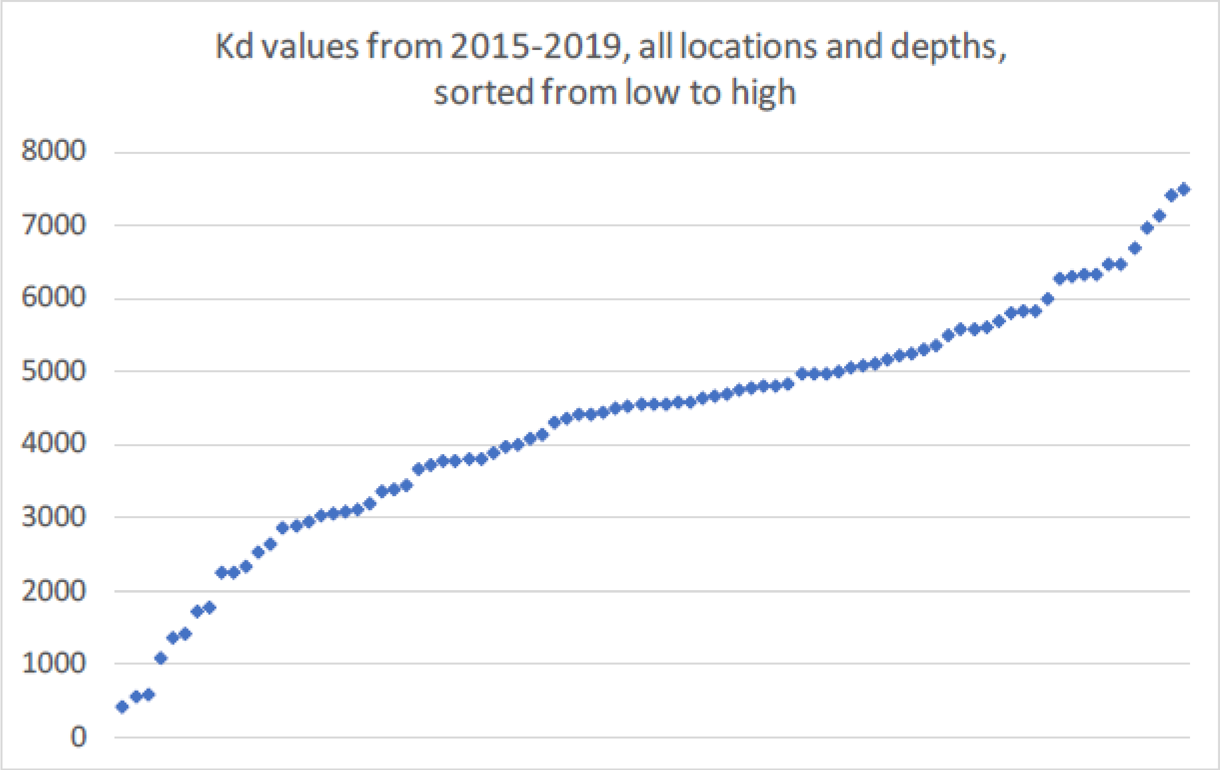


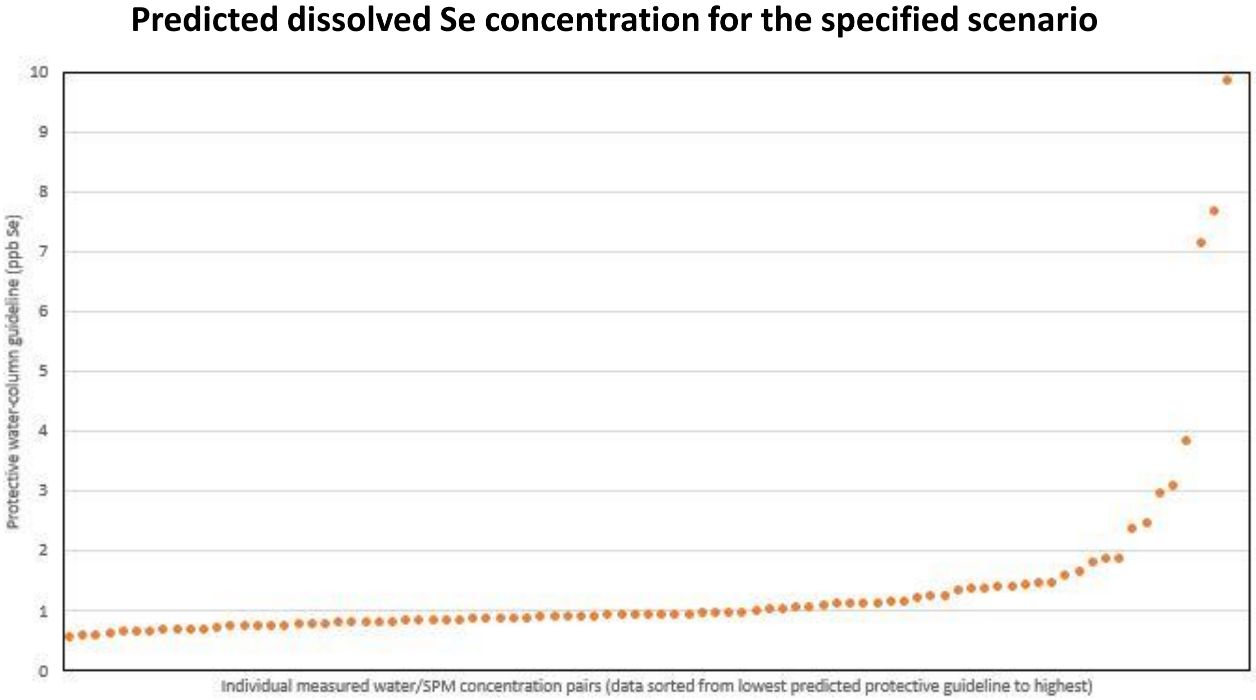
Particulate $\xrightarrow{2.8}$ Aquatic Insects $\xrightarrow{1.1}$ fish

Particulate $\xrightarrow{1.5}$ Zooplankton $\xrightarrow{1.1}$ fish

Particulate $\xrightarrow{2.8}$ Aquatic Insects $\xrightarrow{1.1}$ fish $\xrightarrow{1.1}$ Predator fish

Implication: All K_d values considered as independent scenarios





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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

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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

DEQ & BC-ENV co-developed

Scenario	Whole body tissue threshold (mg/kg dw)	Food Web	diet	TTF Aquatic Insect	TTF Zooplankton	Bioavailability	Kd percentile	Predicted dissolved water column Se (ug/L)
1	5.6	IFM	100% Aquatic Insects	2.8		45%	50th (median)	0.89
2	5.6	TFM TL3	75% Aquatic Insects/ 25% Zooplankton	2.8	1.5	45%	50th (median)	0.91
3	5.6	TFM TL3	100% Aquatic Insects	2.8		45%	50th (median)	0.8

DEQ developed - EPA fish tissue criteria

Whole body tissue threshold (mg/kg dw)	Food Web	diet	TTF Aquatic Insect	TTF Zooplankton	Bioavailability	Kd percentile	Predicted dissolved water column Se (ug/L)
8.5	TFM TL3	100% Aquatic Insects	2.8		60%	75th	0.8

0.8 ug/L

DEQ proposed Se standard

Proposed Se standards for Lake Koocanusa

Parameter	Selenium Concentration
Dissolved selenium (µg/L)	0.8
Egg/Ovary (mg/kg dw)	15.1
Muscle (mg/kg dw)	11.3
Whole body (mg/kg dw)	8.5

Proposed Se standards for Kootenai River

Parameter	Selenium Concentration
Dissolved selenium (µg/L)	3.1
Egg/Ovary (mg/kg dw)	15.1
Muscle (mg/kg dw)	11.3
Whole body (mg/kg dw)	8.5

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