Ministry of Environment
Province of British Columbia

Companion Document to:

Ambient Water Quality Guidelines for Selenium

Update

Additional guidance for the application of

British Columbia's approved selenium water quality guidelines

Water Protection and Sustainability Branch
Environmental Sustainability and Strategic Policy Division
British Columbia Ministry of Environment

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1.0 Introduction

The BC Ministry of Environment (MoE) develops ambient water quality guidelines (WQGs) to assess and manage the health, safety and sustainability of British Columbia's aquatic resources. Guidelines are developed to protect the following uses: aquatic life and wildlife, agriculture (irrigation and livestock watering), drinking water sources, recreation and aesthetics.

The development of WQGs for aquatic life in BC is guided by the following principles:

- WQGs are science-based and intended for generic provincial application;
- WQGs do not account for site-specific conditions or socio-economic factors;
- all components of the aquatic ecosystem (e.g., algae, macrophytes, invertebrates, amphibians, and fish) are considered where data are available;
- interim WQGs may be developed where data are available but limited;
- all forms of aquatic life and all aquatic stages of their life cycle are to be protected during indefinite exposure.

WQGs for the protection of human health are developed through consultation with the BC Ministry of Health (MoH).

This companion document provides a summary of information presented in the technical report and additional guidance on the application of the updated ambient WQGs for selenium (Se) in BC (BC MoE 2014). The Se WQG technical report should be referenced for more complete information.

2.0 Selenium Guidelines

The MOE updated its Se WQGs in 2014 (see Table 1). Recent scientific literature and published chronic Se toxicological endpoints were reviewed with a multi-media focus on Se concentrations in water, sediment, dietary tissue, and receptor tissues for a range of aquatic organisms and their consumers. The updated Se WQGs include long-term (chronic) values for several environmental compartments. Multi-media guidelines can be used to provide more information and greater flexibility in a monitoring and management framework aimed at protecting aquatic ecosystems.

Table 1. List of updated and previous WQGs for selenium recommended for use in British Columbia. Water concentrations are measured as total selenium. Details on guideline derivation may be found in the Technical Appendix (BC MoE 2014).

Water Use	Updated 2014 BC Se WQG	2001 Approved BC Se WQG	Guideline Derivation Method/Approach
Source Drinking Water	10 µg/L	10 µg/L	*Source Drinking Water:* Adopted from Health Canada; a maximum acceptable concentration of 10 µg/L to protect against adverse effects in humans from excessive exposure.
Human Consumption Screening Values			
High fish intake (0.22 kg/day)	1.8 µg/g (ww), 7.3 (dw)[1]	None proposed	*Tissue Consumption*: Values were derived using Health Canada's recommended equation for ingestion of Se-contaminated fish and the dietary reference value's tolerable upper intake.
Moderate fish intake (0.11 kg/day)	3.6 µg/g (ww), 14.5 (dw)	None proposed	
Low fish intake (0.03 kg/day)	18.7 µg/g (ww), 75.0 (dw)	None proposed	
Aquatic Life			*Water column*: Review of previous WQG (uncertainty factor (UF) applied to toxicity threshold); weight of evidence including food web modelling and reported relationships between impacts and Se concentrations in water.
Water column freshwater & marine			
Alert concentration	1 µg/L	None proposed	
Guideline	2 µg/L	2 µg/L	
Sediment - Alert concentration	2 µg/g (dw)	None proposed	*Sediment*: Weight of evidence; lowest published toxicity thresholds, no UF applied; insufficient data for full guidelines at this time.
Dietary			
Invertebrate tissue (interim)	4 µg/g (dw)	2 µg/g (dw)	*Dietary:* Weight of evidence; lowest published toxicity thresholds, no UF applied; insufficient data for full guidelines at this time. Invertebrate tissue as surrogate for aquatic dietary tissue.
Tissue (fish)			
Egg/ovary	11 µg/g (dw)	None proposed	
Whole-body (WB)	4 µg/g (dw)	4 µg/g (dw)	*Egg/ovary:* Combination weight of evidence and mean of published effects data with an UF of 2 applied; *Whole-body*: previous WB guideline compared with published literature, mean of published effects data with UF (2) applied and weight of evidence; *Muscle*: WB translation to derive muscle WQG, no additional UF applied to muscle guideline.
Muscle/muscle plug (interim)	4 µg/g (dw)	None proposed	
Wildlife			The *water column* guideline for aquatic life (fish) is adopted for wildlife since dietary accumulation is most critical. *Bird eggs* were used as surrogate for all wildlife; weight of evidence; egg Se most direct/sensitive measure; mallard EC10 with UF of 2 applied.
Water column	2 µg/L	4 µg/L (maximum)	
Bird egg	6 µg/g (dw)	7 µg/g (dw)	
Recreation and Aesthetics	None proposed	None proposed	No data
Irrigation Water			Not updated at this time
2001 guideline not updated	10 µg/L	10 µg/L	
Livestock Watering			Not updated at this time
2001 guideline not updated	30 µg/L	30 µg/L	
Industrial Water	None proposed	None proposed	No data

[1] Guideline based on edible portions of tissue. Wet weight to dry weight conversion based on 75% moisture content.

The decision to take a multi-media approach in developing the Se WQGs was based on several factors:

- the transformation of aqueous Se and subsequent bioaccumulation of dietary Se is the primary route of exposure in aquatic ecosystems;
- the chronic exposure of waterborne Se also contributes to overall exposure and may result in negative effects on aquatic biota, ranging from subtle changes in behaviour and physiology to increased deformity and mortality, (Hodson *et al*. 1980; Hilton *et al*. 1982; Hamilton and Wiedmeyer 1990; Cleveland *et al*. 1993; Miller *et al*. 2007; Palace *et al*. 2004); and,
- sediments are an important repository for Se and may contribute to the long-term cycling of Se and adverse impacts in an ecosystem long after the Se source is removed (Lemly 2002).

The Se WQGs were developed based on the taxa shown to be most sensitive to Se exposure, namely fish and birds. Differences in the propensity of Se to accumulate exist for different natural aquatic settings. Studies have demonstrated that lentic waters are typically more biologically productive and, due to their slow moving nature, favour the establishment of reducing conditions. Under such conditions, the transport of Se into sediments is enhanced, increasing exposure and enhancing uptake of Se by bottom-dwelling benthic organisms (Simmons and Wallschläger 2005; Orr *et al*. 2006). This enhanced mobilization and bioavailability of Se in lentic environments at the base of the food web, leads to greater uptake and cycling of Se and higher overall bioaccumulation and risk to higher predators (Orr *et al*. 2006; Simmons and Wallschläger 2005). Redox potential and biological activity in sediments largely drive the flux of Se between water and the food web, perpetuating long-term toxic effects in aquatic systems even when Se inputs into the system have been reduced (Simmons and Wallschläger 2005).

The development of the Se WQGs recognized the need to protect the most sensitive hydrologic units (i.e., lentic areas) within an exposed watershed, since fast moving (lotic) streams are connected with, and have within them, slower moving, depositional (lentic) areas such as pools, back-eddies, back-channels, lakes, and wetlands (Lemly 1999). In some locations, background

Se concentrations in water or sediment may be slightly higher, or some species may have naturally higher Se levels in tissues than generic guidelines. In these situations, a site-specific assessment may be required. Further discussion on the application of the Se WQGs is provided in Section 3.

2.1 Source Drinking Water

Health Canada's drinking water guideline for Se was established to prevent adverse health effects at excessive levels; this was adopted by the MoE for use as an ambient source water quality guideline to reduce adverse risks to drinking water sources, and therefore indirectly to human health.

To protect drinking water sources and human health, Se concentrations should not exceed 10 µg /L at any time. This guideline is adopted from Health Canada's drinking water guideline and any future revisions to that number will be reviewed and may result in revisions to the BC WQG.

2.2 Human Consumption Screening Values

Health-based screening values for Se in fish tissue were developed collaboratively by the Ministry of Environment and the Ministry of Health. Screening values are defined in this document as threshold values against which Se levels in the ambient environment can be compared and assessed for potential risks to human health.

The screening values were calculated based on conservative estimates of the population's fish consumption rates, days of exposure, and Se bioavailability. Screening values have been calculated based on three fish consumption scenarios: high, moderate, and low. Determining which screening value to use in a regional monitoring program will depend on what is known about local consumption habits. For example, if only seasonal sport fishing occurs, the 'low' consumption pattern screening value may be adequate. However, if subsistence fishing is occurring, then a high consumption screening value would be appropriate.

Monitoring programs must be undertaken with consideration of several factors to ensure that food samples are representative of those consumed by local populations. Sampling and monitoring considerations and protocols have been outlined by the BC MoE (BC MoE 2012b) and Health Canada (2004).

Exceedances of a screening value may indicate that detailed monitoring and evaluation of risks to human health are appropriate; this would be determined by the Ministry of Health or local Health Authorities. Regional health authorities or the Ministry of Health should be contacted directly if there are any environmental health concerns or questions.

To protect human health, the BC Ministry of Environment and the Ministry of Health recommend the use of the following screening values in environmental monitoring programs where elevated Se concentrations due to natural or anthropogenic activities in aquatic environments is a concern:

- ***1.8 µg/g (wet weight) or 7.3 µg/g (dry weight) for high fish intake (0.22 kg/day)***
- ***3.6 µg/g (wet weight) or 14.5 µg/g (dry weight) for moderate fish intake (0.11 kg/day)***
- ***18.7 µg/g (wet weight) or 75.0 µg/g (dry weight) for low fish intake (0.03 kg/day).***

Sampling and monitoring considerations and protocols have been outlined by the BC MoE (BC MoE 2012b) and Health Canada (2004). Exceeding screening values may lead to site-specific investigations to assess possible health risks.

2.3 Water Column Guideline for Aquatic Life

It is generally accepted that as Se concentrations in water increase, so does the risk of increased Se concentrations in biota, even if the absolute relationship is not well-understood. Strong relationships between Se concentrations in water and fish tissue have been demonstrated, providing a reasonably good predictor of Se accumulation in fish and an important assessment tool (Skorupa and Ohlendorf 1991; Casey and Siwik 2000; deBruyn 2009; Golder 2010). However, the bioaccumulation and toxicity of Se to organisms cannot always be predicted consistently from the concentration of Se in water and some scientists advise against the sole use of a water column guideline (Luoma and Presser 2009; Stewart *et al.* 2010).

Water is probably the most commonly sampled media in environmental monitoring programs because sample collection is relatively easy and inexpensive, and it does not require sacrificing organisms which may be rare or endangered. On a provincial basis, the BC WQG of 2 µg/L is considered protective of all aquatic life and was retained in the update. For more detailed discussion on the justification for this WQG, refer to section 8.4 of BC MoE (2014).

The 30-day average water quality guideline for protection of aquatic life is 2 µg/L, calculated as the mean concentration of 5 evenly spaced samples collected over 30 days, and measured as total Se.

Although the water column guideline of 2 µg/L protects most waters, the cycling rate of Se is not consistent across sites and there are instances in BC where enhanced accumulation of Se may occur (e.g., O'Rourke Lake in the East Kootenay). The extremely low site-specific Se water criterion developed by the San Francisco Bay Water Quality Control Board (0.1 – 0.8 µg/L) is one of several examples illustrating environments where Se cycling and bioaccumulation results in greater potential risk to organisms higher up in the food web (Pease *et al*. 1992). The degree of fish and wildlife exposure to Se varies among habitats according to intensity of use, type of use, and the relative contributions of the various processes that regulate Se cycling. In any assessment of Se contamination, variation among habitat types must be considered. And in the assessment of toxicological risk, how individual species use different habitats, as well as the role of the physical environment in the Se cycle, must be considered (Lemly and Smith 1987). For these reasons, an alert concentration of 1 µg/L is recommended. Where water column Se concentrations increases from natural background concentrations of <1 µg/L to >1 µg/L, key ecosystem compartments should be measured to ensure Se bioaccumulation is not resulting in exceedances of other alert concentrations (e.g. sediments) or guidelines (e.g. invertebrate and fish tissues, bird eggs). This tool will support early detection of potential Se bioaccumulation problems and provide earlier opportunities to commence proactive management actions.

The 30-day average alert concentration for the protection of aquatic life in sensitive ecosystems is 1 µg/L.

The water column guideline for aquatic life is applicable to both fresh and marine waters, since marine water typically has lower Se concentrations than freshwater and Se behaves similarly in both environments (Sui and Berman 1989).

2.4 Sediment Alert Concentration

Selenium in suspended and bed sediments is an important exposure route for organisms at the base of the food web (Lemly and Smith 1987; Fan *et al*. 2002). Mechanisms present in most aquatic systems effectively mobilize sediment Se into food chains and thereby cause long-term

dietary exposure to fish and wildlife (Lemly and Smith 1987). Nagpal and Howell (2001) developed a sediment Se quality guideline (2 µg/g), but it was classified as *interim* due to limited available data at that time. Unfortunately, no new primary literature was available to update the Se sediment guideline at this time. Because of the uncertainty associated with the existing information, the status of the guideline has been changed from an *interim* guideline to an *alert concentration*. No uncertainty factor was applied to this value since it is not a guideline. For most environments, the sediment alert concentration is considered protective and, along with data from other ecosystem compartments, provides an early indication of the increased risk of impacts to aquatic organisms. Where sediment Se are >2 µg/g, key ecosystem compartments should be measured to ensure Se bioaccumulation is not resulting in exceedances of guidelines (e.g. invertebrate and fish tissues, bird eggs). This tool will support early detection of potential Se bioaccumulation problems and provide earlier opportunities to commence proactive management actions. Since background Se concentrations in marine sediments are also typically well below 2 µg/g (Sui and Berman 1989), the sediment alert concentration also applies in marine environments.

The chronic sediment quality alert concentration for the protection of aquatic life is 2 µg/g, calculated as the mean concentration of at least 5 samples collected in a representative area (i.e., site).

2.5 Tissue Guidelines

The bioaccumulation of Se in tissues is important in determining toxicity. Tissue-based guidelines provide a more direct link between Se exposure and toxic effects. While dietary exposure is the predominant route of Se uptake (DeForest and Adams 2011), exposure to Se in the water column also accounts for some uptake in fish (Hodson *et al*. 1980; Hilton *et al*. 1982; Hicks *et al*. 1984; Cleveland *et al*. 1993; Hamilton 2004; Miller *et al*. 2007). Therefore, both exposure routes were considered in updating the Se tissue guidelines.

There are some differences in background tissue concentrations between freshwater and marine aquatic environments. Although it varies by species, some marine animals, such as birds and fish, often have higher tissue concentrations of Se than freshwater animals (Sui and Berman

1989; DeVink *et al*. 2008). Therefore, the tissue residue guideline for aquatic life applies only to freshwater fish.

2.5.1 Dietary Tissue

This section refers to Se concentrations in organisms that serve as prey or food items for higher trophic level organisms. Selenium measurements in dietary organisms provide valuable information for environmental managers and practitioners and may be used as triggers for further action (Lemly and Smith 1987; Lemly 1996; US DOI 1998; Wayland and Crosley 2006; Wayland *et al*. 2006, 2007; Canton *et al*. 2008). There are many advantages to sampling dietary organisms:

- periphyton and benthic invertebrates may be more Se tolerant than higher trophic level organisms;
- invertebrates are more abundant, and easier to sample than higher trophic levels;
- sampling non-commercial or non-charismatic invertebrate species for Se risk assessment does not put sensitive fish populations at risk;
- invertebrates may be alternate bioindicators when target species are rare and collection opportunities are limited; and,
- evaluating subtle changes to aquatic benthic invertebrate communities and, if possible, relating those changes to Se exposure can provide a means of assessing overall ecosystem impacts (e.g., Swift 2002; Pond *et al*. 2008).

For these reasons, Se concentrations in the tissue of prey organisms of fish and birds provides another compartment of the ecosystem to monitor Se bioaccumulation. The direct effects of Se on the prey organisms themselves can also be evaluated.

Some criticisms of using a dietary chronic Se guideline include:

- dietary Se is thought of as an indirect measure of toxicity;
- the observed responses can be highly variable;
- Se concentrations in some trophic levels can be highly variable; and
- characterisation and selection of appropriate indicator dietary species can be problematic (Malloy *et al*. 1999; USEPA 2004; DeForest and Adams 2011).

There are also logistic problems associated with collecting enough dietary tissue for analysis if a laboratory requires larger volumes. Despite these limitations, diet is the critical exposure pathway for those organisms most at risk, so an understanding of dietary Se can aid in predicting bioaccumulation and toxicity (Lemly 1996; Canton *et al*. 2008; Ohlendorf and Heinz 2011). Some studies have shown that fish Se body burdens can be accurately predicted based on dietary Se intake, with an almost 1:1 relationship between dietary and body burden Se concentrations (Stewart *et al*. 2004; Hopkins *et al*. 2004; Stewart *et al*. 2010; Presser and Luoma 2010). Comprehensive monitoring programs evaluating the effects of Se include this important dietary component to provide data for site-specific modelling (Orr *et al*. 2006, 2012).

Since there is a narrow margin between adequate dietary Se concentrations and those thought to pose a risk to fish and wildlife, and because the form of Se is a determinant in the degree of risk for toxic effects, it may be difficult to accurately predict Se toxicity from dietary intake. However, evaluations cited in BC MoE (2014) suggest that dietary Se concentrations above 4 µg/g constitute a risk for excess bioaccumulation resulting in reproductive and non-reproductive effects to sensitive receptor fish and wildlife species. Since fish and birds may be consuming a mix of invertebrates and fish, the fish whole-body tissue residue guideline of 4 µg/g should align with the dietary guideline. Therefore, the BC *interim* dietary guideline is 4 µg/g.

This guideline is designated *interim* because additional data are needed to verify the protection afforded by this value (BC MoE 2012a). Dietary concentrations exceeding this value would serve as a trigger for further investigation. While there are some studies that suggest this interim guideline may not protect highly sensitive invertebrate species, more definitive research is needed to define Se toxicity thresholds before a full guideline for protection of invertebrates can be proposed. No uncertainty factor was applied to this value because Se is a dietary requirement and some background levels of dietary Se are close to this value. Dietary Se evaluation should target organisms that are known or likely prey of sensitive receptor species, including other fish.

While most reference area concentrations of invertebrate tissue will not exceed an interim dietary guideline of 4 µg/g, some areas with naturally high Se may have background tissue concentrations that are close to, or slightly exceed this interim guideline. A careful examination

of environmental conditions is warranted in regions where true background dietary tissue Se exceeds this value.

The interim chronic dietary guideline to protect fish and aquatic-dependent wildlife is 4 µg/g Se (dry weight) measured as the mean concentration of at least eight replicate (composite) tissue samples representing appropriate invertebrate or other prey species. Further guidance on sample collection is provided in BC MoE (2012b).

2.5.2 Egg/Ovary Tissue

A Se guideline must consider both the reproductive effects resulting from the maternal transfer of Se and non-reproductive effects on early life stages (immediately after the onset of exogenous feeding) and juveniles. Both result primarily from the ingestion of dietary Se, but also from direct uptake of Se from water (Hermanutz 1992; DeForest 2008). Toxicity thresholds for non-reproductive effects in early life stages and juvenile fish are not as well defined as those for reproductive effects, but some researchers suggest the thresholds are similar (DeForest 2008; Janz *et al*. 2010; DeForest and Adams 2011; Table 8.13 in BC MoE 2014).

Egg or ripe ovary Se concentrations provide the most direct basis for predicting reproductive effects in fish and other wildlife and are the preferred tissues for environmental assessments (deBruyn *et al*. 2008; Janz *et al*. 2010; DeForest and Adams 2011; Ohlendorf and Heinz 2011). While tissue guidelines may be more ecologically relevant than water or sediment, it presents several challenges in terms of implementation (Lemly and Skorupa 2007). In some cases, constraints on sampling fish, whether seasonal or regulatory, may preclude egg/ovary sampling, in which case analysis of whole-body, muscle, or muscle plug tissues can provide a reasonable indication of risk for reproductive effects from Se toxicity (DeForest and Adams 2011). While generic tissue relationships have been defined, species- and site-specific correlations (the most reliable) between tissue types are often developed and may be used to translate Se concentrations between tissue types to predict reproductive effects (deBruyn *et al*. 2008).

Differences in tissue Se relationships do exist even between closely related species, as demonstrated by Holm *et al*. (2005) who found a 7-fold increase in rainbow trout egg Se compared with muscle Se, while brook trout had only a 2-fold increase in egg Se over muscle Se at the same sites. The egg/ovary guideline was developed using a combination of weight of

evidence and the mean of published effects data with an uncertainty factor of 2 applied. For more details see Section 8.4 in BC MoE (2014).

The chronic egg/ovary tissue guideline for the protection of fish is 11 µg/g, calculated as the mean concentration of at least eight samples (eggs or ripe ovary from eight individual females) collected at a representative area (site), and reported as dry weight.

2.5.3 Whole-Body Tissue

A whole-body Se guideline is broadly applicable, and may be more appropriate for practical reasons (USEPA 2004; DeForest and Adams 2011). For example, when investigating non-reproductive effects of Se on early life-stage and juvenile fish, whole-body Se concentrations are the most appropriate measure. In situations where juvenile or small-bodied fish species are of interest, whole-body Se analysis may be the only option for monitoring. While whole-body Se concentrations may not be the most direct measure of potential reproductive effects in adults, for the reasons stated above, it has been retained as a guideline.

Research assessing toxic responses in fish from water-only exposures has shown that early life stage and juvenile fish may be sensitive to Se when based on whole-body tissue accumulation (Hodson *et al*. 1980; Hamilton and Wiedmeyer 1990; Cleveland *et al*. 1993). Some authors exclude water-only Se exposure studies on juvenile fish when deriving toxicity thresholds, stating those studies have limited relevance to natural Se exposure (i.e., lacking dietary exposure component) (DeForest *et al*. 1999; USEPA 2004; deBruyn *et al*. 2008; DeForest 2008; DeForest and Adams 2011). However, excluding such data has been criticized by other researchers who state that this approach is selective and may result in erroneous conclusions (Skorupa 1999; Hamilton 2003).

Despite the controversy regarding juvenile fish toxicity threshold predictions based on dietary versus water-only exposures to Se, more recent studies have shown that physiological changes can result when early life-stage and juvenile rainbow trout are exposed to waterborne Se (Palace *et al*. 2004; Miller *et al*. 2007). Aqueous Se can contribute to toxicity and, since Se residues in fish are the sum total of dietary and aqueous routes of exposure, water-only exposure evaluations of Se should not be disregarded as irrelevant (Hamilton 2003; Janz *et al*. 2010). Since water contributes at least in part to toxic responses in fish, water-only exposure studies were

considered in the derivation of the whole-body guideline. The whole-body guideline was developed using a combination of the weight of literature-based evidence and the mean of published effects data for multiple species with an uncertainty factor of 2 applied. For more details see Section 8.4 in BC MoE (2014).

The chronic whole-body tissue guideline for the protection of fish is 4 µg/g calculated as the mean concentration of at least eight tissue samples collected at a representative area and reported as dry weight.

2.5.4 Muscle Tissue

Muscle tissue has been used to evaluate the exposure of fish to Se as an alternative to egg and whole-body analysis, though it may not be the most direct measure of toxic response (Waddell and May 1995; deBruyn *et al*. 2008). Muscle can be a reasonable and useful surrogate, particularly if reliable species-specific tissue relationships have been developed (deBruyn *et al*. 2008) such as those for westslope cutthroat trout in the Elk River BC (Minnow *et al*. 2007) and for rainbow trout in Alberta (Holm *et al*. 2005). Unfortunately, toxicity thresholds relating specifically to muscle tissue residues are limited and rarely consider species native to BC (see Table 8.15 in BC MoE 2014).

The egg Se guideline of 11 µg/g was converted to a muscle concentration for two sensitive BC species, rainbow and cutthroat trout using the species-specific regressions in Schwarz (2011). This resulted in Se residue estimates of 3.5 and 6.5 µg/g Se, respectively. The evaluation of the low toxicity thresholds based on muscle in Chinook salmon (Hamilton *et al*. 1990), brown trout (NewFields 2009), rainbow trout (Holm *et al*. 2005) and westslope cutthroat trout (Rudolph *et al*. 2008) all support a muscle tissue guideline of 4 µg/g Se.

Lotic reference site data can present challenges when comparing tissue concentrations to guidelines. Due to the broad home range of some fish species, lotic reference sites may have resident fish which have foraged in Se-contaminated areas, confounding the conclusions regarding background tissue Se concentrations (Minnow *et al*. 2007; DeForest 2009; Golder 2010; Minnow *et al*. 2011). Therefore, caution must be exercised if reference area tissue concentrations are unexpectedly high relative to other reference values or in excess of the guideline.

Based on the low effect concentrations for rainbow trout, brown trout and bluegill sunfish, 4 µg/g (dw) in fish muscle tissue is the recommended guideline. This is an *interim* guideline since there remains some uncertainty in the estimates and there is little primary toxicity data directly linking effects to muscle tissue concentrations. Since we assume that whole-body and muscle Se concentrations in fish are approximately the same, and an uncertainty factor was previously applied to whole-body guidelines, an additional uncertainty factor was not applied to the interim muscle tissue guideline. In regions where natural background fish muscle tissue Se exceeds the guideline, a more complete site assessment may be warranted.

The interim muscle tissue Se guideline for the protection of fish is 4 µg/g, calculated as the mean of at least eight tissue samples from individual fish collected at a representative area, and reported as dry weight.

2.6 Guidelines for the Protection of Wildlife

The previous wildlife guideline developed for BC used birds as the surrogate to represent all sensitive wildlife (amphibians, reptiles), excluding fish and aquatic life (Nagpal and Howell 2001). The 2001 guidelines included a water-based maximum concentration of 4 µg/L, as well as an alert concentration for Se in bird eggs of 7 µg/g (Nagpal and Howell 2001). Since dietary accumulation at the base of the food web is the critical link to body burden in higher trophic levels, the aquatic life guideline (2 µg/L) for the water column has also been adopted in this update for the protection of wildlife.

The previous bird egg tissue guideline of 7 µg/g was reviewed in light of more recent toxicity studies. Unfortunately, toxicity data on amphibians and reptiles is still limited. There are also toxicological studies on aquatic-dependent mammals or other small mammal species exposed to Se contamination, yet concentration-response relationships with Se have not been established for mammalian wildlife. Studies to date, however, suggest that aquatic-dependant mammals may be less sensitive to Se than are fish or birds (Janz *et al*. 2010).

Some authors (Skorupa and Ohlendorf 1991; Skorupa 1999) mention the secondary dietary hazard posed to predators feeding on bird eggs that exceed dietary thresholds. It is important that a protective wildlife guideline value consider these secondary hazards to predators in setting a wildlife guideline (e.g., other birds, some reptiles and larger mammals like marten, coyote, fox,

and bear). A guideline of 6 µg/g (dw) for wildlife is slightly higher than the 4 µg/g dietary guideline for aquatic life. Since there is great uncertainty about the risk posed to predators from consuming bird eggs, and there are too few studies to determine a wildlife consumer guideline, none is proposed at this time.

The water column guideline of 2 µg/L, and the dietary guideline of 4 µg/g in food items, are applicable to wildlife species. The chronic tissue guideline for the protection of wildlife, using birds as a surrogate, is 6 µg/g (dw) in bird egg tissue, calculated as the mean concentration of at least 8 eggs (from 8 individual nests) in a representative area, reported as dry weight.

2.7 Irrigation and Livestock Watering

The WQGs for irrigation and livestock watering have not been updated at this time and therefore the 2001 guidelines stand. Details on their derivation and rationale are provided in Nagpal and Howell (2001).

The approved BC WQG for irrigation water is 10 µg/L. The approved BC WQG for livestock watering is 30 µg/L.

3.0 Recommended Assessment and Management Framework for Se in BC Waters

The assessment and management of Se requires an effective monitoring program for identified water uses (e.g. human health, aquatic life, wildlife, livestock watering and irrigation). An effective monitoring program establishes background concentrations in various ecosystem compartments including water, sediment, invertebrates, fish tissue (egg/ovary, whole body, muscle), bird eggs, and amphibian eggs at critical time periods. A full characterization of Se in all critical environmental compartments (water, sediment, and biota) should be conducted to assist in the evaluation, interpretation, and management of Se in aquatic ecosystems (Lemly 1996; Sappington 2002; Presser and Luoma 2006; Ohlendorf *et al*. 2008). Site-specific considerations will determine the extent of the monitoring program.

Sampling guidance for each environmental compartment is provided in Table 2 and Figure 1 provides guidance for the assessment and monitoring at various Se water quality concentrations.

Table 2. List of updated Se WQGs and sampling guidance for use in British Columbia. Water concentrations are measured as total selenium. Details on guideline derivation may be found in the Se Technical Appendix (BC MoE 2014).

Water Use	Updated 2014 BC Se WQG	Sampling Guidance
Source Drinking Water	10 µg/L	*Source Drinking Water:* This is a maximum acceptable concentration; sampling should occur in surface and groundwater sources during both low and peak flow periods.
Human Consumption Screening Values		*Tissue Consumption*: Monitoring fish for human health risks should be representative of consumption behaviour (e.g., species, fish size, location of catch, parts of fish consumed); risk specialists within the local Health Authority should be consulted before this process begins.
High fish intake (0.22 kg/day)	1.8 µg/g (ww), 7.3 (dw)[2]	
Moderate fish intake (0.11 kg/day)	3.6 µg/g (ww), 14.5 (dw)	
Low fish intake (0.03 kg/day)	18.7 µg/g (ww), 75.0 (dw)	
Aquatic Life		
Water column freshwater & marine		*Water*: 30-day average determined as the mean concentration of 5 evenly spaced samples collected over 30 days and measured as total Se.
Alert concentration	1 µg/L	
Guideline	2 µg/L	
Sediment - Alert concentration	2 µg/g (dw)	*Sediment*: Mean of ≥ 5 samples collected in a representative area.
Dietary		*Dietary:* Mean concentration ≥ 8 replicate (composite) tissue samples representing an appropriate invertebrate or other prey species.
Invertebrate tissue (interim)	4 µg/g (dw)	
Tissue (fish)		*Egg/ovary*: Mean of ≥ 8 egg or ripe ovary (from 8 individual fish) in a representative area, reported as dry weight.
Egg/ovary	11 µg/g (dw)	*Whole-body*: Mean of ≥ 8 fish in a representative area, reported as dry weight.
Whole-body (WB)	4 µg/g (dw)	*Muscle*: Mean of ≥ 8 muscle tissue samples (from 8 individual fish) in a representative area, reported as dry weight.
Muscle/muscle plug (interim)	4 µg/g (dw)	
Wildlife		*Water*: 30-day average determined as the mean concentration of 5 evenly spaced samples collected over 30 days and measured as total Se.
Water	2 µg/L	*Bird egg*: Mean of ≥ 8 eggs (from 8 individual nests) in a representative area, reported as dry weight. A statistical analysis could also be used to determine a more specific sampling design.
Bird egg	6 µg/g (dw)	
Irrigation Water		*Water*: A maximum guideline not to be exceeded.
2001 guideline not updated	10 µg/L	
Livestock Watering		*Water*: A maximum guideline not to be exceeded.
2001 guideline not updated	30 µg/L	

[2] Guideline based on edible portions of tissue. Wet weight to dry weight conversion based on 75% moisture content.

Water [Se] < 1 µg/L

- Continue monitoring to determine trends in concentrations, as necessary;
- Monitoring of other compartments may be desirable to determine baseline conditions.

Water [Se] > 1 µg/L < 2 µg/L

- Continue monitoring to determine trends in concentrations;
- Measure sediment [Se]:
    - If < 2 µg/g (dw), monitor periodically at an appropriate frequency to determine if changes are occurring over time;
    - If > 2 µg/g (dw), monitor other compartments as necessary.

Water [Se] > 2 µg/L

- Recommend:
    - Determine sediment [Se], compare with sediment Se alert concentration;
    - Determine invertebrate tissue [Se], compare with Se interim dietary guideline;
- As necessary:
    - Determine fish tissue [Se];
    - Determine bird egg [Se].
- If natural background [Se] is > 2 µg/L, conduct sufficient sampling of each appropriate compartment above to establish background concentrations;
- If natural background [Se] is < 2 µg/L, conduct ongoing monitoring to determine trends for each appropriate compartment over time.
- Consider assessing other indicators (e.g. fish population structure, environmental effects assessment)

Water [Se] > 10 µg/L and/or fish tissue is > Human Consumption Screening Values

- As necessary:
    - Consult the local health authority

Figure 1. Recommended monitoring and assessment framework for Se.

One of the many uncertainties associated with evaluating Se is the variation in both sampling and analytical techniques, which can be sources of error and variation in data. A very good summary of the potential monitoring pitfalls along with recommendations for conducting a sound monitoring and assessment program for Se is provided in Ohlendorf *et al*. (2008) and Ohlendorf *et al*. (2011). As well, Ralston *et al*. (2008) prepared a document on the biogeochemistry of Se, which includes advice on analytical techniques for Se and its chemical species.

Establishing data quality assurance/quality control (QA/QC) requirements, along with a conceptual monitoring plan, is recommended at the outset of any monitoring and assessment program for Se (Ohlendorf *et al*. 2008, 2011). During the collection of data, care should be taken

to ensure that samples are representative of the area being sampled (control or background versus exposed sites). Sample handling, preservation, preparation, and shipping should follow standardized procedures appropriate for each media (water, sediment, or biological). The appropriate QA/QC checks should be incorporated into the sampling and monitoring program design. Ralston *et al*. (2008) and documents prepared by the BC Ministry of Environment (Cavanagh *et al*. 1998; Ministry of Water, Land and Air Protection 2003) provide more detail on sampling and monitoring programs for interested readers.

The variability in fish tissue dataset concentrations at sites where there is no apparent disturbance or source of Se contamination may be explained by unanticipated Se sources, complex bioaccumulation dynamics that enhance Se uptake, and/or species-specific enhanced Se uptake. In locations where unexpectedly high Se concentrations appear in one or more environmental compartments, or for species that accumulate high levels of Se in undisturbed reference areas, closer examination of the data and the site conditions is recommended. Laboratory quality assurance should be checked carefully, as well as the numbers and representativeness of samples. Highly mobile fish species may move in and out of Se-contaminated areas resulting in variable exposure and higher than expected tissue Se. Some fish species, such as sculpin, could have habitat preferences that put them at greater risk of accumulating Se. Some locations may be more prone to Se bioaccumulation as a result of the natural geology of the area. These factors, alone or in combination, can result in Se concentrations elevated above guidelines, in which case site-specific assessments may be warranted.

One of the most critical monitoring aspects to consider when initiating a monitoring program is a thorough inventory and assessment of organisms potentially at risk in the area of concern. This should include all trophic levels. Knowing what organisms are at risk, and where they occur, helps define the study area and identify key indicator species.

Presser and Luoma (2006) recommend that a full characterization of Se in the critical environmental compartments will greatly enhance the evaluation, interpretation and management of Se in aquatic ecosystems. The co-located sampling of various compartments in the environment (different media) in both exposed and reference areas, and/or across a gradient of Se concentrations provides optimal information (Ohlendorf *et al*. 2008). This will assist in long-

term studies where the objective is to compare results over time to determine trends. This will also facilitate development of important site-specific and species-specific relationships within and between the various environmental compartments and tissue types.

The number and types of samples should consider other possible contaminants, the type of environment being sampled, natural variability (adequate numbers of samples), interactions between media, and target organisms (i.e., dietary organisms and key surrogate species at the top of the food web) (Ohlendorf *et al*. 2008). Assessments should target the correct season to coincide with spawning of important target species, nesting of birds, and/or worst case Se concentrations. As well, establishing relationships between Se concentrations in multiple tissue types within an individual fish species (e.g., egg/ripe ovary with whole-body or muscle tissues) can improve the understanding of Se toxicokinetics and also provide some flexibility in monitoring programs (use of non-destructive sampling techniques) once relationships between tissue types are established. For example, muscle plug tissue samples in westslope cutthroat trout in the Elk River in BC, were found to be highly correlated to muscle fillet tissues, with a correlation coefficient (r^2) of 0.996, making muscle plug samples a non-destructive sampling alternative (Minnow 2004).

Sediment concentrations of Se, by nature, may be highly variable and may not provide a link to Se levels in other environmental compartments, such as tissues (Hamilton and Lemly 1999; Malloy *et al*. 1999). Sampling methods and study designs may help control the high degree of spatial and temporal variability in sediment Se concentrations (Malloy *et al*. 1999). Selenium tends to adsorb to fine-textured, organic-rich sediments, making these characteristics important to define when analysing sediment samples (Besser *et al*. 1989; Wiramanaden *et al*. 2010). Restricting stream sample locations to depositional zones and using only the fine grain size fraction of sediment for metals analysis may reduce this variability (Rex and Carmichael 2002).

The BC MoE recommends that sediments less than 63 μm be evaluated for metals analysis, including Se, to reduce the variability in reported metals concentrations (BC MoE 2012b). It is important when collecting sediments, to analyze key variables such as particle size distribution and total organic carbon (TOC) content. Sediment samples should be composites of at least five

individual samples per location so variability between sites and changes over time can be evaluated.

More guidance and information specific to mining-related monitoring and assessment can be found in the document *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators* (BC MoE 2012b).

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