OPEN-PIT COAL MINING IN THE ELK VALLEY AND RESULTANT SELENIUM POLLUTION: AN EGOLOGICAL RISK ASSESSMENT OF TWO FUTURE ELK VALLEY COAL MINING OPERATIONS

By

Scott Holmgren

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Supervisor: Dr. Susan Gass

Approvals Page

Dalhousie University

Author: Scott Holmgren

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Abstract

Coal mining in the Elk Valley, British Columbia is one of the area's largest industries and is important to local economic development. However, many ecological impacts associated with coal mining are being observed including impacts on one of the area's most valuable sport fish, westslope cutthroat trout (WCT). Selenium (Se) has been particularly of concern due to its ability to biomagnify in aquatic food chains and accumulate in the tissues and eggs of higher trophic species. This has resulted in significant decreases in WCT reproductive success in areas of the Elk and Fording Rivers and has caused species extirpations from areas abroad. There is concern over the development of future coal mining projects in the Elk Valley including the Baldy Ridge Extension (BRE) project, which is an extension of Elkview Operations (EVO), and the Coal Mountain Phase II (CMO2) project, which is an extension of the current Coal Mountain Operations (CMO).

In order to assess the potential ecological risks from these projects, an ecological risk assessment (ERA) was conducted to look at the potential Se loading and associated impacts on WCT. CMO2 has the potential to impact WCT due to its proximity to one of the largest WCT spawning grounds in the region. BRE has the potential to impact WCT populations due to its estimated large quantities of Se loading into Michel Creek and the Elk River. Both projects present significant risk to WCT populations. CMO2 was not estimated to load significant quantities of Se into nearby waterways and WCT populations near BRE are some of Elk Valley's lowest. For these reasons, both projects are considered medium-risk projects and should be further evaluated before their approval and development.

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BRE	Baldy Ridge Extension
BC	British Columbia
Ca	Calcium
CDN	Canadian Dollar
CMO	Coal Mountain Operations
CMO2	Coal Mountain Phase II
ERA	Ecological Risk Assessment
EPA	Environmental Protection Agency
EVO	Elkview Operations
FRO	Fording River Operations
GHO	Greenhills Operations
LCO	Line Creek Operations
N	Nitrogen
NC	North Carolina
S	Sulphur
Se	Selenium
SeO_3^{-2}	Selenite
SeO_4^{-2}	Selenate
SK	Saskatchewan
SO_4^{2-}	Sulphate
UMRR	Upper Mud River Reservoir
US	United States Dollar
WCT	Westslope Cutthroat Trout
WV	West Virginia
WVDEP	West Virginia Department of Environmental Protection

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1.0 Introduction

1.1. Problem Statement

The Elk Valley is a low-lying basin located in southeast British Columbia in the heart of the Rocky Mountains. The Elk Valley sits approximately 60 km from the Alberta and Montana borders and follows the basin of the Elk River, which flows 220 km from the Elk Lakes Provincial Park into Lake Koocanusa (Hauer & Sexton, 2013). The Elk River consists of 838 ha of aquatic habitat consisting of 88% lotic ecosystems and 12% lentic ecosystems (Polzin et al., 2007). Lotic ecosystems are defined as aquatic environments that are in constant or rapid movement such as rivers, streams, and creeks; lentic ecosystems are defined as aquatic environments with standing water including lakes, ponds, and wetlands (Ramachandra & Solanki, 2007).

These ecosystems in the Elk Valley support a variety of aquatic biota including westslope cutthroat trout (WCT) *(Oncorhynchus clarki lewisi*), bull trout *(Salvelinus confluentus),* and mountain whitefish *(Prosopium williamsoni)* (Luoma & Presser, 2009). These species have prominent roles in the area's aquatic food chain and have specific habitat requirements that allow them to be utilized as ecological indicators to measure aquatic environmental health (BC Ministry of Environment, 2010; Luoma & Presser, 2009; COSEWIC, 2006). In particular, WCT have a narrow set of habitat requirements and minor alterations to the physical or chemical characteristics of their habitat can result in forced migration or increased mortality (COSEWIC, 2006). Maintaining WCT populations at a healthy level is not only critical to the composition of the food chain in Elk Valley aquatic ecosystems, but also to the area's prominent recreational angling sector, which is internationally recognized and contributed approximately $1.4 million CDN to the Elk Valley economy in 2002 (Heidt, 2003).

The Elk Valley has been an important part of coal mining in British Columbia for the past 100 years and has developed a strong, resource dependent local economy. Today, the Elk Valley is home to five coal mining operations owned and operated by Teck Resources (Teck) including: Coal Mountain Operations (CMO), Elkview Operations (EVO), Fording River Operations (FRO), Greenhills Operations (GHO), and Line Creek Operations (LCO) (Figure 1). These mines have been operating for numerous years and Teck is currently in the process of applying for extensions of existing operations and developing new mining operation sites in the Elk Valley (Teck, 2013).

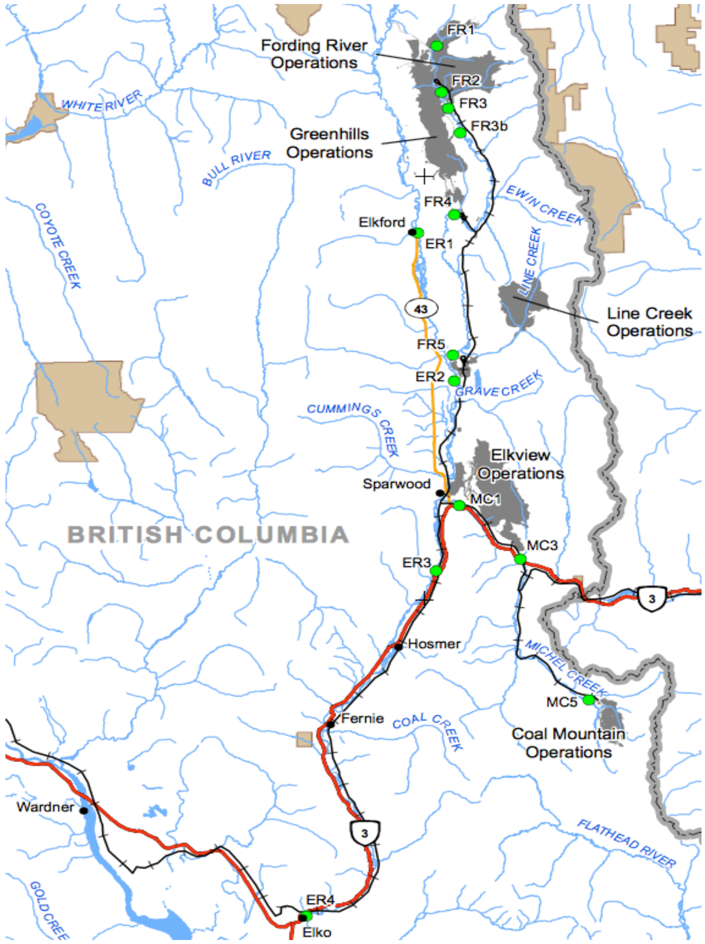

Figure 1 Map of the Elk Valley and the five coal mining operations (highlighted grey areas). In the map, "FR" represents the Fording River and "ER" represents the Elk River. In the bottom right corner, the Flathead Valley and Flathead River sit adjacent to the Elk Valley. Image retrieved from Teck Resources' *Valley-Wide Selenium Management Action Plan* summary report (2013).

The main form of mining in the Elk Valley is open-pit surface mining. Open-pit surface mining involves the removal of rock from the surface to form large, open pits (Banglam, Ataei, & Sayadi, 2012). Rock that is removed from the open pits, referred to as waste rock, overburden, or spoil, is moved to nearby piles or adjacent valleys where they are stored until reclamation of the open pit is commenced (Banglam, Ataei, & Sayadi, 2012). The past 30 years of open-pit mining in the region has created concern for its impacts on local ecosystems (Lemly, 2014). Intensive open-pit coal mining has increased levels of selenium (Se), nitrogen (N) compounds, calcium (Ca), and sulfate (SO_4^{2-}) into the Fording River and Elk River; most of which are released from waste rock overburden and mineral oxidation (Teck, 2013). Krahn (2014) has shown that the significant deposits of Ca, N, and other compounds have led to negative biological effects, such as the growth and development of aquatic plants, periphyton, and algae in areas surrounding the mine sites. However, Se has been particularly damaging to WCT populations in both the Fording River and Elk River watersheds due to its impacts on reproductive success (Krahn, 2014).

Se is a non-metal element and is released during the mining process by surfacing large amounts of overburden, resulting in the oxidation and leaching of Se from the parent material (Teck, 2014b) (Figure 2). Se is an element essential to proper functioning and health in most organisms, but can be toxic at concentrations above a species' dietary requirements. The current BC Water Quality Guideline states that Se concentrations in aquatic habitats should not exceed the 2.0 μg L^{-1} threshold and concentrations in tissues should not exceed 1 μg g^{-1} (Nagpal, 2001). This is based on research conducted by the International Joint Commission and on the lowest observed effect level of 10 μg L^{-1} and a safety factor of five for freshwater biota (Nagpal, 2001). However, acute toxicity of Se has not caused major concern; rather its potential to biomagnify in aquatic food webs has raised distress for its impacts on aquatic ecosystems (Lemly, 2002).

Bioaccumulation is defined as the uptake of organic compounds by biota at a rate that exceeds its ability to remove the compounds and biomagnification is defined as the increase in tissue concentration of a contaminant as it travels up the food chain through multiple trophic levels (EPA, 2010) (Figure 3). In the Elk Valley, Se has been observed to cause extensive damage in lotic ecosystems, mainly in higher trophic levels due its ability to biomagnify in aquatic food chains (Lemly, 2004).

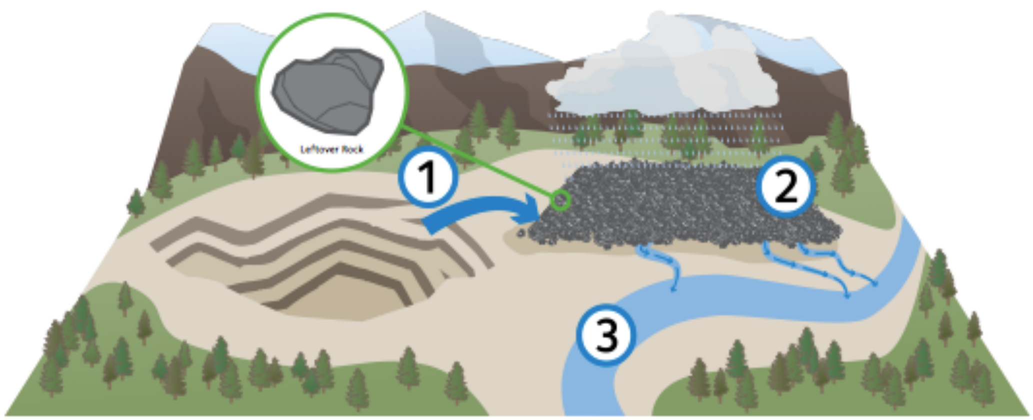

Figure 2 (1) visualization of the surfacing of overburden from open-pit surface mining; (2) the oxidation, liberation, and leaching of nutrients from the overburden into the local watershed; (3) damage to aquatic organisms is observed due to exposure to toxic concentrations of nutrient runoff. Image retrieved from Teck (2013).

Se has severely impacted WCT populations in the Upper Fording River; 54.4% of the annual reproductive output is being killed due to overexposure to high Se concentrations (Lemly, 2014; Krahn, 2014). WCT are a unique and valuable component of Canadian freshwater ecosystems due to their role in structuring aquatic ecosystem food webs; their strict habitat requirements also allow them to be considered a valuable indicator species for general ecosystem health (COSEWIC, 2006). Deleterious effects of Se on freshwater fish species have also been documented in the Central Appalachian Basin in West Virginia (WVDEP, 2010). The West Virginia Department of Environmental Protection (WVDEP) documented morphological deformities and reduced reproductive success of bluegill (*Lepomis macrochirus*) and largemouth bass (*Microterus salmoides*)(WVDEP, 2010).

Teck is currently planning the extension of GHO, FRO, and LCO and are also in the process of approving the extension of EVO (Baldy Ridge Extension project) and CMO (Coal Mountain Phase II project) (Government of British Columbia, 2015; Teck, 2014a). In addition to Teck, other proponents such as CanAus Coal Ltd. and NWP Coal Canada Ltd. (Jameson Resources) also have staked interests in developing new coal mining operations in the Elk Valley (CanAus Coal Ltd., 2015; NWP Coal Canada Ltd., 2014). These new coal mining developments and extensions may pose a serious threat to the health of the Elk River and WCT in this region.

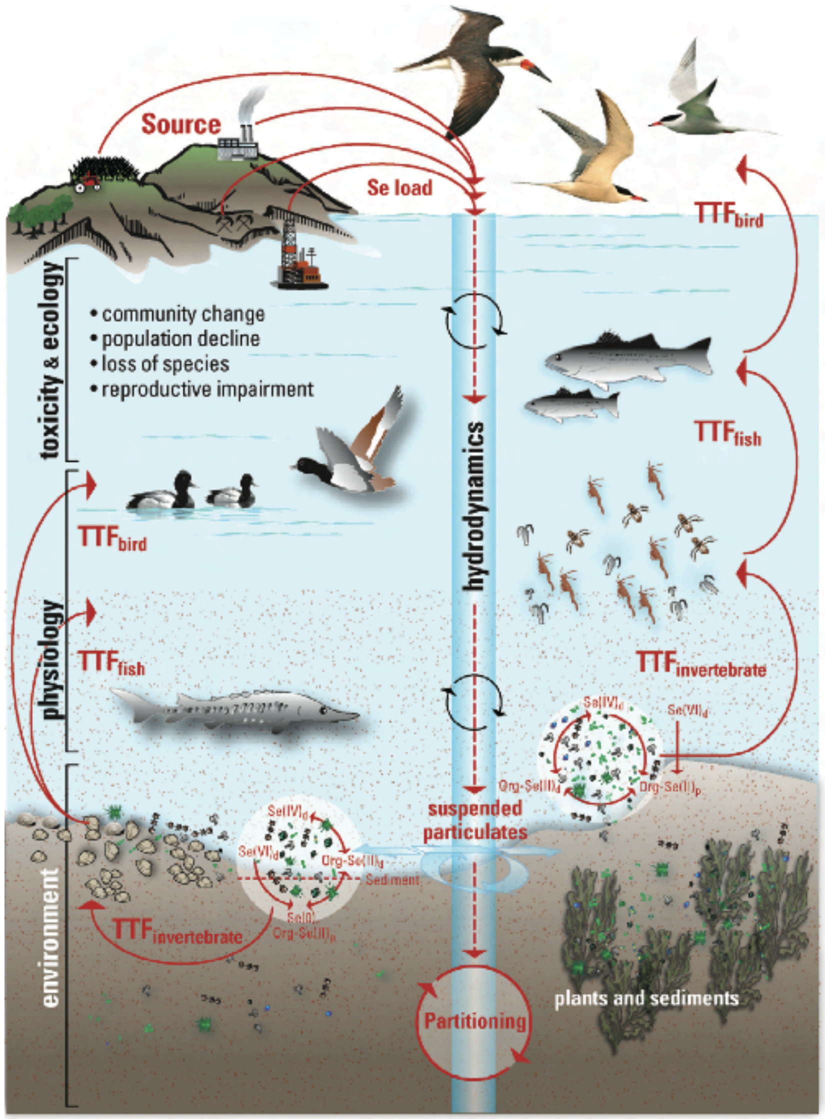

Figure 3 Conceptual model of Se exposure and effects on various trophic levels in two aquatic ecosystem food webs. TTF stands for trophic transfer factor, which refers to Se bioaccumulation amongst trophic tiers. Image retrieved from Luoma and Presser (2009).

Due to increasing pressure, Teck has recently invested $600 million CDN over the next five years into the development of six water treatment facilities in the Elk Valley (Teck, 2014b). These facilities aim to reduce the levels of Se and other elemental pollutants from entering the Fording River, Elk River watersheds by removing Se directly from waterways on the mining property before they flow into the Elk River and Fording River. A single wastewater treatment facility has been already constructed and began operations in 2014 at LCO, two more are planned to be fully operational in 2018 at FRO and 2020 at EVO, and the remaining three planned to be fully operational after 2020 (Teck, 2014b). Although Teck has predicted these treatment facilities will reduce significant amounts of Se in the Elk River and Fording River over time, developing future and extending existing coal-mining projects in the Elk Valley may ultimately increase the amount of Se in these lotic ecosystems, despite water treatment technologies.

1.2. Purpose of the Study and Research Question

As Teck and other proponents continue to plan and develop new coal mining sites in the Elk Valley, the risk for further Se loading increases. Developing additional mining sites could increase waste rock outputs and therefore, potentially increase elemental leachates such as Se. The purpose of this study is to help determine if the development of the Baldy Ridge Extension (BRE) project and the Coal Mountain Phase II (CMO2) project could present a risk of increased Se loading in the Elk Valley and potentially impact WCT and other aquatic organisms.

Research Question

Will the development of the Baldy Ridge Extension Project and Coal Mountain Phase II Project increase selenium loading in the Elk Valley and contribute to a greater risk of adverse impacts on westslope cutthroat trout populations?

In order to assess these potential risks, an ecological risk assessment (ERA) will be conducted which will include the following:

- An evaluation of the potential selenium exposures and effects to westslope cutthroat trout from the Baldy Ridge Extension and Coal Mountain Phase II projects;
- An outline of selenium risk characterization, description, and analyses in an ecological risk assessment format; and
- A spatial visualization of the Baldy Ridge Extension, Coal Mountain Phase II, and potential areas of increased selenium loading.

By conducting an ERA, this study will review potential impacts of increased waste rock production in the Elk Valley and the potential risks associated with an increase of Se in the Elk River and a major tributary, Michel Creek. It will involve assessing the potential exposures (interaction of stressors with receptors) and the analysis of the potential effects and changes in the magnitude of impacts associated with exposure (SETAC, 1997). This will lead to an estimation of risk, which will be evaluated throughout the course of this research. A visual display of the proposed BRE and CMO2 mining sites and potential Se loading increases will aid in developing and assessing the risks associated with these two major projects and the potential routes of Se exposure.

Ultimately, this research will aim to supplement knowledge of the ecological impacts in lotic ecosystems associated with Se loading resulting from open-pit surface coal mining and will attempt to develop an ERA for the two future mining sites in the Elk Valley. Predicting the potential impacts of the two projects will involve the collection of waste rock reserve and Se loading data and an analysis of the geographic extent of each project in comparison to nearby lotic aquatic environments.

1.3. Limitations and Delimitations

Major limitations of this research stem from numerous assumptions and comparisons about the development of the BRE, CMO2, and wastewater treatment facilities. The main limitation of this study is that the ERA will be conducted with the assumption that the wastewater treatment facilities will not be operational near the BRE and CMO2 mining sites during their mining operations. This is in part due to the undetermined capacity and lack of data supporting the relatively new wastewater facilities that remove Se from aquatic environments in the Elk Valley. A second limitation is that the Se loading data obtained is from the operating years 2008 to 2012 and the waste rock production data for EVO and CMO are from the 2014 operating year. This is significant because coal production per year has almost doubled from 2008 to 2014; however, it has been relatively stable (within 3 million tonnes) from 2010 to 2014, therefore may still provide accurate results. Median values of Se data will also be used to get a more precise estimate of Se loading to coincide with the predicted waste rock values from 2008 to 2012. The third limitation is that the BRE and CMO2 projects will be compared to current mining operations (EVO and CMO respectively) in terms of waste rock and Se outputs and risks will be based off these comparisons. The fourth limitation is that potential Se loading will be examined based on surface water activity only. Groundwater movement of Se is not well documented in the Elk Valley and it is assumed that surface water runoff accounts for the majority of Se movement from the mine site to the Elk River and its tributaries. The fifth and final limitation is the ERA will be based on existing research, results found in the literature, and future projections of Se loading. Including these limitations, this research will aim to assess the risks of both BRE and CMO2 developments with a number of assumptions, comparisons, and calculations.

In addition to the limitations, certain delimitations have also been used in this research to limit the scope. First, only the BRE and CMO2 projects are considered in this ERA; including all other proposed mining operations in the Elk Valley lies outside the scope and realm of this study based on time constraints. Second, impacts will be predicted without any mitigation efforts from the wastewater treatment facilities. Third, this research will focus on the impacts Se has had in the Elk Valley and not other nutrients or pollutants from open-pit coal mining. Lastly, only ecological impacts on the lotic ecosystems (Elk River, Fording River, Michel Creek, and tributaries) will be discussed with a focus primarily on effects to WCT; no impacts to lentic or terrestrial ecosystems will be included in this research.

2.0 Literature Review

2.1. Overview

The focus of this literature review is to summarize the current state of knowledge based on previous research conducted on Se exposure, its effects on fish species, and its loading in the Elk Valley and other relevant areas. First, it will begin with a general outline, Se as a potential toxic element, and its exposure pathway to aquatic ecosystems during open-pit coal mining. Second, Se toxicity to fish species and Se biomagnification will be addressed with examples from Lemly (2014). Third, research led by Krahn (2014) and Lemly (2014) on the impacts of Se in the Elk Valley will be examined. Fourth, comparisons of coal mining and Se loading in the Elk Valley to other areas in British Columbia and the United States will be made. The literature review will conclude with a brief summary of the analyzed literature.

2.2. Selenium and Open-Pit Coal Mining

Se is an element that is naturally found in sedimentary shales and minerals containing sulfide compounds; it is commonly distributed worldwide being found in many soils and water globally, including organic materials such as coal (Johnson et al., 2010; Pond et al., 2008). Open-pit surface mining produces large amounts of overburden, which leads to increased Se leachates and can cause excess Se to load in local watersheds. However, elemental Se is not known for its direct toxicity; instead, evidence of deleterious impacts on fish arises from exposure to Se anions, selenate (SeO_4^{-2}) and selenite (SeO_3^{-2}) (Lemly, 2002; & Antweiler, 2015). Natural weathering of overburden material allows elemental Se to become oxidized then liberate from its parent material, leaching out of the waste rock and into local soils and watersheds (Antweiler, 2015). Here, Se can be absorbed by unicellular organisms and plants through Se enriched sediments, which can lead to bioaccumulation within these organisms and eventually biomagnifying to higher trophic species including WCT and can have severe adverse impacts on reproduction rates and success (Lemly, 2002).

2.3. Selenium Toxicity to Aquatic Vertebrates

Acute toxicity to Se occurs in scenarios of extreme exposure, generally limited to aquatic environments such as mine tailings ponds where only certain biota are able to survive (Lemly, 2002). At lower levels of exposure in fish, adult females absorb Se into their ovaries, where it is then passed on to egg tissue. For example, Lemly (2002) was able to determine that excess Se downstream of a coal-fired power plant in Belews Lake, North Carolina, was stored in fish embryos and was exposed to developing fish upon hatching, resulting in various deformities and death. Adult fish appeared to not be impacted by the elevated Se concentrations downstream from the power plant, but there were considerable reductions in reproduction rates raising concern for future populations (Lemly, 2002). This combined with the capability of Se to bioaccumulate from benign to toxic concentrations in various trophic levels has raised considerable concern of Se being a deleterious substance and environmental pollutant.

The leading hypothesis why Se is deleterious to WCT is that Se acts as a substitute for sulfur (S) during amino acid formation. This results in the formation of weaker variations of disulfide bonds and can negatively impact cellular structure and enzymes that are essential in cellular metabolism (Ganther, 1974; Stadtman, 1974; Diplock and Hoekstra, 1976; Reddy and Massaro, 1983; & Sunde, 1984). These inadequate bonds lead to improper protein development and results in teratogenisis in fish species (malformations of the embryo) (Lemly, 2002). It is also understood that Se substitution in sulfur-containing amino acid formation (cysteine and methionine) explains its ability to bioaccumulate and biomagnify in food webs and thus, accumulate from innocuous to toxic concentrations, leading to impacts at various trophic levels (Martin et al., 2008).

2.4. Selenium Impacts in the Elk Valley

In order to assess the magnitude of ecological damage from open-pit coal mining in the Elk River Valley watershed, Environment Canada (EC) conducted an environmental assessment that assessed Se levels and biological impacts on freshwater biota in the Elk River and Fording River from 2012 to 2014 (Krahn, 2014). Initial measurements of the Fording River and its tributaries were taken in February 2012 at FRO and GHO (Figure 1). The concentration of Se above FRO and GHO were measured at 1.0 μg L^{-1}, which is a typical level of Se found in other watersheds in the Elk Valley that have not been directly impacted by coal mining (Krahn, 2014). Se concentrations were measured below the two mining sites, which resulted in much higher concentrations of Se. The upper portion of Fording River reached 30 μg L^{-1}, 15 times greater than the 2 μg L^{-1} aquatic threshold of dissolved Se set out by the Government of British Columbia in the BC Water Quality Guidelines (Krahn, 2014). Tributaries to Fording River such as Porter Creek measured as high as 113 μg L^{-1}, 55 times greater than BC Water Quality Guidelines (Krahn, 2014). Krahn (2014) concluded that the quantity of Se loading in the Fording River was directly correlated to the amount of waste rock deposited. Three Fording River tributaries all adjacent to large quantities of overburden contributed approximately 75% of the Fording River Se inputs, including Kilmarnock Creek with 12.9 kg day^{-1}, followed by Cataract Creek with 4.1 kg day^{-1}, and Swift Creek with 3.6 kg day^{-1} (Krahn, 2014).

In addition to Fording River Se concentration measurements, Krahn (2014) measured Elk River Se concentrations, which is fed by the Fording River. He determined that the Fording River was the single largest source of Se loading into the Elk River. During the spring-melt season, between June and July, Se concentrations in the Elk River rose from 1 μg L^{-1} to 6 μg L^{-1} (Krahn, 2014). This meant that from June until the winter months, the concentration of Se in the Fording River and Elk River were above the BC Water Quality Guidelines for arguably most of the year (Krahn, 2014). EC's environmental assessment of the Fording River was reviewed by Lemly (2014) for quality assurance. Lemly (2014) reviewed the environmental assessment to evaluate several criteria including:

- Is Se deleterious to WCT?;

- Is Krahn's research viable and was a proper environmental assessment conducted without any bias?;
- What are the potential impacts Se may have on the WCT population in the Elk Valley?; and
- How does Krahn's results compare to other research?

Lemly (2014) concluded that Se was deleterious to WCT when concentrations exceed toxic thresholds in fish tissue and excess Se in fish tissue results in reduced hatching success and causes various morphological deformities such as spinal, cranial, and gill deformities in WCT fry and adults (Lemly, 2014). In combination, the effects observed on the WCT in the Fording River and Elk River was a major concern to Lemly where he believed the impacts could potentially result in a total population collapse and a local extinction (Lemly, 2014). Krahn's report provided significant evidence proving Se was a byproduct of coal mining through overburden leachate pollution, which entered the aquatic ecosystems and biomagnified in fish tissues and eventually resulting in Se-induced poisoning (Lemly, 2014). Lemly (2014) found that Krahn's findings were similar to several other studies including those conducted in the West Virginian Central Appalachian Basin (WVDEP, 2010; Lindberg et al., 2011), where mountaintop removal coal mining is a prevalent industry and practice.

Lemly (2014) determined that the WCT population was at-risk in the Elk Valley due to Se loading in the Fording River and Elk River. He also determined that this would impact the tourism industry in a negative way in the Elk Valley, since the Elk River is world renown for its angling, specifically fly-fishing of WCT. A potential WCT population collapse could cripple the angling tourism industry in the Elk Valley (Lemly, 2014). The North Carolina Department of Natural Resources provided Lemly with an economic value of $24.74 US per catchable WCT 7-13 inches in size and combined with Krahn's data of an estimated 180,000 WCT lost each year due to Se poisoning, the total cost exceeds $4.45 US million (Lemly, 2014). This combined with impacts on tourism employment could have major impacts on the Elk Valley economy.

2.5. Selenium Impacts and Potential Impacts in Other Areas

Hauer and Sexton (2013) conducted a comparative study in the United States on WCT populations in the Flathead River, which lies adjacent to the Fording River and Elk River. The Flathead River runs through the Canadian-United States border and poses several issues with trans-boundary pollution. Concern was raised over the potential negative effects of Canadian coal mines on the health of the Flathead River and potentially consequential impacts to local American economies (Hauer & Sexton, 2013).

The Flathead Valley is a low-lying valley, free of industrialized mining and development that is adjacent to the Elk Valley (Figure 1). However, since the early 1970's, coal-mining proposals in the Flathead Valley have been made and more recently in the mid-2000's, a proposal was made to develop an open-pit coal mine (Hauer & Sexton, 2013). Hauer and Sexton (2013) used data collected on the Elk

River and Fording River's water chemistry and made initial comparisons to the Flathead River. They were able to determine that the Fording River and Elk River averaged concentrations of N 1000 times greater, SO_4^{2-} concentrations 40-50 times greater, and Se concentrations 7-10 times greater than the average concentrations in the Flathead River. They proposed that the development of a coal mining operation in the Flathead Valley would ultimately increase nutrient levels in the Flathead River and could have the same negative impacts observed on the WCT in the Elk Valley. Research conducted by the WVDEP supports research by Krahn (2014), Lemly (2014), Hauer, and Sexton (2013) stating that surface coal mining leads to Se loading in aquatic environments and negatively impacts fish populations (WVDEP, 2010).

In West Virginia, mountaintop removal mining is a main form of surface coal mining and creates large quantities of overburden similar to open-pit mining. Areas in West Virginia, including the Upper Mud River Reservoir (UMRR), have been exposed to Se loading for the past 30 years (WVDEP, 2010). This has led various impacts on fish species in the UMRR including the bluegill and largemouth bass. When these species were exposed to high concentrations of Se, they observed similar craniofacial and morphological deformities to those observed in the Elk Valley WCT populations (WVDEP, 2010). In addition, the rate at which the deformities were being discovered was concerning with about 50% of all fish sampled having some sort of deformity similar to Se-induced deformities (WVDEP, 2010). This supports the hypothesis that industrial coal mining results in aquatic Se loading and can have negative impacts on fish populations when concentrations exceed background guidelines.

2.6. Literature Analysis

The consensus presented by the literature review came to universally similar conclusions that increased loading of Se in aquatic ecosystems can have adverse impacts on fish populations and increase deformity rates in fish juveniles and adults; therefore, Se is considered a deleterious substance. Although there are other industrial practices responsible for Se loading including agriculture and electricity production, surface coal mining appeared to be the central focus and primary source of concern. In particular, open-pit and mountaintop removal coal mining were the two most researched practices responsible for large amounts of overburden produced, which is the standard hypothesis to explain the causes resulting in excess Se loading in local watersheds. The research presented in this literature review has created a fundamental base of knowledge, which will help determine the potential impacts the BRE and CMO2 projects may cause during this research and other future projects in the Elk Valley and worldwide. In order to determine these potential impacts, an ERA will be conducted that will contain three different phases: problem identification, risk analysis, and risk characterization.

3.0 Ecological Risk Assessment of Selenium: Methodology

3.1. Overview

This ERA follows the framework designed by Landis and Yu (2004) and consists of three phases: the problem formulation, risk analysis, and risk characterization phases (Figure 4). Each phase uses a variety of methods to calculate the Se loading risk from the BRE and CMO2 projects. This ERA consists of the summary and management of data found in the primary and secondary literature in order to calculate the level of risk posed by the potential inputs of Se from the BRE and CMO2 projects and its impacts on WCT in the Elk Valley region.

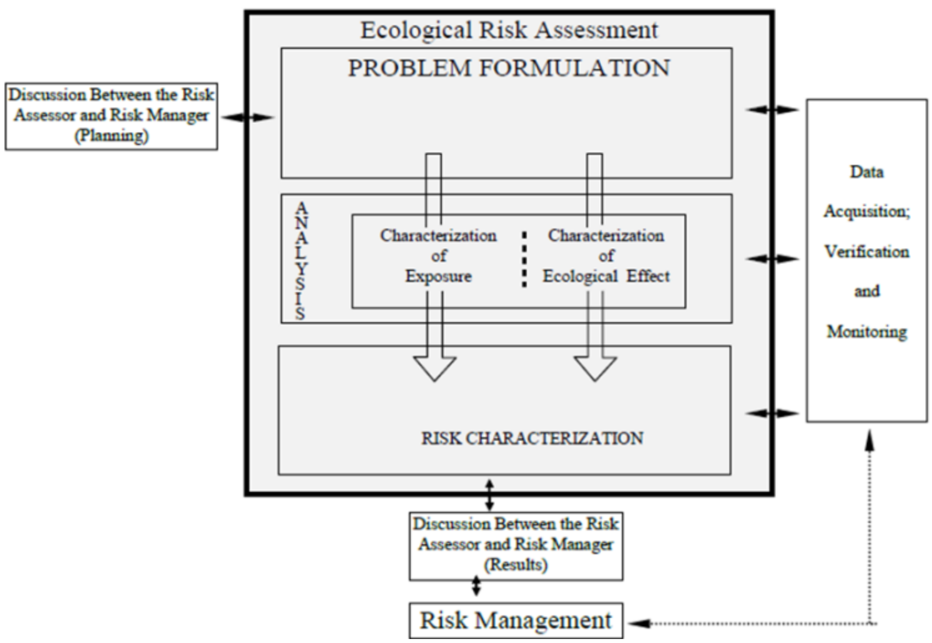

Figure 4 ERA framework with the outlined three phases. The three phases all aim to supplement a potential risk management at the end of the ERA. Image retrieved from Osman (2011).

3.2. Problem Formulation

3.2.1. Stressor Characteristics

The problem formulation phase was initially introduced in section 1.0 of this study. This section will address the methods used to describe six different characteristics of the stressor, Se, including stressor type, intensity, duration, frequency, timing, and scale.

Stressor Type

Se and in its various forms (SeO_4^{-2} and SeO_3^{-2}) is the stressor analyzed in this ERA; Se is a chemical stressor and has the capability to be an organic or inorganic substance leading to a variety of different biological impacts (Landis & Yu, 2004, p. 440; Lemly, 2004). Se has a direct impact on species through its biomagnification in local food chains and its impact on the reproductive success of avian and aquatic species through its bioaccumulation in top level predator species; thus, being labeled a primary stressor (Lemly, 2004; Muscatello & Janz, 2008b; Landis & Yu, 2004, p. 440).

Intensity

The intensity of Se outputs into the Elk River can be measured in terms of its annual loading (tonnes $year^{-1}$) downstream of the EVO and CMO mining sites. Wellen et al. (2015) measured average Se loads from 2008 to 2012 at 30-stream sampling sites (six near EVO and one near CMO on Michel Creek) (Figure 5).

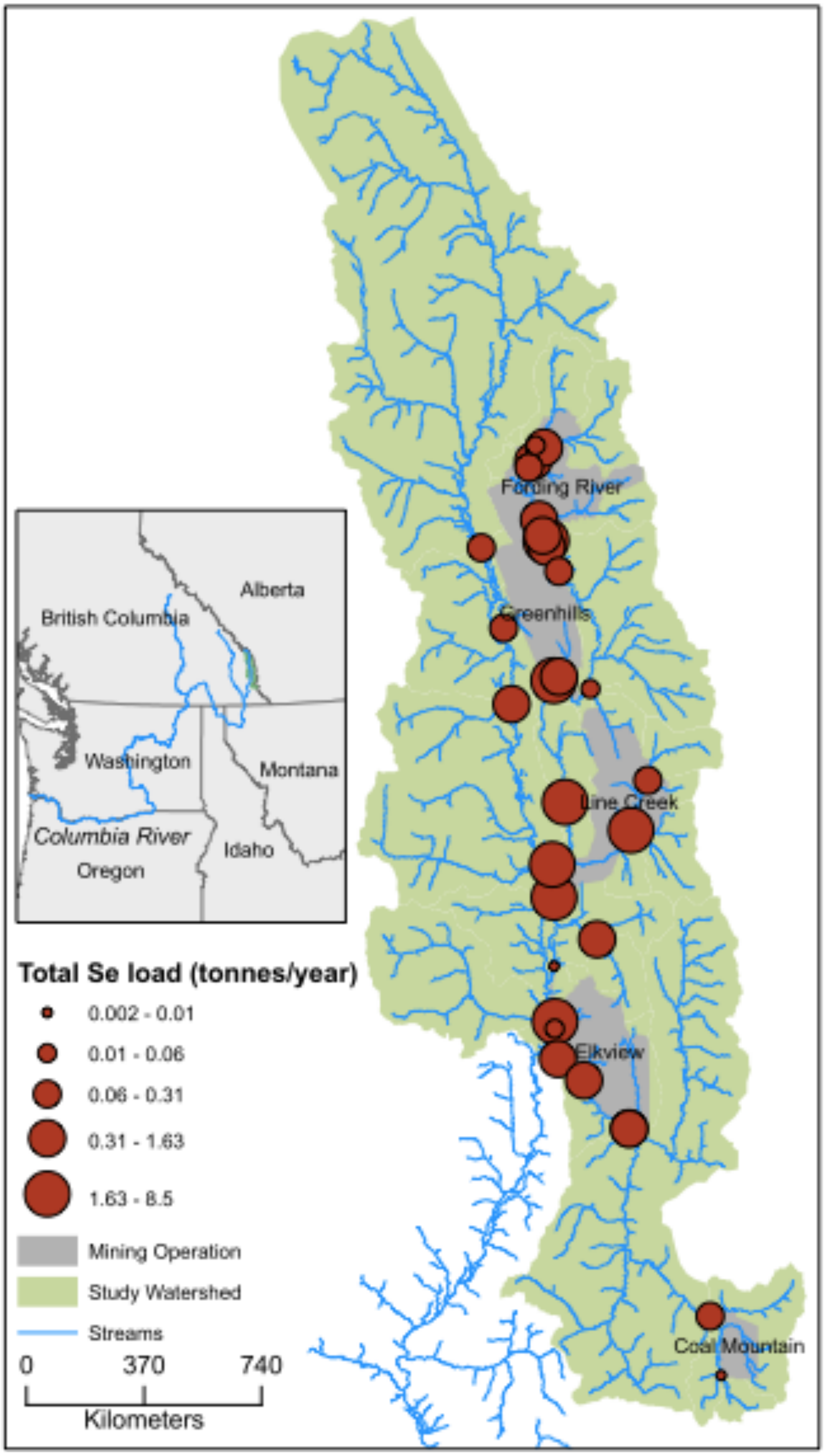

Figure 5 Selenium (Se) load (tonnes year^{-1}) measured from 2008 to 2012 in the Elk Valley. Six stations were used to measure Elkview Operations (one south, four west, and one north) and one station was used to measure Coal Mountain Operations (one north). Stations in the 0.002 to 0.01-tonnes/year category represent reference areas, not impacts by mining developments. Image retrieved from Wellen, Shatilla, and Carey (2015).

Intensity was measured at EVO and CMO by calculating the total quantity of Se loading measured by Wellen et al. (2015). Total Se loading was calculated by the median values measured from 2008 to 2012, and then summing the values from each coinciding mining site (Equations 1 & 2). Using the median values from Wellen et al. (2015), an estimated 2010 value of Se loading was calculated.

Equation 1 - Total Selenium Loading Downstream of Coal Mountain Operations (2008-2012)

One Measuring Site of Se Loading Tonnes Year^{-1} (Median Values)

1) 0.06-0.31 (0.19) Tonnes Year^{-1}

Site 1 = Total Site Value

0.19 Tonnes Year^{-1} (Total Median Value)

Equation 2 - Total Selenium Loading Downstream of Elkview Operations (2008-2012)

Five Measuring Sites of Se Loading Tonnes Year^{-1} (Median Values)

1) 0.31-1.63 (0.97) Tonnes Year^{-1}
2) 0.31-1.63 (0.97) Tonnes Year^{-1}
3) 0.31-1.63 (0.97) Tonnes Year^{-1}
4) 1.63-8.50 (5.07) Tonnes Year^{-1}
5) 0.01-0.06 (0.04) Tonnes Year^{-1}
6) 0.31-1.63 (0.97) Tonnes Year^{-1}

Site 1 + Site 2 + Site 3 + Site 4 + Site 5 + Site 6 = Total Site Value

0.97 + 0.97 + 0.97 + 5.07 + 0.04 + 0.97 = *8.99 Tonnes Year^{-1}* (Total Median Value)

Duration

Duration of Se exposure was measured based on the projected lifespans of the CMO2 and BRE projects and did not include the remediation phases of each project or any time period after project abandonment. Initially, annual Se output estimates were calculated for CMO2 and BRE based on their estimated waste rock outputs compared to CMO and EVO (Equations 3 & 4). CMO2 was projected to have an estimated mining life of 34 years, which was used to estimate the total amount of Se loading during its mining lifetime (Equation 5). In contrast, BRE was projected to operate for a total of 29 years (Equation 6).

Equation 3 – Projected Se Loading Downstream of CMO2

Coal Mountain Operations' Waste Rock = 26.7 M bcmw
Total Annual Se Loading = 0.19 Tonnes $Year^{-1}$

CMO2 Will Produce 56.2% of Coal Mountain Operation's Waste Rock.

0.19 * 0.562 = 0.11 Tonnes of Se $Year^{-1}$ at CMO2

Equation 4 – Projected Se Loading Downstream of BRE

Elkview Operations' Waste Rock = 69.3 M bcmw
Total Annual Se Loading = 8.99 Tonnes $Year^{-1}$

BRE Will Produce 48.3% of Elkview Operation's Waste Rock.
8.99 * 0.483 = 4.34 Tonnes of Se $Year^{-1}$ at BRE

Equation 5 – Projected Se Loading During CMO2 Lifespan

CMO2 Mining Lifespan = 34 years

CMO2 Total Annual Se Loading = [0.11 Tonnes $Year^{-1}$]

34 * 0.11 = 4 Tonnes of Se

Equation 6 – Projected Se Loading During BRE Lifespan

BRE Mining Lifespan = 29 years

BRE Total Annual Se Loading = [4.34 Tonnes $Year^{-1}$]

29 * 4.34 = 126 Tonnes of Se

Frequency

Se output to the Elk River is a continuous event and not a single or episodic occurrence. It will be an ongoing phenomenon from the onset of each project's development and continue past their abandonment into the remediation phases of each project. However, the frequency of Se output is altered based on seasonal fluctuations in precipitation and water volume. For example, Krahn (2014) measured Se concentrations in the upper Fording River, which reached 113 µg L^{-1} during the period of April-May, 2014, a concentration 55 times greater than the BC Water Quality Guidelines. In contrast, during the period of June-July, 2012, Krahn (2014) measured Se concentrations reaching 30 µg L^{-1}, a concentration 15 times greater than the BC Water Quality Guidelines (Krahn, 2014). This was in part due to the low runoff season in the period of April-May, which allowed greater concentrations of Se to accumulate in the lower volume water. In June and July, warmer temperatures led to higher altitude snow and ice melting, leading to greater runoff and eventually diluting Se concentrations downstream (Krahn, 2014). It is likely that seasonal variation will alter Se loading near the BRE and CMO2 projects, which may impact populations of WCT that migrate to smaller streams near the two mining sites during their spawning period. This is discussed further below.

Timing

Se loading from the five mining sites in the Elk Valley is a continuous process that results from surfaced waste rock during the mining procedure (Wellen et al., 2015). However, Se concentrations in various lotic waterways were greater when areas experienced greater amounts of precipitation and during the seasons of low flow (April-May) (Wellen et al., 2015; Krahn, 2014). In contrast, WCT leave their wintering habitats between the months of March-June and retreat to smaller tributaries from the Elk River and Michel Creek (COSEWIC, 2006). This suggested that there is a temporal relationship between the months of the year and the amount of Se loaded in aquatic environments, which may have an impact on WCT that spawn in smaller tributaries in the spring.

Scale

Se concentrations in the Elk River decrease further downstream from coal-mining sites because they are diluted by non-mine influenced waters, a process referred to as stressor spatial heterogeneity (uneven distributions of concentrations in an area) (Krahn, 2014; Landis & Yu, 2004, p. 440). Se concentrations in fish tissue also decrease significantly in fish sampled further downstream from coal-mining operations (Orr, Guiguer, & Russel, 2006). WCT territory is still uncertain, but some individuals have been tracked to travel up to 160 km in a single year (Wilkinson, 2009).

3.2.2. Endpoint Selection

An endpoint is defined as an ecological component or characteristic that may be affected if exposed to a stressor (Landis & Yu, 2004, p. 441). There are two distinguished types of endpoints defined by Landis and Yu, assessment endpoints and measurement endpoints (p. 441). Assessment endpoints are the actual environmental values that the ERA is looking to protect, while measurement endpoints are the measureable responses to the stressor of the assessment endpoints (Landis & Yu, 2004, p. 441). In this study, the assessment endpoint was WCT population viability downstream of the BRE and CMO2 projects. In contrast, the measurement endpoint was WCT juvenile mortality and adult deformity rates, which are both indicative of WCT reproductive success. WCT have ecological, societal, and economic value in the Elk Valley, which gives them considerable validity as endpoints (Landis & Yu, 2004, p. 441). Results for the assessment and measurement endpoints are discussed further in Section 4.0*. Risk Characterization: Results.*

3.2.3. Conceptual Model

The conceptual model is a series of hypotheses that help explain the ecological effects and connections between the stressor and the ecological systems (Landis & Yu, 2004, p. 442) (Figure 6). The conceptual model for Se in the Elk River focused on the potential routes of exposure from the two mining sites to the Elk River and its connections amongst the ecosystem's food web.

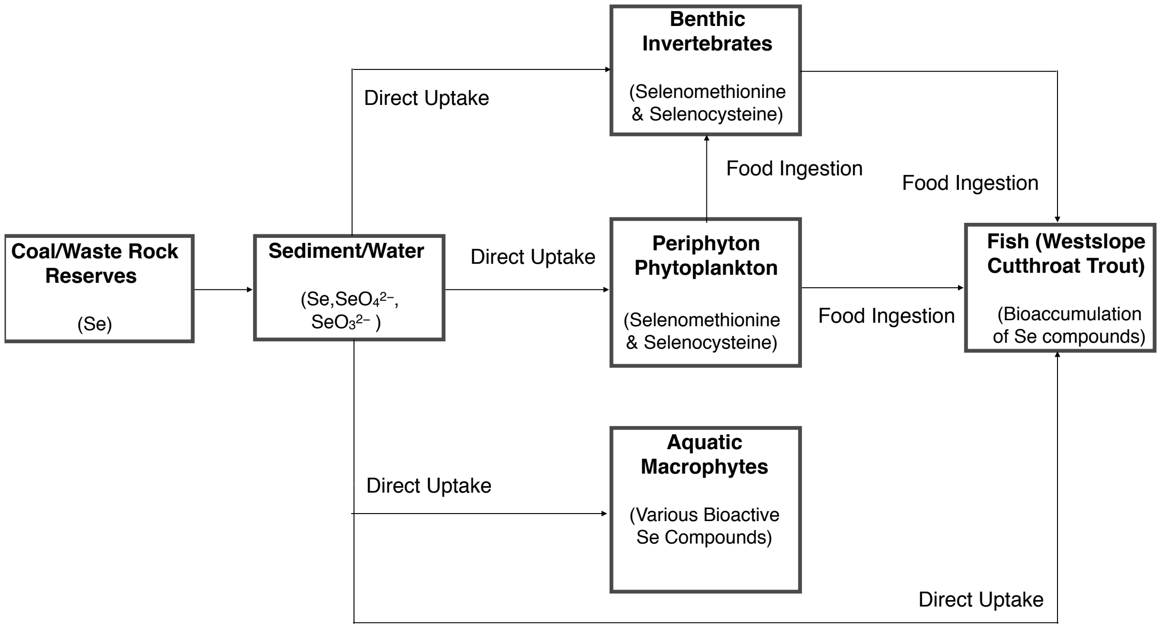

Figure 6 Conceptual model of Elk River food chain and selenium (Se) bioaccumulation in westslope cutthroat trout. Pathways are directed by arrows from the source and the chemical form of Se is described in brackets underneath.

As elemental Se becomes oxidized to soluble forms (SeO_4^{-2} and SeO_3^{-2}), it is leached into local sediments, tributaries, and groundwater. Here, soluble forms of Se are then directly consumed by primary producers and various small organisms including periphyton, aquatic macrophytes, and benthic invertebrates (Martin et al., 2008). Larger species such as WCT are directly exposed to suspended Se in their aquatic environments; however, this may not contribute to overall Se bioaccumulation in WCT or any other higher trophic species (Lemly, 1985). Soluble, oxidized Se can accumulate in individual organisms over time, but various chemical and biological processes also alter Se into amino acids once inside organism tissues. After Se is taken up by smaller organisms from sediments rich in the stressor, it is incorporated into sulfur-amino acid development (methionine and cysteine) to form amino acids selenomethionine and selenocysteine (Lemly, 2002). These weakerbonded amino acids are then transferred through organism consumption and predation, inevitably accumulating up in the top trophic level species including, WCT. Accumulation factors in similar trophic level species range from 1.13 times to 5.89 times (Muscatello, Belknap, & Janz, 2008a). This accumulation of Se and its various forms leads to a variety of biological implications including severe impacts on reproductive success, thus, concluding the conceptual model of Se.

3.3. Risk Analysis

The risk analysis phase of this ERA is an important step in the characterization of the risk in terms of its exposure and effects on the specified endpoints (also referred to as dose-response relationships) (Figure 7). Exposure and effects assessments were the two main deliverables during this risk analysis phase, which were based and characterized on the conceptual model developed in the problem formulation phase. The exposure assessment included analyses on the stressor's spatial and temporal distributions and effects assessment examined the interactions between the stressor and endpoints, the known effects, and the potential effects.

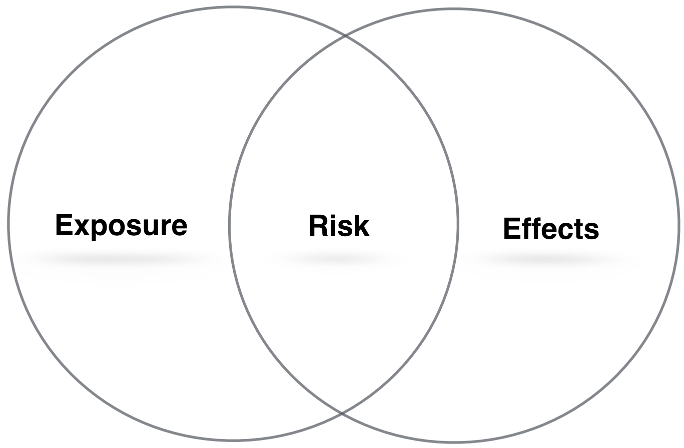

Figure 7 Analysis of risk based on the exposure and effects analyses. The overlapping of exposure to the stressor and at an amount to have considerable effects creates risk.

3.3.1. Exposure Assessment

Characterizing the exposure is an evaluation of stressor and endpoint interactions based on the stressor's spatial and temporal distributions. This was based on the potential quantities and locations Se will be loaded in proximity to WCT populations near the BRE and CMO2 projects. Estimated Se loading from BRE and CMO2 project areas were first projected based on current Se concentrations and waste rock output from EVO and CMO. After Se estimates were made, the spatial distribution of Se loading was observed, focusing on tributaries vulnerable to excessive Se loading near BRE and CMO2 project areas. Temporal distributions of Se loading were then analyzed and compared to temporal distributions of WCT, including WCT spawning seasons; analyzing the stressor's distribution in the environment and its temporal boundaries helped characterize the potential risk of exposure from the BRE and CMO2 projects.

3.3.1.1. Waste Rock and Selenium

There is a strong relationship between the volume of waste rock surfaced and the quantity of Se loading into nearby aquatic ecosystems (Krahn, 2014; Wellen et al., 2015). Therefore, Se loading can be estimated based on the volume of waste rock produced. Teck (2014) estimated the ratio of waste rock volume in millions bank cubic metres waste (M bcmw) to clean coal in millions metric tons of clean coal (M mtcc) produced to be 9.9:1.0 (M bcmw:M mtcc) throughout all five coal mining operations; EVO produced approximately 7.0 M mtcc and CMO produced an estimated 2.7 M mtcc (Teck, 2015a; Teck, 2015b; Teck, 2015c). Applying Teck's ratio of all five mining operations to EVO and CMO estimated waste rock volumes produced in each mining area during 2014 (Equation 7). These waste rock values were then compared to the estimated volumes of waste rock that is going to be surfaced annually at CMO2 and BRE project sites (Equations 8 & 9). Other factors that influence the release of Se from waste rock includes waste rock age, type of rock, seasonal precipitation and other variations in weather, and waste rock placement (Wellen et al., 2015).

Equation 7 - Waste Rock Calculations for Coal Mountain and Elkview Operations

2014 Waste Rock to Clean Coal Ratio = 9.9:1.0 (M bcmw: M mtcc)

Coal Mountain 2014 Clean Coal Production = 2.7 M mtcc

Coal Mountain Waste Rock = Clean Coal * 9.9

2.7 M mtcc * 9.9 M bcmw = 26.7 M bcmw

Elkview 2014 Clean Coal Production = 7.0 M mtcc

Elkview Waste Rock = Clean Coal * 9.9

7.0 M mtcc * 9.9 M bcmw = 69.3 M bcmw

Equation 8 – Waste Rock Calculations for CMO2

Estimated CMO2 Waste Rock Reserves = 510 M bcmw
510 M bcmw / 34 years of Mining Operations = 15 M bcmw $Year^{-1}$

CMO2 Waste Rock Per Year/Coal Mountain Waste Rock $Year^{-1}$
15 M bcmw / 26.7 M bcmw = 0.562

CMO2 Will Produce 56.2% of the Waste Rock Coal Mountain Currently Produces.

Equation 9 – Waste Rock Calculations for BRE

Estimated BRE Waste Rock Reserves = 970 M bcmw
970 M bcmw / 29 years of mining operations = 33.45 M bcmw $Year^{-1}$

BRE Waste Rock/Elkview Waste Rock
33.45 M bcmw / 69.3 M bcmw = 0.483

BRE Will Produce 48.3% of the Waste Rock Elkview Currently Produces.

3.3.1.2. Spatial Distribution

Coal Mountain Phase II

CMO2 is going to be located approximately 20 km west of CMO, entirely within the Michel Creek watershed, which will receive Se loading from both CMO2 and BRE projects (Teck, 2014a). The assessment of the spatial distribution of Se commenced with the data Minnow Environmental Inc., Interior Reforestation Ltd., and Paine, Ledge, and Associates (Minnow et al.) collected in 2009. Minnow et al. (2009) recorded Se and flow data in Michel Creek and the Elk River from 2007 to 2009, using data from existing water monitoring stations, which focus on tributaries directly impacted by mining activity. This data was used to measure and estimate the concentrations of Se in tributaries near the CMO2 project site to provide background data for the current health of local aquatic ecosystems before mining influences. After these background concentrations were determined, potential Se loading areas were established based on the estimated volume of waste rock produced in the area, the total amount of Se enriched waterways in the area, and the relative location of each waterway in the project's footprint (Krahn, 2014). These criteria were dependent upon Krahn (2014), whom determined that waterways in areas containing greater quantities of waste rock and more connecting tributaries, yielded greater concentrations of Se. In this research, for example, Wheeler Creek's potential for Se loading was characterized based on its location within the Wheeler Valley Spoil, the background concentrations of Se prior to CMO2, the number of small creeks that flow into it, and the estimated amount of waste rock surfaced from the Wheeler Ridge (Figure 8).

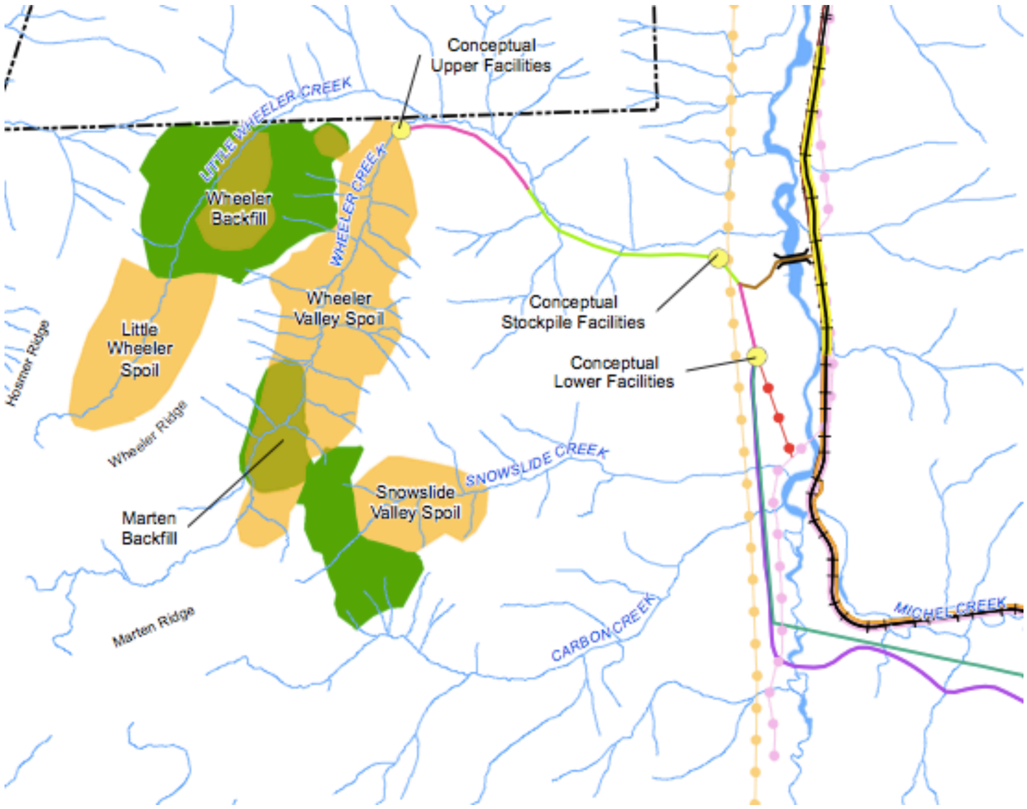

Figure 8 Coal Mountain Phase II proposal area including spoil, backfill areas, and connecting waterways including Little Wheeler Creek, Wheeler Creek, Snowslide Creek, and Carbon Creek, which all connect to Michel Creek. Green areas represent open-pit mining areas, spoil areas represent areas where waste rock will be stored, and brown-yellow areas represent backfill areas. Image retrieved from Teck's *Coal Mountain Phase 2 Project Description* report (2014a).

Baldy Ridge Extension

BRE is going to be an extension of the current EVO coal reserves located in Sparwood, BC, which is situated on both the Elk River and Michel Creek watersheds. Assessing the spatial distributions of Se at BRE involved similar methods used during the analysis of CMO2, but without sectional waste rock estimates, which were not publically available. This was primarily achieved using Se concentration data collected by Minnow et al. (2009) at EVO to establish relative background concentrations of Se to observe which stream were increasing or decreasing. This examination was supplemented by analyses of tributary locations in terms of the amount of Se enriched water feeding into the stream and their potential exposure within the BRE footprint area due to their proximity to waste rock storage areas (Figure 9).

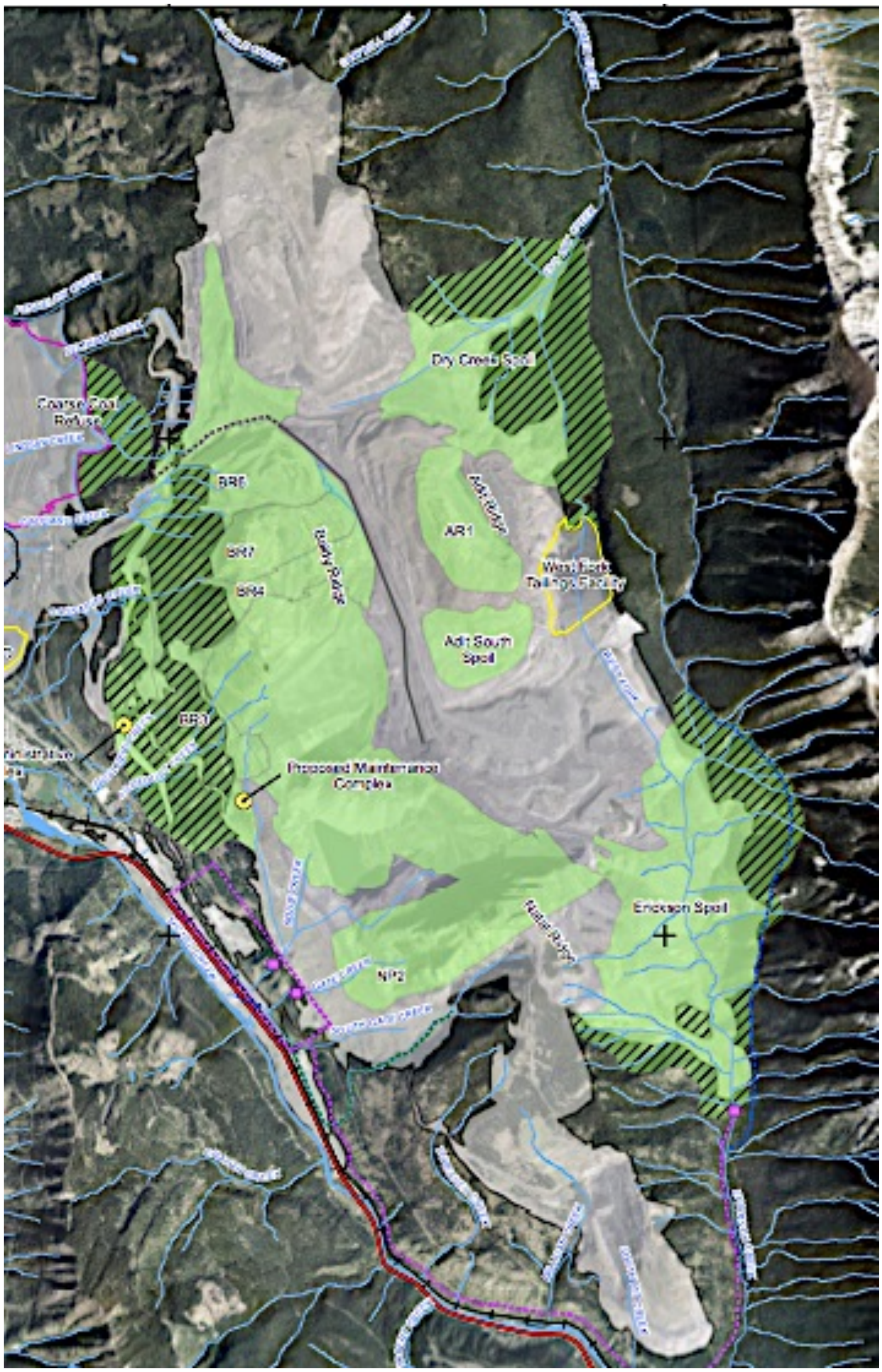

Figure 9 Baldy Ridge Extension project area. Green areas include the project's footprint; the striped-green areas are the project's footprints outside the current C-2 permit boundary, and the yellow area is the project tailings facility. Image retrieved from the Government of British Columbia's *Baldy Ridge Extension Project* report (2015).

3.3.1.3. Temporal Distribution

Se concentrations in the Elk River vary based on seasonal variations and water discharges, thus stressing the importance of WCT spawning timing and location. WCT leave their wintering habitats in the larger portions of the Elk River between April and June, and retreat to smaller tributaries, including Michel Creek (COSEWIC, 2006; Bennett, 2004). WCT populations spawn in small, stable flowing tributaries with low gradient streams between 0.2 and 0.4 m and a large composition of gravel substrates (Bennett, 2004). Similar small streams near coal mining operations measured by Krahn (2014) contained dangerously toxic concentrations of Se, which may pose a serious threat to migrating WCT. The overlapping periods of the low run season and WCT spawning season raises concern over the potential exposure of WCT to these highly toxic concentrations of Se. WCT spawning upstream towards the BRE and CMO2 projects are at risk of exposure to elevated levels of Se, especially during low flow seasons, which may impact their individual health or reproductive success in subsequent years due to Se bioaccumulation (Lemly, 2004).

In order to measure the potential impact the temporal distributions of Se may have on WCT spawning near CMO2 and BRE, population data in streams near each mining area were collected from Wilkinson (2009). Wilkinson (2009) measured the abundance and densities of WCT in various tributaries near the proposed CMO2 and BRE mining sites, including Wheeler Creek, Leach Creek, Michel Creek (upstream of EVO), Erickson Creek, and Harmer Creek. Wilkinson measured WCT abundance and density from July to August 2007, which overlapped the freshet period of June to

July (Krahn, 2014). This showed the approximate WCT populations that are exposed to the lowest Se concentrations on a seasonal basis; they are approximately one-third of the concentrations observed during the low flow season of April to May (Krahn, 2014). This helped determine the number of WCT exposed to the lowest concentrations of Se on a seasonal basis and the potential populations exposed to Se from CMO2 and BRE operations.

3.3.2. Effects Assessment

The bioaccumulation of the organo-selenium compounds, selenocysteine and selenomethionine, into fish tissue and replacing sulfur in protein synthesis is the leading hypothesis for the observed impacts Se has on WCT and other fish species (Lemly, 2002). These organo-selenium compounds concentrate specifically in fish tissue, liver, ovaries, and eggs, which may result in larval exposure and cause teratogenic deformities and edema irregularities (Lemly, 2002; Muscatello et al., 2006; WVDEP, 2010; & Krahn, 2014). Krahn observed that WCT containing Se concentrations of 20 $\mu g\ g^{-1}$ dry weight in their tissues resulted in an increase in mortality rate and when their tissue concentrations exceeded 60 $\mu g\ g^{-1}$, it resulted in 100% mortality of juveniles. Krahn (2014) also stated that there is a correlation between the concentrations of Se found in eggs and the concentrations found in fish muscle. The assessment of Se induced effects on WCT can be greater verified using three criteria suggested by Landis and Yu (2004): strength, consistency, and specificity.

Strength and Consistency

The concentration of dissolved Se measured in aquatic ecosystems coincides with concentrations found in WCT tissues (Krahn, 2014). Krahn (2014) observed that Se concentrations in benthic invertebrates and WCT were highest in areas of the Fording River watershed with excessive concentrations of Se, and intensities in both organisms declined when dissolved Se quantities declined in aquatic environments (Krahn, 2014). However, the WVDEP (2010) have observed low Se concentrations in fish and invertebrate species when they inhabit Se enriched waterways. Lemly (2002) suggests that Se biomagnification through trophic level transfer is an important factor linking its exposure and impacts on WCT and dissolved concentrations in aquatic environments may not be the only factor for an organism's Se uptake.

Observationally, there is a strong relationship between increased Se concentrations in fish and egg tissue and increases in facial, cranial, and spinal deformities and mortality in adults and juveniles (Table 1 & Figure 10). Lemly (2002) determined the deformity rates of 20 fish species in Belews Lake, North Carolina. Lemly found that when whole-body Se concentrations in fry exceeded 30 $\mu g\ g^{-1}$, there was a greater than 80% deformity rate (Lemly, 2002). This is a much greater deformity rate than the 20% irregularity rate found by Muscatello et al. (2006) in northern pike (*Esox lucius)* when Se concentrations were 33.5 $\mu g\ g^{-1}$. This may be due to differences in flow characteristics and chemical composition between Belews Lake and the watersheds in Saskatchewan or due to biological differences in the species examined.

Table 1: Fish species and selenium concentrations found in fish egg tissues and the observed impacts on adult fish and larvae in the coinciding watersheds in British Columbia (BC), Saskatchewan (SK), and West Virginia (WV).

Watershed	Fish Species	Concentration of Selenium in Fish Egg Tissue (μg g^{-1})	Type of Deformity and Impacts	Deformity Rates	Impacts on Fish Larvae	Source
Fording River, BC	Westslope Cutthroat Trout	20	Spinal, craniofacial, edema, and reproductive	N/A	Increased Mortality	Krahn (2014)
Fording River, BC	Westslope Cutthroat Trout	60	Spinal, craniofacial, edema, and reproductive	N/A	100% Mortality	Krahn (2014)
David Creek and Delta Lake, SK	Northern Pike	33.5	Spinal, craniofacial, and edema	N/A	20% Deformity Rate	Muscatello et al. (2006)
Plum Orchard Lake, WV	Bluegill	<0.8	Spinal, craniofacial, and reproductive	1.27%	N/A	WVDEP (2010)
Plum Orchard Lake, WV	Largemouth Bass	8.7	Spinal, craniofacial, and reproductive	0%	N/A	WVDEP (2010)
Mud River, WV	Bluegill	9.8	Spinal, craniofacial, and reproductive	25% (3 Year Average)	N/A	WVDEP (2010)
Mud River, WV	Largemouth Bass	Up to 64.6	Spinal, craniofacial, edema, and reproductive	50%	N/A	WVDEP (2010)

As previously stated, The BC guideline for Se concentration in fish tissue is 1.0 μg g^{-1} to ensure no Se-induced toxicity. However in some instances, Se concentrations less than 1.0 μg g^{-1} have produced small deformity rates and concentrations exceeding 5.0 μg g^{-1} have led to no deformities of inhabiting fish species (WVDEP, 2010). Krahn

(2014) found that Se concentrations in WCT egg tissues exceeding 20 μg g^{-1} resulted in increased mortality rates and absolute mortality when concentrations were greater than 60 μg g^{-1}. Similar results were found in upper portions of Mud River in West Virginia where concentrations of Se exceed background concentrations which has resulted in approximately 50% of the largemouth bass population and 25% of the bluegill population having some craniofacial deformity (EPA, 2004; WVDEP, 2010). However, in Plum Orchard Lake, West Virginia, Se concentrations were greatly lower in fish egg tissues, resulting in much lower deformity rates in largemouth bass and bluegill adults, respectively 0% and 1.27% (WVDEP, 2010). The relationship between Se concentrations in fish egg tissues and deformity rates suggest that aquatic ecosystems with greater concentrations of Se harbor higher populations of deformed fish species and ultimately, produce a greater risk of reproductive failure and mortality.

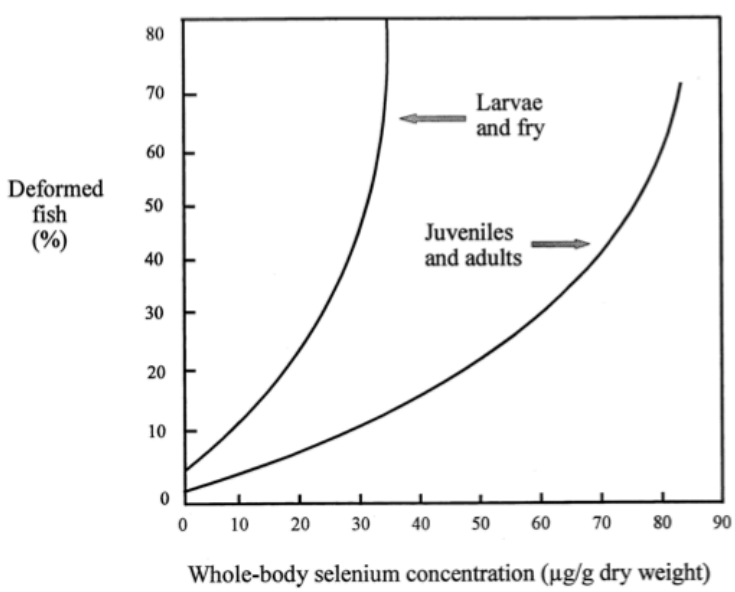

Figure 10 Deformity rates and selenium concentrations of 20 fish species examined in Belews Lake, North Carolina from 1975 to 1996. Lines are representative of a best-fit exponential function with an r^2 value of 0.881. Image retrieved from Lemly (2002).

Specificity

Specificity was determined by the effects induced through Se exposure to WCT and if they were consistent to the effects Se has on other fish species (Landis & Yu, 2004, p. 449). Comparing the deformities observed in WCT in the Elk Valley to fish species in West Virginia, Saskatchewan, and North Carolina allowed a connection to be made between the physical and reproductive effects on various fish species. Exposure to elevated concentrations of Se causes a variety of morphological deformities in fish species. This includes impacts on fish's gills, internal organs such as their liver, kidneys, heart, and ovaries, and causes teratogenic deformities and edema (Figure 11) (Lemly, 2002; Krahn, 2014). This influences the survival of young fry and juveniles, which reduces the reproductive success of contaminated adults.

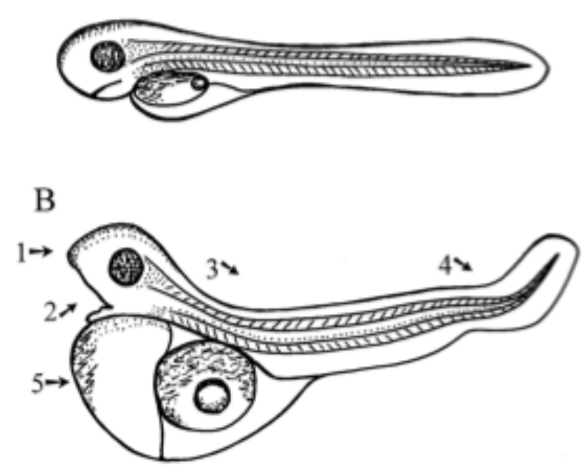

Figure 11 Sample A is the appearance of a healthy larval fish at 2-4 days old. Sample B shows symptoms of Se exposure including a deformed head (1), a deformed, gaping jaw (2), a deformities of the upper spine (3) and lower spine (4), and edema of the yolk-sac underneath the bottom jaw (5). Image retrieved from Lemly (2002).

Other studies have confirmed similar results (Kupsco and Schlenk, 2014; Rigby et al., 2010; Beckon and Maurer, 2008; and Rudolph, Andreller, and Kennedy, 2008). These studies concluded that Se exposure to various fish species resulted in similar physical deformities, impacts on internal organs, swelling of tissues, and in some cases reproductive failure due to post-hatch mortality. Although different Se concentrations may result in different impacts, it is generally concluded that fish exposed in higher concentrations of Se have a higher risk of experiencing one of multiple deformities. This may lead to severe impacts on fish populations and may result in local extinctions and permanently alter food web interactions and organism relationships in aquatic ecosystems (Lemly, 2002). If Se concentrations continue to rise in the Elk River and its tributaries, the risk for total WCT population collapse may also continue to increase.

4.0 Risk Characterization: Results

Characterizing the risk is a process that integrates the results from both the exposure and effects analyses; it is the final phase of the ERA process and consists of two separate sections, risk estimation and risk summary. Estimating the risk includes an assessment of the high, medium, and low-risk areas at both mining sites based on the approximate waste rock volumes surfaced, background concentrations of Se, total amount of Se impacted water, distance to waste rock storage areas, and known WCT populations in nearby waterways. Summarizing the risk will include an analysis of the potential Se loading from each project. Overall, the risk characterization phase provides a framework that allows the determination of Se loading potential in the Elk Valley and if there is a serious ecological risk involved with developing the BRE and CMO2 projects.

4.1. Risk Estimation

Coal Mountain Phase II

Developing the CMO2 project presents a variety of potential ecological impacts on nearby aquatic ecosystems, including Wheeler Creek, Little Wheeler Creek, and Snowslide Creek. These three waterways have not yet been exposed to mining activities, resulting in low background levels of Se. For example, Minnow et al. (2009) measured Se concentrations in Wheeler Creek at 0.9 μg L^{-1}, which is similar to the background concentrations of Se in the Elk Valley. Since tributaries in the Elk Valley that have not been influenced by mining activities contain similar Se concentrations, it can be assumed that all tributaries in the CMO2 mining area contain Se concentrations of roughly 1.0 μg L^{-1}. Each waterway may experience different Se loading intensities due to various quantities of waste rock being surfaced and stored in each area. For example, Mining Wheeler Ridge will surface approximately 315 M bcmw, Martin Ridge will surface 146 M bcmw, and Hosmer Ridge will surface 49 M bcmw (Teck, 2014a). This ultimately results in two high-risk areas near Wheeler Ridge and Martin Ridge, the confluence of Wheeler Creek and Little Wheeler Creek and Snowslide Creek, specifically in Snowslide Valley Spoil (Figure 12).

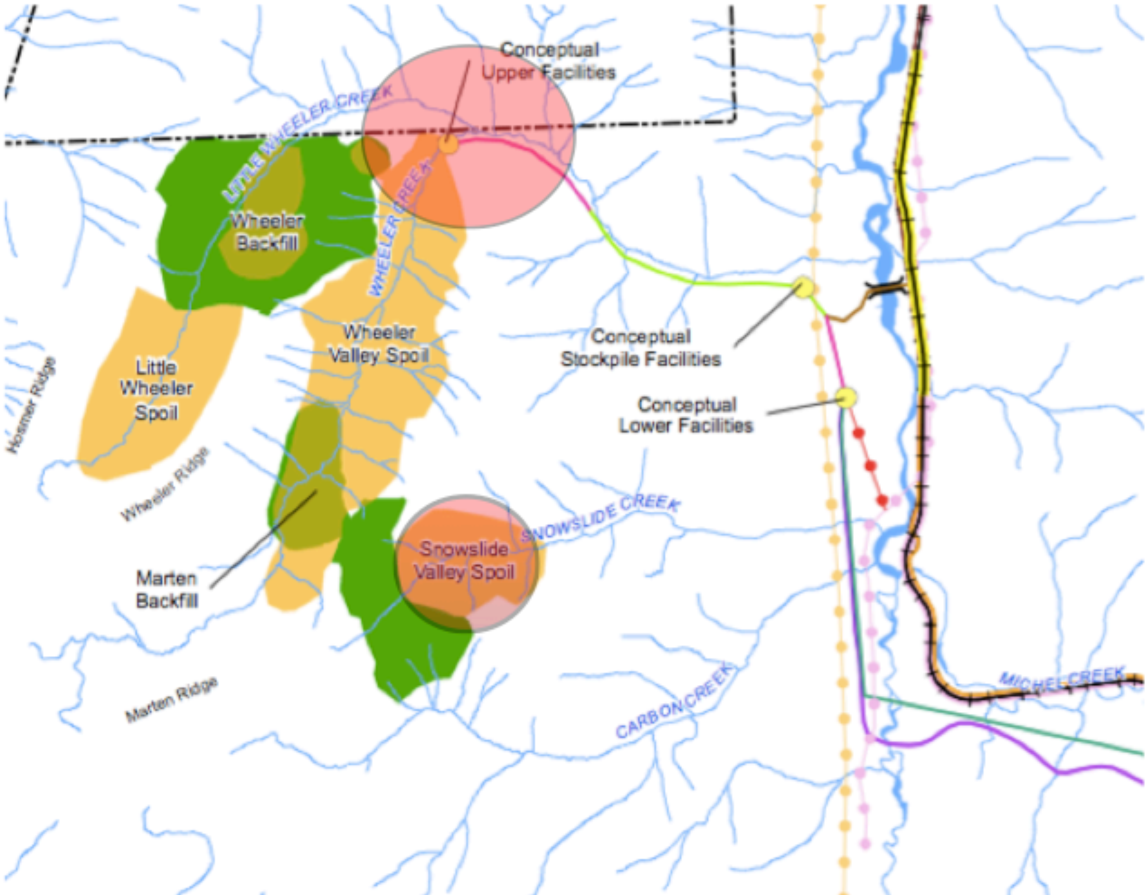

Figure 12 Coal Mountain Phase II proposal area with two high-risk selenium-loading areas. These areas were determined based on background Se concentrations, potential volume of waste rock and selenium-enriched water in the area, and location within the project footprint. Image retrieved from Teck's *Coal Mountain Phase 2 Project Description* report (2014a).

The first reason for Wheeler Creek's high-risk status is due to its location in the center of Wheeler Valley Spoil between Wheeler Ridge and Martin Ridge. Spoil, in the mining industry, is another term for waste rock and refers to the areas where waste rock will be stored at CMO2, which is likely where the Se loading will come from (Krahn, 2014; Park et al., 2013; Minnow et al., 2015). Wheeler Creek has a high-risk to potential Se exposure due to the large amount of waste rock surfaced from Wheeler Ridge and Martin Ridge that will be stored in the Wheeler Valley Spoil. A second factor that dictates a potential risk for Se loading is the numerous amounts of smaller tributaries that run through Wheeler Valley Spoil. The waste rock area contains multiple tributaries, which may increase total Se loading due to increased leaching of the waste rock materials (Krahn, 2014). Wheeler Ridge and Martin Ridge are going to surface approximately 90% of the waste rock at CMO2, which may account for the large area of the Wheeler Valley Spoil (Teck 2014a). A large portion of this waste rock will be stored in this area and may expose the numerous smaller waterways to Se that feed into Wheeler Creek. This may result in a significant accumulation of Se in Wheeler Creek, which may continue to increase past its confluence with Little Wheeler Creek. A final reason for Wheeler Creek's high-risk status is that it contains a significant WCT population with 152 individuals and a population density of 0.502 per m^2 (Wilkinson, 2004) (Table 2). According to Wilkinson (2004), Michel Creek tributaries have the largest populations in the entire Elk Valley, which increases the total risk of developing CMO2. These potential attributes surrounding Wheeler Creek along with its dense population of WCT combine to characterize it as a high-risk waterway for Se loading. Contrary to Wheeler Creek's high-risk status, the confluence of Wheeler Creek and Little Wheeler Creek may be the most significant area for Se loading at CMO2.

Little Wheeler Creek is situated between Hosmer Ridge and Wheeler Ridge and runs through the Little Wheeler Spoil, the second largest waste rock area. Little Wheeler Creek also has a high potential for increased Se loading due to the large amount of waste rock surfaced at Wheeler Ridge and its flow through Little Wheeler Spoil and the Hosmer and Wheeler Ridge surface pit. However, the high-risk Se loading area is the confluence of Little Wheeler Creek and Wheeler Creek, roughly 1 km from the surface pit; thus, lower Wheeler Creek concentrations of Se may be the highest measured at the CMO2 site and is the area of highest risk for WCT populations.

Table 2: Michel Creek, tributary drainages, and total population and density of westslope cutthroat trout near the Coal Mountain Phase II project area.

Waterway	Drainage	Number of Westslope Cutthroat Trout (N)	Density (m^2)
Wheeler Creek	Michel Creek	152	0.507
Leach Creek	Michel Creek	339	0.424
Michel Creek (Upstream of EVO)	Elk River	319	0.399

Population and density data collected from Wilkinson (2009).

Snowslide Creek is another waterway that may also receive intensive Se loading. It is located in the Snowslide Valley Spoil in the south portion of the project area, which is going to receive overburden surfaced from Martin Ridge. Significant deposits of waste rock may be stored within the Snowslide Valley Spoil, which may expose Snowslide Creek to a potential increase in Se loading. Snowslide Valley Spoil also contains several smaller waterways that converge with Snowslide Creek within the waste rock area, which may also contribute to potentially increased Se loading. There is currently no data on WCT populations in Snowslide Creek; however, Wilkinson (2009) does suggest that WCT populations in Michel Creek tributaries are the highest in the Elk Valley.

Remaining waterways in the area may not be impacted by the development of CMO2 include Carbon Creek and Leach Creek. They may not be significantly impacted by

CMO2 because their flow patterns are not directly through or near any waste rock areas. Leach Creek contains the largest WCT population near CMO2 and there is not data available for Carbon Creek populations. They do not receive any surface waters from potentially impacted waterways, such as Wheeler Creek and Snowslide Creek, thus, they considered as low-risk waterways.

Table 3: Waterways near Coal Mountain Phase II project, larger watersheds they drain into, selenium concentrations, and selenium loading potential. Selenium concentration data was not available for four of the listed waterways.

Waterway	Drainage	Selenium Concentration (μg L^{-1})	Potential Selenium Loading Increase
Wheeler Creek	Michel Creek	0.9	High
Little Wheeler Creek	Wheeler Creek	N/A	High
Snowslide Creek	Michel Creek	N/A	High
Carbon Creek	Michel Creek	N/A	Low
Leach Creek	Michel Creek	N/A	Low

Selenium data collected from Minnow et al. (2009) and location data collected from Teck (2014a) and Government of British Columbia (2015).

Baldy Ridge Extension

BRE will include extensive mining of the Baldy Ridge, Adit Ridge, and Natal Ridge and will include the development of the three major waste rock areas, Erickson Spoil, Dry Creek Spoil, and Adit South Spoil. Arising from these spoils, are three potential areas and routes of Se exposure including Erickson Creek, the confluence of Dry Creek and Harmer Creek, and the west bank area of Baldy Ridge (Figure 13).

Erickson Creek is located in the southeast portion of the BRE project area and runs adjacent to the South Pit for approximately 4 km until its confluence with Michel Creek; it is in the center of the Erickson Spoil area, which is the largest spoil in the project area and is the first factor determining it as a high-risk area. Erickson Spoil is going to contain much of the waste rock surfaced from the Baldy Ridge and Natal Ridge; Baldy Ridge is main portion of BRE that is going to be mined, thus it may be a major contributor to the quantity of waste rock surfaced. The storage of large quantities of waste rock is a significant reason contributing to Erickson Creek's high-risk potential. A second reason supporting Erickson Creek's high-risk status is that the waterway is fed by multiple smaller tributaries located throughout the spoil area. This includes West Fork, which is a small tributary that runs about 2 km from the West Fork Tailings Facility, and multiple other tributaries within the Erickson Spoil area. Krahn (2014) observed that the increased amount of waterways there were within areas containing large quantities of waste rock yielded greater quantities of Se. The third and final reason supporting Erickson Creek's high-risk status is that prior to BRE, it had an elevated concentration of Se. Minnow et al. (2009) determined that Erickson Creek contained one of the highest concentrations of Se in waterways at EVO, with a concentration of 86 $\mu g\ L^{-1}$. This is 43 times more than the BC Water Quality Guideline for freshwater biota and may be too toxic to support biota including WCT. Evidently, Erickson Creek fosters a dwindling WCT population of only five measured individuals, which may be determined by toxic concentrations of elemental deposits associated with coal mining, including Se, or other factors inhibiting supportive aquatic ecosystems (Wilkinson, 2004) (Table 4).

The second high-risk area at BRE is the Dry Creek and Harmer Creek confluence. Dry Creek is located in the northeast portion of the project area in the Dry Creek

Spoil, which is the second largest spoil area at BRE. Dry Creek Spoil will contain significant quantities of waste rock surfaced from the Baldy Ridge and the northern portions of the Adit Ridge, which is the first factor contributing to its high-risk status. Dry Creek flows approximately 2 km until its confluence with Harmer Creek, which flows several km until its convergence with Grave Creek, a tributary to the Elk River. The second reason for the confluence's high-risk status is there are multiple tributaries within the Dry Creek Spoil, which may accumulate more Se into Harmer Creek. The third and final reason for Dry Creek and Harmer Creek's status is the high concentration of Se in Harmer Creek prior to BRE. Similar to Erickson Creek, Minnow et al. (2009) measured Harmer Creek containing a high concentration of Se at 25.3 $\mu g\ L^{-1}$, which also contained a relatively small population of WCT with 49 individuals measured by Wilkinson (2009).

Table 4: Waterway drainages and total population and density of westslope cutthroat trout near the Baldy Ridge Extension project area.

Waterway	Drainage	Number of Westslope Cutthroat Trout (N)	Density (m^2)
Erickson Creek	Michel Creek	5	0.005
Harmer Creek	Grave Creek	49	0.105

Population and density data collected from Wilkinson (2009).

The remaining waterways that are potentially high-risk for Se loading flow west from the Baldy Ridge. These include Aqueduct Creek, Qualtieri Creek, Cossarini Creek, Goddard Creek, Lindsay Creek, and Feltham Creek, which flow either into one of two lagoons at the EVO site, or directly into the Elk River. Baldy Ridge is going to be the one of the most heavily mined areas throughout the BRE site, which is the main reason for the increase in risk of total Se loading in all of these waterways. The second reason is that some of the waterways contained significant concentrations of Se, including Goddard Marsh, which is fed by Goddard Creek and Cossarini Creek (Minnow et al., 2009; Government of BC, 2015). Minnow et al. (2009) measured Se concentrations in the Goddard Marsh at 14.3 μg L^{-1}; however, they determined that this concentration was decreasing due to reduced mining in the area. The increase in mining on Baldy Ridge may load more Se into these waterways, thus potentially increasing Se concentrations in the lagoons and the Elk River. The third and final reason for the high-risk status for the west bank area is the numerous waterways that may be exposed to Se loading. These seven waterways may contribute significant concentrations of Se into the Elk River if they are exposed to toxic concentrations during BRE production, which may ultimately elevate Se concentrations in the Elk River. There was no WCT population or density data available for the other tributaries within the BRE project area, which may suggest that populations are relatively low in other tributaries near the mining area or that baseline studies have yet to be conducted.

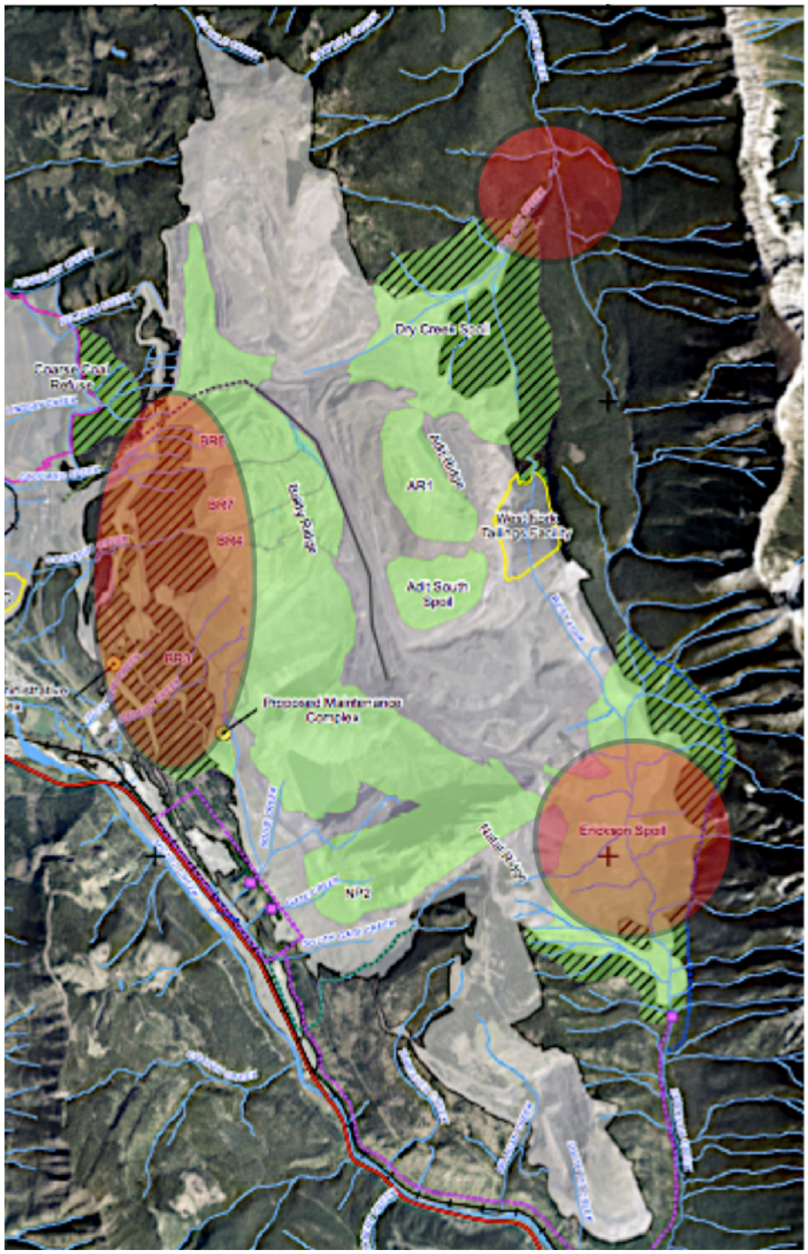

Figure 13 Baldy Ridge Extension project area and potential areas of high-risk selenium loading. These areas were determined based on background Se concentrations, total selenium-enriched water in the area, and location within the project footprint. Image retrieved from the Government of British Columbia's *Baldy Ridge Extension Project* report (2015).

Two waterways may be exposed to an increase in Se loading due to their location near the BRE project footprint. Gate Creek and Bodie Creek are located on the southwest portion of Natal Ridge, in the second pit (NP2). These two creeks descend from the pit into Michel Creek, which may potentially increase Se concentrations in them. However, only small portions of each waterway are directly exposed to the BRE mining area, which may slightly increase Se concentrations in each creek. Therefore, they are considered a medium risk and not a high or low risk.

In contrast to the waterways that may be susceptible to Se loading from BRE, numerous waterways may not be directly impacted by BRE's footprint such as Milligan Creek. Minnow et al. (2009) determined Milligan Creek contained one of the highest concentrations of Se near EVO and was one of the few waterways demonstrating an increasing trend in Se concentrations, which may refer to an increasing amount of mining activity in the area (Minnow et al., 2009). Milligan Creek drains from the south pit roughly two km west from Erickson Creek, but it is not situated near the footprint of BRE due to the contours of the Natal ridgeline. Examining the flow characteristics of each surrounding waterway suggests that surface water from BRE's footprint will not merge with Milligan Creek, which may not lead to an increase of Se loading into it. However, there is the possibility of the atmospheric deposition of Se into the waterway or the underground transport of Se (neither of which were examined in this study). This is also the case in many other creeks located in in the south pit including Thresher Creek, South Pit Creek, and South Gate Creek and in the north pit including Six Mile Creek and Sawmill Creek. These waterways are at a low risk for increased Se loading from BRE due to their location and flow routes outside the BRE footprint area.

Table 5: Waterways near Baldy Ridge Extension project, which larger watershed they drain into, selenium concentration, and selenium loading potential. Selenium concentration data was not available for many of the listed waterways.

Waterway	Drainage	Selenium Concentration ($\mu g\ L^{-1}$)	Potential Selenium Loading Increase
Harmer Creek	Grave Creek	25.3	High
Dry Creek	Harmer Creek	N/A	High
West Fork	Erickson Creek	N/A	High
Erickson Creek	Michel Creek	86.0	High
Milligan Creek	Michel Creek	64.6	Low
Gate Creek	Michel Creek	N/A	Medium
Bodie Creek	Michel Creek	56.6	Medium
Aqueduct Creek	Michel Creek	N/A	High
Qualtieri Creek	Michel Creek	N/A	High
Cossarini Creek	Elk River	N/A	High
Goddard Creek	Elk River	N/A	High
Lindsay Creek	Elk River	N/A	High
Feltham Creek	Elk River	N/A	Low
South Gate Creek	Elk River	N/A	Low
Thresher Creek	Michel Creek	N/A	Low
South Pit Creek	Michel Creek	N/A	Low
Sawmill Creek	Elk River	N/A	Low
Six Mile Creek	Elk River	2.2	Low

Selenium data collected from Minnow et al. (2009) and location data collected from Teck (2014a) and Government of British Columbia (2015).

4.2. Risk Summary: Estimated Selenium Loading and Ecological Risk

Current Selenium Distribution Models

Se concentrations tend to decrease further downstream of coal mining sites in the Elk Valley. This decrease is partially due to the dilution of Se from downstream waterways that are not impacted by mining activity, resulting in lower concentrations further from mining sites (Wellen et. al., 2015). Using data collected by Wellen et al. (2015), Se distribution models were created, depicting the distribution of Se in Michel Creek and the Elk River, upstream and downstream of EVO and CMO (Figures 14 & 15).

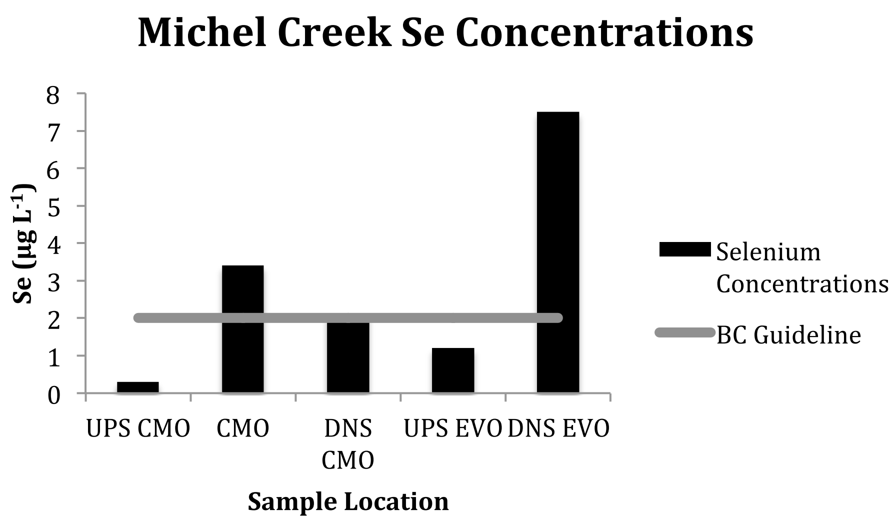

Figure 14 Selenium distributions in Michel Creek downstream of Coal Mountain Operations (CMO). “UPS” represents upstream of the location and “DNS” represents downstream of it; EVO represents Elkview Operations. “UPS CMO” represents background concentrations of selenium. The grey line represents the BC Water Quality Guideline of 2.0 µg L^{-1} for aquatic health. Selenium data obtained from Minnow et al. (2009).

Background concentrations of Se typically peak around 1.0 µg L^{-1} in Elk Valley waterways, which are not generally impacted by mining activity (Minnow et al., 2009). “UPS CMO” (Figure 14) represents background concentrations of Se in Michel Creek above CMO, which steadily peak at 0.3 µg L^{-1}. However, concentrations of Se downstream of CMO increase above the BC Water Quality Guideline at 3.4 µg L^{-1}. This is in part due to the approximate 0.19 tonnes of Se that CMO releases every year from surfacing waste rock. As downstream waters continue to dilute Se concentrations in Michel Creek, it consequently decreases below the 2.0 µg L^{-1} threshold. This phenomenon continues as Michel Creek approaches EVO, where then Se concentrations greatly increase to concentrations exceeding 7.0 µg L^{-1}.

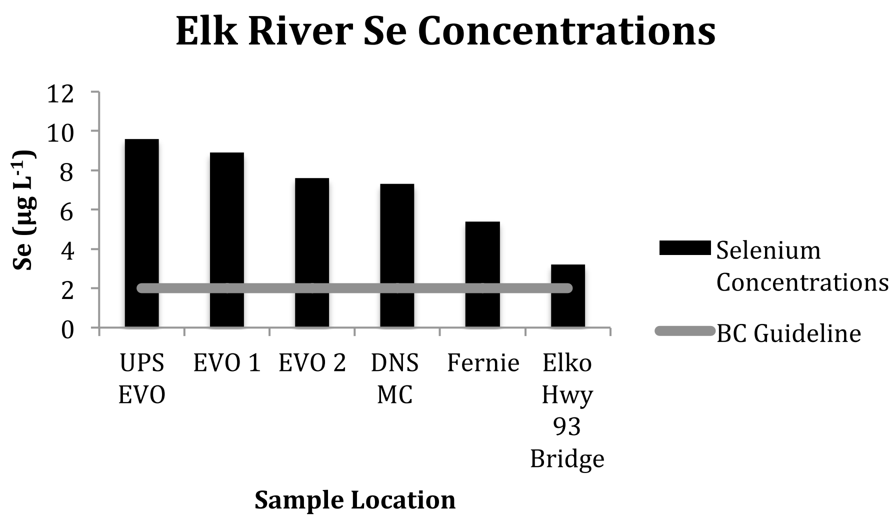

Figure 15 Selenium distributions in Elk River downstream of Elkview Operations (EVO). Two different measurements were taken at EVO (1 & 2). "UPS" represents upstream of the location and "DNS" represents downstream of it. Fernie and Elko represent other municipalities downstream of EVO. The grey line represents the BC Water Quality Guideline of 2.0 µg L^{-1} for aquatic health. Selenium data obtained from Minnow et al. (2009) and Teck (2014b).

The Elk River currently receives substantial quantities of Se from upstream mining areas GHO, FRO, and LCO before it approaches EVO. Se concentrations peak around 10 µg L^{-1} upstream of EVO, but steadily decrease as Se is diluted by non-mining influenced water downstream towards Sparwood (Minnow et al., 2009). After EVO and Michel Creek inputs of roughly 8.99 tonnes of Se per year, Se concentrations continue to decrease to approximately 5.4 µg L^{-1} in Fernie and 3.2 µg L^{-1} in Elko at the Highway 93 bridge (Teck, 2014b). As shown in Figure 15, the Se concentration in the Elk River does not meet the BC Water Quality Guideline at Elko, a municipality 60 km downstream of EVO (refer to Figure 1). This may suggest that WCT populations from FRO to Elko may be exposed to potentially toxic concentrations of Se, which could lead to the various aforementioned morphological and teratogenic deformities.

Coal Mountain Phase II and Baldy Ridge Extension Selenium Loading

In 2014, EVO produced approximately 69.3 M bcmw and CMO produced 26.7 M bcmw. Teck estimated the total amount of waste rock that is going to be produced at CMO2 and BRE over the course of their operating lifetimes; CMO2 is estimated to surface 510 M bcmw or 15 M year^{-1} and BRE is expected to create 970 M bcmw or 34.45 M year^{-1} (City of Fernie, 2013; Teck 2014a). In comparison, CMO2 will annually produce 56.2% of the waste rock CMO currently produces annually and BRE will annually produce 48.3% of the waste rock EVO currently produces annually (Equations 8 & 9). In terms of Se output from each mining site, CMO2 will load approximately 0.11 tonnes year^{-1} or 4 tonnes in the 34-year operation and BRE will load 4.34 tonnes year^{-1} or 126 tonnes in the 29-year mining life (Equations 3-6). Both proposed mining extensions appear to annually load approximately half of the Se that their current counterparts load, however, these Se inputs may be significant enough to increase the total concentrations of Se in Michel Creek and the Elk River.

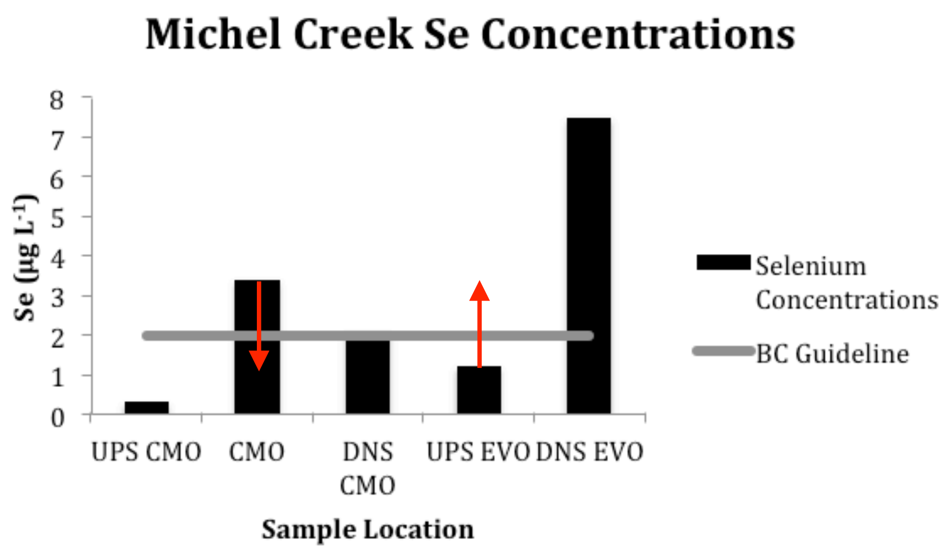

Figure 16 Selenium distributions in Michel Creek and potential decreases near Coal Mountain Operations (CMO) and increase where Coal Mountain Phase II will be located. Selenium data obtained from Minnow et al. (2009).

Se outputs from CMO2 are going to load directly into Michel Creek downstream of CMO. This could lead to an increase in Se concentrations upstream of EVO, where they are currently below the 2.0 μg L^{-1} threshold (Figure 16). Considering Se concentrations vary greatly with seasonal precipitation, it is difficult to estimate the concentration of Se in Michel Creek downstream of CMO2. However, CMO2 will annually produce half the waste rock CMO currently produces, therefore the amount of Se loading could be estimated to be roughly half of the Se concentrations in Michel Creek near CMO. This may increase Se concentrations in Michel Creek above the 2.0 μg L^{-1}, but to a much lesser extent experienced downstream of EVO. In contrast, Se concentrations downstream of CMO may experience prolonged decreases after the mining operation is retired and the mining area is remediated until it is approved by an inspector, as is required under the BC *Mines Act* (1996). Wellen et al. (2015) determined that re-vegetating waste rock areas could reduce the total Se output by 25% or more in areas where waste rock is stored. This could lead to significant decreases in Se concentrations in Michel Creek over time and may reduce concentrations downstream of CMO to less than the 2.0 μg L^{-1} threshold. In contrast to Michel Creek, the Elk River may not experience any significant decreases because of the three upstream mining operations (FRO, GHO, and LCO) and potential increase from EVO caused by the BRE project (Figure 17).

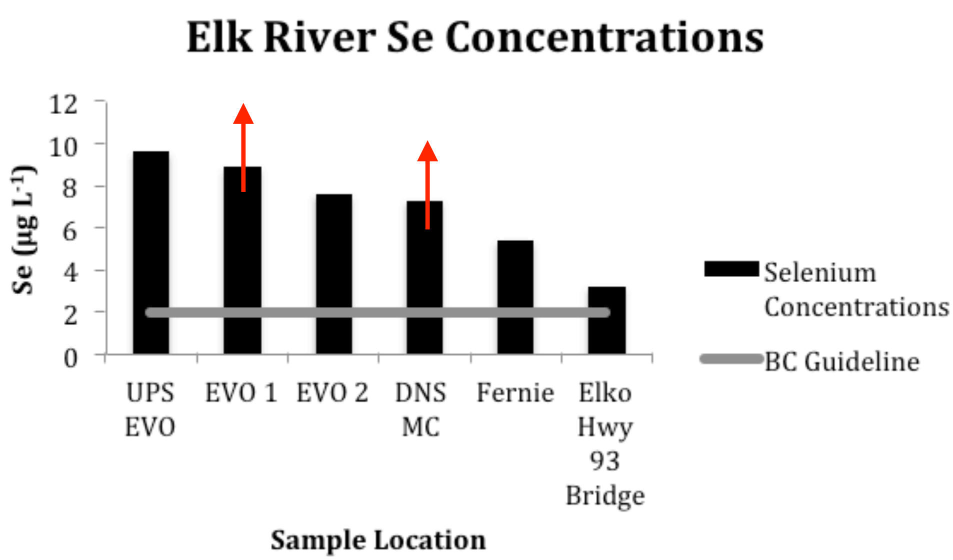

Figure 17 Selenium distributions in the Elk River and potential increases above Elkview Operations (EVO) and below at the Michel Creek confluence. Selenium data obtained from Minnow et al. (2009).

The Elk River may ultimately experience an increase in Se concentrations as mining operations in the Elk Valley continue to operate into the future. BRE has the potential to increase Se concentrations in the Elk River directly by tributaries that flow from the west bank of the Baldy Ridge and through Grave Creek (via Harmer Creek), and indirectly through inputs into Michel Creek. The direct loading from the west bank tributaries and catchment area may be the “smallest” high-risk area because the spoil areas will be located on the east portion of the project area. Minnow et al. (2009) determined that the west bank area did not increase Se concentrations in the Elk River in 2009 and that Se concentrations were continuing to decrease. However, the development of the BRE project may ultimately increase Se concentrations in west bank tributaries and consequently may increase Se concentrations in the Elk River near EVO. Another larger source of Se input into the Elk River may be Grave Creek, which is based on the potential loading into Harmer Creek from the Dry Creek Spoil. This could potentially lead to an increase in Se concentrations above EVO in the Elk River, and may be more substantial than the loading from the west bank tributaries. In contrast to direct loading of Se into the Elk River, a significant portion of the BRE Se output may be in Michel Creek through Erickson Creek. As mentioned earlier, Erickson Creek may receive substantial loading from the Erickson Spoil and the many waterways that flow through it. This could lead to significant Se loading into Michel Creek, which has the potential to increase concentrations in the Elk River after they merge. If significant enough, it could increase Se concentrations in the Elk River from the Michel Creek confluence to Elko.

5.0 Conclusions and Discussion

The Future of Westslope Cutthroat Trout

There is considerable ecological risk from both the CMO2 and BRE projects in terms of Se loading and its potential impacts on WCT. CMO2 is going to be developed in an area not previously exposed to coal mining and has one of the highest populations of WCT in the Elk Valley. In contrast, BRE is going to be a large-scale mining project and could load much greater quantities of Se into the Elk River and Michel Creek, which may potentially impact large populations of WCT throughout the Elk River watershed. It is difficult to quantify the exact amounts of Se that each project will release and the resulting impacts on Se concentrations in the larger waterways such as in the Elk River and Michel Creek. Continuous monitoring of waters downstream of each mining project will determine Se concentrations and the potential impacts on WCT. Seasonal precipitation causes large fluctuations in Se loading with drier seasons, such as the early spring, loading greater quantities of Se than wetter seasons. The WCT spawning season overlaps with the low-flow winter season, which increases the risk of Se exposure to WCT in smaller tributaries near CMO2 and BRE. The relationship between aquatic concentrations of Se and concentrations in fish and organism tissues is still debated. Some suggest that aquatic concentrations are indicative of concentrations found in higher trophic species such as WCT, while others suggest that Se concentrations in lower trophic species that higher trophic species consume are better indicators of Se concentrations in higher trophic species. Nonetheless, increasing Se concentrations to a level greater than the area's background concentrations increases the risk of fish deformation and reduced reproductive success. If the CMO2 and BRE increase Se loading in Michel Creek, the Elk River, and tributaries to each waterway, there is a greater risk of potentially irreversible damage on WCT populations in the Elk Valley.

Ecological Risk Assessment Conclusions

Results from this ERA suggest that CMO2 will not load a significant amount of Se into nearby waterways. It may produce slightly more than 50% of the waste rock currently generated at CMO, which presently does not load large quantities of Se. Therefore, the probability of CMO2 increasing Se concentrations in Michel Creek and the Elk River are low and the potential impacts of Se on WCT downstream of the project area are low. Consequently, the most significant impacts of CMO2 will stem from its development in an undeveloped area. Aquatic habitats in the area support some of the largest populations of WCT in the Elk Valley, which may ultimately be physically or chemically degraded or destroyed by the development of CMO2. This may result in a loss of significant spawning areas, which may impact WCT populations in a more systematic way than overexposure to Se. Due to the low potential for Se loading and the high potential for physical damage to aquatic ecosystems near the project site, CMO2 is a medium-risk project.

This ERA concludes that BRE will load significantly more Se than CMO2, but still not as much as EVO currently loads. BRE may produce less than 50% of the waste rock EVO currently produces, but based on Se loading calculations in this study, there will still be a significant amount of Se loading. It is estimated that one year of mining at BRE will load more Se than the entire CMO2 lifespan due its expansive footprint and waste rock production. BRE is an extension of the current EVO operation, which may increase Se outputs from EVO significantly. This may increase total Se concentrations in waterways downstream of BRE, which may enhance the risk of Se exposure to WCT. However, small populations of WCT have been observed near the BRE project area, which reduces the overall risk of Se exposure to WCT populations. Due to BRE's potentially intensive Se loading and its small populations of WCT, it is also a medium-risk project.

Future Research

Research on the ecological impacts of Se on freshwater biota has been continuously growing over the past 30 years. Increasing our understanding of its bioaccumulative capabilities and its impact on aquatic food chains will be crucial in the development of sophisticated Se abatement technologies. Many gaps in research exist on Se in groundwater and factors that increase Se leaching from waste rock. Future research on the ecological impacts of CMO2 and BRE on WCT should be conducted if the two projects are developed. This could come in the form of water analyses and Se measurements downstream of each project and by measuring WCT populations and deformity rates in waterways near each project. Although briefly discussed during this ERA, each project is going to construct water treatment facilities in downstream waterways. Teck has acknowledged the risk of Se loading from these projects and aims to effectively mitigate or eliminate the risk by developing water treatment facilities. This study shows the importance of these facilities in keeping Se concentrations below toxic levels to WCT. Future research should explore Se abatement technologies and their effectiveness in large-scale mining operations such as in the Elk Valley. Some of these technologies may be very costly, however, due to the high risk of these projects monitoring would be essential to ensure the wastewater treatment facilities are working effectively.

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