Elk Valley Water Quality Plan

Annex H
Integrated Assessment Report

INCLUDING

Appendix A: Habitat Calculation Methods

Appendix B: Dose-Response Curves Developed for Sulphate and Nitrate in the Fording River

Appendix C: Evaluation Tables for Selenium in the Elk and Fording Rivers

Appendix D: Evaluation Tables for Selenium in the Upper Fording River with Habitat Use Reflective of 2012 to 2014 Telemetry Data

Appendix E: Evaluation Tables for Nitrate in the Elk and Fording Rivers

Appendix F: Evaluation Tables for Sulphate in the Elk and Fording Rivers

Appendix G: Evaluation Tables for Cadmium in the Elk and Fording Rivers

Appendix H: Evaluation of the Toxicological Interactions of Mixtures of Sulphate, Nitrate, Selenium and Cadmium

Teck

ELK VALLEY WATER QUALITY PLAN

INTEGRATED ASSESSMENT REPORT

July 2014

Teck

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Summary

Ministerial Order No. M113 (the Order) requires Teck Coal Limited (Teck) to develop an area-based management plan for the Designated Area, which consists of the Elk Valley and the northern portion of Lake Koocanusa. Teck refers to the area-based management plan as the Elk Valley Water Quality Plan (the Plan). The purpose of the Plan includes management of concentrations of selenium, cadmium, nitrate and sulphate in waters of the Designated Area.

This report describes the methods used to complete integrated assessments for the Order constituents and the assessment results. This information is used to support the development of long-term targets for the Order constituents as detailed in Chapter 8 of the Plan. The integrated assessments include both constituent-specific qualitative and quantitative components. The assessment also includes a qualitative, multiple-stressor analysis to examine potential interactions among the Order constituents and other stressors. The results of the multiple stressor analysis are used to support the conclusions of the constituent-specific analyses.

In general, results of the integrated assessments completed for selenium, as well as for nitrate in the Fording River, indicate that use of Level 1 benchmarks as long-term, maximum monthly average concentrations will be protective of aquatic life, as will the use of a Level 2 selenium benchmark in the lower Fording River. Similarly, predicted long-term cadmium and sulphate concentrations in the Elk and Fording rivers are expected to be protective of aquatic life within each Management Unit. Some small scale, local potential effects have been predicted, and will be dealt with through local effects monitoring, effluent permit conditions and future mine development applications.

Results of the multiple stressor analysis provide directional evidence that mixture effects among the Order constituents are unlikely. The results also indicate that the presence of other possible stressors should not result in potential effects greater than those identified through the constituent-specific analyses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1 Introduction

On April 15, 2013, Ministerial Order No. M113 (the Order; BC MOE 2013) was issued by the BC Minister of the Environment. The Order requires Teck Coal Limited (Teck) to develop an area-based management plan for the Designated Area, which consists of the Elk Valley and the northern portion of Lake Koocanusa. Teck refers to the area-based management plan as the Elk Valley Water Quality Plan (the Plan). The purpose of the Plan includes management of concentrations of selenium, cadmium, nitrate and sulphate in waters of the Designated Area. As part of the Plan, Teck must develop long-term targets for selenium, sulphate, nitrate, and cadmium concentrations at the following seven locations in the Fording River, Elk River and Lake Koocanusa (Figure 1-1):

- Fording River downstream of Greenhills Creek, Order Station FR4 (Environmental Monitoring System [EMS] No. 0200378)
- Fording River at the mouth, Order Station FR5 (EMS No. 0200396)
- Elk River downstream of Greenhills Operations, Order Station ER1 (EMS No. E206661)
- Elk River downstream of the Fording River, Order Station ER2 (EMS No. 0200389)
- Elk River downstream of Michel Creek, Order Station ER3 (EMS No. 0200393)
- Elk River at Elko Reservoir, Order Station ER4 (EMS No. E294312)
- Lake Koocanusa south of the mouth of the Elk River, Order Station LK2 (EMS No. E294311).

Based on these locations and natural breakpoints in the system, the Designated Area has been divided into six management units (MUs). As shown in Figure 1-1, the six MUs consist of:

- MU1: upper Fording River, from its headwaters to Josephine Falls (contains FR4)
- MU2: lower Fording River, from Josephine falls to the river mouth (contains FR5)
- MU3: upper Elk River, above its confluence with the Fording River (contains ER1)
- MU4: Elk River from the Fording River to its confluence with Michel Creek (contains ER2)
- MU5: Elk River downstream of Michel Creek to the river mouth (contains ER3 and ER4)
- MU6: Lake Koocanusa, north of the international border (contains LK2).

The process used to develop the long-term water quality targets is outlined Figure 1-2. The process involved:

- defining water quality benchmarks for Order constituents for the protection of aquatic life in the Elk Valley
- comparing long-term water quality predictions with mitigation in place (herein referred to as the initial implementation plan), which includes clean water diversions, active water treatment and contact water handling, against water quality guidelines (WQGs) for the protection of aquatic life
- completing an integrated assessment for those constituents and MUs where predicted concentrations are above WQGs or values that provide a comparable level of protection.

Figure 1-1 Management Units Within the Designed Area

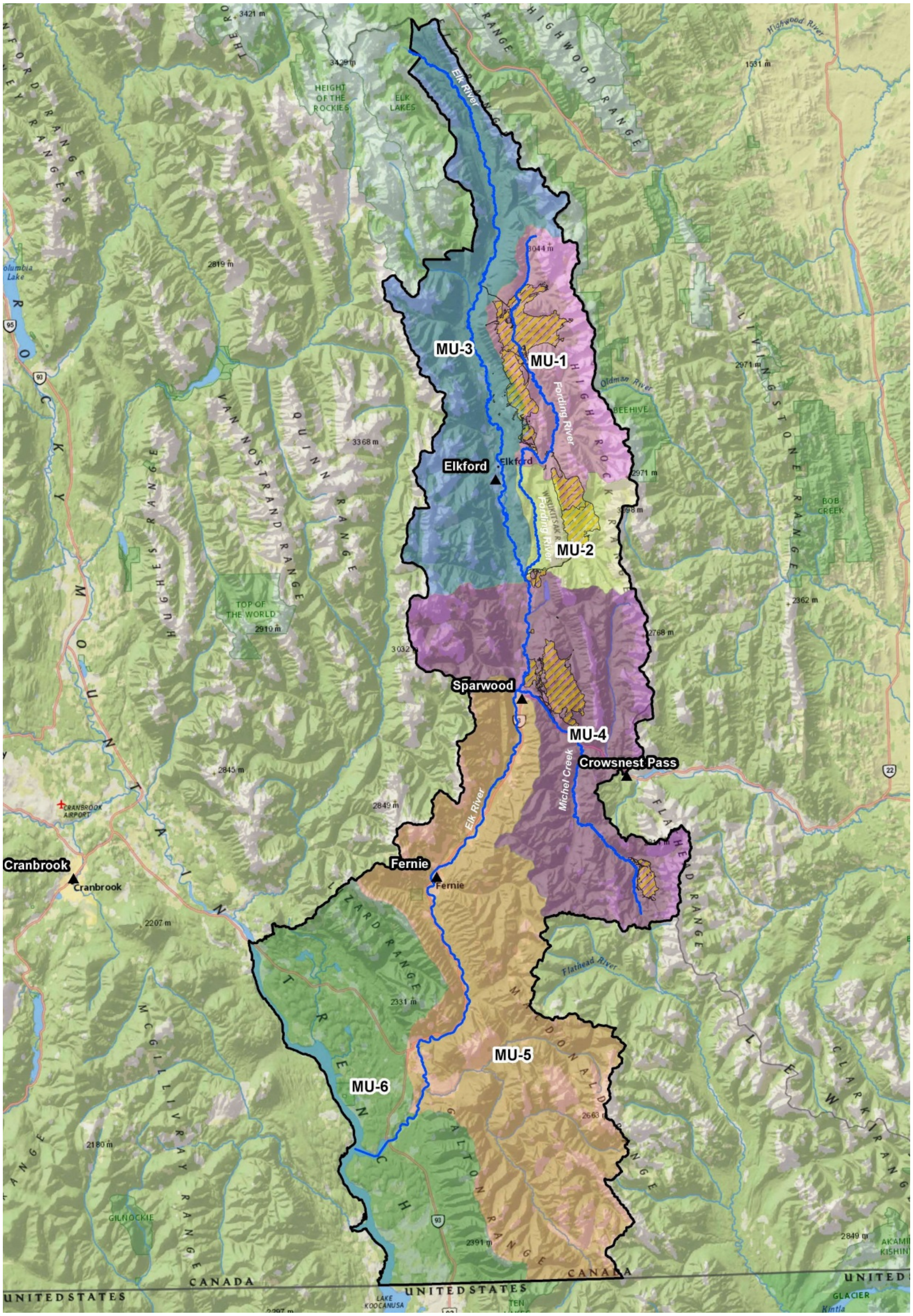
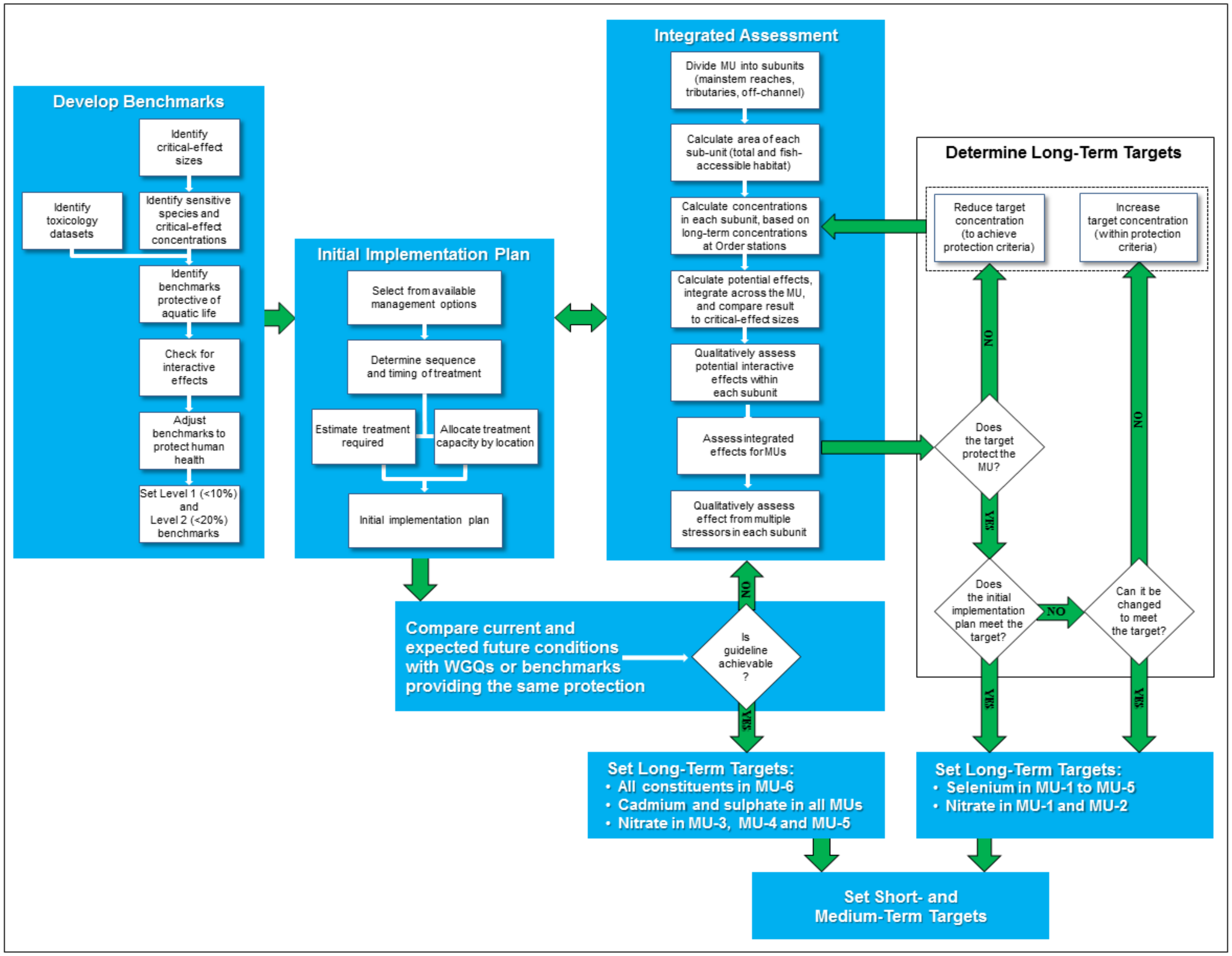


Figure 1-2 Approach to Setting Long-term Targets



As outlined in Chapter 8 of the Plan, the initial implementation plan is expected to produce long-term water quality concentrations that are equal or equivalent to B.C. WQGs in the following parts of the Designated Area:

- selenium, nitrate and sulphate in Lake Koocanusa (MU6)
- nitrate and sulphate in the Elk River (MUs 3 to 5)
- sulphate in the Fording River (MUs 1 and 2).

The initial implementation plan is also expected to produce long-term water quality concentrations equivalent to the Canadian cadmium WQG for the protection of aquatic life at all Order stations in the Designated Area.

For constituents where WQGs cannot be met, conservative toxicological benchmarks were developed (as outlined in Annexes E and F) and used to help establish site-specific water quality targets. To account for the potential interactive and cumulative effects, integrated assessments were completed to identify water quality targets that would be protective on a MU-basis. Integrated assessments were completed for selenium and nitrate in MUs 1 to 5 and MUs 1 and 2, respectively.

Integrated assessments are also required to evaluate long-term sulphate and cadmium concentrations in MUs 1 to 4, and long-term nitrate levels in MUs 3 and 4. The purpose of these evaluations is not to establish long-term targets at Order stations, because targets are set equal or equivalent to WQGs. Rather, the purpose is to evaluate the level of protection afforded to aquatic life in MUs that include mine-influenced tributaries.

This report describes the methods used to complete the aforementioned integrated assessments and the results of the assessments. The integrated assessments include both qualitative and quantitative components that are constituent-specific. In other words, the integrated assessments are completed with a focus on potential effects related to each constituent. A qualitative, multiple-stressor analysis is then undertaken to examine potential interactions among Order constituents and other stressors, such as potential changes to calcite levels, water flows or nutrient status. The results of the multiple stressor analysis are used to support the conclusions of the constituent-specific analyses and to identify how current conditions may change over time.

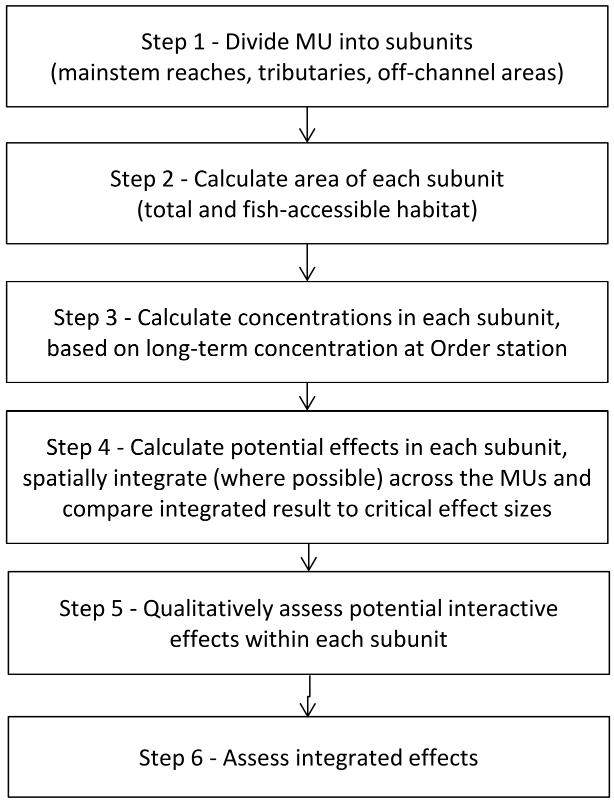
2 Constituent-Specific Integrated Assessments

Integrated assessments were undertaken to identify long-term water quality targets for selenium that are protective of aquatic life in MUs 1 to 5 and similar targets for nitrate in MUs 1 to 2. Integrated assessments were also undertaken to evaluate potential effects related to long-term sulphate and cadmium concentrations in MUs 1 to 4 and nitrate concentrations in MUs 3 and 4. In all cases, the constituent-specific assessments were completed using a similar approach (Figure 2-1). The methods used to complete the constituent-specific evaluations are outlined below in Section 2.1, followed by a discussion of results in Section 2.2.

Analysis of MU5 focused on selenium for the purposes of deriving a long-term target, because MU5 does not include mine influenced tributaries. Integrated assessments were not completed for MU6 (Lake Koocanusa), because it contains no mine-influenced tributaries, concentrations are currently below

WQGs and long-term targets are set to WQGs for selenium, nitrate and sulphate and a value for cadmium that provides the same level of protection as the Canadian WQG.

Figure 2-1 Approach Used to Complete Constituent-Specific Integrated Assessments



2.1 Approach and Methods

The six steps outlined in Figure 2-1 are described below.

2.1.1 Step 1: Divide MU into Subunits

Each MU was divided into subunits to allow an evaluation of potential effects in river mainstems, mine-influenced tributaries and associated off-channel habitats. The Elk and Fording River mainstems and Michel Creek were also subdivided, where appropriate, to account for longitudinal variability in constituent concentrations.

Tributaries not influenced by mining and that are likely to be ephemeral were not included in the integrated assessment because quality of aquatic habitat in these areas is likely to be low and their inclusion would bias the influence of reference tributaries in the assessment. Upstream tributary areas that are isolated from the Fording or Elk River mainstems, such as those in upper Kilmarnock Creek (MU1) and upper Line Creek (MU2), were not incorporated into the integrated assessment, because they are not accessible to fish in the river mainstems, nor would they be a source of benthic drift to downstream areas. They were also excluded to avoid a reference area bias, i.e., dilution of effect through the inclusion of unconnected reference areas. The above-mentioned restrictive decisions were intended to increase the level of conservatism in subsequent calculations.

2.1.2 Step 2: Define Available Habitat

The total area of aquatic habitat present in each subunit was quantified, as well as that which is likely to be accessible to fish. These calculations were completed using GIS map layers with consideration of CanFor stream classifications, stream magnitude and stream slope, as outlined in Appendix A.

Proposed mine development activities were taken into account, as were water management activities related to the initial implementation plan that will result in loss of habitat. Affected subunits include:

- Cataract, Swift and Clode creeks in MU1
- West Line Creek and a small portion of upper Line Creek in MU2
- Leask and Wolfram creeks in MU3
- Gate and Bodie creeks in MU4.

Cataract, Swift, Leask and Wolfram creeks are not fish-accessible, with the possible exception of the last 20 metres of Swift Creek. The lower portions of Clode, Gate and Bodie creeks are fish-accessible, as are a small length of lower West Line Creek and the small area of upper Line Creek that is affected by the operations of the West Line Creek Water Treatment Plant. Aquatic habitat in Lake Mountain Creek will also be lost as part of development of the proposed Fording River Operations (FRO) Swift Project.

Compensation planning for lost habitat in West Line Creek and Line Creek is underway. Offsetting for lost habitat in the other creeks will be developed, if and as required, during permitting and detailed design of the relevant components of the initial implementation plan. Similarly, compensation habitat for Lake Mountain Creek is being developed as part of the Swift Project because disturbance of this creek occurs as a result of mining rather than water management activities.

The aforementioned affected habitats, which are expected to be subject to habitat offsetting policies, were not included in the constituent-specific assessment.

2.1.3 Step 3: Define Constituent Concentrations

Constituent concentrations in tributaries and other subunits unaffected by mining were set to reference conditions, which are described in Chapter 4 of the Plan. They were assumed to remain unchanged over time. Constituent concentrations in other subunits were defined as follows.

2.1.3.1 Selenium and Nitrate

Selenium and nitrate concentrations in mine-influenced subunits were calculated using a two-stage process. First, concentrations in mine-influenced subunits were defined based on predicted long-term performance of the initial implementation plan. Long-term concentrations were estimated using the Elk Valley Water Quality Model (the model), which is described in Annex D.1. The model is designed to simulate regional conditions in the Designated Area, and is used to predict concentrations in the Elk and Fording River mainstems.

The model does not accurately predict concentrations in all mine-influenced tributaries; however, the model can more reliably predict relative changes in selenium and nitrate levels in these areas because they are strongly correlated with changes to waste rock volume. As such, model predictions for current and long-term conditions were used to proportionally scale values observed in 2013 to provide an estimate of long-term nitrate and selenium concentrations in mine-discharge tributaries (long-term concentration in a mine-discharge tributary = current observed concentration × modelled long-term concentration ÷ modelled current concentration).

Long-term concentrations in all mine-influenced subunits were then scaled to reflect concentrations at the Order station. For example, if long-term predictions for the initial implementation plan indicate that a mine-discharge tributary has a concentration twice that predicted at the Order station, the concentration in the tributary was set to twice the long-term target concentration. This approach allowed for an evaluation of how changes to concentrations at an Order station could affect concentrations in different subunits, in a loose reflection of what may occur as a result of applying different levels of water treatment. Potential effects in each subunit and across the MU as a whole were then assessed per Step 4.

2.1.3.2 Sulphate and Cadmium

Sulphate and cadmium concentrations in mine-influenced subunits were defined using a similar process. Concentrations were based on the predicted performance of the initial implementation plan, with tributary concentrations set to 2013 observed values scaled to reflect the relative changes predicted by the model. However, concentrations throughout each MU were not subsequently scaled to reflect concentrations at the Order station as was done for nitrate and selenium. This procedure was not applied to sulphate and cadmium because these constituents are not treated under the initial implementation plan. In other words, the purpose of scaling concentrations relative to the Order station is to allow for an examination of how varying levels of mitigation can affect conditions across a MU. As sulphate and cadmium are not affected by the mitigation measures included in the initial implementation plan, scaling to the Order station was not required.

Sulphate concentrations in MUs 2 to 4 are predicted to remain below the long-term target concentration at the Order stations; therefore, integrated effects were assessed based on predicted performance of the initial implementation plan, i.e., predicted maximum monthly concentrations in the long-term. Sulphate concentrations in MU1 are predicted to reach the long-term target at Order Station FR4 (as discussed in Chapter 8 of the Plan); therefore, integrated effects were assessed based on predicted performance with sulphate concentrations at FR4 set equal to the long-term target concentration of 429 mg/L, and concentrations in other subunits of the Fording River mainstem set to reflect expected spatial variability.

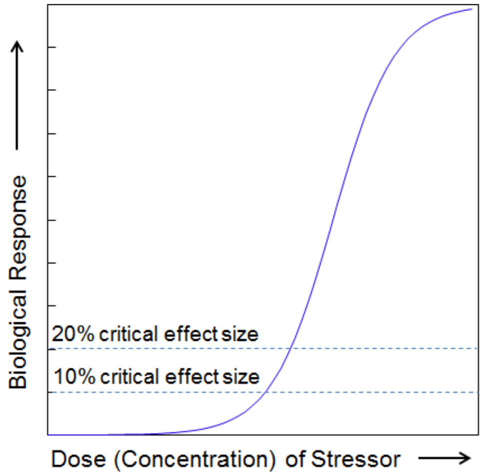
Integrated effects for cadmium were assessed based on predicted performance of the initial implementation plan, i.e., predicted maximum monthly concentrations in the long-term, which results in cadmium concentrations less than the long-term targets at all Order stations. Cadmium predictions are expected to be overestimates of actual concentrations because cadmium levels do not show a consistent increasing trend with increasing mine activity and waste rock deposition. Statistical trends at mainstem river stations tend to be relatively flat, although increasing and decreasing statistical trends have been observed at individual locations (Zajdlik and Minnow 2012). Temporal trends in tributaries have also been inconsistent (Zajdlik and Minnow 2012), demonstrating no clear, consistent response to mining activity.

2.1.4 Step 4: Identify Potential Effects to Sensitive Receptor Endpoints

2.1.4.1 Subunit Evaluation

Toxicological responses of aquatic organisms to increasing constituent concentrations can typically be described using continuous dose-response curves. The curves illustrate how effects to reproduction, growth or other life-history endpoints become greater as constituent concentrations increase (see example in Figure 2-2). Dose-response curves are typically generated based on laboratory testing and can be used to evaluate potential effects at a given constituent concentration.

Figure 2-2 Illustration of a Typical Dose-Response Curve and Critical Effect Sizes



A critical effect size is a level of effect relative to laboratory-generated data below which changes to populations or communities of sensitive aquatic species in the environment are not expected to occur (i.e., cannot be distinguished from differences that may result from normal background variability). The US EPA identifies 20% as a critical effect size for most cases. It represents an effect on laboratory organisms that is statistically distinct from reference or control conditions but that is not expected to cause meaningful and measurable changes in a natural population (US EPA 1999, 2013). Suter et al. (1995) also use a critical effect size of 20% but acknowledge that the minimum detectable effect varies by species, habitat and sampling method. For mobile species, they conclude that a difference of less than 20% can seldom be reliably detected and represent a *de minimis* effects level. A USGS study by Mebane (2010) similarly identifies a 20% critical effect size for benthic invertebrates in any environment and for fish when exposed to a single stressor, although they suggest a smaller effect size of 10% for fish when multiple stressors are present.

Based on the above, potential effects on sensitive aquatic receptors in each subunit were assessed by comparing constituent concentrations with WQGs. Concentrations of selenium, sulphate and nitrate in excess of WQGs were then either compared to Level 1 benchmarks representing a 10% effect size and to Level 2 benchmarks representing a 20% effect size, or else evaluated using dose-response curves if available. Results of the comparison were expressed either as a categorical result (e.g., < Level 1 benchmark) or as a percentage potential effect on the receptor organism and most sensitive life-history endpoint (e.g., an 8% effect on *Ceriodaphnia dubia* reproduction).

The selenium benchmarks used in the analysis are summarized in Annex E, along with available dose-response curves. The nitrate and sulphate benchmarks, along with data to describe 50% effect levels for both constituents, are summarized in Annex F. This information was used to develop the dose-response curves shown in Appendix B for sulphate, which are applicable to high hardness conditions in both the Elk and Fording rivers, and for nitrate in the Fording River. Dose-response curves were not developed for nitrate for the Elk River because long-term nitrate concentrations are expected to be at or below WQGs (as discussed in Chapter 8 of the Plan).

A similar approach was used for cadmium in MUs 1 to 4. The calculated concentrations defined in Step 3 were initially compared to WQGs. Concentrations above WQGs were then compared with Level 1 benchmarks, which are described in Annex G. Level 2 benchmarks and dose-response curves were not developed for cadmium because cadmium concentrations in the Designated Area tend to be low (as outlined in Chapter 4 of the Plan).

2.1.4.2 Spatial Integration

Potential effects expressed as a percentage were spatially integrated using an area-weighted approach to identify the percent effect across the entire MU (e.g., a 5% predicted integrated effect to *C. dubia* reproduction across MU1). This value was then compared to the critical effect sizes of 10% and 20% discussed above to assess protection of aquatic life.

The area-weighted approach relied on the habitat areas defined in Step 2 and was implemented assuming that all habitat is of equal value and receives equal use. The calculation involved multiplying the percent effect in each subunit by the habitat present in the subunit, adding all of the resulting values, and then dividing by the total habitat available in the MU.

A sensitivity analysis of the area-weighted approach was completed for selenium in MU1 using fish telemetry data for westslope cutthroat trout, the only fish species present in the upper Fording River. More specifically, the effects evaluation for MU1 was repeated twice, assuming that fish habitat use first matched with that shown in Table 2-1 for the summer rearing period (mid-July to the end of September) and then again for overwintering use (November-March). The information in Table 2-1 is based on the results of tracking 120 tagged fish over the past two years. As discussed in Section 2.2, the results of the sensitivity analysis indicated that assumptions around habitat use have little influence on the effects evaluation.

Table 2-1 Radio Telemetry Data for Westslope Cutthroat Trout in Upper Fording River (Aug 2012 to Jan 2014)

Habitat Sub-unit[a]	Overwintering		Summer Rearing	
	Counts	Percent of Total	Counts	Percent of Total
Fording River				
Fording River Upstream of FRO	27	10%	51	12%
FR1 - Downstream of Henretta Creek	60	22%	62	14%
FR2 - Downstream of Clode Creek and upstream of Kilmarnock Creek	0	0%	19	4%
FR3 - Between Swift and Cataract creeks	14	5%	62	14%
FR3b - Downstream of Porter Creek	105	38%	177	41%
FR4 - Downstream of Greenhills Creek	16	6%	20	5%
Tributaries				
Henretta Creek downstream of FRO	30	11%	39	9%
Chauncey Creek	15	5%	2	<1%
Off-channel Habitats				
Fording Oxbow	9	3%	5	1%
Total	**276**		**437**	

2.1.5 [a] Only subunits where fish presence was recorded are listed. Data originate from Westslope 2014.Step 5: Assess Interactive Effects Qualitatively

Effects on higher-level sensitive receptors, such as birds, fish and amphibians, may occur as a result of direct effects and indirect effects expressed through changes in food availability. Similarly, effects on benthic invertebrates can be expressed through changes to the population of the most sensitive species or more broadly through changes to the community as a whole (as a result of effects on multiple species). In recognition of these potential pathways, a qualitative evaluation was completed in each subunit to assess whether potential effects on multiple sensitive endpoints could result in community-level effects.

For benthic invertebrates, potential population-level responses were assessed based on predicted effects on the most sensitive invertebrate species tested. Potential changes in community structure or function were evaluated with reference to predicted effects on the next most sensitive species. The results of these evaluations were integrated, as shown in Table 2-2, to generate categorical effect scores 1 through 5, which are defined in Table 2-3.

Table 2-2 Integration of Potential Effects to Benthic Invertebrates

Endpoint and Level of Predicted Effect		Most Sensitive Species Endpoint[a]		
		≤10%	10 to 20%	>20%
Community Endpoint (next most sensitive species)	≤10%	1	2	3
	10 to 20%	n/a	3	4
	>20%	n/a	n/a	5

[a] n/a = Non-applicable scenario (i.e., a community level alteration cannot occur without a response to the most sensitive species); colour-coded categorical scores are defined per Table 2-3.

The scoring system in Table 2-2 is based on the following:

- Effect sizes of ≤10% represent negligible potential for population-level effects.

- Effect sizes of 10% to 20% represent a possibility of population-level effects, although measurable or ecologically meaningful changes in invertebrate populations are unlikely (Suter et al. 1995).
- Effect sizes of >20% represent a potential for measurable and ecologically meaningful population-level effects (Suter et al.1995; Mebane 2010; US EPA 1999, 2013).
- Effects on the most sensitive invertebrate test species may result in changes to diversity of benthic invertebrates but are unlikely to change general function, structure or abundance of the larger community.
- When more than the most sensitive species is potentially affected, changes to community function, structure and/or overall abundance are possible, particularly when effect sizes exceed 20%.

Table 2-3 Definition and Interpretation of Categorical Effect Scores

Score	Definition	Interpretation
0	Within the WQG	No effect
1	≤10% effect on any endpoint	No population effect
2	10% to 20% effect to sensitive invertebrate species endpoint.	Potential effects on populations of sensitive invertebrate species with the effects not expected to be measurable or ecologically meaningful[(a)]
3	*Invertebrates*: >20% effect on sensitive species or 10% to 20% effect on multiple endpoints. *Fish, birds and/or amphibians*: 10% to 20% direct effect or <10% direct effect with >20% effect on food supply	*Invertebrates*: Potential effect on populations of the most sensitive species, or potential effects on multiple species that are not expected to be measurable or ecologically meaningful[(a)] *Fish, birds and/or amphibians:* Potential effects on populations of the most sensitive species that are not expected to be measurable or ecologically meaningful, but that require consideration within the context of other stressors and verification through follow-up monitoring[(a)]
4	*Invertebrates*: >20% effect on sensitive species with 10% to 20% effect on other species *Fish, birds and/or amphibians*: >20% direct effect or 10 to 20% direct effect with >20% effect on food supply	*Invertebrates*: Potential effect on populations of multiple species *Fish, birds and/or amphibians*: Potential effect on populations of one or more sensitive species[(b)]
5	>20% effect on multiple endpoints	Potential effect on populations of multiple species, with potential changes to community structure

(a) Unlikely to be distinguishable from changes that occur as a result of natural variation or to affect the maintenance of an ecologically effective and self-sustaining population.

(b) Must be interpreted with caution when applied to local, subunit scale effects to mobile species.

Potential effects on fish, birds and/or amphibians were evaluated in a similar fashion, considering direct effects on the most sensitive species and life-history endpoint (e.g., brown trout reproduction), and indirect effects that may occur through reduced food supply (i.e., benthic invertebrate abundance).

Categorical effect scores were assigned following the scoring system outlined in Table 2-4. This scoring system was developed based on a rationale similar to that outlined above, considering:

- For fish, birds and amphibians, effect sizes of 10% to 20% represent a possibility of population-level effects that are unlikely to be measurable or ecologically meaningful (Suter et al. 1995), but that require additional consideration within the context of multiple stressors (Mebane 2010).

- At an indirect effect size >20%, benthic community structure and function could be impaired, which could conservatively be assumed to potentially limit food availability.
- Integrated effects are likely to become more severe as indirect and direct effects individually increase.

Table 2-4 Integration of Potential Effects on Fish, Birds and Amphibians

Endpoint and Level of Predicted Effect		Direct (Most sensitive of direct endpoints)[b]		
		≤10%	10 to 20%	>20%
Indirect (Food Supply)[a]	≤20%	1	3	4
	>20%	3	4	5

(a) Indirect effect defined based on invertebrate community endpoint.

(b) Colour-coded categorical scores are defined in Table 2-3.

2.1.6 Step 6: Assess Integrated Effects

The evaluation of integrated effects combines the results of Steps 4 and 5 to assess the integrated effect for the MU in question. This evaluation was completed using the following integrated effects assessment criteria, which are derived from the corresponding critical-effect sizes:

For the protection of benthic invertebrate community structure and abundance, as well as food availability for higher level organisms:

- a predicted integrated effect size of <20% across the MU to the benthic invertebrate community endpoint (if dose-response information is available);
- concentrations less than the Level 2 benthic community benchmark in all mainstem subunits of the Elk and Fording rivers; and
- benthic invertebrate integrated effect scores of <4 in the mainstem subunits of the Elk and Fording rivers.

For the protection of fish, bird or amphibian populations:

- a predicted integrated effect size of <10% across the MU for the most sensitive fish, bird or amphibian life-history endpoint, if dose-response information is available[1];
- concentrations less than the Level 1 benchmark for the most sensitive fish, bird or amphibian life-history endpoint in all mainstem subunits of the Elk and Fording rivers;
- integrated effect scores of <3 in the mainstem subunits of the Elk and Fording rivers; and
- for selenium effects to bird and fish reproduction, a predicted integrated effect size of <20% for the most sensitive receptor endpoint across the MU, based on an upper-bound estimate of the dose-response curve.

[1] For selenium, this evaluation was completed using the best-estimate of the dose-response curves for fish and bird reproduction.

Benthic invertebrate criteria focused on maintaining effect sizes <20% for the most sensitive species and life-history endpoint because Suter et al. 1995, Mebane 2010 and US EPA 1999, 2013 suggest that these will be protective and prevent measurable and ecologically meaningful changes to benthic communities. Lower effect sizes were used for fish in reflection of Mebane 2010, which indicates that effect sizes of 10% are recommended when multiple stressors are present. The same rationale was applied to birds and amphibians, given their longer life spans and lower reproductive output relative to benthic invertebrates.

If all integrated assessment criteria were met, then predicted conditions are expected to be protective of aquatic health in the MU. Exceeding one or more of these integrated assessment criteria for an MU does not necessarily mean that aquatic health would not be protected; however, it does require consideration of any such exceedances to evaluate the level of risk.

2.2 Results

2.2.1 Selenium

Results of the integrated assessments completed for selenium in the upper Fording and Elk rivers indicate that long-term, maximum monthly average concentrations of 57 µg/L in the upper Fording River and 19 µg/L in the Elk River will be protective. As shown in Table 2-5, these concentrations are predicted to be achievable and produce conditions that meet the assessment criteria outlined in Section 2.1.6. The effects information displayed in Table 2-5 originates from the selenium evaluation tables included in Appendix C. These tables show the results generated for each of the six steps shown in Figure 2-1 and discussed in Section 2.1.

In the lower Fording River (MU2), the initial implementation plan cannot generate conditions that meet the assessment criteria outlined in Section 2.1.6 for fish. As discussed in Chapter 8 of the Plan, a long-term selenium concentration of 40 µg/L is achievable, but lower concentrations are not technically or practically feasible. While a long-term concentration of 40 µg/L does not meet the fish criteria (Table 2-5), it is still expected to produce conditions that would be protective of fish and other receptors, although with a lower margin of safety than the long-term concentrations outlined for the other MUs.

A long-term maximum monthly average concentration of 40 µg/L at Order station FR4 is predicted to result in an integrated effect size of 13% across MU2, and concentrations in all sections of the lower Fording River are lower than the Level 2 benchmark for the most sensitive life-history endpoint. The predicted upper bound integrated effect size is <20%, and protection of other aquatic biota sensitive to selenium, i.e., birds and benthic invertebrates, occurs at effect sizes of <10%.

In contrast to the upper Fording River, in which the fish population is isolated because of Josephine Falls, fish in MU2 can freely move between MU2 and the Elk River (MUs 3 to 5), where selenium concentrations and effect sizes are lower. As a result, the integrated effect on fish in MU2 is expected to be closer to 10%, rather than the 12% predicted when fish in the lower Fording River are treated as an isolated population. Based on these considerations, a long-term concentration of 40 µg/L at FR4 in MU2 is expected to be protective, although with a lower margin of safety than those associated with the long-term concentrations outlined above for the other MUs in the Designated Area.

Table 2-5 Results of Integrated Assessment for Selenium in the Elk and Fording Rivers

Assessment criteria		Management Unit (maximum monthly selenium concentration at Order station)[a]				
Description	**Goal**	**MU1 (57 µg/L)**	**MU2 (40 µg/L)**	**MU3 (19 µg/L)**	**MU4 (19 µg/L)**	**MU5 (19 µg/L)**
Protection of Fish						
Integrated effect size for most sensitive endpoint	Best estimate of <10% (with upper bound estimate of <20%)	9% (12%)	**13%** (17%)	5% (8%)	8% (11%)	7% (10%)
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (96%)[b]	**0%** (27%)	100% (99%)	100% (93%)	100% (100%)
Maximum effect score in Fording River mainstem	2	1	**3**	1	1	1
Protection of Birds						
Integrated effect size for most sensitive endpoint	<10%	6%	5%	3%	4%	4%
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (95%)	100% (100%)	100% (99%)	100% (99%)	100% (100%)
Maximum effect score in Fording River mainstem	2	1	1	1	1	1
Protection of Benthic Invertebrates						
Integrated effect size for community endpoint	<20%	-	-	-	-	-
Proportion of MU with concentrations <Level 2 benchmark for the community endpoint	100% in river mainstem	100% (98%)	100% (100%)	100% (100%)	100% (100%)	100% (100%)
Maximum effect score in Fording River mainstem	3	1	1	1	1	1
Achievable by Initial Implementation Plan	Yes	Yes	Yes	Yes	Yes	Yes

(a) "-" = not applicable, because dose-response curve not available. Bolded values do not meet the criteria. Derived from information contained in Appendix C, with the exception of achievability; that information comes from Chapter 8 of the Plan. See Table 2-3 for definition of effect scores.

(b) % of mainstem subunit area below criterion, with % of area in the MU below criterion shown in parentheses.

As noted in Section 2.1.4.2, a sensitivity analysis was completed to evaluate how assumptions concerning habitat use may influence integrated effects of selenium on fish, the most sensitive receptor. When integrated effects on fish in MU1 were calculated using overwintering telemetry data, the predicted integrated effect size increased from 9 to 10%, with a corresponding shift of 2% in the upper bound estimate (i.e., shift from 12% to 14%; see Appendix D). When the calculation was repeated using summer rearing data, there was no appreciable change to either statistic (i.e., best-estimate of 9% integrated effect, with an upper bound of 12%; see Appendix D). These results suggest that assumptions about habitat use have little influence on the integrated effects assessment.

2.2.2 Nitrate

The integrated assessment for nitrate in the Fording River indicates that the hardness-dependent Level 1 benchmark of 11 mg as NO_3-N/L[2] is protective in both MU1 and MU2 when used as a long-term, maximum monthly average concentration. The Level 1 benchmark is predicted to produce conditions that meet the assessment criteria, as shown in Table 2-6 (with further detail provided in Appendix E).

Setting long-term nitrate concentrations at the Order stations in the Elk River to the WQG of 3 mg as NO_3-N/L resulted in conditions in MU3 and MU4 that meet the assessment criteria and would be protective of aquatic health (Table 2-7). As outlined in Appendix E, nitrate concentrations in most habitats in each MU are predicted to be at or below the WQG. One notable exception is Wheeler Creek, where integrated effects from nitrate in the long-term may result in localized changes to fish and benthic invertebrate populations. Projected concentrations in Wheeler Creek do not affect environmental protection across MU4 because Wheeler Creek represents <3% of the total available habitat.

Nitrate predictions for Wheeler Creek will be refined during the completion of the Coal Mountain Operations (CMO) Phase II environmental assessment. Updates will reflect, to the extent possible, the influence of new blasting practices on nitrogen mobilization. The new blasting practices are discussed in Chapter 6 of the Plan.

2.2.3 Sulphate

As noted in Section 2.1.3.2, integrated effects for sulphate were assessed based on predicted performance of the initial implementation plan in MUs 2 to 4, whereas the assessment for MU1 was completed with long-term concentrations at Order station FR4 set to the Level 1 benchmark (i.e., a value of 429 mg/L). This approach was used because predicted concentrations in MUs 2 to 4 are below the WQGs, whereas those in MU1 are predicted to hit the Level 1 benchmark in the long term.

The results of the integrated assessments completed for sulphate in the lower Fording River (MU2) and the Elk River (MUs 3 and 4) indicate that conditions in these MUs will be protective of aquatic life overall. As outlined in Table 2-8, integrated effect sizes for fish and amphibians are below 10%, and other assessment criteria are satisfied.

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[2] Expressed at a hardness of 360 mg/L as $CaCO_3$. Can be adjusted to different hardness levels as outlined in Chapter 8 of the Plan.

Table 2-6 Results of Integrated Assessments for Nitrate in the Fording River (MUs 1 and 2)

Assessment Criteria		Nitrate Concentration of 11 mg as NO3-N/L at Order station[(a)]	
Description	**Goal**	**MU1**	**MU2**
Protection of Fish			
Integrated effect size for most sensitive endpoint	Best estimate of <10%	~4%	~6%
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (93%)[(b)]	100% (98%)
Maximum effect score in Fording River mainstem	2	1	1
Protection of Amphibians			
Integrated effect size for most sensitive endpoint	<10%	~1%	~1%
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (100%)	100% (100%)
Maximum effect score in Fording River mainstem	2	1	1
Protection of Benthic Invertebrates			
Integrated effect size for community endpoint	<20%	~3%	~5%
Proportion of MU with concentrations <Level 2 benchmark for the community endpoint	100% in river mainstem	100% (100%)	100% (100%)
Maximum effect score in Fording River mainstem	3	3	3
Achievable by Initial Implementation Plan	Yes	Yes	Yes

(a) Expressed at a hardness of 360 mg/L as $CaCO_3$. Derived from information contained in Appendix E, with the exception of achievability; that information comes from Chapter 8 of the Plan. See Table 2-3 for definition of effect scores.

(b) % of mainstem subunit area below criterion, with % of area in the MU below criterion shown in parentheses.

Table 2-7 Results of Integrated Assessments for Nitrate in the Elk River (MUs 3 and 4)

Assessment Criteria		Nitrate Concentration of 3 mg as NO3-N/L at Order Station[a]	
Description	**Goal**	**MU3**	**MU4**
Protection of Fish			
Integrated effect size for most sensitive endpoint	Best estimate of <10%	-	-
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (100%)[b]	100% (97%)
Maximum effect score in Elk River mainstem	2	0	0
Protection of Amphibians			
Integrated effect size for most sensitive endpoint	<10%	-	-
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (100%)	100% (98%)
Maximum effect score in Elk River mainstem	2	0	0
Protection of Benthic Invertebrates			
Integrated effect size for community endpoint	<20%	-	-
Proportion of MU with concentrations <Level 2 benchmark for the community endpoint	100% in river mainstem	100% (100%)	100% (98%)
Maximum effect score in Elk River mainstem	3	0	0

(a) '-' = not applicable, because dose-response curve not available. Derived from information contained in Appendix E. See Table 2-3 for definition of effect scores.

(b) % of mainstem subunit area below criterion, with % of area in the MU below criterion shown in parentheses.

Table 2-8 Results of Integrated Assessments for Sulphate in the Elk and Fording Rivers

Assessment Criteria		MU1 (Meeting Long-term Target)	Based on Predicted Performance of the Initial Implementation Plan [(a)]		
Description	Goal		MU2	MU3	MU4
Protection of Fish					
Integrated effect size for most sensitive endpoint	Best estimate of <10%	~9%	~4%	~0%	~1%
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	**34**% (56%)[(b)]	100% (100%)	100% (100%)	100% (99%)
Proportion of MU with concentrations <Level 2 benchmark for most sensitive endpoint	n/a	100% (98%)	100% (100%)	100% (100%)	100% (99%)
Maximum effect score in Fording / Elk River mainstems	2	**3**	1	0	0
Protection of Amphibians					
Integrated effect size for most sensitive endpoint	<10%	~8%	~4%	~0%	~1%
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	**34**% (61%)	100% (100%)	100% (100%)	100% (98%)
Proportion of MU with concentrations <Level 2 benchmark for most sensitive endpoint	n/a	100% (98%)	100% (100%)	100% (100%)	100% (98%)
Maximum effect score in Fording / Elk River mainstems	2	**3**	1	0	0
Protection of Benthic Invertebrates					
Integrated effect size for community endpoint	<20%	~4%	~1%	~0%	~1%
Proportion of MU with concentrations <Level 2 benchmark for the community endpoint	100% in river mainstem	100% (98%)	100% (100%)	100% (100%)	100% (98%)
Maximum effect score in Fording / Elk River mainstems	3	1	1	0	0

(a) n/a = included for information – not an assessment criteria. Bolded values do not meet the criteria. Derived from information contained in Appendix F. See Table 2-3 for definition of effect scores.

(b) % of mainstem subunit area below criterion, with % of area in the MU below criterion shown in parentheses.

There are several smaller subunits in MU3 and MU4 where potential effects may occur, as shown in Appendix F, including Thompson Creek, Dry Creek at EVO and Erickson Creek. These predicted effects are small in geographic scope and do not affect overall protection of aquatic ecosystem health for the MUs in question. They will be managed by local effects monitoring

The integrated assessment for the upper Fording River (MU1) predicted an integrated effect size <10% across the MU for fish, the most sensitive receptor (Table 2-8). However, only ~34% of the Fording River mainstem is predicted to have an effect size <10%, with effect sizes in the remainder predicted to be between 10 to 20% (see Appendix F). Based on the integrated effect size of <10% to the most sensitive receptor, conditions in MU1 are expected to be protective. However, follow-up monitoring and toxicity testing will be used to verify this conclusion, and sulphate concentrations in the upper Fording River will be adaptively managed as described in Chapter 11 of the Plan.

2.2.4 Cadmium

Cadmium levels in the Elk and Fording rivers are currently below the Level 1 benchmark (see Chapter 4 of the Plan) and are expected to remain so. As a result, the integrated assessments for cadmium were completed in a similar manner to sulphate, with a focus on the predicted performance of the initial implementation plan. The integrated assessment results indicate that cadmium levels in all MUs will be protective of aquatic life (Table 2-9), with nearly all habitats predicted to remain below the Level 1 cadmium benchmark (Appendix G).

Predictions of cadmium concentrations using the model are uncertain. Efforts are underway to improve the quantitative understanding of the geochemical release of cadmium from waste rock, allowing improvement of model predictions. This information will be used during implementation of the Plan to adaptively manage cadmium concentrations if necessary.

Table 2-9 Results of Integrated Assessment for Cadmium in the Elk and Fording Rivers

Assessment Criteria		Based on Predicted Performance of the Initial Implementation Plan [a]			
Description	**Goal**	**MU1**	**MU2**	**MU3**	**Management Unit 4**
Protection of Fish					
Integrated effect size for most sensitive endpoint	Best estimate of <10%	-	-	-	-
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (100%)[b]	100% (100%)	100% (100%)	100% (98%)
Maximum effect score in Fording / Elk River mainstems	2	1	0	0	0
Protection of Amphibians					
Integrated effect size for most sensitive endpoint	<10%	-	-	-	-
Proportion of MU with concentrations <Level 1 benchmark for most sensitive endpoint	100% in river mainstem	100% (100%)	100% (100%)	100% (100%)	100% (100%)
Maximum effect score in Fording / Elk River mainstems	2	1	0	0	0
Protection of Benthic Invertebrates					
Integrated effect size for community endpoint	<20%	-	-	-	-
Proportion of MU with concentrations <Level 2 benchmark for the community endpoint	100% in river mainstem	100% (100%)	100% (100%)	100% (100%)	100% (98%)
Maximum effect score in Fording / Elk River mainstems	3	1	0	0	0

(a) "-" = not applicable, because dose-response curve not available. Derived from information contained in Appendix G. See Table 2-3 for definition of effect scores.

(b) % of mainstem subunit area below criterion, with % of area in the MU below criterion shown in parentheses.

3 Multiple Stressor Analysis

A multiple stressor analysis considers the combined effect of individual stressors acting either independently or interactively. The purpose of the multiple stressor analysis was to determine whether the conclusions of the constituent-specific analyses outlined in Section 2 require refinement in consideration of multiple stressors, as part of achieving the overall goal of protecting aquatic ecosystem health. The analysis was completed using a qualitative approach to evaluate the potential for interactions under predicted or expected conditions, taking into account the European Union's (2012) conclusion that interactive effects usually occur at medium or high exposure levels; at low exposure levels, they are either unlikely to occur or are toxicologically insignificant.

3.1 Methods

Conceptual site models developed in support of the Aquatic Environment Synthesis Report (a draft of which is included in Annex K1) identify the following physical stressors to aquatic biota in the Elk and Fording River watersheds:

- changes to water flow;
- formation of barriers that limit connectivity;
- calcite formation; and
- release of suspended sediments, which may elicit effects through direct contact or via deposition on existing habitats.

Chemical stressors consist of changes to the concentrations of the four Order constituents, as well as potential changes to nutrient status related to the release of phosphorus from the active water treatment facilities included in the initial implementation plan.

The potential for these stressors to act in combination and produce greater levels of effect than those predicted for individual Order constituents (see Section 2) was evaluated qualitatively using a lines of evidence approach. More specifically, the potential for mixture effects to occur among selenium, nitrate, sulphate and cadmium was evaluated through examination of the following:

- theoretical potential for interaction based on mechanisms of action of each Order constituent;
- results of standardized site-specific toxicity testing that evaluates the toxicity of mixtures representative of mine-influenced waters; and
- results of toxicity testing using amended waters (i.e., spiking tests) to evaluate how increasing individual substances (in the context of other substances held at stable and site-relevant concentrations) influences magnitude of response.

The potential for interactive effects among the Order constituent and other stressors was then evaluated in consideration of the following:

- the small effect sizes upon which the water quality benchmarks are based;
- existing best management practices that are being used to control sediment releases from mine areas;

- existing permit limits that regulate sediment releases from each operation with the goal of protecting downstream environments;
- existing regulatory protocols that require compensation for disturbed habitats;
- projected changes in water flows related to the initial implementation plan; and
- the medium and long-term calcite targets that are outlined in Chapter 7 of the Plan.

Information sources used to support the evaluation include:

- Phase 1 Mixture Toxicity Study (Golder and Nautilus 2013) – Summarizes the results of toxicity tests conducted on mixtures of constituents spiked into laboratory water or into site water obtained during base flow conditions from the Fording River bridge at Greenhills.
- Fall 2013 toxicity study (Annex F) – Summarizes the results of the site-specific testing of Fording and Elk River water, including testing of unamended waters and samples with additional spiked sulphate or nitrate.
- Evaluation of the toxicological interactions of mixtures of sulphate, nitrate, selenium and cadmium (Appendix H) – Summarizes information on the toxicological interactions of mixtures of sulphate, nitrate, selenium and cadmium, including a review of the available scientific literature on toxicity mechanisms and the results of site-specific testing relating to the toxicity of mixtures.

It is acknowledged that quantitative approaches are available for evaluating integrated effects from multiple chemical stressors. However, such approaches and models are only reliable when the mechanisms of toxicity are well understood, including knowledge of specific interactions among multiple constituents (as is the case for some pesticides - Rider and LeBlanc 2005). For the Order constituents, the mechanistic understanding of toxicity, both individually and in combination, is not at a level to support such an approach. Furthermore, the Order constituents found in site waters exhibit a high degree of inter-correlation in exposure (i.e., similar concentration profiles over space and time), which limits the degree to which potential causal factors can be discriminated. Downes (2010) recognizes that prediction of the effects of multiple stressors is challenging because direct causes of an environmental alteration are difficult to distinguish from factors that merely correlate with responses, making it difficult to disentangle their effects in ways allowing correct prediction for the future.

A qualitative approach was also adopted because of the findings of Staztner and Bêche (2010), who caution against the over-quantification of multiple stressor models where a mechanistic understanding of responses is lacking. They conclude that multiple-stressor evaluations of freshwater communities using quantitative or index-based methods should only be used in association with stressors for which mechanistic *a priori* predictions on their effects are possible. This view is supported by Rider and LeBlanc (2005), who conclude that indiscriminate application of a quantitative model in the absence of a sound mechanistic basis increases the uncertainty associated with predicting mixture toxicity. Gregorio et al. (2013) identified an additional uncertainty in mixture assessment for aquatic ecosystems; specifically, mixture effect predictions have been shown to be consistent only when these models are applied for a single species rather than for communities represented in a species sensitivity distribution. The application of a specific model can therefore lead to over- or underestimations, depending mainly on the slope of the dose-response curves of the individual species. It is for these reasons that a qualitative approach was used. Residual uncertainties inherent in the multiple stressor analysis will be dealt with through on-going monitoring and adaptive management, which are discussed in Chapters 10 and 11 of the Plan.

3.2 Results

Results of the multiple stressor analysis are outlined below, beginning with an evaluation of the potential for mixture effects among the chemical stressors. Information relevant to potential physical stressors is then discussed, followed by an evaluation of the potential for multiple stressor effects in the individual MUs. Based on this information, conclusions are rendered on how the findings of the constituent-specific analyses may be affected, if at all, by multiple stressor considerations.

Although MUs also include reference tributaries, these areas contain no mine-related activity and would not be subjected to the stressors under consideration in this analysis, i.e., no effects are expected. Therefore, reference tributaries were excluded from the analysis.

3.2.1 Mixture Effects from Chemical Stressors

3.2.1.1 Mechanisms of Action

The potential for interactions among chemical stressors depends in large part on their respective mechanisms of action. An interactive or mixture effect occurs when individual constituents combine to produce a level of effect that is different from that which would be expected to occur when considering constituents individually. For example, water hardness is known to ameliorate toxicity for a number of constituents (e.g., cadmium and sulphate), which results in its incorporation into some WQGs. This type of interactive effect is referred to an antagonistic response. Another type of interactive effect is the potential for individual Order constituents to combine in a manner that is additive or synergistic (effects greater than additive), thereby creating a greater level of effect than would otherwise be expected for an individual constituent.

Where responses are determined to be additive, it is useful to discriminate between concentration addition and response addition, which are the models most commonly applied to represent mixture effects. They are defined as follows:

- Concentration addition (also referred to as dose addition) – Constituents with the same mechanisms-of-action cause a combined effect as though they were the same toxicant; the effect level can be estimated using a toxic unit (TU) or toxic equivalents (TEQ) method.
- Response addition (also referred to as independent action) – Constituents with different mechanisms-of-action (i.e., that act on different physiological systems or systems that are functionally independent) result in a combined response that is related to the proportion of organisms that would be affected by the individual response of each constituent when exposed independently.

The distinction between these models is that, under concentration addition, combinations of constituents, each present at concentrations below their individual toxic thresholds, may combine to cause a toxicological effect. In contrast, under response addition, observation of no adverse effects for individual substances connotes no adverse effects for all substances combined.

A review of mechanisms-of-action was conducted (see Appendix H) to identify whether there is evidence to suggest that sulphate, nitrate, cadmium and/or selenium act on the same target organ and follow the same toxicological process. If so, then dose addition might be anticipated to occur. Although there is uncertainty in the toxicokinetics for all four substances, the available information suggests that this is not the case, i.e., that dose addition would not apply. As noted in Appendix H:

- Sulphate appears to act primarily on the iono-regulatory organs of freshwater organisms, such as the gill, and may either exert stress as a result of general osmoregulatory pressure in conjunction with other components of total dissolved solids.
- Although the specific mechanism-of-action is uncertain, nitrate may exhibit toxicity following uptake and conversion to nitrite, which can then impair oxygen transport. In the Elk Valley, nitrate does not contribute meaningfully to the osmotic pressure that may be important for sulphate toxicity because it is present at low concentrations relative to the total ionic content of mine-influenced waters.
- Cadmium appears to exhibit adverse effects primarily at the gill as a result of binding to enzyme receptors in the chloride cells, but cadmium does not influence oxygen-carrying capacity or otherwise impair respiratory function.
- Selenium produces adverse effects following dietary accumulation of seleno-amino acids into protein-rich tissues and, in particular, the yolk of egg-laying vertebrates, where oxidative stress can occur following mobilization of these materials during embryo-larval development.

Although mechanisms-of-action have not been definitively determined, particularly for sulphate and nitrate, the available information suggests that identical mechanisms-of-action do not occur among the four Order constituents. Therefore, the response addition model appears to be the most appropriate tool to assess the potential for adverse effects of mixtures of these constituents. Consequently, mixture effects are not expected when each constituent is present below its threshold for adverse effects.

3.2.1.2 Toxicity Test Results

3.2.1.2.1 Site Waters and Mixtures

In the Phase 1 Mixture Toxicity Study and Fall 2013 toxicity testing program (which are described in Golder and Nautilus 2013 and Annex F, respectively), sensitive test organisms were exposed to site waters containing multiple constituents of potential concern. An advantage of this approach is that the direct aqueous toxicity of various substances, including the effect of any additivity or interactions, is included in the response endpoint.

Site waters for toxicity testing were collected in the fall and winter periods and therefore exhibited concentrations of most substances that were toward the higher end of the annual range. Collectively, site water samples showed no evidence of adverse effects associated with mixtures of sulphate, nitrate, cadmium and selenium (as summarized in Appendix H). Samples from the Fording River (FR-B in Golder and Nautilus [2013], and FR-4 in Golder [2014]) generally contained the highest concentrations of constituents; samples from FR-4 contained ~11 mg/L nitrate, 240 mg/L sulphate, 55 µg/L selenium and 480 mg/L as $CaCO_3$ hardness, and samples from FR-B contained ~14 mg/L nitrate, 180 mg/L sulphate, 46 µg/L selenium and 440 mg/L as $CaCO_3$ hardness.

Site-specific testing was also completed using sample amendments (through simultaneous spiking with sodium nitrate, calcium and magnesium sulphates, sodium selenate, and cadmium chloride) to increase the range of tested conditions. In the winter of 2012/2013, seven mixtures were tested for toxicity to evaluate the effects of combinations of nitrate, sulphate, cadmium and selenium. In most cases, the maximum concentrations of the materials exceeded those that occur in the Elk Valley and were well above benchmarks for individual constituents. Testing of these samples indicated a general lack of toxicity to duckweed growth, green algae population growth, or rainbow trout embryo development for mixtures containing up to 931 mg/L sulphate, 53 mg/L nitrate, 139 µg/L selenium and 0.08 µg/L total cadmium (see Appendix H). Reduced reproduction was observed for the crustacean *C. dubia* in the spiked mixtures; however, the effects observed with *C. dubia* were most likely attributable entirely to nitrate, without evidence of interactions with other components of the mixture (see Appendix H). These results suggest that mixture effects among the Order constituents are unlikely, at least through direct contact (i.e., testing did not include an ingestion pathway, which would be required to evaluate effects related to selenium bioaccumulation).

3.2.1.2.2 Concentration Series

The aforementioned toxicity testing programs included additional treatments to identify threshold concentrations of individual substances in the context of representative site water mixtures. In contrast to the work presented above, this component entailed adjustment of a single substance at a time; more specifically, sulphate and nitrate were (separately) added to site waters without amendment of other Order constituents.

The results of this work provide an assessment of sulphate and nitrate toxicity in association with current concentrations of other constituents, assuming that 100% of any observed toxicity is associated with the constituent being added to the sample waters (sulphate or nitrate). The inhibition concentration estimates (e.g., IC_{10}, IC_{20}, and IC_{50} values) for nitrate or sulphate therefore incorporate any contributions to toxicity from other constituents, such that mixture effects (if present) have been indirectly addressed. Furthermore, the range of concentrations of these other constituents included concentrations close to water quality benchmarks in some samples.

Results of mixture testing completed using site waters generally indicate an absence of additive or synergistic effects (as summarized in Appendix H). A possible exception is when nitrate concentrations above 40 mg as NO3-N/L and sulphate concentrations above 930 mg/L occur in combination (Golder and Nautilus 2013). These values are two to three times higher than the Level 1 benchmarks developed for the Fording River.

The sulphate concentration series tests provide information on the potential for toxicity due to total ionic strength of tested waters. BC MOE (2013) emphasized the need to consider the potential for osmotic challenge at high hardness levels because the ions associated with elevated hardness, particularly calcium and magnesium, could contribute to the overall osmoregulatory challenge faced by aquatic organisms in high total dissolved solids environments. However, the results summarized in Annex F indicate that elevated water hardness does not contribute to toxicity in conjunction with typical concentrations of other constituents. In Fall 2013, no toxicity was observed in spiked samples containing hardness levels of more than 1,400 mg/L as $CaCO_3$ (see Annex F).

Overall, where toxicological effects have been observed in spiked or amended samples, the level of effect appears to be attributable to the concentration of a single constituent, without indication of additive effects from multiple stressors.

3.2.2 Other Considerations

3.2.2.1 Potential Effects Related to Potential Changes to Water Flow and Formation of Barriers That Limit Connectivity

As outlined in Section 2.1.2, the initial implementation plan may result in a loss of water flow in several mine-influenced tributaries. Mining activity associated with the FRO Swift Project will also result in the loss of Lake Mountain Creek. Compensatory habitats will be developed for the affected areas, if and as required, as part of permitting and detailed design. Although the initial implementation plan does not involve the formation of barriers or limits to existing connectivity, such activities, should they arise during detailed design, would also be subject to compensatory planning and implementation, as required.

While compensatory habitats do not eliminate the potential for multiple stressor effects at a local subunit scale where habitat loss may occur, they are expected to prevent habitat loss at the MU scale; hence, eliminating this potential pathway from contributing to multiple stressor effects at a regional scale.

3.2.2.2 Calcite

As outlined in Chapter 7 of the Plan, the objective of calcite management is to protect aquatic habitat and to manage calcite to achieve acceptable long-term conditions. The narrative objective for calcite management is to understand and manage mine-related calcite formation such that streambed substrates in the Elk and Fording rivers and their tributaries can support abundant and diverse communities of aquatic plants, benthic invertebrates, and fish comparable to those in reference areas. Based on this commitment, calcite formation is not expected to contribute to effects to aquatic receptors in the long-term, and would not result in levels of effects beyond those predicted in the individual constituent evaluations outlined in Section 2.

3.2.2.3 Suspended Sediments

The release of suspended sediments from operational mine sites is controlled by the effluent limits included in the waste discharge permits issued by BC MOE. All active mine discharges are subject to these permit conditions and use best management practices to maintain suspended sediment concentrations in discharged waters below these limits. These practices will continue in the future, thus limiting the amount of suspended sediment released to the Elk and Fording rivers and their contribution to multiple stressor effects.

3.2.2.4 Nutrient Status

The use of biological treatment will result in the release of phosphorus to the Elk and Fording rivers. However, the nutrient status of the Elk River is not expected to change with the development of the initial implementation plan (see Eutrophication Memo – Fording and Elk River, Annex I.2). In addition, as outlined in Chapter 6 of the Plan, treatment technologies will be selected and implemented in such a manner as to prevent undesirable effects related to eutrophication in the Fording River, Line Creek, Michel Creek and other large water courses. Consequently, changes to total phosphorus concentrations are not expected to contribute to multiple stressor effects at a regional scale, although monitoring will be required to support the selection of treatment technology during detailed design of active water treatment facilities.

3.2.3 Management Unit Evaluations

The purpose of this section is to determine whether the MU-specific conclusions of the constituent-specific analyses detailed in Section 2 require refinement in consideration of multiple stressors, based on the information outlined above in Sections 3.2.1. and 3.2.2.

3.2.3.1 Upper Fording River – MU1

3.2.3.1.1 Mainstem and Associated Off-Channel Areas

In the mainstem of the upper Fording River, multiple stressor effects that could alter the conclusions of the constituent-specific analysis would be driven primarily through interactions among the four Order constituents, since potential effects from physical stressors and changes to primary productivity (resulting from predicted nutrient levels) are expected to be minor (based on the considerations outlined in Section 3.2.2 and Annex I2). Lines of evidence that inform the evaluation of chemical stressors in the mainstem and associated off-channel areas are as follows:

- Nitrate and cadmium concentrations in mainstem areas are predicted to be below Level 1 benchmarks for all organisms (Appendices E and G, respectively).
- Selenium concentrations are also predicted to be at or below Level 1 benchmarks in mainstem areas (Appendix C).
- Level 1 benchmarks were defined based on 10% responses to sensitive organisms and life stages tested in the laboratory, which is a level expected to provide adequate protection against population-level responses in a multiple stressor context (Mebane 2010).
- Sulphate concentrations may exceed Level 1 benchmarks for fish and amphibians in some portions of the upper Fording River in the long-term, although predicted concentrations remain below Level 2 benchmarks (Appendix F).
- Sulphate predictions are conservative, as the Elk Valley Water Quality Model overestimates sulphate concentrations in the Elk and Fording rivers (Water Quality Model Report, Annex D.1)
- Presence or absence of amphibians is strongly linked to habitat characteristics, with a preference for shallow water, off-channel areas containing emergent vegetation (Minnow 2013). The majority of these areas are predicted to have sulphate concentrations below Level 1 benchmarks.

Based on the above, the potential for multiple stressors to result in greater levels of effect that those outlined in Section 2 is considered unlikely. However, this conclusion is associated with residual uncertainty. Fish are the most sensitive receptor to selenium and sulphate. As concentrations of both constituents are close to (selenium) or over (sulphate) their respective Level 1 benchmarks, it is theoretically possible that response addition for these two constituents could yield a combined effect size of greater than 20%. Follow-up monitoring, additional toxicity testing with sulphate and adaptive management will, therefore, be used to address this residual uncertainty.

3.2.3.1.2 Mine-Influenced Tributaries

Mine-influenced tributaries in MU1 can be placed into one of three groups with respect to potential multiple stressor responses.

Group 1 includes tributaries where effects attributable to multiple stressors are likely. Porter Creek and Greenhills Creek fall into this category based on predicted sulphate and selenium effects on fish. The predicted response sizes for both selenium (>20%) and sulphate (40%) exceed Level 2 benchmarks. These mine-influenced tributaries also currently exhibit calcite formation at levels greater than reference conditions (Aquatic Environment Synthesis Report, Annex K1), which may increase the potential for localized impairments.

Group 2 includes tributaries where effects attributable to multiple stressors are unlikely. In these tributaries, concentrations of all constituents are predicted to meet Level 1 benchmarks. Lower Henretta Creek and Dry Creek fall in this category.

Group 3 consist of tributaries where effects attributable to multiple stressors may occur. Kilmarnock Creek falls in this category based on potential effects to the most sensitive invertebrate species. There is no fish-accessible habitat in Kilmarnock Creek; however, exceedances of Level 1 invertebrate benchmarks are predicted for both nitrate and selenium.

Together, Groups 1 and 3 represent <3% of the total available habitat in MU1. Given the small size of these areas, the potential for multiple stressor effects to occur is insufficient to alter the conclusions of the constituent-specific evaluations outlined in Section 2.2. That said, the effects will be managed as necessary through local effects monitoring.

3.2.3.2 Lower Fording River – MU2

3.2.3.2.1 Mainstem and Associated Off-Channel Areas

Like MU1, multiple stressor effects in the mainstem of the lower Fording River would be driven primarily through interactions among the four Order constituents, since potential effects from physical stressors and changes to nutrient levels are expected to be minor. Lines of evidence that inform the evaluation of chemical stressors in these areas are as follows:

- Sulphate and cadmium concentrations in mainstem areas are predicted to remain at or below the WQGs, providing protection for all organisms, including fish (Appendices F and G, respectively).
- Nitrate concentrations in mainstem areas are predicted to remain below the Level 1 benchmarks for all organisms, with effect sizes to fish being in the order of only a few percent (Appendix E).
- Selenium concentrations are predicted to exceed Level 1 benchmarks for fish in most mainstem areas. The predicted level of response is 13% for reproduction of sensitive fish species. However, selenium concentrations are predicted to remain below Level 2 benchmarks for fish in all mainstem areas of MU2 (Appendix E).
- The predicted effect size for selenium requires evaluation of the potential for response addition to assess whether combined responses from selenium and other chemical stressors could exceed the 20% threshold for ecologically significant responses. Given that cadmium and sulphate are

predicted to contribute a negligible response (because they are below WQGs) and nitrate effect sizes are small (as previously noted), combined effect sizes remain below 20%.

Based on the above, it is unlikely that effects from multiple stressors will be greater than those suggested by the constituent-specific evaluations outlined in Section 2.2.

3.2.3.2.2 Mine Influenced Tributaries

Tributaries directly connected to the lower Fording River include Line Creek and various reference tributaries. Nitrate, cadmium and sulphate concentrations in Line Creek are predicted to be below Level 1 benchmarks (nitrate and cadmium) or WQGs (sulphate), with small potential effect sizes (e.g., ~1% or less for nitrate – Appendix E). Accordingly, potential effects attributable to selenium in the constituent-specific evaluation are expected to be representative of potential combined effects from multiple stressors, given that Line Creek will also be subject to calcite management due to its size.

3.2.3.3 Elk River – MUs 3 and 4

3.2.3.3.1 Mainstem and Associated Off-Channel Areas

As in the Fording River, multiple stressor effects in the mainstem of the Elk River would be driven primarily through interactions among the four Order constituents, since potential effects from physical stressors and changes to nutrient levels are expected to be minor or absent. However, predicted concentrations of selenium, nitrate, sulphate and cadmium are all expected to remain below Level 1 benchmarks, as outlined in Appendices C, E, F and G, respectively. These results suggest a negligible potential for multiple stressor effects in the Elk River mainstem and associated off-channel habitats.

3.2.3.3.2 Mine-Influenced Tributaries

Mine-influenced tributaries in the Elk River can be placed into one of two groups with respect to potential multiple stressor responses.

Group 1 includes tributaries in which effects attributable to multiple stressors are likely. Thompson, Erickson, EVO Dry and Wheeler creeks fall in this category. In these watercourses, concentrations of selenium and nitrate or sulphate are predicted to be elevated relative to Level 1 benchmarks (see Appendices C, E and F). Calcite formation is also occurring or may occur in the future. The four tributaries collectively contribute 14 ha of total habitat, which represents <3% of the available habitat in MUs 3 and 4.

Group 2 includes tributaries in which effects attributable to multiple stressors are unlikely. Carbon, Six Mile, Snowslide, Grace and Harmer creeks fall into this category. In Carbon, Six Mile and Snowslide creeks, predicted concentrations of the Order constituents are below Level 1 benchmarks. In Harmer and Grace creeks, selenium concentrations are predicted to exceed Level 1 benchmarks for fish; however, sulphate and cadmium concentrations are expected to remain below WQGs, and nitrate levels are predicted to remain below Level 1 benchmarks for fish, amphibians and the benthic community endpoint. Given their size, these watercourses would also be targeted for calcite management.

As previously noted, tributaries in Group 1 represent <3% of the total available habitat in MUs 3 and 4. Given the small size of these areas, the potential for multiple stressor effects to occur is insufficient to alter the conclusions of the constituent-specific evaluations outlined in Section 2.2. That said, these effects will be managed as necessary through local effects monitoring.

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APPENDIX A

HABITAT CALCULATION METHODS

GIS Fish Bearing, Fish Access and Habitat Area Classification Process

Overview

To support the analysis of potential impacts to fish and fish habitat from coal mining in the Elk Valley, several data sources were combined and modified to classify stream data in the Designated Area. The results of this analysis is shown in the attached constituent specific evaluation tables (Appendices C-G) as the 'Fish Accessible Habitat Area' and 'Total Habitat Area' columns in each table that provide values for each individual subunit.

Fish Bearing, Fish Accessibility Classification Process

The Elk and Fording Rivers and their respective tributaries were analyzed to determine the amount of fish bearing and non-fish bearing habitat available in the Designated Area. The stream data were categorized as fish bearing utilizing the following data sources:

- MoE Stream base data (BC MoE, 2014)
- Canfor stream classifications (Canfor, 2014)
    - S1-S4 Fish Bearing
    - S5-S6 Non-Fish Bearing
- Interior Reforestation, Lentic and Lotic Mapping of the Elk River Watershed (IR, 2008)
    - Known fish bearing reaches or unclassified
- Known fish location data (BC MoE, 2014)
- Teck Coal LiDAR data (Teck Coal, 2013)
- Teck Coal Orthophotography (Teck Coal, 2013)

A GIS process was run to update the MoE stream base data with the: Canfor fish bearing classification, known fish bearing reaches from the Interior Reforestation report, and the known fish locations from the BC MoE database. Stream reaches were then updated manually based on connectivity downstream of fish bearing class reaches and for known conditions on the mine site. Stream reaches with an average slope greater than %20 (determined from the LiDAR data) were set to non-fish bearing if the fish bearing status was unknown.

Finally the data was updated for fish accessibility (connected to the main-stem). This was done using the orthophotography and local site knowledge.

The QA/QC process for the fish bearing classification included any QA/QC work that was done for the input datasets themselves plus:

- Review of the manual update process for connectivity of fish bearing status downstream of sections classified as fish bearing.
- A review of the data, fish bearing status and fish accessibility on mine site locations with staff at the respective mine intimately familiar with stream characteristics on their site.

The final classification scheme is as follows:

- Known Fish Location – Yes/No
- Fish Bearing From Interior Reforestation Report – Yes/Unknown
- Fish Bearing From Canfor Classification – Yes/No
- Manual Update – Yes/No
- Final Fish Bearing-Yes/No/Unknown
- Fish Accessible-No/Null

Total Habitat Area Calculation Process

The total habitat area calculation used the estimated stream width (for the Elk and Fording Rivers and tributaries) multiplied by the stream length and was built on top of the fish bearing data described above. The estimated stream width used a GIS model and two data inputs:

- Canfor stream classifications (Canfor, 2014)1. The Canfor stream classification is based on on-site forestry surveys for selected streams within the Designated Area which have a stream width range associated with each class. The classes and the associated stream widths are listed below
  - S1-30 m
  - S2-12.5 m
  - S2/3-5 m
  - S3-3.25 m
  - S4-.75 m
  - S5,S5a-3 m
  - S6,S6a,S6b-1.5 m
- Stream Magnitude value (BC MoE, 2014). All streams not classified with a width from the Canfor data were then classified using the Stream Magnitude value (how many streams flow into that stream section) as follows:
  - Magnitude > 225 – 20 m
  - Magnitude > 75 <= 225 – 10 m
  - Magnitude > 25 <= 75 – 5 m
  - Magnitude > 10 <= 25 – 2.5 m
  - Magnitude <= 10 – 1 m
  - Magnitude > 225 – 20 m
  - Magnitude > 75 <= 225 – 10 m
  - Magnitude > 25 <= 75 – 5 m
  - Magnitude > 10 <= 25 – 2.5 m

- Magnitude <= 10 – 1 m

The stream width estimates using the stream magnitude model were compared the range for the Canfor stream classification to assess the validity of the stream magnitude model. The comparison indicated that >90% of the estimated stream widths using the magnitude model were equivalent to the on-site Canfor measurements.

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APPENDIX B

DOSE-RESPONSE CURVES DEVELOPED FOR SULPHATE AND NITRATE IN THE FORDING RIVER

The appendix contains a series of dose-response curves that were created to support the integrated assessments for sulphate and nitrate in the Fording River. The curves were created by fitting sigmoidal functions to the benchmarks identified in the Nitrate and Sulphate Benchmark Derivation Report (Annex F). The dose-response curves for sulphate under high hardness conditions in the Elk or Fording rivers are shown in Figures B-1 to B-4, while those generated for nitrate in the Fording River are shown in Figures B-5 to B-8.

Figure B-1 Dose-Response Curve for Sulphate for Rainbow Trout

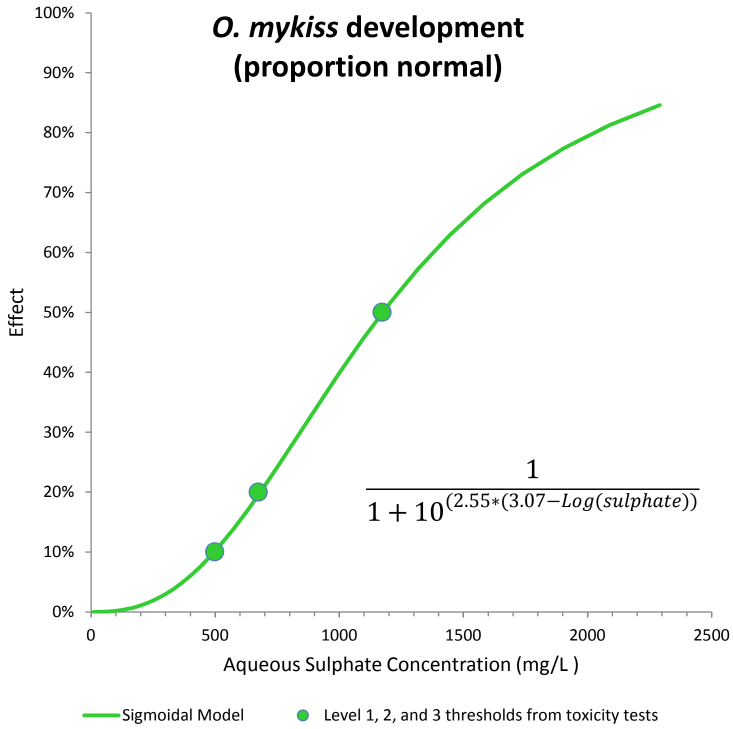


Figure B-2 Dose-Response Curve for Sulphate for Ceriodaphnia dubia

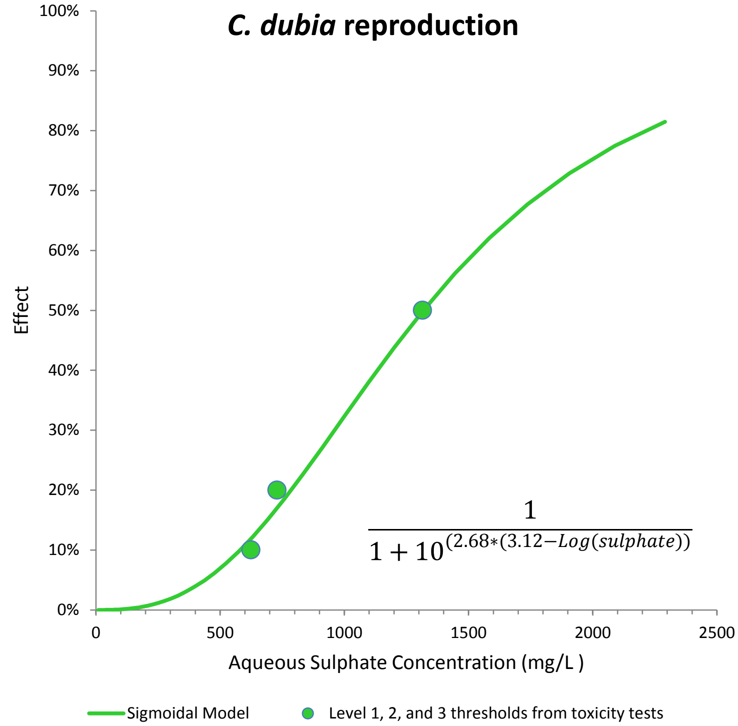


Figure B-3 Dose-Response Curve for Sulphate for Mayfly

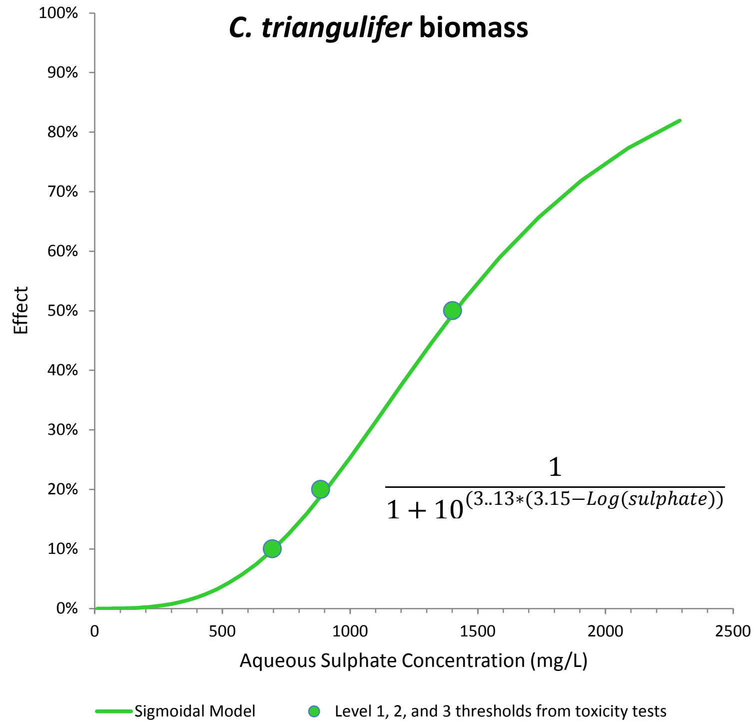


Figure B-4 Dose-Response Curve for Sulphate for Amphibians

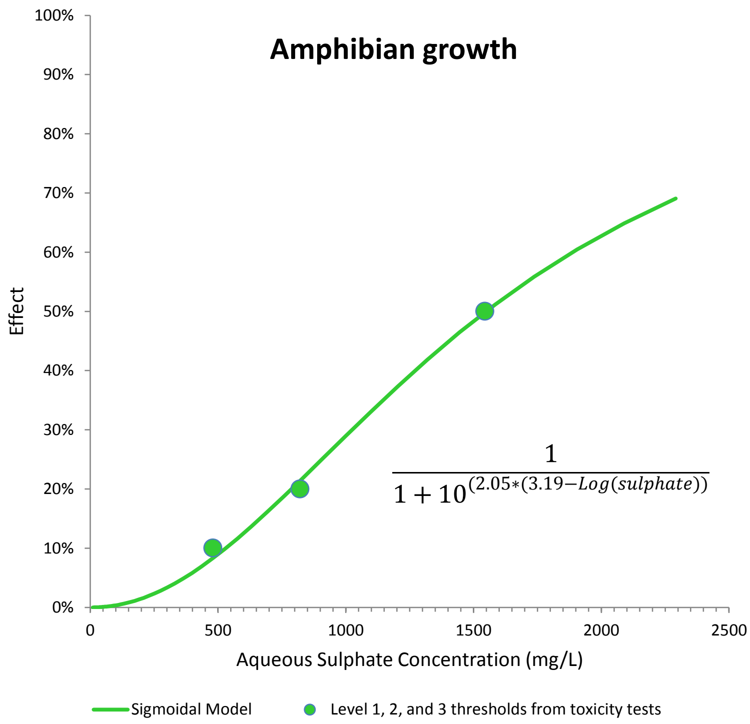


Figure B-5 Dose-Response Curve for Nitrate for Rainbow Trout in the Fording River

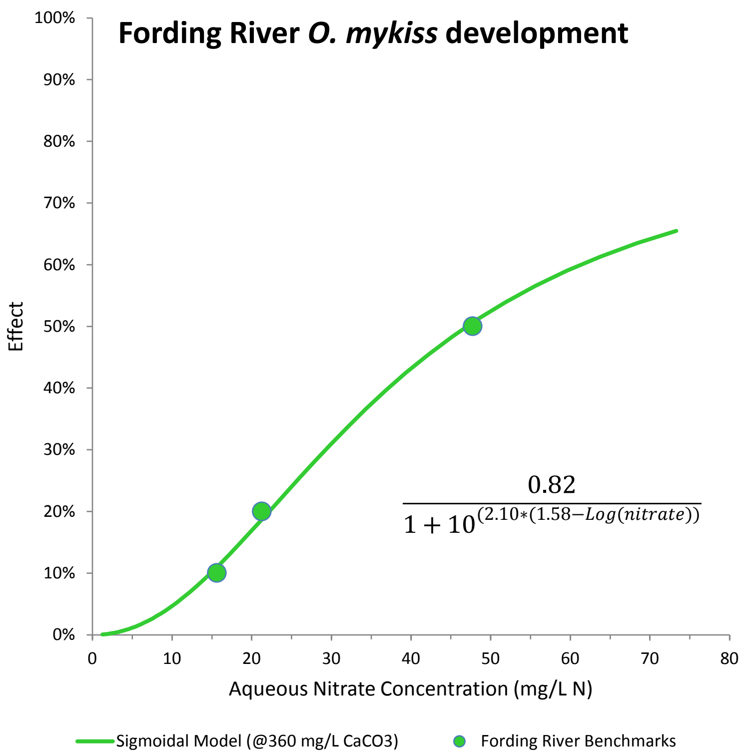


Figure B-6 Dose-Response Curve for Nitrate for Ceriodaphnia dubia in the Fording River

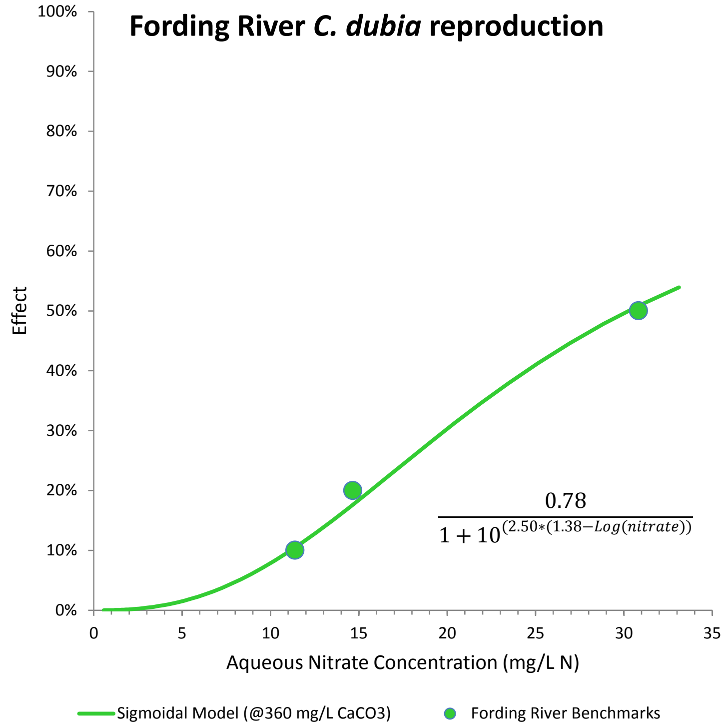


Figure B-7 Dose-Response Curve for Nitrate for Hyalella azteca in the Fording River

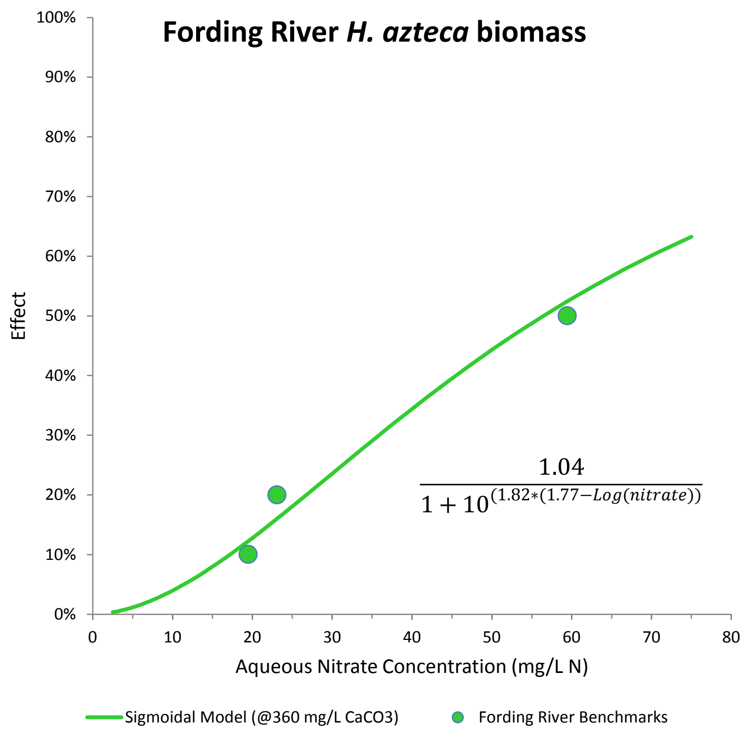
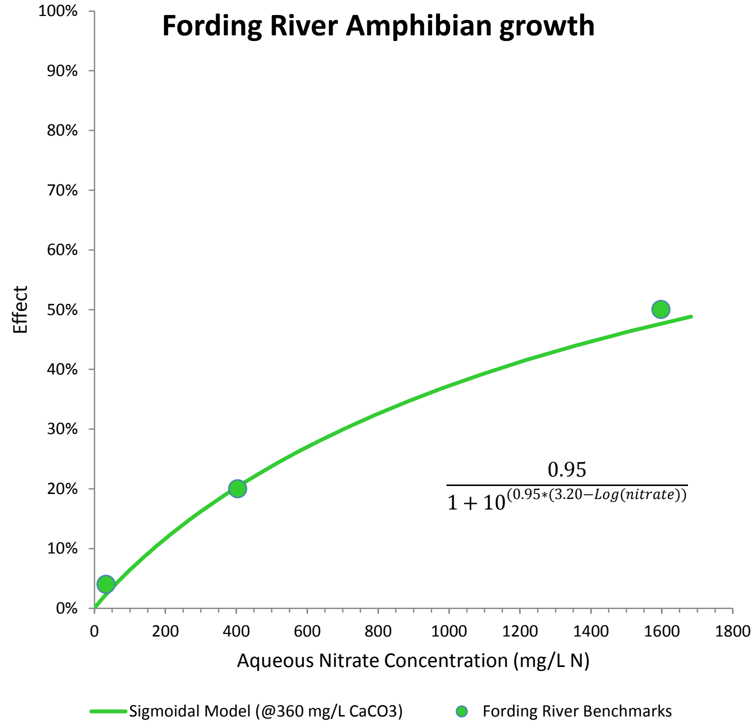


Figure B-8 Dose-Response Curve for Nitrate for Amphibians in the Fording River



APPENDIX C

EVALUATION TABLES FOR SELENIUM IN THE ELK AND FORDING RIVERS

Assessment of potential effects related to selenium

Management unit	1
Time period	2034
Concentration at Order Station	57

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Selenium Concentration (µg/L)	Invertebrate Endpoints		Fish Endpoints		Bird Endpoints		Integrated Potential Effects		
					Sensitive Species	Community	Reproduction	Juvenile Growth	Reproduction	Juvenile Growth	Invertebrates	Fish	Birds
Fording River													
FRus - Upstream of FRO	5.9	5.9	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
FR1 - Downstream of Henretta Creek	10.3	10.3	no	47.9	< L1	< L1	7%	< 10%	6%	6%	1	1	1
FR2 - Downstream of Clode Creek and upstream of Kilmarnock Creek	4.4	4.4	no	50.8	< L1	< L1	8%	< 10%	6%	6%	1	1	1
FR3 - Between Swift and Cataract creeks	9.8	9.8	no	68.4	< L1	< L1	10%	< 12%	7%	6%	1	1	1
FR3b - Downstream of Porter Creek	46.8	46.8	no	69.9	< L1	< L1	10%	< 12%	7%	7%	1	1	1
FR4 - Downstream of Greenhills Creek	9.1	9.1	no	57.0	< L1	< L1	8%	< 11%	6%	6%	1	1	1
Tributaries													
Henretta Creek upstream of FRO	1.8	1.9	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Henretta Creek downstream of FRO	2.7	2.7	no	56.2	< L1	< L1	8%	< 11%	6%	6%	1	1	1
Clode Creek	0.0	0.0	yes		-	-	-	-	-	-	-	-	-
Lake Mountain Creek	0	0	yes		-	-	-	-	-	-	-	-	-
Kilmarnock Creek	0	1.3	no	334	L1-L2	< L1	-	-	11%	13%	2	-	3
Swift Creek	0.0	0.3	yes		-	-	-	-	-	-	-	-	-
Cataract Creek			yes		-	-	-	-	-	-	-	-	-
Porter Creek	0.3	0.3	no	232	L1-L2	< L1	23%	< 19%	10%	11%	2	4	3
Dry Creek	8.4	8.4	no	12.7	< L1	< L1	2%	< 6%	4%	3%	1	1	1
Greenhills Creek	2.4	2.4	no	366	L1-L2	< L1	30%	< 23%	11%	13%	2	4	3
Chauncey Creek	8.0	8.3	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Ewin Creek	3.9	5.6	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Ewin Side Draw	2.9	3.0	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
McQuarrie Creek	0.7	0.8	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Moore Creek	0	0.2	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Todhunter Creek	2.0	2.0	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Other reference tributaries	3.8	3.8	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Off-channel Habitats													
FRus - off-channel	0	0.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR1 - off-channel, mainstem WQ	1.0	1.0	no	47.9	< L1	< L1	7%	< 10%	6%	6%	1	1	1
FR2 - off-channel, mainstem WQ	0.2	1.1	no	50.8	< L1	< L1	8%	< 10%	6%	6%	1	1	1
FR3 - off-channel, mainstem WQ	0.0	0.1	no	68.4	< L1	< L1	10%	< 12%	7%	6%	1	1	1
FR3b - off-channel, mainstem WQ	0.3	1.2	no	69.9	< L1	< L1	10%	< 12%	7%	7%	1	1	1
FR4 - off-channel, mainstem WQ	1.6	6.4	no	57.0	< L1	< L1	8%	< 11%	6%	6%	1	1	1
FR1 - off-channel, intermediate WQ	1.0	1.0	no	24.0	< L1	< L1	4%	< 8%	5%	4%	1	1	1
FR2 - off-channel, intermediate WQ	0.2	1.1	no	25.4	< L1	< L1	4%	< 8%	5%	4%	1	1	1
FR3 - off-channel, intermediate WQ	0.0	0.1	no	34.2	< L1	< L1	6%	< 9%	6%	5%	1	1	1
FR3b - off-channel, intermediate WQ	0.3	1.2	no	34.9	< L1	< L1	6%	< 9%	6%	5%	1	1	1
FR4 - off-channel, intermediate WQ	1.6	6.4	no	28.5	< L1	< L1	5%	< 8%	5%	5%	1	1	1
FR1 - off-channel, reference WQ	1.0	1.0	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
FR2 - off-channel, reference WQ	0.2	1.1	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
FR3 - off-channel, reference WQ	0.0	0.1	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
FR3b - off-channel, reference WQ	0.3	1.2	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
FR4 - off-channel, reference WQ	1.6	6.4	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Fording Oxbow	3.3	3.3	no	57.0	> L2	> L2	100%	< 73%	23%	57%	5	5	5
Overall	135.9	159.5	-	-	-	-	9%	< 10%	6%	6%			
Overall 90th Quantile Reproductive Effects							12%		11%				

Assessment of potential effects related to selenium

Management unit	2
Time period	2034
Concentration at Order Station	40

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Selenium Concentration (µg/L)	Invertebrate Endpoints		Fish Endpoints		Bird Endpoints		Integrated Potential Effects		
					Sensitive Species	Community	Reproduction	Juvenile Growth	Reproduction	Juvenile Growth	Invertebrates	Fish	Birds
Fording River													
Upstream of Line Creek	37.3	37.3	no	51.2	< L1	< L1	17%	10%	6%	6%	1	3	1
FR5 - Downstream of Line Creek	10.3	10.3	no	40.0	< L1	< L1	15%	9%	6%	5%	1	3	1
Tributaries													
Grace Creek	2.7	3.2	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Line Creek	8.4	8.4	no	27.1	< L1	< L1	12%	8%	5%	4%	1	3	1
South Line Creek	4.0	5.2	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Teepee Creek	1.5	1.5	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Unnamed tributaries	12.3	12.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Off-channel Habitats													
Fording River upstream of Line Creek - off-channel, mainstem WQ	0.4	1.3	no	51.2	< L1	< L1	17%	10%	6%	6%	1	3	1
Fording River downstream of Line Creek - off-channel, mainstem WQ	0	0											
Fording River upstream of Line Creek - off-channel, intermediate WQ	0.4	1.3	no	25.6	< L1	< L1	12%	8%	5%	4%	1	3	1
Fording River downstream of Line Creek - off-channel, intermediate WQ	0	0											
Fording River upstream of Line Creek - off-channel, reference WQ	0.4	1.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Fording River downstream of Line Creek - off-channel, reference WQ	0	0											
Overall	77.7	82.1	-	-	-	-	13%	8%	5%	4%			
Overall 90th Quantile Reproductive Effects							17%		10%				

Assessment of potential effects related to selenium

Management unit	3
Time period	2034
Concentration at Order Station	19

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Selenium Concentration (µg/L)	Invertebrate Endpoints		Fish Endpoints		Bird Endpoints		Integrated Potential Effects		
					Sensitive Species	Community	Reproduction	Juvenile Growth	Reproduction	Juvenile Growth	Invertebrates	Fish	Birds
Elk River													
Upstream of GHO	37.3	37.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
ER1 - Downstream of GHO	10.3	10.3	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
Tributaries													
Aldridge Creek	3.7	8.6	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Bingay Creek	7.6	8.2	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Bleasdell Creek	1.9	4.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Boivin Creek	11.7	11.9	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Brûlé Creek	18.7	18.8	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Cadorna Creek	11.3	11.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Crossing Creek	0.0	2.4	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Forsyth Creek	11.9	13.8	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Gardner Creek	0.2	1.6	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Hornickel Creek	1.0	1.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Leask Creek			yes		-	-	-	-	-	-	-	-	-
Lowe Creek	2.1	2.6	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Mickelson Creek	0	0.8	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Osborne Creek	1.0	1.1	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Quarrie Creek	0.7	5.7	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Thompson Creek	1.3	1.3	no	277	L1-L2	< L1	36%	20%	10%	12%	2	4	3
Tobermory Creek	0	2.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Weary Creek	0.7	1.2	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Weigert Creek	10.0	10.0	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Wolfram Creek			yes		-	-	-	-	-	-	-	-	-
Other named tribs	0.8	3.1	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Unnamed tribs	35.1	35.1	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Off-channel Habitats													
Elk River upstream of GHO - off-channel, mainstem WQ	0	0											
Elk River downstream of GHO - off-channel, mainstem WQ	0.8	2.9	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
Elk River upstream of GHO - off-channel, intermediate WQ	0	0											
Elk River downstream of GHO - off-channel, intermediate WQ	0.8	2.9	no	9.5	< L1	< L1	7%	5%	4%	3%	1	1	1
Elk River upstream of GHO - off-channel, reference WQ	0	0											
Elk River downstream of GHO - off-channel, reference WQ	0.8	2.9	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Overall	169.6	201.4	-	-	-	-	5%	2%	3%	1%			
Overall 90th Quantile Reproductive Effects							8%		7%				

Assessment of potential effects related to selenium

Management unit	4
Time period	2034
Concentration at Order Station	19

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Selenium Concentration (µg/L)	Invertebrate Endpoints		Fish Endpoints		Bird Endpoints		Integrated Potential Effects		
					Sensitive Species	Community	Reproduction	Juvenile Growth	Reproduction	Juvenile Growth	Invertebrates	Fish	Birds
Elk River													
ER2 - Downstream of the Fording River	41.4	41.4	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
Michel Creek													
MC5 - Downstream of CMO	5.4	5.4	no	6.0	< L1	< L1	5%	4%	4%	2%	1	1	1
MC4 - Downstream of CMO PII	24.3	24.3	no	15.1	< L1	< L1	9%	6%	4%	3%	1	1	1
MC3 - Upstream of EVO	18.8	18.8	no	9.8	< L1	< L1	7%	5%	4%	3%	1	1	1
MC1 - Mouth	27.9	27.9	no	17.0	< L1	< L1	9%	7%	5%	4%	1	1	1
Tributaries													
Alexander Creek	38.9	40.9	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Bodie Creek	0	0.5	yes		-	-	-	-	-	-	-	-	-
Bray Creek	0.1	1.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Carbon Creek	1.6	2.5	no	1.9	< WQG	< WQG	4%	3%	3%	2%	0	0	0
Cummings Creek	17.9	18.4	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Dalzell Creek	1.0	1.0	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Erickson Creek	0.8	3.7	no	163	L1-L2	< L1	29%	17%	9%	9%	2	4	1
EVO Dry Creek	1.9	1.9	no	479	L1-L2	< L1	44%	25%	12%	15%	2	4	3
Fir Creek	0.9	1.1	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Gate Creek			yes		-	-	-	-	-	-	-	-	-
Grave Creek - Reference reach	3.7	3.7	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Grave Creek - Mine influenced reach	5.1	5.1	no	62.9	< L1	< L1	18%	11%	7%	6%	1	3	1
Harmer Creek - Reference reach	1.1	1.1	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Harmer Creek -Mine influenced reach	6.6	6.6	no	96.5	< L1	< L1	23%	13%	8%	7%	1	4	1
Leach Creek	20.8	21.6	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Littlemoor Creek	1.0	1.1	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Marten Creek	2.4	3.7	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Nordstrum Creek	2.9	3.1	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Saw Mill Creek	0.6	0.6	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Six Mile Creek	0.7	0.7	no	4.3	< L1	< L1	5%	4%	4%	2%	1	1	1
Snowslide Creek	0.5	0.5	no	1.5	< WQG	< WQG	4%	3%	3%	1%	0	0	0
Telford Creek	0.6	2.0	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Wheeler Creek	5.1	6.7	no	144	L1-L2	< L1	27%	16%	8%	9%	2	4	1
Other named tributaries	2.1	6.9	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Unnamed tributaries	23.2	23.2	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Off-channel Habitats													
Elk River downstream of the Fording River - off-channel, mainstem WQ	1.5	4.7	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
Elk River downstream of the Fording River - off-channel, intermediate WQ	1.5	4.7	no	9.5	< L1	< L1	7%	5%	4%	3%	1	1	1
Elk River downstream of the Fording River - off-channel, reference WQ	1.5	4.7	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Overall	261.8	289.9	-	-	-	-	8%	5%	4%	3%			
Overall 90th Quantile Reproductive Effects							11%		8%				

Assessment of potential effects related to selenium

Management unit	5
Time period	2034
Concentration at Order Station	19

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Selenium Concentration (µg/L)	Invertebrate Endpoints		Fish Endpoints		Bird Endpoints		Integrated Potential Effects		
					Sensitive Species	Community	Reproduction	Juvenile Growth	Reproduction	Juvenile Growth	Invertebrates	Fish	Birds
Elk River													
Between Michel Creek and ER3	22.0	22.0	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
ER3 to Elko	115.0	115.0	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
ER4 - Elko to Mouth	36.5	36.5	no	15.5	< L1	< L1	9%	6%	4%	4%	1	1	1
Tributaries													
Named tributaries	205.3	244.5	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Unnamed tributaries	33.3	33.3	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Off-channel Habitats													
Elk River between Michel Creek and ER3 - off-channel, mainstem WQ	0.3	3.5	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
Elk River between ER3 and Elko - off-channel, mainstem WQ	8.4	20.0	no	19.0	< L1	< L1	10%	7%	5%	4%	1	1	1
Elk River downstream of Elko - off-channel, mainstem WQ	0.2	0.2	no	15.5	< L1	< L1	9%	6%	4%	4%	1	1	1
Elk River between Michel Creek and ER3 - off-channel, intermediate WQ	0.3	3.5	no	9.5	< L1	< L1	7%	5%	4%	3%	1	1	1
Elk River between ER3 and Elko - off-channel, intermediate WQ	8.4	20.0	no	9.5	< L1	< L1	7%	5%	4%	3%	1	1	1
Elk River downstream of Elko - off-channel, intermediate WQ	0.2	0.2	no	7.7	< L1	< L1	6%	5%	4%	3%	1	1	1
Elk River between Michel Creek and ER3 - off-channel, reference WQ	0.3	3.5	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Elk River between ER3 and Elko - off-channel, reference WQ	8.4	20.0	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Elk River downstream of Elko - off-channel, reference WQ	0.2	0.2	no	0.5	< WQG	< WQG	4%	2%	3%	1%	0	0	0
Overall	438.8	522.2	-	-	-	-	7%	4%	4%	2%			
Overall 90th Quantile Reproductive Effects							10%		8%				

APPENDIX D

EVALUATION TABLES FOR SELENIUM IN THE UPPER FORDING RIVER WITH HABITAT USE REFLECTIVE OF 2012 TO 2014 TELEMETRY DATA

Assessment of potential effects related to selenium - sensitivity analysis completed with overwinter habitat use

Management unit	1
Time period	2034
Concentration at Order Station	57

Habitat Sub-unit	Fish habitat being used (1=yes; 0=no)	*% Use based on Telemetry Data Aug 12'-Jan14'*	Fish Habitat Use (%)	Total Habitat (ha)	Loss of Majority of Flow	Selenium Concentration (µg/L)	Invertebrate Endpoints		Fish Endpoints		Bird Endpoints		Integrated Potential Effects		
							Sensitive Species	Community	Reproduction	Juvenile Growth	Reproduction	Juvenile Growth	Invertebrates	Fish	Birds
Fording River															
FRus - Upstream of FRO	1	*0.1*	0.1	5.9	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
FR1 - Downstream of Henretta Creek	1	*0.22*	0.22	10.3	no	47.9	< L1	< L1	7%	< 10%	6%	6%	1	1	1
FR2 - Downstream of Clode Creek and upstream of Kilmarnock Creek	1	*0*	0	4.4	no	50.8	< L1	< L1	-	-	6%	6%	1	-	1
FR3 - Between Swift and Cataract creeks	1	*0.05*	0.05	9.8	no	68.4	< L1	< L1	10%	< 12%	7%	6%	1	1	1
FR3b - Downstream of Porter Creek	1	*0.38*	0.38	46.8	no	69.9	< L1	< L1	10%	< 12%	7%	7%	1	1	1
FR4 - Downstream of Greenhills Creek	1	*0.06*	0.06	9.1	no	57.0	< L1	< L1	8%	< 11%	6%	6%	1	1	1
Tributaries															
Henretta Creek upstream of FRO	0		0	1.9	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Henretta Creek downstream of FRO	1	*0.11*	0.11	2.7	no	56.2	< L1	< L1	8%	< 11%	6%	6%	1	1	1
Clode Creek	0		0	0.0	yes		-	-	-	-	-	-	-	-	-
Lake Mountain Creek	0		0	0	yes		-	-	-	-	-	-	-	-	-
Kilmarnock Creek	0		0	1.3	no	334	L1-L2	< L1	-	-	11%	13%	2	-	3
Swift Creek	0		0	0.3	yes		-	-	-	-	-	-	-	-	-
Cataract Creek	0		0		yes		-	-	-	-	-	-	-	-	-
Porter Creek	0		0	0.3	no	232	L1-L2	< L1	-	-	10%	11%	2	-	3
Dry Creek	0		0	8.4	no	12.7	< L1	< L1	-	-	4%	3%	1	-	1
Greenhills Creek	0		0	2.4	no	366	L1-L2	< L1	-	-	11%	13%	2	-	3
Chauncey Creek	1	*0.05*	0.05	8.3	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
Ewin Creek	0		0	5.6	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Ewin Side Draw	0		0	3.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
McQuarrie Creek	0		0	0.8	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Moore Creek	0		0	0.2	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Todhunter Creek	0		0	2.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Other reference tributaries	0		0	3.8	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Off-channel Habitats	0		0												
FRus - off-channel	0		0	0.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR1 - off-channel, mainstem WQ	0		0	1.0	no	47.9	< L1	< L1	-	-	6%	6%	1	-	1
FR2 - off-channel, mainstem WQ	0		0	1.1	no	50.8	< L1	< L1	-	-	6%	6%	1	-	1
FR3 - off-channel, mainstem WQ	0		0	0.1	no	68.4	< L1	< L1	-	-	7%	6%	1	-	1
FR3b - off-channel, mainstem WQ	0		0	1.2	no	69.9	< L1	< L1	-	-	7%	7%	1	-	1
FR4 - off-channel, mainstem WQ	0		0	6.4	no	57.0	< L1	< L1	-	-	6%	6%	1	-	1
FR1 - off-channel, intermediate WQ	0		0	1.0	no	24.0	< L1	< L1	-	-	5%	4%	1	-	1
FR2 - off-channel, intermediate WQ	0		0	1.1	no	25.4	< L1	< L1	-	-	5%	4%	1	-	1
FR3 - off-channel, intermediate WQ	0		0	0.1	no	34.2	< L1	< L1	-	-	6%	5%	1	-	1
FR3b - off-channel, intermediate WQ	0		0	1.2	no	34.9	< L1	< L1	-	-	6%	5%	1	-	1
FR4 - off-channel, intermediate WQ	0		0	6.4	no	28.5	< L1	< L1	-	-	5%	5%	1	-	1
FR1 - off-channel, reference WQ	0		0	1.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR2 - off-channel, reference WQ	0		0	1.1	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR3 - off-channel, reference WQ	0		0	0.1	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR3b - off-channel, reference WQ	0		0	1.2	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR4 - off-channel, reference WQ	0		0	6.4	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Fording Oxbow	1	*0.03*	0.03	3.3	no	57.0	> L2	> L2	100%	< 73%	23%	57%	5	5	5
Overall	9	1	1	159.5	-	-	-	-	10%	< 12%	6%	6%			
Overall 90th Quantile Reproductive Effects									14%		11%				

Assessment of potential effects related to selenium - sensitivity analysis completed with summer rearing habitat use

Management unit	1
Time period	2034
Concentration at Order Station	57

Habitat Sub-unit	Fish habitat being used (1=yes; 0=no)	*% Use based on Telemetry Data Aug 12'-Jan14'*	Fish Habitat Use (%)	Total Habitat (ha)	Loss of Majority of Flow	Selenium Concentration (µg/L)	Invertebrate Endpoints		Fish Endpoints		Bird Endpoints		Integrated Potential Effects		
							Sensitive Species	Community	Reproduction	Juvenile Growth	Reproduction	Juvenile Growth	Invertebrates	Fish	Birds
Fording River															
FRus - Upstream of FRO	1	*0.12*	0.12	5.9	no	0.5	< WQG	< WQG	1%	< 2%	3%	1%	0	0	0
FR1 - Downstream of Henretta Creek	1	*0.14*	0.14	10.3	no	47.9	< L1	< L1	7%	< 10%	6%	6%	1	1	1
FR2 - Downstream of Clode Creek and upstream of Kilmarnock Creek	1	*0.04*	0.04	4.4	no	50.8	< L1	< L1	8%	< 10%	6%	6%	1	1	1
FR3 - Between Swift and Cataract creeks	1	*0.14*	0.14	9.8	no	68.4	< L1	< L1	10%	< 12%	7%	6%	1	1	1
FR3b - Downstream of Porter Creek	1	*0.41*	0.41	46.8	no	69.9	< L1	< L1	10%	< 12%	7%	7%	1	1	1
FR4 - Downstream of Greenhills Creek	1	*0.05*	0.05	9.1	no	57.0	< L1	< L1	8%	< 11%	6%	6%	1	1	1
Tributaries			0												
Henretta Creek upstream of FRO	0		0	1.9	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Henretta Creek downstream of FRO	1	*0.09*	0.09	2.7	no	56.2	< L1	< L1	8%	< 11%	6%	6%	1	1	1
Clode Creek	0		0	0.0	yes		-	-	-	-	-	-	-	-	-
Lake Mountain Creek	0		0	0	yes		-	-	-	-	-	-	-	-	-
Kilmarnock Creek	0		0	1.3	no	334	L1-L2	< L1	-	-	11%	13%	2	-	3
Swift Creek	0		0	0.3	yes		-	-	-	-	-	-	-	-	-
Cataract Creek	0		0		yes		-	-	-	-	-	-	-	-	-
Porter Creek	0		0	0.3	no	232	L1-L2	< L1	-	-	10%	11%	2	-	3
Dry Creek	0		0	8.4	no	12.7	< L1	< L1	-	-	4%	3%	1	-	1
Greenhills Creek	0		0	2.4	no	366	L1-L2	< L1	-	-	11%	13%	2	-	3
Chauncey Creek	0		0	8.3	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Ewin Creek	0		0	5.6	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Ewin Side Draw	0		0	3.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
McQuarrie Creek	0		0	0.8	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Moore Creek	0		0	0.2	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Todhunter Creek	0		0	2.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Other reference tributaries	0		0	3.8	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Off-channel Habitats	0		0												
FRus - off-channel	0		0	0.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR1 - off-channel, mainstem WQ	0		0	1.0	no	47.9	< L1	< L1	-	-	6%	6%	1	-	1
FR2 - off-channel, mainstem WQ	0		0	1.1	no	50.8	< L1	< L1	-	-	6%	6%	1	-	1
FR3 - off-channel, mainstem WQ	0		0	0.1	no	68.4	< L1	< L1	-	-	7%	6%	1	-	1
FR3b - off-channel, mainstem WQ	0		0	1.2	no	69.9	< L1	< L1	-	-	7%	7%	1	-	1
FR4 - off-channel, mainstem WQ	0		0	6.4	no	57.0	< L1	< L1	-	-	6%	6%	1	-	1
FR1 - off-channel, intermediate WQ	0		0	1.0	no	24.0	< L1	< L1	-	-	5%	4%	1	-	1
FR2 - off-channel, intermediate WQ	0		0	1.1	no	25.4	< L1	< L1	-	-	5%	4%	1	-	1
FR3 - off-channel, intermediate WQ	0		0	0.1	no	34.2	< L1	< L1	-	-	6%	5%	1	-	1
FR3b - off-channel, intermediate WQ	0		0	1.2	no	34.9	< L1	< L1	-	-	6%	5%	1	-	1
FR4 - off-channel, intermediate WQ	0		0	6.4	no	28.5	< L1	< L1	-	-	5%	5%	1	-	1
FR1 - off-channel, reference WQ	0		0	1.0	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR2 - off-channel, reference WQ	0		0	1.1	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR3 - off-channel, reference WQ	0		0	0.1	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR3b - off-channel, reference WQ	0		0	1.2	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
FR4 - off-channel, reference WQ	0		0	6.4	no	0.5	< WQG	< WQG	-	-	3%	1%	0	-	0
Fording Oxbow	1	*0.01*	0.01	3.3	no	57.0	> L2	> L2	100%	< 73%	23%	57%	5	5	5
Overall	8	1	1	159.5	-	-	-	-	9%	< 11%	6%	6%			
Overall 90th Quantile Reproductive Effects									12%		11%				

APPENDIX E

EVALUATION TABLES FOR NITRATE IN THE ELK AND FORDING RIVERS

Assessment of potential effects related to Nitrate

		Standard Hardness	Pooled slope
Management unit	1	360	1.0003
Time period	2023		
Concentration at Order Station	11		
Applicable Order Station	FR4		
Hardness Condition - yearly min (yearly) or min from month when peak occurs (n	min monthly		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Nitrate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints				Fish Endpoints		Amphibian Endpoints		Integrated Potential Effects		
						Sensitive Species (*C. dubia*)	Sensitive Species (*C. dubia*) Category	Community (*H. azteca*)	Community (*H. azteca*) Category	Sensitive Species	Sensitive Species Category	Sensitive Species	Sensitive Species Category	Fish	Invertebrates	Amphibians
Fording River																
FRus - Fording River upstream of FRO	5.9	5.9	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR1 - Fording River downstream of Henretta Creek	10.3	10.3	no	1.9	355	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR2 - Fording River downstream of Clode Creek and upstream of Kilmarnock Creek	4.4	4.4	no	11.9	456	~ 7%	< L1	~ 4%	< L1	~ 4%	< L1	~ 1%	< L1	1	1	1
FR3 - Fording River between Swift and Cataract creeks	9.8	9.8	no	11.6	566	~ 4%	< L1	~ 2%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
FR3b - Fording River downstream of Porter Creek	46.8	46.8	no	11.3	563	~ 4%	< L1	~ 2%	< L1	~ 2%	< L1	~ 1%	< L1	1	1	1
FR4 - Fording River downstream of Greenhills Creek	9.1	9.1	no	11.0	494	~ 5%	< L1	~ 3%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
Tributaries																
Henretta Creek - upstream FRO	1.8	1.9	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Henretta Creek - Lower	2.7	2.7	no	2.0	355	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Clode Creek	0.0	0.0	yes	-	-	-	-	-	-	-	-	-	-	-	-	-
Lake Mountain Creek (LM1)	0.0	0.0	yes	-	-	-	-	-	-	-	-	-	-	-	-	-
Kilmarnock Creek	0.0	1.3	no	35.0	566	~ 35%	> L2	~ 15%	L1-L2	-	-	~ 2%	< L1	-	4	1
Swift Creek	0.0	0.3	yes	-	-	-	-	-	-	-	-	-	-	-	-	-
Cataract Creek	0.0	0.0	yes	-	-	-	-	-	-	-	-	-	-	-	-	-
Porter Creek	0.3	0.3	no	1.2	563	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Dry Creek	8.4	8.4	no	10.6	494	~ 4%	< L1	~ 3%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
Greenhills Creek	2.4	2.4	no	0.04	494	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Chauncey Creek	8.0	8.3	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Ewin Creek	3.9	5.6	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Ewin Side Draw	2.9	3.0	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
McQuarrie Creek	0.7	0.8	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Moore Creek	0.0	0.2	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	-	-	~ 0%	≤ WQG	-	0	0
Todhunter Creek	2.0	2.0	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Other reference tribs	3.8	3.8	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Off-Channel Habitats																
FRus - off-channel	0.0	0.0	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	-	-	~ 0%	≤ WQG	-	0	0
FR1 - off-channel, mainstem WQ	1.0	1.0	no	1.9	355	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR2 - off-channel, mainstem WQ	0.2	1.1	no	11.9	456	~ 7%	< L1	~ 4%	< L1	~ 4%	< L1	~ 1%	< L1	1	1	1
FR3 - off-channel, mainstem WQ	0.0	0.1	no	11.6	566	~ 4%	< L1	~ 2%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
FR3b - off-channel, mainstem WQ	0.3	1.2	no	11.3	563	~ 4%	< L1	~ 2%	< L1	~ 2%	< L1	~ 1%	< L1	1	1	1
FR4 - off-channel, mainstem WQ	1.6	6.4	no	11.0	494	~ 5%	< L1	~ 3%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
FR1 - off-channel, intermediate WQ	1.0	1.0	no	0.9	255	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR2 - off-channel, intermediate WQ	0.2	1.1	no	5.9	305	~ 3%	< L1	~ 2%	< L1	~ 2%	< L1	~ 1%	< L1	1	1	1
FR3 - off-channel, intermediate WQ	0.0	0.1	no	5.8	360	~ 2%	< L1	~ 2%	< L1	~ 2%	< L1	~ 0%	< L1	1	1	1
FR3b - off-channel, intermediate WQ	0.3	1.2	no	5.7	358	~ 2%	< L1	~ 1%	< L1	~ 1%	< L1	~ 0%	< L1	1	1	1
FR4 - off-channel, intermediate WQ	1.6	6.4	no	5.5	324	~ 2%	< L1	~ 2%	< L1	~ 2%	< L1	~ 0%	< L1	1	1	1
FR1 - off-channel, reference WQ	1.0	1.0	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR2 - off-channel, reference WQ	0.2	1.1	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR3 - off-channel, reference WQ	0.0	0.1	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR3b - off-channel, reference WQ	0.3	1.2	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
FR4 - off-channel, reference WQ	1.6	6.4	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Fording Oxbow	3.3	3.3	no	11.0	494	~ 5%	< L1	~ 3%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
	135.9	159.5				~ 3%		~ 2%		~ 2%		~ 0%				

Assessment of potential effects related to Nitrate

		Standard Hardness	Pooled slope
Management unit	2	360	1.0003
Time period	2023		
Concentration at Order Station	11		
Applicable Order Station	FR5		
Hardness Condition - yearly min (yearly) or min from month when peak occurs (r	min monthly		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Nitrate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints				Fish Endpoints		Amphibian Endpoints		Integrated Potential Effects		
						Sensitive Species (*C. dubia*)	Sensitive Species (*C. dubia*) Category	Community (*H. azteca*)	Community (*H. azteca*) Category	Sensitive Species	Sensitive Species Category	Sensitive Species	Sensitive Species Category	Fish	Invertebrates	Amphibians
Fording River																
Upstream of Line Creek	37.3	37.3	no	11	494	~ 5%	< L1	~ 3%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
FR5 - Downstream of Line Creek	10.3	10.3	no	11	434	~ 6%	< L1	~ 3%	< L1	~ 4%	< L1	~ 1%	< L1	1	1	1
Tributaries																
Grace Creek	2.7	3.2	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Line Creek	8.4	8.4	no	5.5	434	~ 1%	< L1	~ 1%	< L1	~ 1%	< L1	~ 0%	< L1	1	1	1
South Line Creek	4.0	5.2	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Teepee Creek	1.5	1.5	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Unnamed tributaries	12.3	12.3	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Off-channel Habitats																
Fording River upstream of Line Creek - off-channel, mainstem WQ	0.4	1.3	no	15.1	494	~ 10%	< L1	~ 5%	< L1	~ 6%	< L1	~ 1%	< L1	1	1	1
Fording River downstream of Line Creek - off-channel, mainstem WQ	0.0	0.0														
Fording River upstream of Line Creek - off-channel, intermediate WQ	0.4	1.3	no	7.5	324	~ 5%	< L1	~ 3%	< L1	~ 3%	< L1	~ 1%	< L1	1	1	1
Fording River downstream of Line Creek - off-channel, intermediate WQ	0.0	0.0														
Fording River upstream of Line Creek - off-channel, reference WQ	0.4	1.3	no	0.04	154	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	~ 0%	≤ WQG	0	0	0
Fording River downstream of Line Creek - off-channel, reference WQ	0.0	0.0														
Overall	77.7	82.1	-	-	-	~ 3%		~ 2%		~ 2%		~ 0%		-	-	-

Assessment of potential effects related to Nitrate

		Standard Hardness	Pooled slope
Management unit	3	200	1.0003
Time period	2023		
Concentration at Order Station	3		
Applicable Order Station	ER1		
Hardness Condition - yearly min (yearly) or min from month when peak occurs (	min monthly		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Nitrate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints		Fish Endpoints	Amphibian Endpoints	Integrated Potential Effects		
						Sensitive Species (*C. dubia*) Category	Community (*H. azteca*) Category	Sensitive Species Category	Sensitive Species Category	Fish	Invertebrates	Amphibians
Elk River												
Upstream of GHO	149.8	149.8	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Downstream of GHO (ER1)	57.4	57.4	no	3.0	216	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Tributaries												
Aldridge Creek	3.7	8.6	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Bingay Creek	7.6	8.2	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Bleasdell Creek	1.9	4.3	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Boivin Creek	11.7	11.9	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Brûlé Creek	18.7	18.8	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Cadorna Creek	11.3	11.3	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Crossing Creek	0.0	2.4	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Forsyth Creek	11.9	13.8	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Gardner Creek	0.2	1.6	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Hornickel Creek	1.0	1.3	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Leask Creek	0.0	?	yes	-	-	-	-	-	-	-	-	-
Lowe Creek	2.1	2.6	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Mickelson Creek	0.0	0.8	no	0.04	154	≤ WQG	≤ WQG	-	≤ WQG	-	0	0
Osborne Creek	1.0	1.1	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Quarrie Creek	0.7	5.7	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Thompson Creek	1.3	1.3	no	7.6	494	L1-L2	< L1	< L1	< L1	1	2	1
Tobermory Creek	0.0	2.0	no	0.04	154	≤ WQG	≤ WQG	-	≤ WQG	-	0	0
Weary Creek	0.7	1.2	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Weigert Creek	10.0	10.0	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Wolfram Creek (No FA)	0.0	?	yes	-	-	-	-	-	-	-	-	-
Other named tribs	0.8	3.1	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Unnamed tribs	35.1	35.1	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Off-channel Habitats												
Elk River upstream of GHO - off-channel, mainstem WQ	0.0	0.0										
Elk River downstream of GHO - off-channel, mainstem WQ	0.8	2.9	no	3.0	216	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River upstream of GHO - off-channel, intermediate WQ	0.0	0.0										
Elk River downstream of GHO - off-channel, intermediate WQ	0.8	2.9	no	1.5	185	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River upstream of GHO - off-channel, reference WQ	0.0	0.0										
Elk River downstream of GHO - off-channel, reference WQ	0.8	2.9	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Overall	329.1	360.9	-	-	-	-	-	-	-	-	-	-

Assessment of potential effects related to Nitrate

		Standard Hardness	Pooled slope
Management unit	4	200	1.0003
Time period	2023		
Concentration at Order Station	3		
Applicable Order Station	ER2		
Hardness Condition - yearly min (yearly) or min from month when peak occurs (	min monthly		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Nitrate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints		Fish Endpoints	Amphibian Endpoints	Integrated Potential Effects		
						Sensitive Species (*C. dubia*) Category	Community (*H. azteca*) Category	Sensitive Species Category	Sensitive Species Category	Fish	Invertebrates	Amphibians
Elk River												
Downstream of the Fording River to Confluence with Michel Creek (ER2)	41.4	41.4	no	3.0	320	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Michel Creek												
MC5 - Downstream of CMO	5.4	5.4	no	0.21	433	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
MC4 - Downstream of CMO PII	24.3	24.3	no	2.7	279	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
MC3 - Upstream of EVO	18.8	18.8	no	1.7	230	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
MC1 - Mouth	27.9	27.9	no	2.6	363	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Other Tributaries												
Alexander Creek	38.9	40.9	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Bodie Creek	0.0	0.5	yes	-	-	-	-	-	-	-	-	-
Bray Creek	0.1	1.3	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Carbon Creek	1.6	2.5	no	0.05	279	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Cummings Creek	17.9	18.4	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Dalzell Creek	1.0	1.0	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Erickson Creek	0.8	3.7	no	12.4	363	> L2	< L1	< L1	< L1	1	3	1
EVO Dry Creek	1.9	1.9	no	18.1	363	> L2	< L1	L1-L2	< L1	3	3	1
Fir Creek	0.9	1.1	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Gate Creek			yes	-	-	-	-	-	-	-	-	-
Grave Creek -reference	3.7	3.7	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Grave Creek - MI	5.1	5.1	no	2.5	271	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Harmer Creek -reference	1.1	1.1	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Harmer Creek -MI	6.6	6.6	no	3.9	271	L1-L2	< L1	< L1	< L1	1	2	1
Leach Creek	20.8	21.6	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Littlemoor Creek	1.0	1.1	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Marten Creek	2.4	3.7	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Nordstrum Creek	2.9	3.1	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Saw Mill Creek	0.6	0.6	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Six Mile Creek	0.7	0.7	no	0.09	271	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Snowslide Creek	0.5	0.5	no	0.06	279	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Telford Creek	0.6	2.0	no	0.03	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Wheeler Creek	5.1	6.7	no	37	279	> L2	> L2	> L2	L1-L2	5	5	4
Other named tribs	2.1	6.9	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Unnamed tribs	23.2	23.2	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Off-channel Habitats												
Elk River downstream of the Fording River - off-channel, mainstem WQ	1.5	4.7	no	3.0	320	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River downstream of the Fording River - off-channel, intermediate WQ	1.5	4.7	no	1.5	237	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River downstream of the Fording River - off-channel, reference WQ	1.5	4.7	no	0.04	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Overall	261.8	289.9	-	-	-	-	-	-	-	-	-	-

APPENDIX F

EVALUATION TABLES FOR SULPHATE IN THE ELK AND FORDING RIVERS

Assessment of potential effects related to Sulphate

Management unit	1
Time period	2034
Concentration at Order Station (predicted peak is 483 mg/L)	429
Applicable Order Station	FR4
Hardness Condition - yearly min (yearly) or min from month when peak occurs (r	min monthly

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Sulphate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	Applicable WQG value (mg/L)	Invertebrate Endpoints				Fish Endpoints		Amphibian Endpoints		Integrated Potential Effects		
							Sensitive Species (*C. dubia*) Approximate Effect Size	Sensitive Species Category (*C. dubia*)	Community (*C. triangulifer*) Approximate Effect Size	Community Category (*C. triangulifer*)	Sensitive Species Approximate Effect Size	Sensitive Species Category	Sensitive Species Approximate Effect Size	Sensitive Species Category	Fish	Invertebrates	Amphibians
FRus - Fording River upstream of FRO	5.9	5.9	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
FR1 - Fording River downstream of Henretta Creek	10.3	10.3	no	455	665	429	~ 5%	< L1	~ 3%	< L1	~ 8%	< L1	~ 8%	< L1	1	1	1
FR2 - Fording River downstream of Clode Creek and upstream of Kilmarnock Creek	4.4	4.4	no	468	671	429	~ 6%	< L1	~ 3%	< L1	~ 9%	< L1	~ 8%	< L1	1	1	1
FR3 - Fording River between Swift and Cataract creeks	9.8	9.8	no	620	879	429	~ 12%	< L1	~ 7%	< L1	~ 16%	L1-L2	~ 13%	L1-L2	3	1	3
FR3b - Fording River downstream of Porter Creek	46.8	46.8	no	610	869	429	~ 11%	< L1	~ 7%	< L1	~ 16%	L1-L2	~ 13%	L1-L2	3	1	3
FR4 - Fording River downstream of Greenhills Creek	9.1	9.1	no	429	699	429	~ 5%	< L1	~ 2%	< L1	~ 7%	< L1	~ 7%	< L1	1	1	1
Tributaries																	
Henretta Creek - upstream FRO	1.8	1.9	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Henretta Creek - Lower	2.7	2.7	no	196	665	429	~ 1%	< WQG	~ 0%	< WQG	~ 1%	< WQG	~ 1%	< WQG	0	0	0
Clode Creek	0.0	0.0	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lake Mountain Creek (LM1)	0.0	0.0	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kilmarnock Creek	0.0	1.3	no	620	879	429	~ 12%	< L1	~ 7%	< L1	-	L1-L2	~ 13%	L1-L2	-	1	3
Swift Creek	0.0	0.3	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cataract Creek	0.0	0.0	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Porter Creek	0.3	0.3	no	1070	869	429	~ 36%	> L2	~ 30%	> L2	~ 44%	> L2	~ 32%	> L2	5	5	5
Dry Creek	8.4	8.4	no	19	699	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Greenhills Creek	2.4	2.4	no	1128	699	429	~ 40%	> L2	~ 33%	> L2	~ 47%	> L2	~ 34%	> L2	5	5	5
Chauncey Creek	8.0	8.3	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Ewin Creek	3.9	5.6	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Ewin Side Draw	2.9	3.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
McQuarrie Creek	0.7	0.8	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Moore Creek	0.0	0.2	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	-	< WQG	~ 0%	< WQG	-	0	0
Todhunter Creek	2.0	2.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Other reference tribs	3.8	3.8	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
FRus - off-channel	0.0	0.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	-	< WQG	~ 0%	< WQG	-	0	0
FR1 - off-channel, mainstem WQ	1.0	1.0	no	455	665	429	~ 5%	< L1	~ 3%	< L1	~ 8%	< L1	~ 8%	< L1	1	1	1
FR2 - off-channel, mainstem WQ	0.2	1.1	no	468	671	429	~ 6%	< L1	~ 3%	< L1	~ 9%	< L1	~ 8%	< L1	1	1	1
FR3 - off-channel, mainstem WQ	0.0	0.1	no	620	879	429	~ 12%	< L1	~ 7%	< L1	~ 16%	L1-L2	~ 13%	L1-L2	3	1	3
FR3b - off-channel, mainstem WQ	0.3	1.2	no	610	869	429	~ 11%	< L1	~ 7%	< L1	~ 16%	L1-L2	~ 13%	L1-L2	3	1	3
FR4 - off-channel, mainstem WQ	1.6	6.4	no	429	699	429	~ 5%	< L1	~ 2%	< L1	~ 7%	< L1	~ 7%	< L1	1	1	1
FR1 - off-channel, intermediate WQ	1.0	1.0	no	237	409	429	~ 1%	< WQG	~ 0%	< WQG	~ 2%	< WQG	~ 2%	< WQG	0	0	0
FR2 - off-channel, intermediate WQ	0.2	1.1	no	244	413	429	~ 1%	< WQG	~ 0%	< WQG	~ 2%	< WQG	~ 2%	< WQG	0	0	0
FR3 - off-channel, intermediate WQ	0.0	0.1	no	319	516	429	~ 2%	< WQG	~ 1%	< WQG	~ 3%	< WQG	~ 4%	< WQG	0	0	0
FR3b - off-channel, intermediate WQ	0.3	1.2	no	315	512	429	~ 2%	< WQG	~ 1%	< WQG	~ 3%	< WQG	~ 4%	< WQG	0	0	0
FR4 - off-channel, intermediate WQ	1.6	6.4	no	224	427	429	~ 1%	< WQG	~ 0%	< WQG	~ 1%	< WQG	~ 2%	< WQG	0	0	0
FR1 - off-channel, reference WQ	1.0	1.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
FR2 - off-channel, reference WQ	0.2	1.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
FR3 - off-channel, reference WQ	0.0	0.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
FR3b - off-channel, reference WQ	0.3	1.2	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
FR4 - off-channel, reference WQ	1.6	6.4	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Fording Oxbow	3.3	3.3	no	429	699	429	~ 5%	< L1	~ 2%	< L1	~ 7%	< L1	~ 7%	< L1	1	1	1
	135.9	159.5	-	-		-	~ 7%		~ 4%		~ 9%		~ 8%				

Assessment of potential effects related to Sulphate

Management unit	2
Time period	2034
Concentration at Order Station (predicted peak is 383 mg/L)	383
Applicable Order Station	FR5
Hardness Condition - yearly min (yearly) or min from month when peak occurs	min monthly

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Sulphate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	WQG for Specified Hardness (mg/L SO_4)	Invertebrate Endpoints				Fish Endpoints		Amphibian Endpoints		Integrated Potential Effects		
							Sensitive Species (*C. dubia*) Approximate Effect Size	Sensitive Species Category (*C. dubia*)	Community (*C. triangulifer*) Approximate Effect Size	Community Category (*C. triangulifer*)	Sensitive Species Approximate Effect Size	Sensitive Species Category	Sensitive Species Approximate Effect Size	Sensitive Species Category	Fish	Invertebrates	Amphibians
Fording River																	
Upstream Line Creek	37.3	37.3	no	429	699	429	~ 5%	< L1	~ 2%	< L1	~ 7%	< L1	~ 7%	< L1	1	1	1
Downstream of Line Creek	10.3	10.3	no	383	602	429	~ 4%	< WQG	~ 2%	< WQG	~ 5%	< WQG	~ 5%	< WQG	0	0	0
Tributaries																	
Grace Creek	2.7	3.2	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Line Creek	8.4	8.4	no	259	602	429	~ 1%	< WQG	~ 0%	< WQG	~ 2%	< WQG	~ 2%	< WQG	0	0	0
South Line Creek	4.0	5.2	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Teepee Creek	1.5	1.5	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Unnamed tribs	12.3	12.3	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Off-channel Habitats																	
Fording River upstream of Line Creek - off-channel, mainstem WQ	0.4	1.3	no	429	699	429	~ 5%	< L1	~ 2%	< L1	~ 7%	< L1	~ 7%	< L1	1	1	1
Fording River downstream of Line Creek - off-channel, mainstem WQ	0.0	0.0															
Fording River upstream of Line Creek - off-channel, intermediate WQ	0.4	1.3	no	224	427	429	~ 1%	< WQG	~ 0%	< WQG	~ 1%	< WQG	~ 2%	< WQG	0	0	0
Fording River downstream of Line Creek - off-channel, intermediate WQ	0.0	0.0															
Fording River upstream of Line Creek - off-channel, reference WQ	0.4	1.3	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Fording River downstream of Line Creek - off-channel, reference WQ	0.0	0.0															
Overall	77.7	82.1	-	-		-	~ 3%		~ 1%		~ 4%		~ 4%				

Assessment of potential effects related to Sulphate

Management unit	3
Time period	2034
Concentration at Order Station (predicted peak is 68 mg/L)	68
Applicable Order Station	ER1
Hardness Condition - yearly min (yearly) or min from month when peak occurs	min monthly

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Sulphate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	WQG for Specified Hardness (mg/L SO_4)	Invertebrate Endpoints				Fish Endpoints		Amphibian Endpoints		Integrated Potential Effects		
							Sensitive Species (*C. dubia*) Approximate Effect Size	Sensitive Species Category (*C. dubia*)	Community (*C. triangulifer*) Approximate Effect Size	Community Category (*C. triangulifer*)	Sensitive Species Approximate Effect Size	Sensitive Species Category	Sensitive Species Approximate Effect Size	Sensitive Species Category	Fish	Invertebrates	Amphibians
Elk River																	
Upstream of GHO	149.8	149.8	no	18	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Downstream of GHO (ER1)	57.4	57.4	no	68	200	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Tributaries																	
Aldridge Creek	3.7	8.6	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Bingay Creek	7.6	8.2	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Bleasdell Creek	1.9	4.3	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Boivin Creek	11.7	11.9	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Brûlé Creek	18.7	18.8	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Cadorna Creek	11.3	11.3	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Crossing Creek	0.0	2.4	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Forsyth Creek	11.9	13.8	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Gardner Creek	0.2	1.6	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Hornickel Creek	1.0	1.3	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Leask Creek	0.0	?	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lowe Creek	2.1	2.6	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Mickelson Creek	0.0	0.8	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	-	< WQG	~ 0%	< WQG	-	0	0
Osborne Creek	1.0	1.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Quarrie Creek	0.7	5.7	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Thompson Creek	1.3	1.3	no	2219	699	429	~ 80%	> L2	~ 80%	> L2	~ 83%	> L2	~ 68%	> L2	5	5	5
Tobermory Creek	0.0	2.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	-	< WQG	~ 0%	< WQG	-	0	0
Weary Creek	0.7	1.2	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Weigert Creek	10.0	10.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Wolfram Creek	0.0	?	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other named tribs	0.8	3.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Unnamed tribs	35.1	35.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Off-channel Habitats																	
Elk River upstream of GHO - off-channel, mainstem WQ	0.0	0.0	no														
Elk River downstream of GHO - off-channel, mainstem WQ	0.8	2.9	no	68	200	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Elk River upstream of GHO - off-channel, intermediate WQ	0.0	0.0	no														
Elk River downstream of GHO - off-channel, intermediate WQ	0.8	2.9	no	44	177	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Elk River upstream of GHO - off-channel, reference WQ	0.0	0.0	no														
Elk River downstream of GHO - off-channel, reference WQ	0.8	2.9	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Overall	329.1	360.9					~ 0%		~ 0%		~ 0%		~ 0%				

Assessment of potential effects related to Sulphate

Management unit	4
Time period	2034
Concentration at Order Station (predicted peak is 179 mg/L)	179
Applicable Order Station	ER2
Hardness Condition - yearly min (yearly) or min from month when peak occurs	min monthly

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Sulphate Concentration (mg/L)	Hardness (mg/L as $CaCO_3$)	WQG for Specified Hardness (mg/L SO_4)	Invertebrate Endpoints				Fish Endpoints		Amphibian Endpoints		Integrated Potential Effects		
							Sensitive Species (*C. dubia*) Approximate Effect Size	Sensitive Species Category (*C. dubia*)	Community (*C. triangulifer*) Approximate Effect Size	Community Category (*C. triangulifer*)	Sensitive Species Approximate Effect Size	Sensitive Species Category	Sensitive Species Approximate Effect Size	Sensitive Species Category	Fish	Invertebrates	Amphibians
Elk River																	
Downstream of the Fording River to Confluence with Michel Creek (ER2)	41.4	41.4	no	179	326	429	~ 0%	< WQG	~ 0%	< WQG	~ 1%	< WQG	~ 1%	< WQG	0	0	0
Michel Creek																	
MC5 - Downstream of CMO	5.4	5.4	no	338	538	429	~ 3%	< WQG	~ 1%	< WQG	~ 4%	< WQG	~ 4%	< WQG	0	0	0
MC4 - Downstream of CMO PII	24.3	24.3	no	155	338	429	~ 0%	< WQG	~ 0%	< WQG	~ 1%	< WQG	~ 1%	< WQG	0	0	0
MC3 - Upstream of EVO	18.8	18.8	no	107	269	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
MC1 - Mouth	27.9	27.9	no	272	466	429	~ 1%	< WQG	~ 1%	< WQG	~ 2%	< WQG	~ 3%	< WQG	0	0	0
Other Tributaries																	
Alexander Creek	38.9	40.9	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Bodie Creek	0.0	0.5	yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bray Creek	0.1	1.3	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Carbon Creek	1.6	2.5	no	6	338	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Cummings Creek	17.9	18.4	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Dalzell Creek	1.0	1.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Erickson Creek	0.8	3.7	no	1206	466	429	~ 44%	> L2	~ 38%	> L2	~ 52%	> L2	~ 37%	> L2	5	5	5
EVO Dry Creek	1.9	1.9	no	1523	466	429	~ 60%	> L2	~ 56%	> L2	~ 66%	> L2	~ 49%	> L2	5	5	5
Fir Creek	0.9	1.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Gate Creek			yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Grave Creek -reference	3.7	3.7	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Grave Creek - MI	5.1	5.1	no	249	294	429	~ 1%	< WQG	~ 0%	< WQG	~ 2%	< WQG	~ 2%	< WQG	0	0	0
Harmer Creek -reference	1.1	1.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Harmer Creek -MI	6.6	6.6	no	362	294	429	~ 3%	< WQG	~ 1%	< WQG	~ 5%	< WQG	~ 5%	< WQG	0	0	0
Leach Creek	20.8	21.6	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Littlemoor Creek	1.0	1.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Marten Creek	2.4	3.7	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Nordstrum Creek	2.9	3.1	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Saw Mill Creek	0.6	0.6	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Six Mile Creek	0.7	0.7	no	83	294	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Snowslide Creek	0.5	0.5	no	6	338	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Telford Creek	0.6	2.0	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Wheeler Creek	5.1	6.7	no	123	338	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 1%	< WQG	0	0	0
Other named tribs	2.1	6.9	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Unnamed tribs	23.2	23.2	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Off-channel Habitats																	
Elk River downstream of the Fording River - off-channel, mainstem WQ	1.5	4.7	no	179	326	429	~ 0%	< WQG	~ 0%	< WQG	~ 1%	< WQG	~ 1%	< WQG	0	0	0
Elk River downstream of the Fording River - off-channel, intermediate WQ	1.5	4.7	no	99	240	429	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Elk River downstream of the Fording River - off-channel, reference WQ	1.5	4.7	no	19	154	309	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	~ 0%	< WQG	0	0	0
Overall	261.8	289.9					~ 1%		~ 1%		~ 1%		~ 1%				

APPENDIX G

EVALUATION TABLES FOR CADMIUM IN THE ELK AND FORDING RIVERS

Assessment of potential effects related to Cadmium

		Standard Hardness	Pooled slope
Management unit	1	160	0.83
Time period (model snapshot)	2034		
Concentration at Order Station (max predicted is 0.041 ug/L)	0.041		
Applicable Order Station	FR4		
Hardness	Annual min		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Cadmium Concentration (ug/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints		Fish Endpoints	Amphibian Endpoints	Integrated Potential Effects		
						Sensitive Species (*D. magna*) Category	Community (SSD HC_5) Category	Sensitive Species Category	Sensitive Species Category	Fish	Invertebrates	Amphibians
Fording River												
FRus - Fording River upstream of FRO	5.9	5.9	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR1 - Fording River downstream of Henretta Creek	10.3	10.3	no	0.041	274	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR2 - Fording River downstream of Clode Creek and upstream of Kilmarnock Creek	4.4	4.4	no	0.132	340	< L1	< L1	< L1	< L1	1	1	1
FR3 - Fording River between Swift and Cataract creeks	9.8	9.8	no	0.156	376	< L1	< L1	< L1	< L1	1	1	1
FR3b - Fording River downstream of Porter Creek	46.8	46.8	no	0.099	370	< L1	< L1	< L1	< L1	1	1	1
FR4 - Fording River downstream of Greenhills Creek	9.1	9.1	no	0.041	285	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Tributaries												
Henretta Creek - upstream FRO	1.8	1.9	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Henretta Creek - Lower	2.7	2.7	no	0.032	274	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Clode Creek	0.0	0.0	yes	-	-	-	-	-	-	-	-	-
Lake Mountain Creek (LM1)	0.0	0.0	yes	-	-	-	-	-	-	-	-	-
Kilmarnock Creek	0.0	1.3	no	0.655	376	< L1	< L1	-	< L1	-	1	1
Swift Creek	0.0	0.3	yes	-	-	-	-	-	-	-	-	-
Cataract Creek	0.0	0.0	yes	-	-	-	-	-	-	-	-	-
Porter Creek	0.3	0.3	no	0.023	370	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Dry Creek	8.4	8.4	no	0.250	285	< L1	< L1	< L1	< L1	1	1	1
Greenhills Creek	2.4	2.4	no	0.195	285	< L1	< L1	< L1	< L1	1	1	1
Chauncey Creek	8.0	8.3	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Ewin Creek	3.9	5.6	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Ewin Side Draw	2.9	3.0	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
McQuarrie Creek	0.7	0.8	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Moore Creek	0.0	0.2	no	0.022	154	≤ WQG	≤ WQG	-	≤ WQG	-	0	0
Todhunter Creek	2.0	2.0	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Other reference tribs	3.8	3.8	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Off-Channel Habitats												
FRus - off-channel	0.0	0.0	no	0.022	154	≤ WQG	≤ WQG	-	≤ WQG	-	0	0
FR1 - off-channel, mainstem WQ	1.0	1.0	no	0.041	274	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR2 - off-channel, mainstem WQ	0.2	1.1	no	0.132	340	< L1	< L1	< L1	< L1	1	1	1
FR3 - off-channel, mainstem WQ	0.0	0.1	no	0.156	376	< L1	< L1	< L1	< L1	1	1	1
FR3b - off-channel, mainstem WQ	0.3	1.2	no	0.099	370	< L1	< L1	< L1	< L1	1	1	1
FR4 - off-channel, mainstem WQ	1.6	6.4	no	0.041	285	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR1 - off-channel, intermediate WQ	1.0	1.0	no	0.032	214	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR2 - off-channel, intermediate WQ	0.2	1.1	no	0.077	247	< L1	< L1	< L1	< L1	1	1	1
FR3 - off-channel, intermediate WQ	0.0	0.1	no	0.089	265	< L1	< L1	< L1	< L1	1	1	1
FR3b - off-channel, intermediate WQ	0.3	1.2	no	0.060	262	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR4 - off-channel, intermediate WQ	1.6	6.4	no	0.032	220	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR1 - off-channel, reference WQ	1.0	1.0	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR2 - off-channel, reference WQ	0.2	1.1	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR3 - off-channel, reference WQ	0.0	0.1	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR3b - off-channel, reference WQ	0.3	1.2	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR4 - off-channel, reference WQ	1.6	6.4	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Fording Oxbow	3.3	3.3	no	0.041	285	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
	135.9	159.5								-	-	-

Assessment of potential effects related to Cadmium

		Standard Hardness	Pooled slope
Management unit	2	160	0.83
Time period (model snapshot)	2034		
Concentration at Order Station (max predicted is 0.059 ug/L)	0.059		
Applicable Order Station	FR5		
Hardness	Annual min		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Cadmium Concentration (ug/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints		Fish Endpoints	Amphibian Endpoints	Integrated Potential Effects		
						Sensitive Species (*D. magna*) Category	Community (SSD HC_5) Category	Sensitive Species Category	Sensitive Species Category	Fish	Invertebrates	Amphibians
Fording River												
Upstream of Line Creek	37.3	37.3	no	0.041	285	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
FR5 - Downstream of Line Creek	10.3	10.3	no	0.059	272	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Tributaries												
Grace Creek	2.7	3.2	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Line Creek	8.4	8.4	no	0.200	272	< L1	< L1	< L1	< L1	1	1	1
South Line Creek	4.0	5.2	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Teepee Creek	1.5	1.5	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Unnamed tributaries	12.3	12.3	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Off-channel Habitats												
Fording River upstream of Line Creek - off-channel, mainstem WQ	0.4	1.3	no	0.041	285	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Fording River downstream of Line Creek - off-channel, mainstem WQ	0.0	0.0										
Fording River upstream of Line Creek - off-channel, intermediate WQ	0.4	1.3	no	0.031	220	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Fording River downstream of Line Creek - off-channel, intermediate WQ	0.0	0.0										
Fording River upstream of Line Creek - off-channel, reference WQ	0.4	1.3	no	0.022	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Fording River downstream of Line Creek - off-channel, reference WQ	0.0	0.0										
Overall	77.7	82.1										

Assessment of potential effects related to Cadmium

		Standard Hardness	Pooled slope
Management unit	3	160	0.83
Time period (model snapshot)	2034		
Concentration at Order Station (max predicted is 0.011 ug/L)	0.011		
Applicable Order Station	ER1		
Hardness	Annual min		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Cadmium Concentration (ug/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints		Fish Endpoints	Amphibian Endpoints	Integrated Potential Effects		
						Sensitive Species (*D. magna*) Category	Community (SSD HC_5) Category	Sensitive Species Category	Sensitive Species Category	Fish	Invertebrates	Amphibians
Elk River												
Upstream of GHO	149.8	149.8	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Downstream of GHO (ER1)	57.4	57.4	no	0.011	167	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Tributaries												
Aldridge Creek	3.7	8.6	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Bingay Creek	7.6	8.2	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Bleasdell Creek	1.9	4.3	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Boivin Creek	11.7	11.9	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Brûlé Creek	18.7	18.8	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Cadorna Creek	11.3	11.3	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Crossing Creek	0.0	2.4	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Forsyth Creek	11.9	13.8	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Gardner Creek	0.2	1.6	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Hornickel Creek	1.0	1.3	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Leask Creek	0	0	yes	-	-	-	-	-	-	-	-	-
Lowe Creek	2.1	2.6	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Mickelson Creek	0.0	0.8	no	0.010	154	≤ WQG	≤ WQG	-	≤ WQG	-	0	0
Osborne Creek	1.0	1.1	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Quarrie Creek	0.7	5.7	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Thompson Creek	1.3	1.3	no	0.037	285	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Tobermory Creek	0.0	2.0	no	0.010	154	≤ WQG	≤ WQG	-	≤ WQG	-	0	0
Weary Creek	0.7	1.2	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Weigert Creek	10.0	10.0	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Wolfram Creek (No FA)	0	0	yes	-	-	-	-	-	-	-	-	-
Other named tribs	0.8	3.1	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Unnamed tribs	35.1	35.1	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Off-channel Habitats												
Elk River upstream of GHO - off-channel, mainstem WQ	0.0	0.0										
Elk River downstream of GHO - off-channel, mainstem WQ	0.8	2.9	no	0.011	167	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River upstream of GHO - off-channel, intermediate WQ	0.0	0.0										
Elk River downstream of GHO - off-channel, intermediate WQ	0.8	2.9	no	0.011	161	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River upstream of GHO - off-channel, reference WQ	0.0	0.0										
Elk River downstream of GHO - off-channel, reference WQ	0.8	2.9	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Overall	329.1	360.9	-	-	-	-	-	-	-	-	-	-

Assessment of potential effects related to Cadmium

		Standard Hardness	Pooled slope
Management unit	4	160	0.83
Time period (model snapshot)	2034		
Concentration at Order Station (max predicted is 0.027 ug/L)	0.027		
Applicable Order Station	ER2		
Hardness	Annual min		

Habitat Sub-unit	Fish Accessible Habitat (ha)	Total Habitat (ha)	Physical or Flow-related Loss of Habitat	Cadmium Concentration (ug/L)	Hardness (mg/L as $CaCO_3$)	Invertebrate Endpoints		Fish Endpoints	Amphibian Endpoints	Integrated Potential Effects		
						Sensitive Species (*D. magna*) Category	Community (SSD HC_5) Category	Sensitive Species Category	Sensitive Species Category	Fish	Invertebrates	Amphibians
Elk River												
Downstream of the Fording River to the confluence of Michel Creek (ER2)	41.4	41.4	no	0.027	203	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Michel Creek												
MC5 - Downstream of CMO	5.4	5.4	no	0.110	234	< L1	< L1	< L1	< L1	1	1	1
MC4 - Downstream of CMO PII	24.3	24.3	no	0.070	194	< L1	< L1	< L1	< L1	1	1	1
MC3 - Upstream of EVO	18.8	18.8	no	0.030	178	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
MC1 - Mouth	27.9	27.9	no	0.041	211	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Other Tributaries												
Alexander Creek	38.9	40.9	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Bodie Creek	0.0	0.5	yes	-	-	-	-	-	-	-	-	-
Bray Creek	0.1	1.3	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Carbon Creek	1.6	2.5	no	0.248	194	< L1	< L1	< L1	< L1	1	1	1
Cummings Creek	17.9	18.4	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Dalzell Creek	1.0	1.0	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Erickson Creek	0.8	3.7	no	0.077	211	< L1	< L1	< L1	< L1	1	1	1
EVO Dry Creek	1.9	1.9	no	0.083	211	< L1	< L1	< L1	< L1	1	1	1
Fir Creek	0.9	1.1	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Gate Creek			yes	-	-	-	-	-	-	-	-	-
Grave Creek -reference	3.7	3.7	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Grave Creek - MI	5.1	5.1	no	0.022	205	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Harmer Creek -reference	1.1	1.1	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Harmer Creek -MI	6.6	6.6	no	0.032	205	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Leach Creek	20.8	21.6	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Littlemoor Creek	1.0	1.1	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Marten Creek	2.4	3.7	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Nordstrum Creek	2.9	3.1	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Saw Mill Creek	0.6	0.6	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Six Mile Creek	0.7	0.7	no	0.015	205	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Snowslide Creek	0.5	0.5	no	0.092	194	< L1	< L1	< L1	< L1	1	1	1
Telford Creek	0.6	2.0	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Wheeler Creek	5.1	6.7	no	0.670	194	> L1	< L1	< L1	< L1	1	3	1
Other named tribs	2.1	6.9	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Unnamed tribs	23.2	23.2	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Off-channel Habitats												
Elk River downstream of the Fording River - off-channel, mainstem WQ	1.5	4.7	no	0.027	203	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River downstream of the Fording River - off-channel, intermediate WQ	1.5	4.7	no	0.019	179	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Elk River downstream of the Fording River - off-channel, reference WQ	1.5	4.7	no	0.010	154	≤ WQG	≤ WQG	≤ WQG	≤ WQG	0	0	0
Overall	261.8	289.9	-	-	-	-	-	-	-	-	-	-

APPENDIX H

EVALUATION OF THE TOXICOLOGICAL INTERACTIONS OF MIXTURES OF SULPHATE, NITRATE, SELENIUM AND CADMIUM

Nautilus Environmental

Evaluation of the toxicological interactions of mixtures of sulphate, nitrate, selenium and cadmium

Final Report

Report date: 14 July 2014

Submitted to:

Golder Associates
Burnaby, BC

Nautilus Environmental
8664 Commerce Court
Burnaby, BC
V5A 4N7

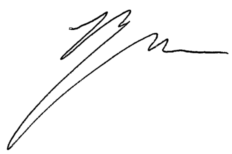
TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

SIGNATURE PAGE



James Elphick, RPBio.
Environmental Toxicologist

1.0 SUMMARY

In response to Ministerial Order M113, Teck Coal Ltd. (Teck) is developing an Area Based Management Plan for the Elk Valley, referred to as the Elk Valley Water Quality Plan (the Plan). The Plan is to include site-specific water quality targets for sulphate, nitrate, cadmium and selenium, and an assessment of potential interactive effects among the four constituents when all are present at target levels. This report reviews the available scientific literature and the results of site-specific testing relating to the toxicity of such mixtures. Collectively, site water samples showed no evidence of adverse interactions associated with mixtures of sulphate, nitrate, cadmium and selenium. At the concentrations considered for target development under the Plan, the four constituents appear to act independently with respect to toxicity. Provided that a mixture contains constituents of interest at concentrations that are each below their threshold for adverse effects, then an adverse effect is not expected in that mixture.

2.0 BACKGROUND INFORMATION

A common toxicological interaction relates to toxicity-modifying factors, whereby a water quality characteristic alters the toxicity of a constituent of interest. For example, water hardness is a toxicity-modifying factor for most divalent cationic metals (e.g., copper, cadmium and zinc), as well as some anions (e.g., sulphate, nitrate and chloride) (Elphick et al. 2011a; 2011b; Baker et al. 2012; BCMoE 2013), for which toxicity decreases as water hardness increases. In some cases, toxicity-modifying factors have exhibited a sufficiently consistent influence to be incorporated into BC water quality guidelines (WQGs), and in guidelines/criteria from other jurisdictions. For example, water hardness is included in BC WQGs for zinc, copper, cadmium, manganese, lead, sulphate and fluoride. Other toxicity-modifying factors in BC WQGs include pH for aluminum and ammonia, and chloride for nitrite.

The mechanism of effect of toxicity-modifying factors varies among constituents, but can generally be described by a combination of:

- chemical interactions (e.g., effects on chemical speciation of the toxicant or binding efficiency to ligands, resulting in an effect on bioavailability)
- physical interactions (e.g., effects on solubility of the material)
- biological interactions (e.g., effects associated with membrane permeability).

Responses are influenced by characteristics of water that, while toxicologically inert on their own, modify (most commonly, reduce) the toxicity of the constituent of interest.

When mixed, constituents may also interact in a manner that reduces or increases the toxicity of one or more of the constituents. Such outcomes are generally summarized as additive concentration addition, additive response addition, more than additive responses (synergism), and less than additive responses (antagonism), as summarized below:

1) Concentration addition (also referred to as dose addition) — Constituents with the same mechanisms-of-action cause a combined effect as though they were the same toxicant. This theory predicts that combinations of constituents, each present at concentrations below its toxic threshold, may combine (by summing of toxic units [TUs]) to cause a toxicological effect. TUs are calculated by dividing the concentration of the constituent by its effect concentration; thus, if an effect level for a constituent is 10 mg/L, and a mixture contains 5 mg/L, then the mixture will contain 0.5 TUs of that constituent.

2) Response addition (also referred to as independent action) — Constituents with different mechanisms-of-action (i.e., that act on different physiological systems or systems that are functionally independent) result in a combined response that is equivalent to the sum of the number of organisms that would be affected by the individual response of each constituent when exposed independently, less the number affected by both independently. For example, if a mixture contained two constituents at concentrations that cause an effect on 50% of organisms when exposed independently, the response addition model would predict that 25% of organisms would be affected by both toxicants, 25% of organisms would be affected by the first toxicant alone, 25% would be affected by the second toxicant alone, and 25% would be affected by neither toxicant. Thus, 75% of organisms would be predicted to be adversely affected in the mixture. Under these conditions, if none of the constituents of a mixture occur above a concentration that affects any individuals when present alone, then no adverse effect is expected from the mixture.

3) Synergism — The mixture of constituents exhibits a response that is greater than the combination of effects of the individual constituents, calculated on the basis of the assumptions of concentration addition or response addition. Some cases of synergism can be described as potentiation, in which the presence of a toxicologically inconsequential dose of one constituent produces a significant increase in the toxicity of another. Synergism (including potentiation) can occur, for example, as a result of one constituent in a mixture impairing the detoxification mechanism used for metabolic breakdown of another.

4) Antagonism — The mixture exhibits a response that is less than additive, in which the effect is less than the combination of effects of the individual components, calculated on the basis of the assumptions of concentration addition. A special case of antagonism occurs when the toxic response of all combined toxicants is lower than that associated with the single most toxic component. For example, the relationship between calcium and a number of metals, such as cadmium, would be considered to be antagonistic, since increasing water hardness results in a decrease in toxicity of cadmium.

The combined action of mixtures depends on the mechanism-of-action of the constituents, which is the molecular sequence of events from uptake of a dose to generation of an adverse effect, including uptake, transport, biotransformation (if any) and effect at the target tissue.

Investigations of the toxicity of mixtures have had a wide range of outcomes. A review of studies of metal mixtures by Norwood et al. (2003) indicated that less than additive, additive, and more than additive responses were reported in 43, 27, and 29% of cases, respectively. Thus, it is reasonable to anticipate that in most cases, combined activity is additive or less than additive. Far fewer studies have addressed the combined effects of metals with other materials such as sulphate, nitrate or selenium. Studies of these materials have tended to focus on water quality constituents that would be expected to act as toxicity-modifying factors, such as water hardness.

Mixture studies reported in the literature have generally involved binary mixtures or, at most, three of four constituents. Consequently, site-specific testing provides the most appropriate assessment of potential risk for adverse mixture effects.

3.0 MECHANISMS-OF-ACTION

To understand the potential toxicological consequences of mixtures, it is helpful to understand the mechanism-of-action of the constituents in the mixture. Mechanisms may differ among fish, invertebrates and plants, or between individual species. However, a general understanding of the likely mechanisms-of-action is helpful in evaluating ecological risk. In particular, it is helpful to identify cases where toxicants are thought to act in an identical manner, since this would indicate that dose addition is likely.

3.1 Sulphate

Sulphate represents a significant contributor to total dissolved solids (TDS) in most natural waters. Organisms actively regulate sulphate concentrations and use sulphur in a variety of biological processes and materials, including amino acids (methionine and cysteine).

The mechanisms-of-action of major ions has not been definitively shown; however, these effects from these ions are likely to exhibit adverse effects by either (1) contributing to osmotic pressure associated with overall ionic strength, leading to disruption of cellular osmo-regulatory function, or (2) by specific ion toxicity (Davies and Hall 2007). These authors concluded that the mechanism-of-action for sulphate is likely related to the interference of cell permeability, resulting in ion leaching from cells.

Freshwater species are most often osmoregulators, rather than osmoconformers as is often the case in marine species; osmoregulators actively maintain intracellular fluids at an osmolality that differs from the external environment. Hyperosmotic regulation (i.e., maintaining internal fluids that are higher in osmotic stress relative to the external environment) requires energy and, consequently, the exterior surfaces of freshwater organisms often comprise cells withlimited permeability. Osmoregulation typically occurs at the gill, although other organs are involved in some organisms (e.g., amphibians' skin) and/or life stages (e.g., chorion in fish eggs).

Hardness appears to be the most influential toxicity-modifying factor associated with sulphate. Increasing hardness reduces toxicity in a variety of species including *Hyalella azteca, Daphnia magna, Ceriodaphnia dubia, Pimephales promelas* and *Oncorhynchus mykiss* (Davies and Hall 2007; Soucek and Kennedy 2005; Elphick et al. 2011a; BCMoE 2013). However, hardness is a non-specific measure of the concentration of polyvalent cations in the water column. When *H. azteca* and *D. magna* were exposed to sulphate at a constant hardness of 100 mg/L as $CaCO_3$ and different Ca:Mg ratios of 0.7 and 7, the concentration associated with 50% mortality (i.e., the

LC50) increased from 2,101 to 2,725 mg/L, and from 3,203 to 4,395 mg/L, respectively (Davies and Hall 2007). This suggests that calcium plays a larger role than magnesium in modifying toxicity of sulphate. Increased hardness likely leads to greater calcium binding at cell binding sites, and reduced ion leaching from the gills of invertebrates and fish. The permeability of the cell membrane is stabilized by increased binding of calcium cations (Davies and Hall 2007; Soucek and Kennedy 2005).

Chloride also decreases sulphate toxicity (Soucek and Kennedy 2005). This is likely because chloride is a major anion that is actively transported across the membrane of the hemolymph in anthropods for osmoregulation. Chloride ions are important in maintaining osmotic equilibrium and decreasing membrane permeability.

In summary, when present at high concentrations, sulphate can interfere with osmoregulation by acting on the external membranes of osmoregulatory organs such as the gill. This effect is mitigated by changes in water hardness (in particular, calcium) and to a lesser extent, chloride.

3.2 Nitrate

The mechanism-of-action for toxicity of nitrate has not been definitively described; however, Camargo et al. (2005) concluded that it is likely as a result of conversion to nitrite in the enterohepatic metabolic system, which oxidizes the iron in oxygen-carrying blood pigments (e.g., hemoglobin and hemocyanin). Following oxidation, these pigments lose their oxygen-carrying capacity (e.g., through conversion to methaemoglobin); at higher effect levels, this can result in methaemoglobinemia. Although conversion of nitrate to nitrite is thought to be the dominant mechanism-of-action for nitrate toxicity, chronic exposures to nitrate may also be detrimental due to the conversion of nitrate to nitrosamines, which are potent mammalian carcinogens (Camargo et al. 2005).

Nitrate also appears to disrupt the endocrine system in some cases. Siberian sturgeon exposed to nitrate have displayed elevated concentrations of cortisol, glucose, estradiol, testosterone, and 11-ketotestosterone in their plasma (Hamlin et al. 2008). The mechanism for increased concentrations of plasma steroids was speculated to be either up-regulation of steriodogenic function, causing increased gonadal synthesis of sex hormones; or damage to transport proteins, which could alter nitrate transport to the liver (decreased detoxification). Alternatively, Hamlin et al. (2008) speculated that nitrate may impair liver function, which could reduce clearance of steroid hormones.

Nitrate contributes to the overall ionic strength of samples and, consequently, may contribute to osmoregulatory stress on freshwater organisms in high-TDS environments as a result of osmotic pressure. However, in general, nitrate is a small component of TDS in most water types, including in the Elk Valley. As such, the contribution of nitrate to overall ionic strength is low and this mechanism is unlikely to meaningfully influence the degree of toxicity in Elk Valley water samples.

Water hardness reduces nitrate toxicity in *C. dubia*, *P. promelas, H. azteca, O. mykiss,* and *S. namaycush* (Nautilus Environmental 2013; Baker et al. 2012). The underlying mechanism has not been determined, but may relate to effects of calcium on membrane permeability. It may also result from competitive interaction with anions associated with higher hardness waters (such as chloride, bicarbonate or sulphate), since any increase in water hardness must correspond to an equivalent increase in anions. Salinity has also been shown to be a toxicity-modifying factor (Tsai and Chen 2002; Lin and Chen 2003; Li et al. 2007; Kuhn et al. 2010).

In summary, the available data suggests that nitrate exhibits toxicological effects primarily through uptake into the organism and reduction to nitrite, which impairs oxygen-carrying capacity. Other mechanisms of toxicity may exist, but have not been determined. Toxicity of nitrate appears to be reduced by increasing ionic strength, likely either as a result of effects of calcium on membrane permeability, or competition from other anions.

3.3 Cadmium

Cadmium toxicity is typically associated with the dissolved divalent form Cd^{2+} (Pagenkopf 1983; Niyogi et al. 2004), which competes with calcium for binding sites in chloride cells of the gill (Wicklund-Glynn et al. 1994; Niyogi et al. 2004) and, following uptake, tends to accumulate in the kidney, liver and gill (Hollis et al. 1999, 2000a, 2000b).

The mechanism-of-action of cadmium may relate to interference of cellular calcium transport (i.e., disruption of physiological homeostasis and osmoregulation), and/or the production of reactive oxygen species (Stohs and Bagchi 1995; Pyle et al. 2003; Barata et al. 2007). Once bound, cadmium inhibits Ca^{2+}-adenosine triphosphate (ATP) transporters, blocking the uptake of Ca^{2+}. Cadmium can also elicit toxic effects on organisms through depletion of glutathione and protein-bound sulfhydryl groups, which produce reactive oxygen species such as hydrogen peroxide, superoxide ions and hydroxyl radicals. Reactive oxygen species can cause lipid peroxidation, damage DNA (deoxyribonucleic acid), and alter homeostasis of calcium and sulfhydryl within cells (Stohs and Bagchi 1995).

In fish, the liver is the main cadmium-detoxifying organ. It is also the primary organ that accumulates this metal. Cadmium concentrations in hepatic tissues appear to depend on water concentration and exposure period, although dietary exposure can also be a significant route (Chun-Min et al. 2010). Following exposure to cadmium, depuration from tissues typically occurs at the greatest rate from the gill, followed by the gut, and finally the liver. However, the gill appears to be the most sensitive (Chun-Min et al. 2010).

Water hardness is a primary toxicity-modifying factor for cadmium, likely due to competition resulting from increased concentrations of Ca^{2+} for Ca^{2+}-ATP transporters. This reduces cadmium binding and its effects on the disruption of calcium homeostasis. Dissolved organic carbon (DOC) is also an important factor in modifying the exposure and toxicity of cadmium, although to a lesser degree than it does for copper. This is likely due to cadmium having one-tenth of copper's binding affinity for DOC (Giesy et al. 1977; Winner 1984; Block and Part 1986). Finally, alkalinity and pH may also influence toxicity of cadmium.

In summary, although the mechanism of action of cadmium has not been definitively described, it appears to relate to binding to the gill, and interference with Ca-ATP transporters. Cadmium toxicity is influenced water quality characteristics, including water hardness, DOC, alkalinity and pH.

3.4 Selenium

Selenate and selenite are the two most common inorganic forms of selenium (Bailey et al. 2005). Selenate is more soluble than selenite and tends to dominate in neutral to alkaline oxic environments. Inorganic forms of selenium exhibit a relatively low degree of toxicity, and should not contribute directly to adverse effects on freshwater organisms. Adverse responses to selenium at higher trophic levels are generally associated with diet rather than contact with water.

Selenium is an essential element for most organisms; however, toxicity can occur when concentrations exceed those required for proper metabolic function. In fish, concentrations for proper functioning typically range from 0.1 to 0.5 mg Se/kg dry weight (dw) (Mayland 1994). It appears that the most sensitive toxic endpoint in birds and fish is the development of offspring (reproductive endpoint).

Selenium is typically incorporated into proteins either through non-specific incorporation of selenomethionine via selenium-specific binding proteins, or in enzymes that selectively incorporate selenium to form selenocysteine, commonly referred to as the 21st amino acid (Allan et al. 1999; Janz et al. 2010). Early studies postulated that substitution of seleno-amino acids for cysteine or methionine during protein synthesis may disrupt sulfur-sulfur bonds in the tertiary structure of polypeptides, resulting in improper folding of proteins, altered protein function and larval deformities such as edema and spinal curvatures (Diplock and Hoekstra 1976; Reddy and Massaro 1983; Sunde 1984; Maier and Knight 1994). More recently, the role of seleno-amino acids in production of reactive oxygen species has been identified as a more likely mechanism for adverse effects (Palace et al. 2004; Janz et al. 2010).

Speciation of selenium within cells is complex, and only certain forms are believed to produce oxidative stress. This stress is believed to be caused by cleavage of selenomethionine and selenocysteine in eggs to more reactive metabolites (e.g., methylselenol) (Janz et al. 2010).

Fish provide vitellogenin to their eggs as a nutrient during development, and this is cleaved in the egg to produce lipovitellin and phosvitin (Arukwe and Goksoyr 2003). Both proteins are sulphur-containing and thus have the potential for selenium substitution and subsequent exposure to the embryo. Species-specific variability in terms of timing and duration of vitellogenin accumulation in developing eggs can have significant influence on selenium exposure to offspring. Accumulation of selenium in the eggs is likely associated with vitellogenin accumulation, which occurs for months before spawning (Janz et al. 2010). Other differences in sensitivity of species likely relate to different reproductive physiologies, maternal transfer dynamics from diet or tissue to the eggs, and life history traits (Janz et al. 2010).

Toxicity-modifying factors for selenium can be broadly categorized into those that affect accumulation into the food-web, and those that alter the expression of accumulated selenium. Sulphate is the primary factor that alters uptake of selenate into the base of the food-web; these two anions are structurally similar and appear to compete for active uptake sites (Simmons and Wallschläger 2005).

Other exposure and toxicity-modifying factors associated with selenium include interactions with other trace metals, diet, ion concentrations, and temperature. Interactions with other trace metals (including cadmium) tend to decrease toxicity (Janz et al. 2010). For example, Lin et al. 2012 reported that selenium modified toxicity to cadmium in rice through its antioxidant properties, and through membrane stabilization due to competition with cadmium for ion channel uptake into the cell.

3.5 Summary of mechanisms-of-action

The review of mechanisms-of-action was conducted to identify whether there is evidence that suggests that any combination of sulphate, nitrate, cadmium and selenium acts on the same target organ and following the same toxicological process. If this had been the case, then dose addition might be anticipated to accur. In fact, the available information for the four toxicants is suggestive of different physiological pathways:

- Sulphate appears to act primarily on the iono-regulatory organs of freshwater organisms, such as the gill, and may either exert stress as a result of general osmoregulatory pressure in conjunction with other components of total dissolved solids, or result in ion loss.
- Nitrate may exhibit toxicity following uptake and conversion to nitrite, which then impairs oxygen-carrying capacity. It is possible that there are other mechanisms of toxicity of nitrate that are unrelated to oxygen-carrying capacity, but these have not been determined. As discussed in Section 3.2, the contribution of nitrate to overall ionic strength is low, such that nitrate does not contribute meaningfully to the osmotic pressure which may be important for sulphate toxicity.
- Cadmium appears to exhibit adverse effects primarily at the gill, as a result of binding to Ca-ATPase receptors in the chloride cells, but does not influence oxygen carrying capacity or otherwise impair respiratory function.
- Selenium produces adverse effects following dietary accumulation of seleno-amino acids into protein-rich tissues and, in particular, the yolk of egg-laying vertebrates, where oxidative stress can occur following mobilization of these materials during embryo-larval development.

Although mechanisms-of-action have not been definitively determined, particularly for sulphate and nitrate, the information presented above does not indicate that there is a high probability of an identical mechanism-of-action occurring.

Based on the available information, the mechanism-of-action of nitrate is distinct from the other three constituents, with the potential exception being that nitrate and sulphate are both anions and consequently can contribute to an osmotic pressure on freshwater organisms in high-TDS environments. Nitrate concentrations in the Elk Valley are lower than other TDS contributors such as sulphate, bicarbonate and calcium (Appendix A of Golder and Nautilus 2013). Thus, nitrate is not likely to be present at concentrations that would materially affect any impact of sulphate on organisms, and it appears reasonable to conclude that nitrate acts independently with respect to the other constituents.

The mechanism-of action of selenium is also distinct, both in terms of the uptake pathway and the expression of toxicity in protein-rich tissues. Selenium is expected to exhibit an adverse response independently of the other constituents.

Cadmium and sulphate both have a mechanism-of-action associated with disruption of osmoregulatory function at the surface of the gill. In the case of cadmium, this appears to be specific to Ca-ATPase receptor sites, which are not expected to have an affinity for sulphate because of differences in charge. Although there is a potential for these materials to act on the same organ, the mechanisms of toxicity differ. For example, respiratory capability and osmoregulation are two discrete functions that are performed by the gill.

Antagonism and synergism, involving a substantial deviation from additivity of effects of components in a mixture, are relatively uncommon, and the mechanisms of toxicity described above for the four constituents do not identify systems that might be expected to interact in this manner. Thus, there appears to be no reason to anticipate synergistic or antagonistic effect on the basis of the mechanisms described herein. The response addition model appears to be the most appropriate tool to assess the potential for adverse effects of mixtures of these constituents, rather than the concentration addition model, since there is no evidence that any of these materials would act in the same toxicological manner as one another. Consequently, mixture effects are not expected when each constituent is present below its threshold for adverse effects. Conversely, two or more constituents that are present at concentrations in excess of their effect thresholds might be expected to result in a combined response commensurate with the response addition model.

4.0 SITE-SPECIFIC INFORMATION ON MIXTURE TOXICITY

Three types of studies on waters from the Elk Valley provide information on mixture toxicity responses (Golder and Nautilus 2013; Golder 2014):

- Receiving water samples – Toxicity test data are available from unmodified samples collected directly from the receiving environment. These contained varying concentrations of sulphate, nitrate, selenium and cadmium, along with associated water quality characteristics including hardness.
- Targeted mixtures – Mixtures of selenium, sulphate, nitrate and cadmium were prepared for the purpose of evaluating potential interactive effects. This work was completed through chemical addition of multiple constituents simultaneously to samples.
- Concentration series – Sulphate and nitrate were added to site waters without amendment of other water quality constituents, other than the counter-ions required for addition of the anion into solution. The results provide an assessment of the toxicity of sulphate and nitrate in association with current concentrations of other constituents.

Key findings from these studies are outlined below.

4.1 Receiving water samples

Toxicity tests were conducted on samples from the Fording River in 2012, and from the Fording and Elk Rivers in 2013. Samples were tested as unmodified receiving water samples, and were evaluated for toxicity in conjunction with other exposures (e.g., those in which sulphate and nitrate were spiked into the test solutions). A variety of tests were conducted:

- Tests in January/February 2013 used water from Fording River Bridge (FR-B), and evaluated for toxicity using survival and reproduction of *C. dubia* (7 days' duration); embryo development of rainbow trout, *O. mykiss* (7 days); embryo-alevin development of rainbow trout (28-39 days); embryo-alevin development of lake trout, *S. namaycush* (68 days duration); growth of duckweed, *Lemna minor* (7 days); and growth of a green alga, *Pseudokirchneriella subcapitata* (3 days) (Golder and Nautilus 2013).
- Tests in September/October 2013 used water from the Fording River (two sampling locations [FR-4, FR-5]) and Elk River (three sampling locations for nitrate [ER-US, ER-2, ER-3], and evaluated for toxicity using *C. dubia* (7-day survival and reproduction test); *H. azteca* (14-day survival and growth test); fathead minnows, *P. promelas* (7-day survival and growth test); and rainbow trout, *O. mykiss* (7-day survival and growth test).

The results of these tests are summarized in Table 1, 2 and 3 for invertebrates, fish and plants/algae, respectively. The performance of the test organisms in the site waters are shown both as a percentage of the performance of the control treatments, and in comparison to the upstream reference location (i.e., ER-US), where applicable. The concentrations of nitrate, sulphate, cadmium and selenium are also shown.

For *C. dubia*, survival of the organisms was generally high in all tests and was within 10% of control and reference sample performance. Reproduction (at 8 days of exposure, following production of three broods) was not reduced relative to the control by >20%, and in no case did a sample have <90% of the reproduction observed in sample from the reference location. There did not appear to be evidence of collective adverse effects to *C. dubia*.

For *H. azteca*, survival and growth were lower than the laboratory control in the reference sample (ER-US), but generally within 20% of control performance of the remaining samples. These organisms' survival and growth rates appeared to increase with higher concentrations of ionic constituents. Performance was generally highest in the Fording River samples, lower in the downstream Elk River samples, and lowest in the reference site water; this pattern likely reflects differences in an essential nutrient that is unrelated to concentrations of sulphate, nitrate, selenium or cadmium.

Rainbow trout and fathead minnow survival and growth were comparable to that observed in the controls and the upstream reference station. Sample FR-4 produced survival that was 67% of control performance on one occasion; however, the mortalities observed in this test were limited to one replicate which had no survival, compared with 100% survival in the other replicates , suggesting an anomaly unrelated to toxicological properties. Similarly, there was no evidence of adverse effects on duckweed (*L. minor*) or a unicellular green alga (*P. subcapitata*).

Collectively, site water samples showed no evidence of adverse effects associated with mixtures of sulphate, nitrate, cadmium and selenium. Samples from FR-B and FR-4 generally contained the highest concentrations of constituents; samples from FR-4 contained approximately 11 mg/L nitrate, 240 mg/L sulphate, 55 µg/L selenium and 480 mg/L as $CaCO_3$ hardness, and samples from FR-B contained approximately 14 mg/L nitrate, 180 mg/L sulphate, 46 µg/L selenium and 440 mg/L as $CaCO_3$ hardness. Cadmium was generally below detection (<0.05 µg/L) in the samples.

Table 1. Toxicity test results for unmodified site water samples using invertebrates.

Date		Percent of control performance		Percent of reference performance [1]		Total NO_3-N (mg/L)	Total SO_4 (mg/L)	Total Se (mg/L)	Total Cd (mg/L)	Hardness (mg/L as $CaCO_3$)
Ceriodaphnia		Survival	Repro.	Survival	Repro.					
24-Jan-13	FR-B	100%	106%	NT	NT	14.0	165	0.046	<0.00005	436
24-Jan-13	FR-B	111%	89%	NT	NT	14.0	179	0.046	<0.00005	436
29-Jan-13	FR-B	100%	115%	NT	NT	12.2	179	0.046	<0.00005	436
28-Feb-13	FR-B	89%	105%	NT	NT	13.4	172	0.047	<0.00005	442
26-Sep-13	ER-US	100%	75%	NA	NA	0.0	15.5	<0.001	<0.00005	161
26-Sep-13	ER-3	100%	102%	100%	148%	2.2	63	0.01	<0.00005	245
26-Sep-13	FR-4	111%	124%	100%	145%	10.7	244	0.056	<0.00005	485
26-Sep-13	FR-5	100%	77%	100%	99%	10.3	158	0.041	<0.00005	378
11-Oct-13	ER-US	100%	105%	NA	NA	0.0	16.9	<0.001	<0.00005	169
11-Oct-13	ER-2	100%	99%	100%	99%	3.3	70.9	0.013	<0.00005	252
11-Oct-13	ER-3	100%	101%	100%	96%	2.3	67.8	0.01	<0.00005	242
11-Oct-13	FR-4	100%	99%	100%	94%	10.8	241	0.054	<0.00005	473
11-Oct-13	FR-5	90%	93%	90%	90%	10.2	162	0.04	<0.00005	385
Hyalella		Survival	Growth	Survival	Growth					
26-Sep-13	ER-US	67%	62%	NA	NA	0.01	15.4	<0.001	<0.00005	161
26-Sep-13	ER-3	78%	133%	123%	175%	2.23	62.2	0.01	<0.00005	245
26-Sep-13	FR-4	89%	93%	135%	143%	10.7	228	0.056	<0.00005	485
26-Sep-13	FR-5	79%	97%	119%	160%	10.3	154	0.041	<0.00005	378
02-Oct-13	ER-US	86%	79%	NA	NA	0.155	16.5	<0.001	<0.00005	161
02-Oct-13	ER-2	85%	107%	95%	102%	3.23	69.3	0.0122	<0.00005	243
02-Oct-13	ER-3	89%	100%	100%	140%	1.7	58.4	0.0067	0.000098	206
02-Oct-13	FR-4	90%	67%	105%	76%	10	254	0.057	<0.00005	480
02-Oct-13	FR-5	98%	66%	100%	90%	9.38	154	0.0356	<0.00005	364

NT – not tested (a reference sample was not tested as part of this program)
NA – not applicable (these are the results for the reference sample)
1 - Performance relative to reference, rather than laboratory control, is considered to be the most appropriate comparison in these tests

Table 2. Toxicity test results for unmodified site water samples using fish.

Date		Percent of control performance		Percent of reference performance[1]		Total NO_3-N (mg/L)	Total SO_4 (mg/L)	Total Se (mg/L)	Total Cd (mg/L)	Hardness (mg/L as $CaCO_3$)
Rainbow trout		Embryo-alevin development								
16-Jan-13	FR-B	90%		NT	NT	13.8	182	0.047	<0.00005	436
		Embryo development								
24-Jan-13	FR-B	105%		NT	NT	14	179	0.046	<0.00005	436
		Fry survival	Growth	Survival	Growth					
03-Oct-13	ER-US	91%	91%	NA	NA	0.0227	17	<0.001	0.0001	161
03-Oct-13	ER-3	104%	104%	100%	108%	3.22	55.4	0.0067	<0.00005	206
03-Oct-13	FR-4	99%	99%	100%	106%	9.99	232	0.057	<0.00005	480
03-Oct-13	FR-5	109%	109%	100%	114%	9.51	148	0.0356	<0.00005	364
03-Oct-13	ER-US	91%	91%	NA	NA	0.05	16.5	<0.001	<0.00005	161
03-Oct-13	ER-2	97%	97%	100%	99%	3.45	69.3	0.0122	<0.00005	243
03-Oct-13	ER-3	97%	97%	100%	96%	1.66	58.4	0.0067	0.000098	206
03-Oct-13	FR-4	90%	90%	100%	94%	10.2	254	0.057	<0.00005	480
03-Oct-13	FR-5	93%	93%	90%	90%	9.43	154	0.0356	<0.00005	364
Fathead minnow		Larval survival	Growth	Survival	Growth					
26-Sep-13	ER-US	90%	95%	NA	NA	0.01	18.4	<0.001	<0.00005	161
26-Sep-13	ER-3	112%	103%	104%	87%	2.23	55.2	0.01	<0.00005	245
26-Sep-13	FR-4	86%	92%	93%	92%	10.7	238	0.056	<0.00005	485
26-Sep-13	FR-5	76%	85%	81%	78%	10.3	149	0.041	<0.00005	378
11-Oct-13	ER-US	93%	85%	NA	NA	0.04	16.9	<0.001	<0.00005	169
11-Oct-13	ER-2	100%	98%	107%	95%	3.36	70.9	0.013	<0.00005	252
11-Oct-13	ER-3	103%	93%	107%	101%	2.22	67.8	0.01	<0.00005	242
11-Oct-13	FR-4	67%	66%	71%	79%	11.2	241	0.054	<0.00005	473
11-Oct-13	FR-5	96%	93%	100%	102%	10.6	162	0.04	<0.00005	385

NT – not tested (a reference sample was not tested as part of this program)
NA – not applicable (these are the results for the reference sample)
1 - Performance relative to reference, rather than laboratory control, is considered to be the most appropriate comparison in these tests

Table 3. Toxicity test results for unmodified site water samples using a plant and an alga.

Date		Percent of control performance		Percent of reference performance [1]		Total NO_3-N (mg/L)	Total SO_4 (mg/L)	Total Se (mg/L)	Total Cd (mg/L)	Hardness (mg/L as $CaCO_3$)
Duckweed		# fronds	Weight							
24-Jan-13	FR-B	92%	99%	NT	NT	14	179	0.046	<0.00005	436
Algae		Cell density								
25-Jan-13	FR-B	228%		NT	NT	14	179	0.046	<0.00005	436

NT – not tested (a reference sample was not tested as part of this program)

4.2 Targeted mixtures

In the winter of 2012/2013, seven mixtures were tested for toxicity to evaluate the effects of combinations of nitrate, sulphate, cadmium and selenium. These constituents were added to the test solutions by spiking with sodium nitrate, calcium and magnesium sulphates, sodium selenate, and cadmium chloride, to achieve the pre-determined test concentrations. In most cases, the desired concentrations of the materials exceeded those that occur in the Elk Valley.

Mixture 1 was prepared using reconstituted laboratory water to achieve a balance comparable to major ions in the Fording River under low-flow conditions. The remaining six mixtures were created using samples collected close to the Fording River Bridge. Concentrations of nitrate, sulphate, selenium, cadmium, and hardness in the mixtures are shown in Table 4.

The following toxicity tests were conducted using Environment Canada methods:

- 7-day survival and reproduction of a cladoceran, *C. dubia*
- 7-day growth test using duckweed, *L. minor*
- 72-hour population growth test using a green alga, *P. subcapitata*
- 7-day embryo development test using rainbow trout, *O. mykiss*.

Results are presented in detail in Golder and Nautilus (2013), and are summarized in Table 4. Adverse effects were not generally observed in the mixtures using *L. minor, P. subcapitata* or *O. mykiss*, with the exception of small (14 to 20%) reductions in frond numbers of *L. minor*. In these instances, reductions in frond numbers did not correspond to a reduction in dry weight and, in fact, dry weight of the plants in these mixtures exceeded the control. Thus, mixtures containing up to 931 mg/L sulphate, 52.7 mg/L nitrate, 139 µg/L selenium and 0.08 µg/L total cadmium produced no adverse effects on growth of duckweed or algae, or on embryonic development of rainbow trout. Reduced reproduction was consistently observed for *C. dubia* in the mixtures.

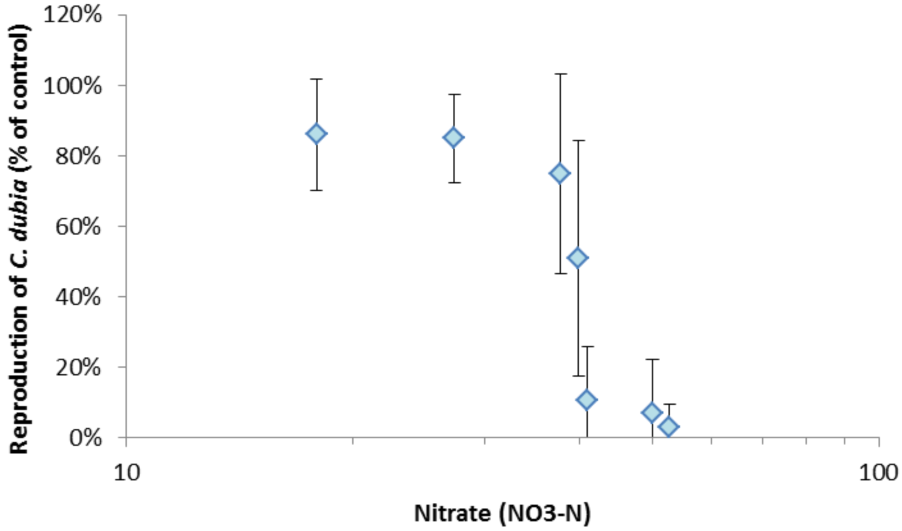
As discussed in Golder and Nautilus (2013), the effects observed with *C. dubia* were most likely attributable entirely to nitrate, without evidence of interactions with other components of the mixture. Figure 1 shows the reproduction of *C. dubia* as a function of nitrate concentrations in the mixtures; the pattern of effects seen here follow a classic sigmoidal dose-response, which is consistent with nitrate explaining the observed effect.

Table 4. Toxicity test results for mixtures spiked with nitrate, sulphate, selenium (selenate) and cadmium.

	Total mg/L	*C. dubia*	*L. minor*	*P. subcapitata*	*O. mykiss*
Mixture 1 – December 2012					
NO_3-N	17.9	12% reduction of reproduction	No effect	No effect	No effect
SO_4	468				
Se	0.0775				
Cd	0.00008				
Hardness, $CaCO_3$	512				
Mixture 2 – January 2013					
NO_3-N	41.0	89% reduction of reproduction	No effect on dry weight; 16% reduction in # of fronds	No effect	No effect
SO_4	931				
Se	0.139				
Cd	0.00007				
Hardness, $CaCO_3$	1200				
Mixture 3 – January 2013					
NO_3-N	50.0	93% reduction of reproduction	No effect on dry weight; 14% reduction in # of fronds	No effect	No effect
SO_4	440				
Se	0.079				
Cd	0.00006				
Hardness, $CaCO_3$	702				
Mixture 4 – January 2013					
NO_3-N	52.7	93% reduction of reproduction	No effect on dry weight; 20% reduction in # of fronds	No effect	No effect
SO_4	773				
Se	0.077				
Cd	0.00006				
Hardness, $CaCO_3$	1020				
Mixture 5 – February 2013					
NO_3-N	27.3	15% reduction of reproduction	Not tested	Not tested	Not tested
SO_4	934				
Se	0.112				
Cd	0.001				
Hardness, $CaCO_3$	1180				
Mixture 6 – February 2013					
NO_3-N	37.8	25% reduction of reproduction	Not tested	Not tested	Not tested
SO_4	455				
Se	0.047				
Cd	0.001				
Hardness, $CaCO_3$	696				
Mixture 7 – February 2013					
NO_3-N	39.9	51% reduction of reproduction	Not tested	Not tested	Not tested
SO_4	788				
Se	0.051				
Cd	0.001				
Hardness, $CaCO_3$	1050				

"No effect" is defined here as a response of <10% inhibition or effect relative to the negative control.

Figure 1. Reproduction of *C. dubia* (mean ± SD) in mixture tests shown as a function of nitrate concentrations (mg/L as N) in the mixtures.



4.3 Spiked water tests using concentration series

Toxicity tests were conducted on samples from the Fording and Elk Rivers in September and October 2013. Sulphate and nitrate were spiked into samples and evaluated for toxicity. Samples were tested using one upstream reference station on the Elk River (ER-US); two exposed stations on the Elk River (ER-2 and ER-3, although ER-2 was not tested using sulphate), and two stations on the Fording River (FR-4 and FR-5). The purpose of these tests was to establish point estimates associated with toxicity of sulphate and nitrate under water quality conditions associated with the Elk Valley (i.e., in the context of other constituents currently observed).

Tests conducted on these site water samples included:

- 7-day survival and reproduction of a cladoceran, *C. dubia*
- 14-day survival and growth of an amphipod, *H. azteca*
- 7-day survival and growth of swim-up rainbow trout fry, *O. mykiss*
- 7-day survival and growth of larval fathead minnows, *P. promelas*.

Results are presented in detail in Golder (2014), and summarized in Table 5. Concentrations of constituents of interest in the unmodified samples are shown in Tables 1 and 2.

Table 5. Point estimates for toxicity tests conducted using site water supplemented with sulphate and nitrate.

Species	Site water	Sulphate (mg/L)		Nitrate (mg/L as N)	
		IC20	IC50	IC20	IC50
***Ceriodaphnia* reproduction**					
	ER-US	>951	>951	4.9	19
	ER-2	Not tested	Not tested	5.1	23
	ER-3	>894	>894	7.2	37
	FR-4	>1165	>1165	16.6	41
	FR-5	>1030	>1030	17.2	37
***Hyalella* biomass**					
	ER-US	>947	>947	28	58
	ER-2	Not tested	Not tested	23	>62
	ER-3	>950	>950	29	55
	FR-4	>1150	>1150	13	>68
	FR-5	>1150	>1150	41	52
Fathead minnow biomass					
	ER-US	>973	>973	>59	>59
	ER-2	Not tested	Not tested	>61	>61
	ER-3	>948	>948	>60	>60
	FR-4	>1170	>1170	>68	>68
	FR-5	>1085	>1085	>67	>67
Rainbow trout growth					
	ER-US	>905	>905	>68	>68
	ER-2	Not tested	Not tested	>68	>68
	ER-3	>945	>945	>68	>68
	FR-4	>1140	>1140	>68	>68
	FR-5	>1050	>1050	>68	>68

Sulphate concentrations as high as 1030 to 1150 mg/L had no adverse effect on any of the four species when tested in site waters that contained up to approximately 10 mg/L nitrate and 50 µg/L selenium. These results contrast somewhat to test results for *C. dubia* presented in Golder and Nautilus (2013), in which IC20 values for sulphate of 595 and 840 mg/L were reported[1]. Regardless, the results from both studies indicated that 50% effect levels for this species were well over 1000 mg/L.

Nitrate concentrations as high as 68 mg/L had no adverse effect on survival and growth of rainbow trout and fathead minnows over the 7-day exposure period in water that also contained up to approximately 250 mg/L sulphate and 50 µg/L selenium (Golder 2014). Exposures of nitrate to *H. azteca* produced IC20 values from 13 to 41 mg/L NO_3-N, although there were differing growth rates of this species in individual unmodified water types, which was likely associated with differences in concentrations of essential nutrients. This makes it difficult to achieve a direct comparison of the effect levels of nitrate for this species at different sites.

C. dubia exhibited the highest degree of sensitivity to nitrate, with IC20 values ranging from 4.9 to 17.2 mg/L NO_3-N in five site waters from the Fording and Elk Rivers (Golder 2014). Of interest to an evaluation of the toxicity of mixtures is *C. dubia*'s sensitivity to nitrate was higher in the Elk River than the Fording River, which demonstrates that that the higher concentrations of sulphate, selenium and hardness in the Fording River did not act in an additive manner. Indeed, the opposite appears to be the case, since sensitivity to nitrate was lower in the Fording River, where influence from mining operations is highest. Thus, it is reasonable to conclude that sulphate and nitrate do not act in an additive manner when sulphate is below its threshold for toxicity.

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[1] The two results presented are for Fording River water (alkalinity 140 mg/L) and alkalinity-supplemented Fording River water (alkalinity 180 mg/L), respectively.

5.0 DISCUSSION

Although the mechanisms-of-action have not been determined definitively, it appears that the mechanisms-of-action associated with toxicity of sulphate, nitrate, selenium and cadmium are largely independent. Sulphate likely presents primarily an osmoregulatory challenge at external membranes of freshwater aquatic organisms, whereas effects associated with nitrate and inorganic selenium both appear to require uptake and transformation in the organism before exhibiting an adverse effect in internal tissues. Similar to sulphate, cadmium acts on osmoregulatory membranes such as the gill; however, unlike sulphate, the mode-of action of cadmium is believed to be associated with binding to Ca-ATPase binding sites. The differences in mode-of-action of these four materials suggest that they should not interact in a synergistic or antagonistic manner, and that the response-addition, rather than dose-addition, model is likely to describe their combined presence. Response addition predicts that multiple toxicants, each at a concentration lower than that associated with individual adverse response levels, should not combine in a manner that produces an adverse response.

The extent to which sulphate and nitrate act in an additive manner can be assessed on the basis of effect concentrations presented in Golder and Nautilus (2013), and on the test results summarized in Section 4.2. The data for *C. dubia* are particularly useful, since these organisms are among the most sensitive to both sulphate and nitrate. For example, the IC50 values reported for sulphate and nitrate in sample FR-B were 1315 and 37.8 mg/L, respectively. Mixture 7 contained 788 mg/L, or approximately 0.6 times the concentration necessary to cause an IC50 (0.6 IC50 toxic units), and 39.9 mg/L nitrate, which was approximately the same as the concentration necessary to cause an IC50 (1.0 IC50 toxic units). On the basis of a dose-addition model, this mixture contained 1.6 IC50 toxic units of sulphate and nitrate; however, the mixture caused only a 51% reduction in reproduction relative to the control, indicating that only 1.0 IC50 toxic units was expressed. The mixture thus elicited less toxicity than the dose-addition model would predict. When evaluated on the basis of response addition, the nitrate concentration is estimated to have elicited a 50% reduction in reproduction, and the sulphate concentration a reduction of ~20%. The response addition model would predict a combined effect of a 60% reduction in reproduction relative to the control[2], close to the 51% reduction observed.

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[2] Using the response addition model, the predicted effect resulting from a combination of two individual contaminants exerting a response of 50% and 20% respectively is calculated as: 50% + 20% - (50% x 20%) = 60% (i.e., an organism is only counted as affected once).

Effects associated with mixtures and, in particular, the relationship between sulphate and nitrate with respect to toxicity to *C. dubia*, was discussed in detail in Golder and Nautilus (2013). This study concluded that the level of observed effect could be explained by nitrate, with sulphate appearing to have no interaction with nitrate at concentrations as high as 750 to 800 mg/L.

Results shown in Section 4.3 for *C. dubia* (from Golder 2014) provide further evidence that sulphate and nitrate do not act in an additive manner according to the dose-addition model, since sensitivity to nitrate did not increase with increased sulphate when sulphate was below its threshold for adverse effects. Indeed, the opposite appeared to be the case, likely as a result of differences among samples in terms of other toxicity-modifying factors such as hardness.

This evaluation focuses on mixtures of sulphate, nitrate, selenium and cadmium, but information on hardness is also presented. Hardness is important because it reduces the toxicity of sulphate, nitrate and cadmium; however, it has also been identified as a water quality characteristic of potential concern when at high concentrations, because the ions associated with elevated hardness (in particular, calcium and magnesium) also contribute to the overall osmoregulatory challenge faced by aquatic organisms in high total-dissolved-solids environments. The results summarized here and evaluated in Golder (2014) indicate that elevated water hardness does not contribute to toxicity. For example, in spite of spiked water hardness levels of more than 1400 mg/L as $CaCO_3$ in site-specific tests conducted in fall 2013, in which calcium sulphate and magnesium sulphate was added to site waters, no adverse effects were observed up to the highest concentration tested. In addition, thresholds developed for sulphate should account for any contribution of hardness to ecological risk, since sulphate was introduced to the test water as calcium and magnesium salts. In other words, the assessment conducted for sulphate has accounted for the presence of hardness-causing cations.

The selenium exposures summarized here reflect an evaluation of the effect of inorganic water-borne selenium, rather than dietary accumulation of seleno-amino acids. No test was performed to determine an interaction between accumulated selenium and waterborne sulphate and nitrate. The effect of dietary uptake and maternal transfer of selenium was assessed separately using alternative approaches to standardized toxicity tests, since these are not well-suited to the evaluation of bioaccumulative substances. However, an interaction does not appear likely.

At the concentrations considered for target development, sulphate, nitrate, cadmium and selenium are expected to act independently with respect to toxicity, and the response addition model is most likely to explain the toxicological effects of mixtures of these constituents. Importantly, this model predicts that if a mixture contains constituents of interest at concentrations that are each below their threshold for adverse effects, then an adverse effect is not expected in that mixture. However, the additive effects of nitrate and sulphate, or other constituents, may occur at much higher concentrations if they each occur above their threshold for effects.

The conclusions of this report are drawn from site-specific toxicity testing conducted at exposure levels of constituents that are either representative of current conditions in the Fording and Elk rivers, or exceed those of current conditions through spiking of site waters with additional concentrations. Although it is possible that toxicity interactions may occur at higher concentrations than those tested in this program, such conditions are not relevant to the conditions contemplated in the Plan for target development. For example, the proposed target for sulphate in very high hardness waters is 429 mg/L; this concentration is well below the concentrations of 750-800 mg/L for which no interactions among constituents were observed.

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