Teck

Geochemical Source Term Methods and Inputs for the 2020 Update of the Elk Valley Regional Water Quality Model

Prepared for

Teck Coal Limited

Prepared by

srk consulting

SRK Consulting (Canada) Inc.
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List of Abbreviations

ABA	acid base accounting
AI	available inventory
ANFO	ammonia nitrate fuel oil
AP	acid potential
ARD	acid rock drainage
BRE	Baldy Ridge Extension
CCR	coarse coal rejects
CGMs	conceptual geochemical models
CMO	Coal Mountain Operations
COI	constituent of interest
CR	coal refuse
EAs	Environmental Assessments
EMPR	BC Ministry of Energy, Mines and Petroleum Resources
ENV	BC Ministry of Environment
EVCC	Elk Valley Coal Corporation
EVO	Elkview Operations
EVWQP	Elk Valley Water Quality Plan
FF	Fernie Formation
FRO	Fording River Operations
GHO	Greenhills Operations
HCTs	humidity cell tests
ICP-MS	inductively coupled plasma mass spectrometry
LCO	Line Creek Operations
MF	Morrissey Formation
ML	metal leaching
MMF	Mist Mountain Formation
MMM	Moose Mountain Member
MSRRR	metal to sulphate release rate ratios
NP	neutralization potential
NSRRR	nickel/sulphate release rate ratio
ORP	oxidation reduction potential
PAG	potentially acid generating
PI	potential inventory
PZC	point of zero charge
R&D	research and development
RWQM	Regional Water Quality Model
SFE	shake flask extraction
SMEs	subject matter experts
SOZs	Sub-oxic zones
SRFs	Saturated Rock Fills
WRM	Weary Ridge Member

1 Introduction

1.1 Context

Teck Coal Limited, as part of its overall water quality management program authorized under Environmental Management Act Permit 107517 and associated approvals, has the need to estimate future concentrations of constituents of interest in the Elk River watershed and its tributaries resulting from operation of its five coal mines; namely Fording River Operations (FRO), Greenhills Operations (GHO), Elkview Operations (EVO), Line Creek Operations (LCO) and Coal Mountain Operations (CMO). The RWQM is used to evaluate short (e.g., during operations) and longer term (e.g., closure) constituents in support of several studies (e.g., water treatment evaluations, permitting, new project EAs, etc.) Essential inputs into such estimation work are geochemical source terms for the chemical loadings into the water from mine facilities.

Beginning in 2010, SRK Consulting (Canada) Inc. developed geochemical source terms and methods as part of water quality projections for permit amendment activities related to expansion of mining at EVO into Baldy Ridge. The calculation method was subsequently updated and used to support Environmental Assessments (EAs) for the LCO Phase II and FRO Swift projects, and to support permit amendment applications for the GHO West Spoil project and EVO Baldy Ridge Extension (BRE). The source term methods were consolidated and applied in the Regional Water Quality Model (RWQM) to support development of the Elk Valley Water Quality Plan (SRK 2014a) and subsequently updated to incorporate the results of additional study as part of the 2017 (SRK 2017a) source term update.

The methods developed as part of the 2017 RWQM have been refined as a result of additional investigations by Teck, its university partners and consultants that have contributed since 2017 to support the 2020 update of the RWQM to meet requirements of provincial permits. This report includes all input assumptions and relationships used for the geochemical source terms and provides explanations of source term development and application.

Source terms are numerical representations of the weathering of geological materials disturbed by mining or by blasting of those materials using ammonium nitrate-based explosives (e.g., nitrate). The source terms and methodology used to develop them evolves as experience and data collection improve conceptualization of weathering and leaching mechanisms.

A core principle of the methodologies used to develop source terms is the use of regional (Elk Valley) full-scale operational data collected over many years that relies less on small-scale laboratory data and theoretical approaches (INAP 2009) that are often required for development of source terms where full-scale empirical data are limited. The latter assist with interpretation of full-scale data but are not the primary basis for the prediction methodologies. Application of data from different mining operations in the Elk Valley is supported by the consistency of bulk geochemical characteristics (acid rock drainage potential and trace element content of the coal-hosting rocks throughout the region (SRK 2014b, SRK 2014c, SRK 2015a, SRK 2015b, SRK 2015c, and SRK 2015d, SRK 2017b)).

1.2 Structure of this Document

This report is one of several technical reports included in the October 2020 submission to BC Ministry of Environment (ENV) and BC Ministry of Energy, Mines and Petroleum Resources (EMPR). Other supporting documents included in the submission are:

- The 2020 RWQM Update is documented in the 2020 Elk Valley Regional Water Quality Model Update Report (Teck 2020a), to which the supporting documents are attached.
- 2020 Elk Valley Regional Water Quality Model Update – Annex B – Hydrology Modelling (Teck 2020b), which describes the set-up and configuration of the flow model and the results of the calibration.
- 2020 Elk Valley Regional Water Quality Model Update – Annex C – Water Quality: Model Set-up and Calibration (Teck 2020c), which describes the set-up and configuration of the 2020 RWQM and the results of the calibration.
- 2020 Elk Valley Regional Water Quality Model Update – Annex D – Water Quality: Future Projections (Teck 2020d), which describes the future water quality conditions predicted by the model, taking into account planned mitigation.

This report includes the sections described below. The flow diagram shown in Figure 1 is provided in order to illustrate how the information in this report is linked together to support the derivation of source terms. Figure 1 highlights the dependency of the source term approach and derivation of source terms on the conceptual geochemical models. As a result, preceding sections of this report can be dependent on subsequent sections. For example, an approach is initially developed (Section 2), which may have to be modified based on the supporting evidence for the conceptual models developed in Section 4.

The information provided in each section follows:

- Section 2: background on the overall process to develop source terms including the collaborative process with others, and general concepts such as handling uncertainty.
- Section 3: relevant setting context (geology, geochemistry, climate, mining and processing methods, water quality).
- Section 4: conceptual geochemical models for each source building on the background and setting.
- Section 5: numerical implementation of the conceptual geochemical models.
- Section 6: input databases used to derive the inputs.
- Section 7: data processing steps to develop the source terms.
- Section 8 and 9: input source terms as well as some additional supporting evidence for the implementation methods.

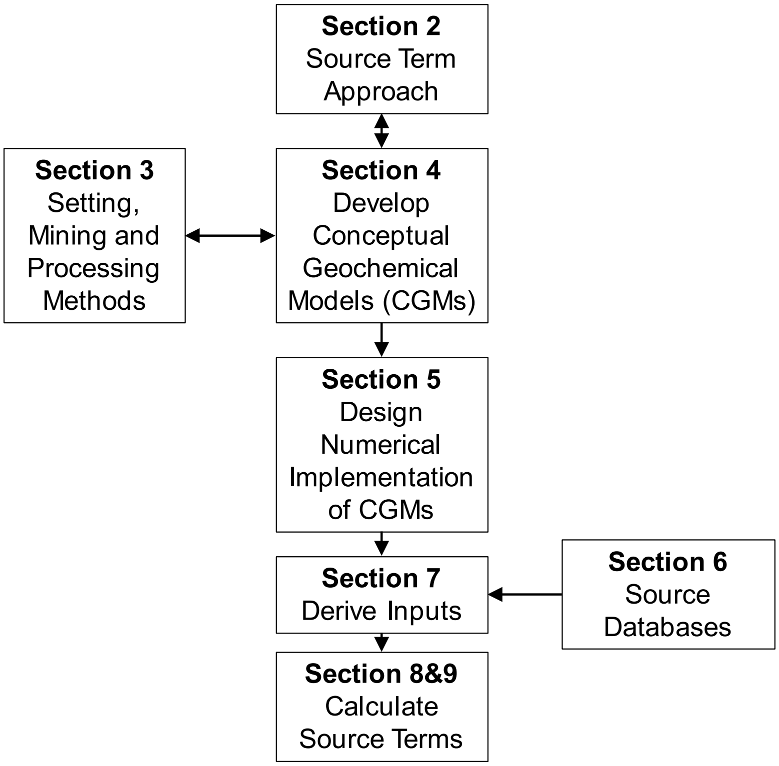

Figure 1. Flow Diagram for Derivation of Source Terms

1.3 Acknowledgements

This report has benefitted from the input and review of numerous individuals, including:

- Teck – Marko Adzic, Mark Digel, Nicolas Francoeur, Kirsten Gillespie, Jessica Mackie, Alexandra Wade
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- SRK – Lisa Barazzuol, Stephen Day, Laura Donkervoort, Michael Herrell, Daryl Hockley, Shannon Shaw
- Lorax Environmental – Alan Martin, Bruce Mattson, Justin Stockwell
- Golder Associates – JP Bechtold, Apurva Gollamudi, Dennis Kramer, Amanda Snow
- SNC Lavalin – Stefan Humphries
- Geochimica Inc. – Mark Logsdon

2 Geochemical Source Term Method Development Process

2.1 Background

Development of geochemical source-term methods for use as inputs to water quality models at various scales in the Elk Valley has occurred since the late 2000s. These methods are supported by evolving conceptual geochemical models (CGMs). The methods are mainly empirically based using inputs derived from interpretation of the extensive water quality monitoring data. The CGMs consider weathering and leaching mechanisms to ensure that the numerical source terms represent these mechanisms accordingly.

The primary early observation supporting the initial conceptual models was that selenium concentrations in the Elk River have been increasing in parallel with waste rock accumulation. This correlation implied that selenium release could be projected from the planned waste volumes generated by future mining operations. This understanding was consistent with the source of selenium as oxidation of sulphide minerals. Geochemical testing of waste rock from each of the operations also supported that release mechanisms were consistent throughout the Elk Valley with similar selenium content, among other parameters, within the dominant geological formation.

These basic observations remain as the underlying support for predictive models for selenium, sulphate and nitrate, and to a lesser degree metals such as cobalt, cadmium and nickel.

With each iteration of the source term and water quality model updates, Teck has aimed to refine the CGMs with targeted research and data collection to reduce uncertainties in the source terms and water quality model in a manner that is consistent with Teck’s Adaptive Management Plan (Teck 2018a). Refinements to the source term as part of each iteration have been developed through a continuous collaborative process starting in the late 2000s which at each stage resulted from learnings due to interpretation of information collected at Teck Coal’s operations, and experience at coal and other mines in B.C. and elsewhere. The chronology of source term development and major changes in methods that have occurred through 2020 are summarized in the following sections.

2.1.1 Pre-2014 Selenium-Specific Leaching Model

Elk Valley Coal Corporation (EVCC, a predecessor of Teck Coal) initiated development of a selenium leaching model as part of investigation of selenium management approaches with the Elk Valley Selenium Task Force, a joint industry-government group with representatives from the provincial and federal governments and Teck. This process led to an experimental design to understand the weathering and leaching characteristics of different types of waste materials at several scales (SRK 2008a,b). The design was implemented, and testing and monitoring proceeded over several years at LCO and GHO in the Elk Valley. A parallel study with the same components was started at Teck’s Cardinal River Operations near Hinton, AB.

The findings of these studies, notably monitored concentrations and loads over time at different test scales, resulted in support for the CGM describing selenium and sulphate leaching from waste rock and coarse coal rejects (SRK 2016a).

This understanding was an input into interpretation of the Elk Valley regional water quality database which resulted in source term methods for the EA of LCO's Phase 2 Project (SRK 2011). Nitrate predictions linked to leaching of explosives residuals were based on the Ferguson and Leask (1988) method which was developed by Environment Canada by interpreting drainage chemistry data from Elk Valley coal mines in the 1980s when cumulative waste quantities were much lower. Source terms for other regulated parameters such as trace metals were derived as fixed concentrations based on the data obtained for the selenium leaching method.

The LCO Phase 2 Project also included a methodology to project calcite precipitation downstream of waste rock dumps.

2.1.2 2014 Elk Valley Water Quality Plan

The source term methods developed for the LCO Phase 2 EA were updated to provide input into projections of Elk Valley water quality required for the Elk Valley Water Quality Plan (EVWQP) (SRK 2014a) developed in response to Ministry of Environment Order No. M113. Loadings for selenium and sulphate were linked to waste rock quantities, metal concentrations were evaluated using fixed source concentrations reflecting solubility limits, and the Ferguson and Leask (1988) method continued to be used to predict nitrate with an adaptation to allow for decay in concentrations after waste placement ended. Sulphate concentrations were linked to the solubility of gypsum, and selenium concentrations were assumed to be constrained by co-precipitation with gypsum. Methods were also included for several minor source terms including submerged waste rock, re-handled waste rock, pit walls, and coal rejects.

The conceptual model is based on the assumptions that source terms for similar facilities at the different operations would be the same (e.g. waste rock at LCO will behave the same as waste rock at FRO) because geochemical characteristics are relatively uniform in the rock formations. However, to calibrate modelled selenium and sulphate concentrations at downstream locations required large calibration factors to address differences in selenium loadings from individual catchments.

The focus of this model was on projecting selenium concentrations. Other parameters (nitrate and cadmium) were identified as needing improvement.

2.1.3 Developments Between 2014 to 2017

Research and Development

Between the 2014 Elk Valley Water Quality Plan and the 2017 RWQM update, and in parallel with the regulatory processes being followed to continue coal mining in the Elk Valley, Teck continued and expanded its applied watershed research and development programs. A critical component of this research and development (R&D) work was achievement of a better understanding of waste rock spoil hydrological processes. This work was conducted by the R&D team and has made extensive use of nitrate introduced by explosive residues as a tracer for hydrological processes. The major outcome of the research has been updates to the waste rock hydrology conceptual model that has informed the geochemical conceptual models for leaching of nitrate, selenium and sulphate.

Planning for Mitigation

The initial implementation plan in the EVWQP relied on active water treatment to meet the objectives of the EVWQP until other technologies can be developed. The need for improved understanding of nitrate release to support projections was identified due to the use of biological processes for treatment of selenium and the need to manage nitrate to meet nitrate compliance limits and site performance objectives. Biological treatment removes nitrate in parallel with removal of selenium. The Ferguson and Leask (1988) nitrate source term method had to be refined to align with the updated hydrology conceptual model to be used for this purpose.

Input into Environmental Assessments and Mines Act Permit Applications

There was variability in the geochemical characteristics of the rocks mined to access the coal seams at GHO and CMO, notably a proportion of the Morrissey Formation (MF) rock underlying the coal bearing formation with greater potential for ARD and leaching of trace metals such as cadmium and cobalt compared to the coal-hosting Mist Mountain Formation (MMF).

The source term methods used for Environmental Assessments and *Mines Act* Permit Amendment Applications were updated to reflect this finding (SRK 2015d).

2.1.4 Source Term Update for the 2017 Regional Water Quality Model

The 2017 source term update for the 2017 RWQM substantially refined and modified the methods used in 2014. The source term method for the 2017 update considered the same sources as the 2014 model and a major focus of the 2017 update was on subaerial waste rock due to the dominance of loading from this source to surface waters in the Elk Valley (Teck 2014a). Loading from other sources (e.g., backfilled waste rock, re-handled waste rock, coarse process rejects and tailings) was included in the water quality model and source terms were included in the 2017 update; however, these source term methods did not change except where new monitoring data informed updates based on the same methods.

The waste rock source term method had been progressively modified since the 2014 EVWQP water quality model to reflect longer monitoring records, updates to the conceptual models and understanding of the regional setting. The source term method added hydrological aspects of the updated conceptual model that reflect the delay in appearance of chemical loading due to travel time of infiltrating water and entrained chemical load. Based on concepts developed by the University of Saskatchewan (Kuzyk et al. 2014), the method used nitrate loading trends to indicate the delay in loading which was assumed to be a consistent delay for the release of all other parameters. The delay was reflected in a time factor referred to as “initial lag” (t_{IL}). In addition, a distribution parameter (referred to as the adjusted leach time, or t_{AL}) was developed to better represent the release of nitrate after the waste is placed. This parameter replaced the one-year delay time specified in the Ferguson and Leask (1998) method for arrival of nitrate load after waste placement.

In 2017, the change was made from a valley wide to tributary-specific source terms. This approach allowed the variability between catchments to be reflected in the source terms and reduced the need for calibration factors. Catchment specific factors were release rates for sulphate and selenium, proportion of MF in the waste rock, explosives usage (powder factors), explosives loss factors, and initial lag times. For areas not affected by mining, inputs from analogous catchments were used as predictive inputs.

The pit wall source term was refined to consider two formation types in the pit walls (MF and other formations) and two types of pit walls (benched highwalls, and non-benched footwalls).

Fixed source term concentrations for cadmium and cobalt were replaced with catchment-specific methods which considered the strong seasonal influence of co-precipitation with calcite in the downstream surface water environments.

2.1.5 Saturated Rock Fills (SRFs)

Teck has been advancing research on saturated rock fill technology beginning in 2015 as an alternative water treatment technology to treat selenium and nitrate. This has been a major focus of R&D activities. Pilot and full-scale trialing of the F2 SRF resulted in a source term method for the performance of SRFs which is ready for use in the 2020 RWQM.

2.1.6 Conceptual Model Refinement Process in 2018

In parallel with continued R&D activities and to prepare for the 2020 RWQM update, Teck initiated a systematic process with its own subject matter experts (SMEs), and specialists at the University of Saskatchewan and consulting companies to update the conceptual models for source terms in the Elk Valley. This process began in September 2018 and continued through November 2018 with nine focused meetings facilitated by leads (Table 1).

Table 1. Conceptual Model Refinement Meetings

Meeting	Date	Topic	Lead
1	12-Sep-18	NO_3 and Se Interactions	S Day (SRK)
2	26-Sep-18	Duration of Release	S Day (SRK)
3	3-Oct-18	Drainage Basin Histories	A Wade (Teck)
4	17-Oct-18	Infiltration and Load Reductions	T Birkham (OKC)
5	31-Oct-18	Early release, t_{IL}	S Shaw (SRK), J Hendry (USask)
6	7-Nov-18	Flow and Load Seasonal Distribution	JP Bechtold (Golder)
7	14-Nov-18	Hydrogeochemical Model	J Hendry (USask) and L Barbour (USask)
8	21-Nov-18	Se Attenuation in Spoils	J Hendry (USask)
9	28-Nov-18	Groundwater release pathway	L Barbour (USask)

Source: P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.200_CM_Meetings_Workshop\2018-12-12_Workshop\2.Lead_Table_input\[Compilation_of_CMIdeas_1CT017200_SJD_20181205.xlsx]

The process culminated in a workshop in December 2018 attended by 16 individuals from Teck, Golder Associates, Lorax Environmental, SRK Consulting, University of Saskatchewan and Wood at which 50 conceptual model refinements were reviewed to determine which were ready for incorporation in the 2020 RWQM update and which needed further study. The following aspects were considered ready for incorporation into the 2020 RWQM:

- Consideration of inventories of constituents of interest.
- In spoil transport processes related to water balance and seasonality.
- Initial flush of COIs.
- Decrease in weathering rates due to depletion of inventories.
- Consideration of the influence of groundwater and surface water pathways.
- Influence of calcite on downstream water quality.

Examples of some aspects which were not considered ready for full numerical implementation in the 2020 RWQM update were: specific mechanism to explain first flush, decrease in weathering rates due to depletion of inventories, effect of local sub-oxic zones in waste rock and co-disposed CCR, effect of long term breakdown of spoil on weathering, and selenium attenuation due to in-spoil and groundwater processes.

2.1.7 2020 RWQM Update

With the intent of moving towards a more mechanistic understanding of unsaturated waste rock release rates, the geochemical source terms for 2020 update have sought to constrain uncertainty in tributary-specific release rates to return to the concept of “valley-wide” release rates reflecting the consistent geochemical characteristics of waste rock and the similarities in waste rock dump construction methods. Calculation of release rates at the tributary scale considered the effect of local factors affecting release rates such as hydrological lag (t_{HL}), year-on-year flow variability, pit dewatering and partitioning of flow into surface and ground water. These interpretations have been supported by detailed tributary-specific site information, studies of new spoils at LCO Dry Creek (Lorax Environmental), understanding of local hydrological conditions (Golder Associates) and detailed groundwater studies (Golder Associates and SNC Lavalin).

These refinements are described in greater detail in Section 5.

2.2 Scope

The following source terms were developed for previous iterations of the RWQM and updated for the 2020 RWQM with site monitoring data collected over the past three years to include learnings from focused studies over the past three years:

- Unsaturated waste rock
- Submerged waste rock
- Pit wall runoff
- Coal rejects

- Coal rejects co-disposed with waste rock
- Tailings impoundments

A source term for re-handled waste rock was also developed in 2017. No new data was available to update this source term and the 2017 source term was maintained in 2020.

Much of the focus of the 2020 update was on refinement of the unsaturated waste rock source term as it is the dominant loading source to downstream catchments in the Elk Valley. A key objective of the 2020 update was to reduce uncertainty in the unsaturated waste rock source term at the catchment and valley-wide levels, to approach a valley-wide rather than catchment-specific source term method. This involved reconciling loads between the spoil and monitoring location to account for influences of improved tributary specific information on unsaturated waste rock source terms.

In addition to updates to the above source terms, the source terms for the following were introduced into the 2020 RWQM:

- Quantification of initial soluble load (i.e., load produced by weathering of waste rock prior to placement in the spoil);
- Inventories of constituents of interest (COIs);
- Inclusion of non-Order constituents (i.e., nickel, cobalt, ammonia, arsenic, chromium, manganese, nitrite, phosphorus and uranium); and
- Development of declining release rates.

The following surface water attenuation mechanisms were also included in the 2020 RWQM source term update:

- Adsorption and co-precipitation with calcite;
- Active saturated rock fills (active SRFs);
- Passive load reduction in backfilled pits (passive SRFs); and
- Tailings storage facilities.

This report focuses on developing source terms for the Order and non-Order constituents listed above. The 2020 RWQM model predicts concentrations for a more comprehensive list of constituents so the model can be used to evaluate changes to water quality from a full suite of parameters as part of future projects. Other constituents are assumed to have constant concentrations from each source. The constant concentration source terms developed for the Baldy Ridge Expansion remain current for these constituents. Derivation of these source terms is provided in Appendix A of this report.

2.3 Approach to Handling Uncertainty

Unsaturated waste rock is the largest loading source from the Elk Valley operations and therefore produces the largest degree of uncertainty in the RWQM projections. Evaluation of the bounds on the unsaturated waste rock source terms (release rates) was a focus for the 2020 RWQM update. The unsaturated waste rock source terms are derived based on site monitoring data (e.g., water quantity and quality monitoring results and waste rock volumes, placement history, etc.) and geochemical testing results, all of which have inherent variability and uncertainty. This uncertainty in the source term input data sets can be exacerbated during data processing (e.g., data gap filling) and combining several inputs to calculate the source term. To account for this in the source terms, unsaturated waste rock loading rates for average and 95% confidence limits were calculated. Sensitivity analyses were completed to evaluate the influence of variability in lag and groundwater bypass inputs on the source term outputs.

In previous updates of the RWQM, calibration factors were applied to the source terms to align predicted tributary concentrations to measured concentrations. For the 2020 update, if calibration factors resulted in a calibrated source term being outside the confidence limits, the reason for the degree of calibration was explored and modified as necessary.

Uncertainty in other source terms developed as part of this update (e.g., non-Order constituents, coarse coal rejects, etc.) is represented as follows:

- A central tendency case (or best estimate case) based on average statistics of data distributions for rates and concentrations; and
- Upper and lower bounds based on:
  - 95% upper and lower confidence limits on the mean when source terms are provided as rates, or
  - 5th and 95th percentiles of a data distribution when source terms are provided as concentrations.
- These bounds are intended to provide a range of possible variability.
- Specifics are described for each method in more detail in Section 5.

3 Setting of Coal Mining Operations in the Elk Valley

3.1 Geological Setting

Economically-recoverable coal in the Elk Valley occurs in the Mist Mountain Formation (MMF) of the Jurassic-Cretaceous Kootenay Group. The MMF conformably overlies the Morrissey Formation (MF) and is overlain by the Elk Formation. The MMF is comprised predominantly of non-marine sandstone, siltstone, mudstone, shale, and thin to thick bituminous coal seams and interbedded conglomeritic sandstone (Table 2).

Regionally, the paleo-environment of deposition was an easterly pro-grading coastline of the Fernie Sea with sediments being eroded from uplands to the west and deposited in deltaic and beach environments along the coast. The older Fernie Formation (FF) was deposited in a marine environment, whereas the younger MMF was dominantly non-marine. The depositional environment of the MF, which consists of the Moose Mountain Member (MMM) and Weary Ridge Member (WRM), has been debated (Gibson 1985), but the depositional environment is transitional from marine to non-marine. Gibson concluded that marine and non-marine environments in a beach-dune complex were probably present. It is unclear if diagenetic conditions in the MF were dominated by saltwater or freshwater, but the overall trend downward through the stratigraphy is towards increased marine influence. The MMM is a very competent distinctive sandstone known for being cliff-forming in the Elk Valley. The MMM grades downwards into the textually-finer WRM and into the FF.

Table 2. Regional Stratigraphy

Period	Litho-Stratigraphic Units			Principal Rock Types
Recent	-			colluvium
Quaternary	-			clay, silt, sand, gravel, cobbles
Lower Cretaceous	Blairmore Group			massive bedded sandstones and conglomerates
Lower Cretaceous to Upper Jurassic	Kootenay Group	Elk Formation		sandstone, siltstone, shale, mudstones, chert pebble conglomerate, minor coal
		Mist Mountain Formation		sandstone, siltstone, shale, mudstones, thick coal seams
		Morrissey Formation	Moose Mountain Member	medium to coarse-grained quartz-chert sandstone
			Weary Ridge Member	fine to coarse-grained, slight ferruginous quartz-chert sandstone
Jurassic	Fernie Formation			shale, siltstone, fine-grained sandstone
Triassic	Spray River Formation			sandy shale, shale quartzite
	Rocky Mountain Formation			quartzite
Mississippian	Rundle Group			limestone

Source: Gibson (1985)

Reactive minerals in Elk Valley rocks are sulphides (primarily pyrite and minor marcasite, sphalerite, chalcopyrite and arsenopyrite) and carbonate minerals (mainly dolomite with lesser calcite, ankerite and siderite). The main mineral in the rocks is quartz which is considered geochemically inert in this context. Other silicates are present and will generally require acidic conditions to contribute meaningful buffering capacity and to contribute significantly to pore water chemistry.

The reactive minerals typically occur in matrix of the rock, but pyrite may occur as a fracture filling. Minerals occurring the matrix of large blasted rock particles (cobbles and boulders) will be sheltered from oxidation until long term physical process result in exposure of the minerals to oxidation.

3.2 Geochemical Characteristics

3.2.1 Rock Composition

Geochemical characterization of mined materials in the Elk Valley has proceeded through several phases. Earlier work beginning in the late 1990s and continuing into the mid-2000s was performed jointly by the operators of the five mines (prior to consolidation under Teck Coal Limited), the University of British Columbia, and British Columbia Ministry of Energy Mines and Petroleum Resources (EMPR). This work was primarily focused on selenium content and leaching characteristics.

Geochemical characterization studies have been performed as part of the numerous Environmental Assessments and/or Mines Act Permit Amendment applications for all five Elk Valley Operations, Coal Mountain Phase 2 (CMO2) and as part of R&D projects. These studies have resulted in collection of mineralogical, and static and kinetic geochemical data for rock in the Elk Valley, and provided a comparative basis for assessment of rock at each operation (SRK 2004, SRK 2008a, SRK 2011, SRK 2012, SRK 2013, SRK 2014b, SRK 2014c, SRK 2014d, SRK 2015a, SRK 2015b, SRK 2015c, SRK 2015d, SRK 2016a, SRK 2016b, SRK 2016c, SRK 2018a, SRK 2018b, SRK 2018c). A summary of the results from these studies is provided in the subsections below.

Acid Rock Drainage Potential

The Mist Mountain Formation is the primary rock unit and exhibits consistent geochemical characteristics throughout the valley (Figure 2). Specifically, the MMF has negligible ARD potential due to low sulphur content (0.1%, primarily as pyrite) and the presence of abundant carbonate minerals (mainly calcite, dolomite and ankerite) that result in neutralization potential (NP) that more than offsets acid potential (AP). NP/AP is nearly always well above conventional thresholds for defining potentially acid generating (PAG) materials.

The upper part of the Morrissey Formation, the MMM, can be potentially ARD generating (PAG) within 20 m or less of the contact with the MMF (Figure 3). The MMM typically averages 0.3% sulphur as sulphide and pyrite is rarely visible. The 95th percentile concentrations are 0.8% sulphur as sulphide. The upper part of this formation also contains negligible carbonate. The

MMM data presented in Figure 3 includes all samples of the MMM. As a result, statistics also include the lower part of the MMM which is non-PAG and skews the NP/AP towards higher values. Laboratory and field kinetic tests on PAG MF rock confirm the rock generates acid and as a result Metal Leaching and Acid Rock Drainage Management Plans have been developed for all five Teck Coal Sites (Teck 2017, Teck 2018b, Teck 2018c, Teck 2019a, Teck 2019b).

The lower part of the Morrissey Formation, the WRM is non-PAG due to higher carbonate content compared to the upper part (Figure 4).

The MF is usually a minor component of the rock mined within the valley and is not expected to result in net acidic drainage from any of the waste spoil areas. The Fernie Formation which underlies the MF is non-PAG due to its carbonate content. Unlike the MF, FF is usually classified as non-PAG as it contains higher sulphur concentrations than MF (average 0.5%) but higher NP than the MMF (average valley-wide 130 kg$CaCO_3$/t compared to 82 kg$CaCO_3$/t) (Figure 5). The lower MF (WRM) also has higher NP than the upper MF. The presence of NP therefore distinguishes FF and WRM from the PAG components of the MF. Like the MF, the FF is a very low proportion of the waste rock.

Selenium

The main water quality concern related to weathering processes is the leaching of selenium, which originates from the oxidation of pyrite (Kennedy et al. 2012). Studies by provincial geologists (Ryan et al 2002), the University of BC (Lussier 2001), and consultants (Kennedy et al. 2012; SRK 2004, 2008a) showed that selenium concentrations are associated with specific rock types. Lowest concentrations of selenium and sulphur occur in sandstones (typically less than 2 mg/kg) and higher concentrations in mudstones (2 to 3 mg/kg). Concentrations in siltstones range between these values. Higher end selenium concentrations typically do not exceed 6 mg/kg (Figure 2). Comparison between sites indicates CMO has the lowest selenium concentrations compared to other sites (Figure 2). Comparisons between formations indicates selenium is lower compared to the MMF in the MMM, WRM and FF (Table 3).

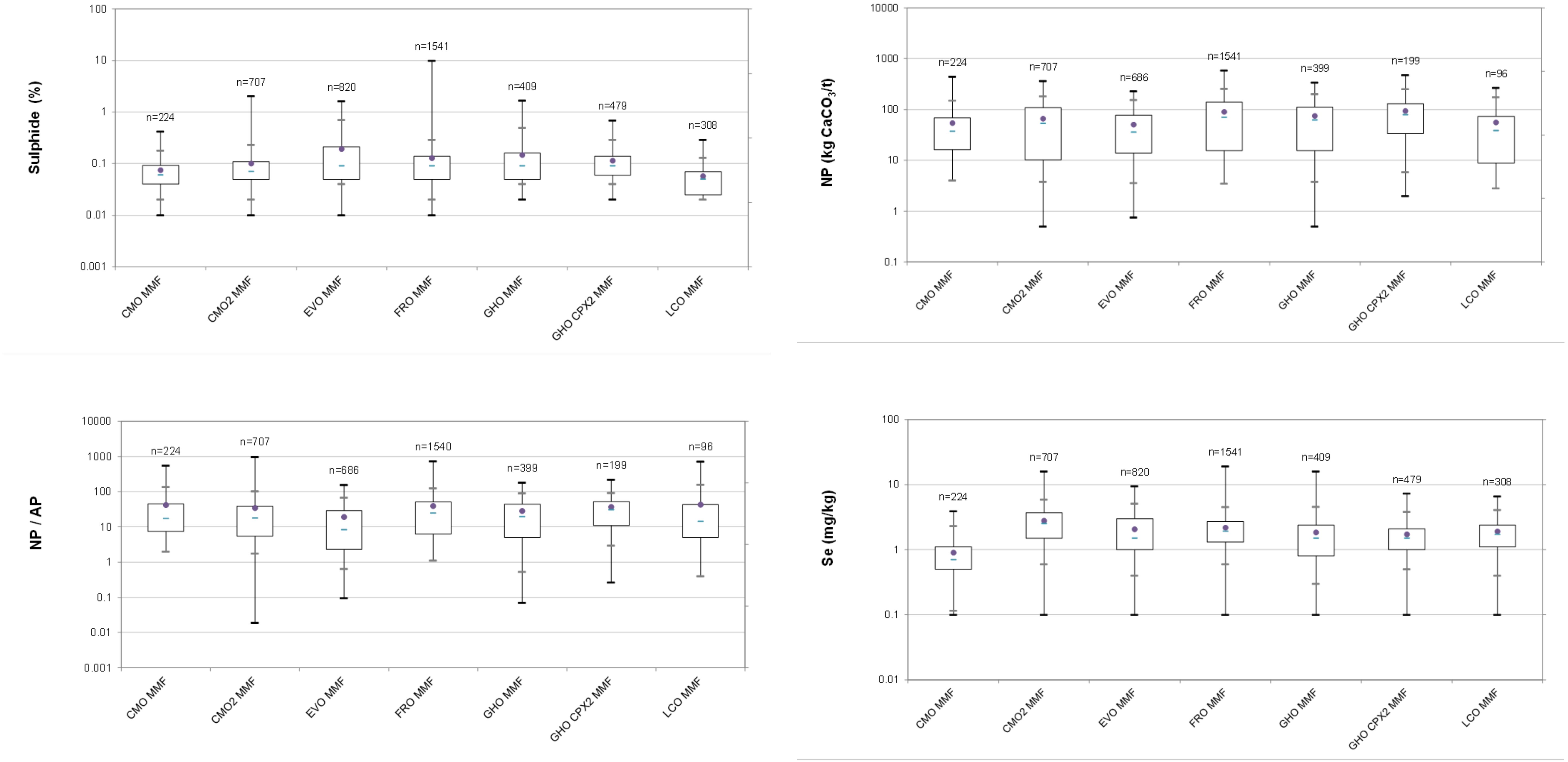

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Figure 2: Box and Whisker Plots of Key Parameters in the Mist Mountain Formation (MMF)

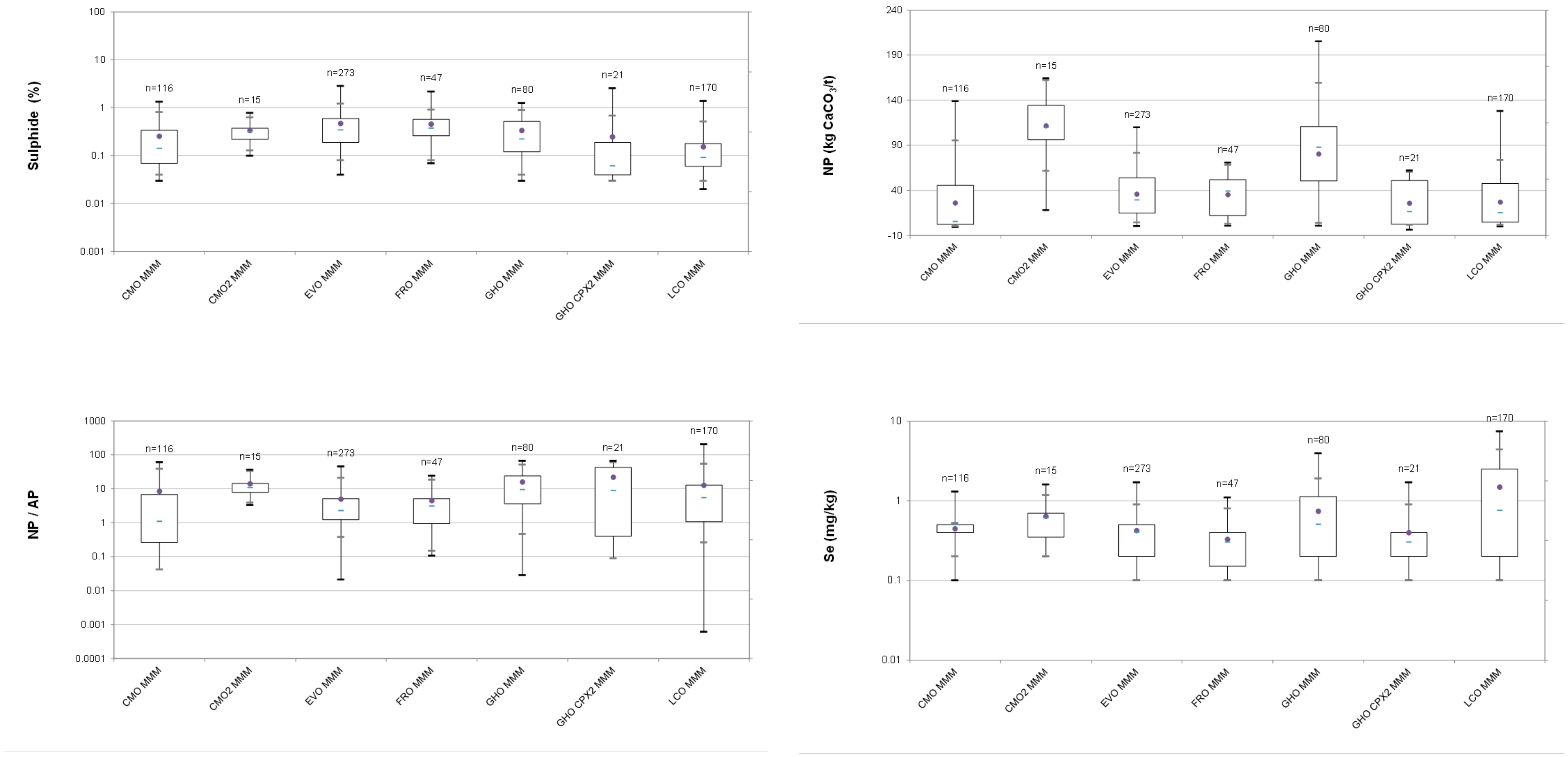

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Figure 3. Box and Whisker Plots of Key Parameters in the Moose Mountain Member (MMM) of the Morrissey Formation

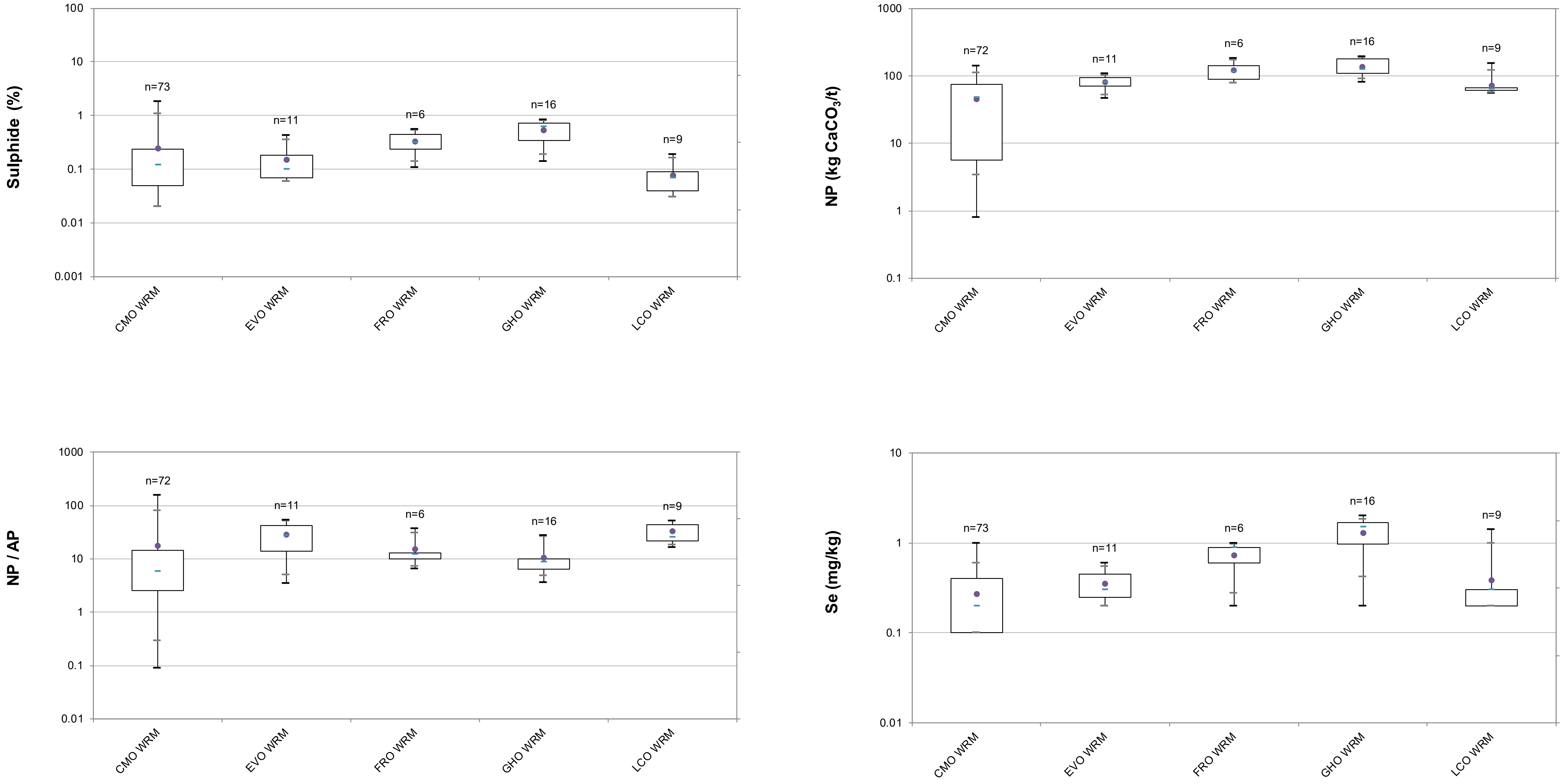

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Figure 4. Box and Whisker Plots of Key Parameters in the Weary Ridge Member (WRM) of the Morrissey Formation

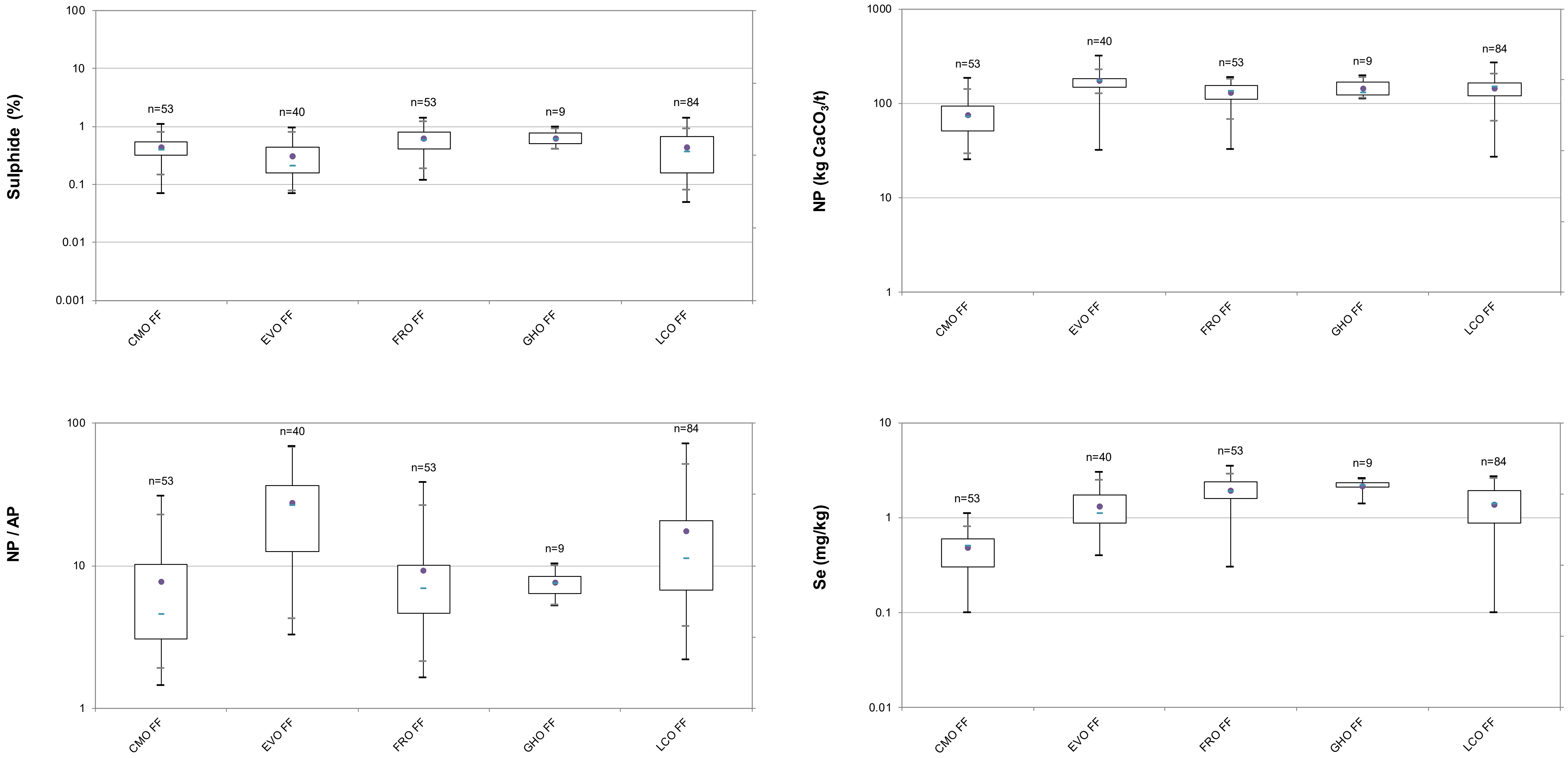

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Figure 5. Box and Whisker Plots of Key Parameters in the Fernie Formation

Other Trace Elements

With the exception of selenium, the concentrations of all other trace elements evaluated in this report are comparable to global average values for sedimentary rocks (sandstones and shales) as compiled by Price (1997). A statistical comparison by site is presented in Table 3 and by formation in Table 4.

Results demonstrate the concentrations of parameters are similar between sites with the exception of CMO which has lower values than the other sites for the majority of parameters with the exception of As. Non-MMF formations have lower Cd, Se and U compared to the MMF, and higher Co and Cr compared to the MMF.

Table 3. Concentration of Selected Elements by Mining Area Determined on Drill Core

		CMO	CMO2	EVO	FRO	GHO	GHO CPX2	LCO
As (mg/kg)	n	224	707	701	1540	409	479	308
	Low	3.9	4.8	4.9	4.2	4	4.5	4.1
	Average	4.5	5.3	5.3	5.2	4.5	4.9	4.7
	High	5.1	5.8	5.7	6.3	4.9	5.2	5.3
Cd (mg/kg)	n	224	707	820	1540	409	479	308
	Low	0.95	1.7	1.7	1.8	1.5	1.8	1.8
	Average	1.1	1.8	1.8	1.9	1.6	1.9	2
	High	1.2	2	1.9	1.9	1.8	2	2.2
Co (mg/kg)	n	224	707	820	1541	409	479	308
	Low	5.3	6.2	6.3	5.7	6.2	6	5.8
	Average	5.8	6.4	6.4	5.9	6.5	6.2	6.3
	High	6.3	6.7	6.6	6	6.9	6.4	6.8
Ni (mg/kg)	n	224	707	820	1541	409	479	308
	Low	17	22	23	23	22	23	23
	Average	19	24	24	23	24	24	25
	High	21	25	24	24	27	25	27
U (mg/kg)	n	224	707	820	1540	409	479	308
	Low	0.94	1.3	1.3	1.5	1.2	1.6	1.5
	Average	1	1.3	1.3	1.5	1.3	1.6	1.6
	High	1.1	1.4	1.4	1.6	1.3	1.7	1.7
P (%)	n	224	707	820	1540	409	479	308
	Low	0.059	0.11	0.11	0.12	0.11	0.13	0.12
	Average	0.066	0.11	0.11	0.12	0.12	0.14	0.13
	High	0.073	0.12	0.12	0.13	0.13	0.14	0.14
Se (mg/kg)	n	224	707	820	1540	409	479	308
	Low	0.82	1.9	2	2.1	1.7	1.6	1.8
	Average	0.91	2.1	2.1	2.2	1.8	1.7	1.9
	High	1	2.2	2.2	2.2	2	1.8	2
Cr (mg/kg)	n	224	707	701	1540	409	479	308
	Low	45	45	46	28	35	19	29
	Average	53	49	49	30	38	20	32
	High	62	52	52	31	41	21	35
Mn (mg/kg)	n	224	707	820	1541	409	479	308
	Low	130	230	240	210	230	260	170
	Average	160	250	250	220	260	280	190
	High	200	270	270	230	300	300	210

Source: D:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.195_Historical_Geochem\!020_Project_Data\010_SRK\Static Database\Teck_HistoricalGeochem_Box&Whisker_1CT017.195_ld_rev01.xlsx

Notes: Low=arithmetic average - 95% confidence limit, High=arithmetic average + 95% confidence limit; All values rounded to two significant figures.

Table 4. Concentration of Selected Elements by Rock Unit Determined on Drill Core

		MMF	MMM	WRM	FF
As (mg/kg)	n	4368	721	115	239
	Low	5	5.5	5.4	6.4
	Average	5.4	5.7	6.3	7.5
	High	5.7	6	7.1	8.7
Cd (mg/kg)	n	4487	722	115	239
	Low	2.1	0.73	0.35	0.6
	Average	2.1	0.8	0.39	0.64
	High	2.2	0.86	0.44	0.69
Co (mg/kg)	n	4488	722	115	239
	Low	6.4	7	7.1	6.9
	Average	6.5	7.1	7.5	7.1
	High	6.6	7.3	7.9	7.3
Ni (mg/kg)	n	4488	722	115	239
	Low	24	21	22	25
	Average	24	22	23	25
	High	25	23	24	26
U (mg/kg)	n	4487	722	115	239
	Low	1.5	0.9	0.95	1
	Average	1.5	0.94	1	1.1
	High	1.5	0.97	1	1.1
P (%)	n	4487	722	115	239
	Low	0.12	0.11	0.11	0.14
	Average	0.13	0.11	0.12	0.14
	High	0.13	0.12	0.12	0.14
Se (mg/kg)	n	4487	720	115	239
	Low	2.1	0.64	0.37	1.2
	Average	2.1	0.7	0.46	1.3
	High	2.1	0.77	0.54	1.4
Cr (mg/kg)	n	4368	722	115	239
	Low	34	71	79	46
	Average	36	74	87	49
	High	37	77	95	53
Mn (mg/kg)	n	4488	722	115	239
	Low	220	160	170	230
	Average	230	180	210	240
	High	240	200	250	250

Source: D:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.195_Historical_Geochem\!020_Project_Data\010_SRK\Static Database\Teck_HistoricalGeochem_Box&Whisker_1CT017.195_ld_rev01.xlsx

Notes: Low=arithmetic average - 95% confidence limit, High=arithmetic average + 95% confidence limit; All values rounded to two significant figures.

3.2.2 Process Waste Characteristics

Geochemical characterization of tailings and coarse coal rejects (CCR) indicate low potential for ARD. Where tailings are disposed in tailings facilities that are at least partially saturated, sulphide mineral oxidation is limited (INAP 2009) and as a result, the potential for ARD and selenium leaching is limited. Similarly, discrete dumping of reject results in oxygen consumption or low gas permeabilities where oxygen concentrations decrease at depth supporting reducing conditions that result in nitrate and selenium microbial reduction (Section 4.7).

3.3 Climate

Climate conditions in the Elk Valley are variable depending on location (e.g. orographic effects), elevation and aspect. Data from the government-operated climate station at Sparwood is typical of the southern interior of BC, characterized by warm, dry summers and cool winters with average daily maximum temperatures of 24°C in the summer to an average daily minimum of -11°C in the winter.

The Sparwood area receives an average of 613 mm of precipitation annually, of which 411 mm occurs as rain, mostly from May to November, with the greatest rain occurring in May and June and the least occurring in August. Precipitation occurs predominantly as snow from December through March.

In addition to long term data from government sources, Teck Coal also operates several climate stations throughout the Elk Valley.

3.4 Mining and Coal Processing

3.4.1 Mining Operations

Current coal mining in the Elk Valley is exclusively by open pit using truck-and-shovel methods. Multiple coal seams are mined from the MMF. Due to the gentle dip of coal seams at most operations, mining involves following each seam down its footwall leading to final benched highwalls composed of the MMF (or Elk Formation if present), and an unbenched footwall which is the floor of the last seam mined. Most waste rock mining occurs using large equipment. Close to the seams, smaller equipment is used to scrape off waste rock immediately above the seam before mining the seam. The resulting “seam cleanings” are hauled for disposal with waste rock.

Mining of formations below the MMF (MF, FF) typically occurs for the following reasons:

- Where seams are steep, the footwall may need to benched or pushed back into the underlying MF and FF formations for geotechnical stability.
- Folding or thrusting over the MMF requiring pre-stripping.
- Pit access (typically using a footwall notch).

A site survey intended to inventory the historical proportion of MF and FF at each of the operations was completed by SRK with input from Teck (SRK 2014c). Estimates of historical non-MMF material at each of the operations is summarized below.

- CMO: MF and FF were mined at CMO due to isoclinal folding and thrusting of the stratigraphy which results in steeply dipping coal seams and the need to pushback pit walls into the footwall well below the lowest coal seam. The quantity of MF varies from about 5% in the West Spoils and Middle Mountain refuse area to 30% in 34 Pit, 14 Pit backfill, and the East Spoils. Mining of the formations below the MMF occurs for infrastructure and to ensure that the pit walls are stable.
- EVO: MF rock constitutes an estimated 1% of total historical waste rock at the operation based on 400 m total stratigraphic thickness mined of which 4 m are estimated to be PAG. The greatest potential for MF rock to be mined is in the Adit Ridge area where the FF and MF have been thrust over the MMF. This structural complexity appears to be absent in the Baldy Ridge and Natal mining areas.
- FRO: Some MF rock was mined in the Turnbull and Eagle Mountain pits. This occurred due to the lowest seam being thrust over the upper seams and mining of MF was required to access seams below the thrust fault. At Turnbull Mountain, 5 million BCMs (bank cubic meters) of MF were mined and then re-handled. Total waste volumes were not available but based on typical rock volumes mined elsewhere at FRO, this represents at most a few percent. No quantities were available for Eagle Mountain but based on a cross-section, the quantities appear to be of the same magnitude.
- GHO: Mining of MF and FF occurred in the Cougar Pit to stabilize the pitwall and provide access to the West Spoil. GHO concluded that 1 million BCM of these formations was likely to have been mined from other open pits in Greenhills Ridge. SRK concluded from other datasets that this represents less than one percent.
- LCO: The MF and FF have been mined in the Horseshoe Ridge, North Line Extension and Burnt Ridge South Pits. In each case, mining below MMF occurred because the footwall of Seam 110 was very steep (vertical in some cases) and laying back was required to form a stable pit wall. The estimated MF proportion of spoil varied from 5% to 12% for these three pits but would drop to 1 to 3% if the top 10 m of the MF is considered to be PAG rather than the entire MF thickness. In each pit, exposures of MF and FF occur mainly at the top of the highwall.

Each site reports the volume of PAG material mined each year as part of annual reclamation reporting for the C permit compliance.

3.4.2 Blasting Practices

Mining of waste rock takes place by blasting using ammonium nitrate and fuel oil recipes of various types designed for the rock being blasted and the amount of water in the pit. Blasting practices have been changed over decades to improve economics of mining.

Two main types of explosives are used. Ammonia nitrate fuel oil (ANFO) is a product which is used in blast holes that are classified as “dry” based on pumping of the blast hole before loading and recovery of the water level. ANFO is highly soluble and has a density less than water so it is unable to be used in wet locations. In wet holes, water-resistant products (historically slurry, then emulsion) is used to limit dissolution prior to the blast.

Given the importance of nitrate for water management planning, Teck has been evaluating blasting practices to better understand if operational changes could influence nitrate residuals in waste rock. Historically, there have been several major changes to procedures and products used to blast rock at Teck’s five coal operations in the Elk Valley (Figure 6).

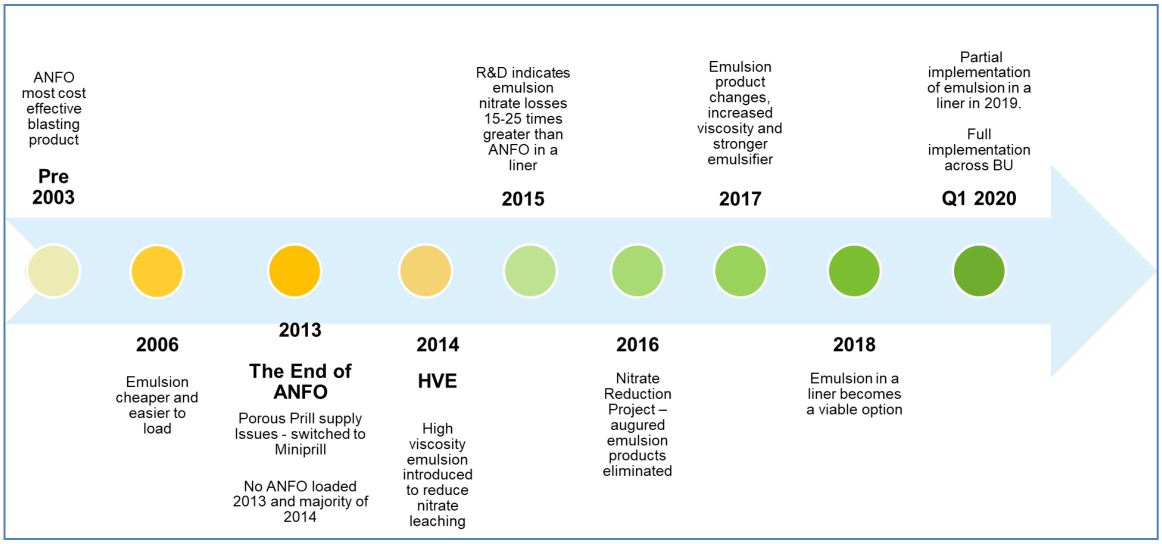

Figure 6. Chronology of Changes in Explosives Management Practices. Source: Teck Coal

In the 1990s, all of Teck’s operations in the valley switched from using water gels (slurry) to emulsion products for wet conditions. Emulsion products contain an oxidizer phase suspended in an emulsified fuel. They are considered higher energy and contain less water but may also be more water resistant due to the outer oil phase. This may influence the leaching efficiency of blasting residuals in the waste rock dump environment. In 2004, some sites changed suppliers but continued to use emulsion products.

Between 2009 and 2011, a product change to smaller diameter NH_4NO_3 prills caused Teck operations in the Elk Valley to transition away from using ammonia nitrate fuel oil (ANFO) and the use of blast hole liners (which could only be used with ANFO), in favor of emulsion products . In 2013, the addition of mineral oil as part of the fuel oil component in ANFO allowed the smaller prills to be used in ANFO, and Teck began using ANFO in dry conditions once more. The effect of these changes on blasting residuals has not been quantified at full scale, and at this stage, directional changes to water quality are hypothesized.

More recently, Teck has made a concerted effort to evaluate and improve blasting practices to minimize losses and improve efficiency. Each operation tracks the average mass of explosive used to blast 1 BCM of waste rock. This is called the powder factor. The annual powder factor at each of the operations is shown on Figure 7. Variations in losses result from changes in products, suppliers, operational practices and conditions in the field.

Teck began lining all holes where ANFO is used in 2016 and has been implementing new methods to line emulsion holes starting in 2019. The liners are intended to reduce pre- and post-blast (in misfires) nitrogen releases through minimizing water contact with ANFO. The effectiveness of the liners is currently being studied to focus future efforts to minimize nitrogen release from blasting practices.

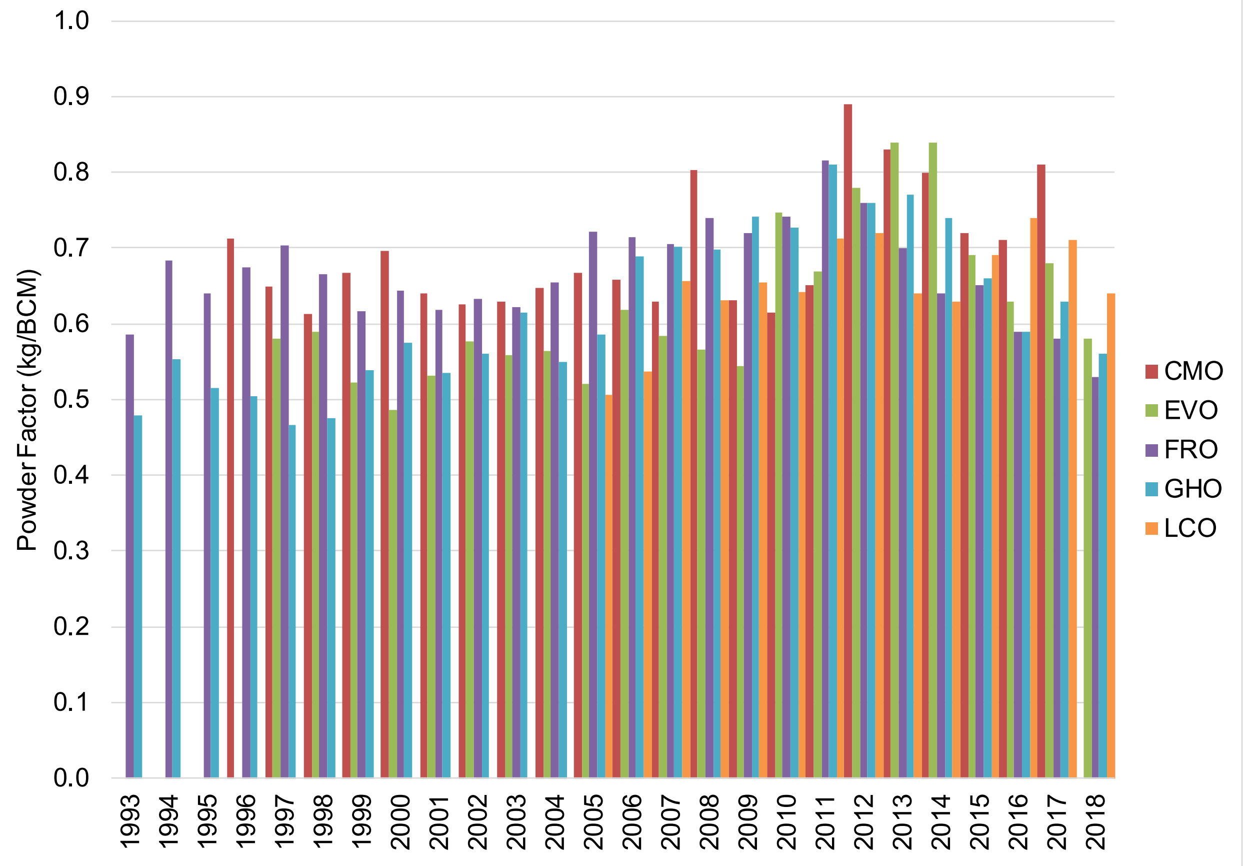

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Figure 7. Powder Factor over Time at each of the Operations.

3.4.3 Coal Processing

Coal processing occurs by washing to remove coarse and fine non-coal components of the seams. The coarser gravelly fraction is referred to as coarse coal reject (CCR). The finer fraction (referred to as tailings) varies from fine sand to silt. Both materials have tens of percent carbon as coaly material. At FRO, GHO and EVO, these materials are disposed separately in unsaturated CCR dumps (and co-disposed with waste rock at FRO) and conventional wet impoundments, respectively. At LCO, the wastes are combined (as coal reject, CR) and co-disposed in unsaturated dumps. When it was operating, CMO also disposed of CR in the same way.

3.4.4 Waste Rock Management

Blasting of rock at Elk Valley operations yields well-graded waste rock mixtures varying from cobbles to silt (OKC 2020). Examples of particle distributions for waste rock samples (with larger rocks screened out) are provided in Figure 8.

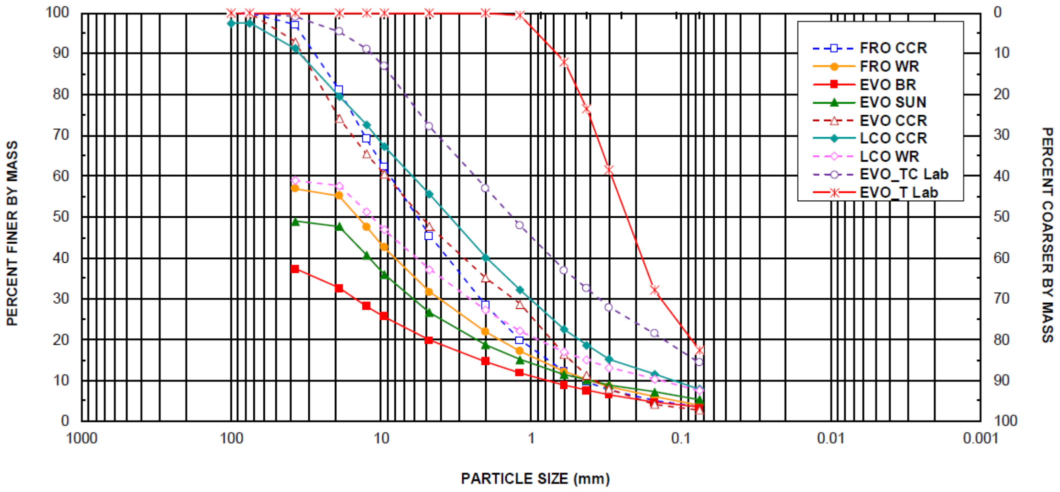


Figure 8. Particle Size Distributions for Waste Rock (labelled as WR, BR, SUN) Samples Compared to Other Wastes (CCR, tailings (T)) (OKC 2020)

Waste rock disposal occurs in a number of different configurations at the Elk Valley operations including valley headwater fills, cross-valley fills, side hill dumps, and pit backfills. Waste placement occurs from the bottom and top-down and lift heights range from 10 m to greater than 100 m. The primary construction method is end-dumping though free-dumping (or plug dumping) (Figure 9) is also used depending on availability of equipment for management of end-dumping.

Figure 9. Free Dumped Waste Rock (Background) and Compacted Traffic Surface (Foreground) at Coal Mountain Operations.

The dominance of end-dumping means that strong textural segregation occurs on faces with fine materials tending to accumulate at dump crests and coarser material at the base resulting a distinctive basal rubble zone (Bard et al. 2011). The degree of segregation is greater for higher dump faces with the rubble zone becoming less distinctive for short lifts and non-existent for free dumps.

The majority of waste rock dumps are constructed using multiple lifts with fine grained compacted layers between the lifts resulting from traffic during construction. As a result, the distinctive repeating stratigraphy is a basal rubble zone, fining upwards through free-dumped material to a strongly compacted layer overlain by the rubble zone at the base of the next lift.

Ex-pit waste rock spoils in the Elk Valley are in unsaturated conditions. While some waste rock becomes permanently saturated when disposed as pit backfill, this represents a small overall proportion of waste.

3.5 Infiltration into Waste Rock Dumps

O’Kane Consultants (2019) report annually on research performed to refine the conceptual model for the near surface water balance in Elk Valley waste rock dumps. Six years of data are now available. This work indicates net percolation into waste rock dumps is typically more than 50% of total precipitation and surface runoff is negligible with the balance as evapotranspiration. Due to the limited store-and-release capacity of waste rock, percolation is seasonal due to the seasonality resulting from snow melt and larger rainfall events.

Vegetation can be an important factor in decreasing net percolation by several hundred millimetres annually.

Teck uses locally obtained water for dust control in its active mining and hauling operations. The water used is pumped into water trucks from a variety of locations where consistent supply of water is available including wells in backfilled pits. These water sources may range from dilute to the chemistry of waste rock contact waters. The bulk chemistry of these waters will be dominated by calcium, magnesium, sulphate and bicarbonate, and to a lesser extent nitrate (depending on the source) and sodium. Trace element (e.g. selenium) concentrations depend on the source.

Teck pumps water from active open pit operations for the purpose of maintaining dry conditions for mining. Historical mining and water management information provided by Teck shows the resulting water may be pumped onto sumps in waste rock dumps which then report to drainage points and settling ponds.

3.6 Internal Conditions in Waste Facilities

Monitoring of internal gas and temperatures conditions inside waste facilities has occurred at LCO (waste rock), EVO (waste rock, pit backfill), FRO (waste rock backfill) and GHO (CCR). These monitoring data have shown unsaturated waste rock (Figure 10 bottom) may have near atmospheric oxygen concentrations at depth but can also have sub-oxic zones within the facilities. Concentrations of CO_2 may be up to three orders-of-magnitude greater than atmospheric and internal temperatures may be well above average ambient conditions (SRK 2013b).

Profiles of O_2 in CCR (Figure 10 top) show an internal sub-oxic zone that is spatially correlated to increases in CO_2 indicative of sulphide oxidation, carbonate dissolution and less complicated air transport through the CCR profile.

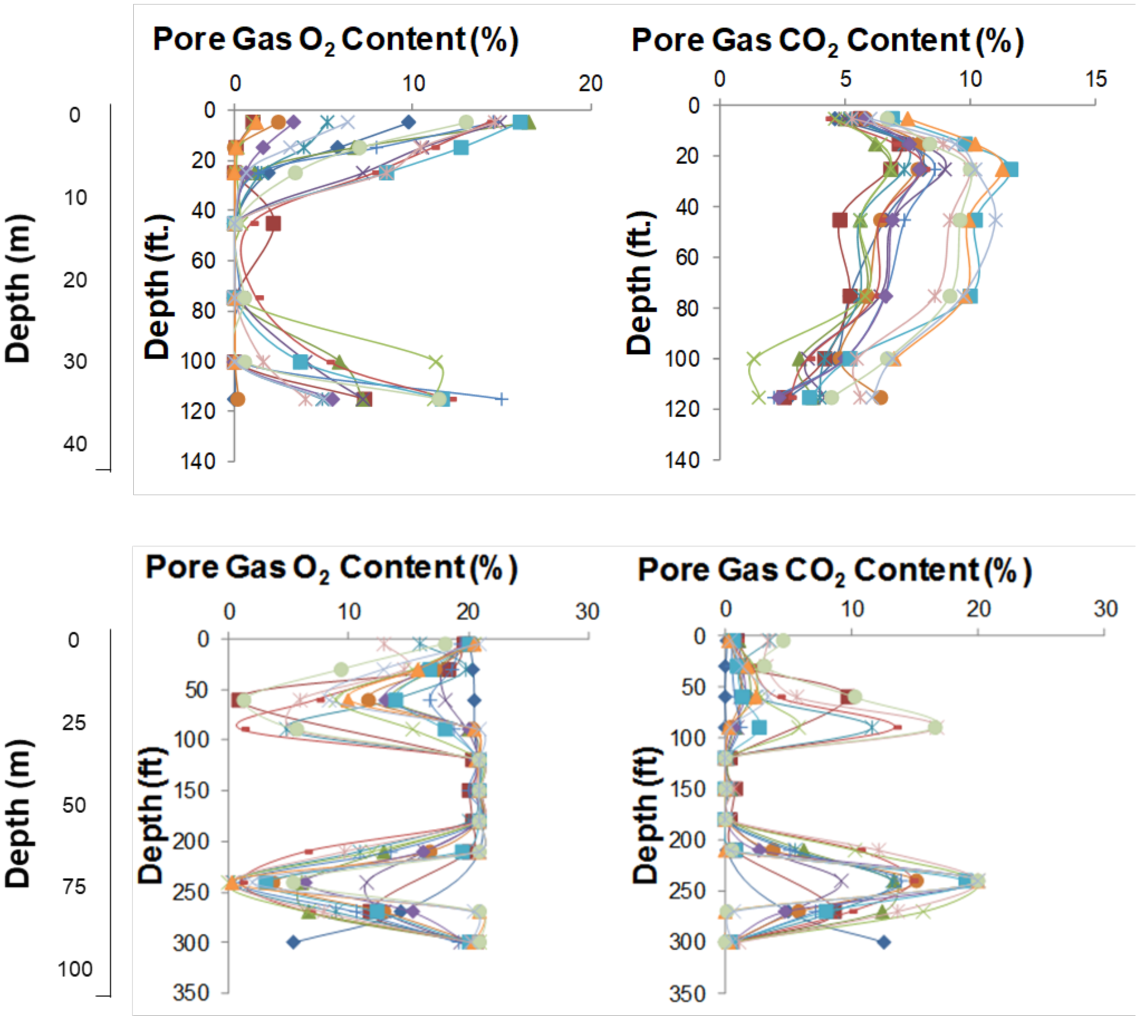


Figure 10. Examples of Gas Profiles in CCR at GHO (top) and Waste Rock at LCO (bottom) (SRK 2013b). Individual lines are different sampling dates.

3.7 Water Quality of Mine Waste Contact Waters

Elk Valley mine waste contact waters are consistently pH basic with major ion chemistry dominated by sulphate, bicarbonate alkalinity, calcium and magnesium. The cations are roughly molar equivalent. Waters emerging from waste disposal areas also contain nitrate as a significant anion and are over-saturated with respect to calcite which results in secondary calcite precipitation in streams receiving contact waters.

Major ion chemistry at monitoring locations downstream of spoils shows consistent seasonality with highest concentrations of major ions in low flow periods (October through April), a sharp decrease in concentrations in freshet (typically May and June) followed by more gradual increasing concentrations (July through September). Selenium also follows these trends correlating strongly with sulphate.

Trace metals (including cadmium, cobalt, manganese, nickel, zinc) occurring in solution as divalent cations also show seasonal trends (when detected) but concentrations may peak at the tail end of freshet then decrease during low flow periods in response to calcite precipitation (SRK 2017a). This concept is presented in more detail in Section 9.

4 Conceptual Models and Evidential Basis

4.1 Introduction

The following sections describe the conceptual geochemical models (CGMs) for each facility for which a source term is subsequently numerically implemented (Section 5) as an input to the RWQM. The CGMs build on understanding of the geological, environmental and mining setting described in Section 3 and use ongoing experience of the performance of individual facilities acquired through monitoring, research and development, and previous modelling. This section provides an update to the CGMs developed to support the previous iterations of the RWQM (SRK 2014a, 2017a). Due to the COI loading significance of waste rock, most effort is focussed on refining its conceptual model.

For consistency with previous reports, the general structure of the section has been maintained.

4.2 CGM for Unsaturated Waste Rock

4.2.1 Summary of Waste Rock CGM from SME Workshops

The CGM for unsaturated waste rock has been substantially updated and refined since the 2017 RWQM (Figure 11) through a series of workshops held in 2018 and early 2019 (SRK 2019) and attended by subject matter experts (SMEs) in geochemical, biogeochemical, hydrological and hydrogeological processes. A descriptive tabulation of components of the CGM is provided in Table 5 which was reviewed by attendees at the workshops. It mainly represents the understanding of processes early in 2019.

Each description is colour coded according to the degree to which the component of the CGM is supported:

- GREEN: Well supported by Elk Valley data or basic scientific principles.
- AMBER: Hypothesised with indirect indications from observations.
- RED: Hypothesised but not currently supported by data.

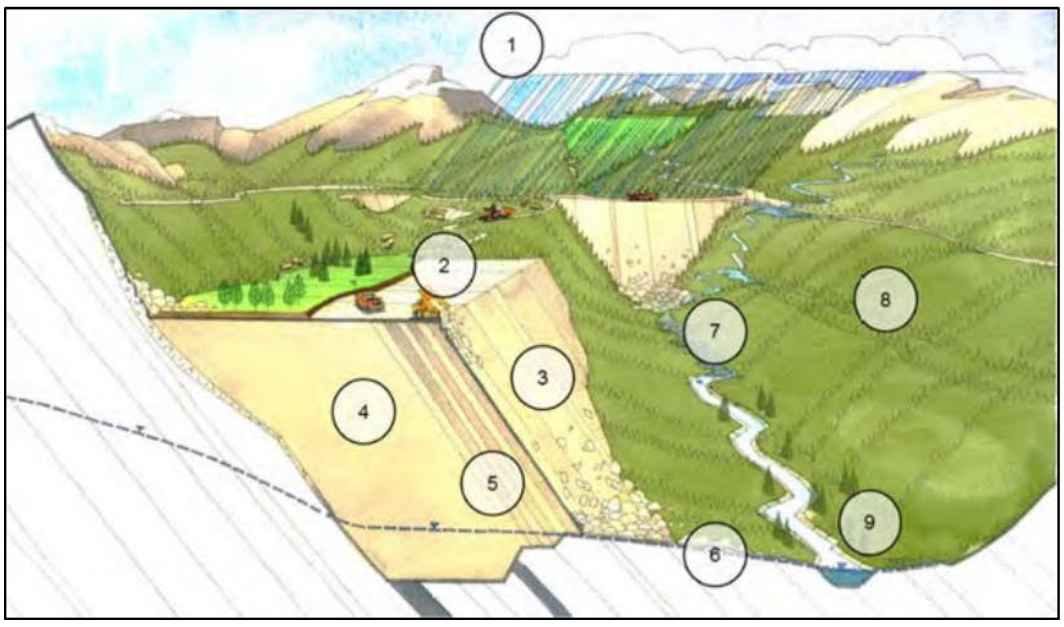
For each aspect of the CGM, shown in Table 5, the subsequent additional discussion provides the evidential basis for the conclusions drawing on the setting, monitoring data and research and development activities.

Table 5. Components of the Unsaturated Waste Rock CGM

Component	Narrative
Geological and Geochemical Setting	**Geological Units** • Bituminous coal is mined from several seams in the non-marine Mist Mountain Formation (MMF). • The Morrissey Formation (MF) is the immediate underlying footwall of the lowest coal seam. It comprises both the Moose Mountain and Weary Ridge members. • The immediate footwall is the Moose Mountain Member (MMM) and it contains pyrite and carbonates at negligible levels. **Lithology** • The MMF unit is composed of sandstones, siltstones, shales and coal. **Mineralogy** • The dominant mineral in the rock is quartz (SiO_2) followed by clay minerals (illite and kaolinite) and carbonate minerals. The latter are typically around 10%. • The dominant carbonate mineral is dolomite ($CaMg(CO_3)_2$) followed by siderite ($FeCO_3$), ankerite ($CaFe(CO_3)_2$) and lesser calcite ($CaCO_3$). • The rock contains 0.2% pyrite (FeS_2) on average. Trace levels of sphalerite (ZnS) are present. Primary gypsum ($CaSO_4.2H_2O$) appears to be absent. **Geochemical Testing** • The MMF is not acid generating and its characteristics are well defined throughout the Elk Valley. • The MMM is potentially acid generating (PAG) becoming acid typically in time frames of weeks to months. • The Fernie Formation is below the MF and due to its carbonate content is deemed mainly non-acid generating. • Sulphur in the rock occurs mainly in association with pyrite but also with carbonaceous matter. • Selenium occurs in association with pyrite and carbonaceous matter. Primary selenium minerals are very rare. • Pyrite is also a host for other heavy elements in addition to iron including arsenic, antimony, cobalt, copper, molybdenum and nickel. • Cadmium and zinc are hosted by sphalerite (ZnS).
Climate	• The climate in the Elk Valley is strongly seasonal with significant inter-annual variations. • In the Elk Valley, transpiration accounts for more of the water balance than evaporation but occurs only during the growing season. • Local climate is controlled by factors such as elevation and aspect in a rugged mountainous setting. • Average monthly temperatures at the mines are below zero from October or November to March or April. • Stream flows respond strongly to snowmelt with greatest flows occurring in June. • Average annual total precipitation at Sparwood, BC is 613 mm with about 1/3 as snowfall and 2/3 as rainfall. • Precipitation amount and proportion of precipitation as snowfall generally increases with elevation. • Monthly precipitation peaks occur in the late spring (May and June) and late fall each year.
Mining and Blasting	**Mining, Pre-Excavation and Rock Weathering** • Mining in the Elk Valley has been by open pit truck and shovel methods since the early 1970s. • Prior to being blasted and excavated, and additionally after blasting and before excavation, waste rock exposed in benches is weathered by O_2 and leaching processes similar to spoils. • Waste rock weathering results in the accumulation of soluble and insoluble minerals phases. **Effects of Blasting** • Blasting shatters the rock in the target bench and fractures the rock in the bench below. • Blasting releases heat, nitrogen (which is chemically inert) and nitrous oxides (NO_x). The latter is not a typical outcome but occurs when the blast is inefficient, or the explosives are de-graded. Nitrous oxides may act as an oxidant. • Blasting results in rapid exposure of rock to atmospheric O_2 and in combination with heat may oxidize pyrite. • The amount of nitrogen residuals depends on blasting practices, the characteristics of the rock (e.g. degree of fracturing) and the presence of water in the blast holes. **Blasting Practices** • Specific products and procedures have varied over the years. • Ammonium nitrate and fuel oil recipes are the blasting agent. • The amount of blasting agent used per bank cubic metre is referred to as the powder factor. • Emulsion rather than prilled ANFO is selected if the blast hole is wet. • Plastic liners have been used to reduce loss of ANFO to the formation since 2016 and used to reduce loss of emulsion since 2019. • Bulk explosives are loaded into blast holes which are drilled through the bench to be blasted about 2 m into the rock below. • During the blast, explosives are not completely consumed, and residues remain in the rock.
Waste Rock Placement and Spoil Configuration	**Waste Rock Haulage** • Waste rock is hauled and placed in the spoil with lift heights typically varying from 10 m to more than 100 m depending on design considerations (for example, geotechnical stability, PAG management). • CCR and coal reject (combined CCR and tailings) have been co-disposed with waste rock at some locations. **Spoil Configuration** • Shorter lifts are used where stability is an important consideration. Other factors such as topography and haul distance are also considerations for design • Higher lifts are used where stability is less of a concern or to encourage mixing of PAG rock. • Dumping processes influence particle size distributions throughout the dump profile. • Short lifts result in less particle segregation on faces whereas long lifts result in development of a distinctive coarse rubble zone. • Traffic activity results in particle size reduction. • Waste rock may be placed as a near horizontal layer for levelling purposes as the dump crest lowers in elevation due to consolidation and foundation movement. • Particle size reduction occurs in the long term due to gravity crushing and slaking. • Rock drains may be constructed in the foundation to allow for efficient passage of water. • Spoil failures cause downward movement of waste rock which disrupts internal layering and changes flow paths resulting in flushing of previously unflushed rock.
Initial Pore Water Concentrations	• Moisture entrained in waste rock and incorporated into the spoil contains dissolved constituents • These initial concentrations reflect the source of the moisture (e.g., groundwater, snow melt, rainfall, dust control), explosives residuals and oxidation products generated prior to delivery of the rock to the spoil). • Leaching of explosives residuals diminish with time since a finite amount of explosives are introduced during mining and nitrogen forms are not expected to be generated significantly by rock weathering.
7	**Net Infiltration from Rainfall and Snowmelt** • Run-off from the unsaturated waste rock is negligible. • The amount of water that enters from the surface of the waste piles is a function of precipitation and snowmelt minus evaporation, transpiration and sublimation. • Slope and aspect of spoil slopes affects degree of infiltration. • The presence and type of vegetation affects degree of infiltration. • Infiltration varies by watershed. • Infiltration is strongly seasonal. Highest rates occur in the spring due to snowmelt and lowest rates occur in winter during sub-zero conditions.

Component	Narrative
8	**Net Infiltration from Water Used for Dust Control** • Water is sprayed on to haul roads to control dust dispersion. • The area of spoils sprayed is a small fraction of the total area. • Depending on the source, the water used may have contacted mined materials and contain more dissolved solids than rainfall and snowmelt. • The water serves to bind small particles making them less mobile. • Due to placement under dry conditions, the water is expected to evaporate causing efflorescent salts to form. • Based on typical composition of contact waters, the salts will be calcium and magnesium carbonates and sulphates. • Co-precipitation of other components of the water may occur with these salts. • The resulting salts may become incorporated into the rock solids. • Following the next rainfall or snowmelt infiltration event, the salts will dissolve. • Some fraction of the salts may be retained in the rock solids and not leached. • The dissolved load will add to loading from entrainment of initial pore water and weathering products.
9	**Infiltration of Water from Pit De-Watering** • Water pumped from pit sumps may be discharged to infiltration sumps on the surface of spoils. • The chemistry of pit sump water depends on the characteristics and configuration of the walls relative to the sump, the source of water to the sump (walls, groundwater, surface run-in), blasting practices in the pit and the sump water balance. • The discharge point to the spoil is a constructed infiltration basin. • Due to the concentrated flow over a comparatively small area, rapid plug flow is expected resulting in the flow exiting the spoil well ahead of infiltrating rainfall and snowfall which is much slower as piston flow. • Water introduced by pit dewatering can be expected to leach rock that may not normally be contacted by infiltrating water. Initial water may create a flush of COIs adding on to the load resulting from entrainment of initial pore water and weathering products.
10	**Downward Water Transport and Leaching Processes** • The moisture content of typical fresh spoil is expected to be close to field capacity and does not require an extended wetting period to begin transmitting water. Effects of spoil leaching are usually observed within 2 years for new spoils. • Dominantly in the Elk Valley, water is transported through the spoil by “piston flow”. Water applied to the top of spoil by melting snow or rainfall events creates a pressure wave which acts within weeks to displace an equal volume of water from the base of the spoil. • The travel time of water from the top to the base of the spoil is a function of the infiltration rate, moisture content and height from the top to base of the spoil. Given relatively consistent physical properties and infiltration rates in the Elk Valley, travel time is roughly a function of lift height and is approximately 10 m/year. • Locally finer materials may retain moisture resulting in slower movement compared to coarser materials. • Under rare very high flows events, water may be transported rapidly by activating plug flow. • The method of construction of spoils can influence the flowpaths. • COIs are dissolved in water transported by piston flow. • The introduction of freshwater in the surface of spoil pushes out lower pore waters. In the case of nitrate, the freshwater will contain nitrate inefficiently leached by the first pore volume. For parameters produced by rock weathering processes, incoming water will dissolve new weathering products. As a result, concentrations of nitrate remain “constant” in pore waters whereas sulphate and other soluble parameter concentrations will increase with depth as load is accumulated along the flow path. • The piston flow model for water transport combined with near constant generation of load (in the short term) by weathering indicates that the concentration of COIs in pore waters will increase with depth and therefore that seasonal loading at the base of the spoil will vary exactly in proportion to the input flow through the surface of the spoil. • When waste rock piles are disturbed (e.g. during re-handling or by spoil failures), pore spaces not previously leached may leach.
12	**Upward Water Transport** • Movement of water upward into the base of the spoil may occur seasonally as a result of increased underflow in rock drains • The upward moving water can be expected to entrain water moving downward from infiltration
10	**Gas Transport** • Gas transport is expected to be advective and diffusive. Advection refers to bulk movement (flow) and includes convection and barometric pumping. Diffusion refers to slower transfer of individual gases due to concentration differences. • The mode of delivery of oxygen is a strong control on its availability for oxidation reactions. Advection can result in deep penetration of oxygen whereas diffusion can, in a relative sense, limit penetration. • Convection is driven by differences in temperature between inside and outside the spoil. Internal temperatures may exceed 10°C compared to average external temperatures of 4°C and lower. External summer temperatures exceed internal temperatures whereas winter external temperatures are well below internal temperatures. The latter is a strong driver for convective air flow by pulling air in through the coarse rubble zones at the bases of lifts. • Diffusion is driven by gas concentration gradients which are expected to develop in finer materials where moisture is entrained, and oxygen consuming processes result in locally lower O_2 concentrations. • Due to the coarse nature of the spoils, advective transport is expected to dominate; however, long term decrease in the particle size of spoils may result in an increase in sectors where diffusive transport occurs. • Initial gas entrained during dumping will be atmospheric. • Initial O_2 is consumed by reaction with pyrite. Heat generated by reaction raises the temperature and pulls in more air. Decrease in O_2 also sets up a diffusion gradient. • O_2 is mainly not a limiting reactant for oxidation reactions

Component	Narrative
13	**Geochemical Weathering Processes – Oxygenated Spoils** • The initial inventory of minerals defines the total available COIs potentially available for release by weathering. • Due to the particle size distribution, some fraction of COIs are unavailable for release by weathering in the short to medium term due to sheltering from O_2 inside large rock particles. • Geochemical processes in the spoils include incongruent dissolution of carbonate minerals by carbonic acid formed by dissolution of carbon dioxide in water, weathering of silicates by carbonic acid, oxidation of pyrite and other sulphides, oxidation of carbonaceous matter and neutralization of sulphuric acid by carbonates minerals. • Weathering of silicates releases mainly silicon, aluminum, calcium, magnesium, potassium and sodium but also traces of barium and strontium. • Dissolution of carbonates yields calcium, magnesium, iron, manganese and bicarbonate. • Oxidation of pyrite results in release of soluble components of pyrite, mainly sulphate and iron acidity, but also traces of elements including selenium and other elements contained in pyrite (arsenic, antimony, cobalt, copper, molybdenum and nickel). • Se/SO_4 ratios are useful metric to evaluate attenuation of selenium due to selenium occurring in solution as selenate (SeO_4^{2-}) under oxic conditions. • Oxidation of sphalerite releases sulphate, cadmium, iron and zinc. • Iron released by oxidation of pyrite replaces the pyrite forming iron (ferric) oxyhydroxides. • The rate of pyrite oxidation decreases in the long term as the inventory of pyrite decreases. This will result in a long-term decreasing release of elements released by oxidation including sulphate and selenium, which have a strong regional correlation. • Acid produced by pyrite oxidation reacts with dissolved alkalinity and carbonate minerals increasing dissolved CO_2, lowering the pH of pore waters and increasing the partial pressure of CO_2 in the pore gases. • Pore water conditions are pH neutral to slightly alkaline (pH>7) with partial CO_2 pressures up to two orders of magnitude greater than atmospheric (i.e. $pCO_2>10^{-3.4}$ or ~ 0.04%). • Barite ($BaSO_4$) is formed by combining barium and sulphate. • If sulphate concentrations are sufficiently elevated, gypsum ($CaSO_4.2H_2O$) may precipitate. As gypsum forms, calcium is removed from solution allowing gypsum to require a higher sulphate concentration to form. • In the long term, as the sulphate generation rate decreases due to depletion of pyrite, gypsum re-dissolves prolonging sulphate concentrations (and selenium if sequestered) • Selenium released by oxidation of pyrite may be attenuated by coprecipitation with ferric oxyhydroxides, adsorption to ferric oxyhydroxides, co-precipitation with barite. • Selenium may be co-precipitated with gypsum. • These selenium-attenuating processes do not result in concentration limits but remove a fraction of the load (e.g. fixed K_d) • Heavy elements forming cations (e.g. Cd, Co, Cu, Mn, Ni, Pb and Zn) are attenuated by adsorbing to ferric oxyhydroxides. The degree of attenuation varies by parameter depending on the zero point of charge of the reactive surface. Copper is expected to be strongly attenuated whereas cadmium and zinc are less attenuated at the expected prevailing pHs. Concentrations are constrained. For these COIs, pH is a strong control on mobility and SO_4 ratios are not useful. • Nitrate is not generated by spoil weathering.
13	**Geochemical Weathering Processes – Sub-oxic Zones** • Sub-oxic zones occur in spoils where oxygen is a limiting reactant for oxidation reactions due to the presence of finer, more saturated O_2-consuming material for which water residence times are longer and O_2 transport is by diffusion rather than advection. • Co-disposed CCR could create sub-oxic conditions. • Oxygen consumption, nitrate reduction to nitrogen gas and selenate reduction to selenite and element selenium occurs by reaction with dissolved organic carbon and pyrite. • Selenium released from pyrite oxidation under these conditions would be attenuated as selenite.
14	**Transport of COIs via Seepage, Run-off and Groundwater Pathways** • Water carrying COIs from the dump exit the dump as surface water and groundwater. • Where groundwater pathways occur, there is a potential for load bypass at specific monitoring stations and sub-oxic reduction of Se and NO_3.



Item	Description
1	Net percolation
2	Rock placement & physical conditions
3	Leaching of explosives residuals
4	Oxidative weathering
5	Hydrological processes
6	Transport of COIs via seepage, runoff & GW pathways
7	In-stream precipitation processes
8	Undisturbed area influences
9	Monitoring location and data record

Figure 11. Conceptual for Unsaturated Waste Rock Used as the Basis for 2017 Source Terms (SRK 2017a)

4.2.2 Supporting Evidence for the Waste Rock Dump CGM

The following sections refer to geochemical aspects of each component of the CGM.

Geological and Geochemical Setting

The geological and geochemical setting of the coal deposits are described in Sections 3.1 and 3.2. Understanding of the geological setting is provided by geological studies both regionally (Gibson 1985) and at the mine scale. Geochemical studies have been completed at all five mine operations in support of permit applications and environmental assessments. As described in Section 3.2, geochemical characteristics of the dominant Mist Mountain (MMF) and Morrissey (MF) Formations are well-defined and consistent throughout the mining area which supports valley-wide rather than site-specific conceptual models.

Mining

The ratio of ammonium nitrate to fuel oil in explosives (93:7) is consistent throughout the Elk Valley and determined by the stoichiometry of the blasting reaction which converts the explosives into gases (nitrogen, carbon dioxide and water). Based on handling of explosives and effectiveness of the blast, the waste rock contains explosives residuals. The degree to which residuals are present (referred to as the loss factor) needs to be estimated for use in the RWQM.

Values in the literature indicate a range between approximately 1% of ANFO and 5% of nitrogen in slurry form (Ferguson and Leask 1988) which is consistent with more recent findings of Mahmood et al. (2017) indicating a range between 3% to 6% in explosives, though values greater than 10% have also been reported (e.g. Golder 2014; Morin and Hutt 2008). This factor is a variable when quantifying the initial mass reservoir of nitrate available for leaching.

Blasting practices have varied through time (Section 3.4.2), but for the purpose of the conceptual model two general phases are recognized:

- Prior to 2020, and over several years, Teck has made various changes to use explosives that may have resulted in increase and decreases of residuals (Section 3.4.2). These practices are reflected in current water chemistry and will continue to be reflected in drainage chemistry due to hydrological lag in waste rock spoils.
- Beginning in early 2020, Teck began lining nearly all blast holes with plastic liners and has fully implemented practices intended to limit creation of explosives residuals through changes to handling practices (e.g. spillage near drill holes, management of misfires).

SRK (2017a) used drainage chemistry to estimate explosives residuals by comparing nitrate loading in drainage to powder factors resulting in valley-wide average residual of about 4% with a range consistent with an earlier study by Ferguson and Leask (1988). For the period prior to 2020, residuals are represented by a factor that combines for all the various aspects of explosives use that have changed over the last one or two decades (Section 3.4.2).

An important conceptual consideration for lining of blast holes is the degree of tearing which result in leakage of the blasting product from the bags and entrainment by flowing groundwater in wet holes. Installation of liners in holes classified as dry involves placing the empty bag in the hole and ensuring it reaches the bottom of the hole with a weight (Figure 12). The ANFO product is then loaded into the bag. For wet holes, the bag and the emulsion product are extruded into the hole together (Figure 13).

Based on observation and testing of installed bags, Teck has found that 50% of liners in wet holes tear to some degree (SRK 2020) whereas the rate of tearing in dry holes has not been quantified. A lined blast hole with a torn liner is expected to reduce nitrate leaching compared to a completely unlined hole. Teck is continuing field and lab studies to better quantify the rate of liner tearing and the leaching rate of various degrees of tears compared to unlined holes and the conceptual and numerical representation of the effects of lining blast holes will be revised as new information is available.

SRK (2020) concluded that post-blast residuals are negligible based on Teck's extensive monitoring needed to track misfires for safety reasons. The misfire rate is estimated at 1 in every 100,000 blast holes, and therefore that the residuals from misfires is 0.001% of the explosives used.

Figure 12. Example of Liner in a Dry Hole Prepared for ANFO Loading. Source: Teck.

Figure 13. Example of Liner and Emulsion Being Loaded into a Wet Hole. Source: Teck.

Nitrogen in residual explosives is highly soluble and will be mobilized by water flushing unlined blast holes (pre-blast) or from flushing of residual explosives transported to waste rock spoils. Depending on the pH and redox conditions in the spoil, nitrogen will be present as nitrate, nitrite or ammonium (Figure 14). Nitrate is typically the most abundant nitrogen form occurring from explosives usage and monitoring data downstream of spoils also supports this.

Ammonium and nitrite are present at lower concentrations than nitrate nitrogen in tributaries in the Elk Valley and demonstrate unique ratios with nitrate on a catchment basis. Monitoring results at stations downstream of spoils indicated nitrite/nitrate (NO_2^-/NO_3^-) and ammonia/nitrate (NH_3/NO_3^-) ratios are generally constant when nitrate concentrations are greater than baseline concentrations (Figure 15). These ratios tend to increase when nitrate is closer to baseline, and concentrations of nitrite and ammonia are below or are near the detection limit.

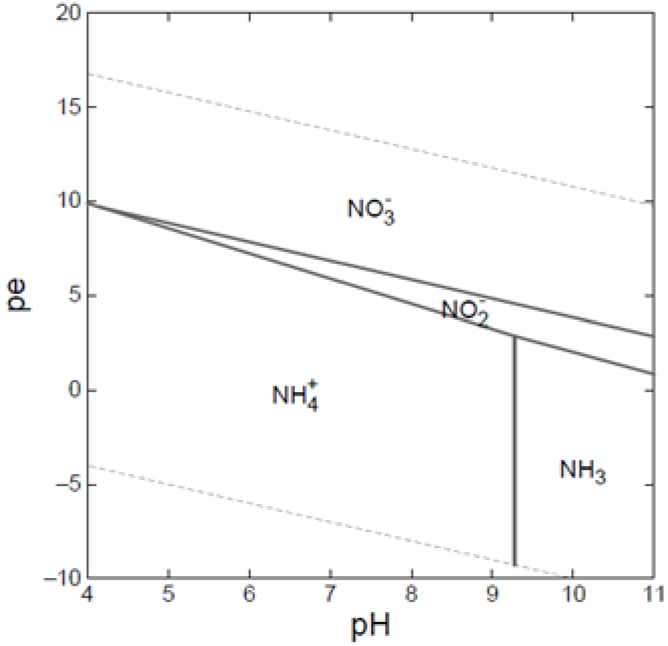


Figure 14. Eh-pH Diagram for Nitrogen in a Fe-S System at 25°C System (Dockrey et al., 2015)

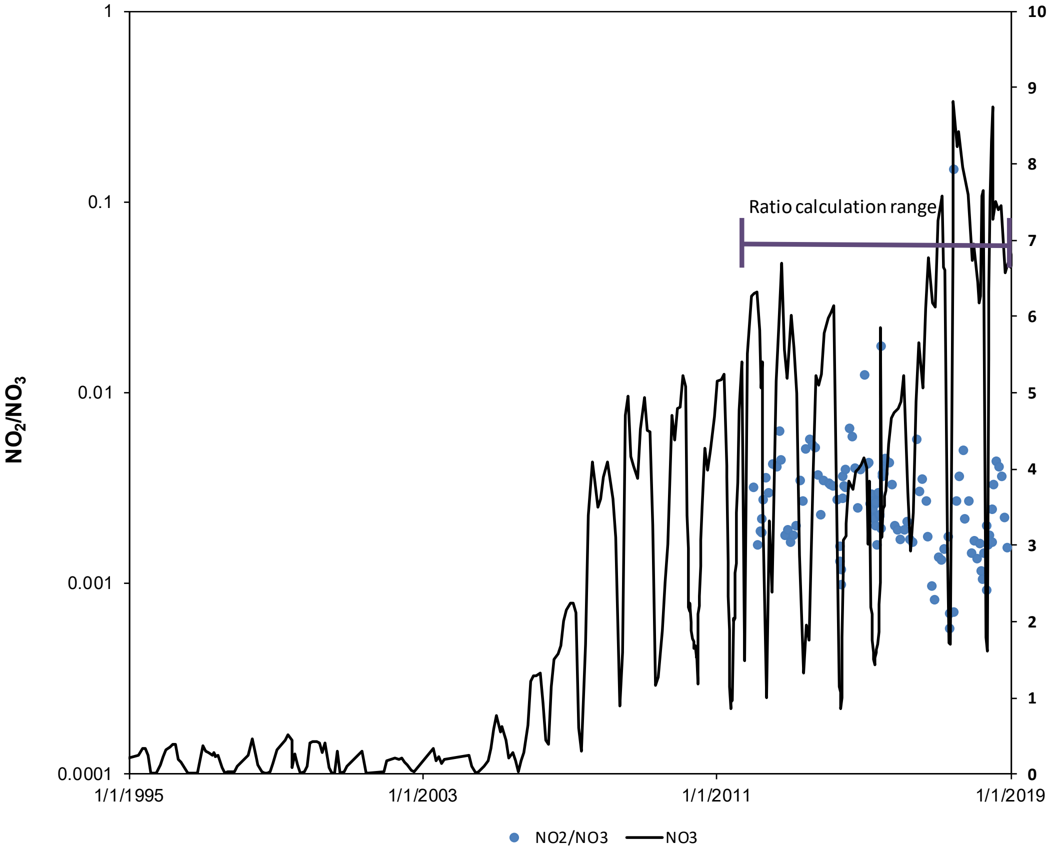


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Figure 15. NO_2^-/NO_3^- Ratios at Monitoring Location GHO_GH1

Pre-Excavation Weathering

Rock begins to weather physically and chemically as soon as it is exposed to atmospheric conditions. These weathering processes are the same as those occurring in spoils after placement and include physical breakdown due to slaking and freeze-thaw, and chemical weathering processes such as dissolution, oxidation of sulphide minerals and carbonation of silicates. Exposure occurs as the surrounding rock is removed and may be short in duration if the exposed rock is blasted relatively quickly, or longer if the rock remains in a phase pit wall or bench before being mined and hauled to the spoil. Oxidation may also occur during the blast.

The resulting weathering products may be partly dissolved by infiltrating rainwater or snow melt and flushed, or retained if not in contact with waters. Retained weathering products become available for flushing in waste rock spoils following handling and will add to the load produced as the rock continues to weather in the spoil.

Evidence for pre-excavation weathering comes from kinetic tests and other water leach tests on blasted waste rock. Laboratory kinetic tests (humidity cells) initially show elevated release rates followed by a steep decline before reaching more stable lower rates (Figure 16). This effect is not always apparent (see HC-17 in Figure 16) and may be weakly expressed or absent at the larger test scales (Figure 17). Hendry (unpublished data) collected eight bulk samples of freshly blasted rock a mining area at Line Creek Operations and performed leach tests. The data indicated 80±70 mg/kg sulphate on the <4.75 mm fraction and 9±9 mg/kg on the >4.75 mm fraction. The data indicate the presence of leachable sulphide oxidation products equivalent to tens of weeks of oxidation by comparison with the data shown in Figure 16 and Figure 17.

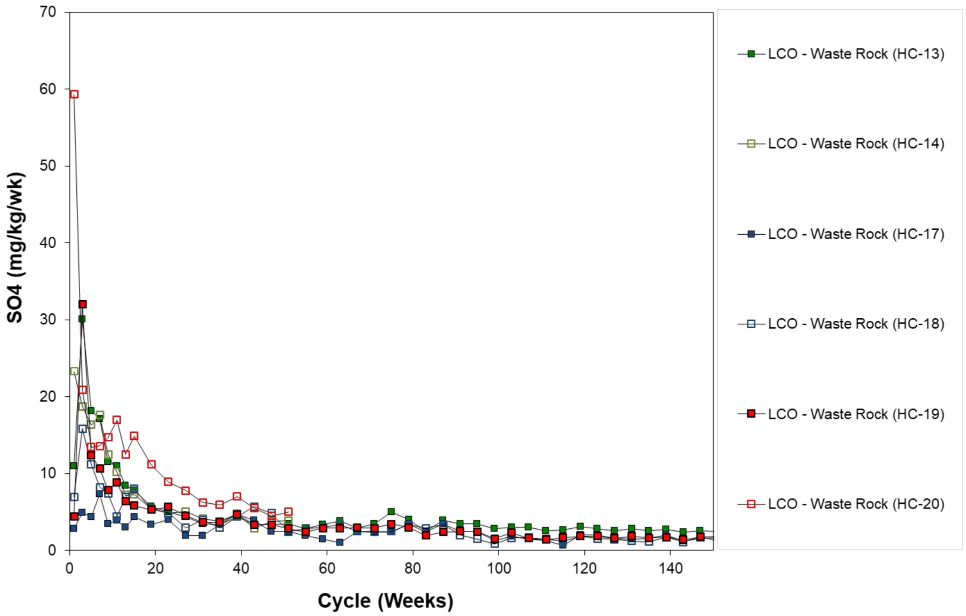

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Figure 16. Sulphate Release Rates for Humidity Cell on Blasted Rock from Line Creek Operations

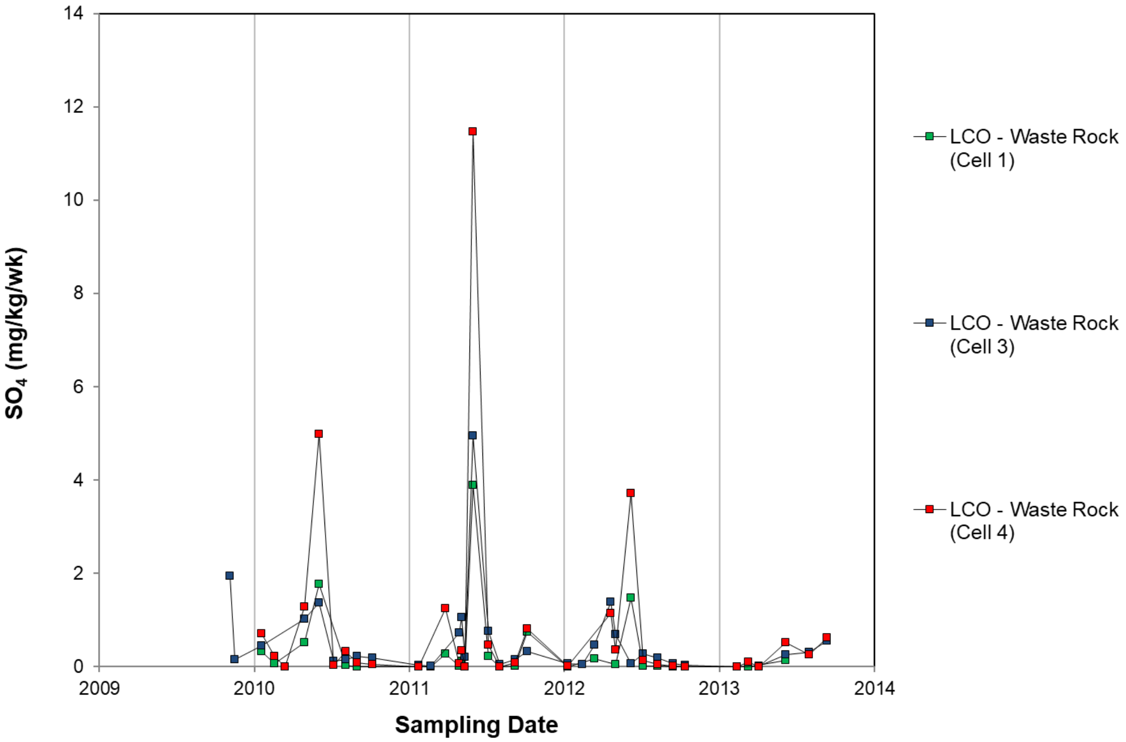

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Figure 17. Sulphate Release Rates for Leach Pads on Blasted Rock from Line Creek Operations (same samples as Figure 16).

Conceptually, the flush of pre-placement weathering products can therefore be represented by the rate at which the rock weathers multiplied by the accumulated period over which the rock is exposed prior to being disposed in the spoil. Reasonable approximations of the timeframe of pre-excavation weathering appears to be on the order of zero to several months.

Rock Placement and Physical Conditions

From a source term standpoint, a critical consideration for spoil placement is the dump construction method (Section 3.4.4) which affects water flow and gas availability and movement. Direct observation indicates that in free (or plug) dumping, the bulk particle size distribution is retained in the pile. In end-dumping, particle size segregation on the face results in retention of finer material at the crest and coarser material at the toe. Steeply dipping layers defined by differences in particle size may also be retained at shorter lift heights but on higher lifts, the layers become thin and indistinguishable as shown by post-deposition investigations to evaluate placement of PAG rock at CMO, EVO and GHO. Ongoing small scale failures resulting from localized over-steepening result in disruption of the layers on faces.

Regardless of the construction method, internal structure results from traffic on the lift surfaces leading to a hard compacted and fine-grained surface (Figure 9), and possibly also particle size reduction due to gravitational crushing (Bard et al. 2013).

Initial Pore Water Concentrations

Waste rock reporting to spoils contains moisture reflecting incident precipitation (rainfall and snowmelt), entrained groundwater and possibly also water from dust control measures. This initial water is the first source of water draining from the spoils. The chemistry of this water, referred to as C_0 (or concentration at time zero) will reflect the contributing waters (effectively negligible for precipitation), dissolution of explosives residuals, pre-placement weathering products and efflorescent salts formed from dust control waters (Section 4.2.2). This chemistry is continually modified by ongoing weathering processes including oxidation of sulphide minerals.

Evidence that initial pore waters have concentrations of COIs exceeding zero is provided by leach testing of freshly blasted rock (Figure 17) (Hendry, unpublished data). Initial drainage of waters from new spoiling areas at LCO Dry Creek showed an initial increase in sulphate and nitrate from baseline conditions in 2016 which show the arrival of initial pore waters (SRK 2018d).

Net Infiltration from Water Used for Dust Control

Waters applied as dust control to compacted traffic surfaces during climatic dry conditions can be expected to mainly evaporate rather than infiltrating significantly leading to the formation of efflorescent salt and concentration of the residual waters. The first salts formed by evaporation would be expected to be calcium carbonate and bicarbonate leading to concentration of sulphate and magnesium (SRK 2010). Further evaporation could result in precipitation of gypsum and magnesium sulphates (e.g. epsomite). Co-precipitation of trace elements in these salts might occur as shown by trace element enrichment in calcite (SRK 2019b) and sulphate (Hendry et al. 2015). The resulting salts then become available for flushing during the next wetter periods (i.e. resulting in a delay in the load applied in the water contributing to percolating waters), or storage as solids which could then contribute to the loading elsewhere if the rock is subsequently excavated and combined with other spoils. These salts might then contribute to initial pore water chemistry (Section 4.2.2).

In general, the areas of Teck’s operations receiving water for dust control is limited. For the purpose of the 2020 RWQM, the contribution of chemical loading in dust control waters is conceptualized in terms of inter-basin transfer of load if the dust control waters are used in a different catchment from where the water is acquired. The specifics of delay of loading due to evaporative processes are not considered pending investigations of specifics of the mechanism.

Infiltration of Water from Pit De-Watering

Discharge to the surface of waste rock dumps represents much higher infiltration over a small area than infiltration from natural sources. It is hypothesized this water will travel as plug flow rather than the dominant piston flow (Section 4.2.2) resulting in rapid transmission of the water and its associated load to the base of the spoil. In addition, this water may also transport more load from ongoing spoil weathering than would occur by climate drive infiltration.

These processes are not well understood. For the purpose of geochemical sources, loading from pit de-watering is assumed to report rapidly (effectively instantaneously) to the base of spoils and settling pond, and that leaching effects are unquantifiable. Where pit de-watering is active, interpretation of chemical loadings in spoils must account for load in pit water indicated by flow and chemistry.

Downward Water Transport and Leaching Processes

Downward water transport (percolation) in unsaturated waste rock spoils is described in terms of plug and piston flow. Plug flow in fluid mechanics is a model describing flow in a pipe of which the key feature is that the velocity of water in the pipe is constant. That is, water at the beginning of the pipe flows at the same rate as water at the end. In an unsaturated waste rock dump, plug flow can occur by water moving rapidly through coarse materials. In contrast, piston flow describes water moving in response to a pressure wave. In this case, water applied to the top of the spoil creates a pulse of pressure that results in rock moisture being pushed downward but velocities vary seasonally and are much slower than plug flow.

Recent hydrological modelling for the relatively small newer spoils in Dry Creek (LCO) indicate that piston flow dominates but monitored flow patterns indicate that plug flow must also be occurring during high flow events such as snow melt (ref). It has been concluded this is transient effect reflecting the short (<20 m) flowpaths in the spoil.

Barbour et al. (2016) profiled stable isotopes of oxygen and hydrogen in pore waters recovered from the West Line Creek dump at LCO which averages about 100 m in thickness. The vertical profiles were consistent with seasonal variation in infiltration originating as snow and rain which indicated residence times varying from 5 to 20 years. These observations were consistent with flow occurring dominantly as piston flow which is the expected mechanism for larger mature spoils. The actual travel time for water entering the top of the spoil to reach the bottom depends on the infiltration rate, moisture content and spoil height. The moisture content and spoil height define the overall reservoir of water which combined with the infiltration rate indicates the residence time of water in the spoil, and timeframe over which load moves through the spoil. Monitoring data from LCO Dry Creek indicate that contact water emerged within two years of the start of spoil placement which implies that the moisture content of the spoil at placement is sufficient to allow piston flow to be initiated soon after placement.

SRK (2017a) provided further evidence for the timeframes indicated by Barbour et al. (2016) and the piston flow concept by showing the multi-year lag between placement of waste rock containing explosives residuals and the arrival of nitrate load at monitoring points. These load lags vary from a few years to two decades though a component of the lag likely also reflects other factors such as over-dumping of waste rock and travel time in groundwater.

The piston flow model has several implications for the geochemical source terms including:

- Multi-year site-specific delays in arrival of load from mature spoils at monitoring points which indicate load measured at monitoring points reflects a past condition of the spoil.
- Pore water chemistry in the spoil is “chemostatic” meaning that for a given spoil height and constant weathering rate, the chemistry of water (i.e., concentrations of COIs) leaving the spoil at the base will be relatively constant.

- Load will vary seasonally and inter-annually due to precipitation variations. Since concentrations are relatively constant (for a given spoil), higher loads will be the result of higher infiltration rates.

Upward Water Flow

Szmigielski et al. (2018) studied the groundwater system below the West Line Creek spoil at LCO. As part of the studies, it has been hypothesised that water flow beneath the pile seasonally interacts with the base of the spoil resulting in entrainment of pore waters and higher loads than are expected simply from increase in infiltration and the effects of the piston flow model. This effect could result in incomplete characterization of the seasonal variation in load but probably does not affect determination of total annual loads.

This mechanism of flushing is site-specific and poorly understood. At this stage, it is not considered sufficiently developed to influence derivation of source terms.

Gas Transport

The mechanism for gas transport is an important factor in unsaturated waste rock dumps because it determines whether oxygen is or is not a limiting reactant for oxidation of sulphide minerals and concurrent release of selenium and other elements associated with sulphides. It also determines if oxygen could be depleted thereby allowing denitrification to proceed.

Gas transport in waste rock dumps occurs by advective and diffusive processes. Advection refers to bulk movement whereas diffusion refers to movement of gases along concentration gradients. Convection is an important process for transporting gases. It results in bulk transport of gas (compared to diffusion) but it occurs in response to temperature gradients which develop seasonally as a result of warmer temperatures inside spoils and cooler ambient temperatures. Internally elevated temperatures exceeding 10°C (SRK 2016a) compared to average external temperatures less than 4°C may be a legacy of the temperature at the time of construction or a result of exothermic oxidation reactions (sulphide and carbonaceous materials).

Barometric pumping is advective gas movement in response to the difference between in internal and external pressures.

A number of factors point to advective rather than diffusive transport of gas dominating for Elk Valley spoils:

- Internal oxygen concentrations in spoils that have been monitored tens of metres below surface are well above the concentrations (1 to 5%) at which conditions are considered to be sub-oxic (SRK 2016a).
- Visual observations of snow melt patterns on typical spoils indicate convective air flow. Figure 18 shows a line of snowmelt part way up two lifts of spoils at GHO which is consistent with air being drawn in through the basal rubble zone, rising internally due to warm conditions followed by venting.

- Sulphate release rates varying over a fairly narrow range throughout the Elk Valley implying that oxygen is not a limiting reactant (Day et al. 2012; SRK 2017a). One factor causing variability could be the presence of local zones of lower oxygen concentrations resulting from diffusive transport.

Figure 18. Snowmelt on GHO Spoils as Seen from FRO. November 2019.

In general, it is concluded that oxygen is not a limiting reactant for weathering processes at the macro-scale. Locally diffusive conditions likely exist as shown by zones in West Line Creek where oxygen concentrations are below 5% (SRK 2016a) which can be linked to traffic surfaces. The following two sections describe geochemical processes under oxygen unlimited and oxygen limited conditions.

Geochemical Weathering Processes – Oxygenated Spoils

Geochemical weathering processes consider the mineral assemblages, the trace elements associated with each mineral, weathering processes for the minerals, secondary minerals formed by the weathering processes, the solubility of the secondary minerals and subsequent attenuation of the reaction products. These processes are conceptualized in the following sections.

Weathering Environment

The weathering environment in Elk Valley rocks is dominantly alkaline due to excess of carbonate minerals in the rocks (Sections 3.1 and 3.2). The exception is the top 10 m or so of the Morrissey Formation which lacks carbonate minerals and can generate acid (Section 3.2); however, Teck manages this unit by mixing with the MMF to prevent acid generation.

The dominant weathering process in the spoils are dissolution of carbonate minerals which occurs in response to carbonic acid formed by dissolution of carbon dioxide in pore waters, and sulphuric acid produced by oxidation of pyrite (and to a much lesser extent chalcopyrite). The latter reaction occurs under alkaline conditions releasing sulphate and iron. The iron oxidizes immediately and replaces pyrite as solid iron (III) oxyhydroxides (Biswas et al. 2017). Trace elements in the pyrite (including arsenic, cobalt, nickel and selenium) are expected to be partially attenuated with iron in the process. Hendry et al. (2015) found that iron oxyhydroxides were a significant reservoir for selenium in weathered Elk Valley rock. Biswas et al. (2017) reported similar findings for arsenic. Nickel is being studied specifically in this context and elsewhere it is well-known to co-precipitate with iron oxyhydroxides (Fix et al. 2015).

Several elements occur as chalcophile elements in the Elk Valley, in particular, cadmium, cobalt and nickel. Release rates for these parameters are correlated to sulphate production rates in humidity cell tests (Figure 19). While these elements can be attenuated by the sorption process described above, empirical sulphate release rates can be used as a proxy to estimate loading rates for these constituents based observed metal to sulphate ($[M]/SO_4$) ratios observed in humidity cell tests.

Due to the reaction of acidity with carbonates, carbon dioxide is released which, based on pore gas monitoring (SRK 2016a), does not immediately equilibrate with the atmosphere resulting in carbon dioxide accumulation in solution and a slight decrease of pH. This allows additional carbonate minerals to dissolve until equilibrium is achieved. Pore waters in the spoils are expected to be in equilibrium with the abundant dolomite and elevated carbon dioxide concentrations. Under these conditions, carbonic acid reacts with silicate minerals contributing to increase in bicarbonate (alkalinity) concentrations. Dissolution of silicate minerals may be the source of barium which subsequently participates in the formation of barite (Hendry et al. 2015).

Oxidation of sphalerite does not generate acid but contributes to pore sulphate, cadmium and zinc.

Uranium occurs naturally in coals in the detrital minerals and organic matter. The primary source of uranium in the Elk Valley is thought to be oxidative dissolution of carbonaceous matter (SRK 2019a) under alkaline conditions, which are typical of the Elk Valley. As a result, there is a direct common cause correlation of sulphate (produced from sulphide oxidation) and uranium water quality trends in drainage from waste rock spoils in the Elk Valley (Figure 20) and sulphate can also be used as a proxy to estimate uranium concentrations in tributaries downstream of spoils.

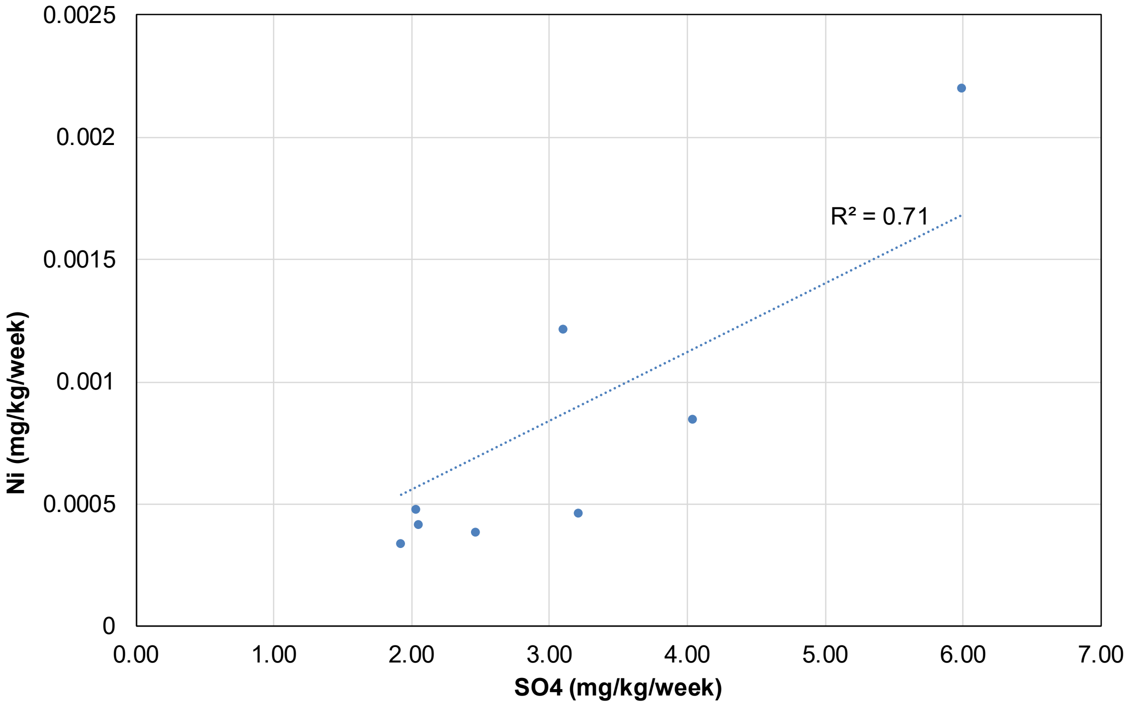

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Figure 19. Nickel Release Rates versus Sulphate Release Rates in Line Creek Operation's HCT Results

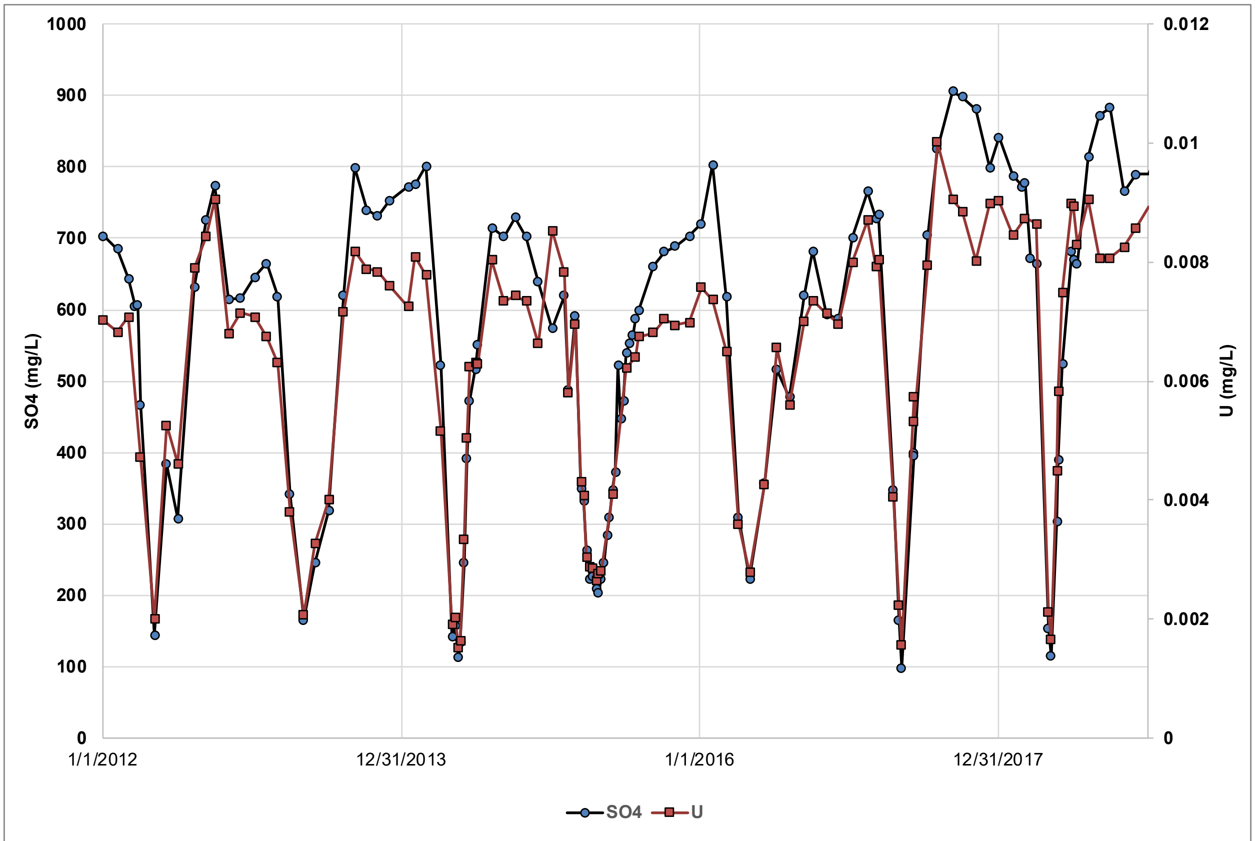

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Figure 20. Monitored Sulphate and Uranium Concentrations at GHO_GH1

Geochemical Controls by Important Secondary Minerals

The main secondary mineral expected to form by the above weathering processes is iron (III) oxyhydroxide. Due to its very low solubility under alkaline and oxic conditions, it forms very readily and removes effectively all iron produced by sulphide oxidation. As noted above, it is important as a sink for selenium and other trace elements both by adsorption and co-precipitation. At this stage, the significance of adsorption is not well understood for selenium which is expected to be speciated in solution as $Se^{VI}O_4^{2-}$ (selenate). Pore water pHs may be below the point of zero charge (PZC) at which adsorption occurs. In addition, selenate weakly adsorbs so that sorption is only expected to be an important attenuation mechanism under sub-oxic conditions when selenium is speciated as $Se^{IV}O_3^{2-}$ (selenite). Iron (III) oxyhydroxides will remain stable under alkaline oxic conditions since dissolution requires acidic or reductive conditions.

The attenuation of metals occurring as cations (e.g. Ni^{2+}, Cu^{2+}, Cd^{2+}, Co^{2+}, Mn^{2+}) also depends on the PZC but for these elements, adsorption occurs at pHs greater than PZC. Using nickel as an example, Figure 21 shows the scatter of nickel and sulphur in rocks from FRO compared to average Ni/SO_4 ratio in leachates from humidity cells performed on LCO waste rock and the valley-wide range in Ni/SO_4 ratios for drainage waters not influenced by calcite precipitation. The latter enable evaluation of attenuating effects at full scale.

The rock is the source of nickel (partially as sulphide) and shows the highest Ni/SO_4 ratio. The lower ratios for humidity cells and drainage from spoils implies that nickel attenuation occurs under weathering conditions because SO_4 is not likely to be attenuated. The decrease in ratio tracks the attenuation of nickel as sulphate is conserved in waters. Humidity cells show ratios between the rock and drainage waters probably due to the lower pHs observed in humidity cells compared full scale. These relationships are being further explored using the valley wide datasets.

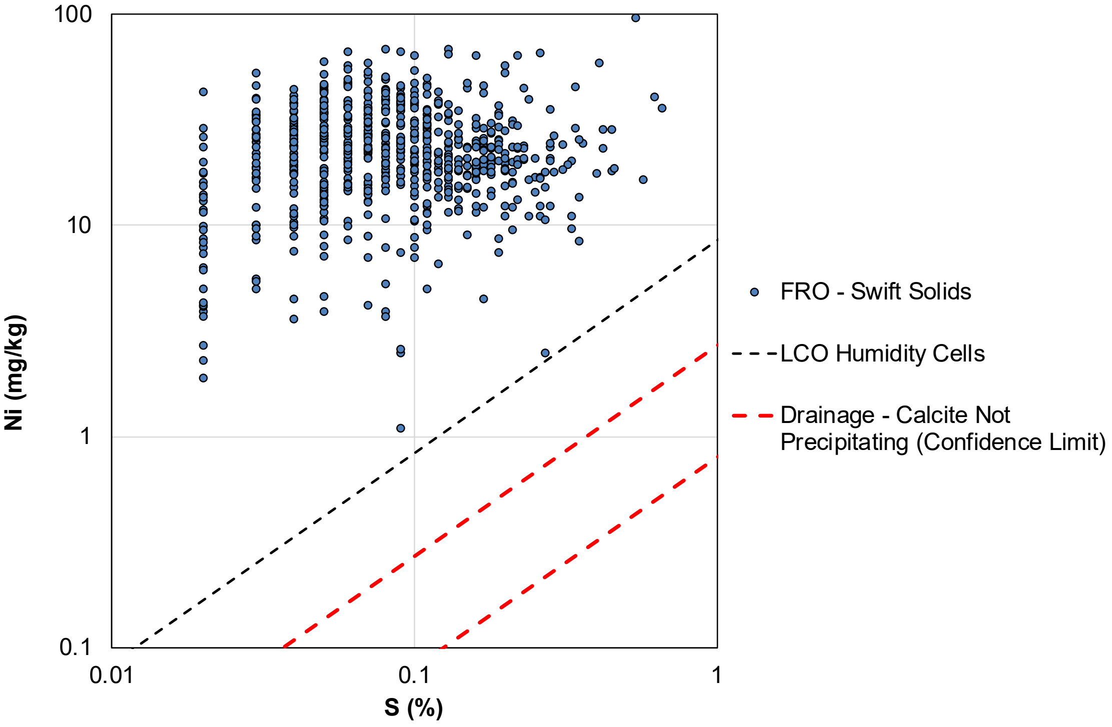

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Figure 21. Nickel-Sulphur Relationships Showing Ni vs Sulphur Concentrations in Rocks, Average Ni/S Ratios in Humidity Cells and 95% Confidence Limits on Ratios in Mine Drainages in the Elk Valley.

Gypsum was predicted by modelling to form at greater than about 100 m depth in spoils due to the accumulation of sulphate and calcium in downward moving waters (SRK and HGI 2019). The presence of gypsum was recently confirmed on deep drill hole samples from FRO. Gypsum may be a sink for selenium (Fernández-González et al. 2006; Lin et al. 2020) by selenate substituting for sulphate like barite (Andara et al, 2005, Hendry et al, 2015). SRK (2004, 2010) showed that selenium is sequestered by gypsum formed by evaporation, but SRK and HGI (2019) showed negligible sequestration in gypsum formed under lab conditions by reaction of sulphuric acid with dolomite. Elemental analysis using laser ablation on gypsum grains observed in drilling chips is in progress at Queens University.

Long Term Processes

Previous conceptualization of geochemical processes (SRK 2017a) did not consider aspects of the conceptual model that apply to long term effects, namely depletion of COIs and decrease in weathering rates.

Depletion of COIs occurs as weathering processes break down the host minerals allowing them to be leached into contact waters. The potential inventory (PI) describes the total available COIs that could be leached if the entire rock mass were to be broken down by weathering processes. In practice, some part of the PI is not available due to encapsulation in larger rock particles. The available inventory (AI) is the fraction of the PI which is available for weathering. The definition of AI is in part dependent on the timeframe because all rock which eventually breakdown over geological time. Particles finer than 2 mm may be operationally defined as the “reactive fraction” because below this particle size, the total surface area of particles increases rapidly. Based on Figure 8, this is about 20% to 30% of the rock mass for the two samples.

Oxidation rates are expected to decrease with time based on the hypothesis that sulphide oxidation will follow a shrinking core model. In this concept, the reaction depends on the surface area of the particles and as the surface area decreases due to mass removal by oxidation, the available mass for oxidation also decreases. Evidence for this type of process is provided by long term humidity cell tests (Figure 22) which show log-linear declines in oxidation rates for some tests following the initial steeper decreases during the initial phase (Section 4.2.2). The approximately log linear relationship is consistent with a first order decay model (i.e. the rate of reaction decreases in proportion to the remaining mass of reactant).

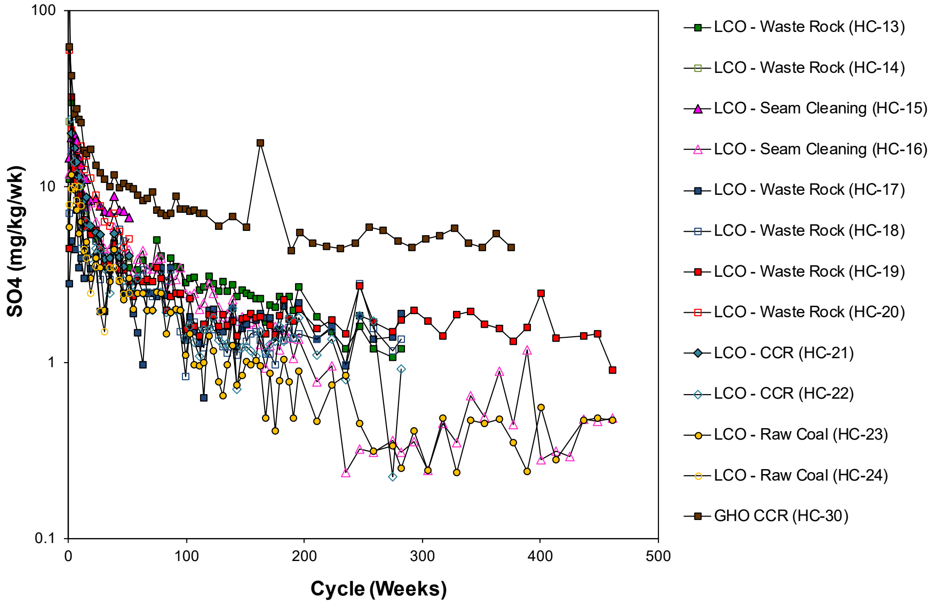

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Figure 22. Sulphate Release from Long Term Humidity Cells (LCO)

Geochemical Weathering Processes – Sub-Oxic Zones

Sub-oxic zones (SOZs) in unsaturated spoils are environments where oxygen delivered by diffusion is greater than advection typically due to fine-grained materials (such as a traffic surface) which results in greater moisture retention. Oxygen may become a limiting reactant as it is consumed by biochemical reactions catalysed by autotrophs (sulphide as the electron donor) or heterotrophs (organic carbon in carbonaceous matter as the electron donor). After oxygen reaches sub-oxic levels (e.g. less than 1 mg/L in the water), denitrification occurs to remove nitrate (as nitrogen gas) and selenate can reduce to selenite and elemental selenium both of which allow selenium to be removed from water.

Evidence of SOZs in dominantly oxic environments is shown in gas monitoring data from West Line Creek Dump (Figure 10). The low oxygen concentrations indicate oxygen consuming conditions with slow exchange by diffusion with the surrounding oxic environments. Elevated carbon dioxide concentration support that the electron donor for oxygen reduction is likely organic carbon mediated by heterotrophic bacteria. These data do not provide evidence for denitrification and selenium reduction, but the sub-oxic environments needed for those processes to occur may exist locally and cause variability in the nitrate and selenium release from unsaturated waste rock.

Transport of COIs via Seepage, Run-Off and Groundwater Pathways

Flows and concentrations from unsaturated spoils are monitored at downstream locations and used to calculate mass release from the spoil (Figure 23). However, the SRK (2017a) showed lower apparent loads in the downstream modelling nodes in the main stem rivers than indicated by the model. Several hypotheses were advanced to explain this apparent load loss of which three were evaluated:

- Groundwater flow paths (Figure 23) resulting in travel time delays between the source and monitoring points, and surface waters incompletely accounting for load.
- Loss of nitrate and selenium load in groundwater due to denitrification and selenium reduction.
- Removal of COIs dissolved in surface waters by attenuation processes such as precipitation and adsorption.

Field investigations in 2018 to test these hypotheses resulted in the conclusion that COI load moving in groundwater needs to be considered when assessing COI release from spoils as a basis for development of source terms, and that load removal in surface waters is unimportant for sulphate, nitrate and selenium (SRK 2019b). Precipitation of metals forming divalent cations (cadmium, cobalt, manganese, nickel, zinc) in calcite is highly significant for moderating loads in surface waters (MacGregor et al. 2012, SRK 2019b, Section 9). Assessment of groundwater transport and biochemical processes is continuing (SRK 2019c).

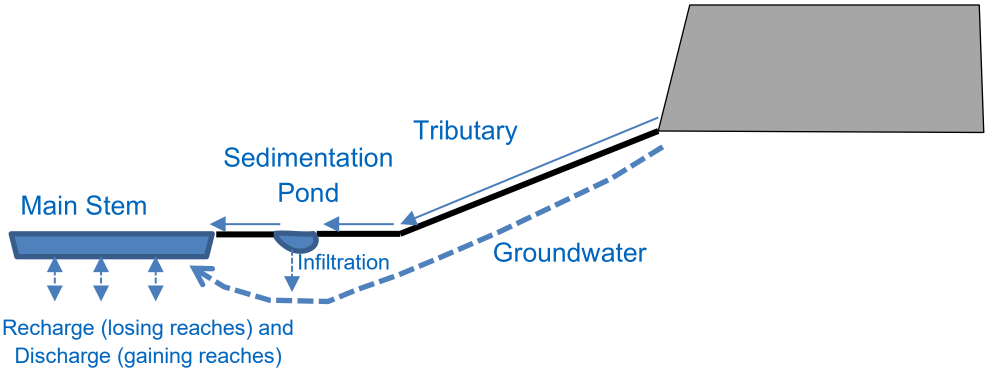

Figure 23. Flow Pathways Downgradient of Sources (Teck 2020).

4.3 CGM for Pit Walls

The conceptual model for the pit wall source term is similar to the unsaturated waste rock piles with two key differences:

- The volume of rock in contact with water is much smaller than waste rock. The reactive volume of rock is limited to the exposed pit wall surface area and a relatively shallow depth of rock (including talus) that is considered reactive.
- The hydrological processes influencing pit walls are much less complicated than for the waste rock dump. There is no anticipated delay related to hydrological wetting up and flow path travel distance in the pit wall system.

The non-benched areas of the pit comprise the footwall of the lowest seam. The footwall is comprised of nearly smooth surfaces and limited rock fines; therefore, the amount of rock available to interact with surface water and atmospheric oxygen is much lower when compared to benched pit walls and is limited to rock fines and small cracks within the surface (Figure 24). Conceptually, this is addressed by varying the assumed reactive thickness.

As with waste rock, the majority of pit wall exposures is within the MMF which is non-PAG though there are some zones of PAG pit wall rock from the MF. Weathering of PAG non-MMF pit walls is expected to occur in the same manner as MMF pit walls. The difference is runoff from these walls may be acidic resulting in accelerated sulphide oxidation and metal leaching.

The pit wall source terms are therefore differentiated into four types as follows:

- Benched non-PAG (MMF) pit walls,
- Unbenched non-PAG (MMF) pit walls,
- Benched PAG (MF) pit walls, and
- Unbenched PAG (MF) pit walls.

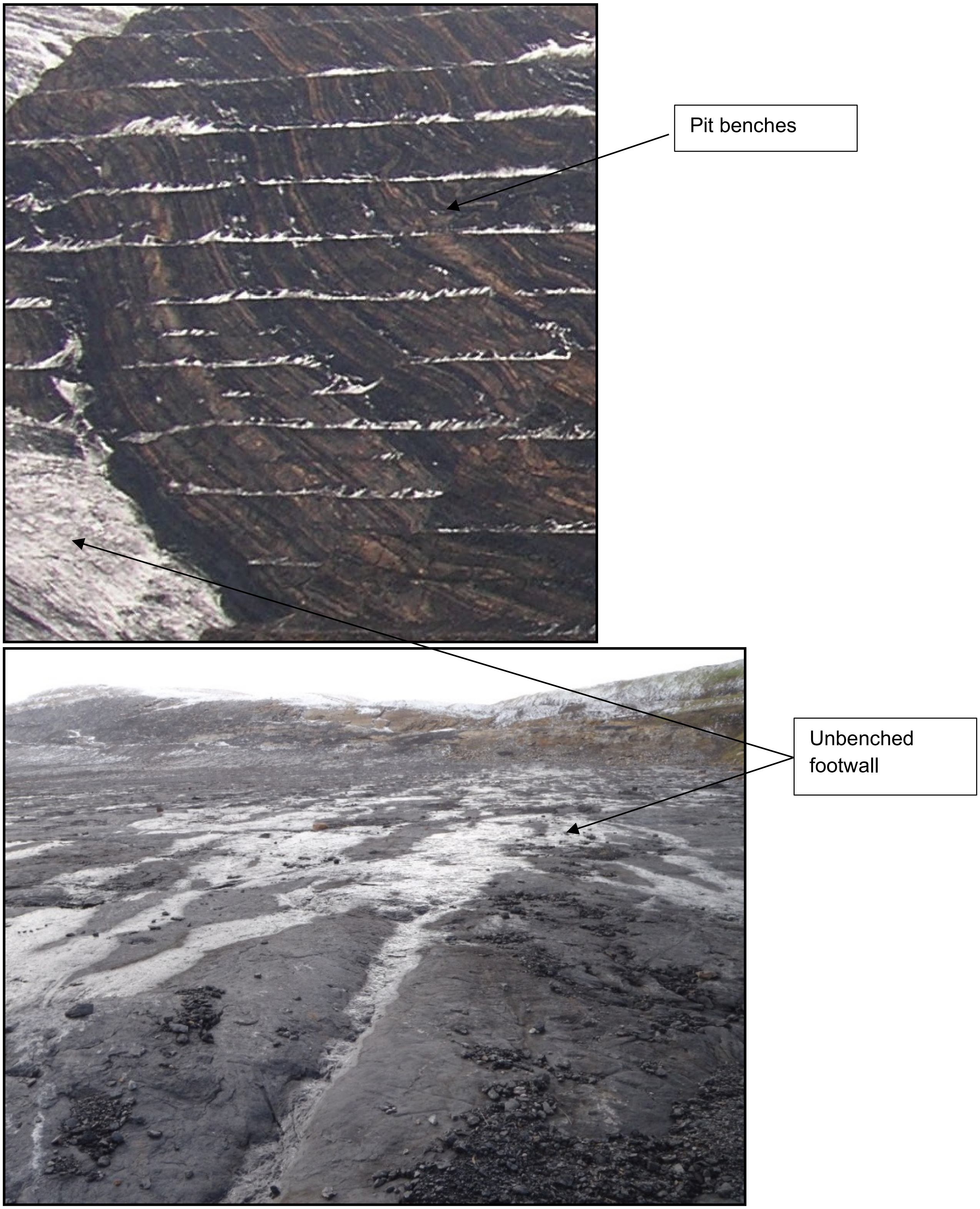

Figure 24. Examples of Benched and Unbenched Walls at LCO (top) and Bullmoose Mine, QCO (Bottom).

4.4 CGM for Submerged Waste and Saturated Rock Fills (SRFs)

As waste rock is submerged (for example, when placed in a backfilled flooding pit), soluble weathering products are not flushed by meteoric water (as described for unsaturated waste rock, Section 4.2) may be released to the water column. For the purpose of the source term, the flushing process is assumed to be instantaneous, though in practice a rapid initial flush can be expected following by slow flushing of residual load.

Following this flushing process, the rock oxidizes at much lower rates than occurs under subaerial conditions due to low concentrations of dissolved oxygen in water relative to atmospheric conditions. Therefore, for the purpose of source term calculations, load released under saturated conditions is considered to be zero. This is supported by literature describing subaqueous disposal as a technology to significantly limit sulphide mineral oxidation (INAP 2009).

Low oxygen (sub-oxic) conditions in the saturated zone of these backfilled pits potentially provide the opportunity for microbial reduction and therefore passive control of parameters with multiple oxidation states which in this context are mainly nitrate and selenium. Selenium has a strong propensity to be attenuated as its redox state decreases from selenate to selenite and further to elemental selenium and selenides. In addition, nitrate can be removed from contact waters by denitrification to nitrogen gas. While denitrification occurs slightly above selenium reduction in the redox ladder and is therefore energetically favoured, groundwater monitoring data from backfilled pits at FRO and EVO showed Se/SO_4 ratios consistent with 99% removal of selenium in the presence of nitrate concentrations ranging from 10 to 100 mg-N/L. It does not appear that denitrification blocks selenium reduction, but the reductive processes may compete for electrons so that the rate of selenium reduction may be slower in the presence of nitrate.

4.5 CGM for Active Saturated Rock Fills (SRF)

Active SRFs refers to the use of backfilled pits to actively treat nitrate and selenium by amendment with a labile carbon source such as methanol and nutrient source such as phosphoric acid. The current understanding of the performance of the F2 SRF at EVO and implications for the conceptual model are provided in SRK (2020a).

In the context of the 2020 update to the RWQM, the key points are that through microbially mediated reactions, carbon and phosphorus added to support the biological community are consumed completely and nitrate and selenium are treated to greater than 90% removal). Other COIs are mostly unaffected by the SRF except for changes due to mixing with existing groundwater in the SRF. These latter processes may result in lower or higher concentrations in the effluent compared to the influent.

Reductive dissolution of iron (III) and manganese oxides and oxyhydroxides within the treatment zone of the SRFs and leaching of adsorbed and co-precipitated elements has been identified as occurring in the F2 SRF due to the lowered redox potential resulting from the use of methanol to provide carbon for denitrification and selenium reduction. The parameter most affected by reductive dissolution is arsenic but other trace element such as cobalt and nickel might be released. At even lower redox potential, sulphate reduction and sulphide mineral precipitation may also occur within microenvironments in the SRF. Under these conditions, metals such as cadmium, cobalt, nickel and zinc might be co-precipitated. To minimize the effect of the lower redox reactions, performance monitoring of these parameters is used to inform carbon dosing and thereby control redox conditions within the SRF.

The effluent from active SRFs is also over-saturated with calcium carbonate also due to the use of methanol. Calcite precipitation occurs in the effluent buffer pond, discharge infrastructure and potentially within the rock drain environment and can be expected to sequester metals to some degree.

4.6 CGM for Re-handled Waste Rock

Re-handling of existing spoils and placement at a new location can occur as a result of pit expansions and construction of infrastructure. Prior to re-handling, waste rock may have been exposed to oxic conditions in ex-pit spoils resulting in accumulation of weathering products such as iron oxides and sulphate, or sub-oxic conditions in flooded pits. The latter could lack oxidation but may have secondary minerals formed under reducing conditions (e.g. elemental selenium).

When the re-handled spoil is exposed to infiltrating waters, oxidation and flushing of secondary minerals will occur and add to the load generated by ongoing weathering. This can result in a loading flush (Section 4.2.2).

4.7 CGM for Coarse Coal Rejects (CCR) and Coal Rejects (CR)

Coal rejects may be coarse coal rejects (CCR) produced at EVO, GHO, and FRO, or coal refuse (CR) mixed with fines as produced at CMO and LCO. Coal rejects are typically placed in small dedicated facilities constructed in short lifts and compacted.

Weathering processes in coal rejects are similar to waste rock; however, monitoring of gas concentrations in the Greenhills Area A CCR dump (Figure 10) has shown that oxygen penetration into coal reject dumps may be limited by oxygen-consuming reactions such as oxidation of organic carbon which is ubiquitous in plant rejects (SRK 2014, 2016). As a result, leaching is assumed to be a function of the footprint area of the coal rejects facilities, rather than their volume, with oxygen penetration occurring to a fixed depth.

In addition, the presence of coal fines in coal rejects indicates that reactive surfaces may serve to control trace element concentrations to low levels, and the presence of oxygen-limited conditions may limit selenium leaching by transformation to chemically reduced forms.

4.8 CGM for Coal Reject and Waste Rock Co-Disposal

The conceptual model for co-disposal of coal reject and waste rock needs to consider the co-disposal design due to the implications for oxygen concentrations. If coal rejects and waste rock are intimately co-disposed used conventional dumping methods, it is likely that oxygen concentrations will not be limited due to the coarse nature of waste rock. At the other extreme, engineering approaches like thick layers and pods of coal reject may allow sub-oxic conditions to develop thereby locally limiting oxidation of both rock and reject and allowing denitrification and selenium reduction to occur.

The monitoring data for CCR Area A at GHO (Figure 10) show that sub-oxic conditions developed within 10 m of the surface implying that a layer of CCR thicker than 10 m would limit oxidation of the CCR. Area “A” is constructed by conventional dumping of CCR. Measures to reduce oxygen diffusion rates such as increase in the fines content by using tailings and compaction to decrease pore spaces could lower the scale at which sub-oxic zones develop in coal rejects.

4.9 CGM for Tailings Impoundments

The wet carbon-rich conditions in tailings impoundments favour chemical reduction allowing oxygen to be removed resulting in development of sub-oxic to anoxic conditions. Denitrification and selenium reduction are expected to occur when sufficient labile carbon is available. Oxidation of pyrite in tailings is not expected to be an important except possibly in the immediate surface of dry tailings beaches.

Monitoring of groundwater downgradient of the FRO South Tailings Pond indicated removal of nitrate and selenium introduced to the pond by use of mine contact waters for coal processing (SRK 2017a). Follow-up studies (SRK 2019a, 2019d) confirmed this finding and showed through the use of stable oxygen and nitrogen isotopes in nitrate that denitrification is occurring. Detailed investigations of the facility showed that sub-oxic conditions exist and that reductive processes are likely occurring due to mediation by heterotrophic bacteria. There are periods in the monitoring data record where break through of nitrate and selenium is occurring during times when concentrations of these constituents increase in the FRO South Tailings Pond. It is postulated that labile carbon is the limiting reactant during these breakthrough periods; however, data needs to be collected to confirm this hypothesis. The CGM for tailings considers that denitrification and selenium reduction occurs but is constrained by the availability of organic carbon.

The source of organic carbon for the reductive processes may be the coal fines and organic process reagents such as frothers used to recover fine coal. The abundant carbon in coal fines is present as long-chain organic molecules that are resistant to breakdown and may not be available to provide labile carbon. Process reagents are immediately labile. The current conceptual model is that carbon is provided by process reagents and therefore that the stoichiometry of carbon required for denitrification needs to be considered when evaluating the role of tailings in removing nitrate and selenium. A further consideration is if waste rock contact waters containing nitrate are introduced to the pond without the organic carbon in process reagents (e.g., when the plant finishes operations, there may not be sufficient carbon for denitrification).

The current CGM indicates that these reductive processes are expected to occur at all tailings facilities that meet the following criteria

- The site is operational – In an operational site, chemistry is likely to be dominated by a mix of process waters, dam materials. A closed site is likely to be less influenced by process waters.

- The site has been in operation for several years – Age of the facility may have an impact on the strength and depth of reductive conditions.
- There is a labile carbon source available for heterotrophic denitrification which may be limited due to the chemistry of the process solution.

Dam size and construction with larger dams have a greater influence on chemistry.

5 Numerical Implementation Methods

5.1 Nomenclature and Definition of Symbols

The following sections describe methods used to calculate source terms for permanently exposed waste rock piles, pit walls and other waste components (i.e. re-handled waste rock, process rejects etc.). Each section provides the conceptual model for the indicated source term, which was then implemented in the calculation. Table 6 provides a summary of symbols used in equations provided.

Table 6. List of Symbols

Symbol	Units	Definition	Assigned Values
J	None	Constituent (e.g. sulphate).	-
R_j	mg/m^3/year	Rate of generation of parameter j from a bank cubic metre (bank m^3) of waste rock	Table 18
$V_{rock}(t)$	bank m^3 (BCM)	Equivalent in-situ volume of rock placed at disposal location in year t	Mine plan
V_{rock}	bank m^3 (BCM)	Equivalent in-situ cumulative volume of rock at a disposal location	Calculated
t_{HL}	years	Time adjusted hydraulic lag (time from waste placement to initial increase at monitoring station)	Table 15
t_{AL}	years	Leaching efficiency, or estimated time frame for which nitrate placed in any one year takes to exit the waste pile in seepage	Nominally estimated to be 10
L_j	mg/day	Calculated daily load of parameter j from waste rock	Calculated
$L_{i,j}$	mg/year	Initial calculation of load leached of parameter j from waste rock	Calculated
C_{s,SO_4}	mg/L	Solubility limit for sulphate as defined by gypsum solubility	Section 8.2.5
$M_{Mg/Ca}$	mol/mol	Average molar ratio of magnesium to calcium	Section 8.2.5
$C_{c,j}$	mg/L	Calculated annual pore water concentrations	Calculated
$L_{a,j}$	mg/year	Annual load of parameter j calculated from $C_{c,j}$ x $Q_{a\ j}$	Calculated
$p_{m,j}$	Unitless	Fraction of load of parameter j released in week m	Section 7.1.3
$L_{m,j}$	mg/week	Weekly load of parameter j calculated from $L_{a,j}$	Calculated
Q_d	L/day	Daily flow	Monitored/Interpolated
Q_a	L/year	Annual flow	Calculated
$p_{uncontacted}$	unitless	Fraction of rock not contacted by meteoric water	Estimated to be 0.5
$V_{flooded}$	bank m^3	Volume of rock inundated by water	Mine plan and water balance

Symbol	Units	Definition	Assigned Values
t_{flood}	year	Time when rock is flooded	Mine plan and water balance
$t_{placement}$	year	Time when rock is placed	Mine plan
$L_{uncontacted,j}$	mg	Mass leached by flooding of rock volume not contacted by meteoric water	Calculated
$L_{contacted,j}$	mg	Mass leached by flooding of rock volume contacted by meteoric water	Calculated
$L_{flush,j}$	mg	Total mass leached by flooding of rock	Calculated
A_{wall}	m^2	Area of pitwall	Mine plan
D	m	Reactive thickness of pitwall	Estimated at 2 m
V_{wall}	m^3	Reactive volume of pitwall	Calculated
P_f	kg/BCM	Powder factor	Provided by Operations
f_N	% as NO_3, NO_2 and NH_4	Nitrogen forms as provided by explosives products and recipes	Provided by Operations, calculated based on $(0.31*f_{anfo}+0.25*f_{emulsion})$.
f_R	%	Residual nitrogen	Estimated
$R_{M,HCT}$	mg/kg/week	Humidity cell metal release rate	Calculated
$R_{SO4,HCT}$	mg/kg/week	Humidity cell sulphate release rate	Calculated
MSRRR	mg/mg	Metal sulphate release rate ratio	Calculated
$L_{IS,J}$	mg/bcm/year	Initial soluble load of parameter J	Calculated
T_{PDW}	Year	Waste rock pre-deposition time	1 year
$M_{Se,oxic}$	mg/L	Selenium concentration of backfilled pit influent	Variable
$M_{Se,SRF}$	mg/L	Selenium concentration of backfilled pit effluent	Variable
$M_{NO3,oxic}$	mg/L	Nitrate concentration of backfilled pit influent	Variable
$M_{NO3,SRF}$	mg/L	Nitrate concentration of backfilled pit effluent	Variable
$C_{influent,x}$	mg/L	SRF influent concentration of parameter x	Variable
$C_{effluent,x}$	mg/L	SRF effluent concentration of parameter x	Variable
$f_{capture}$	%	Percentage of flow captured at SRF pumping wells	95%
$f_{in\text{-}situ}$	%	Expected percent capture of in-situ pit water at the pumping wells	5%
$C_{in\text{-}situ,x}$	mg/L	In-situ F2 concentration for constituent x as represented by C level wells	Variable
f_{sink}	%	1 - expected percent removal, or sink, within the SRF	90% (i.e. 10% removal)

5.2 Unsaturated Waste Rock

5.2.1 COI Inventory

The potential inventory (PI) was calculated using averages from the valley-wide static lithogeochemical database expressed as low (average – 95% confidence limit), average and high (average + 95% confidence limit).

The proportion of PI available for reaction (i.e. available inventory, AI) was calculated by combining the proportion of reactive particle size (Barbour et al. 2016) with size reduction due to gravitational crushing (Bard et al. 2013). The AI is expressed as low, expected and worst case using the following equations:

- Low AI = Low PI x 46%
- Expected AI = Average PI x 46%
- Worst Case = High PI x 92%

5.2.2 Ongoing Release

Waste rock placed in the spoil will weather and release constituent load to the downstream watersheds until the constituent is depleted or no longer physically available (i.e., locked in the matrix of the waste rock). The mechanism for release is parameter specific (SRK 2019a) and as such, the numerical implementation methods are also parameter specific. The numerical implementation methods for each parameter are provided in the following subsections.

Nitrate

The 2017 nitrate source term methodology was used for the current update. The 2017 RWQM source term estimated the delay between initial waste placement and the appearance of the corresponding nitrate at the monitoring stations. This time delay was termed initial time lag or t_{IL} (in years). This term is referred as the hydraulic lag t_{HL} in 2020 and is used subsequently in place of t_{IL}. The terminology was updated to more accurately reflect that the lag is effectively the time required for a particle of water infiltrating a spoil to reach the toe. In addition, the initial lag terminology is misleading because the lag reflects the average time for load to be leached from the spoil and it is an ongoing continuous and variable process. In particular, in younger spoils whose hydraulic regimes have not yet stabilized.

The apparent nitrogen loss factor was estimated accounting for the following variables:

- Waste placement schedules provided by Teck. The volume of waste delivered to the spoiling location as a function of time (V(t), BCM/year).
- The annual powder factor obtained from Teck. The quantity of explosives per volume of rock (Pf, kg/BCM). Pf may be a constant or vary by year. Teck began recording powder factors in the late 1970s. In locations where mining began earlier (e.g., FRO), the average powder factor, calculated based on the data record for each operation, was used.
- The proportion of nitrogen in all forms in the explosives (fN). fN depends on the product being used (either ANFO or emulsion mixture) and the percent N in the product. The explosive recipes, fN may be constant or vary by year. Information is obtained from each of the mine operations.
- The residual nitrogen remaining after detonation (fR). fR reflects the efficiency of utilization of explosives and is expected to be variable responding to changes in explosives types, blasting practices and blasting conditions (e.g. wet and dry holes) (Section 3.4.2). fR is operation specific and may vary as a function of time.

- The hydraulic lag to appearance of loading after waste is placed (t_{HL}). The variable t_{HL} is catchment -specific as described further below (Section 8.2.1).
- Average leach time (t_{AL}) expressed as the number of years for the explosives residuals to be released following t_{HL}. As pile geometry (and related net percolation, volumetric water content etc.) changes with time, t_{AL} will also change (Section 8.2.1).
- The volume of water and load bypassing each monitoring location downstream of each spoil.

The calculations steps for each catchment are as follows:

1. Calculate the potential NO_3 as N available for waste deposited in year n (mg/year):

$$N(n) = V(n) \cdot Pf(n) \cdot fN \cdot fR$$

2. Calculate the N released to drainage (mg/year) from waste placed in year n for each year beginning in $t = n+t_{HL}$ and continuing to year $n+t_{HL}+tAL$:

The equation in the second step distributes the potential N in waste placed in year n over t_{AL} years starting in year $n+t_{HL}$ until the potential N has been fully leached t_{AL} years later. This approach distributes the N load of several years rather than it instantaneously being leached out in a single year after the initial lag (t_{HL}) time is accounted for. The t_{AL} is nominally assumed to be 10 years for all waste rock piles.

Total load released in each year n is the sum of load released from all waste placed prior to the current year where the age of the waste is greater than t_{HL} and less than $t_{HL}+t_{AL}$.

Ammonium and Nitrite

Ammonium and nitrite were represented as monthly average ratios over ranges where detectable concentrations of ammonia and nitrite are reported, and ratios were observed to be stable. The ratios were established based on monitoring results downstream of the spoils. These ratios may be different than ratios observed in pit sumps, but the downstream monitoring locations are considered appropriate for estimating the ratios since they are applied at downstream locations in the RWQM.

The numerical implementation steps were as follows:

- Calculate NO_2^-/NO_3^- and NH_4^+/NO_3^- ratios as a timeseries for each drainage;
- Identify ranges in the ratios where nitrogen from explosives is evident (i.e., where nitrate concentrations were increasing); and
- Calculate monthly averages for the NO_2^-/NO_3^- and NH_4^+/NO_3^- ratios.

Sulphate and Selenium

The methods used to calculate catchment specific sulphate and selenium rates from unsaturated waste rock were similar to those used in the 2017 RWQM update. This includes estimating the hydraulic lag based on observed nitrate concentrations and calculating the sulphate and selenium release rates using empirical loadings of these constituents observed downstream of each spoil. Additional detail on the approach is provided in Section 7.3.1. The following modifications were made to the approach in the 2020 update:

- Natural catchment loads were removed from the dataset used to estimate release rates;
- Estimates of groundwater bypassing the monitoring locations were added to the measured flow rates to more accurately calculate the total catchment load upstream of the monitoring location;
- Operational water management influences were removed from the dataset used to estimate release rates; and
- Calculated selenium and sulphate release rates were normalized to account for annual flow differences.

Additional details on the source term derivation approach is provided in Section 7.3.1.

Input variables to develop the sulphate and selenium source terms included:

- Cumulative waste placed. The volume of waste at the spoiling location as a function of time ($\sum V(t)$, BCM) as provided by mine plans.
- Catchment specific sulphate and selenium release rate (R in g/BCM/year and mg/BCM/year respectively).
- The initial time adjustment to the appearance of loading after waste is placed (t_{HL}) as quantified in the nitrate source terms in the previous section.
- The volume of water bypassing monitoring locations downstream of the spoils.

The calculation for sulphate release to the drainage in year n follows:

$$\text{Sulphate Release (g/year)} = \text{RSO4}\cdot\sum V(n-t_{HL}).$$

Literally, the sulphate release to drainage in year n is the rate of release multiplied by the cumulative waste $n-t_{HL}$ years ago. A similar equation is used for selenium:

$$\text{Selenium Release (mg/year)} = \text{RSe}\cdot\sum V(n- t_{HL})$$

Solubility limits for gypsum could apply to the unsaturated waste rock sulphate source terms if concentrations were sufficient to support precipitation of gypsum (Section 8.2.5).

Cadmium, Cobalt and Nickel

Cadmium, cobalt and nickel source terms are based on the conceptual linkage of these parameters to sulphate based on their presence as chalcophile elements in the Elk Valley (i.e., their mobility is directly proportional to sulphide oxidation). This was evidenced through correlations of these parameters to other chalcophile elements (e.g., Zn, Figure 25). Therefore, as the volume of waste rock increases in a spoil, the load of these parameters also increases.

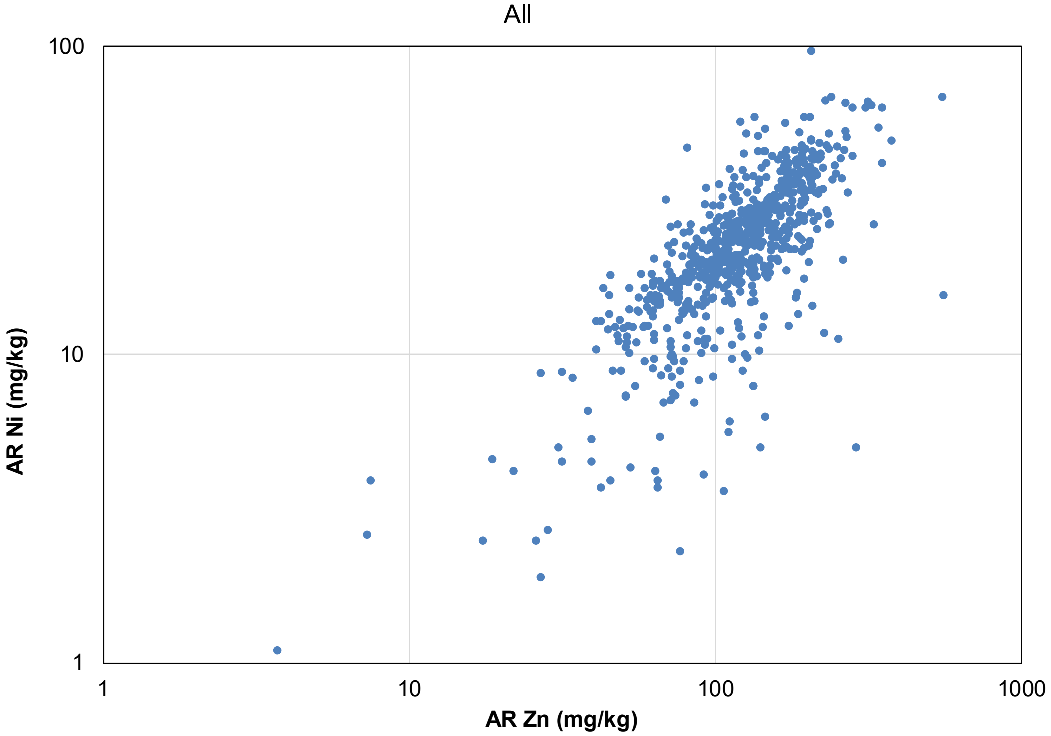

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Figure 25. Aqua Regia Digest Nickel Concentrations versus Aqua Regia Digest Zinc Concentrations – Fording River Operations Data

The cadmium, cobalt and nickel source terms from spoils (R_M in mg/bcm/yr) is obtained from:

$$\mathrm{R_M} = MSRRR \times \mathrm{R_{SO_4}}$$

$\mathrm{R_{SO_4}}$ (mg/bcm/yr) is the catchment specific release rate for sulphate. The metal sulphate release rate ratio (MSRRR, $\left(\frac{\bar{\mathrm{R}}_{\mathrm{M,HCT}\ (\mathrm{mg/kg/week})}}{\bar{\mathrm{R}}_{\mathrm{SO_4,HCT}\ (\mathrm{mg/kg/week})}}\right)$) is the average of the rates (R) observed in humidity cells and reflects the proportion of PAG (P_{PAG}):

$$\left(\frac{\bar{\mathrm{R}}_{\mathrm{M}}}{\bar{\mathrm{R}}_{\mathrm{SO_4}}}\right)_{\mathrm{HCT}} = \frac{\mathrm{R_{M,HCT,PAG}P_{PAG}+R_{M,HCT,\ non\text{-}PAG}(1\text{-}P_{PAG})}}{\mathrm{R_{SO_4,HCT,\ PAG}P_{PAG}+R_{SO_4,HCT,non\text{-}PAG}(1\text{-}P_{PAG})}}$$

$R_{M,HCT\ PAG}$ and $R_{SO_4,HCT,\ PAG}$ are different depending on the implementation of PAG management practices. MSRRR will be higher prior to implementation of PAG management practices. Source terms were developed for both pre- and post-implementation of PAG management practices.

The source term accounts for the proportion of Morrissey Formation (i.e., PAG) rock that has or will be placed in each spoil. Humidity cell tests of Mist Mountain and Morrissey Formations from each of the operations (Section 6.2) were used to develop the source term. The humidity cell results were incorporated into the source term as follows:

- Assign the humidity cells to Morrissey and Mist Mountain Formation groups;
- Calculate P_{50} and P_{95} long-term release rates for cadmium, cobalt, nickel and sulphate in each formation;
- Calculate P_{50} and P_{95} metal to sulphate release rate ratios (MSRRR); and
- Estimate the MSRRR for 0 to 30% MF in the spoil for pre- and post-PAG management strategies.

The release rate ratios were provided for a range of percentages of MF. This approach was selected so the source term could be built into the 2020 RWQM as a look-up table and applied globally to several locations with varying amounts of MF waste rock in each spoil.

A key assumption in the source term derivation is that PAG management strategies will result in non-acidic drainage from all of the spoils and there will be no localized “hot spots” with sufficient PAG rock to depress the pH and increase metal release. To account for this in the source term, MF humidity cells with pH values less than 6 were used to calculate the MSRRR prior to PAG management. MF humidity cells with pH values greater than 6 were used in the calculations of the post-PAG management MSRRRs.

Uranium

The uranium/sulphate (U/SO_4) ratios are generally constant at monitoring locations downstream of spoils. Figure 26 provides an example from GH_GH1. The U/SO_4 ratio was used to estimate uranium concentrations based on sulphate concentrations.

The numerical implementation steps to derive the U/SO_4 ratio were as follows:

- Calculate U/SO_4 as a timeseries for each drainage;
- Identify ranges in the ratios where the ratio is not influenced by elevated detection limits, which can be abundant in historical monitoring records; and
- Calculate the monthly U/SO_4 averages for each drainage.

The uranium source term was calculated as the monthly average U/SO_4 ratio. The ratios are catchment specific.

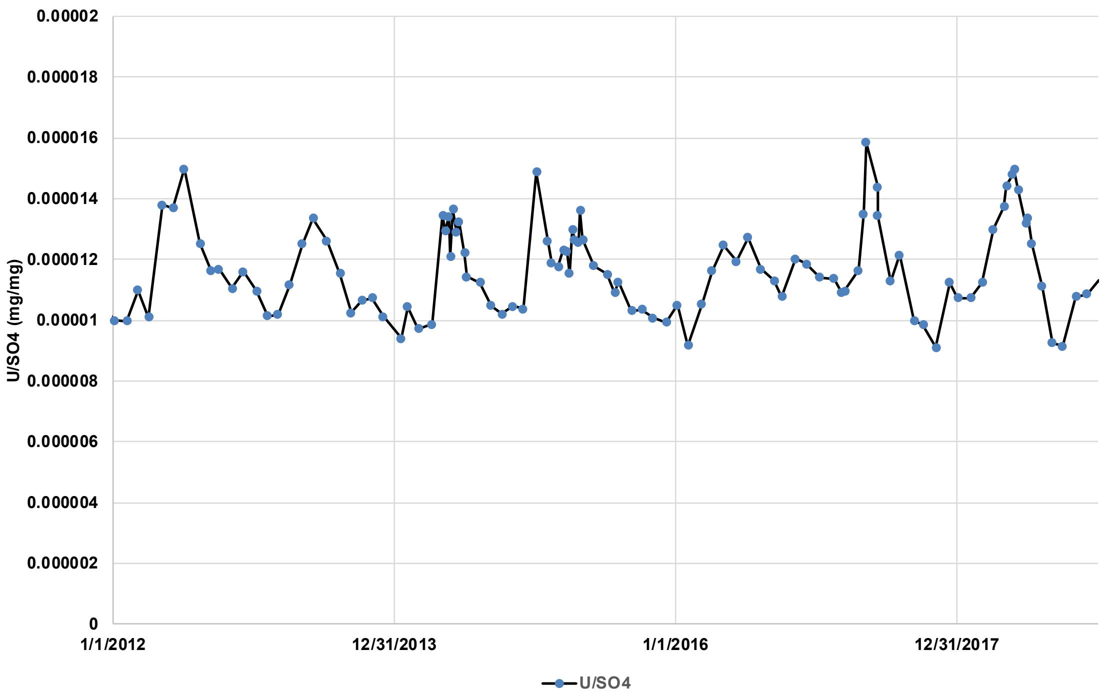

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Figure 26. U/SO_4 at GH_GH1

Other Non-Order Parameters

Source terms were also developed for non-order parameters arsenic, chromium, manganese and phosphorus. These parameters have not demonstrated persistent increasing trends at monitoring locations downstream of the spoils and constant concentration source terms were derived following similar methods in 2014 and 2017. Catchment specific monthly average source term concentrations were calculated for each of these constituents. P90 concentrations were also calculated to provide to assess uncertainty in the input concentrations.

5.2.3 Initial Soluble Load

Rock exposed in pit benches can oxidize prior to, and during blasting. This load my be flushed out in the pit from incident precipitation; however, mass that remains in the waste rock will be flushed out following placement in the spoil. This load is referred to as the initial soluble load.

The initial soluble load was calculated as follows:

$$L_{IS_J}=T_{PDW}\times\bar{R}_J\times T_{AL}\times V_n$$

Where: L_{IS_J}= initial soluble load of parameter J

T_{PDW}= Pre-deposition weathering time

$\bar{R}_j$= valley wide average release rate of parameter J

T_{AL}= Adjusted leach rate

V_n= Volume of blasted waste rock

5.2.4 Decay in Release

Loading rates in humidity cell tests indicate that sulphate and selenium release rates decrease as sulphide is depleted (Figure 27).

Decay rates were calculated assuming first-order decay model for humidity cell rates. Long term humidity cell loading rates from waste rock samples at LCO were selected to evaluate long-term changes to loading rates as sulphide is depleted. These cells were initiated to evaluate selenium release rates using waste rock from Line Creek Operations and consisted of six waste rock humidity cell tests. Four of these cells, which ran for extended periods of time (e.g., 282 to 480 weeks) were used to evaluate long-term rates.

The decay rate was estimated by calculating the rate constant k for the following equation:

$$\frac{dm}{dt} = -km$$

Where: $\frac{dm}{dt}$ is the change in rate as a function of time

-k is the rate constant in units of t^{-1}; and

m is the mass remaining

To develop a source term that can be implemented in the 2020 RWQM, the rate constant (k) was estimated based on observed trends in the humidity cell test loading rates as a function of the percent of the initial mass remaining. The source term is then presented as the percent reduction in rate over time.

The source term is based on the decay of sulphate in the humidity cell and is applied to other parameters. Parameter specific decay rates were not calculated since there may be attenuation mechanisms influence the loadings of these parameters in the humidity cell tests that are not scalable to full scale conditions. Sulphate is expected to behave conservatively, and the decay rate is more appropriately scaled to site conditions.

The following processing steps were completed to derive the source term:

1. **Interpolate humidity cell loading rates.** The frequency of sulphate analysis in the humidity cell test decreased as testing continued. However, samples are still collected weekly. To account for mass removed on weeks when samples were not analyzed, rates were linearly interpolated between weeks with measured values.

2. **Remove the effects of initial flushing in the humidity cell tests**. Release rates in early time humidity cell test results are dominated by flushing of readily soluble oxidation products. Assuming there are no soluble sulphate minerals (e.g., gypsum) in the test charge, the sulphate production occurs from sulphide oxidation once the initial flush is removed. Including the initial flush in the rate constant calculations will exaggerate the decay rate. Therefore, the initial mass, when sulphate is produced from sulphide oxidation, was calculated after the initial flush is removed. The timing to removal of the initial flush was estimated visually as week 19 for sulphate and week 35 for selenium. Figure 28 provides the post-initial flush sulphate and selenium release rates that were considered in the first-order decay rate calculations.

3. **Regress the log of the mass remaining as a function of time**. The slope of the regression is the decay constant (k).

4. **Estimate the decrease in sulphate release rate over time.** The decay rate is expressed as percentage of the initial rate over time using the rate constant after integrating the above formula to express mass remaining as a function of time.

To account for variability in the decay rates in each of the humidity cells, average, high and low source terms using the minimum, maximum and average decay rate constants, as estimated based on the humidity cell test results.

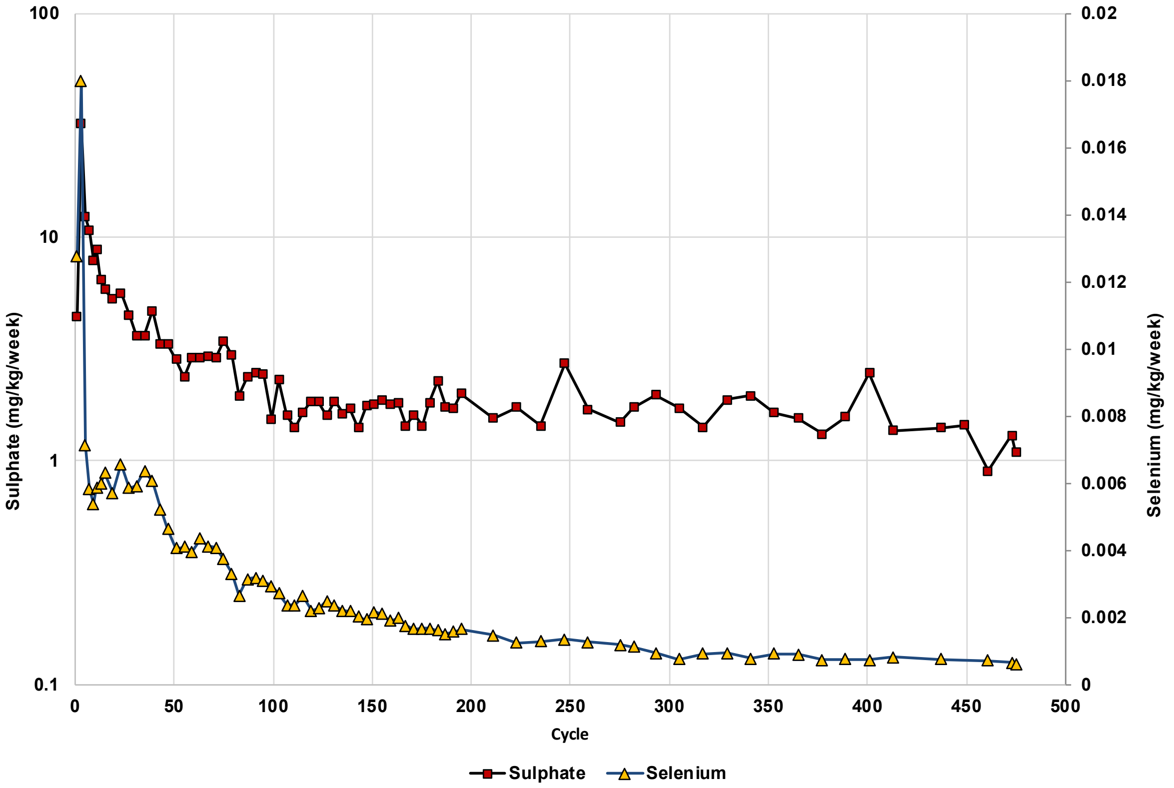

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Figure 27. Sulphate and Selenium Release Rates – LCO HC-19

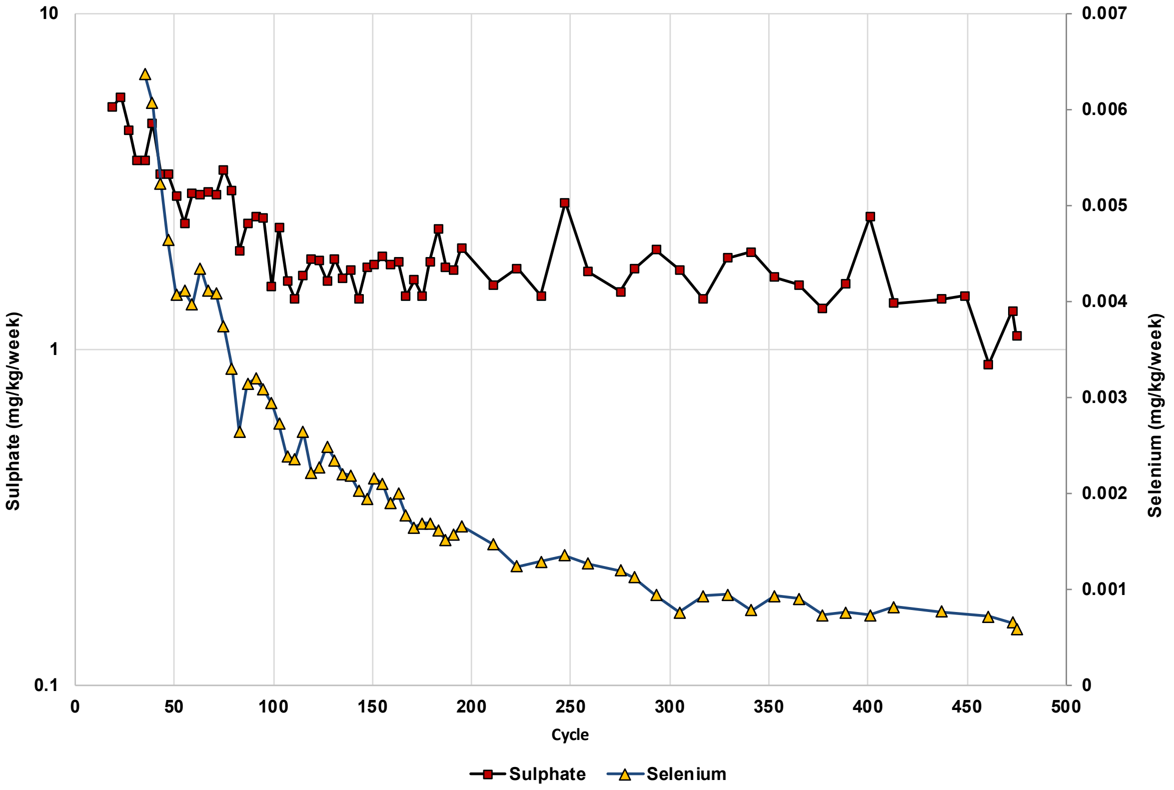

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Figure 28. Post-Initial Flush Sulphate and Selenium Release Rates – LCO HC-19

5.3 Pit Walls

All Walls

The method calculating the nitrate source term for benched pitwalls is the same as that for exposed waste rock, except as noted in Section 4.3, for two key aspects:

- There is no time delay associated with hydrological processes assumed for leaching of blasting residues from pit walls, and
- The volume of rock is calculated from the exposed area of the walls (Awall) and an assumed reactive surface thickness (d) as follows:

$$V_{wall} = A_{wall} \cdot x\ d$$

Exposed seam footwalls in pit floors (i.e., non-benched pit walls) tend to be composed of shales that may be more reactive than waste rock; however, the footwall is not blasted and is therefore not fractured to the same degree as walls in interburden rocks. Using V_{wall} to calculate leaching of the footwall is therefore considered to be conservative.

The thickness depth (d) was set at 2 m, which is a typical overblast depth for mining in the Elk Valley.

The estimate of loss factors for the purposes of this evaluation are assumed to be the same as for waste rock (Section 8.2.1) and nitrogen species are assumed to be mostly in the form of nitrate.

Benched Non-PAG Pit Walls

Source terms for sulphate and selenium for benched non-PAG pit walls are similar to unsaturated waste rock except there was no time delay component assumed. Inputs to sulphate and selenium source term calculations include:

Sulphate and selenium release rate (R in g/BCM/year, mg/BCM/year, respectively) as indicated for unsaturated waste rock.

Reacting volume of rock (V_{rock}) in m^3 is calculated from the exposed area of the walls (A_{wall}) in m^2 and an assumed reactive surface thickness (d) in m:

$$V_{rock} = A_{wall} \times d$$

- Concentration is determined using incident precipitation to provide a flow:

$$C_j = \frac{R\ V_{Rock}}{Q}$$

As with the waste rock source terms, solubility limits for gypsum could apply to the pit wall source terms if concentrations were sufficient to support precipitation of gypsum.

COI's other than sulphate and selenium were calculated using average stable rates from MMF humidity cell testing at CMO, EVO, CMO2 and GHO.

Benched PAG Pit Walls

Benched PAG pit wall source terms were developed using the following inputs:

- Average stable release rates under acidic conditions for humidity cell testing at CMO, EVO and LCO.
- Concentrations observed in on-site barrel tests which produced acidic leachate at CMO and GHO.

The latter dataset is expected to provide a reasonable proxy for actual pit wall rubble because the flowpath length in a barrel is of the same order-of-magnitude as pit wall rubble.

Unbenched Pit Walls

The source term for unbenched benched walls is calculated using the same method as for benched walls except that R is derived from humidity cells (appropriately scaled from laboratory to field conditions) and d is reduced to a low nominal value to reflect the thin reacting surface.

5.4 Submerged Waste

The one time load of sulphate, selenium and nitrate (Luncontacted,j, in mg) flushed from uncontacted parts of rock mass volume (Vflooded, in BCM) as they are inundated has not changed from previous source term updates (SRK 2017), specifically the load is calculated as:

$$L_{\mathrm{uncontacted},j}=p_{\mathrm{uncontacted}} \cdot V_{\mathrm{flooded}} \cdot R_j \cdot (t_{\mathrm{flood}} - t_{\mathrm{placement}})$$

where $p_{\mathrm{uncontacted}}$ is the proportion of rock not contacted by meteoric water, t_{flood} (year) is the time when flooding occurs and $t_{\mathrm{placement}}$ (year) is the time when the rock was placed so that (t_{flood}-$t_{\mathrm{placement}}$) is the time in years since exposure by mining.

The load flushed from contacted areas ($L_{\mathrm{contacted},j}$ in mg) is:

$$L_{\mathrm{contacted},j}=(1-p_{\mathrm{uncontacted}}) \cdot V_{\mathrm{flooded}} \cdot R_j \cdot \left(t_{\mathrm{flood}} - t_{\mathrm{placement}}\right) - \sum_{a=t_{\mathrm{placement}}}^{a=t_{\mathrm{flood}}} L'_{a,j}$$

This expression is based on total load generated less the load removed by infiltrating water. For sulphate, this load may be zero if all concentrations are less than C_{s,SO_4}.

Total load released by flushing ($L_{\mathrm{flush},j}$, in mg) was calculated from:

$$L_{\mathrm{flush},j} = L_{\mathrm{uncontacted},j} + L_{\mathrm{contacted},j}$$

5.5 Passive Saturated Rock Fills

Selenium attenuation is expressed as a proportional reduction relative to influent selenium loading ($M_{Se,oxic}$):

$$\text{Se Attenuation Factor } (k_{Se}) = \frac{M_{Se,SRF} - M_{Se,Oxic}}{M_{Se,Oxic}}$$

The mass of selenium leaving the passive SRF is therefore:

$$M_{Se,SRF} = M_{Se,OXIC}(1+k_{Se})$$

A similar equation can be used to calculate nitrate removal:

$$M_{NO3,SRF} = M_{NO3,OXIC}(1+k_{NO3})$$

The attenuation factors (k) for Se and NO_3 are negative. For all other parameters, including SO_4, attenuation factors are assumed to be 0 (i.e. the SRF does not influence the mass).

5.6 Active Saturated Rock Fills

The source term for active SRFs, at the time of this update to the 2020 RWQM, were limited to those for the EVO SRF Phase 2 Project which were provided in SRK (2020b) and in Teck (2020e). The source terms are provided as effluent concentrations which were projected by simulating the effects of operating the EVO SRF to the projected influent water quality using the 2020 RWQM as presented in Teck (2020e). To account for the expected changes in concentrations due to the SRF, the following steps were added to the model calculations:

1. Timeseries of influent concentrations were provided for each constituent based on the methods described in Teck 2020e (Section 5.3.2).
2. The trailing 74 day average concentration of the influent timeseries was calculated to account for variable travel or hydraulic resident times through the SRF (i.e., the SRF is expected to have a range of travel or resident times, with some influent water passing through quickly and other influent water taking over two months to pass though the SRF; thus the effluent from the SRF is assumed to be a mixture of the influent that entered the SRF for the preceding 74 days (SRK 2020b and 2020c).
3. Calculated averages were mixed with 5% of the in-situ water from F2 Pit (SRK 2020b) as represented by the equation below. For this calculation the 50th percentile of the observed data in C level monitoring wells (i.e., the monitoring wells located just below the treatment zone in the SRF) monitored during the Phase 1 Trial was used to represent the in situ F2 water quality being extracted along with the treated water.

$$C_{effluent,x}=((C_{influent,x} \times f_{capture}) + (C_{in\text{-}situ,\ x} \times f_{in\text{-}situ})) \quad \text{[Equation 1]}$$

   Where:

   $C_{effluent,x}$ = effluent concentration for constituent x
   $C_{influent,x}$ = influent concentration for constituent x
   $f_{capture}$ = expected percent capture of influent at the pumping wells, or 95%
   $C_{in\text{-}situ,\ x}$ = in-situ F2 concentration for constituent x as represented by C level wells
   $f_{in\text{-}situ}$ = expected percent capture of in-situ F2 pit water at the pumping wells, or 5%

4. The influence of chemical additions and/or processes within the SRF were applied (either as a fixed concentration or as an equation dependent on the concentrations calculated using the steps above) to the constituents expected to change due to operation of the SRF (SRK 2020b). This includes:
   (a) Carbon added as methanol and phosphorus nutrients dosed into the SRF to support microbial reactions are consumed within the SRF. Effluent predictions are based on effluent monitoring through the Phase 1 Trial.

(b) Nitrate and selenium removal efficiency is assumed to be 90% with effluent representing 10% of the influent concentrations based on a conservative interpretation of the performance monitoring data collected through the Phase 1 Trial.

(c) Alkalinity source term accounts for 3.6 mg/L as HCO_3 produced for every 1 mg/L NO_3-N removed (US EPA 2009).

(d) Other redox sensitive species such as dissolved oxygen, iron and manganese were based on performance monitoring through Phase 1 of the Trial, as were associated parameters of interest such as arsenic and molybdenum.

(e) Trace metals such as cadmium, cobalt, nickel and zinc included a ‘sink’ function based on performance monitoring through Phase 1 of the Trial as described in SRK 2020b and accounted for as f_{sink} in the equation as given below.

$$C_{\text{effluent},x}=((C_{\text{influent},x}\times f_{\text{capture}}\times f_{\text{sink}})+(C_{\text{in-situ},\ x}\times f_{\text{in-situ}})) \qquad \text{[Equation 2]}$$

Where:

$C_{\text{effluent},x}$ = effluent concentration for constituent x
$C_{\text{influent},x}$ = influent concentration for constituent x
f_{capture} = expected percent capture of influent at the pumping wells, or 95%
f_{sink} = 1 - expected percent removal, or sink, within the SRF, or 90% (i.e. 10% removal)
$C_{\text{in-situ},\ x}$ = in-situ F2 concentration for constituent x as represented by C level wells
$f_{\text{in-situ}}$ = expected percent capture of in-situ F2 pit water at the pumping wells, or 5%

5.7 Re-handled Waste Rock

The source term for re-handled waste rock has not changed from SRK (2017a). Flushed load from re-handled waste rock was calculated using data obtained from water extraction tests (shake flask extraction, Price 1997) performed on legacy waste (waste rock, tailings, CCR, hot waste) samples from the Swift Project area at FRO (SRK 2014d). The load was calculated from the concentration in the extraction test multiplied by the volume of leachate divided by the volume of sample tested to yield load released on a one-time basis when re-handled in mg/BCM of waste moved.

For legacy waste rock, the load released was reduced by a generic factor 0.2 based on experience to account for the difference in particle size used in the extraction test (-2 mm) compared to run of mine waste rock.

5.8 Coal Rejects

The source term for CCR consists of fixed concentrations applied to all infiltrating waters, based on the conceptual model and empirical data (Section 4.7, SRK 2012, 2013). As a result, loadings are a function of assumed infiltration.

5.9 Co-disposed Waste Rock and CCR

The source term for co-disposed waste rock and CCR (i.e., waste rock and CCR deposited in the same spoil) is calculated from the sum of waste rock rates and CCR weathering rates under fully atmospheric conditions. No site drainage data are available from which to calculate release rates for co-disposed CCR under site conditions. Co-disposed CCR release rates are therefore based on laboratory rates indicated by humidity cells (for example, SRK 2013).

Laboratory rates were decreased by a factor to account for the lower temperatures onsite, and decreased by a conventional generic factor of 50% ($p_{uncontacted}$) to allow for incomplete contact with infiltrating water (Section 8.9). This approach is supported by site-specific data on scaling factors (Kennedy et al. 2012) and is near the high end of the range reported by Kempton (2012).

5.10 Tailings

Monitoring data indicate that denitrification and selenium reduction occur in seepage from tailings (Section 4.9). Nitrate and selenium source terms for tailings was derived from existing monitoring data from ground water wells and seepage of the FRO's tailings facilities. This facility has the largest monitoring dataset and also represents the largest tailings facility in terms of constituent loading to the valley. The monitoring dataset was also used to identify when denitrification and selenium reduction was limited to account for breakthrough of these constituents. The predicted concentrations of all other constituents were used to represent the tailings seepage source term.

6 Databases Used to Derive Inputs

6.1 Static Lithogeochemical Database

A database of all static geochemical data collected for Teck's coal mines in the Elk Valley was compiled for all studies completed by Teck since approximately 2004.

Most static data consisted of acid base accounting (ABA) which included paste pH, total sulphur (Leco), sulphate (hydrochloric acid or HCl leach), total carbon (Leco), total carbonate (Leco), modified Sobek NP (Lawrence and Wang 1996), and trace elements using aqua regia digestion followed by inductively coupled plasma mass spectrometry (ICP-MS) finish (Table 7). Other types of static data completed on a sub-set of the database included mineralogy (XRD with Rietveld refinement), shake flask extraction (Price 1997) and meteoric water mobility procedure (NDEP 1997) and fluorine measured using ion chromatography.

Samples were coded based on mine location, formation and lithology which enabled comparison between sites. As shown in Figure 2 to Figure 5, the database consists of approximately 4500 samples from the MMF, 720 samples from the MMM, 120 samples from the WRM and 240 samples from the FF.

Table 7: Trace Elements digested using Aqua Regia and Measured with ICP-MS

Parameter	Unit	Detection Limit[1]
Mo	mg/kg	0.01
Cu	mg/kg	0.01
Pb	mg/kg	0.01
Zn	mg/kg	0.1
Ag	ppb	2
Ni	mg/kg	0.1
Co	mg/kg	0.1
Mn	mg/kg	1
Fe	%	0.01
As	mg/kg	0.1
U	mg/kg	0.05
Au	ppb	0.2
Th	mg/kg	0.1
Sr	mg/kg	0.5
Cd	mg/kg	0.01
Sb	mg/kg	0.02
Bi	mg/kg	0.002
V	mg/kg	2
Ca	%	0.01
P	%	0.001
La	mg/kg	0.5
Cr	mg/kg	0.5
Mg	%	0.01
Ba	mg/kg	0.5
Ti	%	0.001
B	mg/kg	20
Al	%	0.01
Na	%	0.001
K	%	0.01
W	mg/kg	0.05
Sc	mg/kg	0.1
Tl	mg/kg	0.02
Hg	ng/kg	5
Se	mg/kg	0.1
Te	mg/kg	0.02
Ga	mg/kg	0.1
S	%	0.02

Source: Bureau Veritas Laboratories, standard detection limits

Notes:

[1] Current detection limits

6.2 Kinetic Geochemical Database

Collection of kinetic weathering data has occurred in conjunction with static data since approximately 2004. The database consists of test results from humidity cells, barrel tests and leach pads.

A total of 62 humidity cell tests (HCTs) were included in the database (Table 8). All HCTs were completed using the ASTM (2001) method which flushes the cell at a 1:1 water to solid ratio on a weekly basis.

Table 9 summarizes on-site barrel tests by site. Leaching of barrel material is designed to mimic natural conditions and chemistry data along with water volume are collected on a monthly basis. Parameters and detection limits for HCT and barrel testing are provided in Table 10.

Six leach pads at LCO were also included in the database and were monitored from 2009 to 2016. Leachate from the piles proceeds through a collection drain. Water flow is measured using a tipping bucket system, and a plastic pail is used to collection water for sampling. Samples are taken once a month. For all facilities, field measurements of pH, temperature, conductivity, dissolved oxygen, flow, and oxidation reduction potential (ORP) were taken. Laboratory analysis included all site measurements (with the exception of flow) and parameters listed in Table 10.

Table 8. Summary of Humidity Cell Tests by Site

Formation/Material Type	FRO	GHO	LCO	EVO	CMO	CMO2
MMF		2	6	4	2	2
MF[1]		3				
MMM		2	5	3	2	2
WRM					2	
FF		2		2	2	
Rejects	4	1	2		1	2
Tailings	7					
Coal			4			
Total	**11**	**10**	**17**	**9**	**9**	**6**

Source: D:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.195_Historical_Geochem\!020_Project_Data\010_SRK\EV_KineticTestSummary_1CT017.195_ld_rev00.xlsx

Notes: [1] indicates sample is undifferentiated between the MMM and WRM members of the MF

Table 9. Summary of On-Site Barrel Tests by Site

Formation/Material Type	FRO	GHO	LCO	EVO	CMO	CMO2
MMF		2	10		2	
MF[1]		3				
MMM		2			2	
WRM					2	
FF		2			2	
Rejects		2	2			
Tailings						
Coal			2			
Total	**0**	**9**	**12**	**0**	**8**	**0**

Source: D:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.195_Historical_Geochem\!020_Project_Data\010_SRK\EV_KineticTestSummary_1CT017.195_ld_rev00.xlsx

Notes: [1] indicates sample is undifferentiated between the MMM and WRM members of the MF

Table 10: Summary of Kinetic Test Parameters

Parameter	Units	Reported Detection Limit (HCT and Barrels)[1]	Reported Detection Limit (Leach Pads) [2]
pH	pH Units	--	
EC	uS/cm	1	
ORP	mV	5	
SO_4	mg/L	0.5	0.3
Acidity to pH 4.5	mg $CaCO_3$/L	0.5	1
Acidity to pH 8.3	mg $CaCO_3$/L	0.5	1
Total Alkalinity	mg $CaCO_3$/L	0.5	1
Nitrate-N	mg/L	0.02	0.05
Nitrite-N	mg/L	0.005	0.01
Total Ammonia	mg/L	0.005	0.005
P	mg/L	0.005/0.003	0.002
TOC	mg/L	--	0.5
DOC	mg/L	--	0.5
Ortho- PO_4	Mg/L	--	0.001
Br	mg/L	--	1
Cl	mg/L	--	1
F	mg/L	--	0.2
Hardness $CaCO_3$	mg/L	0.5	0.5
Al	mg/L	0.003	0.003
Sb	mg/L	0.00002	0.0001
As	mg/L	0.00002	0.0001
Ba	mg/L	0.00002	0.00005
Be	mg/L	0.00001	0.0001
Bi	mg/L	0.000005	0.00005
B	mg/L	0.05	0.01
Cd	mg/L	0.00005/0.000005	0.000005
Ca	mg/L	0.05	0.05
Cr	mg/L	0.0001	0.0001
Co	mg/L	0.000005	0.0001
Cu	mg/L	0.0003	0.0005
La	mg/L	0.00005	--
Fe	mg/L	0.005	0.01
Pb	mg/L	0.00005	0.00005
Li	mg/L	0.0005	0.001
Mg	mg/L	0.05	0.1
Mn	mg/L	0.0002	0.0001
Hg	mg/L	0.00001	0.000005
Mo	mg/L	0.00005	0.00005
Ni	mg/L	0.0002	0.0005
K	mg/L	0.05	0.05
Rb	mg/L	0.00005	--

Parameter	Units	Reported Detection Limit (HCT and Barrels)[1]	Reported Detection Limit (Leach Pads) [2]
Se	mg/L	0.00004	0.05
Si	mg/L	0.1	0.05
Ag	mg/L	0.000005	0.00001
Na	mg/L	0.05	0.05
Sr	mg/L	0.0003	0.0002
S	mg/L	10	--
Te	mg/L	0.00002	--
Tl	mg/L	0.000002	0.00001
Th	mg/L	0.000005	--
Sn	mg/L	0.002	0.0001
Ti	mg/L	0.0005	0.01
W	mg/L	0.00001	--
U	mg/L	0.000002	0.00001
V	mg/L	0.0002	0.0005
Zn	mg/L	0.001	0.003
Zr	mg/L	0.0001	--

[1] Source: Bureau Veritas Laboratories, [2] ALS Laboratories (2016)

Note: All parameters are dissolved, -- indicates not measured.

6.3 Historical Mine Development Information

In 2019, Teck completed a waste rock reconciliation to account for differences between historically compiled data versus surveyed volumes. This reconciliation resulted in some important differences in volumes in some drainages between the SRK (2017a) and 2020 RWQM updates. In addition, some years were reported as having negative volumes in the data record. This occurred because either the waste rock was re-handled or the catchment of the spoil changed (i.e., the waste rock was identified to be in a neighboring catchment). The negative volumes of waste rock did not result in any of the cumulative spoil volumes being less than zero.

Waste rock volumes up to the end of the 2018 were used in the derivation of source terms. This date was selected because year end 2019 volumes were not available at the time the source terms were developed in Q3 of 2019. Waste rock volumes for each operation are provided in the 2020 RWQM overview report.

6.4 Surface Water Chemistry and Flow

6.4.1 Datasets

The following datasets were the basis for inputs developed for the source-terms:

- Water quality data for monitoring points downstream of waste rock dumps.
- Accompanying flow data for the same locations.

The database used for the 2017 RWQM source term development was updated as part of the 2020 update. Effectively, this adds two years of data. For new parameters that were included in the 2020 update (e.g., uranium) the entire data record for each location was used for the source term development for that parameter. Data were excluded from the calculations where detection limits appeared to be elevated in the historical data record. To avoid bias in the source terms, elevated detection limits were not carried forward into statistical calculations and more recent data was used in the source term derivation due to improved detection limits and data QA processes.

6.4.2 Drainage Areas

Monitoring data at the following monitoring points were used in the development of source terms:

- FRO: FR_CC1, FR_HC1, FR_KC1, GH_CC1, GH_SC1/2
- GHO: GH_GH1, GH_LC2 GH_PC1, GH_TC1, GH_WC2
- LCO: LC_WLC, LC_LCUSWLC
- EVO: EV_BC1, EV_DC1, EV_EC1, EV_GT1, EV_HC1
- CMO: CM_CC1

The location of these monitoring points is provided in Figure 29.

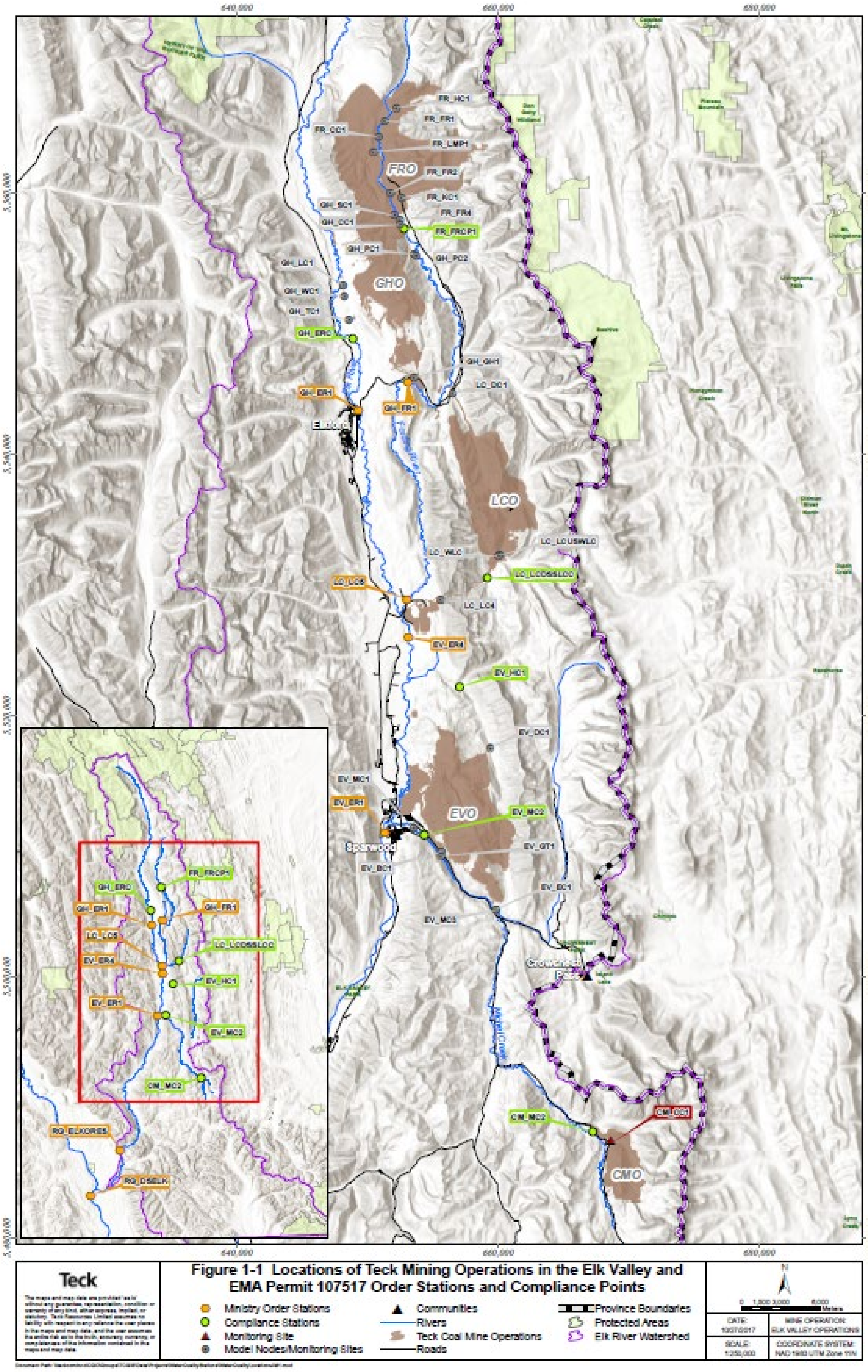


Figure 29. Location of Elk Valley Operations (map from SRK 2017)

6.4.3 Description of Datasets

Handling of Duplicate Values

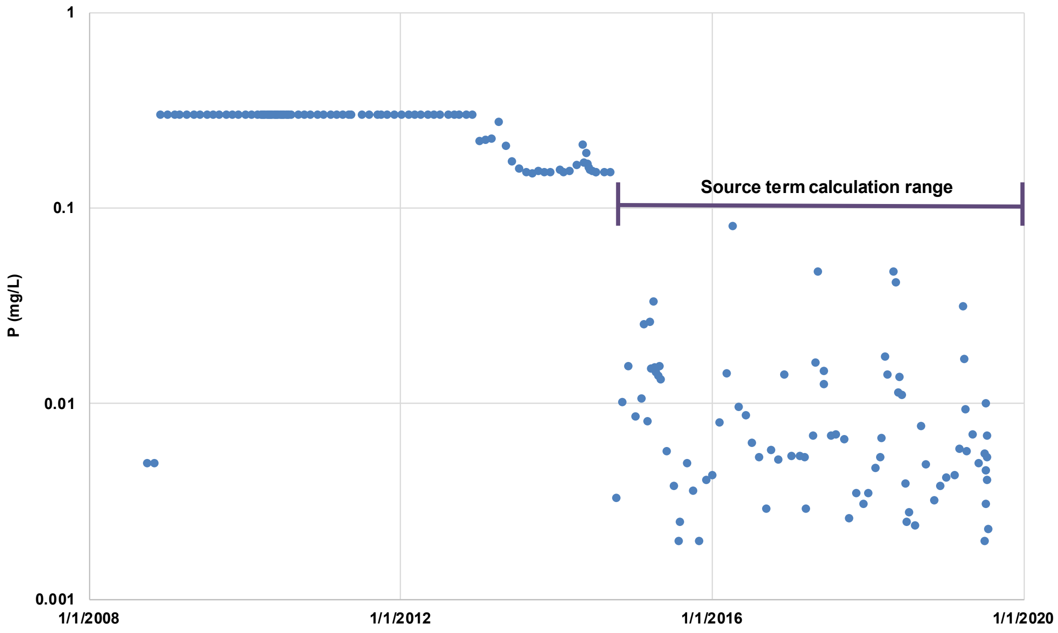
Teck maintains a flow and water quality database which formed the basis for developing the source terms. The database includes water quality monitoring results for each of the source term parameters as well as field-based flow measurements at each location. Dissolved concentrations and flow measurements were used to estimate loadings at each monitoring location. The average of duplicate water quality values, defined as results collected on the same day, were used in loadings calculations. All flow measurements had unique time stamps and no duplicates were encountered. The detection limit value was used in calculations for concentrations that were reported below the instrument detection limit.

Operational Water Management

Data were excluded in source term calculations where operational water management (e.g., pit dewatering) could influence the monitoring dataset. One exception was the source term derived for Bodie and Gate Creek. These catchments are highly influenced by dewatering from the Natal Pit, but it is not always evident in the pumping records whether the pit water was directed to Gate or Bodie Creek. Therefore, the waste rock volumes from Bodie Creek, Gate Creek and the Natal Pit were combined to estimate a single source term for Bodie and Gate Creeks. Pit dewatering was not removed from these catchments because much of the load in the pit dewatering is assumed to be attributed to waste rock stored in the Natal Pit, which is accounted for in the source term derivation.

Handling of Variable Detection Limits

Much of the historical monitoring dataset included elevated detection limits of these parameters, or elevated concentrations that were not consistent with observed concentrations in recent years. An example is provided for phosphorus concentrations at GH_G1 in Figure 30. To avoid bias in the source term calculations, data ranges with elevated detection limits, or elevated historical values, were excluded from the monthly average calculations (Figure 30). A value equal to the detection limit was used in numerical calculations for non-detect values carried forward.



Z:\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\200_Unsaturated Waste Rock Terms\230_COI Weathering Rates & Solubility\020_GHO\01_Data_Interpolations\[GH_GH1_1CT017.229_MKH_R2.xlsx

Figure 30. Measured Phosphorus Concentrations at GHO_GH1

Consideration of Groundwater/Surface Water Partitioning

The flow measurements in the database represent the surface water flow at that location. However, hydrogeological studies (Golder 2019) indicate that a flow component of drainage from the spoil can be lost to groundwater prior to reaching the monitoring location. Therefore, the measured flows in the Teck monitoring database only represent a component of the total flow originating from the spoil. Therefore, to use the monitored flow value in loading calculations would result in an underestimate of the load from the spoil. The results of the groundwater studies, compiled by Golder (2019), were used to correct the total flow from the spoil by adding the groundwater bypass values to the monitored flows. The groundwater bypass estimates are provided in Table 11. Some of the flows were provided as a percentage of the total flow and others were provided as a rate. Additional details on how the range of flows is used in the source term derivation is provided in Section 8.2.2.

Changes Since 2017

Water quality and flow data are collected at the inlet (GH_SC2) and outlet (GH_SC1) of the Swift Creek settling pond. Flow and water quality monitoring occurs intermittently since water upstream of the inlet is occasionally diverted around the pond resulting in zero discharge from the pond. Since the water quality at these two locations is representative of the same source, monitoring results from these two locations were combined to create a single dataset to derive a source term for Swift Creek. The average of water quality measurements was used when data was reported from both locations on the same day.

Source terms were derived for the following locations using different water quality monitoring results in comparison to SRK (2017a):

- Thompson Creek – Monitoring location GH_TC2 was used in 2020 and GH_TC1 in 2017;
- Dry Creek – Monitoring location LC_DC3 was used in 2020 and LC_DC1 in 2017; and
- Wolfram Creek – flow data was used from GH_WC2 in 2020 and GH_WC1 in 2017.

The change was made in 2020 to use the most upstream monitoring data in these tributaries as the monitoring data is less influenced by other sources (e.g., groundwater bypass, natural runoff), reducing the uncertainty in calculation to remove loads associated with these sources. This change resulted in a large difference in the source term for Wolfram Creek. This occurred because the flow record at GH_WC2 is more complete than GH_WC1, since GH_WC1 is downstream of a settling pond that loses water to ground and only discharges intermittently.

It is important to note that the source term for LC_DC3 was not carried forward into the 2020 RWQM because there is still only a limited amount of data available for this location. This location will be included in future updates when additional monitoring data are available.

Table 11. Groundwater Bypass Estimates

Monitoring Location	**Groundwater Bypass Estimate Used in Source Term Development**
FR_CC1	2,250-9,000 m^3/d
FR_HC1	5-10% of flow
FR_KC1	5,800-12,800 m^3/d
GH_CC1	0 m^3/d
GH_SC1/SC2	50-200 m^3/d
GH_GH1	520-1,704 m^3/d
GH_LC2	0 m^3/d
GH_TC2	0 m^3/d
GH_WC2	0 m^3/d
LC_WLC	2-60% of flow (average of 15%)
LC_LCUSWLC	0.1-36% of flow (average of 2%)
EV_BC1/EV_GT1	0 m^3/d
EV_EC1	0 m^3/d
EV_HC1/EV_DC1	2-10% of flow
CM_CC1	0 m^3/d

Source; Golder (2019)

6.5 Other Water Chemistry

6.5.1 Passive SRF

SRK developed an inventory of existing backfilled pits and associated monitoring stations where passive reduction of selenium and nitrate may be occurring. The compilation was based on review of SRK (2012) and consultation with Teck and other SRF investigators. Data sources included Teck's internal water quality monitoring database, files provided by specific Teck operations, OKC (2015) and internal files from individual SRF investigations. The operations and pits that were part of the scope of the passive SRF assessment were CMO (14 Pit), EVO (F2 Pit), FRO (Eagle 4, F Seam, Henretta Dragline, Shandley, Taylor), GHO (Cougar North Pit), LCO (South Pit) and CRO (B5, Cheviot). For F2, only the passive SRF data record were considered, e.g., prior to addition of methanol. Henretta Dragline was excluded from the source terms because the complete data set was not available at the time of source term derivation.

Data considered in the assessment included the complete monitoring record for selenium (dissolved or total (when dissolved measurements were not available)), sulphate, nitrate, field oxygen, manganese, field ORP, ammonia, and/or for limited sites, selenium speciation (selenite and selenate). The data record was incomplete for a number of stations, for example selenium was not analyzed for all sampling events and/or the temporal record was limited, however this was taken into consideration during data interpretation.

6.5.2 Active SRF

Data used for source terms for the active SRFs included:

- Future projected influent concentrations developed using the 2020 RWQM and the operational plan for blending of influent waters as described in Teck (2020e).
- EVO SRF Phase 1 performance monitoring database from December 2018 through August 2019 for water associated with the SRF.

Data sources included Teck's internal master database for the EVO SRF including monitoring data representing effluent at the effluent buffer pond as well as internal monitoring wells and projected influent concentrations as given in Teck (2020e). Data were accepted as received by SRK. Data considered in the assessment included parameters representing tracers (bromide, chloride, potassium, sodium), reagents (chemical oxidation demand, dissolved organic carbon, phosphorus), treatment target parameters (nitrate, nitrite, ammonia, selenium, selenate, selenite, dimethylselenoxide, methylseleninic acid, selenocyanate), parameters that may change through the SRF (alkalinity, sulphate, calcium, magnesium, dissolved oxygen, iron, manganese, sulphide, arsenic, molybdenum, cadmium, cobalt, nickel, zinc) and parameters unlikely to change through the SRF (fluoride, aluminum, barium, beryllium, bismuth, boron, chromium, copper, lead, lithium, mercury, silicon, silver, strontium, thallium, tin, titanium, uranium, vanadium).

7 Data Processing

7.1 Geochemical Database: Static Testing

The static lithogeochemical database was used to estimate inventories of COIs (Section 8.1). Arithmetic average concentrations were calculated using results obtained from the commonly used analytical methods. For results reported at the detection limit, the reported detection limit was used to calculate the averages. 95% confidence intervals on averages were calculated to indicate uncertainty.

7.2 Geochemical Database: Kinetic Testing

Kinetic data from humidity cells were reduced to express results as average release rates (for example, mg/kg/week). The steps used were:

- Calculate average release rate

$$\text{Average Release Rate}\left(\frac{\frac{\text{mg}}{\text{kg}}}{\text{week}}\right)=\text{Concentration}\left(\frac{\text{mg}}{\text{L}}\right)\times\text{Output Volume (L)}\div\text{Mass of HCT (kg)}$$

- The sulphate release rate trend was visually assessed to determine when release rates stabilized following the commonly observed initial flush.
- Average leaching rates were then calculated from the time sulphate leaching rates were judged to be stable (i.e., unchanging from week to week after removal of flushing effects).

For data with results less than the detection limit, the reported detection limit was used.

Barrel test data were also reduced to express results as average release rates (mg/kg/week) using the following equation:

$$\begin{aligned}\text{Average Release Rate}\left(\frac{\frac{\text{mg}}{\text{kg}}}{\text{week}}\right)\\ =\text{Concentration}\left(\frac{\text{mg}}{\text{L}}\right)\times\text{Volume of Water when Sample Collected (L)}\\ \div\text{Mass of rock in Barrel (kg)}\div\text{Number of Weeks Since Last Sampled}\end{aligned}$$

7.3 Monitoring Database: Flow and Water Chemistry

7.3.1 Nitrate, Sulphate and Selenium

Figure 31 illustrates the processing steps that were used to reduce the data for use in the derivation of unsaturated waste rock source terms. Steps indicated with bolded font were included in the 2020 RWQM source terms but not previous updates. These steps were applied to monitoring results for each catchment where a source term was developed.

Initially, the data were screened to only carry forward data representative of waste rock drainage into the source term calculations (Section 6.4). Initially the data was screen for site water management activities that could influence the representativeness of the monitoring data. In addition to screening the monitoring data for water management influences, only years where more than six data measurements were collected were carried forward into the source term calculations. This was done to maximize the months in a year where data was collected so data interpolations (see below) would be representative of seasonal variations.

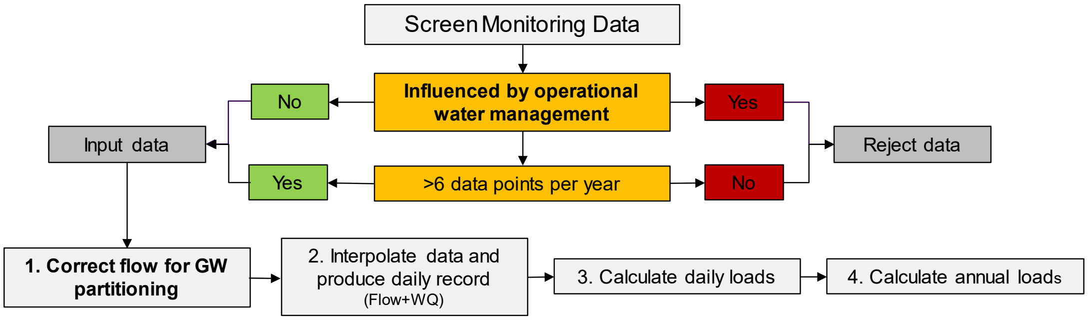


Figure 31. Source Term Data Processing and Calculation Steps

Once a representative dataset was compiled, the following data processing steps were followed (step numbers correspond to Figure 31):

Step 1: Correct flow for groundwater partitioning

Flow measurements in the monitoring data record represent surface water measurements. However, groundwater studies (Golder 2019) indicate that a component of the drainage form the spoil are expected to “bypass” the monitoring location in catchments that have losing reaches upstream of the monitoring location. Flows used to calculate source terms were increased in catchments where groundwater is predicted to bypass the monitoring station (Table 11).

Step 2: Interpolate data to produce daily record

The compiled datasets were interpolated linearly between monitored data records to produce a daily record. Data interpolations were completed using the information timeseries element in the GoldSim® modelling software package. Examples are shown in Figure 32 (flow) and Figure 33 (nitrate concentrations) for the monitored and interpolated data. Each figure provides an example station showing the entire data record and an annual snapshot.

Step 3: Calculate daily loads released.

Daily loads for parameters nitrate, selenium and sulphate (L_j in mg/day) were calculated from:

$$L_{j,day}\ \text{(mg/day)} = Q\ (\text{m}^3\text{/day})\cdot 1000\ (\text{L/m}^3)\cdot C_j\ \text{(mg/L)}$$

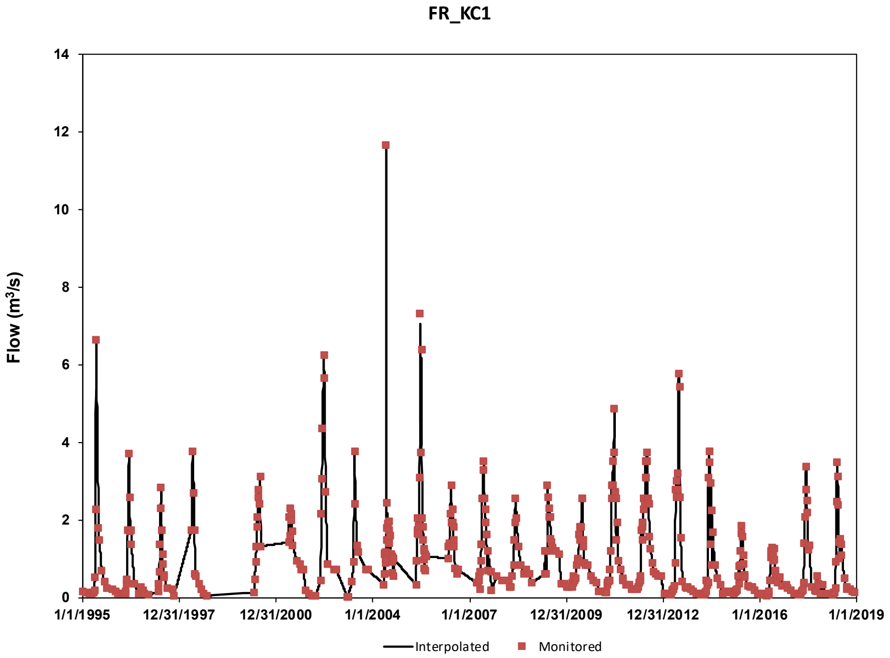
Step 4: Calculate annual loads released.

Annual loads ($L_{j,year}$, in mg/year) were calculated by summing the daily loads for each parameter.

$$L_{i,year} = \sum_{\text{day=December 31, Year}}^{\text{day=January 1, Year}} L_{i,day}$$

As noted above, only years for which there were at least six monitoring points for flow and chemistry were included. This target was based mainly on having data for at least six months representing the six months of open water (May to October) to ensure that highest chemical loadings during the snowmelt period were included in the assessment.

a)



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b)

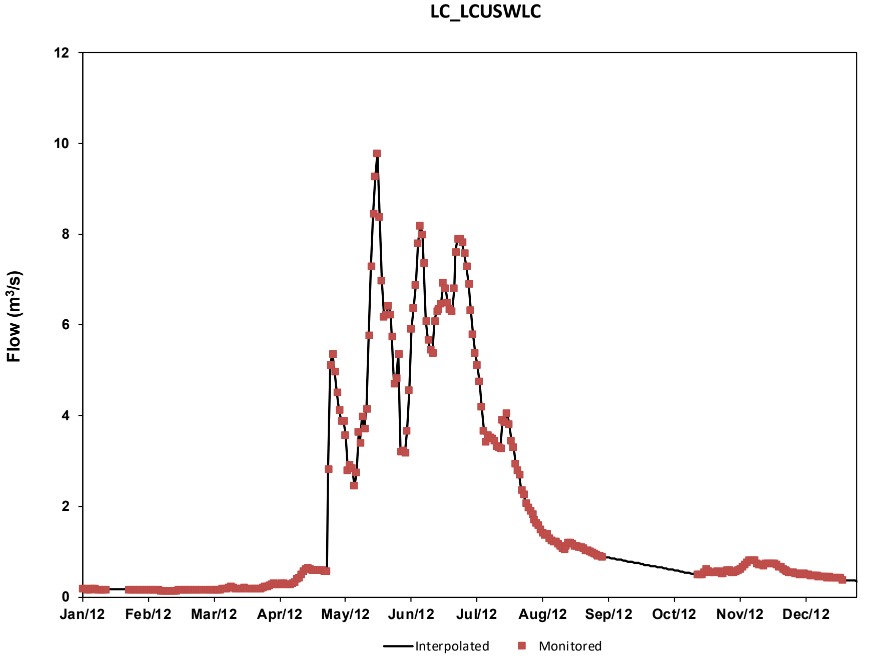

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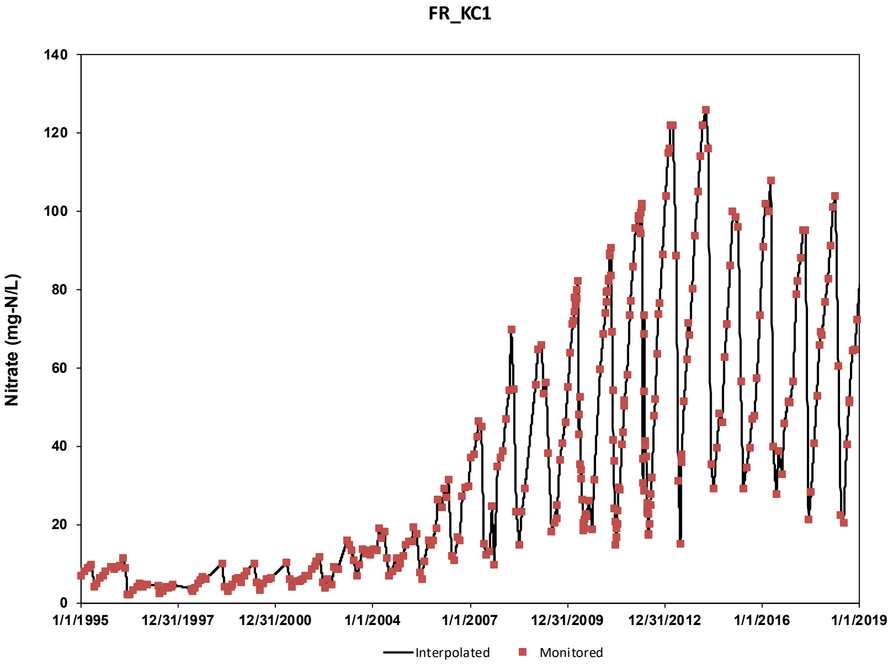
Figure 32. Example Showing Monitored and Extrapolated Data Record for Flow at Monitoring Stations (a) FR_KC1 over the Period of Record and (b) LC_LCUSWLC for a One Year Period.

a)



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b)

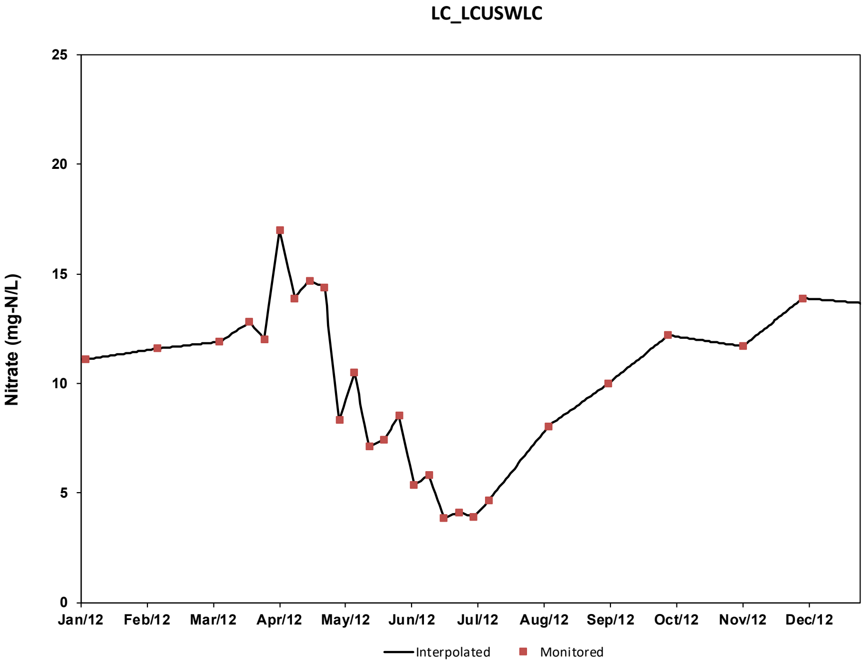

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Figure 33. Example Showing Monitored and Extrapolated Data Record for Nitrate Concentrations at Monitoring Stations (a) FR_KC1 over the Period of Record and (b) LC_LCUSWLC for a One Year Period.

7.4 Other Water Chemistry

7.4.1 Passive SRF

The following data processing steps related to the passive SRF source terms were implemented as follows:

- All data were accepted as received by SRK.
- For data with results less than the detection limit, the reported detection limit was used for the calculation.
- Source terms include expected and upper bound concentrations and were derived from median and 95th percentile monitoring concentrations, respectively.
- $(Se/SO_4)_{oxic}$ is the ratio of selenium to sulphate in $mgSe/mgSO_4$ in unsaturated waste rock contact waters due to pyrite oxidation. Values for each operation were derived based on stable rates from waste rock humidity cell tests and/or empirical source term rates derived from seepage monitoring from waste rock dumps (Section 5.2). The final value was determined as the average ratio from all data sets.
- For a passive SRF with multiple monitoring stations, the final selenium attenuation factor (k_{Se}) was the average value of all stations indicating selenium attenuation.

7.4.2 Active SRF

The following data processing steps related to the active SRF source terms were implemented as follows:

- Only data collected using the same laboratory methods were used in statistical calculations.
- For data with results less than the detection limit, the reported detection limit was used for the calculation.
- Source terms include expected concentrations and upper bound concentrations.
- Expected concentrations were generally based on existing average effluent monitoring data from performance monitoring of the EVO SRF Phase 1 trial, as well as expected influent concentrations and typical SRF performance as related to removal efficiencies.
- Upper bound concentrations to represent upset conditions were parameter specific to reflect each parameter's participation in processes within the SRF or buffer pond. In brief, upper bound concentrations were typically represented by maximum measured concentrations in the monitoring wellfield for parameters that could be generated as a result of redox reactions within the SRF (e.g., ammonia, arsenic, molybdenum, selenium species) or maximum concentrations from the buffer pond for parameters that are affected by re-aeration in the pond after extraction from the SRF (e.g., dissolved oxygen, iron).

8 Source Terms

8.1 COI Inventory

Table 12 provides the COI inventory. Potential inventory statistics were calculated using the static lithogeochemical database and are presented as average, low (average minus 95% confidence limit) and high (average plus 95% confidence limit).

Available inventory is expressed as low, expected and worst case calculated as described in Section 5.2.1. The “others” term should be applied to all sites with the exception of CMO where a separate term has been developed to reflect differences in static geochemical composition of the rocks (Section 3.2.1).

Table 12. COI Inventory

Parameter	Inventory	Scenario	CMO	Others
ICP S (%)	Potential	Low	0.069	0.12
		Average	0.083	0.13
		High	0.098	0.14
	Available	Low	0.031	0.056
		Expected	0.038	0.06
		Worst Case	0.09	0.13
As (mg/kg)	Potential	Low	4.5	4.7
		Average	5.5	5.2
		High	6.6	5.7
	Available	Low	2.1	2.1
		Expected	2.5	2.4
		Worst Case	6.1	5.3
Cd (mg/kg)	Potential	Low	0.77	2.1
		Average	0.9	2.1
		High	1.0	2.2
	Available	Low	0.35	0.94
		Expected	0.41	0.96
		Worst Case	0.96	2.0
Co (mg/kg)	Potential	Low	5.5	6.1
		Average	6.2	6.2
		High	7.0	6.3
	Available	Low	2.5	2.8
		Expected	2.8	2.8
		Worst Case	6.4	5.9
Ni (mg/kg)	Potential	Low	16	25
		Average	19	25
		High	22	26
	Available	Low	7.5	11
		Expected	8.7	12
		Worst Case	20	24
U (mg/kg)	Potential	Low	0.82	1.6
		Average	0.92	1.6

Parameter	Inventory	Scenario	CMO	Others
		High	1.0	1.6
	Available	Low	0.37	0.71
		Expected	0.42	0.73
		Worst Case	0.93	1.5
P (%)	Potential	Low	0.053	0.13
		Average	0.063	0.13
		High	0.073	0.14
	Available	Low	0.024	0.06
		Expected	0.029	0.061
		Worst Case	0.068	0.13
Se (mg/kg)	Potential	Low	0.64	2.2
		Average	0.73	2.3
		High	0.82	2.3
	Available	Low	0.29	1.0
		Expected	0.33	1.0
		Worst Case	0.76	2.1
Cr (mg/kg)	Potential	Low	81	37
		Average	96	38
		High	110	39
	Available	Low	37	17
		Expected	44	17
		Worst Case	100	36
Mn (mg/kg)	Potential	Low	100	220
		Average	140	230
		High	170	240
	Available	Low	48	100
		Expected	62	100
		Worst Case	160	220

Source: D:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\240_COI Inventory\SiteGeochemData_GrainSizeCompiled_1CT017.229_ld_rev01.xlsx

8.2 Unsaturated Waste Rock

8.2.1 Nitrogen Source Term Inputs

Teck monitors the type and quantity (i.e., powder factor) of explosives used and nitrogen loadings downstream of the spoil provide a signal of the percentage of undetonated explosives and the timeframe required to leach undetonated explosives from the spoil. This concept was used to estimate the following inputs into the nitrogen source term inputs:

- The apparent loss factor (i.e., the amount of undetonated explosives) for each spoil.
- The time required to flush residual nitrogen from the spoil.
- Derivation of these source term inputs are discussed in the following subsections.

Estimation of Blasting Residuals (f_R)

Estimates of blasting residuals or loss factors (f_R), i.e. the proportion of blast residues entrained within waste rock, depend on the type of explosives used, whether conditions are dry or wet, and explosive management practices (e.g., lining of blast holes).

This loss factor was estimated using two approaches:

1. By curve-fitting theoretical and empirical cumulative nitrate loadings over time. The underlying approach is the same as that used by SRK (2017a). Results using this approach were applied historically and in future predictions of nitrogen loading.
2. Estimating future reductions in blasting residuals occurring from current changes to explosives management practices.

The second method was developed to recognize, that in concept, lining of blast holes will reduce the blasting residuals that are leached from spoils.

The two methods are described below.

Empirical Estimation of Blast Residues

Figure 34 provides the cumulative nitrate load measured at the monitoring location in GH_CC1. Also shown on the graph is the calculated curve based on cumulative waste rock produced, known powder factors (i.e. how many kilograms of explosives are used per BCM of rock) and loss factors varied between 1% and 6%, as suggested in literature (Section 4.2.2), to provide a range. Conceptually, other variables could also influence the slope of this curve, including redistribution of flow paths (e.g. re-handling or disturbing material), changing explosives products and practices, or water management activities. Therefore, this slope is not necessarily representing only the loss factor. As such, this term has been defined here as the apparent loss factor.

The slope is a function of the mass of waste rock and the apparent loss factor for each drainage (Figure 35). Steeper sections of the cumulative curve correspond to higher apparent loss factors whereas flatter sections correspond to lower apparent loss factors. The slope of the observed line was matched by varying the apparent loss factor iteratively each year until a reasonable visual match was achieved. As an example, the output from the curve-matching conducted for GH_CC1 over the period of record is shown in Figure 35.

Once the curves were matched, a weighted average loss factor (Table 13) was calculated for each spoil as follows:

$$\frac{\sum_i^n WR_{volume_{i,n}} \times fR_{i,n}}{\sum_i^n WR_{volume_n}}$$

Where: $WR_{volume_{i,n}}$ equals the waste rock volume in years i to n

$fR_{i,n}$ is the apparent loss factor in years i to n

In the example provided in Figure 35, the volume weighted apparent loss factor was 3.6%. The average apparent loss factor of the drainages evaluated was 4.5% and ranged between 1.5% and 7.7% (Table 13), consistent with values reported elsewhere. Results from all catchments are provided in Appendix B.

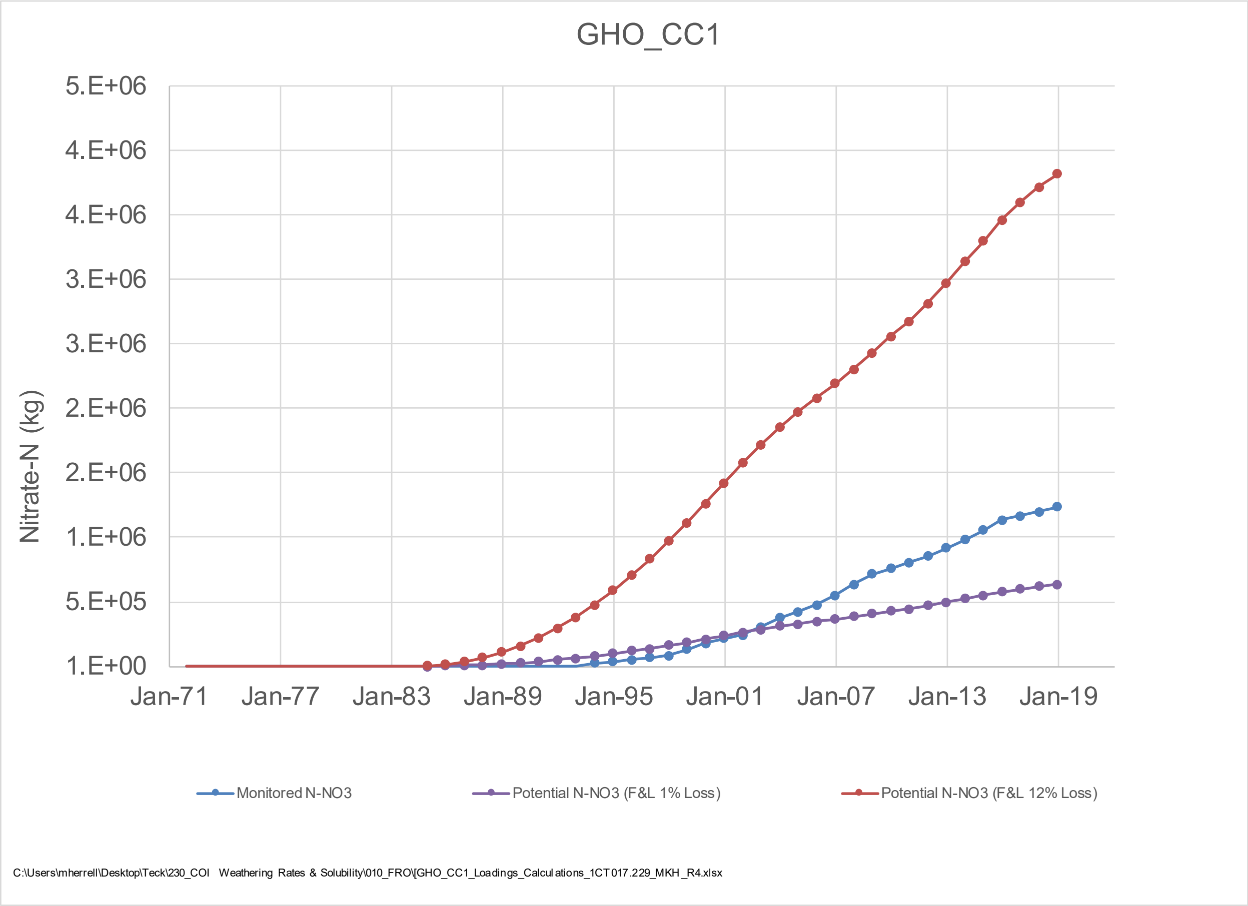

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Figure 34. Cumulative Nitrate Load Measured versus Time at GH_CC1 Showing Range as Indicated in Literature from 1 to 6% Apparent Loss Factors

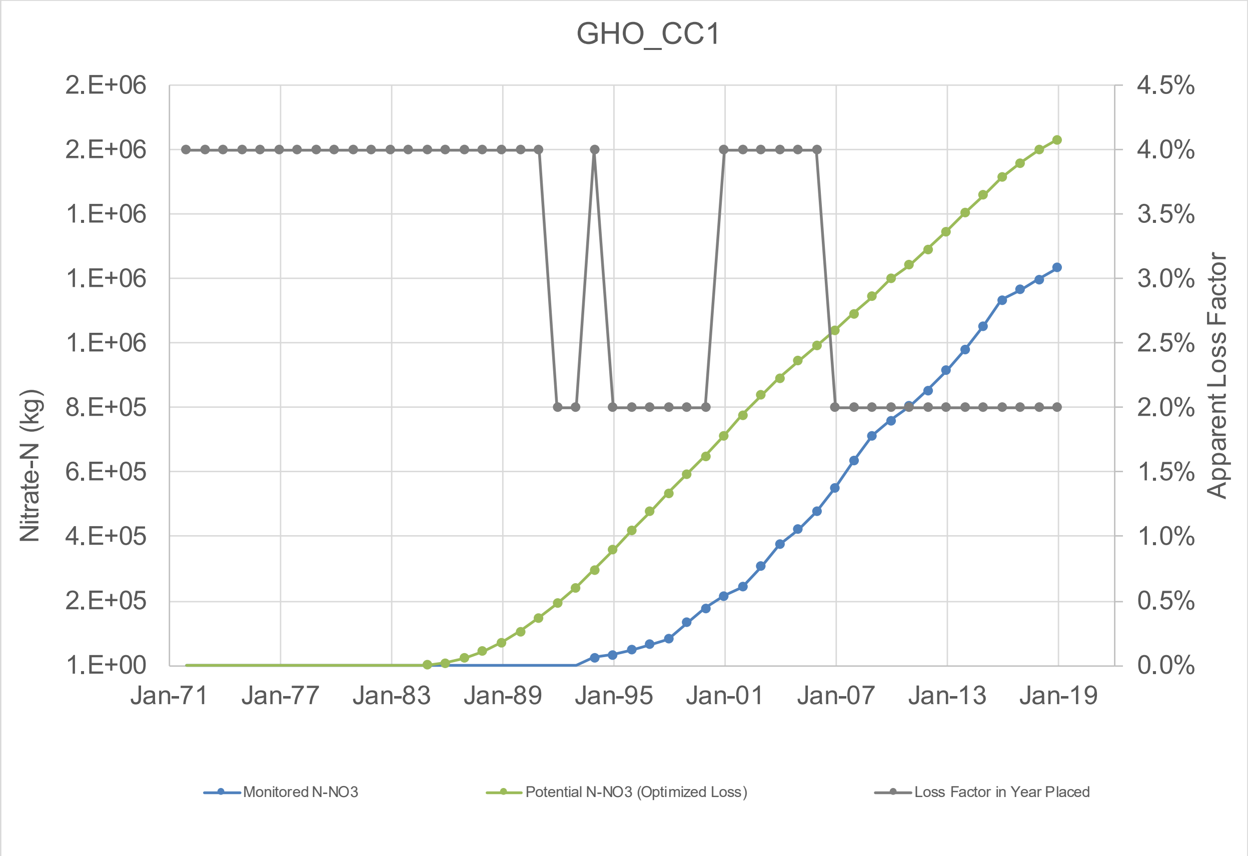

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Figure 35. Apparent Loss Factor versus Time and Resulting Cumulative Nitrate Load Curve

Table 13. Catchment Specific Apparent Loss Factors

Station	Volume Averaged Apparent Loss Factor
FR_CC1	6.0%
FR_HC1	7.0%
FR_KC1	7.7%
GH_CC1	3.6%
GH_SC1/SC2	4.0%
GH_GH1	1.5%
GH_LC2	6.3%
GH_TC2	1.5%

Station	Volume Averaged Apparent Loss Factor
GH_WC2	1.8%
LC_WLC	3.2%
LC_LCUSWLC	6.5%
EV_BC1 & EV_GT1	5.4%
EV_EC1	6.9%
EV_HC1 & EV_DC1	3.7%
CM_CC1	2.9%
Valley Wide Average	4.5%

Estimation of Future Reductions to Blasting Residuals

Teck has made changes to their nitrogen management to reduce nitrate concentrations in the receiving environment. These include refinement of product formulations (e.g., different blends of explosives), improvement in housekeeping (i.e. avoiding spills), and lining (or bagging) the blast holes. All of these approaches are expected to result in considerably lower explosive residuals than have been estimated using historical drainage monitoring data (Table 13).

The empirical approach used to estimate the apparent loss factor (Section 8.2.1) has the following two limitations:

- The apparent loss factor is not explosive specific (e.g., it is unknown how the loss factor is influenced when different blends of explosives are used); and
- Improvements from implementing improved nitrogen management practices may not be measured in the monitoring record due to the hydraulic lag times.

Therefore, application of the estimated loss factors based on the empirical dataset will not account for changes to explosives types and will overestimate the residual nitrogen that will be produced. The following method can be used to account for full implementation of management improvements:

$$E_{met} = E_{pre,lined} + E_{pre,unlined} + E_{blast}$$

$$E_{pre,lined} = p_f(t) \times V \times j \times (n_{emulsion} \text{ x } k_{tear,emulsion} + (1-n_{emulsion}) \times R_H \times k_{tear,ANFO})$$

$$E_{pre,unlined} = p_f(t) \times V \times (1-j) \times R_H$$

$$E_{blast} = p_f(t) \text{ x } V \text{ x } k_{blast}$$

Table 14 defines the symbols in the above equations and indicates placeholder inputs based on current input from Teck and SRK calculations.

R_H was calculated from monitoring data for 19 drainage monitoring locations and currently indicates an average loss of 4.5%. Uncertainty is indicated by the 95% confidence limit on the average value shown.

The starting assumption in the above approach was that $k_{tear,emulsion}$ was 0%. Teck recently developed a study to quantify the number of liners tearing in blast holes loaded with emulsion explosives. The study involved collected water samples in the blast holes prior to and after loading and evaluating trends in changes to nitrogen concentrations through time. Based on the trends, liner tears were grouped into one of the following categories:

- No failure;
- Plausible failure;
- Failure likely;

- Inconclusive; or
- Insufficient data.

The results of the study indicated there were no failures in 20% of the holes tested and 34% and 46% of the holes sampled were categorized as plausible failure or likely failure, respectively. The results of the study indicated that lined emulsion holes fail to some degree. However, the learnings of the study can be used to support quantifying the benefits of lining blast holes because 20% of the liners in the holes sampled remained intact and plausible failures were identified in 34% of the holes. The latter category highlights that a torn liner is not synonymous with a lost liner and the liner still provides benefit at reducing nitrogen loadings to the receiving environment. Based on the findings of the study, lined emulsion holes have a success rate between 20% to 50%.

Table 14. Symbols and Placeholder Inputs for Lined Blast Holes

Symbol	Definition	Units	Placeholder Inputs
$E_{Historical}$	Historical total residuals prior to full implementation of management improvements	kg	Calculated
E_{met}	Total explosive residuals following full implementation of management improvements	kg	Calculated
$E_{pre,lined}$	Explosive residual from pre-blast mechanisms for lined holes	kg	Calculated
$E_{pre,unlined}$	Explosive residual from pre-blast mechanisms for unlined holes	kg	Calculated
E_{blast}	Explosive residual from blast mechanisms	kg	Calculated
$p_f(t)$	Powder factor	kg/BCM	Mine plan
V	Volume of rock	BCM (bank cubic metres)	Mine plan
j	Fraction of blast holes lined	Unitless	Mine plan
$n_{emulsion}$	Fraction of blast holes using emulsion explosives.	Unitless	Mine plan
$k_{tear,emulsion}$	Fraction of torn blast hole liners in emulsion holes.	Unitless	0.5
$(1-n_{emulsion})$	Fraction of blast holes using ANFO explosives.	Unitless	Mine plan
R_H	Residual fraction from historical monitoring	Unitless	0.045 ± 0.014
$k_{tear.ANFO}$	Fraction of torn blast hole liners in ANFO holes.	Unitless	1
k_{blast}	Fraction of misfires	Unitless	$1x10^{-5}$

The above method should be applied where the following conditions are met:

- Differences in product performance are not considered a significant variable in generation of blast residuals.
- Handling losses have been reduced so as to be insignificant in the context of other mechanisms.
- Estimated lag times draining residuals from past blasting practices have expired (see section below).

For transitional periods when any of the above conditions have not been fully met in a catchment, the method can only be applied to that volume of rock blasted and meeting the conditions. For blast patterns not meeting the conditions, the historical loss for that catchment ($E_{historical}$) should be applied to the volume of rock blasted ($V_{not\text{-}met}$). The total residual during transitional periods is therefore:

$$E_{historical} = p_f \cdot V_{not\text{-}met} \cdot R_H$$

Estimation of the Hydraulic Lag (t_{HL})

Lag times are catchment specific as they depend on several factors (e.g., waste deposition approaches, spoil hydrology, etc.). The initial lag times were updated for the 2020 RWQM source terms using one of the two following approaches:

- Matching the cumulative nitrate loading curve (as described above) to the timing of waste placement; or
- Comparing water quality trends to waste placement volumes to estimate the time to increases in nitrate concentrations.

The second approach was applied in instances where the cumulative curve fitting exercise resulted in a high degree of uncertainty because water quantity and quality monitoring data were not available when load from the spoil was discharged to the tributaries. This can occur because of long gaps between initial waste placement and nitrogen monitoring, gaps in the water quality or flow data precluding calculation of annual loads, or in instances when data sets are limited (e.g., LCO Dry Creek).

Figure 36 provides an example showing the estimated lag time aligning cumulative nitrate curves at GH_CC1. The curves indicate that a hydraulic lag of 8 years occurs prior to nitrogen load being measured at GH_CC1. As discussed above, the slope of the curve is a function of apparent loss factor. This means that the initial lag can influence the apparent loss factor and vice versa (i.e., there can be more than one feasible solution to the curve fitting exercise). The loss factor and lag therefore have to be solved simultaneously.

When there are sufficient data to track changes in slope in the cumulative curves, the confidence in the parameter estimates (i.e., hydraulic lag and apparent loss factor) increase. The uncertainty in the loss factor and lag increases where there is insufficient data to complete the curve fitting exercise. To minimize uncertainty in these instances, the hydraulic lag was estimated by comparing waste placement volumes to nitrate trends to estimate the breakthrough time of the nitrogen load (Figure 37). When this approach was used, the loss factor was subsequently calculated to match the slope in the cumulative curves.

Table 15 provides a summary of the estimated lag times for each catchment, the method used and the degree of confidence in the lag time estimates. Those drainages assigned a confidence assessment of ‘high’ were well supported by monitoring data whereas those with a confidence assessment of ‘low’ were limited with respect to data.

A low confidence was provided for the EV_HC1&EV_DC1 source term, which is based on the EV_HC1 dataset because the early data record which overlapped the period of time with the most waste placement is missing flow, the water quality data record does not capture the increasing limb of a concentration trend, recent nitrate concentrations are lower than earlier concentrations.

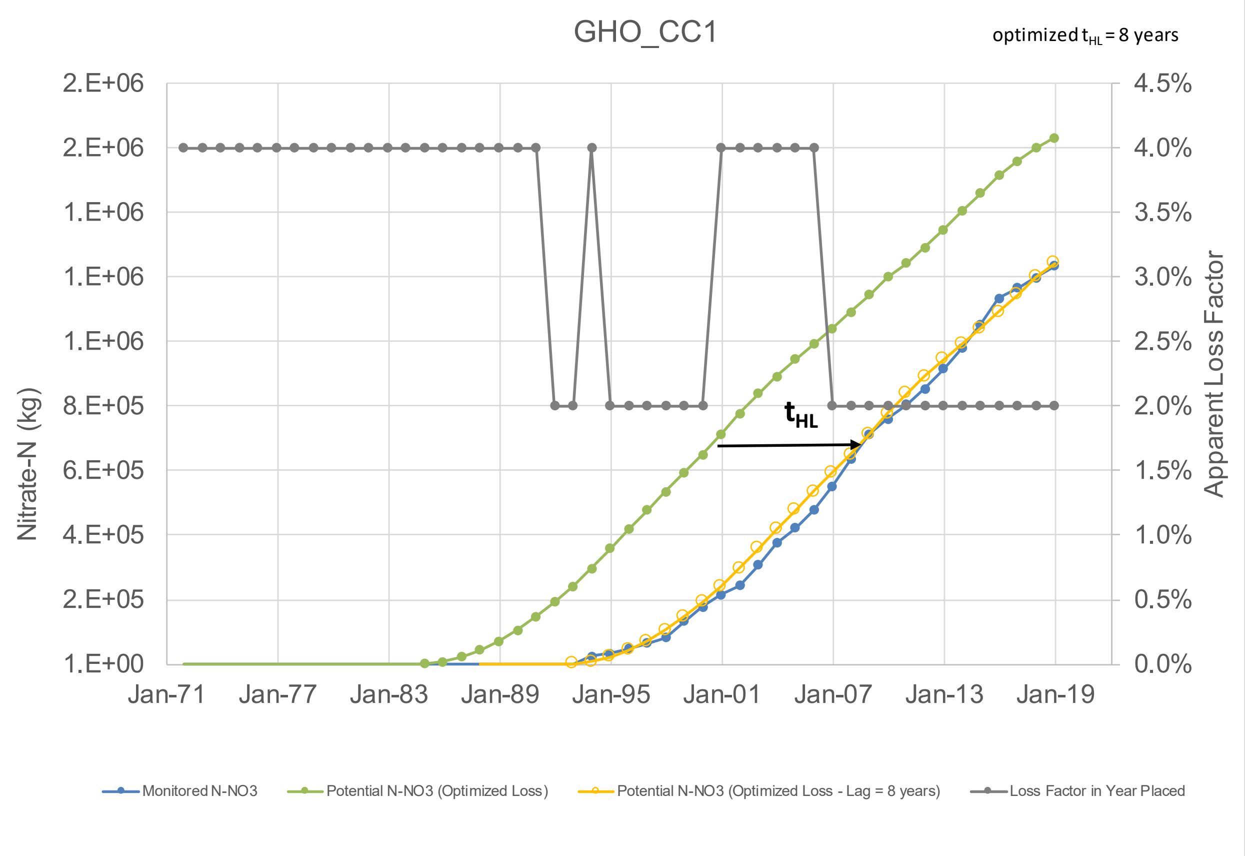

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Figure 36. Potential Nitrate Release and Monitored Nitrate Release Versus Time.

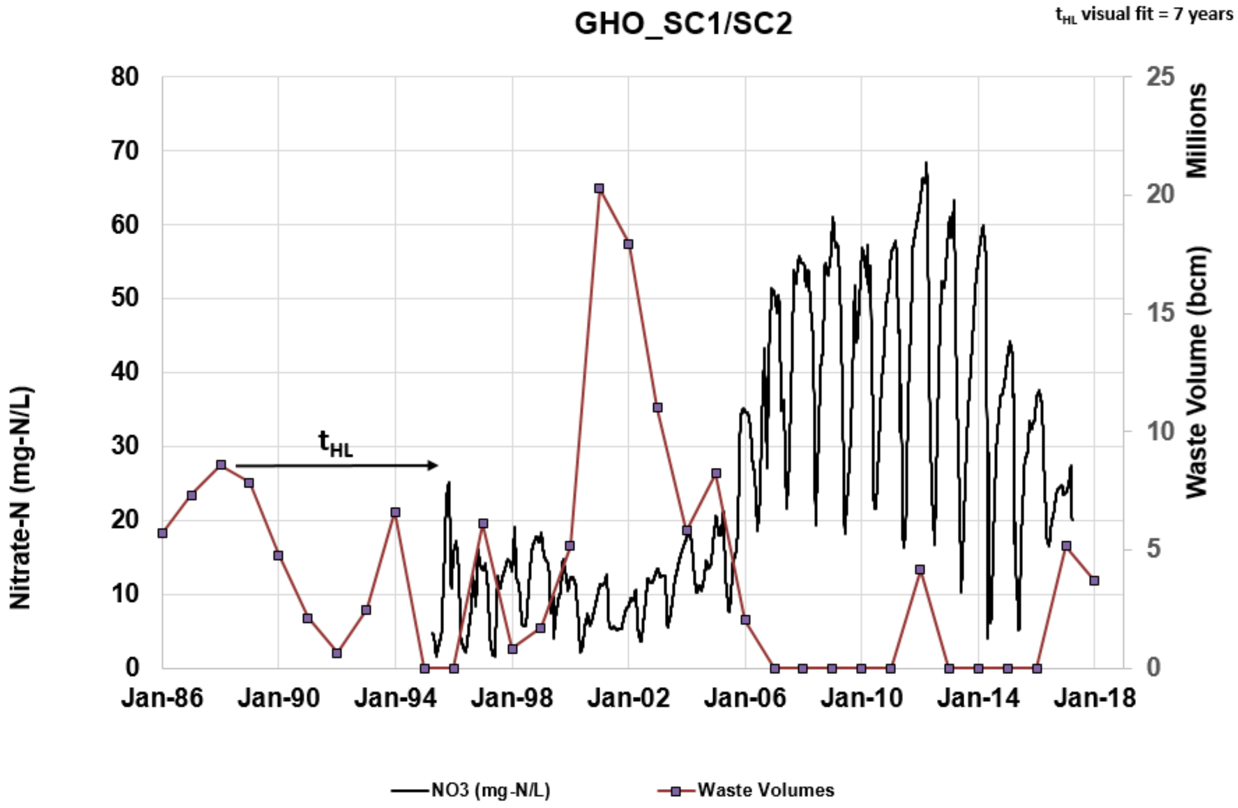

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Figure 37. Concentration of Nitrate over Time and Annual Waste Placement History at EVO_EC1.

Table 15. t_{HL} Estimates by Drainage

Station	Creek Name	t_{HL} (years)	Confidence in Assessment [a]	Method Used [b]
FR_CC1	Clode Creek	4	High	Cumulative nitrate load curve-fitting
FR_HC1	Henretta Creek	8	Moderate	Concentration trend / waste placement method
FR_KC1	Kilmarnock Creek	7	High	Cumulative nitrate load curve-fitting
GH_CC1	Cataract Creek	8	High	Cumulative nitrate load curve-fitting
GH_SC1/SC2	Swift Creek	7	Moderate	Concentration trend / waste placement method
GH_GH1	Greenhills Creek	7	High	Cumulative nitrate load curve-fitting
GH_LC2	Leask Creek	3	Moderate	Cumulative nitrate load curve-fitting
GH_TC2	Thompson Creek	7	Moderate	Cumulative nitrate load curve-fitting
GH_WC2	Wolfram Creek	3	Moderate	Cumulative nitrate load curve-fitting
LC_WLC	West Line Creek	16	Moderate	Concentration trend / waste placement method
LC_LCUSWLC	Line Creek upstream of WLC	9	Moderate	Cumulative nitrate load curve-fitting

Station	**Creek Name**	**t_{HL} (years)**	**Confidence in Assessment [a]**	**Method Used [b]**
EV_BC1 & EV_GT1	Bodie and Gate Creeks	3	Moderate	Cumulative nitrate load curve-fitting
EV_EC1	Erickson Creek	12	Moderate	Concentration trend / waste placement method
EV_HC1 & EV_DC1	Harmer and Dry Creeks	13	Low	Concentration trend / waste placement method
CM_CC1	Corbin Creek	2	Moderate	Concentration trend / waste placement method
Valley Wide Average		7.7	---	---

Notes:

[a] A confidence level for the time adjustment has been provided for reference. This is a subjective assessment intended to indicate the evaluator's confidence in the ability to define the hydraulic lag time based on the data available.

[b] Methods are described as:
Cumulative nitrate load curve-fitting method Concentration trend / waste placement comparison method = visual match of the waste placement history and concentration trend

Nitrate Release Over Time, t_{AL}

The time-release component to the nitrate source term to better predict the dispersed release of blasting residuals over time developed as part of the 2017 source terms was carried forward into the 2020 RWQM source term update. The term was previously defined as the time adjusted leach term, or t_{AL} and was nominally been estimated to be 10 years (SRK 2017a). In other words, blasting residuals deposited with waste in any given year take 10 years to leach from the pile (10% per year) and that all of the blasting residuals deposited in any given year are available for leaching.

For the 2020 update, the term has been modified to reflect a leaching efficiency, which is the percent of residual explosives in a spoil that is leached on an annual basis. This change in approach results in an asymptotical decay curve versus assuming an equal amount of explosives is leached on an annual basis (Figure 37). The leaching efficiency has been defined as 20%/year based on a comparison to theoretical leaching efficiencies to observed concentrations in the Mesa B and Mesa C sedimentation ponds at the Quintette Coal Mine, as well as in Mesa Creek approximately 50 m downstream of the McKonkey Slide 1660 (Figure 37).

The empirical data from the Quintette Coal Mine indicates that the leaching efficiency varies between 10% and 20% (Figure 38). Although Figure 38 compares a relative theoretical mass reduction to an empirical relative percent concentration decrease, the comparison is considered reasonable since nitrate concentrations will be a function of the mass remaining in the upstream spoils. A value of 20% is conservatively selected as the source term based on general agreement with the Mesa B and Mesa C sedimentations ponds. This leaching efficiency results in the bulk of the residual nitrogen (approximately 90%) being flushed from the spoil after 10 years, which is consistent with data from Quintette Coal Operations Station BC1. The period of time from the concentration peak (2004) to reaching baseline concentration (~2013 to 2015) was approximately 10 years (Figure 39).

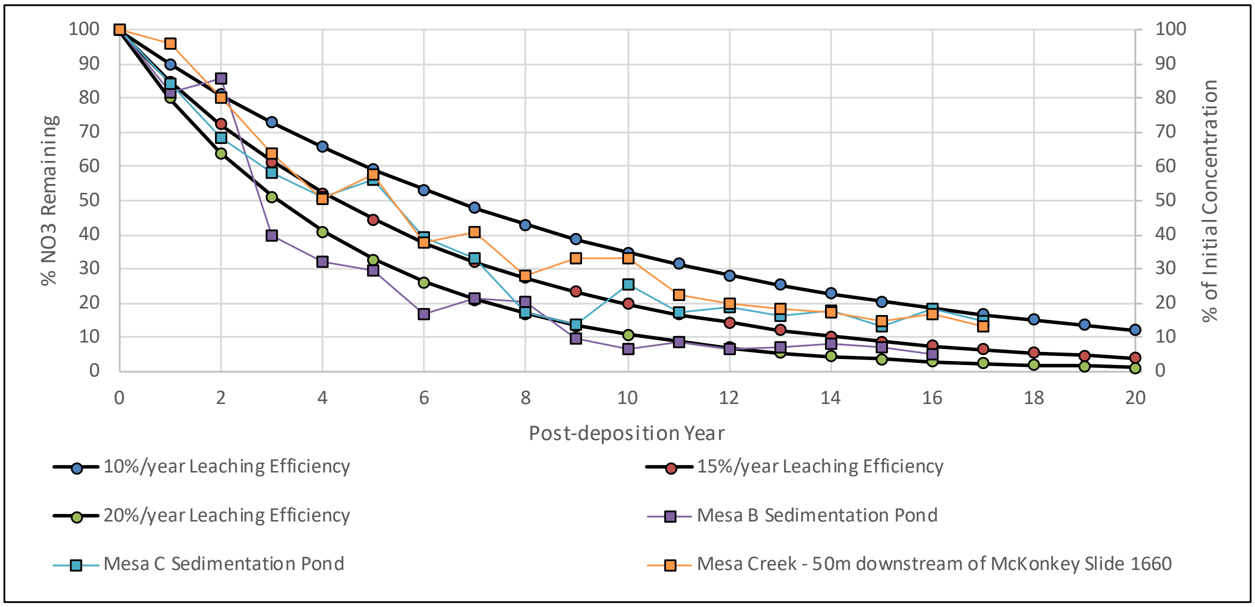

Figure 38. Theoretical Nitrate Leaching Efficiencies compared to Percent Decreases in Nitrate Concentrations at the Quintette Coal Mine

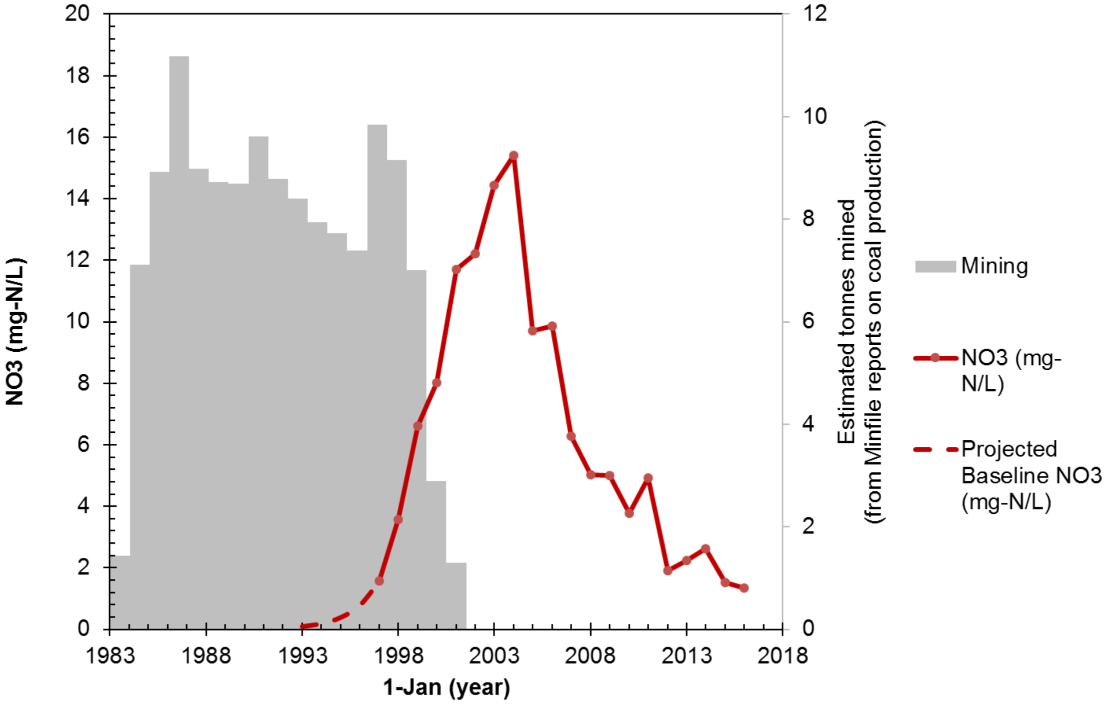

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Figure 39. Nitrate Concentration Trend Relative to Period of Mining and Waste Placement at Quintette Coal Operations Mesa Mining Area. The grey shading is coal production which is assumed to be roughly proportional to waste rock volume.

Speciation of Nitrogen Forms

While the predominant nitrogen form is nitrate, other forms may be present. For the purpose of downstream projections within the 2020 RWQM, nitrate concentrations calculated in the water quality model can be used to estimate nitrite and ammonia nitrogen based on their ratios to nitrate (Section 5.2.2) using the following formula:

$$C_{NO_2} \text{ (in mg N/L)} = \frac{C_{NO_2}}{C_{NO_3}} \cdot C_{NO_3}$$

$$C_{NH_3} \text{ (in mg N/L)} = \frac{C_{NH_3}}{C_{NO_3}} \cdot C_{NO_3}$$

$\frac{C_{NO_2}}{C_{NO_3}}$ and $\frac{C_{NH_3}}{C_{NO_3}}$ are catchment specific. These ratios are provided in Table 16 and Table 17, respectively.

Table 16. Monthly Nitrite/Nitrate Ratios (mg N/mg N) by Catchment

Location	Month											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Fording River Operations (FRO)												
FR_CC1	0.0031	0.0023	0.0042	0.0022	0.0031	0.0036	0.0039	0.0041	0.0039	0.0028	0.0035	0.0037
FR_HC1	0.00083	0.00094	0.00086	0.001	0.00076	0.00092	0.0012	0.0011	0.0011	0.00088	0.0007	0.00068
FR_KC1	0.00017	0.00017	0.00019	0.0002	0.00019	0.00042	0.00036	0.0002	0.00015	0.00016	0.00012	0.00015
GH_CC1	0.00039	0.00062	0.00063	0.00073	0.00071	0.00061	0.00065	0.00068	0.00073	0.00061	0.001	0.00054
GH_SC1/SC2	0.00034	0.00056	0.00042	0.00074	0.0013	0.00083	0.0011	0.0012	0.001	0.00079	0.00053	0.00038
Greenhills Operations (GHO)												
GH_GH1	0.0036	0.0024	0.0021	0.0024	0.0018	0.014	0.0036	0.0046	0.0048	0.0033	0.0021	0.0021
GH_LC2	0.0036	0.0023	0.0016	0.0011	0.001	0.00049	0.0009	0.00056	0.0013	0.00084	0.00057	0.00052
GH_PC1	0.004	0.0053	0.0055	0.0039	0.0035	0.0044	0.0046	0.0055	0.0087	0.0045	0.0035	0.004
GH_TC2	0.0017	0.0014	0.001	0.0012	0.0013	0.0022	0.0027	0.0029	0.0019	0.0013	0.00094	0.00099
GH_WC2	0.00052	0.0024	0.00046	0.0014	0.00047	0.00098	0.00048	0.00053	0.00057	0.00059	0.00043	0.00042
Line Creek Operations (LCO)												
LC_DC3	0.00063	0.0017	0.0025	0.0047	0.0098	0.011	0.0079	0.01	0.014	0.014	0.016	0.0085
LC_LCUSWLC	0.00035	0.00041	0.00038	0.00049	0.00037	0.001	0.00047	0.00028	0.0003	0.0003	0.00042	0.00029
LC_WLC	0.00027	0.00028	0.002	0.00046	0.00042	0.00066	0.00048	0.00058	0.0036	0.00047	0.00035	0.00029
Elkview Operations (EVO)												
EV_BC1	0.00077	0.0011	0.0031	0.0013	0.0017	0.0012	0.0014	0.0018	0.0015	0.0019	0.0028	0.00077
EV_GT1	0.00033	0.0005	0.0028	0.00074	0.0011	0.00095	0.0009	0.0011	0.0023	0.0014	0.00057	0.00041
EV_DC1	0.0023	0.0019	0.0031	0.0018	0.0022	0.0023	0.0026	0.0034	0.0029	0.0023	0.0023	0.0027
EV_EC1	0.00056	0.00072	0.00078	0.00075	0.00083	0.0008	0.0011	0.00089	0.0013	0.00069	0.00079	0.00052
EV_HC1	0.0065	0.0025	0.003	0.0038	0.0019	0.0023	0.0055	0.0038	0.0075	0.0048	0.0029	0.0027
Coal Mountain Operations (CMO)												
CM_CC1	0.012	0.0074	0.011	0.012	0.0063	0.0053	0.007	0.0052	0.0087	0.0085	0.0079	0.0088

Source:

Table 17. Monthly Ammonia/Nitrate Ratios (mg N/mg N) by Catchment

Location	Month											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Fording River Operations (FRO)												
FR_CC1	0.02	0.016	0.013	0.0092	0.015	0.013	0.015	0.012	0.013	0.0095	0.022	0.028
FR_HC1	0.0014	0.0013	0.0012	0.0014	0.0045	0.0067	0.0052	0.0032	0.0024	0.0022	0.0019	0.0015
FR_KC1	0.000059	0.00005	0.000074	0.00043	0.00017	0.00044	0.00025	0.00014	0.00011	0.000088	0.00010	0.000097
GH_CC1	0.00034	0.00042	0.00034	0.00039	0.00032	0.00029	0.0003	0.00038	0.00054	0.0012	0.0008	0.00034
GH_SC1/SC2	0.00021	0.00051	0.00028	0.00049	0.0016	0.00062	0.0004	0.00084	0.00043	0.00034	0.00026	0.0042
Greenhills Operations (GHO)												
GH_GH1	0.0075	0.0035	0.0022	0.0034	0.0054	0.0022	0.0025	0.0017	0.0019	0.0018	0.0012	0.0018
GH_LC2	0.0027	0.0011	0.00065	0.00071	0.00042	0.00021	0.00027	0.00026	0.00036	0.00021	0.00031	0.00024
GH_PC1	0.0059	0.0085	0.0097	0.0052	0.0042	0.0046	0.0048	0.0072	0.018	0.0061	0.0048	0.0052
GH_TC2	0.0021	0.0017	0.0019	0.0018	0.0022	0.0017	0.0019	0.0014	0.00077	0.00065	0.00054	0.0013
GH_WC2	0.00026	0.0068	0.00026	0.0042	0.00026	0.0025	0.00022	0.00033	0.00029	0.0003	0.0002	0.0006
Line Creek Operations (LCO)												
LC_DC3	0.0028	0.009	0.0052	0.011	0.0042	0.0017	0.0015	0.0014	0.0011	0.0017	0.0015	0.0022
LC_LCUSWLC	0.00055	0.00038	0.00038	0.00041	0.001	0.0016	0.0014	0.00075	0.00052	0.0011	0.00088	0.00067
LC_WLC	0.00022	0.00022	0.0002	0.00022	0.00033	0.00046	0.00042	0.00041	0.00033	0.00065	0.00033	0.00037
Elkview Operations (EVO)												
EV_BC1	0.0027	0.0032	0.0047	0.0023	0.0027	0.003	0.0032	0.0032	0.0032	0.0041	0.0036	0.0027
EV_GT1	0.0011	0.001	0.0028	0.00083	0.00058	0.0011	0.0011	0.00039	0.0085	0.0055	0.0013	0.0014
EV_DC1	0.0014	0.0019	0.0018	0.0017	0.0018	0.0021	0.0021	0.0024	0.0032	0.0019	0.0026	0.0029
EV_EC1	0.00086	0.0023	0.0007	0.00067	0.00061	0.00075	0.00087	0.0023	0.001	0.0012	0.001	0.001
EV_HC1	0.016	0.0077	0.0084	0.013	0.0092	0.011	0.012	0.012	0.02	0.013	0.011	0.0094
Coal Mountain Operations (CMO)												
CM_CC1	0.014	0.0077	0.018	0.024	0.018	0.018	0.018	0.014	0.017	0.0079	0.015	0.014

8.2.2 Weathering Rates

Selenium and Sulphate

Annual selenium and sulphate loading rates were calculated on a per unit volume (i.e., bcm) based on calculated loadings (Figure 31) at monitoring locations downstream of each spoil and the cumulative volume of rock placed in the spoil as follows:

$$L_{i,year} = \frac{L_{M,obs}}{V_{year}}$$

Where: $L_{i,year}$ represents the loading rate in units of mg/bcm/year or g/bcm/year

$L_{M,\,obs}$ is the calculated annual loading rate based on monitoring results downstream of the spoil (see Section 5.2.2); and

V_{year} is the cumulative volume (bcm) of rock in the spoil that corresponds to the load at the downstream monitoring location.

V_{year} was determined based on the hydraulic lag calculated for each spoil based on cumulative curve fitting of nitrate or comparison of the nitrate concentrations and waste placement histories (Section 8.2.1).

A strong correlation exists between the ratio of the annual load to the average annual load and the annual flow to the average annual flow (Figure 40 and Figure 41). This is identified based on the thick dashed line on the figures; the thin dashed line represents the 1:1 line. For example, when the annual load is greater than average load (i.e., ${SO_4}/{\overline{SO_4}} > 1$) the annual flow is generally greater than the average annual flow (i.e., ${Q}/{\bar{Q}} > 1$). This implies that the variance in annual loadings from the spoils are predominantly a function of the volume of water produced in a given year and to a lesser degree, changes in concentration of the toe seepage from the spoil. This concept has the inherent assumption that a particle of water flowing through the spoil will mobilize an equivalent amount of mass (i.e., the concentration is the same) regardless of the velocity of that particle of water as occurs in a piston flow model (Section 4.2.2). To account for variance in annual flows, the annual loads were normalized as follows:

$$L_{i,year}(\text{normalized}) = \frac{L_{i,year}}{Q_{year}/\bar{Q}}$$

$\bar{Q}$ equals the average annual flow for monitored years. Applying the above formula increases the loads when flow are less than the average annual flow and decreases the load when flows are greater than the annual average flow.

Following normalization of the loads, average and 95th confidence limits were calculated based on the annual values. These values represent the base case selenium and sulphate source terms

To evaluate uncertainty in the hydraulic lag and the groundwater bypass estimates, the following sensitivity scenarios were evaluated for each catchment:

- t_{HL} was varied by ±2 years; and
- The source terms were recalculated using the minimum and maximum bypass values (Table 11).

Confidence limits were also calculated for these scenarios and then the minimum and maximum selenium and sulphate loading rates were selected to represent the full range of loadings that could occur in each catchment. Catchment selenium and sulphate source terms are provided in Table 18. Average selenium and sulphate loading rates to the 2017 values are compared in Table 19.

Explanations for differences between the 2020 and 2017 source terms include:

- Changes to the waste rock volumes as part of the waste rock reconciliation;
- Introduction of groundwater partitioning into the source term calculations;
- Removal of loads from undisturbed areas;
- Use of different datasets (e.g., Wolfram Creek);
- Inclusion of three years of additional monitoring data into the calculations; and
- Change in THL.

Table 19 describes explanations for differences between 2017 and 2020.

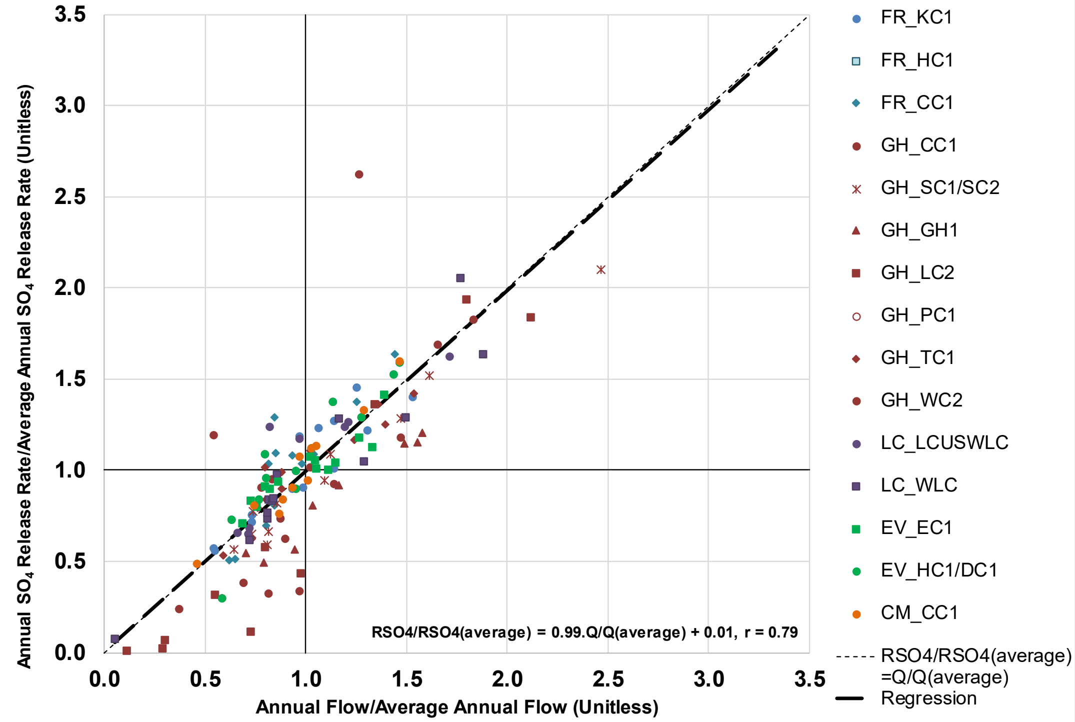

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Figure 40. Relationship between Normalized Annual Flow and Normalized Annual Sulphate Release Rates

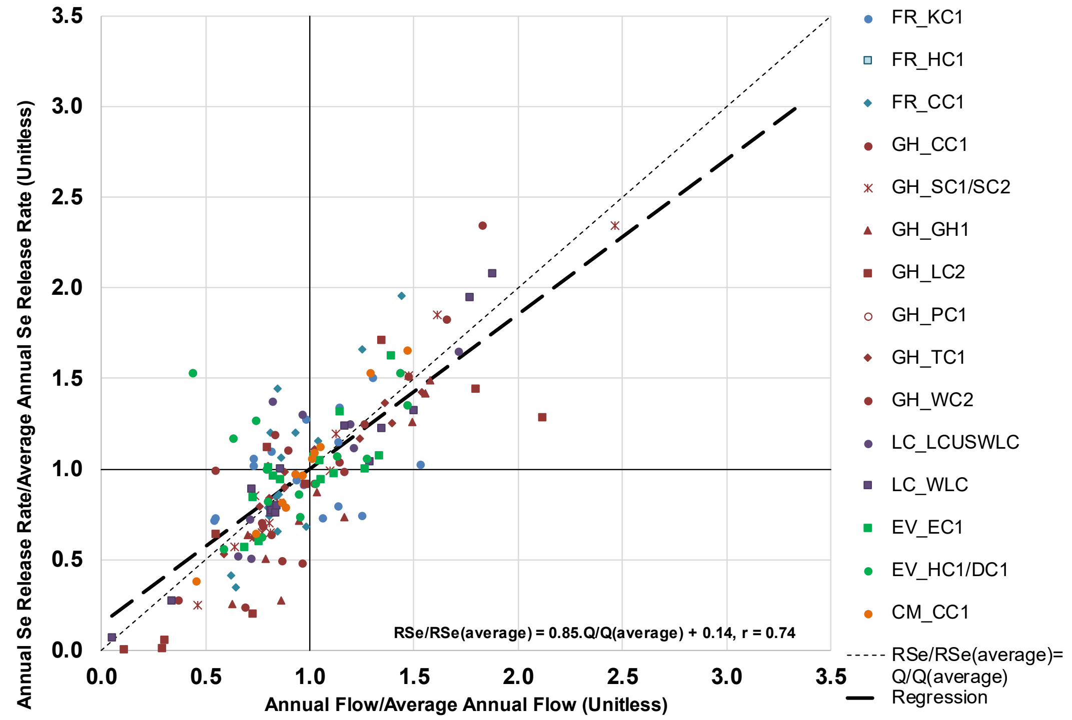

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Figure 41. Relationship between Normalized Annual Flow and Normalized Annual Selenium Release Rates

Table 18. Sulphate and Selenium Release Rates for Permanently Exposed Waste Rock by Drainage

Station	Unsaturated Waste Rock Release Rate (Lag-adjusted)												
	Assumed Bypass Volume (% or flow)	SO_4 Source Term (g/BCM/yr)						Se Source Term (mg/BCM/yr)					
		Years of Data	Lower Limit on Mean	Base Case			Upper Limit on Mean	Years of Data	Lower Limit on Mean	Base Case			Upper Limit on Mean
				Lower 95% Confidence Limit	Arithmetic Mean	Upper 95% Confidence Limit				Lower 95% Confidence Limit	Arithmetic Mean	Upper 95% Confidence Limit	
FR_CC1	2,250-9000 m^3/d	13	3.9	4.7	5.3	5.9	7.9	15	1.1	1.3	1.7	2.0	2.7
FR_HC1	5-10%	13	19	21	27	33	45	15	3.1	3.8	4.4	5.0	7.5
FR_KC1	5,800-12,800 m^3/d	14	8.4	9.7	10	11	14	15	2.4	2.8	3.5	4.1	4.9
GH_CC1	n/a	10	10	11	14	17	18	12	3.3	3.7	4.6	5.5	6.0
GH_SC1/SC2	50-200 m^3/d	11	8.4	12	13	15	21	13	3.6	4.5	5.1	5.8	6.9
GH_GH1	520-1,704 m^3/d (avg of 600 m^3/d)	13	17	20	22	24	28	15	3.2	3.6	4.4	5	6
GH_LC2	n/a	11	2.4	5.9	14	23	34	11	0.32	0.78	1.8	2.7	4.3
GH_TC2 (a)	n/a	11	15	17	33	49	98	11	0	2.6	6.9	11	30
GH_WC2	n/a	13	14	23	39	55	88	13	1.6	2.6	3.6	4.7	9.4
LC_WLC	2-60% (avg of 15%)	13	10.5	12	14	16	22	15	5.4	6.1	7.7	9.3	13
LC_LCUSWLC	0.1-36% (avg of 2%)	8.0	18	21	27	33	67	8.0	3.2	3.6	5.4	7.3	15
EV_BC1 & EV_GT1	n/a	17	0	4.4	23	43	72	18	1.6	2.0	5.2	8.3	16
EV_EC1	n/a	14	8.1	8.3	8.9	9.4	9.6	14	1.4	1.4	1.6	1.8	1.8
EV_HC1 & EV_DC1	2-10%	18	12	13	15	17	18	16	2.3	2.4	2.6	2.8	3.0
CM_CC1	n/a	11	17	19	20	22	24	11	0.47	0.53	0.58	0.63	0.7
Valley Wide Average (b)	---	---	11	13	19	26	39	---	2.3	2.9	4.1	5.3	9.0

Notes:

a) Results from GH_TC1 presented in 2017

b) Valley wide average calculated based on all locations presented in Table 1 except CM_CC1

Table 19. Comparison of 2020RWQM and 2017RWQM Selenium and Sulphate Release Rates

Location	Sulphate Release Rate (g/bcm/year)			Selenium Release Rate (mg/bcm/year)			Commentary
	2017RWQM	2020RWQM	RPD	2017RWQM	2020RWQM	RPD	
FR_CC1	5.1	5.3	4%	1.7	1.65	-2.8%	Rate increased due to bypass but T_{HL} decreased
FR_HC1	27	28	4%	4.8	4.5	-6%	2020 rates are similar to 2017 source terms.
FR_KC1	9.3	10	7%	2.4	3.5	37%	Rates increased in 2020 due to groundwater bypass and lower cumulative waste rock volumes in 2020 following the waste rock reconciliation. These increases were partly offset by a decrease in the lag time.
GH_CC1	8.7	14	47%	4.2	4.6	9%	Rates increased because cumulative waste rock volumes were lower in 2020 compared to 2017 following the waste rock reconciliation.
GH_SC1/SC2	8	13	48%	2.6	5.1	65%	Rates increased because cumulative waste rock volumes were lower in 2020 compared to 2017 following the waste rock reconciliation. T_{HL} also increased by one year in 2020.
GH_GH1	20	22	10%	4.9(a)	4.4	-11%	Cumulative waste rock volumes were lower compared to 2017 following the waste rock reconciliation. T_{HL} also increased by one year in 2020.
GH_LC2	I.D.	14	---	I.D.	1.6	---	No source term developed in 2017.
GH_TC2	47	33	-35%	7.6	6.9	-10%	2020 source term derived at monitoring location GH_TC2 versus GH_TC1, which was used in 2017.
GH_WC2	9.4	39	122%	0.8	3.6	127%	Flow from GH_WC1 and water quality from GH_WC2 was used in loading calculations in 2017. There were several gaps in the GH_WC1 flow record resulting in a limited dataset for loadings calculations. Flow and water quality from GH_WC2 were used in the 2020 update.
LC_WLC	11	14	24%	6.3	7.7	20%	Load increased in 2020 from inclusion of bypass and cumulative waste rock volumes were lower in 2020 following the waste rock reconciliation.
LC_LCUSWLC	31	27	-14%	6	5.4	-11%	Additional data carried forward into source term calculations.
EV_BC1/EV_GT1	15(b)	23	35%	3.8 (b)	5.2	27%	EV_BC1 and EV_GT1 combined into one source term in the 2020 update. Pit dewatering loads were backed out during derivation of the waste rock source terms. Therefore, rates from 2017 are not directly comparable.
EV_EC1	20	8.9	-77%	3.5	1.6	-75%	Cumulative waste rock volumes were higher in 2020 following the waste rock reconciliation.
EV_HC1/EV_DC1	6.1(c)	15	59%	1.1 (c)	2.6	58%	Cumulative waste rock volumes were higher in 2020 following the waste rock reconciliation.
CM_CC1	19	20	5%	0.56	0.58	4%	Source term is similar to 2017. Main differences in calculations are a decrease in T_{HL} and additional years of data included in calculations.
Valley Wide Average	17	19	11%	4.3	4.1	-5%	n/a

Notes:

a) A value of 8.8 mg/bcm/year was incorrectly reported in SRK (2017)

b) 2017 source term for EV_BC1 presented.

c) 2017 source term for EV_HC1 presented.

Cadmium, Cobalt and Nickel

The 2017 source terms considered that cadmium and cobalt were related to sulphide oxidation in unsaturated waste rock but also inherently accounted for the downstream influence of calcite precipitation on cadmium and cobalt source terms concentrations. For this update, these two processes (i.e., release with sulphide oxidation and attenuation through calcite precipitation) have been separated. Cadmium, cobalt and nickel release rates are derived and the percentage attenuation from adsorption and co-precipitation (with calcite) is subsequently applied at each monitoring location. The conceptual model and attenuation factors for these parameters is presented in Section 9.

The conceptual model for cadmium, cobalt and nickel is these metals are released through sulphide oxidation (Section 5.2.2) and the source term for these parameters are represented as the metal sulphate release rate ratio (MSRRR) derived based on observed loading rates in humidity cell tests. Source terms for cadmium, cobalt and nickel, derived using the method discussed in Section 5.2.2, are provide in Table 20 and Table 21. The source terms are provided for pre- and post-PAG management strategy implementation. The source terms are also provided as a look-up table to account for the presence of Morrissey Formation in each of the spoils.

It is notable that the post-PAG management nickel source term slightly decreases as the proportion of Morrissey Formation increases. This occurs because the sulphate release rate increases more rapidly than the nickel release rate as the proportion of Morrissey Formation increases. The increased production of sulphate will result in higher nickel release rates even though the MSRRR decreases.

Table 20. MSRRRs for Cadmium, Cobalt and Nickel prior to Implementation of PAG Management Strategies

Percent Morrisey Formation	Metal Sulphate Release Rate Ratio (MSRRR)					
	P50			P95		
	Ni	Cd	Co	Ni	Cd	Co
0%	0.00012	0.000006	0.00002	0.00019	0.000006	0.00004
1%	0.00020	0.000007	0.00005	0.00029	0.000009	0.00007
5%	0.00044	0.000012	0.00012	0.00061	0.000019	0.00019
10%	0.00063	0.000015	0.00018	0.00091	0.000029	0.00030
15%	0.00076	0.000017	0.00022	0.00114	0.000036	0.00039
20%	0.00085	0.000019	0.00025	0.00133	0.000042	0.00046
25%	0.00091	0.000020	0.00027	0.00148	0.000047	0.00052
30%	0.00096	0.000021	0.00029	0.00160	0.000051	0.00056

Note: ratios are provided in units of mg/mg SO_4

Table 21. MSRRRs for Cadmium, Cobalt and Nickel after Implementation of PAG Management Strategies

Percent Morrisey Formation	Metal Sulphate Release Rate Ratio (MSRRR)					
	P50			P95		
	Ni	Cd	Co	Ni	Cd	Co
0%	0.00012	0.000006	0.00002	0.00019	0.000006	0.00004
1%	0.00012	0.000006	0.00002	0.00019	0.000006	0.00004
5%	0.00012	0.000006	0.00002	0.00018	0.000006	0.00005
10%	0.00011	0.000005	0.00002	0.00017	0.000005	0.00006
15%	0.00010	0.000005	0.00002	0.00016	0.000005	0.00007
20%	0.00010	0.000005	0.00002	0.00016	0.000005	0.00007
25%	0.00009	0.000005	0.00002	0.00015	0.000005	0.00008
30%	0.00009	0.000004	0.00002	0.00015	0.000005	0.00008

Note: ratios are provided in units of mg/mg SO_4

Uranium

Water quality monitoring results trends indicate that uranium concentrations are correlated to sulphate, with the lowest concentrations occurring during freshet and peak concentrations occurring during low flow periods (Figure 20). The parallel trends of uranium and sulphate also indicate that uranium concentrations are not attenuated during periods of calcite precipitation.

The conceptual model for uranium release is considered to be through oxidative dissolution of carbonaceous matter in waste rock spoils. The source term for uranium is represented as a catchment specific ratio to the sulphate release rate. The uranium/sulphate source term ratios for each catchment are provided in Table 22.

Table 22. Catchment Specific Uranium/Sulphate Release Rate Ratios

Location	Month											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Fording River Operations (FRO)												
FR_CC1	0.000022	0.00002	0.00002	0.00002	0.000019	0.00002	0.000021	0.000021	0.000021	0.000021	0.000021	0.000022
FR_HC1	0.0000082	0.0000078	0.0000073	0.0000082	0.000012	0.000021	0.000013	0.000011	0.0000098	0.0000096	0.0000089	0.0000081
FR_KC1	0.000018	0.000017	0.000018	0.000018	0.000021	0.000026	0.000024	0.000023	0.00002	0.00002	0.000018	0.000019
GH_CC1	0.00001	0.00001	0.000010	0.00001	0.0000093	0.000010	0.00001	0.000011	0.00001	0.000010	0.000011	0.00001
GH_SC1/SC2	0.0000099	0.00001	0.0000097	0.0000095	0.0000094	0.0000099	0.0000096	0.0000098	0.0000097	0.0000098	0.0000099	0.00001
Greenhills Operations (GHO)												
GH_GH1	0.000011	0.000011	0.000011	0.000012	0.000014	0.000013	0.000012	0.000012	0.00001	0.00001	0.000011	0.000011
GH_LC2	0.000014	0.000016	0.000016	0.000015	0.000013	0.000014	0.000015	0.000014	0.000014	0.000015	0.000015	0.000014
GH_PC1	0.000012	0.000012	0.000012	0.000012	0.000011	0.000012	0.000012	0.000012	0.000012	0.000012	0.000012	0.000012
GH_TC2	0.0000065	0.0000063	0.0000065	0.0000062	0.000007	0.0000078	0.0000079	0.0000075	0.0000069	0.000007	0.000007	0.0000067
GH_WC2	0.000016	0.000016	0.000018	0.000016	0.000017	0.000015	0.000016	0.000017	0.000016	0.000017	0.000017	0.000016
Line Creek Operations (LCO)												
LC_DC3	0.000024	0.000025	0.00003	0.000028	0.000018	0.000018	0.000024	0.000017	0.000016	0.000019	0.00002	0.000019
LC_LCUSWLC	0.000015	0.000014	0.000015	0.000015	0.000019	0.000019	0.000018	0.000017	0.000016	0.000016	0.000016	0.000016
LC_WLC	0.000017	0.000016	0.000016	0.000015	0.000017	0.000016	0.000016	0.000017	0.000018	0.000019	0.000019	0.000018
Elkview Operations (EVO)												
EV_BC1	0.000015	0.000014	0.000014	0.000014	0.000012	0.000014	0.000014	0.000014	0.000014	0.000013	0.000015	0.000015
EV_GT1	0.000016	0.000014	0.000012	0.000013	0.000011	0.000013	0.000014	0.000014	0.000013	0.000015	0.000016	0.000014
EV_DC1	0.000012	0.000012	0.000012	0.000013	0.000013	0.000013	0.000012	0.000012	0.000012	0.000012	0.000012	0.000012
EV_EC1	0.0000091	0.0000091	0.000009	0.0000088	0.0000091	0.0000094	0.0000095	0.0000095	0.0000094	0.0000094	0.0000097	0.0000094
EV_HC1	0.000013	0.000013	0.000013	0.000014	0.000016	0.000016	0.000014	0.000014	0.000013	0.000013	0.000013	0.000013
Coal Mountain Operations (CMO)												
CM_CC1	0.00001	0.000010	0.00001	0.0000088	0.0000093	0.000010	0.0000097	0.0000096	0.0000095	0.0000097	0.0000095	0.00001

Notes:

Values represent U/SO_4 ratios in mg/mg SO_4

Arsenic, Chromium, Manganese and Phosphorus

Measured arsenic, chromium, manganese and phosphorus concentrations have remained generally stable in the monitoring data record (Section 5.2.2) but do demonstrate seasonality. Source terms for these parameters are represented as constant catchment specific monthly concentrations. Average and P95 source terms for these parameters are provided in Table 23 to Table 26.

Table 23. Monthly Source Term Concentrations for Arsenic

Location	Statistic	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Fording River Operations (FRO)													
FR_CC1	Average	0.00022	0.0002	0.00021	0.00024	0.00021	0.00021	0.00022	0.00021	0.00022	0.00022	0.00021	0.00022
	P95	0.0004	0.00045	0.00041	0.00041	0.00032	0.00029	0.00041	0.00033	0.00034	0.00038	0.0004	0.00043
FR_HC1	Average	0.00013	0.00011	0.0001	0.00011	0.00011	0.00012	0.00011	0.00011	0.0001	0.0001	0.0001	0.00012
	P95	0.0002	0.00013	0.00011	0.00017	0.00016	0.00013	0.00013	0.00013	0.00011	0.00012	0.00011	0.00018
FR_KC1	Average	0.00015	0.00015	0.00018	0.0002	0.00017	0.00011	0.00013	0.0001	0.00015	0.00011	0.00012	0.00012
	P95	0.0002	0.00021	0.0002	0.00031	0.00033	0.00013	0.00027	0.00012	0.00035	0.00017	0.00018	0.00019
GH_CC1	Average	0.00027	0.0002	0.0002	0.00024	0.0002	0.0002	0.0002	0.0002	0.00029	0.00028	0.00029	0.0002
	P95	0.00045	0.0002	0.00021	0.00041	0.0002	0.00021	0.0002	0.0002	0.00046	0.00046	0.00047	0.0002
GH_SC1/SC2	Average	0.00027	0.0002	0.00024	0.00026	0.00029	0.00026	0.00026	0.0002	0.00029	0.00026	0.00021	0.00031
	P95	0.0005	0.00021	0.0005	0.0005	0.0005	0.0005	0.0005	0.00022	0.00067	0.0005	0.00026	0.0005
Greenhills Operations (GHO)													
GH_GH1	Average	0.00025	0.00024	0.00024	0.00034	0.00033	0.00023	0.00025	0.00024	0.00024	0.00024	0.00022	0.00021
	P95	0.00033	0.0003	0.0003	0.0007	0.00049	0.00026	0.00032	0.0003	0.00033	0.00029	0.00024	0.00026
GH_LC2	Average	0.00054	0.00057	0.0018	0.00083	0.00068	0.0007	0.00053	0.00046	0.00057	0.00045	0.00089	0.0005
	P95	0.00067	0.00077	0.00714	0.00173	0.00139	0.0014	0.00083	0.00057	0.00095	0.00061	0.0025	0.00072
GH_PC1	Average	0.00023	0.00023	0.00022	0.00022	0.00023	0.00022	0.00022	0.00022	0.00022	0.00022	0.00022	0.00029
	P95	0.00026	0.00026	0.00023	0.00025	0.00028	0.00025	0.00024	0.00024	0.00026	0.00027	0.00026	0.00049
GH_TC2	Average	0.0002	0.00021	0.0002	0.00021	0.00023	0.00023	0.00024	0.00027	0.00023	0.0002	0.00022	0.0002
	P95	0.00024	0.00029	0.00024	0.0003	0.00033	0.00031	0.00032	0.00031	0.00027	0.00024	0.00041	0.00023
GH_WC2	Average	0.00029	0.00031	0.00038	0.00051	0.00041	0.00059	0.0005	0.00035	0.00039	0.00035	0.00084	0.00036
	P95	0.00034	0.00043	0.00078	0.00117	0.00085	0.00183	0.00124	0.00064	0.00071	0.00079	0.00303	0.00061
Line Creek Operations (LCO)													
LC_DC3	Average	0.00028	0.0003	0.0003	0.00036	0.00036	0.00034	0.00035	0.00034	0.0003	0.00032	0.00034	0.00032
	P95	0.00032	0.00036	0.00033	0.00049	0.00056	0.00039	0.00055	0.00044	0.00036	0.00045	0.00043	0.00038
LC_LCUSWLC	Average	0.00015	0.00017	0.00023	0.00017	0.00015	0.00014	0.00013	0.00019	0.00017	0.00018	0.00013	0.00017
	P95	0.0002	0.00029	0.00055	0.00022	0.00018	0.00016	0.00015	0.0005	0.0005	0.0005	0.00015	0.0005
LC_WLC	Average	0.00028	0.00031	0.00034	0.00031	0.00026	0.00017	0.00018	0.00023	0.00022	0.00025	0.00023	0.00028
	P95	0.00035	0.00041	0.0005	0.00035	0.0005	0.0002	0.00023	0.0005	0.0005	0.0005	0.00028	0.00037
Elkview Operations (EVO)													
EV_BC1	Average	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
	P95	0.0005	0.0004	0.0005	0.0004	0.0004	0.0004	0.0003	0.0004	0.0003	0.0004	0.0003	0.0003
EV_GT1	Average	0.0002	0.0003	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
	P95	0.0003	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0004	0.0003	0.0004
EV_DC1	Average	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001
	P95	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0002
EV_EC1	Average	0.00023	0.00024	0.00022	0.00022	0.00025	0.00028	0.00026	0.00022	0.00023	0.00025	0.00023	0.00023
	P95	0.00027	0.00031	0.00025	0.00025	0.00028	0.0005	0.00037	0.00024	0.00026	0.00033	0.00026	0.00027
EV_HC1	Average	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	P95	0.0003	0.0002	0.0002	0.0002	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002
Elkview Operations (EVO)													
CM_CC1	Average	0.00026	0.00025	0.00025	0.00031	0.00028	0.00097	0.00024	0.00025	0.00023	0.00027	0.00036	0.00027
	P95	0.00043	0.00039	0.0003	0.0005	0.0005	0.0007	0.0003	0.00033	0.00027	0.00043	0.0005	0.00041

Notes:

Concentrations in mg/L

Table 24. Monthly Source Term Concentrations for Chromium

Location	Statistic	Month											
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Fording River Operations (FRO)													
FR_CC1	Average	0.00029	0.0003	0.00028	0.00032	0.00026	0.00018	0.00021	0.00016	0.00024	0.00025	0.00017	0.00014
	P95	0.0008	0.00081	0.00065	0.0005	0.0005	0.00027	0.00037	0.00019	0.00037	0.00046	0.00027	0.00016
FR_HC1	Average	0.00015	0.00013	0.00017	0.00018	0.00018	0.00021	0.00018	0.00018	0.00016	0.00016	0.00018	0.00015
	P95	0.00019	0.00016	0.00028	0.0003	0.00027	0.00035	0.00032	0.00029	0.0002	0.00022	0.00035	0.00021
FR_KC1	Average	0.00015	0.00013	0.00018	0.00026	0.00031	0.00013	0.00015	0.00011	0.00012	0.00012	0.00014	0.00012
	P95	0.0002	0.0002	0.0002	0.00064	0.00093	0.00018	0.00033	0.00012	0.00017	0.0002	0.0002	0.00019
GH_CC1	Average	0.00026	0.00021	0.0002	0.00024	0.00021	0.0002	0.00022	0.00021	0.00028	0.00028	0.00028	0.0002
	P95	0.00044	0.00023	0.00021	0.00041	0.00025	0.0002	0.00028	0.00025	0.00046	0.00046	0.00046	0.0002
GH_SC1/SC2	Average	0.00026	0.00019	0.00021	0.00035	0.00022	0.00014	0.00014	0.00019	0.00018	0.00026	0.00022	0.0003
	P95	0.0005	0.00023	0.00033	0.00117	0.00043	0.00022	0.00022	0.0002	0.0002	0.0005	0.00032	0.0005
Greenhills Operations (GHO)													
GH_GH1	Average	0.00022	0.00018	0.00022	0.00057	0.00072	0.0002	0.00019	0.00017	0.00018	0.00023	0.00018	0.00021
	P95	0.00037	0.00025	0.00046	0.00189	0.00171	0.00034	0.00039	0.00024	0.00025	0.00038	0.00025	0.00033
GH_LC2	Average	0.00013	0.00015	0.00219	0.00085	0.00058	0.00075	0.00038	0.0002	0.00054	0.0002	0.00111	0.00027
	P95	0.0002	0.00022	0.01051	0.00249	0.00235	0.00276	0.00112	0.00037	0.00177	0.00036	0.00441	0.0007
GH_PC1	Average	0.00031	0.0003	0.00028	0.00028	0.0003	0.00029	0.00033	0.00033	0.00033	0.00036	0.00029	0.00038
	P95	0.00036	0.00035	0.00033	0.00036	0.00049	0.00035	0.00048	0.00039	0.00038	0.00042	0.00036	0.00051
GH_TC2	Average	0.0001	0.0001	0.00016	0.00022	0.0003	0.00011	0.00015	0.00011	0.00011	0.00011	0.00016	0.00011
	P95	0.0001	0.00011	0.00033	0.00042	0.0009	0.00015	0.00025	0.00012	0.00012	0.00012	0.00038	0.00014
GH_WC2	Average	0.00011	0.00019	0.00043	0.00054	0.00059	0.00053	0.0006	0.00021	0.00041	0.00037	0.00164	0.00033
	P95	0.00012	0.00029	0.0014	0.00174	0.00254	0.00224	0.00237	0.00053	0.00117	0.00134	0.0070	0.00072
Line Creek Operations (LCO)													
LC_DC3	Average	0.00013	0.00012	0.00012	0.00027	0.00029	0.00022	0.00022	0.00015	0.00013	0.00017	0.00016	0.00014
	P95	0.00019	0.00016	0.00017	0.00059	0.00063	0.00062	0.00079	0.00024	0.00019	0.00039	0.00021	0.00018
LC_LCUSWLC	Average	0.00015	0.00017	0.00026	0.00023	0.00039	0.00015	0.00017	0.00021	0.00019	0.00021	0.00015	0.00019
	P95	0.00173	0.0020	0.00145	0.00167	0.00104	0.00024	0.00038	0.0005	0.0005	0.0005	0.00026	0.0005
LC_WLC	Average	0.00017	0.0002	0.00025	0.00019	0.00018	0.00014	0.00015	0.0002	0.00021	0.00021	0.0002	0.00022
	P95	0.0002	0.00034	0.0005	0.00028	0.00028	0.0002	0.00034	0.0005	0.0005	0.0005	0.00045	0.00045
Elkview Operations (EVO)													
EV_BC1	Average	0.0002	0.0002	0.0003	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001
	P95	0.0005	0.0002	0.0006	0.0003	0.0003	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002
EV_GT1	Average	0.0002	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001
	P95	0.0003	0.0017	0.0007	0.0004	0.0006	0.0003	0.0005	0.0003	0.0003	0.0003	0.0001	0.0002
EV_DC1	Average	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001
	P95	0.0002	0.0002	0.0002	0.0002	0.0003	0.0004	0.0002	0.0002	0.0002	0.0003	0.0006	0.0002
EV_EC1	Average	0.00038	0.00023	0.0002	0.0002	0.00023	0.00021	0.00023	0.0002	0.00021	0.00021	0.00018	0.00036
	P95	0.00109	0.00029	0.00026	0.00025	0.00028	0.00028	0.00028	0.00023	0.00026	0.00025	0.00022	0.00099
EV_HC1	Average	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	P95	0.0002	0.0004	0.0002	0.0003	0.0005	0.0006	0.0003	0.0004	0.0004	0.0003	0.0004	0.0003
Coal Mountain Operations (CMO)													
CM_CC1	Average	0.00018	0.00021	0.00026	0.00031	0.00029	0.00119	0.00017	0.00015	0.00016	0.00026	0.00034	0.0002
	P95	0.00032	0.00045	0.00036	0.0005	0.00053	0.00213	0.00033	0.00025	0.00022	0.00045	0.0005	0.00038

Notes:
Concentrations in mg/L

Table 25. Monthly Source Term Concentrations for Manganese

Location	Statistic	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Fording River Operations (FRO)													
FR_CC1	Average	0.00712	0.00411	0.00775	0.00608	0.00377	0.00409	0.00341	0.00234	0.00208	0.00257	0.00299	0.00702
	P95	0.0187	0.01178	0.02525	0.0105	0.00699	0.00904	0.01065	0.00539	0.00377	0.00777	0.00552	0.01604
FR_HC1	Average	0.00807	0.00965	0.01165	0.01161	0.00607	0.00458	0.00413	0.00464	0.00497	0.00455	0.00505	0.00755
	P95	0.01587	0.01425	0.01814	0.0167	0.01257	0.00829	0.00527	0.00644	0.00931	0.00646	0.0079	0.01586
FR_KC1	Average	0.00015	0.00015	0.00022	0.00165	0.00366	0.00337	0.00171	0.00038	0.00028	0.00025	0.0002	0.00016
	P95	0.00021	0.00021	0.00039	0.00736	0.0125	0.00858	0.00513	0.0005	0.00036	0.00034	0.00024	0.00023
GH_CC1	Average	0.00057	0.00055	0.00079	0.00076	0.0009	0.0009	0.00094	0.00093	0.00088	0.00083	0.00077	0.00054
	P95	0.00064	0.0006	0.00128	0.00096	0.00122	0.00115	0.00121	0.00099	0.00099	0.00097	0.0008	0.00059
GH_SC1/SC2	Average	0.00384	0.00252	0.0064	0.00954	0.00988	0.00452	0.00578	0.00463	0.00626	0.00726	0.00759	0.01057
	P95	0.00792	0.00327	0.01984	0.02019	0.02973	0.01594	0.01815	0.01205	0.01885	0.01783	0.02388	0.03765
Greenhills Operations (GHO)													
GH_GH1	Average	0.00792	0.00786	0.00648	0.01248	0.01089	0.00576	0.00403	0.00197	0.00288	0.00198	0.00324	0.0044
	P95	0.02455	0.01929	0.0117	0.01347	0.01331	0.0031	0.0022	0.00187	0.00849	0.00281	0.00193	0.00265
GH_LC2	Average	0.00487	0.00487	0.1027	0.0312	0.02162	0.02156	0.01057	0.00622	0.01045	0.00481	0.01647	0.00808
	P95	0.01071	0.00962	0.52357	0.10603	0.09402	0.09669	0.03143	0.01315	0.02857	0.00618	0.01787	0.0271
GH_PC1	Average	0.00095	0.00077	0.00068	0.00076	0.00147	0.00063	0.00105	0.0011	0.00095	0.0008	0.00071	0.00079
	P95	0.00138	0.00143	0.00142	0.00109	0.00494	0.00092	0.00247	0.00149	0.00165	0.00108	0.00131	0.00131
GH_TC2	Average	0.01702	0.01824	0.01303	0.01088	0.00638	0.00412	0.00568	0.00582	0.00224	0.00203	0.00445	0.01262
	P95	0.03806	0.0334	0.02936	0.02021	0.01123	0.0057	0.01521	0.01952	0.00446	0.0044	0.00805	0.03068
GH_WC2	Average	0.01583	0.00481	0.00786	0.01578	0.01188	0.01486	0.02198	0.02825	0.01058	0.00836	0.02624	0.0090
	P95	0.03769	0.00997	0.02339	0.05695	0.03808	0.0613	0.07649	0.1295	0.03302	0.0261	0.11128	0.02277
Line Creek Operations (LCO)													
LC_DC3	Average	0.00137	0.00173	0.00097	0.00722	0.01392	0.00784	0.00656	0.00422	0.00384	0.00691	0.01606	0.00789
	P95	0.00158	0.00255	0.00193	0.01901	0.03936	0.01768	0.01427	0.00773	0.00565	0.01403	0.02839	0.01433
LC_LCUSWLC	Average	0.00021	0.00015	0.00045	0.00066	0.00027	0.00022	0.00028	0.00032	0.00026	0.00025	0.00021	0.00018
	P95	0.00066	0.00036	0.00147	0.00042	0.00048	0.00019	0.00068	0.00052	0.0005	0.00062	0.00033	0.00031
LC_WLC	Average	0.00033	0.00036	0.00067	0.00057	0.00045	0.00076	0.00172	0.00185	0.00168	0.00104	0.00051	0.0006
	P95	0.00117	0.00135	0.00273	0.00266	0.00115	0.00143	0.00264	0.00258	0.00286	0.00319	0.00263	0.0031
Elkview Operations (EVO)													
EV_BC1	Average	0.0082	0.010	0.0141	0.0083	0.0061	0.0054	0.0063	0.0051	0.0059	0.006	0.008	0.0058
	P95	0.0274	0.0272	0.0282	0.0216	0.0145	0.0151	0.0209	0.0175	0.0217	0.0204	0.0263	0.0259
EV_GT1	Average	0.0022	0.0022	0.0081	0.0053	0.0043	0.0035	0.0023	0.0019	0.0029	0.0076	0.002	0.0016
	P95	0.0025	0.0035	0.0252	0.0161	0.0087	0.0066	0.0067	0.0038	0.0073	0.0318	0.0047	0.0031
EV_DC1	Average	0.0004	0.0005	0.0005	0.0005	0.001	0.0008	0.0005	0.0005	0.001	0.0004	0.0003	0.0006
	P95	0.0007	0.001	0.001	0.0007	0.0023	0.0015	0.0008	0.0008	0.0028	0.0007	0.0005	0.0008
EV_EC1	Average	0.00008	0.00008	0.00009	0.00009	0.0002	0.00013	0.00012	0.0001	0.00012	0.00008	0.00009	0.00009
	P95	0.00015	0.00015	0.00024	0.00019	0.00062	0.00027	0.00017	0.00011	0.00024	0.0001	0.00013	0.00017
EV_HC1	Average	0.0025	0.0028	0.0029	0.003	0.0041	0.0031	0.0032	0.0054	0.006	0.003	0.0024	0.0032
	P95	0.0035	0.0051	0.0053	0.0063	0.010	0.0094	0.0055	0.0125	0.0116	0.0042	0.0038	0.0054
Coal Mountain Operations (CMO)													
CM_CC1	Average	0.03172	0.02638	0.03538	0.03487	0.02596	0.05008	0.03791	0.02843	0.04457	0.01897	0.03978	0.03345
	P95	0.05267	0.05412	0.10036	0.08575	0.06795	0.1182	0.09265	0.07619	0.08629	0.03948	0.07429	0.06121

Notes:

Concentrations in mg/L

Table 26. Monthly Source Term Concentrations for Phosphorus

Location	Statistic	Month											
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Fording River Operations (FRO)													
FR_CC1	Average	0.0322	0.03256	0.03212	0.03295	0.02348	0.0334	0.02863	0.02698	0.03308	0.00294	0.00182	0.0092
	P95	0.12154	0.12182	0.11925	0.12386	0.10628	0.12282	0.11643	0.11393	0.1230	0.00418	0.0020	0.03116
FR_HC1	Average	0.00238	0.0021	0.00513	0.00351	0.00731	0.00509	0.00308	0.00373	0.00458	0.0024	0.0033	0.00178
	P95	0.00328	0.00294	0.0125	0.00735	0.01869	0.01158	0.0071	0.00795	0.00789	0.00301	0.00614	0.00209
FR_KC1	Average	0.00175	0.00243	0.00273	0.0019	0.0036	0.00185	0.0020	0.0019	0.00322	0.00228	0.00175	0.01158
	P95	0.0020	0.00346	0.00481	0.00251	0.00536	0.0020	0.00217	0.0020	0.00592	0.00323	0.0020	0.03501
GH_CC1	Average	0.00315	0.0020	0.00268	0.00218	0.0020	0.00206	0.0020	0.0020	0.0020	0.0020	0.0020	0.0027
	P95	0.00365	0.0020	0.0033	0.00246	0.0020	0.00224	0.0020	0.0020	0.0020	0.0020	0.0020	0.0027
GH_SC1/SC2	Average	0.00458	0.00425	0.00691	0.00876	0.01986	0.01508	0.01055	0.00505	0.00443	0.00438	0.00774	0.0029
	P95	0.00718	0.00594	0.01818	0.01614	0.04664	0.03613	0.02352	0.00718	0.00532	0.00614	0.01758	0.00387
Greenhills Operations (GHO)													
GH_GH1	Average	0.00545	0.00992	0.01439	0.02306	0.02515	0.00947	0.00405	0.0043	0.00555	0.00423	0.00348	0.00628
	P95	0.00812	0.02173	0.03048	0.06128	0.04753	0.01425	0.00675	0.00675	0.00754	0.00567	0.00495	0.0126
GH_LC2	Average	0.02105	0.0210	0.5984	0.1521	0.07916	0.0717	0.06342	0.07802	0.09309	0.03899	0.10116	0.11008
	P95	0.03221	0.0358	3.0644	0.49355	0.14005	0.1740	0.13833	0.05069	0.09592	0.0144	0.04207	0.2416
GH_PC1	Average	0.0052	0.00863	0.00972	0.01687	0.02171	0.0089	0.00587	0.0039	0.00596	0.00456	0.00395	0.00538
	P95	0.00626	0.01931	0.01837	0.05418	0.0475	0.01403	0.01098	0.00658	0.00754	0.00576	0.0052	0.00853
GH_TC2	Average	0.0100	0.01162	0.01606	0.01823	0.01394	0.00788	0.00873	0.00858	0.00955	0.00502	0.00605	0.0075
	P95	0.01152	0.01545	0.03711	0.04304	0.03254	0.00956	0.01088	0.01161	0.01264	0.00822	0.00963	0.0086
GH_WC2	Average	0.00863	0.00873	0.02261	0.0138	0.01414	0.01286	0.01416	0.0229	0.0731	0.1032	0.01008	0.02723
	P95	0.02083	0.04424	0.14108	0.06339	0.06817	0.05787	0.05916	0.07022	0.24039	0.29543	0.02467	0.08048
Line Creek Operations (LCO)													
LC_DC3	Average	0.03478	0.0345	0.03825	0.06545	0.05776	0.0418	0.04889	0.02628	0.02657	0.03144	0.03551	0.03289
	P95	0.0380	0.04285	0.05077	0.1222	0.09781	0.0719	0.1376	0.0342	0.0339	0.05791	0.04714	0.04536
LC_LCUSWLC	Average	0.00339	0.00514	0.00959	0.00667	0.00363	0.00452	0.00401	0.00416	0.00418	0.00375	0.00342	0.00373
	P95	0.00435	0.01225	0.03014	0.0185	0.00703	0.0107	0.0071	0.0076	0.00818	0.0062	0.00691	0.00736
LC_WLC	Average	0.00584	0.00625	0.00936	0.00746	0.00651	0.0038	0.02898	0.00592	0.00516	0.00573	0.00514	0.00691
	P95	0.00666	0.00916	0.02216	0.0118	0.0123	0.00466	0.1352	0.01113	0.00786	0.00765	0.0071	0.00992
Elkview Operations (EVO)													
EV_BC1	Average	0.0025	0.0032	0.0155	0.0056	0.0073	0.0034	0.0035	0.0051	0.0038	0.0052	0.0036	0.0029
	P95	0.0034	0.0055	0.0293	0.0106	0.0169	0.0084	0.0071	0.012	0.0057	0.0097	0.0075	0.0058
EV_GT1	Average	0.0033	0.0103	0.0182	0.0093	0.010	0.0044	0.005	0.0056	0.0044	0.0052	0.0045	0.0035
	P95	0.0054	0.032	0.0445	0.0205	0.0237	0.0059	0.0101	0.0126	0.0075	0.009	0.0101	0.0058
EV_DC1	Average	0.0064	0.0072	0.0067	0.0051	0.005	0.0051	0.0075	0.0045	0.0131	0.0044	0.0063	0.005
	P95	0.0072	0.0097	0.0092	0.0074	0.0106	0.0068	0.0139	0.005	0.0349	0.0061	0.0096	0.0057
EV_EC1	Average	0.0101	0.01116	0.00748	0.00788	0.0115	0.01214	0.0119	0.0113	0.01218	0.00943	0.0085	0.0094
	P95	0.01303	0.01425	0.01028	0.01108	0.01295	0.01421	0.01246	0.01443	0.01411	0.01097	0.00972	0.01229
EV_HC1	Average	0.0086	0.0089	0.0075	0.0097	0.0172	0.0112	0.008	0.0079	0.0084	0.0069	0.0078	0.0079
	P95	0.0095	0.0108	0.0122	0.0163	0.0401	0.0209	0.0107	0.0119	0.0135	0.010	0.0117	0.0087
Coal Mountain Operations (CMO)													
CM_CC1	Average	0.00275	0.0036	0.0040	0.00413	0.00674	0.00354	0.00314	0.00318	0.00386	0.0035	0.00364	0.00215
	P95	0.00314	0.00694	0.01184	0.0083	0.01495	0.00684	0.00676	0.00511	0.00628	0.00612	0.00579	0.00237

Notes:

Concentrations in mg/L

8.2.3 Initial Soluble Load

The conceptual model for the initial soluble load is that the weathering rates, prior to placement in the spoil, are similar for pre- and post-blasted waste rock (i.e., the rates derived for in-situ waste rock (Section 5.2.2) can be used to estimate the initial soluble load). The rate is also assumed to be similar during blasting. Applying this assumption, the pre-deposition weathering timeframe (T_{PDW}) was estimated by aligning calculated selenium and sulphate loads for different timeframes with those observed in shake flask extraction (SFE) tests (Hendry, unpublished data) scaled to field conditions. This approach indicated a year of oxidation would be required to yield a similar amount of mass as produced in the SFE tests. Better agreement was also achieved when the average and maximum valley wide leach rates for sulphate and selenium, respectively, were used in the calculations.

Teck indicated that waste rock is typically placed in a spoil within weeks of blasting. This is shorter than the estimated pre-deposition weathering timeframe (T_{PDW}) implying that the pre-blast load contribution to the initial soluble load is much greater than the post-blast load, or the weathering rates increase during the blast. Due to the uncertainty in the pre-blast weathering time periods, it is effectively impossible to accurately calculate if (and the extent of) loading rates increase during blasting. The initial soluble load source term is therefore intended to provide an apparent pre-deposition weathering load but the contribution of the above processes (e.g., pre-blast weathering load, etc.) to the initial soluble load cannot be isolated.

The validity of the approach was tested for sulphate at monitoring location LC_DC3. LC_DC3 was selected because the relative contribution of the initial soluble load to the total catchment load is higher in new spoils since, as the spoil matures, ongoing weathering of the cumulative waste rock becomes the dominant source of load to downstream catchments (Figure 42). In comparison to other spoils in the Elk Valley, the spoil upstream of LC_DC3 is relatively young.

The annual load was estimated assuming the following input parameters:

- $\overline{R}_{SO_4}$ = 19 g/BCM/year
- T_{PDW} = 1 year
- T_{AL}= 10 years
- T_{HL} = 2 years

Predicted annual loads are compared to observed loads at monitoring location LC_DC3 in Figure 43. It can be seen in Figure 43 that the approach provides reasonable estimates for model years 3 and 5, but underpredicts the constituent load during year 4. Several variations of the calculation input variables were tested that improved the predictive performance in year 4; however, these resulted in overpredictions in other years with monitoring data. Based on the variations applied to the calculation inputs, the difference between calculated and observed in year 4 is sensitive to both the hydraulic lag (T_{HL}) and adjusted leach time (T_{AL}), implying that these parameters are variable in younger spoils and assuming constant values in future predictions of new spoils may not be appropriate. These analyses indicate that young spoils can have hydraulic lag times as low as one year at their inception, which can increase to several years as the spoil grows.

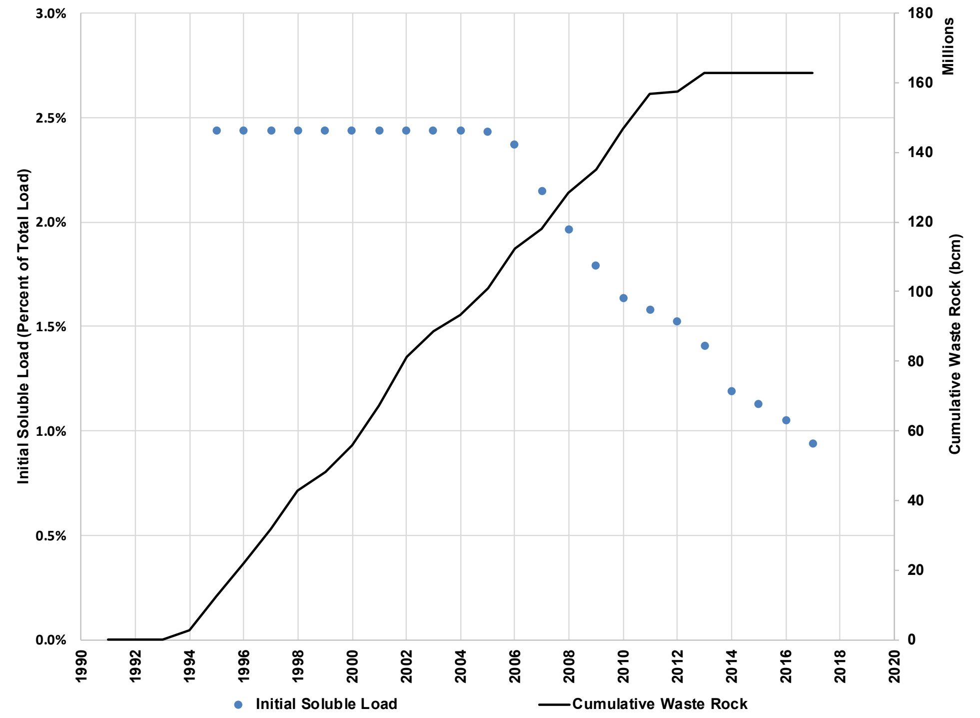

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Figure 42. Comparison of Initial Soluble Load to Total Load at Monitoring Location FR_HC1

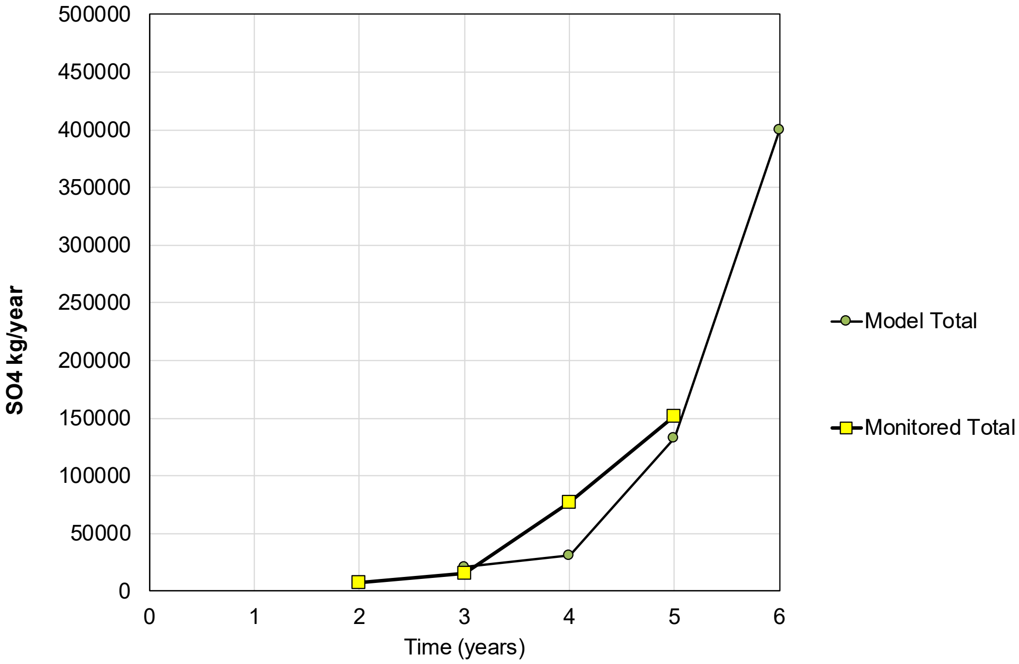

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Figure 43. Calculated versus Predicted Annual Loads at Monitoring Location LC_DC3

8.2.4 Decay in Release Rates

The decay rate source term, using the method described in Section 5.2.4, is provided in Table 27. Decay rates are based on observed humidity cell sulphate decay. Parameters conceptually linked to sulphate can use the same decay rate. For those parameters assumed to maintain constant concentrations, leach rates effectively remain constant until their inventory is depleted (Section 5.2.1).

It is important to note that the laboratory program provided strong evidence for declining rates. However, drainage monitoring records for sulphate and selenium, which now span up to two decades for waste rock spoils in the Elk Valley, do not show declining sulphate and selenium release rates. There are several factors that can mask the expected decline in sulphate concentrations, but the main ones are the ongoing addition of new wastes (which increases sulphate release) and climatic variation at seasonal and year-on-year time scales.

Due to the lack of empirical evidence to support the decline in sulphate and selenium rates at the field scale, the base case for the 2020 RWQM should be no decay of leach rates. The decay rate source term can be applied as a sensitivity in the model to evaluate long-term concentrations in the Elk Valley catchments following the cessation of spoiling in that catchment (e.g., the period when declining rates are not masked by placement of new waste rock in the spoil).

Table 27. Selenium and Sulphate Release Rate Decay

Year	SO_4 Rate Change (proportion of initial rate)		
	Lowest k	Average k	Highest k
1	0.97	0.98	0.99
10	0.71	0.81	0.86
20	0.5	0.66	0.75
30	0.35	0.53	0.65
40	0.25	0.43	0.56
50	0.18	0.35	0.48
60	0.12	0.28	0.42
70	0.087	0.23	0.36
80	0.062	0.18	0.31
90	0.043	0.15	0.27
100	0.031	0.12	0.23
110	0.022	0.098	0.2
120	0.015	0.079	0.17
130	0.011	0.064	0.15
140	0.0076	0.052	0.13
150	0.0054	0.042	0.11
160	0.0038	0.034	0.097
170	0.0027	0.028	0.084
180	0.0019	0.022	0.073
190	0.0013	0.018	0.063
200	0.00094	0.015	0.054

Source: Z:\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\200_Unsaturated Waste Rock Terms\230_COI Weathering Rates & Solubility\090_1st_order_decay\WR_1st_order_decay_rates_1ct017.229_MKH_SJD_R2.xlsx

8.2.5 Sulphate Solubility Limits

Previous source term evaluations have shown a strong correlation between calcium and magnesium for drainage waters from spoils in the Elk Valley and have been used to predict sulphate solubility concentrations based on the molar ratio of magnesium and calcium (SRK 2014a, 2017a) recognizing that as concentrations of magnesium increase, the solubility limit for sulphate also increases due to common ion effects.

Figure 44 provides the magnesium to calcium relationship for the current dataset. The slope of the regression line provides an updated Mg/Ca ratio of 1.19, whereas previously it was 1.18 in the 2017 update (SRK 2017). Relating that molar ratio to the corresponding sulphate concentration at which gypsum saturation occurs (Figure 45) provides an updated gypsum-constrained sulphate concentration, or upper bound sulphate value for application in the 2020 RWQM of 2530 mg/L. For comparison, sulphate concentration in equilibrium with pure gypsum in the absence of magnesium (i.e., Mg/Ca = 0) is calculated to be 1400 mg/L.

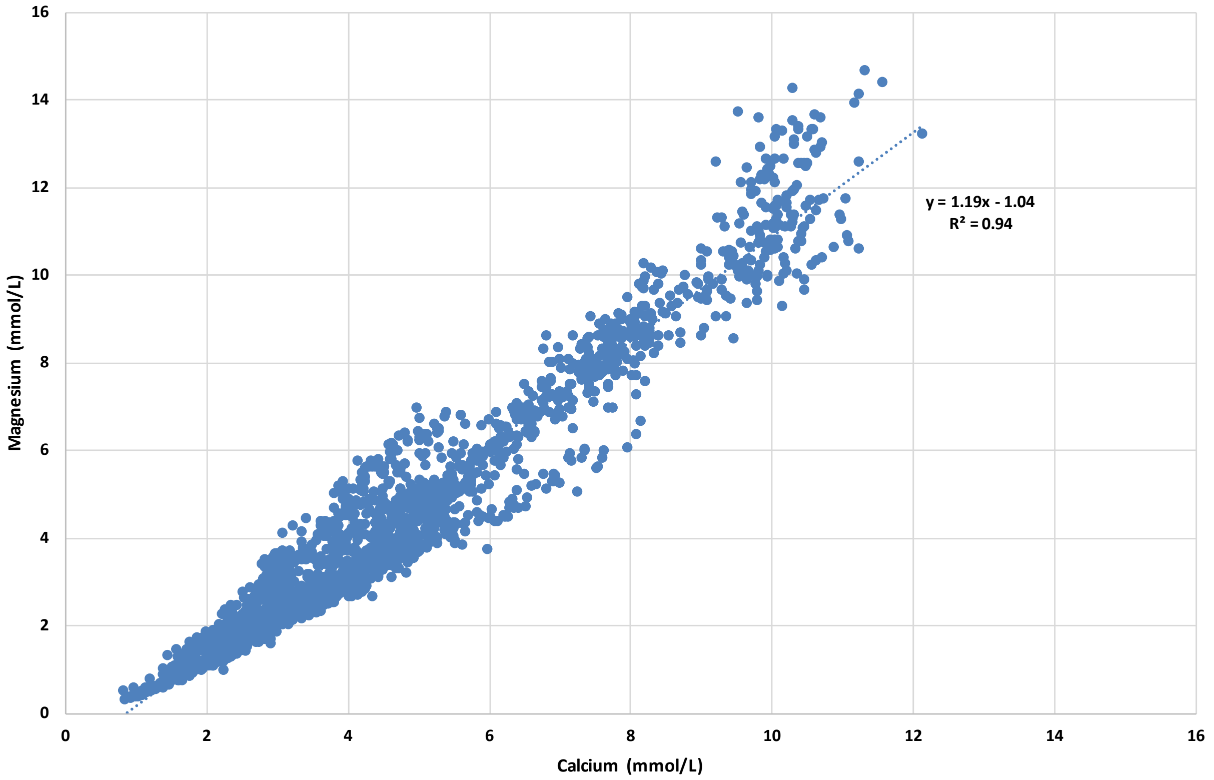

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Figure 44. Calcium versus Magnesium in Updated Monitoring Dataset.

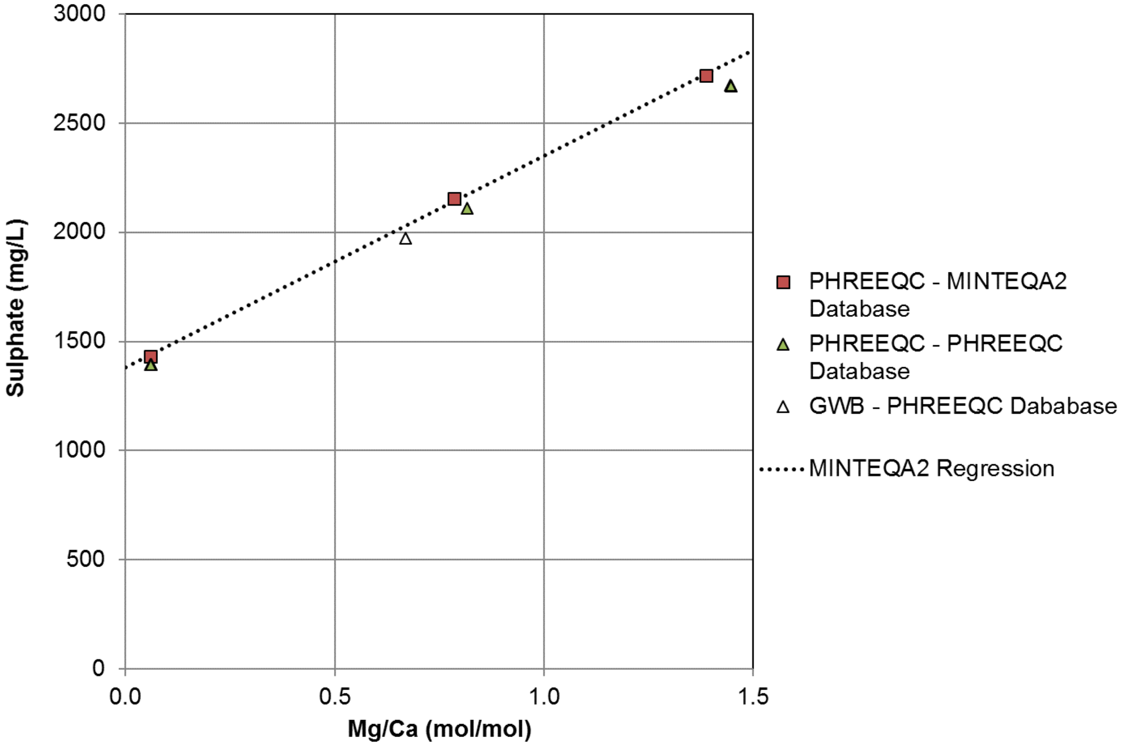

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Figure 45. Magnesium-Calcium Molar Ratio versus Sulphate in Waters in Equilibrium with Gypsum.

8.3 Pit Walls

Benched Non-PAG Pit Walls

The conceptual model for the pit wall source term is similar to the unsaturated waste rock piles in that the main source of nitrate is from blasting residues and that the mineralogical make-up of the rock is the same as the waste rock. The time related factors reflecting waste rock pile hydrological processes etc. (t_{HL} and t_{AL}) are not incorporated into the pit wall terms as the delay to release seen from waste rock piles is not expected to be the same from the pit walls. Rates were derived using monitoring data for the same set of monitoring locations as were used for the unsaturated waste rock dumps. While watershed-specific values were developed, pit wall release rates are expected to be consistent operation-to-operation because rock characteristics are uniform. Catchment-specific source terms were therefore averaged to provide a regional source term (Table 28).

Unbenched Non-PAG Pit Walls

The source term for the unbenched non-PAG pit wall was developed using 50th (P50) and 95th (P95) percentiles release rates for MMF humidity cell testing performed. The method presented below was developed based largely on professional judgement rather than using standard methods. These walls are not expected to be a significant source of loading.

Humidity cell tests were scaled to concentrations expected to be observed at field scale using the following formula:

$$\text{Field Scale Concentration}\left(\frac{\text{mg}}{\text{L}}\right)$$
$$=\text{Average Release Rate}\left(\frac{\frac{\text{mg}}{\text{kg}}}{\text{week}}\right)$$
$$\times\text{Geochemical Scaling Factors x Mass of reactive rock}\left(\frac{\text{kg}}{\text{m}^2}\right)\text{x Volume of pitwall runoff }(\frac{\text{L}}{\text{m}^2})$$

Inputs into the formula included:

- Geochemical scaling factors used to translate laboratory-calculated weathering rates to field conditions.
  - Temperature factor of 0.4, calculated to represent summer conditions.
  - Contact factor of 0.1 which accounts for 10% of the smooth surface of the wall being the reactive material.
  - Particle size factor of 1 which assumes the reactive particle size (rock fines) have approximately the same particle size as those tested in laboratory humidity cell tests.
- Reactive thickness of 2.5 cm. As shown in Figure 24 (bottom), unbenched walls are nearly smooth due to the use of scraping equipment (rather than blasting to remove the seam from its footwall). The selection of a low reactive thickness is nominal to reflect the small amount of broken rock in the footwall.
- Density of 1.9 tonnes per cubic meter to represent rock that has been broken up by mining.
- Pitwall runoff of 582.3 L/m^2 per year assuming average annual precipitation of 647 mm/year and a runoff fraction of 0.9. This precipitation value is for GHO but in this context is broadly applicable in the Elk Valley

Field concentrations should be applied on an annualized basis over the area of exposed non-benched MMF pit wall until submerged.

Benched PAG Pit Walls

Source terms were predicted as annual concentrations in runoff from pit walls. Steps undertaken for these calculations were:

- Acidic humidity cell rates were scaled to site conditions using:
  - Reactive thickness of 2 m.
  - Geochemical scaling factors used to translate laboratory-calculated weathering rates to field conditions.
    - Temperature factor of 0.4, calculated to represent summer conditions.

        - Contact factor of 1 which assumes complete wetting of the bench rubble and talus slopes.
        - Particle size factor of 0.2 which reflects the presence of large rock fragments having high mass but relatively low surface area.
    - Density of 2.6 cubic tonnes to represent typical rock density.
    - Pitwall runoff of 582.3 L/m^2 per year assuming average annual precipitation of 647 mm/year and a runoff fraction of 0.9.
- Resulting scaled concentrations were then compared to observed barrel concentrations. For the majority of elements, the higher of the two concentrations (barrel or scaled) was selected except for the elements described in the bullet below.
- Concentrations of aluminum, barium, iron, fluoride and calcium were predicted using the following solubility controls within the Geochemists Workbench, geochemical modelling software:
    - alunite ($KAl_3(SO_4)_2(OH)_6$);
    - barite ($BaSO_4$);
    - iron hydroxide ($Fe(OH)_3$);
    - fluorite (CaF_2); and
    - gypsum ($CaSO_4 \cdot 2H_2O$).

These concentrations are applied to the exposed PAG non-MMF benched pit wall area on an annualized basis until submerged.

Unbenched PAG Pit Walls

Weathering of unbenched PAG (non-MMF) pit walls is expected to occur in the same reactive surface (fine material and limited cracking) as MMF unbenched pit walls. The difference is runoff from these walls will be acidic and will also leach additional pH sensitive elements cadmium, cobalt, nickel, and zinc.

The source term was developed using the P50 and P95 release rates under acidic conditions for humidity cell testing at EVO. Humidity cell tests were scaled using the same factors as unbenched non-PAG (MMF) zones. Field concentrations should be applied on an annualized over the area of exposed non-benched PAG MF pit wall until submerged.

Table 28. Pit Wall Source Terms

Geological Formation	Pit Wall Configuration	Statistic	SO_4 [b]	Units	As	Units	Se [b]	Units	Cd	Units	Cr	Units	Co	Units	Mn	Units	Ni	Units	P	Units	U	Units
Non-PAG MMF	Benched	P5	12	g/BCM/yr	0.0014	mg/L	2.8	mg/BCM/yr	0.00015	mg/L	0.0016	mg/L	0.0015	mg/L	0.013	mg/L	0.0088	mg/L	0.038	mg/L	0.0015	mg/L
		P50	19	g/BCM/yr	0.0045	mg/L	4.1	mg/BCM/yr	0.001	mg/L	0.0019	mg/L	0.0038	mg/L	0.041	mg/L	0.016	mg/L	0.076	mg/L	0.0037	mg/L
		P95	26	g/BCM/yr	0.018	mg/L	5.4	mg/BCM/yr	0.0032	mg/L	0.0023	mg/L	0.018	mg/L	0.1	mg/L	0.054	mg/L	0.13	mg/L	0.0099	mg/L
Non-PAG MMF	Unbenched	P5	0.24	mg/L	0.0000065	mg/L	0.00012	mg/L	0.0000007	mg/L	0.0000074	mg/L	0.0000069	mg/L	0.00006	mg/L	0.00004	mg/L	0.00017	mg/L	0.0000068	mg/L
		P50	1.2	mg/L	0.000021	mg/L	0.0004	mg/L	0.0000046	mg/L	0.0000085	mg/L	0.000017	mg/L	0.00019	mg/L	0.000073	mg/L	0.00035	mg/L	0.000017	mg/L
		P95	4.6	mg/L	0.00008	mg/L	0.0014	mg/L	0.000014	mg/L	0.00001	mg/L	0.000082	mg/L	0.00046	mg/L	0.00025	mg/L	0.00059	mg/L	0.000045	mg/L
PAG MF[a]	Benched	P5		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L
		P50	3981	mg/L	0.17	mg/L	0.042	mg/L	0.14	mg/L	0.085	mg/L	3.8	mg/L	23	mg/L	8.2	mg/L	0.1	mg/L	0.098	mg/L
		P95	15700	mg/L	2.0	mg/L	0.26	mg/L	0.74	mg/L	0.34	mg/L	15	mg/L	137	mg/L	32	mg/L	0.2	mg/L	0.42	mg/L
PAG MF[a]	Unbenched	P5		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L		mg/L
		P50	7.4	mg/L	0.00002	mg/L	0.00004	mg/L	0.00012	mg/L	0.000062	mg/L	0.0015	mg/L	0.077	mg/L	0.0059	mg/L	0.00035	mg/L	0.000022	mg/L
		P95	35	mg/L	0.0006	mg/L	0.000055	mg/L	0.00031	mg/L	0.00056	mg/L	0.0017	mg/L	0.12	mg/L	0.0076	mg/L	0.14	mg/L	0.00039	mg/L

Source: D:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\300_Pit Walls\Pit_wall_Source_Terms_1CT017.135_update for 1CT017.229_ld_rev00.xlsx

Notes:

[a] no P5 sample included in testing program used to derive these source terms, assume equal to the Non-PAG MMF P5 for purposes here.

[b] Non-PAG MMF Benched walls SO_4 and Se release rates are from updated waste rock release rates

8.4 Submerged Waste Rock

As discussed in Section 5.4, a one-time load or flush from submerged waste rock is calculated assuming a proportion of the rock has been uncontacted prior to being inundated which flushes once inundated. Assumptions to calculate this flush have remained consistent with previous source term updates (SRK 2017a), specifically, these include:

- The proportion of rock that considered uncontacted by meteoric waters ($p_{uncontacted}$) is assumed to be 50%.
- The volume of rock to be flooded (Vflooded, in BCM) is provided by mine plans.
- The mine plan will also provide estimates of when the rock was initially placed (tplacement) and when flooding occurs (tflood) to calculate the time in years since exposure by mining.
- Rates used in calculating the load flushed are the same as those derived from unsaturated waste rock and provided in Section 8.2.

8.5 Suboxic Backfilled Pits

Calculation of the selenium attenuation factor (k_{Se}) using the equation in Section 5.5 is described below.

The monitoring stations for SRFs indicate the concentration of Se in the SRF ($[Se]_{SRF}$) but the influent concentration $[Se]_{oxic}$ in the equation is not known. However, it can be estimated from the ratio of Se to SO_4 indicated by monitoring data for fully oxidized spoils ($(Se/SO_4)_{oxic}$) by assuming that sulphate is conserved as it passes through the SRF:

$$\frac{[\mathrm{Se}]_{\mathrm{oxic}}}{[\mathrm{SO_4}]_{\mathrm{SRF}}} = \left(\frac{\mathrm{Se}}{\mathrm{SO_4}}\right)_{\mathrm{oxic}}$$

$$[\mathrm{Se}]_{\mathrm{oxic}} = \left(\frac{\mathrm{Se}}{\mathrm{SO_4}}\right)_{\mathrm{oxic}} [\mathrm{SO_4}]_{\mathrm{SRF}}$$

Values of $(Se/SO_4)_{oxic}$ were derived for each operation (CMO, EVO, FRO, GHO, LCO and CRO) based on average values of rates of selenium and sulphate oxidation rates from unsaturated waste rock.

Resulting k_{Se} values are presented in Table 29 calculated by pit using measured $[Se]_{SRF}$ concentrations. The base case was calculated using median inputs for selenium concentration whereas the lower case represents weaker attenuation shown by the 95th percentile concentrations of $[Se]_{SRF}$. For new pits, the lowest base case and lowest lower case are recommended.

It is not currently possible to estimate k_{NO_3} primarily because monitored nitrate concentrations in backfills may reflect denitrification but also reflect flushing. There is no analogous constant NO_3/SO_4 ratio that can be used to estimate NO3 flushing from the oxic portions of SRFs.

Table 29. Passive SRF Selenium Attenuation Factors

Site	Pit Name	Source Term Case	k_{Se} (mg/mg)
CMO	14 Pit	Base	-0.97
		Lower	-0.96
EVO	F2	Base	-1.00
		Lower	-1.00
FRO	Eagle 4	Base	-0.91
		Lower	-0.72
	Shandley	Base	-0.87
		Lower	-0.80
GHO	Cougar North	Base	-0.90
		Lower	-0.89
LCO	South Main	Base	-1.00
		Lower	0.95
CRO	B5	Base	-1.00
		Lower	-0.54
	Cheviot	Base	-0.93
		Lower	-0.89
Any	New	Base	-0.87
		Lower	-0.54

Source: P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\400_Saturated Rock Fills\420_PassiveSRF\[EV_2020_PassiveSRF_1CT017.229_Rev12_lnb_NV.xlsx]

8.6 Active Saturated Rock Fills

The source terms predicted for the active SRF (EVO SRF Phase 2) were developed to support the commissioning and operations permit application for the Phase 2 SRF at EVO (Teck 2020e). Details were given in SRK 2020b and summarized in Sections 4.5, 5.6 and 6.5.2 above. Values are reproduced in Table 30.

For other future anticipated active SRFs that are not yet characterized or designed, a more general approach to is provided as given in SRK (2019e). For these cases, source terms for nitrate and selenium assume a 95% removal efficiency for the expected case and a 90% removal efficiency for the upper bound to represent upset conditions. For the purposes of this RWQM update, other parameters for future active SRFs assume no change until detailed characterization, design and effluent predictions can be made.

Table 30. Summary of Expected and Upper Bound Effluent Water Quality for Active SRFs Under Normal Operations (from SRK 2020b)

Parameter		Normal Operations Expected Effluent Quality	Comment	Upper Bound Effluent Quality	Comment
Tracers	Bromide	Equation 1 [a]	Expected percent influent capture x the average influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells	30	Maximum set point concentration for period when bromide tracer may be utilized.
	Chloride	Equation 1 [a]	Expected percent influent capture x the average influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells	150	Maximum set point concentration for period when chloride tracer may be utilized.
	Potassium	Equation 1 [a]	Expected percent influent capture x the average influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells	Equation 1[a] + 15	Stoichiometrically balanced to bromide plus accounting for background.
	Sodium	Equation 1 [a]	Expected percent influent capture x the average influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells	98	Stoichiometrically balanced to chloride and includes an increase from the antiscalant chosen for the EVO SRF (Scaletrol PDC9317) which contains sodium hydroxide and sodium molybdate.
Reagents	Chemical Oxidation Demand	3.5	Calculated from average DOC concentration from Phase 1 trial at the effluent retention pond	50	Alarm Level 3 for COD
	Dissolved Organic Carbon	0.87	Average concentration from Phase 1 trial at the effluent retention pond	12.5	Stoichiometric conversion from COD alarm level
	Phosphorus	0.004	Average concentration from Phase 1 trial at the effluent retention pond	0.1	Level 3 alarm for phosphorus
Nitrogen Species	Nitrate, mg/L (as N)	Equation 1 [a] followed by 95% removal efficiency	95% removal efficiency based on observations from Phase 1 trial. Assumes 95% removal of average influent concentrations.	Equation 1 [a] followed by 90% removal efficiency	90% removal efficiency based on observations from Phase 1 trial. Assumes 90% removal of maximum influent concentrations
	Nitrite, mg/L (as N)	0.03	Average measured concentration from pumping wells (Dec 2018 through Aug 2019)	0.4	Level 3 alarm for nitrite
	Ammonia, mg/L (as N)	Equation 1 [a]	Expected percent influent capture x the average influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells)	1.2	Maximum measured concentration from shallow treatment zone (A and B level wells, Dec 2018 through Aug 2019)
Selenium Species	Selenium, µg/L	Equation 1 [a] followed by 95% removal efficiency	95% removal efficiency based on observations from Phase 1 trial. Assumes 90% removal of average influent concentrations.	Equation 1 [a] followed by 90% removal efficiency	90% removal efficiency based on observations from Phase 1 trial. Assumes 90% removal of maximum influent concentrations.
	Selenate, µg/L	0.9 x Se	90% of expected selenium concentration	0.9 x Se	90% of upper bound selenium concentration
	Selenite, µg/L	0.1 x Se	10% of expected selenium concentration	0.1 x Se	10% of upper bound selenium estimate
	Dimethylselenoxide, µg/L	0.012	Average measured concentration from effluent retention pond (Dec 2018 through Aug 2019)	0.09	Maximum measured concentration from shallow monitoring wells through Phase 1 of the trial (Dec 2018 through Aug 2019)
	Methylseleninic Acid, µg/L	0.011	Average measured concentration from effluent retention pond (Dec 2018 through Aug 2019)	0.09	Maximum measured concentration from shallow monitoring wells through Phase 1 of the trial (Dec 2018 through Aug 2019)
	Selenocyanate, µg/L	0.04	Average measured concentration from effluent retention pond (Dec 2018 through Aug 2019)	2.1	Maximum measured concentration from shallow monitoring wells through Phase 1 of the trial (Dec 2018 through Aug 2019)
Major Ions	Alkalinity as Bicarbonate, mg/L as $CaCO_3$	Equation 1 [a] + (3.6 x average projected influent NO_3)	Equation 1 (Expected percent influent capture x the average influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells))+ 3.6 mg/L per 1 mg/L NO3-N removed, assuming average projected influent NO_3-N	Equation 1 [a] + (3.6 x maximum projected influent NO_3)	Equation 1 (Expected percent influent capture x the maximum influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells)) + 3.6 mg/L per 1 mg/L NO3-N removed assuming maximum projected influent NO_3-N
	Sulphate, mg/L	Equation 1 [a]	Average future projected sulphate concentrations	Equation 1 [a]	Maximum future projected sulphate concentrations
	Calcium, Magnesium, mg/L	Equation 1 [a]	Average future projected sulphate concentrations	Equation 1 [a]	Maximum future projected sulphate concentrations
Redox Sensitive Species	Dissolved Oxygen, mg/L	9.7	Average measured concentration from the effluent retention pond outlet (Dec 2018 through Aug 2019)	12	Maximum measured concentration from effluent retention pond outlet (Dec 2018 through Aug 2019)
	Dissolved Iron, mg/L	0.01	Average measured concentration from the effluent retention pond outlet (Dec 2018 through Aug 2019)	0.06	Maximum measured concentration from effluent retention pond outlet (Dec 2018 through Aug 2019)
	Total Iron, mg/L	0.22	Average measured concentration from the effluent retention pond outlet (Dec 2018 through Aug 2019)	0.40	Maximum measured concentration from effluent retention pond outlet (Dec 2018 through Aug 2019)
	Total Manganese, mg/L	0.63	Average measured concentration from the effluent retention pond outlet (Dec 2018 through Aug 2019)	1.43	Maximum measured concentration from the shallow treatment plume A and B level wells (Dec 2018 through Aug 2019)
	Sulphide, mg/L	0.002	Average measured concentration from the effluent retention pond outlet (Dec 2018 through Aug 2019)	0.08	Level 3 alarm for sulphide
	Arsenic, mg/L	0.0004	Average measured concentration from the effluent retention pond outlet (Dec 2018 through Aug 2019)	0.006	Maximum measured concentration from shallow treatment zone (A and B level wells, Dec 2018 through Aug 2019)
	Molybdenum, mg/L	0.052	Average measured concentration from the effluent retention pond outlet (Dec 2018 through Aug 2019) and includes an increase from the antiscalant chosen for the EVO SRF (Scaletrol PDC9317) which contains sodium hydroxide and sodium molybdate	0.072	Maximum measured concentration from shallow treatment zone (A and B level wells, Dec 2018 through Aug 2019) and includes an increase from the antiscalant chosen for the EVO SRF (Scaletrol PDC9317) which contains sodium hydroxide and sodium molybdate

Parameter		Normal Operations Expected Effluent Quality	Comment	Upper Bound Effluent Quality	Comment
Key Trace Metals	Nickel, mg/L	Equation 2	Expected percent influent capture x the average influent concentration x a sink function (removal) + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells)	Equation 2	Expected percent influent capture x the maximum influent concentration x a sink function (removal) + the expected in-situ F2 water capture x the maximum in-situ F2 concentration (from C level wells)
Other Parameters	Other Parameters [b], mg/L	Equation 1 [a]	Expected percent influent capture x the average influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells)	Equation 1 [a]	Expected percent influent capture x the maximum influent concentration + the expected in-situ F2 water capture x the average in-situ F2 concentration (from C level wells)

Notes:

Data record used from December 2018 through August 2019 for EVO F2 SRF and all data available for influent sources. Refer to SRK 2020a for data time series and more detailed discussion of performance monitoring

(a) Equation 1 provided in Section 5.6

(b) Includes fluoride, aluminum, barium, beryllium, bismuth, boron, cadmium, chromium, cobalt, copper, lead, lithium, mercury, silicon, silver, strontium, thallium, tin, titanium, uranium, vanadium and zinc

8.7 Re-handled Waste Rock

Load released by re-handling of wastes is the same as those provided previously (SRK 2017a) and reproduced in Table 31.

The initial estimate of potential soluble load release was calculated from dissolved concentrations (mg/L) measured by shake flask extraction (SFE). The next step was to assess which parameters were solubility controlled during flushing. Extraction tests were performed using meteoric water mobility procedure or MWMP (NDEP 1996) and SFE (Price 1997) test methods, which use different leaching water to test material ratios (MWMP 1:1 and SFE 3:1, milligrams water to milligrams solid). These test results were interpreted to determine if solubility limits are operating. If no solubility limit is operating at this test work scale for a given parameter, the concentration observed in the MWMP leachate should be three times that observed in the SFE (i.e., all soluble load is dissolved but in different solution volumes). The other end-member outcome is that the MWMP concentration is the same as the SFE, in which case a solubility limit is implied. Ratios of leachate concentrations (concentration in MWMP leachate divided by concentration in the SFE leachate) between 1 and 3 imply solubility controls are operating but with less certainty as the ratio approaches 3.

Results of this interpretation are as follows:

- Parameters showing solubility controls.
- Parameters not showing solubility controls.

For the parameters in the first group, the source term is a fixed concentration applied to contact water. The concentrations used are the P50 and P95 of the SFE results. Solubility controls are assumed to operate at all scales and therefore do not need to be corrected for differences in leaching processes under laboratory and site conditions.

For the parameters in the second group, the source term is expressed as cubic milligrams (mg/m^3) loose cubic metres (LCM) calculated using the equation below:

$$mg/m^3LCM = SFE(mg/L) \times 0.75\ (L)/0.25\ (kg) \times 1000 \times k_p \times \rho\ (t/m^3LCM)$$

In this equation, a unitless particle size scaling factor (k_p) 0.2 is used to account for difference in particle size for the laboratory sample compared to the full-scale waste rock, ρ is the density of waste rock.

This term is applied as a one-time flush of soluble weathering products (in mg/m^3 LCM for parameters without a solubility control and mg/L for parameters found to have a solubility control) beginning in the year in which waste rock is re-handled to the new disposal location. In the RWQM, it is assumed that 20% of the load is released annually.

The flush is added to the overall term for the relevant storage facility in which it is placed and then corrected for solubility for the combined loading sources as for the freshly placed waste rock term.

Table 31. Load Released by Re-Handling of Legacy Wastes (mg/m^3)

Parameter	Historical Tailings			Historical CCR			Historical Waste Rock		
	P5	P50	P95	P5	P50	P95	P5	P50	P95
Ca	42000	85000	130000	25000	33000	65000	12000	16000	23000
Cd	0.08	0.12	0.25	0.2	0.4	1.2	0.020	0.043	0.11
Mg	15000	34000	83000	9300	11000	26000	4100	6300	8500
Na	690	1500	4100	521	840	1200	200	480	1100
Nitrate (N)	98	230	600	3000	4500	13000	730	1500	2700
Se	50	77	89	13	22	34	5.2	15	31
SO4	10000	180000	510000	34000	56000	96000	20000	26000	52000

Source: P:\01_SITES\Fording_River\1CT017.007_MLARD\400_Water Quality Predictions\412_Predict Loadings\Hisotric_Waste_Flushing_Terms\[Historic_Waste_Flushing_Terms_1CT017.007_rev05_ld_AML.xls

Note:

Cations are included for charge balance purposes only.

8.8 Coal Rejects

Table 32 provides observed concentrations in seepage from Greenhills Area A CCR Dump. The statistics were calculated based on 98 samples collected between mid-2009 and mid-2019. These concentrations are updated from those used as a fixed concentration source term for coal reject in past versions of the water quality model. The Greenhills Area A CCR are considered an appropriate valley-wide analog because their bulk mineralogy and chemical composition are comparable at all operations.

Table 32. Coal Reject Fixed Concentrations

Parameter	Units	P5	P50	P95
Alkalinity	mg $CaCO_3$/L	340	530	680
Hardness	mg $CaCO_3$/L	1100	1900	2500
SO_4	mg/L	630	1400	1900
Se	mg/L	0.00044	0.0037	0.034
NH_3	mg N/L	0.005	0.058	0.54
NO_3	mg N/L	0.025	0.1	0.4
NO_2	mg N/L	0.005	0.02	0.02
DOC	mg/L	1.4	2.6	5.6
TDS	mg/L	1400	2500	3300
Ag	mg/L	0.00001	0.00002	0.00005
Al	mg/L	0.001	0.003	0.0073
As	mg/L	0.0001	0.0002	0.0005
B	mg/L	0.015	0.021	0.05

Parameter	Units	P5	P50	P95
Ba	mg/L	0.014	0.019	0.055
Be	mg/L	0.00002	0.0001	0.001
Ca	mg/L	220	370	460
Cd	mg/L	0.0000058	0.000043	0.00039
Cl	mg/L	2.5	8.5	56
Co	mg/L	0.0001	0.001	0.0052
Cr	mg/L	0.0001	0.0002	0.0005
Cu	mg/L	0.0002	0.0005	0.0013
F	mg/L	0.1	0.4	0.4
Fe	mg/L	0.01	0.03	3.4
Hg	ug/L	0.01	0.01	0.01
K	mg/L	2.9	5.6	6.8
Mg	mg/L	120	240	340
Mn	mg/L	0.0035	0.81	2.3
Mo	mg/L	0.00022	0.00096	0.0019
Na	mg/L	3.6	6.2	11
Ni	mg/L	0.0015	0.0054	0.012
P	mg/L	0.3	0.3	0.3
Pb	mg/L	0.00005	0.0001	0.00025
Sb	mg/L	0.0001	0.0002	0.0005
Ti	mg/L	0.01	0.01	0.023
Tl	mg/L	0.00001	0.000028	0.0002
U	mg/L	0.0028	0.0052	0.0079
V	mg/L	0.0005	0.001	0.005
Zn	mg/L	0.001	0.005	0.018

P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\500_Coal Rejects\[EV_2020_CR_1CT017.229_Rev02_lnb_nv.xlsx]

8.9 Coal Reject and Waste Rock Co-Disposal

Table 33 provides release rates for CCR based on humidity cell tests performed on CCR from CRO, LCO, GHO and FRO. For selenium, CCR release rates are an order of magnitude higher than waste rock, with the finer particle size distribution of CCR likely an important difference. These rates were decreased by a factor of 0.3 to reflect lower site temperatures.

For disposal sites where CCR is co-disposed with waste rock at low proportions, the total loading from mixed waste rock and CCR would be obtained from summing the loadings from waste rock and CCR. However, as the proportion of CCR increases, the mixture would behave more like a CCR disposal facility due to the oxygen-consuming properties of CCR.

Nitrite was not measured in the humidity cell tests. Nitrite can be estimated in tributaries using the ratios presented in Table 16.

Table 33. CCR Release Rates

Parameter	Unit	P5	P50	P95
SO_4	g/m^3/year	25	53	97
Se	mg/m^3/year	13	29	51
Alkalinity	g/m^3/year	82	250	410
NH3	mg/m^3/year	120	190	250
NO3	mg/m^3/year	280	920	3600
NO2	mg/m^3/year	--	--	--
Ca	g/m^3/year	28	77	130
Mg	g/m^3/year	15	29	53
Co	mg/m^3/year	0.16	0.35	5.9
Cd	mg/m^3/year	0.19	0.4	1
As	mg/m^3/year	0.24	0.39	1
Cr	mg/m^3/year	0.73	0.81	1.2
Mn	mg/m^3/year	1.2	2.7	18
Ni	mg/m^3/year	2.1	3.3	27
P	mg/m^3/year	45	57	110
U	mg/m^3/year	0.2	0.91	1.8

P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\600_Coal Waste Rock Co-Disposal\[EV2020_CCR_WR_1CT017.229_Rev01_lnb.xlsx]

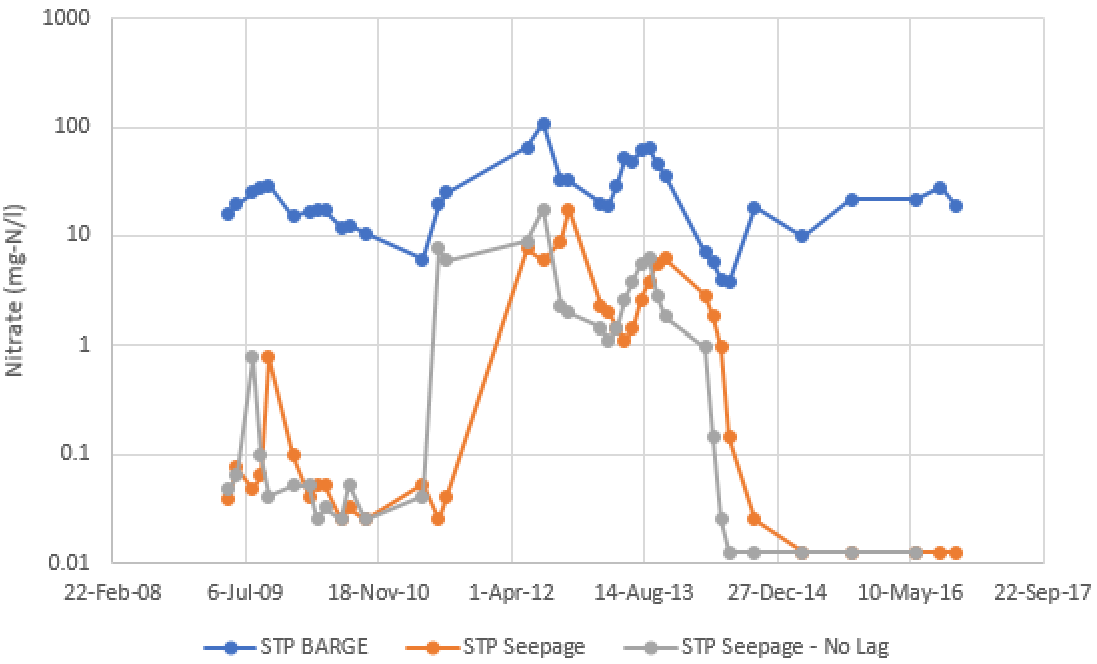
Notes: -- denotes not analyzed during HCT operation therefore data not available.

8.10 Tailings

Monitoring data in the FRO STP indicate that denitrification and selenium reduction occurs in seepage draining towards the Fording River. These processes can be limited as concentrations of these constituents increase in the STP (Figure 46). A positive correlation exists between nitrate concentrations in the STP and at the downstream monitoring location, following correction for lag (Figure 47). Figure 47 shows that as the STP nitrate concentrations increase above 15 mg-N/L, concentrations in the seepage are greater than the median seepage concentration. To account for this increase, the tailings nitrate source term is assigned the median concentration (0.07 mg-N/L) when the modelled STP nitrate concentrations are less than 15 mg-N/L. The 95th percentile concentration (7.5 mg-N/L) is applied when STP nitrate concentrations are greater than 15 mg-N/L.

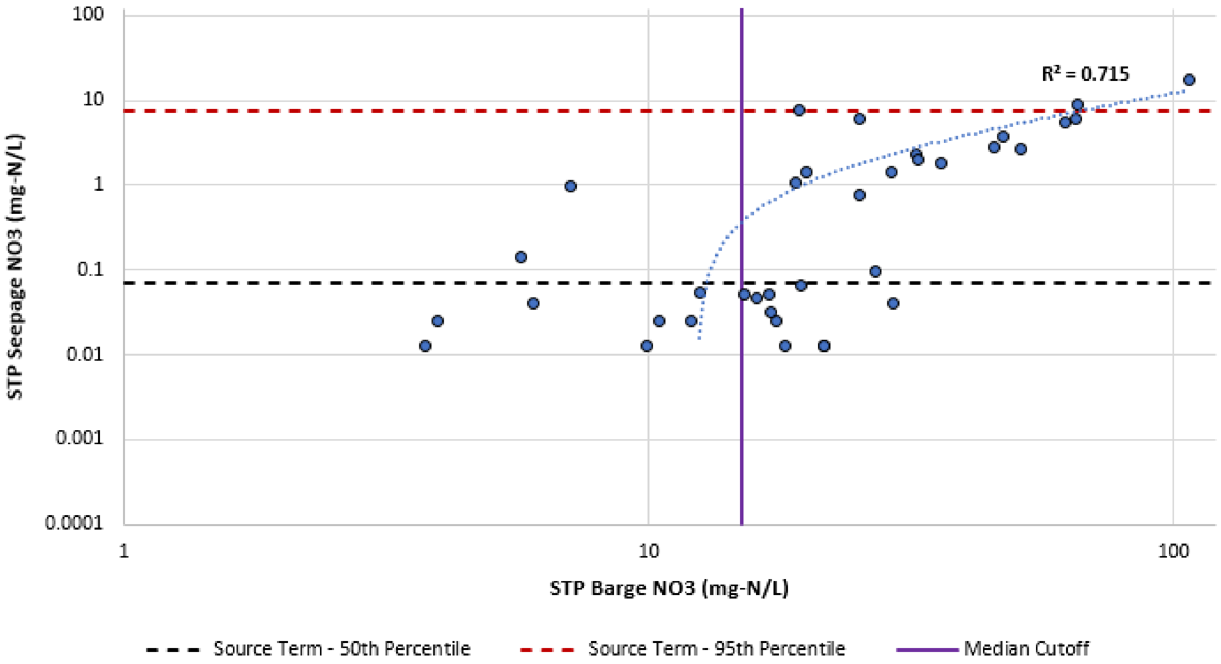
Selenium breakthrough is also observed in seepage from the STP at different points in time (Figure 48). However, there does not appear to be a correlation between STP and STP seepage concentrations (Figure 49) that can be used to establish when median versus 95th percentile concentrations should be applied in the 2020 RWQM. The tailings source term for selenium is therefore conservatively assigned the 95th percentile concentration of 1.5 ug/L.

All other parameters are assigned the modelled STP concentrations in STP seepage flowing towards the Fording River.



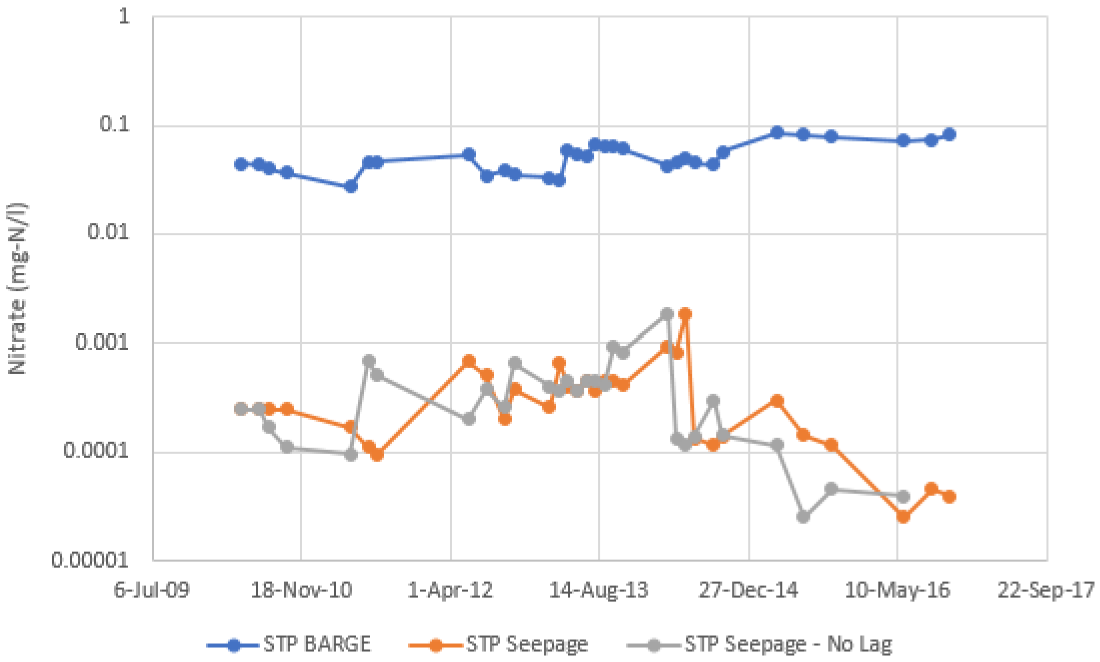
Source: Z:\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\700_Tailings Impoundments\Se_NO3_breakthrough_eva\South Tailings Pond Se NO3 Breakthrough Graphs Rev02.xlsx

Figure 46. Daily Interpolation of Measured FRO STP Barge and Seepage Nitrate Concentrations



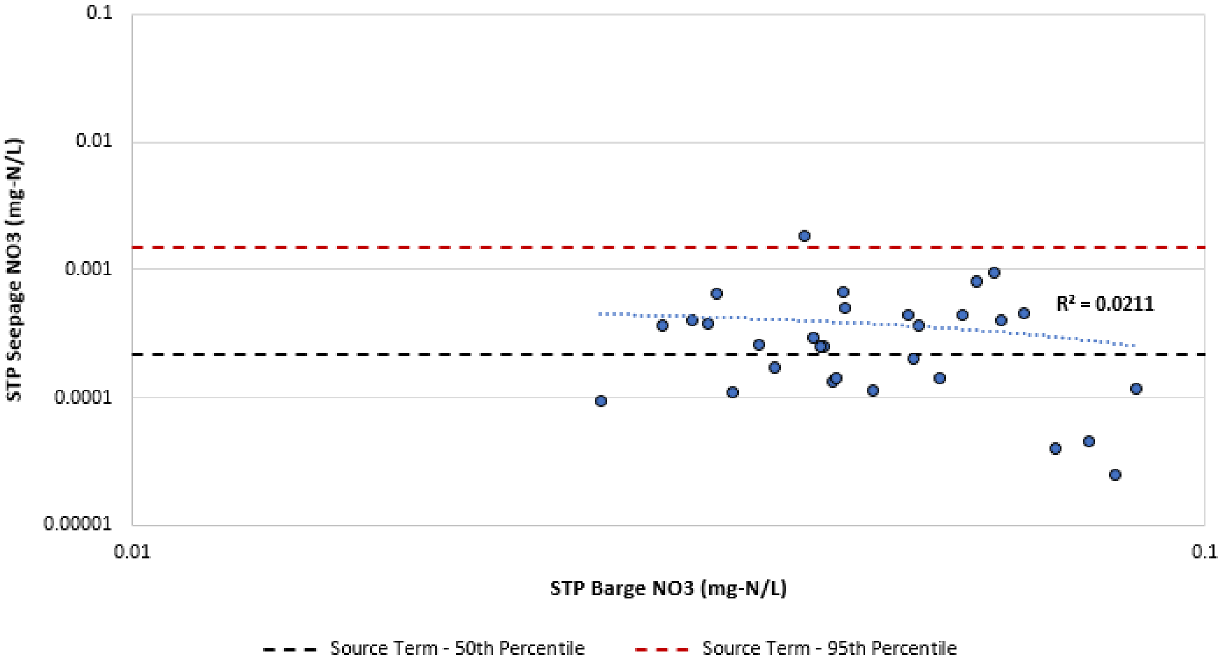
Source: Z:\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\700_Tailings Impoundments\Se_NO3_breakthrough_eva\South Tailings Pond Se NO3 Breakthrough Graphs Rev02.xlsx

Figure 47. STP Seepage Nitrate Concentrations versus STP Nitrate Concentrations



Source: Z:\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\700_Tailings Impoundments\Se_NO3_breakthrough_eva\South Tailings Pond Se NO3 Breakthrough Graphs Rev02.xlsx

Figure 48. Daily Interpolation of Measured FRO STP Barge and Seepage Selenium Concentrations



Source: Z:\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.229_2020_Regional_WQ\700_Tailings Impoundments\Se_NO3_breakthrough_eva\South Tailings Pond Se NO3 Breakthrough Graphs Rev02.xlsx

Figure 49. STP Seepage Selenium Concentrations versus STP Selenium Concentrations

9 Surface Water Adsorption and Co-precipitation

9.1 Conceptual Geochemical Model

In the Elk Valley, moderation of COI load downstream of mineral sources in pore water and surface water environments can occur through co-precipitation with oxidation products, in-spoil and downstream electrostatic adsorption to reactive surfaces (e.g. oxides, clays) and co-precipitation with calcite. Consideration of these removal mechanisms resulted in improvements in the prediction of cadmium concentrations between the 2014 and 2017 RWQMs.

These processes favour dissolved species occurring as cations because reactive surfaces become negatively charged as pH values increase due to lower proton concentrations in water. In addition, heavy metal cations substitute for Fe^{3+} and Ca^{2+} in the crystal structures of ferric oxyhydroxides and calcite resulting in co-precipitation of the metals with these minerals. Also, anions can substitute for CO_3^{2-} in calcite.

In-spoil removal of cations is expected to occur close to mineral oxidization sites by co-precipitation with ferric oxyhydroxides and along flow paths by adsorption to ferric and manganic oxides.

Adsorption and calcite precipitation result in removal of COI load from surface water but calcite appears to be the most significant for cations resulting in seasonal patterns in dissolved metal concentrations which are reversed from sulphate and other major ion concentrations (Figure 50). When calcite is precipitating under low flow conditions (concentrations of calcium, bicarbonate and sulphate are higher, and calcite saturation indices are at their highest), concentrations of base metal cations may be lower on an annual basis. In contrast at high flows, calcium, bicarbonate and sulphate concentrations, and calcite saturation indices are lower due to dilution effects lowering the potential for calcite precipitation and resulting in higher metal concentrations.

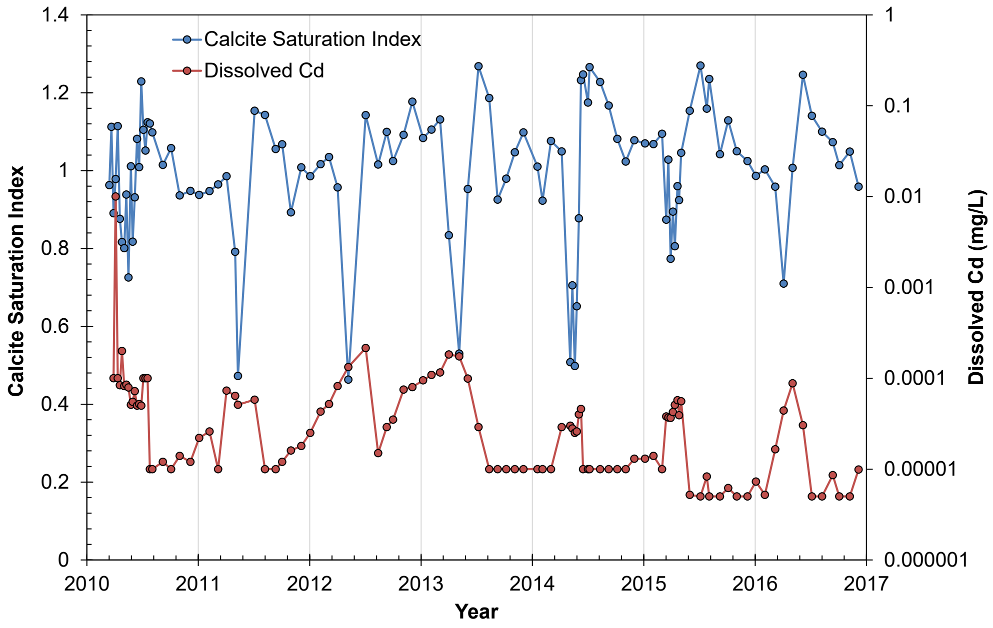


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Figure 50. Trend in Calcite Saturation Index and Cadmium Concentrations at GH_GH1 (GHO).

The degree to which calcite removes various metals from waters is represented by distribution coefficients (K_d) which are calculated from average COI concentrations (M) in solids (s) and water (w) (SRK 2018d):

$$k_d = \frac{[\bar{M}]_s}{[\bar{M}]_w}$$

Table 34. Calculated K_d for Greenhills Creek

Parameter	Unit	As	Cd	Co	Mn	Mo	Ni	Se	U	Zn
Concentration in Calcite	mg/kg	0.94	0.9	7.2	270	0.33	55	10	1.6	46
Average Concentration in Water 2016	mg/L	0.00023	0.000013	0.00012	0.0016	0.003	0.018	0.096	0.0063	0.003
K_d	L/kg	4000	70000	58000	170000	110	3100	110	240	15000

Source: P:\01_SITES\Greenhills_Operations\1CT017.124_Chem Interaction WQ Model\400_Effects Assessment\[GH1_CalciteSolids_1CT017124_SJD_REV03xlsx]

Higher K_ds indicate higher tendencies to co-precipitate in calcite. The K_ds for cadmium, cobalt and manganese indicate they are most likely to show reductions in concentrations when calcite is precipitating. Zinc and nickel are divalent cations but the K_ds are lower which indicates removal effects may be less pronounced. Selenium, molybdenum and uranium are speciated in solutions as oxyanions (SeO_4^{2-}, MoO_4^{2-}, $UO_2(CO_3)_2^{2-}$) and show lower K_ds indicating some removal occurs but the moderating effect is expected to be minimal. Arsenic also forms an oxyanion (AsO_4^{3-}) but seems to show a stronger removal effect than the other oxyanions.

In surface waters, adsorptive processes are likely important in moderating concentrations when calcite is not precipitating. Figure 21 shows that nickel/sulphate ratios are lower in surface waters compared to waste dump solids when calcite is not precipitating implying that nickel is removed by adsorption or some other in stream process.

9.2 Numerical Implementation

A conceptual approach for calculating nickel attenuation at the following locations was developed:

- Between the spoil and tributary monitoring locations;
- Between the tributary and the mainstem monitoring locations; and
- Between mainstem monitoring locations and other further downstream mainstem monitoring locations.

The calculation of combined attenuation (co-precipitation with ferric oxyhydroxides + adsorption + co-precipitation with calcite) between the oxidizing minerals and the tributary requires unsaturated waste rock source terms and therefore attenuation factors within this spatial boundary is included in this report. Surface water attenuation downstream of the tributary monitoring locations are not calculated and will be applied as calibration factors in the model however, the mechanisms are expected to be similar. Attenuation downstream of the spoil is documented in 2020 RWQM calibration report.

The following two step approach is used to calculate total attenuation between the oxidizing mineral and tributary monitoring locations:

- **Step 1**: The total sorption (i.e. in spoil and downstream) when calcite is not precipitating is calculated using the following formula by assuming that sulphate is conserved (not sorbed) and can be used to estimate the nickel concentration before it is attenuated.

$$\%_{\text{no-cal, i}} = \left(1 - \frac{[\text{Ni }]_{\text{i,MJ}} / [\text{SO4 }]_{\text{i,MJ}}}{R_{\text{iNisp}} / R_{\text{iSO4sp}}} \right) \times 100$$

Where:

$\%_{\text{no-cal,i}}$ = sorptive loss without calcite realized between the oxidizing mineral and monitoring station "*i*" (%)

$[\ ]_{\text{iNiMJ}}$ = average nickel concentration observed between May and July at monitoring station "*i*" (mg/L)

$[\ ]_{\text{iSO4MJ}}$ = average sulphate concentration observed between May and July at monitoring station "*i*" (mg/L)

$R_{\text{iNisp}}/R_{\text{iSO4sp}}$ = spoil nickel/sulphate release rate ratio

- **Step 2**: The percent co-precipitation as calcite is calculated using the following formula (from Golder 2020) in months when calcite is precipitating:

$$\%_{\text{Calisp}} = \text{Total Attenuation - Sorption without calcite}$$

$$\%_{Calisp}=\left(1-\frac{[\,]_{iNiAA}/[\,]_{iSO4AA}}{R_{iNisp}/R_{iSO4sp}}\right)*100-\%_{adisp}$$

Where:

$\%_{Calisp}$ = loss due to co-precipitation with calcite between the waste rock spoil and monitoring station “*i*” (%)

$[\,]_{iNiAA}$ = average nickel concentration observed between August to April at monitoring station “*i*” (mg/L)

$[\,]_{iSO4AA}$ = average sulphate concentration observed between August to April at monitoring station “*i*” (mg/L)

While the formulas were developed for nickel, they are also applied to cadmium and cobalt. Although the K_d for manganese was high (Section 9.1), the source term for this parameter is currently derived as a constant concentration (Section 8.2.2) and attenuation was not estimated for this metal.

The inputs to the above formulas are derived using monitoring data at single points in streams and source term loading rates for sulphate (Section 8.2.2) and cadmium, cobalt and nickel (Section 8.2.2), which accounts for the presence of Morrissey Formation in the attenuation factors. This represents a limitation in the method because it is likely that processes will vary spatially and temporally so that the water quality at individual monitoring points will not likely show a consistent signal from instream processes. Source terms are derived for each catchment to account for this variability.

9.3 Derivation of Inputs

Stream-specific inputs estimates of the were derived as follows.

The water chemistry data for each monitoring location were initially interpreted to understand seasonal patterns of calcite precipitation in each catchment. For each water sample with suitable data (pH, water temperature and complete major ion chemistry), calcite saturation indices were calculated. However, a little over 10% of the water chemistry dataset had suitable inputs. To expand the interpretation of calcite formation the relationship between calcite saturation indices and calcium was evaluated. It was determined that at calcium concentrations exceeding about 200 mg/L it is likely calcite would precipitate though this concentration varies by monitoring location.

Using average calcium concentrations in monitoring data, each site was then manually optimized to identify a calcium concentration that identify the time of the months of the year when calcite is not precipitating based on the assumption that these months will be linked to the time of the year when flows are greatest. The range of discriminant calcium concentrations derived was 60 to 240 mg/L (median 200 mg/L). April, May, June and July were the months when calcite precipitation was least likely to occur.

For months when calcite was predicted to not be precipitating, adsorption was calculated using the formula provided in Section 9.2. This approach resulted in large percent decreases of cadmium, cobalt and nickel concentrations even when calcite is not precipitating. Surface water quality monitoring trends (Section 9.1) support that co-precipitation of metals with calcite is the dominant instream attenuation process. This implies that a large component of adsorption occurs within the spoil, upstream of the catchment. The nickel/sulphate release rate ratio (NSRRR) used in the adsorption calculation equation (Section 9.2) represents the oxidative release at the reaction site and is not necessarily analogous to the NSRRR at the toe of the spoil where drainage enters the tributary. It is unsafe to collect seepage at the toe of the spoil and the percent adsorption occurring from the toe of the spoil to the monitoring location cannot be quantified. A total attenuation (adsorption + co-precipitation) source term was derived using the first equation in Section 9.2 for all months. Monthly average attenuation factors were calculated for cadmium, cobalt and nickel. The source term values are provided in Table 35 to Table 37

Table 35. Cadmium Surface Water Attenuation Factors

Location	Time Period	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Fording River Operations (FRO)													
FR_CC1	Pre-PAG Management	79.4%	87.6%	86.4%	85.7%	88.9%	85.2%	84.6%	93.6%	96.0%	94.3%	91.9%	80.6%
	Post-PAG Management	74.1%	84.4%	82.9%	82.0%	86.1%	81.3%	80.6%	91.9%	94.9%	92.8%	89.8%	75.7%
FR_HC1	Pre-PAG Management	96.8%	96.9%	95.8%	94.6%	94.1%	87.3%	92.2%	94.4%	95.8%	96.3%	96.7%	96.9%
	Post-PAG Management	96.8%	96.9%	95.8%	94.6%	94.1%	87.3%	92.2%	94.4%	95.8%	96.3%	96.7%	96.9%
FR_KC1	Pre-PAG Management	81.3%	84.8%	84.6%	79.1%	64.5%	38.8%	43.3%	57.8%	64.8%	69.8%	75.5%	79.4%
	Post-PAG Management	81.3%	84.8%	84.6%	79.1%	64.5%	38.8%	43.3%	57.8%	64.8%	69.8%	75.5%	79.4%
GH_CC1	Pre-PAG Management	97.9%	98.0%	97.9%	97.2%	94.5%	94.4%	94.2%	94.5%	94.5%	81.9%	95.8%	97.3%
	Post-PAG Management	97.9%	98.0%	97.9%	97.2%	94.5%	94.4%	94.2%	94.5%	94.5%	81.9%	95.8%	97.3%
GH_SC1/SC2	Pre-PAG Management	95.6%	96.5%	96.6%	94.4%	90.6%	89.4%	90.9%	95.2%	95.1%	94.7%	95.9%	95.0%
	Post-PAG Management	95.6%	96.5%	96.6%	94.4%	90.6%	89.4%	90.9%	95.2%	95.1%	94.7%	95.9%	95.0%
Greenhills Operations (GHO)													
GH_GH1	Pre-PAG Management	99.4%	99.3%	98.4%	95.1%	90.3%	95.3%	98.2%	99.7%	99.7%	99.6%	99.5%	99.5%
	Post-PAG Management	99.4%	99.3%	98.4%	95.1%	90.3%	95.3%	98.2%	99.7%	99.7%	99.6%	99.5%	99.5%
GH_LC2	Pre-PAG Management	99.0%	98.0%	96.5%	93.5%	91.1%	95.1%	96.7%	97.6%	97.4%	98.1%	97.0%	98.2%
	Post-PAG Management	98.9%	98.0%	96.4%	93.3%	90.8%	95.0%	96.6%	97.5%	97.3%	98.1%	96.9%	98.1%
GH_TC2	Pre-PAG Management	99.5%	99.3%	98.9%	97.6%	98.4%	98.4%	98.8%	99.8%	99.8%	99.8%	99.7%	99.6%
	Post-PAG Management	99.2%	98.6%	97.0%	98.0%	97.9%	98.5%	99.8%	99.8%	99.8%	99.6%	99.5%	0.0%
GH_WC2	Pre-PAG Management	98.8%	99.2%	97.9%	94.5%	93.0%	96.6%	95.9%	98.0%	97.7%	97.9%	95.0%	97.8%
	Post-PAG Management	99.0%	97.3%	93.1%	91.2%	95.8%	94.9%	97.5%	97.1%	97.4%	93.8%	97.2%	0.0%
Line Creek Operations (LCO)													
LC_LCUSWLC	Pre-PAG Management	87.2%	87.8%	88.0%	84.3%	65.3%	51.3%	53.5%	67.1%	74.4%	77.2%	79.1%	84.6%
	Post-PAG Management	83.9%	84.6%	85.0%	80.3%	56.4%	38.7%	44.5%	58.7%	67.9%	71.3%	73.7%	80.7%
LC_WLC	Pre-PAG Management	89.9%	91.1%	85.1%	85.5%	73.6%	42.8%	36.2%	45.9%	51.3%	69.5%	81.4%	83.4%
	Post-PAG Management	89.9%	91.1%	85.1%	85.5%	73.6%	42.8%	36.2%	45.9%	51.3%	69.5%	81.4%	83.4%
Elkview Operations (EVO)													
EV_BC1	Pre-PAG Management	98.0%	96.9%	95.5%	95.3%	93.0%	95.1%	95.8%	97.9%	98.6%	98.1%	98.4%	97.4%
	Post-PAG Management	98.0%	96.9%	95.5%	95.3%	93.0%	95.1%	95.8%	97.9%	98.6%	98.1%	98.4%	97.4%
EV_GT1	Pre-PAG Management	97.3%	97.4%	94.2%	96.4%	95.1%	94.2%	94.6%	95.3%	97.1%	96.7%	97.7%	97.6%
	Post-PAG Management	97.3%	97.4%	94.2%	96.4%	95.1%	94.2%	94.6%	95.3%	97.1%	96.7%	97.7%	97.6%
EV_DC1	Pre-PAG Management	99.1%	98.8%	98.9%	98.5%	95.6%	96.5%	98.2%	98.8%	99.0%	99.3%	99.2%	99.0%
	Post-PAG Management	99.1%	98.8%	98.9%	98.5%	95.6%	96.5%	98.2%	98.8%	99.0%	99.3%	99.2%	99.0%
EV_EC1	Pre-PAG Management	99.8%	99.8%	99.8%	99.8%	99.5%	99.4%	99.5%	99.6%	99.7%	99.8%	99.8%	99.8%
	Post-PAG Management	99.7%	99.8%	99.8%	99.7%	99.4%	99.3%	99.4%	99.5%	99.6%	99.7%	99.7%	99.8%
EV_HC1	Pre-PAG Management	98.6%	98.4%	97.5%	97.5%	93.8%	95.1%	97.0%	95.0%	98.1%	98.4%	98.4%	98.4%
	Post-PAG Management	98.6%	98.4%	97.5%	97.5%	93.8%	95.1%	97.0%	95.0%	98.1%	98.4%	98.4%	98.4%
Elkview Operations (EVO)													
CM_CC1	Pre-PAG Management	99.4%	99.5%	99.4%	98.9%	96.5%	94.9%	98.7%	95.1%	96.8%	99.7%	95.9%	84.4%
	Post-PAG Management	97.3%	98.0%	97.4%	95.4%	85.0%	81.9%	94.4%	98.1%	97.7%	98.5%	96.2%	97.0%

Table 36. Cobalt Surface Water Attenuation Factors

Location	Time Period	Month											
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Fording River Operations (FRO)													
FR_CC1	Pre-PAG Management	98.8%	99.2%	98.8%	98.4%	98.1%	97.7%	98.2%	99.1%	99.3%	99.1%	99.4%	98.5%
	Post-PAG Management	97.5%	98.2%	97.6%	96.7%	96.1%	95.1%	96.2%	98.1%	98.5%	98.0%	98.6%	96.8%
FR_HC1	Pre-PAG Management	97.3%	97.6%	97.8%	97.4%	93.3%	88.5%	91.0%	94.0%	96.0%	95.9%	96.9%	97.3%
	Post-PAG Management	97.3%	97.6%	97.8%	97.4%	93.3%	88.5%	91.0%	94.0%	96.0%	95.9%	96.9%	97.3%
FR_KC1	Pre-PAG Management	99.2%	99.1%	99.2%	99.1%	98.3%	96.4%	96.5%	97.9%	98.4%	98.4%	98.9%	99.1%
	Post-PAG Management	99.2%	99.1%	99.2%	99.1%	98.3%	96.4%	96.5%	97.9%	98.4%	98.4%	98.9%	99.1%
GH_CC1	Pre-PAG Management	99.4%	99.3%	99.3%	99.6%	99.8%	99.8%	99.8%	99.6%	99.6%	99.4%	99.6%	99.3%
	Post-PAG Management	99.4%	99.3%	99.3%	99.6%	99.8%	99.8%	99.8%	99.6%	99.6%	99.4%	99.6%	99.3%
GH_SC1/SC2	Pre-PAG Management	94.8%	93.8%	93.2%	95.9%	96.8%	93.3%	94.4%	94.9%	95.9%	96.4%	96.7%	94.0%
	Post-PAG Management	94.8%	93.8%	93.2%	95.9%	96.8%	93.3%	94.4%	94.9%	95.9%	96.4%	96.7%	94.0%
Greenhills Operations (GHO)													
GH_GH1	Pre-PAG Management	84.6%	85.1%	89.8%	92.2%	96.5%	98.4%	98.7%	99.3%	99.4%	90.0%	90.2%	84.8%
	Post-PAG Management	84.6%	85.1%	89.8%	92.2%	96.5%	98.4%	98.7%	99.3%	99.4%	90.0%	90.2%	84.8%
GH_LC2	Pre-PAG Management	97.7%	97.4%	97.8%	96.7%	95.0%	96.1%	97.0%	96.6%	96.6%	97.0%	97.2%	98.1%
	Post-PAG Management	95.2%	94.5%	95.3%	93.0%	89.5%	91.8%	93.7%	92.9%	92.9%	93.7%	94.1%	96.0%
GH_TC2	Pre-PAG Management	89.0%	88.8%	85.9%	95.0%	99.1%	99.2%	93.9%	92.6%	93.3%	94.9%	93.9%	88.6%
	Post-PAG Management	99.3%	98.9%	98.1%	98.1%	98.4%	98.6%	99.3%	99.4%	99.4%	99.0%	99.3%	0.0%
GH_WC2	Pre-PAG Management	78.7%	98.1%	98.6%	95.2%	91.8%	95.4%	89.7%	86.6%	83.5%	85.3%	83.9%	77.9%
	Post-PAG Management	96.1%	97.0%	89.8%	86.7%	90.2%	87.8%	91.7%	80.0%	82.0%	83.6%	90.3%	0.0%
Line Creek Operations (LCO)													
LC_LCUSWLC	Pre-PAG Management	99.2%	95.3%	95.3%	98.9%	97.8%	97.3%	97.9%	98.0%	98.5%	94.6%	92.1%	94.4%
	Post-PAG Management	98.3%	98.1%	97.4%	97.7%	95.4%	94.3%	95.7%	95.9%	96.8%	96.7%	98.1%	97.6%
LC_WLC	Pre-PAG Management	97.4%	97.1%	93.1%	93.9%	97.9%	98.4%	97.6%	99.1%	99.2%	95.1%	96.6%	96.6%
	Post-PAG Management	97.4%	97.1%	93.1%	93.9%	97.9%	98.4%	97.6%	99.1%	99.2%	95.1%	96.6%	96.6%
Elkview Operations (EVO)													
EV_BC1	Pre-PAG Management	92.9%	92.8%	93.5%	90.8%	96.8%	96.1%	96.0%	91.8%	90.2%	92.7%	90.0%	91.4%
	Post-PAG Management	92.9%	92.8%	93.5%	90.8%	96.8%	96.1%	96.0%	91.8%	90.2%	92.7%	90.0%	91.4%
EV_GT1	Pre-PAG Management	99.9%	99.9%	99.9%	99.9%	99.9%	99.7%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
	Post-PAG Management	99.9%	99.9%	99.9%	99.9%	99.9%	99.7%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
EV_DC1	Pre-PAG Management	99.4%	99.4%	99.3%	99.3%	91.9%	99.0%	92.5%	99.2%	91.6%	94.4%	92.0%	99.4%
	Post-PAG Management	99.4%	99.4%	99.3%	99.3%	91.9%	99.0%	92.5%	99.2%	91.6%	94.4%	92.0%	99.4%
EV_EC1	Pre-PAG Management	99.7%	99.7%	99.7%	99.7%	99.7%	99.7%	99.6%	99.6%	99.7%	99.7%	99.7%	99.7%
	Post-PAG Management	99.4%	99.4%	99.3%	99.3%	99.3%	99.3%	99.3%	99.2%	99.3%	99.3%	99.3%	99.3%
EV_HC1	Pre-PAG Management	98.7%	98.4%	99.0%	99.1%	98.9%	99.0%	98.9%	98.2%	97.2%	99.0%	98.9%	97.4%
	Post-PAG Management	98.7%	98.4%	99.0%	99.1%	98.9%	99.0%	98.9%	98.2%	97.2%	99.0%	98.9%	97.4%
Elkview Operations (EVO)													
CM_CC1	Pre-PAG Management	95.9%	96.5%	96.1%	96.5%	96.0%	93.8%	94.5%	95.7%	94.4%	97.1%	95.9%	95.6%
	Post-PAG Management	42.4%	54.5%	59.5%	60.4%	63.8%	66.0%	54.9%	57.6%	69.9%	72.4%	56.8%	40.6%

Table 37. Nickel Surface Water Attenuation Factors

Location	Time Period	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Fording River Operations (FRO)													
FR_CC1	Pre-PAG Management	85.9%	89.9%	86.0%	86.0%	85.1%	83.3%	82.6%	84.1%	85.1%	85.1%	86.6%	86.3%
	Post-PAG Management	76.5%	83.2%	76.7%	76.7%	75.2%	72.2%	71.1%	73.6%	75.3%	75.2%	77.8%	77.2%
FR_HC1	Pre-PAG Management	93.5%	93.3%	92.6%	91.7%	88.4%	81.4%	86.8%	90.2%	91.5%	92.5%	93.3%	94.7%
	Post-PAG Management	93.5%	93.3%	92.6%	91.7%	88.4%	81.4%	86.8%	90.2%	91.5%	92.5%	93.3%	94.7%
FR_KC1	Pre-PAG Management	72.2%	72.9%	73.7%	72.0%	60.0%	31.2%	41.3%	60.0%	64.4%	67.3%	69.2%	71.3%
	Post-PAG Management	72.2%	72.9%	73.7%	72.0%	60.0%	31.2%	41.3%	60.0%	64.4%	67.3%	69.2%	71.3%
GH_CC1	Pre-PAG Management	98.3%	98.2%	98.3%	98.3%	98.1%	98.1%	98.0%	97.8%	97.9%	92.1%	98.1%	98.1%
	Post-PAG Management	98.3%	98.2%	98.3%	98.3%	98.1%	98.1%	98.0%	97.8%	97.9%	92.1%	98.1%	98.1%
GH_SC1/SC2	Pre-PAG Management	65.0%	68.1%	66.5%	65.6%	62.3%	59.9%	58.3%	62.9%	63.6%	64.5%	65.5%	62.5%
	Post-PAG Management	65.0%	68.1%	66.5%	65.6%	62.3%	59.9%	58.3%	62.9%	63.6%	64.5%	65.5%	62.5%
Greenhills Operations (GHO)													
GH_GH1	Pre-PAG Management	75.8%	74.5%	71.2%	68.4%	73.5%	75.0%	81.6%	83.5%	87.0%	80.5%	80.7%	76.6%
	Post-PAG Management	75.8%	74.5%	71.2%	68.4%	73.5%	75.0%	81.6%	83.5%	87.0%	80.5%	80.7%	76.6%
GH_LC2	Pre-PAG Management	76.9%	73.5%	71.1%	75.7%	70.7%	82.2%	82.9%	82.5%	82.0%	86.0%	85.0%	84.2%
	Post-PAG Management	61.6%	70.2%	68.7%	68.4%	61.2%	70.4%	71.5%	70.8%	83.0%	76.8%	75.0%	73.7%
GH_TC2	Pre-PAG Management	85.1%	84.8%	81.4%	92.3%	95.9%	95.5%	96.1%	88.9%	90.4%	92.1%	90.5%	84.6%
	Post-PAG Management	95.7%	95.2%	95.1%	93.1%	92.5%	93.5%	95.1%	96.6%	96.2%	95.1%	95.8%	0.0%
GH_WC2	Pre-PAG Management	53.3%	60.3%	59.9%	44.6%	33.8%	42.5%	32.6%	31.3%	31.1%	28.8%	34.2%	32.4%
	Post-PAG Management	38.3%	41.5%	26.5%	29.7%	21.8%	23.0%	8.8%	15.6%	17.8%	17.9%	17.4%	0.0%
Line Creek Operations (LCO)													
LC_LCUSWLC	Pre-PAG Management	83.5%	81.0%	80.5%	81.7%	70.9%	62.5%	62.9%	71.0%	75.8%	77.4%	79.1%	80.2%
	Post-PAG Management	72.6%	74.7%	73.5%	69.5%	51.7%	37.6%	42.6%	51.8%	59.7%	62.4%	65.2%	67.0%
LC_WLC	Pre-PAG Management	84.0%	84.7%	82.9%	82.3%	70.1%	47.6%	44.4%	53.1%	57.8%	67.1%	74.8%	80.9%
	Post-PAG Management	84.0%	84.7%	82.9%	82.3%	70.1%	47.6%	44.4%	53.1%	57.8%	67.1%	74.8%	80.9%
Elkview Operations (EVO)													
EV_BC1	Pre-PAG Management	47.1%	49.0%	50.8%	47.4%	56.6%	49.8%	48.1%	53.2%	51.0%	56.2%	45.5%	43.5%
	Post-PAG Management	47.1%	49.0%	50.8%	47.4%	56.6%	49.8%	48.1%	53.2%	51.0%	56.2%	45.5%	43.5%
EV_GT1	Pre-PAG Management	97.7%	97.9%	98.5%	98.2%	98.8%	98.3%	98.3%	98.2%	98.4%	98.0%	97.3%	97.8%
	Post-PAG Management	97.7%	97.9%	98.5%	98.2%	98.8%	98.3%	98.3%	98.2%	98.4%	98.0%	97.3%	97.8%
EV_DC1	Pre-PAG Management	95.4%	95.2%	95.5%	94.6%	87.5%	93.4%	91.0%	94.5%	88.1%	91.0%	89.1%	95.3%
	Post-PAG Management	95.4%	95.2%	95.5%	94.6%	87.5%	93.4%	91.0%	94.5%	88.1%	91.0%	89.1%	95.3%
EV_EC1	Pre-PAG Management	99.5%	99.2%	99.6%	99.6%	99.6%	99.6%	99.5%	99.5%	99.5%	99.6%	99.4%	99.4%
	Post-PAG Management	99.2%	98.7%	99.3%	99.3%	99.3%	99.3%	99.2%	99.2%	99.2%	99.3%	99.0%	99.1%
EV_HC1	Pre-PAG Management	99.3%	98.5%	97.7%	98.8%	98.8%	98.5%	99.3%	97.4%	97.3%	99.0%	98.9%	98.1%
	Post-PAG Management	99.3%	98.5%	97.7%	98.8%	98.8%	98.5%	99.3%	97.4%	97.3%	99.0%	98.9%	98.1%
Elkview Operations (EVO)													
CM_CC1	Pre-PAG Management	98.3%	98.2%	98.3%	98.3%	98.1%	98.1%	98.0%	97.8%	97.9%	92.1%	98.1%	98.1%
	Post-PAG Management	98.3%	98.2%	98.3%	98.3%	98.1%	98.1%	98.0%	97.8%	97.9%	92.1%	98.1%	98.1%

10 Strengths and Limitations of the 2020 RWQM Source Term Update

Teck has made several advances to reduce uncertainty in the source terms as part of the 2020 RWQM update. Past and ongoing studies have resulted in additional strengths in the source term derivation methods. However, there are still some assumptions that are considered limitations in the approach that will be considered for future study as part of the 2023 update. The key strengths and limitations of the 2020 RWQM source term updates are listed below.

The following are strengths of the approaches used to derive the source terms:

- Coal is mined almost exclusively from a single geological formation, with well-established relatively-uniform regional geochemical characteristics which allows the methods to be applied throughout the Elk Valley. The weathering rates are therefore expected to be consistent across the valley and differences in empirical release rates at the catchment scale can be attributed to other processes that can be studied. The outcomes of these studies can be applied to reduce differences in catchment specific release rates to converge on a regional source term.
- The conceptual models described in the following sections, and used to develop the geochemical source-term methods, are mainly based on empirical evidence, but are also informed by mechanistic (theoretical) understanding of the geochemical processes that influence source terms. An empirical method is considered better in this case than a construct based on theory because it uses actual measurements from an extensive long-term dataset.
- The conceptual models used to develop the geochemical source-term methods are based on a good understanding of the underlying weathering and leaching mechanisms.
- The piston flow model concept considered in the 2020 RWQM update allows the empirically derived release rates to be used to evaluate future source mitigation measures, such as infiltration reduction by covers or reduced release rates by water diversion. This was a limitation in the 2017 RWQM.
- The method for developing source terms empirically are based on a lengthy flow and water chemistry monitoring database accumulated by the mine operations over several years and more than a decade in some cases. Deriving source terms using this approach may “lump” together several mechanistic processes that cannot be isolated; however, the existing data record can be used to usefully predict behaviour of mine materials that will persist over several decades.
- Results of hydrogeological studies have been used in the derivation of the source terms, which has reduced the variability in the release rates between catchments.
- The influence of water management activities (e.g., pit dewatering) on data sets used to derive source terms have been removed to the extent practicable as part of the 2020 RWQM update.

- The COI inventory provides a mechanism for tracking the available mass that can be leached from the spoil so that loadings are finite and do not persist in perpetuity, as was the assumption in previous versions of the RWQM.
- A non-zero order representation of weathering rate decay is included in the model as a sensitivity to evaluate how the longer-term reduction in solute release rates will influence downstream water quality.
- Teck has made advances to minimizing nitrogen release from explosive usage. This includes lining blast holes. Teck has also completed a recent study to quantify extent lining holes limits nitrogen release. Evidence from this study has been incorporated into the 2020 RWQM update.

The following are limitations of the geochemical source-term method:

- The non-zero order weathering rate decay relies on lab-based data and is not yet supported based on full-scale empirical evidence. Until sufficient empirical data are available to support this hypothesis, the approach is considered theoretical and may not be representative of weathering rate decay under ambient conditions. Until empirical evidence is available to support the rates provided in this report, non-zero weathering rate decay should be included in the model as a sensitivity.
- There remains variation in release rates between drainages so that projections for new disposal areas continues to rely on the distribution of release rates indicated by developed catchments and modifying hydrological assumptions. Additional data are available from LCO Dry Creek to better understand the release rates from new spoils; however, additional data are still needed to evaluate how hydrologic processes evolve as a function of spoil age. For example, the lag time for transport through the spoil could increase as the spoil matures. Data collected from continued on-going monitoring in all mine-affected drainages will be used to inform periodic updates of source-terms and will address this limitation moving forward.
- An attempt has been made as part of the 2017 RWQM update to remove water management influences, such as pit dewatering, from the dataset used to derive the source terms. Additional effort was taken to further isolate water management influences on the data used to derive the source terms as part of the 2020 RWQM update. However, the water management summaries used to inform impacted data are coarse (e.g., do not track water management at a high enough frequency), which can result in inclusion of data that may be influenced by water management or removal of data that are not. As such the dataset used to derive the source terms may still include loadings from other sources (e.g., pit dewatering) and waste rock weathering rates may be overestimated.
- The inventory of nitrate residuals from blasting residues in deposited waste is not measured directly and a key assumption in the model is all residual nitrogen produced during blasting is transported to the spoil. This limitation could result in an overestimate of the apparent loss factor.

11 Conclusions

This report describes development of geochemical source term methods and inputs for nitrogen species (ammonia, nitrite and nitrate), sulphate and selenium, as well as arsenic, chromium, cobalt, cadmium, manganese, phosphorus and uranium from various sources within the Elk Valley with a stronger emphasis on loading from the unsaturated waste rock piles. The data analysis and interpretation used to develop the source terms resulted in the following conclusions:

- Release of nitrate from waste rock spoils can be estimated using the volume of spoil, estimated blasting residuals loss factors and an estimation of time adjustments to account for hydrological processes.
- Release of selenium and sulphate from waste rock spoils can currently be predicted using the cumulative volume of spoil. Also included in this update is an estimate of hydrological processes such as losses to groundwater and influence of annual average precipitation on source term variability.
- The unsaturated waste rock loading rates can also be used to estimate the initial soluble load that is produced from waste rock prior to being placed in the spoil.
- Variation in selenium and sulphate release rates can be attributed to several factors related to measurement methods, geochemical factors, waste rock dump construction, reclamation methods, and hydrological factors. This update has accounted for these factors to the extent possible on a drainage-by-drainage basis. Expected variability was assessed through a sensitivity analysis and is represented by confidence limits.
- Release of cadmium, cobalt and nickel from waste rock is represented as a ratio to sulphate derived based on observed loadings in humidity cells.
- Calcite precipitation has a moderating effect on cadmium, cobalt and nickel concentrations due to co-precipitation in the calcite matrix. Calcite precipitation occurs seasonally resulting in seasonal variation in metal concentrations.
- Based on correlations in the monitoring data, the uranium source term is expressed as a ratio to sulphate concentrations.
- The following parameters exhibit seasonal variability but based on the lack of distinct increasing trends are assigned constant monthly source term concentrations in the 2020 RWQM: arsenic, chromium, manganese and phosphorus.

In addition to source terms for the unsaturated waste rock piles, source terms are provided for pit walls, re-handled wastes, submerged waste rock, coal rejects and CCR as well as tailings. The following new source terms are introduced as part of this update:

- Quantification of the initial soluble load (i.e., load produced from waste rock prior to placement in the spoil);
- A constituent of interest (COI) inventory;

- Inclusion of non-Order constituents (i.e., ammonia, arsenic, chromium, manganese, nitrite, phosphorus and uranium);
- Development of a 1st order decay of weathering rates;
- Surface water attenuation mechanisms;
- Active saturated rock fills (SRFs);
- Passive SRFs; and
- Tailings sinks.

This report, Geochemical Source Term Methods and Inputs for the 2020 Update of the Elk Valley Regional Water Quality Model, was prepared by

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All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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Appendix A – Elkview Operations Baldy Ridge Extension – Initial Source Terms Transmittal

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Memo

To:	Dennis Kramer, Golder	**Client:**	Teck Coal
From:	Laura Donkervoort, SRK	**Project No:**	1CG006.004
Cc:	Lucy Eykamp, Teck; Megan Hewitt, Golder; Laura Darling, Golder	**Date:**	April 17, 2015
Subject:	Elkview Operations Baldy Ridge Extension – Initial Source Terms Transmittal DRAFT		

1 Background

This memorandum provides geochemical source terms for the EVO Baldy Ridge Extension Project and outlines how to apply them in the overall site water quality model. Details of derivation will be provided as an appendix in the Elkview Operations Baldy Ridge Extension Geochemistry Baseline Report.

This memorandum is the deliverable for Task 300 Interpret data and source term calculation in SRK's work scope dated May 7, 2013.

2 Consideration of Acidity

Unlike previous source terms developed for use elsewhere in the Elk Valley (Attachment 1), some pit walls at EVO are predicted to have acidic runoff. The approach for evaluation of the influence of these walls and locations receiving pit waters is as follows:

- Determine mass balance alkalinity (in mg $CaCO_3$/L) using the same source term methods as described in Attachment 1.
- For non-acidic source terms, assume acidity (in mg $CaCO_3$/L) is zero.
- For acidic source terms, use mass balance Fe, Al and Mn concentrations (in mg/L) to calculate acidity concentrations in pit sumps and other internal collection points from:

$$\text{Acidity (mgCaCO}_3\text{/L)} = \left(\text{Al}\frac{3}{27} + \text{Fe}\frac{3}{55.9} + \text{Mn}\frac{2}{55} \right) \cdot 50$$

- Determine net alkalinity at these locations from:

$$\text{Net Alkalinity (mg CaCO}_3\text{/L)} = \text{Alkalinity (mg CaCO}_3\text{/L)} - \text{Acidity (mg CaCO}_3\text{/L)}$$

- If net alkalinity is positive, adjust all trace element concentrations (except Cd, Zn, Co and Ni) to non-acidic values (presented as exposed waste rock in Table 3-3). For Cd, Zn, Co and Ni use mass balance concentrations.

- If net alkalinity is negative at the above modelling points, use mass balance trace element concentrations.
- In addition, if the water is predicted to be acidic and will mix with other sources before discharge repeat the same approach for these mixing locations.

3 Recommended Source Terms

3.1 Waste Rock

3.1.1 Permanently Exposed Waste Rock

The method for calculating the source term for sulphate, selenium and nitrate is provided in Attachment 1. Terms for other parameters are provided below including seasonal cobalt terms for the Dry Creek spoil (containing waste from both Baldy Ridge pit and Adit Ridge Pit), Erikson Spoil (containing waste from Adit Pit) and in-pit (spoils from Baldy Ridge Pit) are provided below.

Except for cobalt, all other terms are to be applied as fixed concentrations for all flow and seasonal conditions (Table 3-3).

The cobalt source term accounts for the presence of Morrissey Formation in the Dry Creek Spoil, Erikson Spoil and in-pit disposal locations. It is to be calculated using the predicted P50 and P95 sulphate concentration (mg/L) by spoil location and year. The term is to be calculated based on two periods in the year:

- Start of snow melt influence flows in May, through June and July:

$$\mathrm{P95Co} = 10^{0.95\times\mathrm{LOG(MF)}-5.7} \times \mathrm{P95SO_4}$$

$$\mathrm{P50Co} = 10^{0.95\times\mathrm{LOG(MF)}-5.7} \times \mathrm{P50SO_4}$$

Where MF is the cumulative percentage of Morrissey Formation present in the spoil in each year (Table 3-1), cobalt and sulphate are calculated as mg/L, P95 is the 95th percentile concentration and P50 is the 50th percentile concentration. It is assumed that May is the month when high flows begin.

- August to April:

Statistic	Co (mg/L)
P50	0.0009
P95	0.003

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Table 3-1: Morrissey Formation Schedule and Disposal Location

Year	Dry Creek Valley	Erikson Valley	In Pit
	(Cumulative % of total new waste)	(Cumulative % of total new waste)	(Cumulative % of total waste)
2017	1.5	7.2	1.5
2020	1.5	33	1.5
2021	3.4	33	1.5
2022	6.0	35	1.5
2023	18	34	1.5
2024	18	34	1.5
2025	17	34	1.5
2026	15	34	1.5
2027	13	34	1.5
2028	13	34	1.5
2029	12	34	1.5
2034	12	34	1.5
2035	11	34	1.5
2036	12	34	1.5
2037	12	34	1.5
2038	12	34	1.5
2039	12	34	1.5
2040	12	34	2.6
2041	12	34	4.6
2042	12	34	5.8
2043	12	34	7.5
2044	12	34	11
2045	12	34	13

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Note: 0.38% of MF is assumed for years when no MF is expected to be mined to generate a term that is not lower than the maximum value observed during monitoring of West Line Creek where MF is negligible.

3.1.2 Backfilled Waste Rock (Pit F2)

Source terms for backfilled waste rock are the same as those calculated for permanently exposed waste rock with the exception of considering selenium attenuation in Pit F2. This term incorporates the reduction in selenium concentrations due to the effects of sub-oxic conditions in backfill and a residence time of greater than five years. The pre-attenuation source term calculation method is provided in Attachment 1.

This prediction should be applied to waste rock that will be backfilled into Pit F2 as a percent reduction of the predicted pre-attenation selenium concentration (95% reduction; average case, 90% reduction; worst case).

3.2 Adit Ridge Waste Rock Rehandle

This term should be applied as a one-time flush of soluble weathering products (mg/m^3) during the year in which waste rock is rehandled to the new disposal location.

The flush will be added to the overall term for the relevant storage facility in which it is placed (Table 3-2) and then corrected for solubility for the combined loading sources.

Table 3-2: Adit Ridge Legacy Waste Rock Rehandle Schedule and Disposal Locations

Year	Volume (LCM)	Destination	Drainage
2020	3,107,957	Adit South	Erickson Valley
2021	1,890,075	Adit South	Erickson Valley
2022	5,135,962	Adit North	Dry Creek
2023	4,666,343	Adit North	Dry Creek
2024	3,620,923	Adit North	Dry Creek
2025	831,344	Adit North	Dry Creek
2026	284,343	Adit North	Dry Creek

Source: Teck 2015b

3.3 Dry Creek Spoils Waste Rock Rehandle

The term should be applied as a one-time flush of soluble weathering products (mg/m^3) during the year in which waste rock rehandled to the new disposal location The flush will be applied as an additive to the overall term for the Dry Creek waste rock dump and then corrected for solubility for the combined loading sources. The rehandle schedule is in progress (Table 4-1).

3.4 Pit Walls

3.4.1 Nomenclature

Pit walls of two general types require source terms:

1. Benched walls. These consist of flat benches and steep berms forming an overall stepped pit wall.
2. Footwalls. These walls typically follow the gently dipping lower surface of the bottom-most seam and are stable without benching.

3.4.2 Natal and Baldy Pit Walls

Both types of walls will be present in Natal and Baldy Pits.

All benched walls in the final pit will consist of the Mist Mountain Formation. The source term method to be applied to the entire exposed final pit wall area is provided in Attachment 1.

Additional terms for the Natal and Baldy footwalls and provided in Table 3-3 to account for the presence of potentially ARD generating (PAG) rock in the footwall of the lowest seam mined. These terms are to be applied to over the area of the final exposed footwall in each pit until the corresponding area of the pit is submerged.

Footwall runoff will be acidic (see Section 2).

3.4.3 Adit Pit Wall

Adit Pit will only have benched walls which will be composed of both MMF and MF. A single term has been developed that combines the rock type effects (Table 3-3). The term is to be applied to the entire final pitwall area until the pitwall is submerged.

Runoff is predicted to be acidic (refer to Section 2).

3.5 Access Road Exposures of Moose Mountain Member in the Baldy Ridge Area

This source term accounts for the presence of potentially ARD generating rock in the Baldy Ridge access roads (Table 3-3). These walls will be benched.

The term is to be applied to the Baldy Ridge drainage area over a final exposed area of 1.25 million m^2 (Teck 2015c). It is assumed this material will remain exposed.

Runoff is predicted to be acidic (refer to Section 2).

3.6 West Fork Tailings Facility

The predicted effluent chemistry is provided in Table 3-3 and was calculated from historical monitoring data from the GEHO tailings line which discharges at the WFTF and represents tailings effluent (Teck 2015a). This term represents future effluent chemistry at the WFTF.

3.7 Coarse Coal Reject Storage Facility

The source term is provided in Table 3-3 and was calculated from historical monitoring data of seepage from the Greenhills Area A CCR facility where seepage flow represents primarily contact with CCR. This term represents future surface seepage chemistry at the CCR facility.

Table 3-3: Recommended Source Terms

Source Term	Statistic	Units	Acidic Term	Alkalinity	DOC	F	Cl	NO3	NO2	NH4	SO_4	Al	Sb	As	Ba	Be	B	Cd	Ca
Exposed Waste Rock	P50	mg/L	No	*	1.7	0.66	4.4	*	*	0.013	*	0.0047	0.0044	0.00039	0.085	0.00038	0.032	0.0011	*
	P95	mg/L	No	*	8.6	1.2	44	*	*	1.4	*	0.074	0.014	0.0026	0.27	0.005	0.1	0.0029	*
Backfilled Waste rock F2 Pit	P50	mg/L	No	*	1.7	0.66	4.4	*	*	0.013	*	0.0047	0.0044	0.00039	0.085	0.00038	0.032	0.0011	*
	P95	mg/L	No	*	8.6	1.2	44	*	*	1.4	*	0.074	0.014	0.0026	0.27	0.005	0.1	0.0029	*
Adit Ridge Rehandle	P50	mg/m3 LCM	No	33	1.7	350	510	1500	11	73	26000	0.093	0.94	0.00024	0.11	0.01	51	0.043	16000
	P95	mg/m3 LCM	No	46	8.6	550	780	2700	250	150	52000	0.12	1.4	0.00049	0.19	0.01	51	0.11	23000
Dry Creek Spoil Rehandle	P50	mg/m3 LCM	No	33	1.7	350	510	1500	11	73	26000	0.093	0.94	0.00024	0.11	0.01	51	0.043	16000
	P95	mg/m3 LCM	No	46	8.6	550	780	2700	250	150	52000	0.12	1.4	0.00049	0.19	0.01	51	0.11	23000
Natal Footwall	P50	mg/L	Yes	0	1.7	0.68	0.31	0	0	0	320	2.2	0.000028	0.0092	0.0054	0.002	0.017	0.005	21
	Max	mg/L	Yes	0	8.6	1.3	0.37	0	0	0	580	4.2	0.000047	0.018	0.0082	0.0033	0.023	0.0088	34
Baldy Footwall	P50	mg/L	Yes	0	1.7	0.68	0.31	0	0	0	320	2.2	0.000028	0.0092	0.0054	0.002	0.017	0.005	21
	Max	mg/L	Yes	0	8.6	1.3	0.37	0	0	0	580	4.2	0.000047	0.018	0.0082	0.0033	0.023	0.0088	34
Adit Pitwall	P50	mg/L	Yes	140	1.7	5.3	5.6	8.3	2.9	1.3	2100	14	0.0065	0.056	0.21	0.012	0.29	0.03	180
	Max	mg/L	Yes	170	8.6	9.8	6.1	14	6.4	2.6	4000	25	0.014	0.11	0.3	0.02	0.53	0.053	330
Access Road Exposed non-MMF in Baldy Pit area	P50	mg/L	Yes	0	1.7	14	6.3	11	2.7	2	6500	45	0.00056	0.18	0.11	0.04	0.34	0.099	410
	Max	mg/L	Yes	0	8.6	25	7.3	21	5.3	3.7	12000	84	0.00093	0.36	0.16	0.066	0.47	0.18	680
CCR Storage Facility Seepage Chemistry	P50	mg/L	No	510	2.1	0.42	26	0.12	0.022	0.31	1200	0.0058	0.00025	0.0003	0.02	0.00057	0.028	0.00019	350
	P95	mg/L	No	600	3	0.41	74	0.23	0.045	0.54	1800	0.015	0.0005	0.0005	0.027	0.0025	0.05	0.00053	460
WFTF Effluent Chemistry	P50	mg/L	No	140	1.9	0.69	3.2	1.6	0.25	#N/A	110	0.019	0.0043	0.0011	0.096	0.0015	0.05	0.00048	63
	Max	mg/L	No	140	2.6	0.85	6.7	1.6	0.25	#N/A	120	0.033	0.0048	0.0015	0.11	0.0025	0.05	0.00048	70

Source Term	Statistic	Units	Cr	Co	Cu	Fe	Hg	Pb	Mg	Mn	Mo	Ni	P	K	Se	Ag	Na	Tl	Ti	Zn
Exposed Waste Rock	P50	mg/L	0.00025	0.0017*	0.0028	0.015	0.000005	0.000078	*	0.0064	0.044	0.042	0.15	4.8	*	0.00001	#N/A	0.000075	0.01	0.03
	P95	mg/L	0.0013	0.0017*	0.0085	0.03	0.000005	0.001	*	0.14	0.15	0.2	0.15	14	*	0.000025	#N/A	0.00025	0.018	0.12
Backfilled Waste rock F2 Pit	P50	mg/L	0.00025	0.0017*	0.0028	0.015	0.000005	0.000078	*	0.0064	0.044	0.042	0.15	4.8	*	0.00001	#N/A	0.000075	0.01	0.03
	P95	mg/L	0.0013	0.0017*	0.0085	0.03	0.000005	0.001	*	0.14	0.15	0.2	0.15	14	*	0.000025	#N/A	0.00025	0.018	0.12
Adit Ridge Rehandle	P50	mg/m3 LCM	0.00034	0.13	0.0013	0.014	0.01	0.000077	6300	3.6	5	0.69	0.028	2.8	15	0.0051	480	0.000041	0.52	0.0018
	P95	mg/m3 LCM	0.0099	0.48	0.0091	0.035	0.01	0.00012	8500	8.1	14	5.4	0.067	5.4	31	0.0058	1100	0.000062	1.1	0.004
Dry Creek Spoil Rehandle	P50	mg/m3 LCM	0.00034	0.13	0.0013	0.014	0.01	0.000077	6300	3.6	5	0.69	0.028	2.8	15	0.0051	480	0.000041	0.52	0.0018
	P95	mg/m3 LCM	0.0099	0.48	0.0091	0.035	0.01	0.00012	8500	8.1	14	5.4	0.067	5.4	31	0.0058	1100	0.000062	1.1	0.004
Natal Footwall	P50	mg/L	0.0095	0.025	0.054	61	0.0000088	0.0013	7.1	0.91	0.0002	0.11	1.6	0.37	0.00057	0.000044	0.12	0.0002	0.00039	0.35
	Max	mg/L	0.018	0.033	0.11	110	0.00001	0.0019	11	1	0.00038	0.14	3.2	0.69	0.00087	0.000086	0.14	0.00028	0.00055	0.56
Baldy Footwall	P50	mg/L	0.0095	0.025	0.054	61	0.0000088	0.0013	7.1	0.91	0.0002	0.11	1.6	0.37	0.00057	0.000044	0.12	0.0002	0.00039	0.35
	Max	mg/L	0.018	0.033	0.11	110	0.00001	0.0019	11	1	0.00038	0.14	3.2	0.69	0.00087	0.000086	0.14	0.00028	0.00055	0.56
Adit Pitwall	P50	mg/L	0.057	0.15	0.33	360	0.00011	0.0082	73	5.4	0.05	0.65	9.6	17	0.036	0.0003	15	0.0015	0.0056	2.1
	Max	mg/L	0.11	0.2	0.64	640	0.00012	0.012	130	5.9	0.12	0.87	19	37	0.071	0.00054	48	0.0022	0.0066	3.4
Access Road Exposed non-MMF in Baldy Pit area	P50	mg/L	0.19	0.5	1.1	1200	0.00018	0.026	140	18	0.0041	2.2	32	7.5	0.011	0.00089	2.4	0.0039	0.0078	7
	Max	mg/L	0.36	0.65	2.1	2200	0.0002	0.039	210	20	0.0076	2.9	65	14	0.017	0.0017	2.7	0.0055	0.011	11
CCR Storage Facility Seepage Chemistry	P50	mg/L	0.00057	0.003	0.00083	1.5	0.000005	0.00012	210	1.4	0.0013	0.0079	0.3	5.7	0.014	0.000025	9	0.00011	0.015	0.0093
	P95	mg/L	0.0025	0.006	0.0025	8.7	0.000005	0.00025	290	2.4	0.0019	0.013	0.3	6.4	0.061	0.00005	14	0.0005	0.025	0.016
WFTF Effluent Chemistry	P50	mg/L	0.0015	0.0011	0.001	0.03	0.00001	0.00025	21	0.038	0.028	0.0032	0.3	3.9	0.01	0.00005	4.7	0.00028	0.02	0.0075
	Max	mg/L	0.0025	0.0014	0.0015	0.05	0.00001	0.00025	25	0.063	0.038	0.0039	0.3	4.4	0.013	0.00005	6.4	0.0005	0.03	0.0098

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Note: #N/A denotes term not calculated due to lack of available data, * denotes term calculation described in Attachment 1 or in text above

4 Further Work

Table 4-1 describes the data needed to complete final generation of source terms.

Table 4-1: Further Work

Data Needs	Affected Source Term(s)	Purpose	Status
Waste rock density, runoff coefficient	Baldy Ridge Pitwall, Adit Pitwall, Natal Pitwall	Confirm the waste rock density and runoff coefficients used in modelling calculations at the site are the same as used in source term prediction.	EVO – In progress
Dry Creek waste rock rehandle schedule	Dry Creek waste rock rehandle	Determine the re-handle schedule.	EVO – In progress
Refinement of Adit Ridge geological interpretation	Unsaturated waste rock (Specifically Dry Creek and Erikson dumps) and Adit Pitwall	Current model assumes only MMF and non-MMF. Can better refine term to include Morrissey and Fernie Formations. In addition, waste rock volumes and final pit compositions are currently based on a preliminary pit shell.	EVO – Expected delivery April 21, 2015

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Teck 2015b. Summary of Adit Rehandle Quantities (RFI 083 and 084). E-mail from Brian Wong March 27, 2015.

Teck 2015. Source Terms Discussion – Final Pit Wall Areas. E-mail from Brian Wong March 16, 2015c.

Attachment 1

Teck

Geochemical Source Term Inputs and Methods for the Elk Valley Water Quality Planning Model

Prepared for

Teck Coal Limited

Prepared by

srk consulting

SRK Consulting (Canada) Inc.
1CT017.054
June 2014

Geochemical Source Term Inputs and Methods for the Elk Valley Water Quality Planning Model

June 2014

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File Name: G-03-05_Geochemical_Source_Term_Inputs_and_Methods_20140626

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Executive Summary

Geochemical source terms were developed as inputs into the water quality planning model to support the Elk Valley Water Quality Plan. This report summarizes the method used to develop the geochemical source terms.

All source terms were derived starting from conceptual geochemistry based on current understanding of the geochemical characteristics of the mines waste and the performance of the disposal facilities.

For waste rock spoils, pitwalls, and co-disposed waste rock and coal rejects, releases of selenium, sulphate and nitrate were calculated based on the volume of material in each catchment, the release rate of each parameter derived from monitoring data and the predicted infiltration rate. Selenium and sulphate originate from oxidation of pyrite whereas nitrate is from leaching of explosives residuals. The method assumed that a significant proportion of spoils is active in generating soluble load. The resulting concentrations of selenium and sulphate derived by the method were constrained to not exceed maximum possible concentrations indicated by the solubility of gypsum, a secondary mineral expected to form in the spoils.

For nitrate, leaching rate decreases as a function of increasing age of spoil. Therefore, the source term was based on the average of the spoil. The resulting concentrations were not constrained due to the high solubility of nitrate.

The source terms for other elements (for example, cadmium) leaching from waste rock spoils were based on fixed concentrations indicated by monitoring data.

The source terms for spoils account for observed seasonal variation in loads released (greatest loads during highest flows generated by snowmelt) and response to differences in annual flows.

For coal reject disposal facilities, weathering and leaching occurs by similar processes as waste rock but it was observed that oxygen penetration is limited to a surface zone and that the cores of coal reject facilities do not oxidize. Therefore, the source term was based on fixed concentrations applied to all infiltrating water into the facilities rather than calculated from the entire volume of coal reject.

1 Introduction

1.1 Background

Teck Coal Limited (Teck), as part of its overall water quality management program, has the need to estimate current and future concentrations of selenium, sulphate, nitrate and cadmium in the Elk River resulting from operation of its five coal mines. Essential inputs into such estimation work are geochemical source terms for the chemical loadings into the water resources from mine facilities and workings.

SRK was originally requested to develop the geochemical source terms as part of water quality predictions for permit amendment activities related to expansion of mining at Elkview Operations (EVO) into Baldy Ridge. The method of estimating was subsequently updated and used to support environmental assessments for the Line Creek Operations (LCO) Phase II and Fording River Operations (FRO) Swift projects, and to support permit amendment applications the Greenhills Operations (GHO) West Spoil project. The source terms were also used in the water quality model that supported the valley-wide selenium management plan.

The same geochemical source terms are now being applied to the Elk Valley water quality model, which supports the development of the Elk Valley Water Quality Plan (the Plan). This report includes all input assumptions and relationships used in the model, and provides explanations of source term development and application.

1.2 Data Sources

Input data used to support source-term calculations were largely provided by Teck and are listed in Table 1.

Table 1. Information Used to Develop Inputs into the Source-term method

Information	Teck Coal Operation	Time Period Covered
Spoil volumes by operation	All	To 2011, depending on operation
Near-source surface water chemistry	All	To 2011, depending on operation
Near-source flows	All	To 2011, depending on operation
CCR humidity cell data	LCO, GHO	N/A
Waste solids chemistry	EVO, LCO, FRO, GHO	N/A
In-situ gas monitoring	GHO, LCO	2009 to 2012

Note: CCR = coarse coal reject

1.3 Structure of this Document

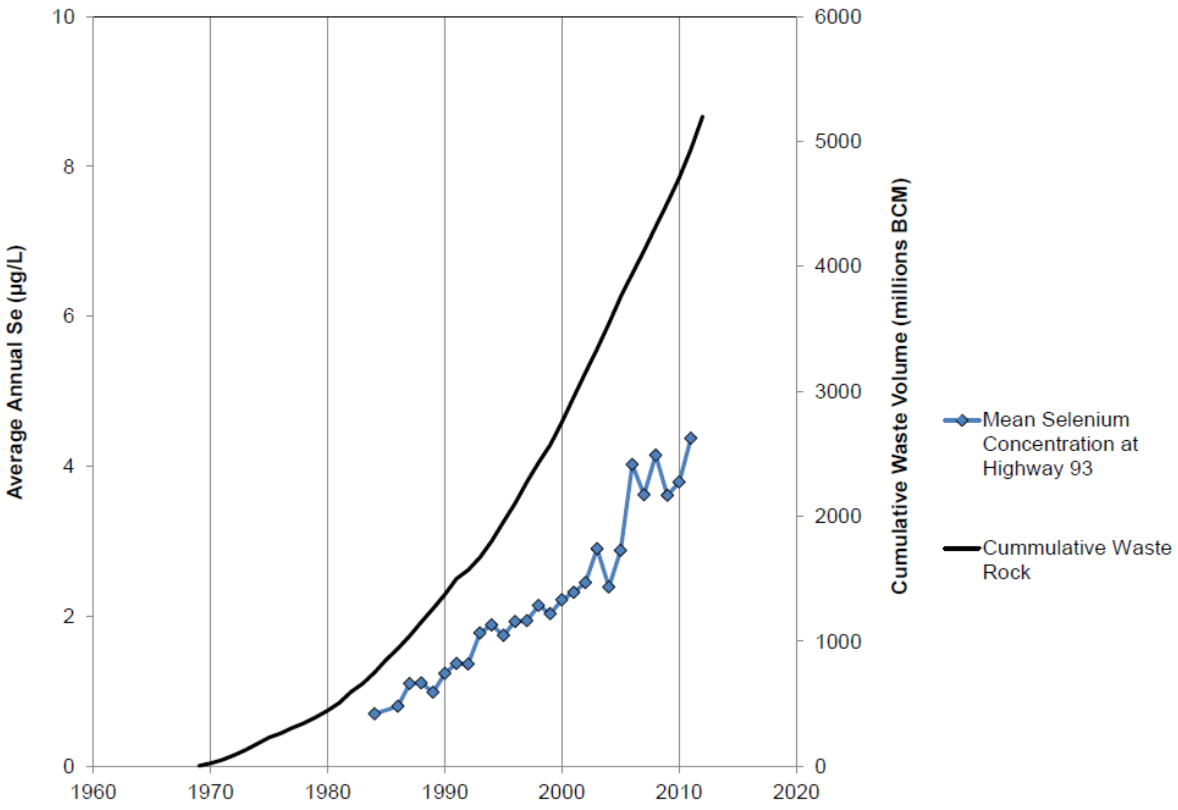
This report is structured as follows:

- Section 2 describes the conceptual geochemical model (CGM) for each facility requiring a source term and the mathematical implementation of the CGM.
- Section 3 describes data sources and analysis undertaken to develop the inputs into the geochemical source-term method.
- Section 4 provides discussion of various aspects of the geochemical source term calculations.

2 Geochemical Source Term Calculation Method

2.1 Overview of Methodology

The geochemical source-term method was selected to be consistent with conceptual models formulated in the late 2000s describing leaching of selenium and other constituents from mine wastes in the Elk Valley. The primary observation justifying the conceptual models was that selenium concentrations in the Elk River were increasing with waste rock accumulation (Figure 1), which implied that selenium release could be predicted from the waste volumes generated by future mining operations.



P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CT017.054_Geochem Documentation for EVWQP\100_Report\Figures\[Elk River Concentration

Figure 1. Mean Annual Selenium Concentrations (in µg/L) in the Elk River Compared to Spoil Volume in Millions of Bank Cubic Metres (BCM)

(Source: Teck Coal)

The geochemical source-term method for describing leaching of selenium and other constituents from mine wastes in the Elk Valley was developed to achieve two main objectives:

- To be generally consistent with predictive water chemistry methods used elsewhere in BC, so that the method used for the Elk Valley would be recognizable and generally accepted by other industry and regulatory practitioners in this field.

- To use data primarily from geologically analogous sites in the Elk Valley, with the intent of eliminating inherent limitations and conservatism resulting from determining field-scale release rates based upon laboratory test results.

The first objective was achieved by using a conventional methodology that links weathering rates of primary minerals to generation of soluble weathering products, and the finite solubility of the weathering products. This approach has been applied and accepted for numerous projects in BC (for example, Western Canadian Coal 2005; Western Coal 2010; SRK 2012).

The second objective was achieved by demonstrating the geological and geochemical consistency of the Mist Mountain Formation throughout the Elk Valley. Studies of selenium distribution by Lussier (2001), Ryan and Dittrick (2001) and Ryan et al. (2002), and studies subsequently performed to prepare for regulatory submissions by Teck have shown that selenium and sulphur concentrations range over similar values throughout the Elk Valley (Figure 2). Sulphide-sulphur concentrations are typically less than 0.2% and selenium concentrations vary from less than 1 mg/kg to typically about 5 mg/kg (with some exceptions). Selenium concentrations tend to be lowest in sandstones and highest in mudstones. These observations support the application of information obtained on geochemical characteristics at four operations (EVO, LCO, GHO, FRO) to expansion of the operations, or watersheds with less data, provided they are in the same geological setting. Coal Mountain Operations (CMO) has some structural and stratigraphic differences and, therefore, is considered separately.

To summarize the geochemical source-term method, the amount of waste generated per year is multiplied by the amount of soluble rock components generated per m^3 (cubic metre) of waste to give the amount of soluble rock components generated per year. That quantity is then divided by the volume of water estimated to infiltrate the rock during the year, giving the concentration of soluble components. The resulting concentration is then compared to the solubility limit to determine if the calculated concentration needed to be constrained to the limit. For less soluble components for which experience suggests that release by weathering far exceeds solubility limits, the source term concentration is set to the solubility limit. The approach was modified slightly for nitrate released from explosives residue.

2.2 Scenarios

To provide an evaluation of prediction uncertainty and to align the geochemical source-term method with similar methods used elsewhere, inputs to the calculations were provided for two cases: the best-estimate case based on mean or median statistics of data distributions for rates and concentrations, and the reasonable worst case, based on 95% upper confidence limit on the mean, 95th percentile or maximum of a data distribution. The mean and confidence limits on the mean were used to define the range of release rates because the mean of monitoring data is expected to define a typical value for the Elk Valley. Percentile statistics (median, 95th, maximum) for monitoring data were used to constrain solubility limits, because solubility is most likely constrained by high values representing minimal dilution of source waters. The choice of 95th percentile or maximum depended on the size of the dataset. For small datasets, the maximum value was used.

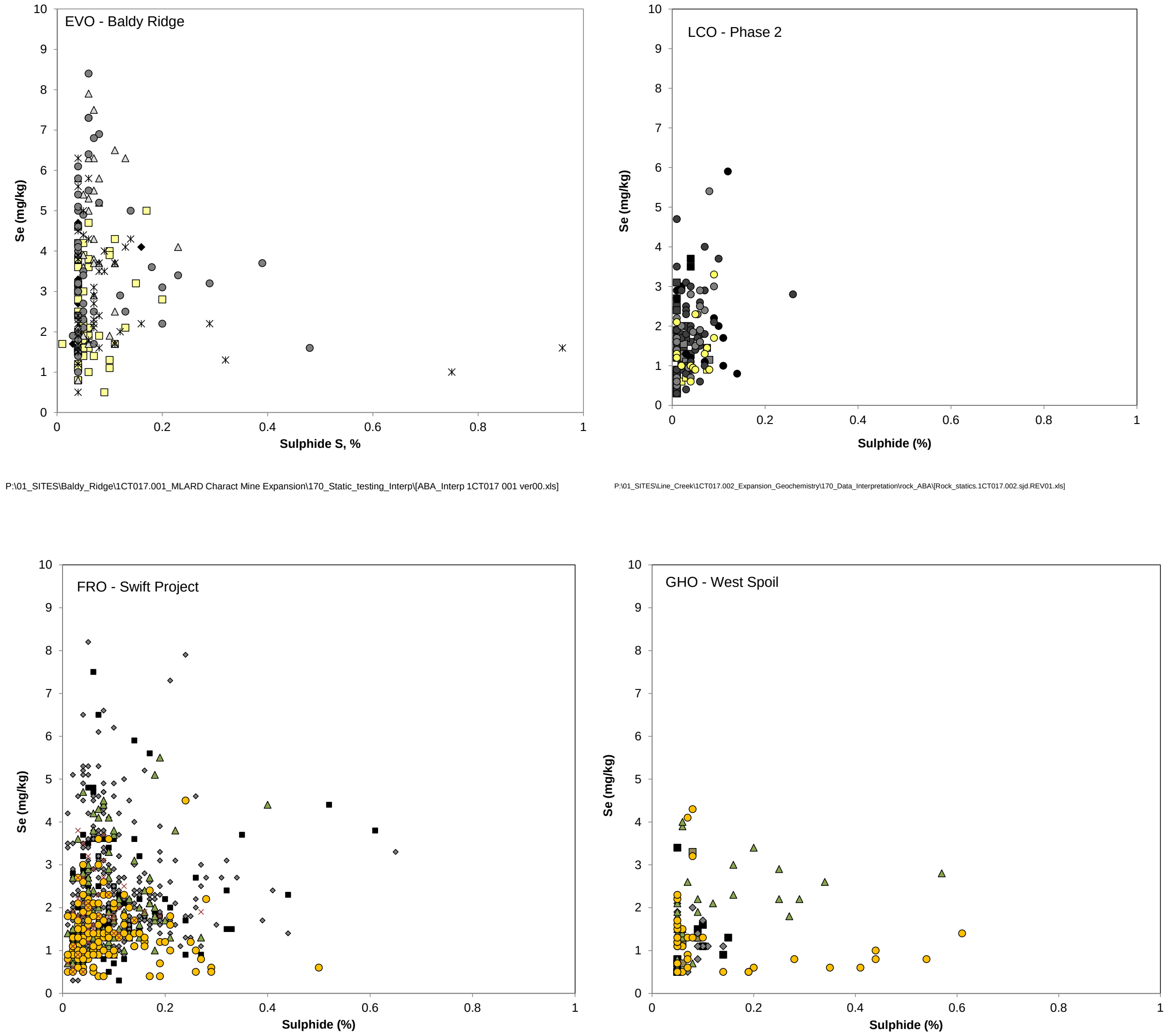


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Figure 2. Selenium and Sulphur Concentrations in Rock Samples from the Mist Mountain Formation of Elk Valley.

Colours of symbols are rock types (yellows – sandstone, greys – siltstones and mudstones, black – coal)

2.3 Strengths and Limitations

The following are strengths of the method:

- The conceptual model used to develop the geochemical source-term method is based on a good understanding of the underlying weathering and leaching mechanisms.
- Coal is mined almost exclusively from a single geological formation, with what appears to be relatively uniform regional characteristics which allows the method to be applied throughout the Elk Valley.
- The conceptual model described in the following sections and used to develop the geochemical source-term method is primarily empirical rather than theoretical. An empirical method is considered better than a construct based on theory because it uses actual observations.
- Inputs to the method are based on a very large unique regional flow and water chemistry monitoring database accumulated by Teck over several years and more than a decade in some cases.
- Application of the method to valley-wide predictions of selenium, sulphate and nitrate has shown that predicted water chemistry aligns with observations.
- The geochemical source-term method developed from the conceptual model can be applied to historical wastes for which monitoring data are not available. However, if the method is applied retrospectively to sites for which site-specific monitoring data are available, factors must be applied to the predictions to calibrate the monitoring data to reflect local conditions. The benefit of using calibration factors is that they allow deviations from average valley-wide rates to be compared across sites, thereby facilitating evaluation of explanations for differences. As a potential future improvement to the method, monitoring data may be used to develop specific loading terms for the monitoring locations. Calculation of site-specific rates ensures that predictions will match observations, and may result in higher certainty for future predictions.

The following limitations of the geochemical source-term method should be considered:

- The method does not attempt to mathematically define geochemical processes but rather is an empirical tool to support simulation of downstream water quality concentrations. While some effort is made to achieve ion-balanced water chemistry, the method is largely focused on providing source terms for trace elements (e.g. selenium) rather than major ions (e.g. sulphate). The result of this limitation is that synergistic effects among ions may not be reflected. For example, elevated barium concentrations could be predicted with elevated sulphate concentrations, but, in reality, barium concentrations are suppressed by the low solubility of barite (barium sulphate).
- The geochemical source-term method was developed for application to future wastes for which drainage monitoring data are not yet available; but these wastes will mainly come from the Mist Mountain Formation, for which waste placement approaches are similar to elsewhere

in the valley. The method is not yet suitable for application to wastes from the Morrissey and Fernie Formations beyond where they occur at CMO; however, these have much smaller volumes than the Mist Mountain Formation.

- The method does not consider year-on-year lag effects. It is likely that there will be a lag in placement of wastes and contribution of the waste to chemical loadings. Consequently, the method may over-predict chemical loadings for new waste sources.
- The method is steady state for rock weathering components (selenium and sulphate), and does not consider factors that could cause long-term changes in chemical loadings, such as depletion of mineral sources.
- Since the method is empirical rather than mechanistic and based on existing monitoring data, the effect of source control measures, such as infiltration reduction by covers, cannot be readily assessed, and/or must use conservative assumptions to address uncertainty. As Teck develops information about the influence of covers on geochemical processes, the approach to estimating the influence of source control measures will be refined.

The method was developed before some of the supporting research related to the Plan was started; it therefore only partially incorporates ongoing findings of that research. Periodic reviews of the approach are planned to consider and incorporate findings of the program, particularly as they pertain to weathering, infiltration, leaching, and the performance of control measures. Moreover, monitoring over time will be required to confirm the implied linkage of tonnage to loading as mining methods and dump placement methodologies are refined in the future.

2.4 Implementation of the Source-Term method

The following sections describe the method used to calculate source terms for open pits and waste management facilities (i.e., waste rock dumps). Each section provides the conceptual model for the indicated source term as developed in 2010, which was then implemented in the calculation.

Table 2 provides a list of symbols used for the equations in the subsequent sections.

Table 2. List of Symbols

Symbol	Units	Definition	Assigned Values
J	None	Parameter (e.g. sulphate).	-
R_j	mg/m^3/year	Rate of generation of parameter j from a bank cubic metre (Bank m^3) of waste rock	Table 3 and Table 4
$V_{rock}(t)$	bank m^3 (BCM)	Volume of rock placed at disposal location in year t	Mine plan
V_{rock}	bank m^3	Cumulative volume of rock at a disposal location	Calculated
$\bar{t}$	years	Average age of rock at disposal location	Calculated
$L_{i,j}$	mg/year	Initial calculation of load leached of parameter j from waste rock	Calculated
$\overline{Q}$	L/year	Average volume of water infiltrating the waste rock facility in a year	Infiltration estimate
Q	L/year	Volume of water infiltrating the waste rock facility in a year	Water balance
$C_{i,j}$	mg/L	Initial pore water concentration of parameter j	Calculated
C_{s,SO_4}	mg/L	Solubility limit for sulphate as defined by gypsum solubility	Section 3.1.4
$C_{s,Se}$	mg/L	Solubility limit for selenium assuming co-precipitation with gypsum	Section 3.1.4
$M_{Mg/Ca}$	mol/mol	Average molar ratio of magnesium to calcium	Section 3.1.4
$C_{s,j}$	mg/L	Constraining concentrations for parameter j	Section 3.1.4
$C_{c,j}$	mg/L	Calculated annual pore water concentrations	Calculated
$L_{a,j}$	mg/year	Annual load of parameter j calculated from $C_{i,j}$	Calculated
$p_{m,j}$	Unitless	Fraction of load of parameter j released in month m	Table 5
$L_{m,j}$	mg/month	Monthly load of parameter j calculated from $L_{a,j}$	Calculated
Q_m	L/month	Flow in month m	Water balance
$C_{m,j}$	mg/L	Monthly seepage concentrations	Calculated
$C'_{m,j}$	mg/L	Adjusted monthly seepage concentrations from Step 8 (See Section 2.5.2)	Calculated
$L_{m,j}$	mg/month	Monthly loads from Step 8 (See Section 2.5.2).	Calculated
C_{TDS}	mg/L	Calculated total dissolved solids concentrations	Calculated
$p_{uncontacted}$	unitless	Fraction of rock not contacted by meteoric water	0.5
$V_{flooded}$	bank m^3	Volume of rock inundated by water	Mine plan and water balance
t_{flood}	year	Time when rock is flooded	Mine plan and water balance
$T_{placement}$	year	Time when rock is inundated	Mine plan
$L_{uncontacted,j}$	mg	Load leached by flooding of rock volume not contacted by meteoric water	Calculated
$L_{contacted,j}$	mg	Load leached by flooding of rock volume contacted by meteoric water	Calculated
$L_{flush,j}$	mg	Total load leached by flooding of rock	Calculated
A_{wall}	m^2	Area of pitwall	Mine plan
D	M	Reactive thickness of pitwall	2
V_{wall}	m^3	Reactive volume of pitwall	Calculated

2.5 Permanently Exposed Waste Rock Source Term

2.5.1 Conceptual Model

The conceptual model for weathering of waste rock is well-established in the geochemical literature, though release of selenium may be affected by its specific chemical properties. Specifics of the model for coal wastes and leaching of selenium have been defined previously (e.g., SRK 2008) and refined through ongoing efforts (e.g., SRK 2013b).

Weathering and leaching of waste rock occurs predominantly through several groups of processes:

- **Oxidation of pyrite under oxygenated conditions**: This results in release of soluble components of pyrite, mainly sulphate and acidity, but also traces of elements including selenium and other metals. Release is followed by consumption of the resulting acidity by excess quantities of acid-neutralizing minerals and release of soluble components of those minerals, mainly base cations.
- **Interaction of trace elements with reactive surfaces, e.g. iron oxides**: Under dominantly basic conditions, this results in attenuation of elements in solution as cations, e.g. cadmium, cobalt, copper and zinc. Elements released as oxyanions, e.g. selenium and sulphate, remain mobile and show limited attenuation unless precipitated as secondary minerals, e.g., sulphate as gypsum and/or barite.
- **Leaching of explosives residuals contributes inorganic nitrogen (e.g., nitrate) to contact waters**: Since explosives are introduced during mining and nitrogen forms are not expected to be generated significantly by rock weathering, loadings of explosives residuals are expected to diminish with time.

In the context of the general approach described in Section 2.1, selenium, sulphate and nitrate are considered to be relatively soluble, because processes limiting their solubility are either not occurring or are poorly understood. As a result, leaching of these elements is calculated mainly based on rate rather than solubility, with exceptions as noted below. Based on the apparent regional correlation of cumulative waste rock volume with increasing selenium concentrations in the Elk River (Figure 1), the working assumption is that the rate of release of these parameters is a function of waste volume.

Leaching of elements forming cations in solution, including cadmium, calcium and magnesium, are calculated based on solubility. Load released is therefore a function of infiltration rate, which is generally proportional to facility footprint rather than volume.

The hydrological aspects of waste rock leaching are complex, and are being further evaluated to support overall water management in the Elk Valley. Empirically, leaching effects (both concentrations and loadings) are expected to vary seasonally in response to changes in infiltration caused by snowmelt and other climatological events. High flow events may expose more rock to leaching, resulting in higher chemical loads, but such events may also provide dilution, leading to lower concentrations.

The hydrological model also has implications for the potential for chemical loadings to lag behind waste placement, due to the need for wetting to occur before water can drain from the waste. These effects are also being investigated further (reference). For the purpose of this source term, lag in loadings is not explicitly considered, because monitoring data for the Elk Valley as a whole shows increasing selenium concentrations in the Elk River correlating with cumulative waste placement (Figure 1), with no clear lag effect. Monitoring data for from a Coal Mine in BC shows that sulphate concentrations began increasing in settling ponds shortly after the mine became fully operational in 1983 (Figure 3).

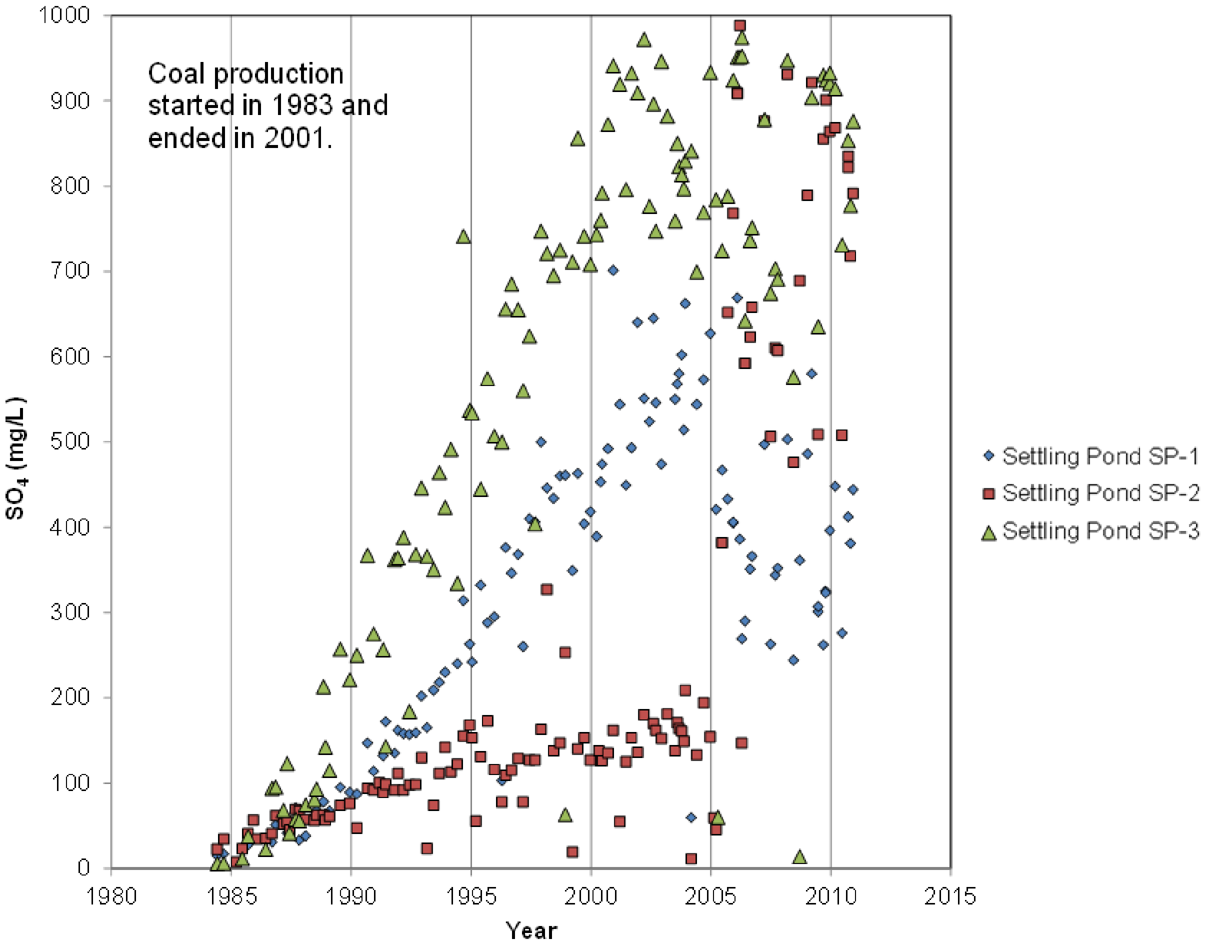

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Figure 3. Sulphate Concentrations in Settling Ponds at a Coal Mine in BC

2.5.2 Method Steps

The steps in the source-term method are described below. Derivation of inputs is provided in Section 3.

Step 1: Calculate Load Generated for the Soluble Elements Sulphate, Selenium and Nitrate

Based on the conceptual model used for this method, the average sulphate, selenium and nitrate loads generated and released are based primarily on the quantity of contributing waste rock, with less influence from the annual volume of infiltrating water, though there are seasonal and flow intensity effects as described subsequently. As a result, the method does not require well-defined infiltration estimates.

An initial estimate of the average annual selenium and sulphate load generated of each parameter j ($L_{i,j}$, in mg/year) was calculated as a function of average annual rate from:

$$L_{i,j} = V_{rock}.R_j$$

where V_{rock} is the cumulative volume of rock at a disposal location in bank m^3, and R_j is the generation rate for parameter j in mg/m^3/year.

Based on an observed relationship between normalized selenium release and normalized drainage flow (see Section 3.1.3), L_j can be calculated for any average annual flow condition using an empirical relationship, indicating that unitless flow and unitless release rates are nearly equivalent.

In contrast, nitrate is highly soluble and not generated by weathering of rock. R_j is expected to be high initially, and to decrease as the inventory of soluble nitrate decreases. The decay of nitrate may follow a non-zero-order relationship in which the amount leached is related to the amount remaining. The observed relationship is described in Section 3.1.3.

Step 2: Calculate Initial Concentrations

An initial estimate of average annual pore water concentration for parameter j ($C_{i,j}$, in mg/L) was calculated from:

$$C_{i,j} = \frac{L_{i,j}}{\overline{Q}}$$

where $\overline{Q}$ is the average volume of water in L/year infiltrating through the waste.

Step 3: Evaluate Initial Sulphate and Selenium Concentrations for Potential Solubility Controls

Initial sulphate concentrations were evaluated against concentrations controlled by gypsum solubility. If the raw sulphate concentration exceeded the solubility of gypsum (C_{s,SO_4}), the initial concentration was reduced to C_{s,SO_4}. If the raw concentration was less than C_{s,SO_4}, the initial concentration was used.

Step 4: Add Concentrations of Less Soluble Parameters

Concentrations of other parameters ($C_{s,j}$) were then added to the source term at fixed levels or solubility limits.

Calcium and magnesium concentrations (C_{Ca} and C_{Mg}, in mg/L) were calculated to achieve an approximate ion balance using bicarbonate, sulphate and fluoride as the major anions:

$$C_{Ca} = \left(\frac{40}{2 \cdot (1 + M_{Mg/Ca})} \right) \cdot \left(\frac{2 \cdot C_{Alkalinity}}{100} + \frac{2 \cdot C_{SO_4}}{96} + \frac{C_{NO_3}}{14} + \frac{C_F}{19} - \frac{C_{Na}}{23} - \frac{C_K}{39} \right)$$

$$C_{Mg} = M_{Mg/Ca} \cdot \left(\frac{24}{40} \right) \cdot C_{Ca}$$

In these equations, the concentration in mg/L is divided by the molar mass (in mg/mmol; e.g., 96 mg/mmol for sulphate) and multiplied by the charge on the ion (e.g., -2 for sulphate). $M_{Mg/Ca}$ is the average molar ratio of magnesium to calcium in surface waters.

The resulting concentrations from Step 4 for each parameter j were calculated concentrations $C_{i,j}$.

Step 5: Calculate Load Released

Annual load released ($L_{a,j}$, in mg/year), for each parameter j was calculated from:

$$L_{a,j} = Q \cdot C_{c,j}$$

Where $C_{c,j}$, in mg/L is the pore water concentration for each parameter obtained from steps 3 and 4 and Q is the associated infiltrating flow.

Step 6: Calculate Monthly Load Distribution in Seepage

The monthly load distribution in seepage was calculated by distributing $L_{a,j}$ according to monthly fractions for each parameter $p_{m,j}$. The load released in month m ($L_{m,j}$, in mg/month) was:

$$L_{m,j} = L_{a,j} \cdot p_{m,j}$$

Step 7: Calculate Monthly Seepage Concentrations

Monthly concentrations ($C_{m,j}$, in mg/L), were calculated from the monthly flow distribution ($Q_{m,j}$, in L/month):

$$C_{m,j} = \frac{L_{m,j}}{Q_m}$$

Step 8: Compare Monthly Concentrations with Fixed Concentrations and Calculate Final Loadings

Values of $C_{m,j}$ were compared with constraining con concentrations ($C_{s,j}$ in mg/L). If values of $C_{m,j}$ exceeded constraining values $C_{s,j}$, the constraining values replaced $C_{m,j}$.

The resulting final monthly concentrations ($C'_{m,j}$, in mg/L), can be used to calculate final loadings:

$$L'_{m,j} = Q_m \cdot C'_{m,j}$$

The total load released in a year ($L'_{a,j}$, in mg/year) is the sum of loads released in each month:

$$L'_{a,j} = \sum_{m=\text{January}}^{m=\text{December}} L'_{m,j}$$

Step 9: Speciate Nitrogen Forms

For the purpose of downstream predictions, nitrate concentrations were calculated and then used to speciate nitrate to nitrite and ammonia nitrogen according to the following:

$$C_{NO_2} \text{ (in mg N/L)} = f_{NO_2} \cdot C_{NO_3}$$

$$C_{NH_3} \text{ (in mg N/L)} = f_{NH_3} \cdot C_{NO_3}$$

where f_{NO_2} and f_{NH_3} are fixed factors used to calculate C_{NO_2} and C_{NH_3} from C_{NO_3}.

Step 10: Calculate Total Dissolved Solids

Total dissolved solids (TDS) concentrations (C_{TDS}, in mg/L), were estimated from the sum of all major ions as determined in Step 4:

$$C_{TDS} = C_{Ca} + C_{Mg} + C_K + C_{Na} + \frac{C_{Alkalinity}}{50} \cdot 61 + C_{SO_4} + C_{NO_3} + C_F + C_{Cl}$$

$\frac{C_{Alkalinity}}{50} \cdot 61$ was used to convert alkalinity concentrations, in mg $CaCO_3$/L, to bicarbonate concentrations, in mg/L.

2.6 Submerged Waste Rock

2.6.1 Conceptual Model

As waste rock is submerged (for example, when placed in a backfilled flooding pit), soluble weathering products not flushed by meteoric water may be released to the water column. For the purpose of the source term, the flushing process is assumed to be instantaneous, though in practice a rapid initial flush can be expected following by slow flushing of residual load.

Following this flushing process, the rock oxidizes at much lower rates than occurs under subaerial conditions due to low concentrations of dissolved oxygen in water relative to atmospheric conditions. Therefore, for the purpose of source term calculations, this load is considered to be zero based on extensive literature supporting subaqueous disposal as a technology to significantly limit sulphide mineral oxidation (The International Network on Acid Prevention 2009).

2.6.2 Calculation of Flushed Load

Stored load originates as weathering products in areas of the waste rock that have never been contacted by meteoric water, and in areas that are contacted, but in which weathering products are retained due to solubility limitations.

The one time load of sulphate, selenium and nitrate ($L_{\text{uncontacted},j}$, in mg) flushed from uncontacted parts of rock mass volume (V_{flooded}, in bank m^3) as they are inundated is:

$$L_{\text{uncontacted},j} = p_{\text{uncontacted}} \cdot V_{\text{flooded}} \cdot R_j \cdot (t_{\text{flood}} - t_{\text{placement}})$$

where $p_{\text{uncontacted}}$ is the proportion of rock not contacted by meteoric water, t_{flood} (year) is the time when flooding occurs and $t_{\text{placement}}$ (year) is the time when the rock was placed so that (t_{flood}-$t_{\text{placement}}$) is the time in years since exposure by mining.

The load flushed from contacted areas ($L_{\text{contacted},j}$ in mg) is:

$$L_{\text{contacted},j} = (1 - p_{\text{uncontacted}}) \cdot V_{\text{flooded}} \cdot R_j \cdot (t_{\text{flood}} - t_{\text{placement}}) - \sum_{a=t_{\text{placement}}}^{a=t_{\text{flood}}} L'_{a,j}$$

This expression is based on total load generated less the load removed by infiltrating water. For sulphate or selenium, this load may be zero if all concentrations are less than C_{s,SO_4} and $C_{s,Se}$, respectively.

Total load released by flushing ($L_{\text{flush},j}$, in mg) was calculated from:

$$L_{\text{flush},j} = L_{\text{uncontacted},j} + L_{\text{contacted},j}$$

2.7 Waste Rehandling

2.7.1 Conceptual Model

During rehandling, new flow paths are created within the waste during excavation resulting in leaching of previously unflushed waste by meteoric water. The flushed load reflects weathering products that have accumulated since the waste was originally deposited. Therefore, short-term increases in chemical loadings are expected, because the load from accumulated weathering products is added to ongoing load generation by and other weathering processes. These flushing processes are conceptually the same as those for Submerged Waste Rock (Section 2.6).

2.7.2 Calculation of Flushed Load

Flushed load was calculated using data obtained from water extraction tests (shake flask extraction, Price 2009) performed on legacy waste (waste rock, tailings, CCR, hot waste) samples from the Swift Project area at FRO. The load was calculated from the concentration in the extraction test multiplied by the volume of leachate divided by the volume of sample tested to yield load released on a one time basis when re-handled in mg/m^3 of waste moved.

For legacy waste rock, the load released was reduced by a factor 0.2 to account for the difference in particle size used in the extraction test (-2 mm) compared to run of mine waste rock.

2.8 Pitwall Source Term

The method for pitwalls is the same as that for exposed waste rock, except that V_{rock} is calculated from the exposed area of the walls (A_{wall}) and an assumed reactive surface thickness (d):

$$V_{wall} = A_{wall} \cdot d$$

Exposed seam footwalls in pit floors tend to be composed of shales that may be more reactive than waste rock; however, the footwall is not blasted and is therefore not fractured to the same degree as walls in interburden rocks. Using V_{wall} to calculate leaching of the footwall is therefore considered to be conservative.

Subsequent calculations of $C'_{m,j}$ for wall rock runoff followed the same methods as described in Section 3.2.

2.9 Coal Rejects

2.9.1 Conceptual Model

Coal rejects may be coarse coal rejects (CCR) produced at EVO, GHO, and FRO, or coal refuse mixed with fines as produced at CMO and LCO. Coal rejects are typically placed in small dedicated facilities constructed in small lifts, and compacted.

Weathering processes in coal rejects are similar to waste rock; however, monitoring of gas concentrations in the Greenhills Area A CCR dump has shown that oxygen penetration into coal reject dumps may be limited by oxygen-consuming reactions (SRK 2013b). As a result, leaching was assumed to be a function of the footprint area of the coal rejects facilities, rather than their volume, with oxygen penetration occurring to a fixed depth.

In addition, the presence of coal fines in coal rejects indicates that reactive surfaces may serve to control trace element concentrations to low levels, and the presence of oxygen-limited conditions may limit Se leaching by transformation to chemically reduced forms.

If CCR is co-disposed with waste rock, it may oxidize without oxygen limitation, like the associated waste rock.

2.9.2 Calculation of Source Term

CCR Dumps

The source term for CCR consists of fixed concentrations applied to all infiltrating waters, based on the conceptual model and empirical data (SRK 2012a, 2013b). As a result, loadings are a function of assumed infiltration.

CCR Co-Disposed with Waste Rock

The source term for co-disposed waste rock and CCR is calculated from the sum of waste rock rates and CCR weathering rates under fully atmospheric conditions. No site drainage data are available from which to calculate release rates for co-disposed CCR under site conditions. Co-disposed CCR release rates are therefore based on laboratory rates indicated by humidity cells (for example, SRK 2013b and unpublished data).

Laboratory rates were decreased by a factor to account for the lower temperatures onsite, and decreased by a conventional generic factor of 50% to allow for incomplete contact with infiltrating water. This is near the high end of the range reported by Kempton (2012).

3 Input Data

3.1 Derivation of R_j and Related Factors for Waste Rock Using Analog Datasets

Seasonal distribution of loadings, R_j, (j=selenium, sulphate and nitrate) and relationships between annual load release and flow were developed by interpretation of monitoring datasets provided by Teck.

3.1.1 Database Description

Three datasets were needed to calculate inputs into the source-term method for waste rock:

- Near-source water quality data for monitoring points downstream of waste rock dumps.
- Accompanying flow data for the same locations.
- Waste rock quantities upstream of the monitoring point.

Teck provided the data for each component. The need for all three components was assessed and used as the basis to determine which sites could be used for the calculation. Figure 4 shows the availability of data by operation and monitoring location.

Fording River Operation (FRO)

Teck provided waste rock quantities for ten monitoring points at FRO. Based on review of the available water quality and flow data, two of the site locations (Kilmarnock Creek [KC] and Henretta Creek [HC]) had the required coincident waste rock volumes, water chemistry and flow data.

Kilmarnock Creek drains mainly the Brownie and Kilmarnock spoils, as well as a large undisturbed catchment to the south of the current FRO mining area. The catchment contains over 1 billion m^3 of spoil placed since 1980. The weighted average age of the spoil was 11 years calculated from:

$$\text{Weighted Age(years)} = 2011 - \frac{\sum_{t=2011}^{t=start} V_t \cdot t}{\sum_{t=2011}^{t=start} V_t}$$

where V_t is the volume of rock placed in year t. Year 2011 was the latest year for which waste rock quantities were available.

Henretta Creek mainly drains spoil from Henretta Ridge. Mining on the ridge began in 1992 and is continuing. The weighted average age of the spoil was 10 years in 2011. The quantity of spoils to the end of 2011 was approximately 150 million m^3.

Greenhills Operation (GHO)

Teck provided waste rock quantities for seven drainage basins on Greenhills Ridge (Swift, Cataract, Porter, Greenhills, Thompson, Wolfram and Leask). Chemistry and flow data were available for three monitoring locations (Cataract, Swift, Porter). All three creeks drain catchments are dominated by waste rock, with relatively low proportions of undisturbed areas.

Cataract Creek (CC) drains approximately 400 million bank cubic metre (BCM) of waste rock placed since 1984. The average age of the spoil was 13 years.

Swift Creek drains approximately 213 million BCM of waste rock placed between 1993 and 2006. The average age of the spoil was 14 years.

Porter Creek (PC) drains approximately 79 million BCM of waste rock placed since 1986. The average age of the spoil was 16 years.

Line Creek Operations (LCO)

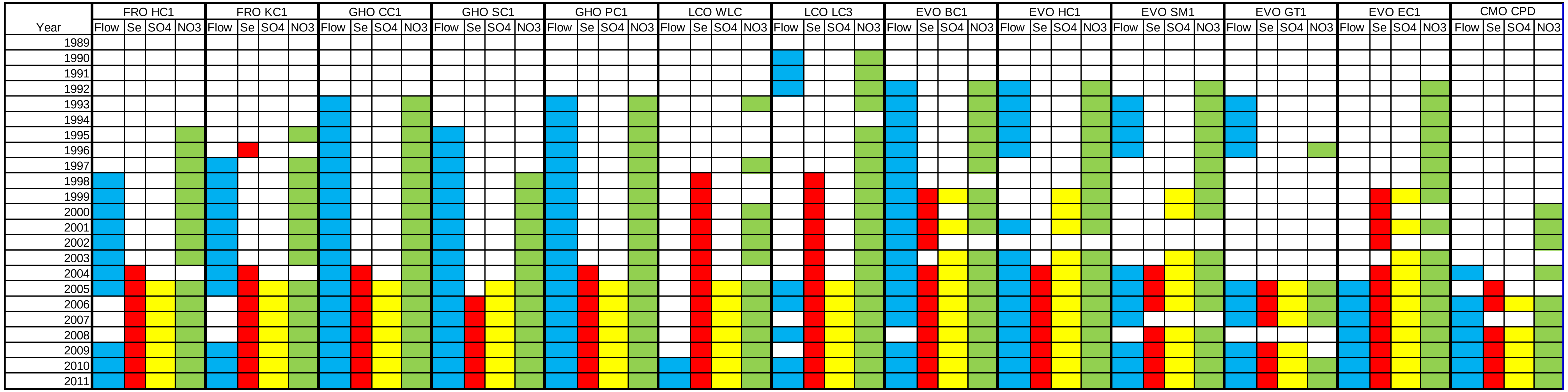
LCO tracks waste rock placement at 13 locations. Drainage monitoring occurs in West Line Creek and Line Creek. Two suitable monitoring locations were West Line Creek (WLC), which drains the WLC spoil, and Line Creek (LC) downstream of LCO (LC3).

Flow data for WLC were available for 2010 and 2011. Due to the more extensive database available, LC3 was also included, though it represents the entire drainage from the site including WLC.

Elkview Operations (EVO)

EVO tracks waste placement in seven surface water catchments (Bodie Creek, Dry Creek, Erickson Creek, Goddard Creek, Harmer Creek, Michel Creek and Six Mile Creek). Except for Goddard and Michel creeks, water quality monitoring data from all locations could be used for this evaluation. Michel Creek was unsuitable because it is in a large catchment that has other influences including CMO.

Of the available sites at EVO, suitable datasets were available for Bodie (BC1), Harmer (HC1), Erickson (EC1) and Six Mile Creeks (SM1). Gate Creek (GT1) also had a suitable monitoring database but no assigned waste rock quantity. Bodie Creek’s catchment was dominated by spoil. Harmer, Erickson and Six Mile Creeks had spoils in their headwaters but also significant proportions of their catchments undisturbed by mining activities.



	FRO HC1				FRO KC1				GHO CC1				GHO SC1				GHO PC1				LCO WLC				LCO LC3				EVO BC1				EVO HC1				EVO SM1				EVO GT1				EVO EC1				CMO CPD			
Year	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3	Flow	Se	SO4	NO3
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1994									🟦			🟩					🟦			🟩									🟦			🟩	🟦			🟩	🟦			🟩	🟦							🟩				
1995				🟩				🟩	🟦			🟩	🟦				🟦			🟩								🟩	🟦			🟩	🟦			🟩	🟦			🟩	🟦							🟩				
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1999	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩		🟥				🟥		🟩	🟦	🟥	🟨	🟩			🟨	🟩			🟨	🟩						🟥	🟨	🟩				
2000	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩		🟥		🟩		🟥		🟩	🟦	🟥		🟩			🟨	🟩			🟨	🟩						🟥						🟩
2001	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩		🟥		🟩		🟥		🟩	🟦	🟥	🟨	🟩	🟦		🟨	🟩										🟥	🟨	🟩				🟩
2002	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩		🟥		🟩		🟥		🟩	🟦	🟥																🟥						🟩
2003	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩	🟦			🟩		🟥		🟩		🟥		🟩	🟦		🟨	🟩	🟦		🟨	🟩			🟨	🟩							🟨	🟩				
2004	🟦	🟥			🟦	🟥			🟦	🟥		🟩	🟦			🟩	🟦	🟥		🟩		🟥				🟥		🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩						🟥	🟨	🟩	🟦			🟩
2005	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦		🟨	🟩	🟦	🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩		🟥		
2006		🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩
2007		🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩		🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦				🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦			🟩
2008		🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩		🟥	🟨	🟩					🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩
2009	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩		🟥	🟨	🟩		🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨		🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩
2010	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩
2011	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩	🟦	🟥	🟨	🟩

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Figure 4. Summary of Monitoring Data Used

Note: Coloured bars indicate years for which at least six monitoring points are available.

Bodie Creek contained a total spoil volume of approximately 243 million BCM placed since 1993, with an average age of eight years in 2010, the latest year for which spoil volumes were available. Bodie Creek is highly influenced by pit dewatering.

The flow and water quality monitoring point in Harmer Creek (HC1) reflected loadings contributed from spoils assigned to Harmer Creek and Dry Creek. The total spoil volume was approximately 557 million BCM with an average age of 23 years. Spoil had been placed there since 1969, with a brief hiatus between 1999 and 2003.

Erickson Creek (EC1) contains a spoil volume of approximately 399 million BCM placed continuously since 1969, with an average age of 18 years.

Six Mile Creek contains approximately 7 million BCM of spoil, all placed in 1980.

Coal Mountain Operations (CMO)

CMO tracks spoil placement at five locations, two of which report to the Corbin Creek Pond monitoring location which has suitable monitoring data from 2004. Total volume of spoil placed since 1985 in 2009 was 157 million BCM, with an average age of nine years in 2011.

3.1.2 Data Processing

Steps used to calculate selenium, sulphate and nitrate loading rates from the monitoring data are described below. The same procedure was used for each site.

Step A – Calculate Daily Loads

Monitoring data were available on up to a daily basis for flows, and much less frequently for water chemistry. In concept, this information permitted simulation of a continuous record of daily loadings.

Missing concentration and flow values for individual days were extrapolated by using the last date for which daily flow and chemistry data were recorded. For example, if flow data were collected on May 10 and May 13, flows for May 11 and 12 were based on the May 10 measurement. The same approach was used for concentrations. The combined flow (Q) and concentration data (C_j) for parameter j on each dataset were used to calculate loadings ($L_{j,day}$) for parameter j using the conventional formula:

$$L_{j,day}\ (\text{mg/day}) = Q\ (\text{m}^3/\text{day}) \cdot 1000\ (\text{L/m}^3) \cdot C_j\ (\text{mg/L})$$

Step B – Calculate Annual Loads

Annual loads ($L_{j,year}$, in mg/year) were then calculated by summing the daily loads for each parameter.

$$L_{i,year} = \sum_{day=December\ 31,\ Year}^{day=January\ 1,\ Year} L_{i,day}$$

Only years for which there were at least six monitoring rounds for flow and chemistry were included. This target was based mainly on having data for at least six months representing the six months of open water (May to October) to ensure that highest chemical loadings during the snowmelt period were included in the assessment.

Step C – Calculate Annual Load Leached on Rock Mass Basis

The load leached per volume of rock ($L'_{i,year}$, in mg/year/m^3) was calculated based on the cumulative volume of rock in a year indicated by the waste rock placement history:

$$L'_{year} = \frac{L_{i,year}}{\sum_{t=year}^{t=start} V_t}$$

Step D – Calculate Average Annual Loads

Loading rates obtained in Step B for each site were used to calculate average annual loads.

Step E – Calculation of Monthly Loading Distribution

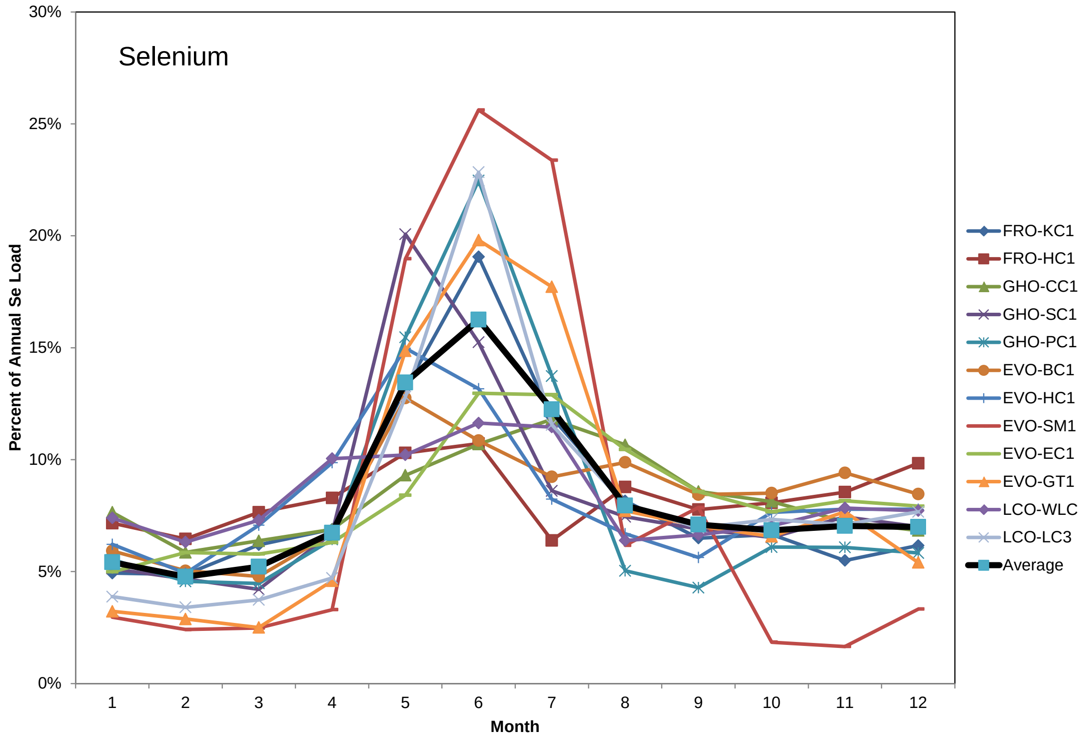
Loadings on monthly time-step was calculated for years in which data were available, by summing daily loads in each month. The proportion of load in each month is therefore the load released in the month divided by the annual load. These distributions were developed using data from existing spoils that are either active or have been reclaimed using conventional revegetation techniques. Different distributions can be expected when spoils have been covered with materials intended to significantly modify infiltration.

3.1.3 Results

Description of Trends

Monthly distributions of the fraction of flow, and selenium, sulphate and nitrate loadings are shown in Figure 5. All sites experienced peak flows typically between late March and May. Erickson Creek appeared to have a late flow peak in June and August, but flow information was limited and Erickson Creek is sub-surface in some sections.

The relationship between flow peak and loadings showed some consistency. Greatest loadings were commonly apparent during the flow peak. The strong similarity of loading and flow trends imply that seasonal flushing of soluble components occurs in response to increased infiltration during the melting of snow.



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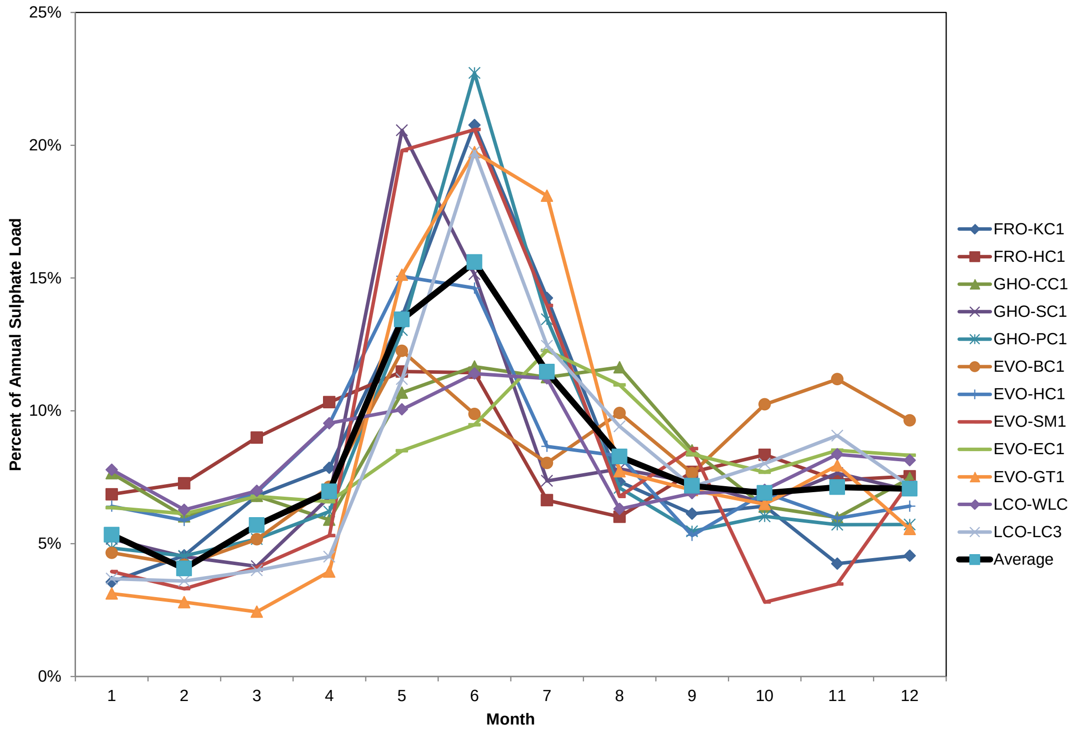

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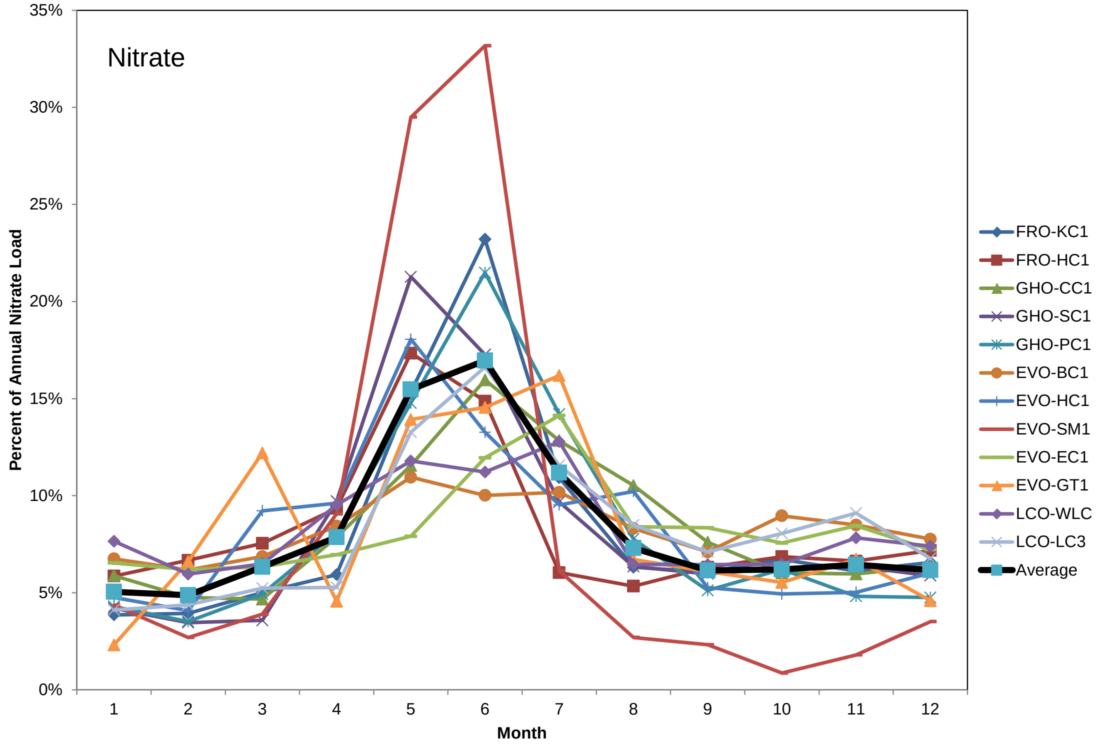

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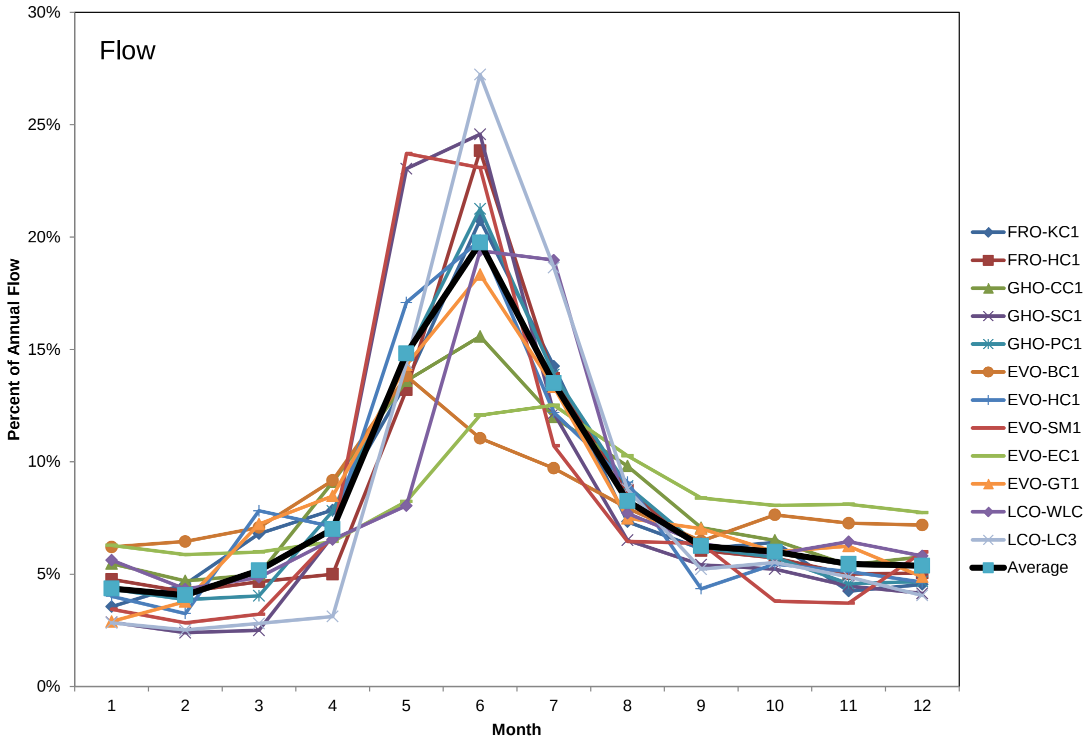

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Figure 5. Monthly Distribution of Load and Flows

Trends in Annual Loadings

Trends in annual loadings were evaluated when data were available as total loadings (L in mg/year or g/year), and normalized with respect to cumulative waste rock volume.

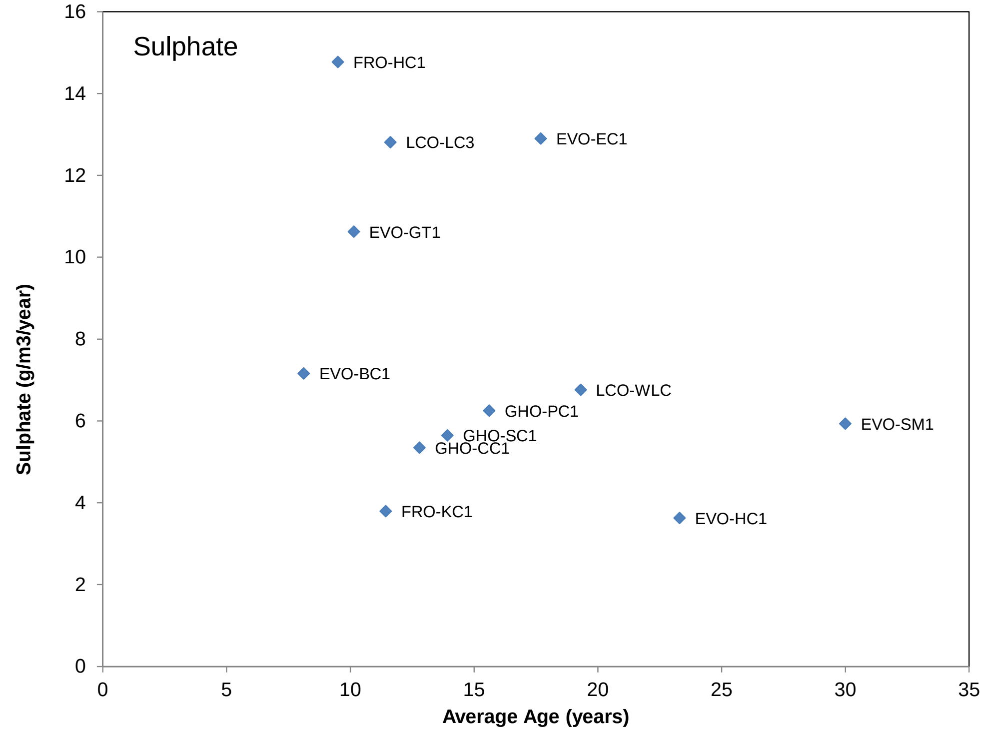
There was a lack of consistent trends for both expressions of load for sulphate and selenium, and a lack of sufficient data points to evaluate trends. Nitrate total load either showed no trend, or else increasing trends that discontinued or decreased when normalized to waste rock volume.

Monitoring data showed a relationship between average age ($\bar{t}$ in years) of waste rock and leaching nitrate (Figure 6). Equations of the general form could be fitted to the trend:

$$L_{i,NO_3} = 10^{-a_k \log \bar{t} + a_1}$$

No evidence of a similar relationship was apparent for selenium or sulphate (Figure 6).

Correlation coefficients for selenium and sulphate were not significantly different from zero at a significance level of 0.05; and therefore do not allow change in release rates as a function of spoil age to be incorporated into the method. Coefficients for the nitrate equations are provided in Table 3.



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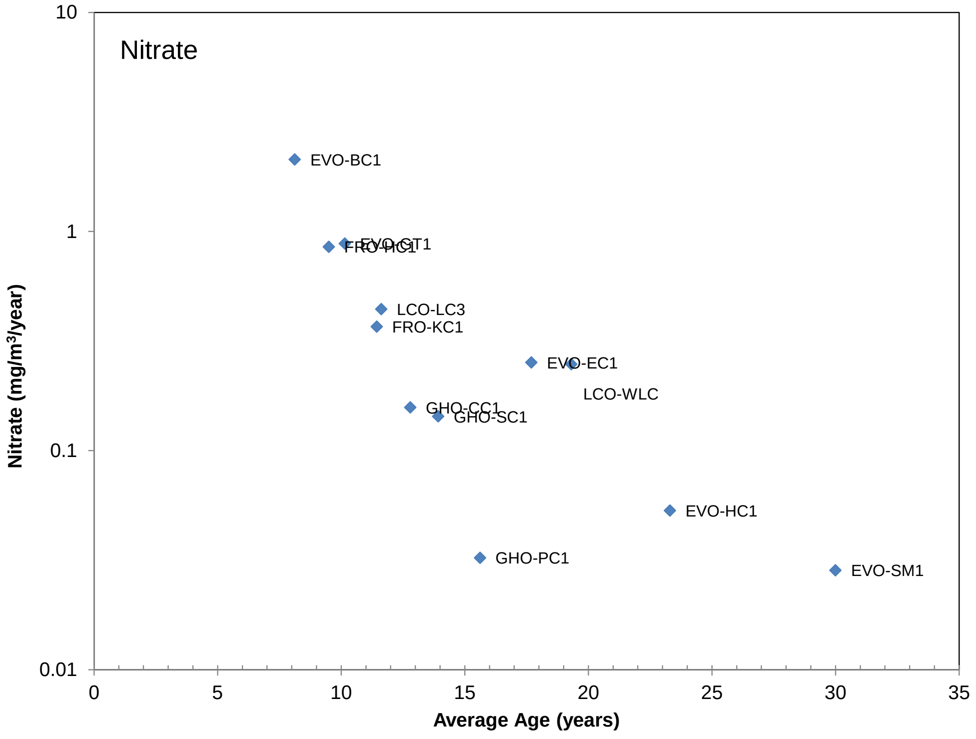

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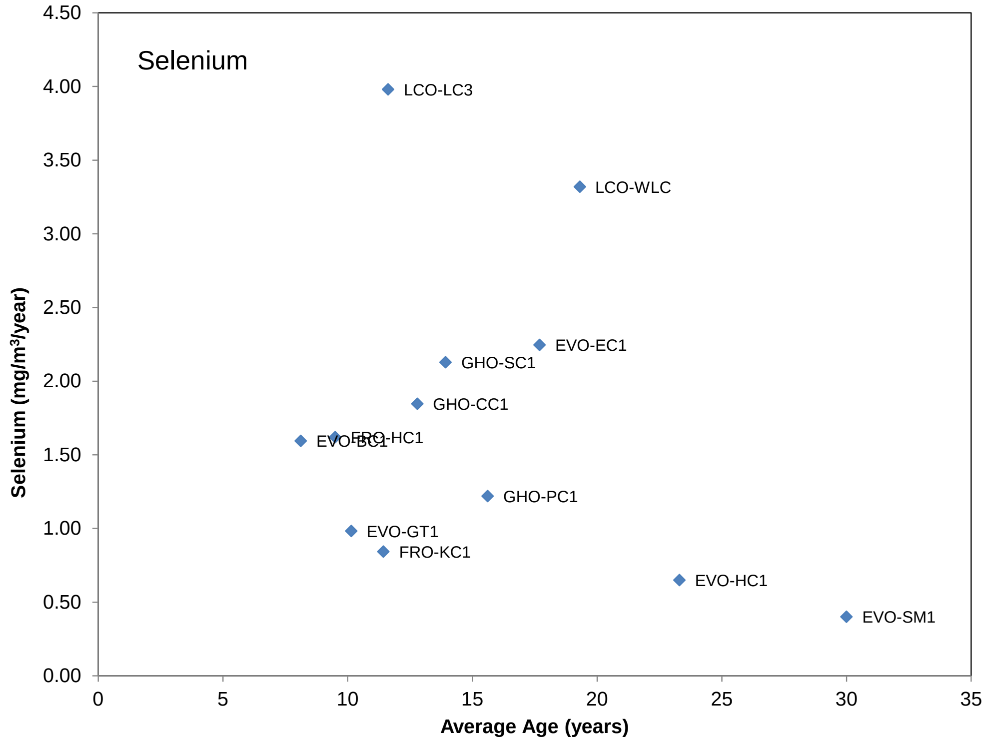

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Figure 6. Relationship Between Age of Spoil and Average Release Rates

Average Normalized Load for Selenium and Sulphate

Average waste volume normalized loads for each site were calculated using individual annual average measurements. An indication of the spread of data was obtained by calculating the 95% confidence limits on the mean (Figure 7). The range of normalized loads for each parameter is narrow and nearly within an order of magnitude in each case.

Average selenium and sulphate release rates and ranges are provided in Table 3 for operations other than CMO, which are provided in Table 4. Nitrate release rates are the same for all sites.

Table 3. Generation Rates (R_j) – Operations Other Than CMO

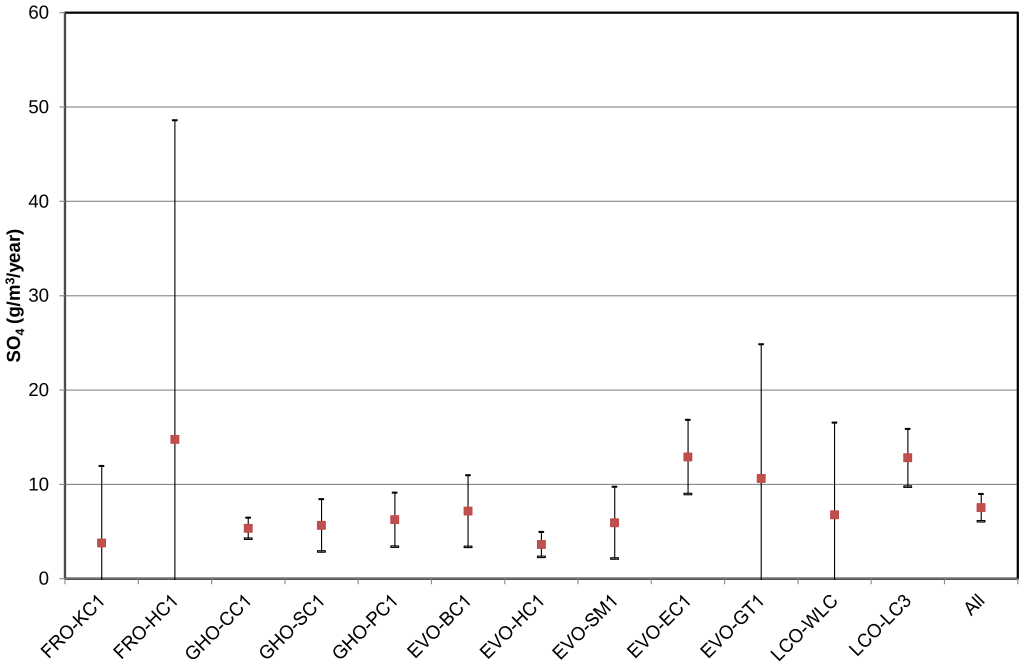
Case	**Based on Monitoring Data to 2011**		
	SO_4	**Se**	**NO_3**
	n=69	**n=77**	**n=128**
	g/m^3/year	**mg/m^3/year**	**g N/m^3/year**
Arithmetic Average	7.5	1.6	$10^{-2.9\log\bar{t}+2.7}$
95% Upper Confidence Limit	9	1.9	$10^{-3.0\log\bar{t}+3.0}$

Source: P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CE003.001_Selenium_Geochemistry\Selenium_Release_Model\2012-06_Loading_Empirical_Report_2012_Update\[LoadingCalculations_1CE003001_REV12.xlsx

Table 4. Summary of CMO Generation Rates

Case	**Based on Monitoring Data to 2011**		
	SO_4	**Se**	**NO_3**
	n=5	**n=5**	**n=128**
	g/m^3/year	**mg/m^3/year**	**g N/m^3/year**
Arithmetic Average	17	0.55	$10^{-2.9\log\bar{t}+2.7}$
95% Upper Confidence Limit	27	1.0	$10^{-3.0\log\bar{t}+3.0}$

Source: \\van-svr0\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CE003.001_Selenium_Geochemistry\Selenium_Release_Model\2012-06_Loading_Empirical_Report_2012_Update\[LoadingCalculations_1CE003001_REV12.xlsx



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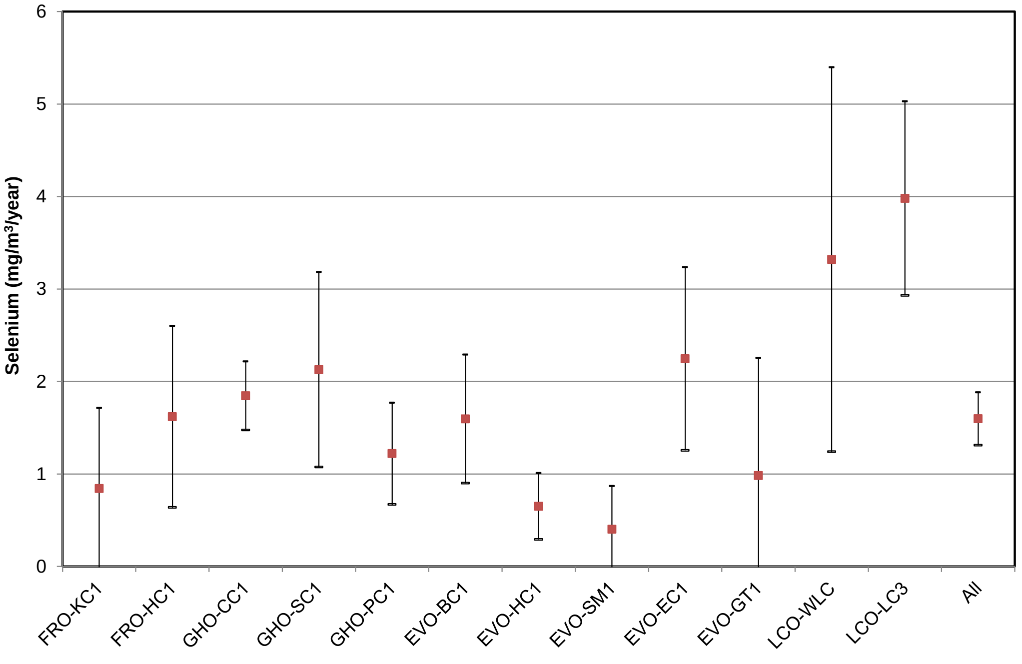

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Figure 7. Average Annual Loads and Confidence Limits for Sulphate and Selenium

Seasonal Variations

Average monthly load distributions obtained from the data shown in Figure 3 are provided in Table 5.

Table 5. Average Monthly Loading Distribution ($p_{m,j}$)

Month	Sulphate	Selenium	Nitrate
January	4%	5%	5%
February	4%	5%	5%
March	5%	5%	6%
April	7%	7%	8%
May	15%	13%	15%
June	20%	16%	17%
July	14%	12%	11%
August	8%	8%	7%
September	6%	7%	6%
October	6%	7%	6%
November	5%	7%	6%
December	5%	7%	6%

Source: \\van-svr0\Projects\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CE003.001_Selenium_Geochemistry\Selenium_Release_Model\2012-06_Loading_Empirical_Report_2012_Update\[LoadingCalculations_1CE003001_REV12.xlsx

Comparison of Sulphate and Selenium Release

The conceptual model indicates sulphate and selenium release ought to be correlated because they are released by the same process (pyrite oxidation). Figure 8 compares average sulphate and selenium release rates. There is weak evidence of a regional correlation between sulphate and selenium; however, some site differences are apparent when considering the ratio of selenium to sulphate

- The ratio of selenium to sulphate is greatest at 0.0011 mgSe/mgS for LCO WLC and two monitoring locations at GHO (SC1 and CC1). GHO_PC1 (Porter Creek) has a lower ratio, though the drainage from that location may be influenced by saturated fills in historical pits, which causes the ratio to decrease due to Se attenuation (SRK 2013a). LCO_LC3 also shows a high ratio, but this monitoring location is influenced by LCO_WLC.
- At 0.0001 mgSe/mgS, the ratio at CMO is an order of magnitude lower than LCO and GHO.
- EVO and FRO sites show an intermediate ratio near 0.0004 mgSe/mgS. This is four times the CMO ratio and about one third the ratio for LCO and GHO. EVO-SM1 showed the lowest ratio in this group, which was also the oldest average spoil in the Elk Valley.

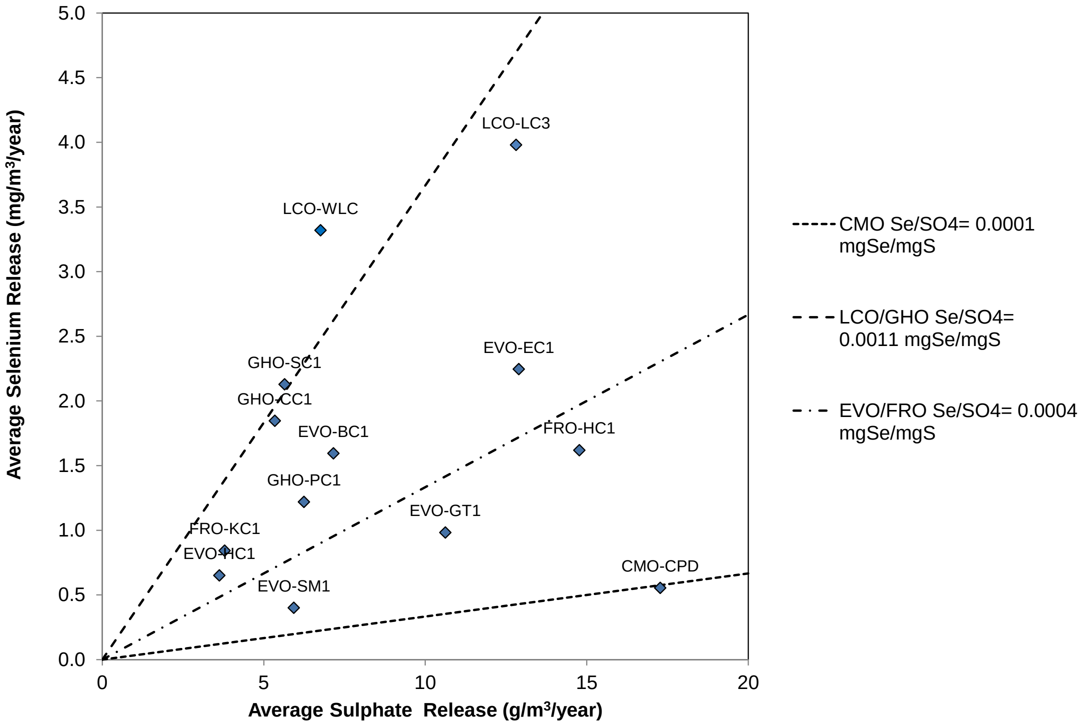

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Figure 8. Comparison of Average Sulphate and Selenium Release Rates for Arithmetic Averages

The relationships between release of nitrate, and release of sulphate, and release of nitrate and release of selenium were investigated, but none were apparent, which is consistent with the conceptual model.

Relationship between Flow and Selenium Loading

Figure 9 shows annual flow and selenium loading as ratios to the averages for each monitoring location. A strong positive correlation indicates that as flow increases, annual selenium load also increases. The regression relationship is statistically the same as the equivalence line along which average normalized flow is equal to average normalized load. As a result, there does not appear to be a tendency for higher loads to be disproportionately associated with higher flows, though there is a tendency for scatter in the data points shown in Figure 9 to increase at higher loads and flows.

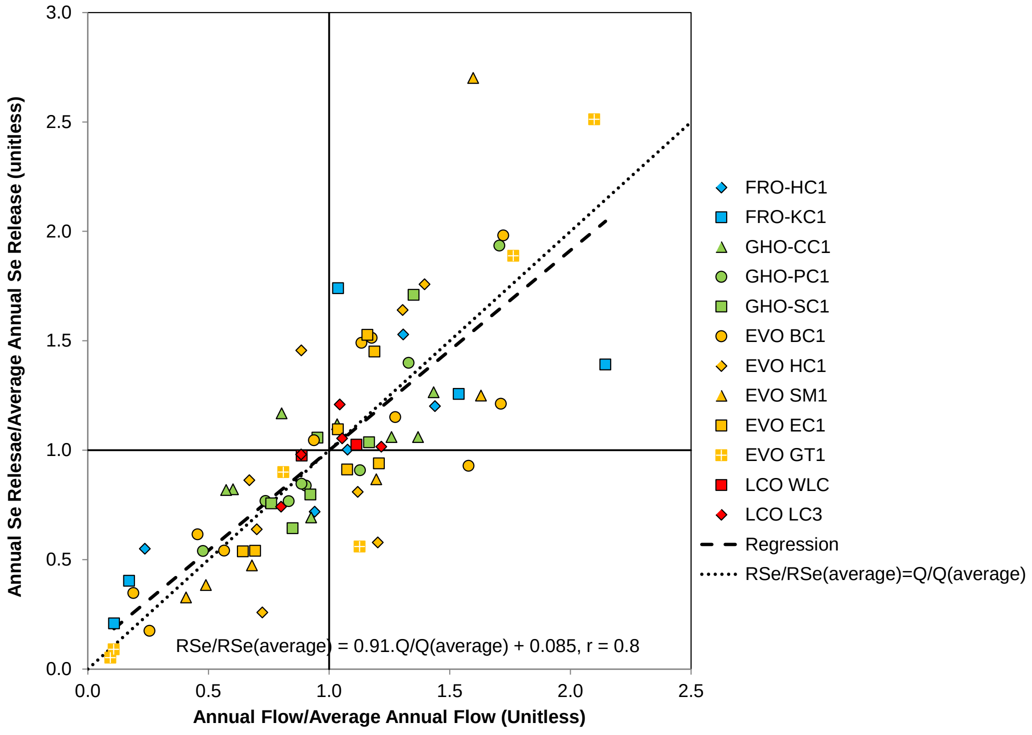

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Figure 9. Relationship between Normalized Annual Flow and Normalized Annual Selenium Loading

3.1.4 Element Solubility Constraints

Calcium to Magnesium Molar Ratio ($M_{Mg/Ca}$)

The value of 1.1 for $M_{Mg/Ca}$ was calculated based on the slope of the relationship observed between Ca and Mg in drainage data throughout the Elk Valley available in 2010 (Figure 10).

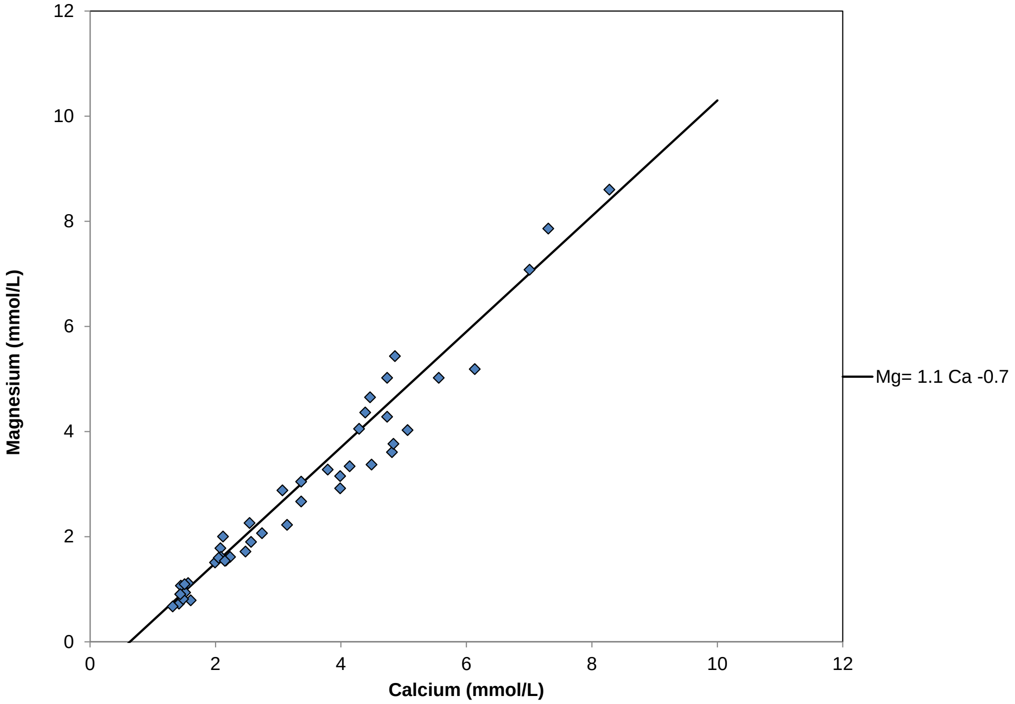

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Figure 10. Relationship of Ca and Mg in Elk Valley Spoil Drainage Used to Estimate $M_{Mg/Ca}$

Sulphate

Solubility limits for individual dissolved ions are often a result of the finite solubility of minerals containing the ions. Gypsum ($CaSO_4.2H_2O$) is a mineral commonly considered to exert strong control on sulphate solubility because it is observed as a product of rock weathering and can form at typical mine drainage sulphate concentrations. Other sulphate minerals that form from common major ions, including magnesium, potassium and sodium, are much more soluble.

The relationship defining the solubility of gypsum and the resulting concentration in the solution is the solubility product[1]:

$$k_{sp,gypsum} = [Ca^{2+}].[SO_4^{2-}]$$

$[Ca^{2+}]$ and $[SO_4^{2-}]$ are the concentrations of calcium and sulphate in water, and k_{sp} is the equilibrium constant for the dissolution of gypsum in water, which is defined by the thermodynamics of the reaction:

$$CaSO_4.2H_2O \Leftrightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$$

---

[1] Concentration is strictly expressed as activity, which is the concentration adjusted by the activity coefficient (γ). For simplicity in this report, γ=1 for all ions.

The solubility product indicates the range of calcium and sulphate concentrations in solution that are consistent with the presence of the mineral gypsum. If gypsum dissolves in pure water, the resulting calcium and sulphate concentrations will be exactly equal when expressed in moles. However, if sulphate and/or calcium originate from other sources, sulphate concentrations for water in equilibrium with gypsum are defined by:

$$[SO_4^{2-}] = \frac{k_{sp,\,gypsum}}{[Ca^{2+}]}$$

The solution must remain in charge balance, so that as sulphate increases relative to calcium, other positive ions must be present. For example, if magnesium is in solution, the charge balance is:

$$[SO_4^{2-}] = [Ca^{2+}] + [Mg^{2+}]$$

If gypsum is present but a magnesium sulphate (e.g., epsomite [$MgSO_4.7H_2O$]) is not, the gypsum solubility product and charge balance equations can be solved to calculate the concentration of sulphate as a function of magnesium concentration and $k_{sp,gypsum}$:

$$[SO_4^{2-}] = \frac{[Mg^{2+}] + \sqrt{[Mg^{2+}]^2 + 4k_{sp,\,gypsum}}}{2}$$

The equation indicates that the concentration of sulphate in equilibrium with gypsum increases as the magnesium concentration increases.

Calculation of Sulphate Solubility for the Elk Valley

For the purpose of calculating sulphate solubility in the current source-term method, the following assumptions were made:

- Gypsum is a logical controlling secondary mineral due to the presence of abundant calcium-containing carbonate in the Mist Mountain Formation.
- The presence of dolomite ($CaMg(CO_3)_2$) in the host rocks is important because it contributes calcium and magnesium in equal molar proportions and therefore can be expected to elevate the gypsum solubility limit above that expected for calcium only.
- Data collected as part of the Applied R&D Program shows that waste rock pore waters may be at equilibrium with gypsum. Therefore, the Mg/Ca ratio in drainage waters can be used to calculate the sulphate concentration in equilibrium with gypsum.

Sulphate concentrations for waters in equilibrium with gypsum as a function of the Mg/Ca ratio were calculated using the public-domain equilibrium thermodynamic modelling software PHREEQC. Main inputs were thermodynamic data that describe the solubility of minerals and the speciation of ions in solution.

Since the thermodynamic databases are experimentally-derived and can be variable, the two publicly-available databases of Allison et al. (1991, MINTEQA2, United States Environmental Protection Agency) and Parkhurst and Appelo (1999, PHREEQC, United States Geological Survey) were used as inputs. In addition, since algorithms used to perform the calculations can be different, Geochemist's Workbench (GWB) software (Bethke 2009) was used as a check of the calculation method using the PHREEQC database.

Figure 11 shows sulphate concentrations in equilibrium with gypsum as a function of Mg/Ca at a temperature of 5°C. The individual plots indicate model predictions that are highly correlated with Mg/Ca. The two databases yielded nearly the same relationships, and use of the GWB software did not affect the solubility relationship calculated using PHREEQC. The MINTEQA2 database yielded slightly higher concentrations.

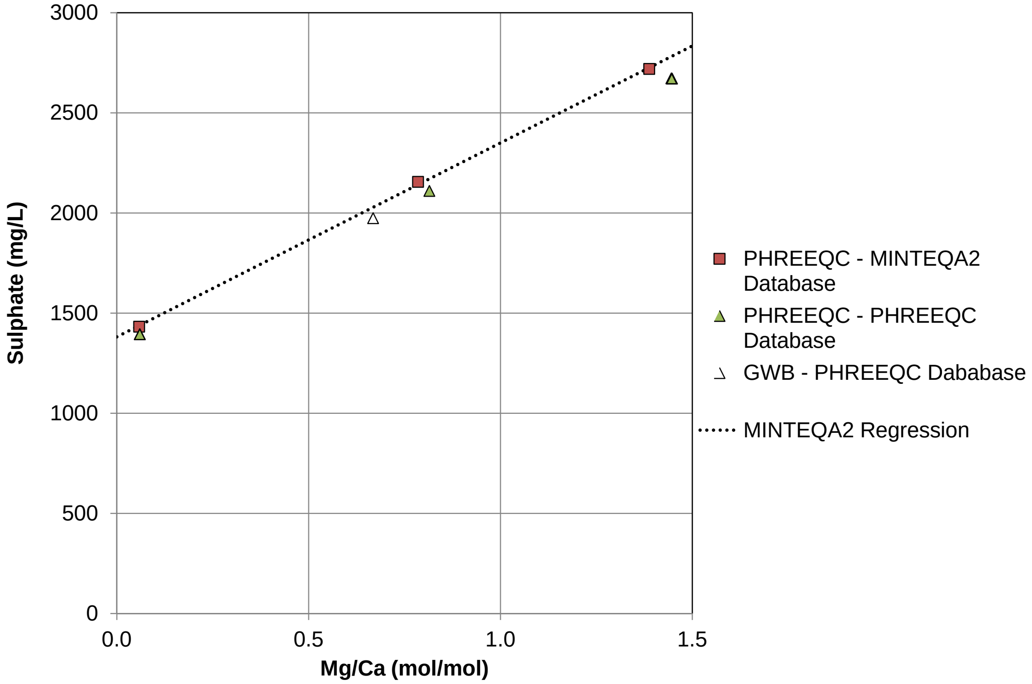

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Figure 11. Modelled Sulphate Concentrations as a Function of Mg/Ca Ratio Using Two Databases and Two Geochemical Modelling Programs

Figure 10 shows the strong correlation between calcium and magnesium for drainage waters from spoils in the Elk Valley. The slope of the regression line is Mg/Ca=1.1, which can be used to calculate a gypsum-constrained sulphate concentration of 2400 mg/L. For comparison, sulphate concentration in equilibrium with pure gypsum in the absence of magnesium (i.e., Mg/Ca = 0) is calculated to be 1400 mg/L.

The observed Mg/Ca ratio (i.e., the slope of the regression equation) is greater than the most Mg-enriched mineral (dolomite, $CaMg(CO_3)_2$) in the rock, implying that leaching processes are leading to preferential enrichment of Mg in drainage waters relative to Ca. The following linked processes may explain the ratio above 1.

Reaction of acidity generated by sulphide oxidation with dolomite yields water with molar equivalent Ca and Mg concentrations:

$$2H^+ + CaMg(CO_3)_2 \rightarrow Ca^{2+} + Mg^{2+} + 2HCO_3^-$$

As Ca^{2+} and HCO_3^- concentrations increase, calcite saturation will be reached, causing Ca^{2+} to be removed from solution as calcite ($CaCO_3$):

$$Ca^{2+} + Mg^{2+} + HCO_3^- \rightarrow CaCO_3 + Mg^{2+} + H^+$$

However, dolomite or magnesite ($MgCO_3$) are not expected to precipitate in the same way, due to their slow kinetics of formation at atmospheric temperatures. A number of factors preclude unlimited enrichment of magnesium in waters, including:

- The presence of primary calcite ($CaCO_3$) and ankerite ($CaFe(CO_3)_2$) in the rock, which adds Ca^{2+} to water without adding Mg^{2+}
- The role of H^+ (i.e., pH), which causes an equilibrium to be reached
- The decreasing tendency for calcite to form and remove Ca as the Mg/Ca ratio in the water increases
- Co-precipitation of Mg in calcite.

Together, this appears to provide the explanation for the regional consistency of Mg/Ca in Elk Valley drainage waters shown in Figure 10. As a result, sulphate concentrations can be constrained using the relationship shown in Figure 11.

Discussion of Evidence for Sulphate Solubility Limits

Drainage Chemistry in the Elk Valley

Recent data for concentrations of sulphate in mine drainages in the Elk Valley show that the highest concentrations measured approach 1800 mg/L in the drainages from GHO. As of 2012 at Swift Creek and Cataract Creek, the sulphate concentration trend currently appears to be upward, though a significant decrease in the rate of increase occurred in 2010 and has continued. The well-studied West Line Creek Dump at LCO has yielded a maximum sulphate concentration of 1300 mg/L on a stable trend. The maximum sulphate concentration in drainage from GHO's Area A CCR dump is 1900 mg/L.

These monitoring locations are all affected to some degree by dilution with non-contact waters and the mixing of different types of contact waters. An estimate of the dilution fraction can be obtained from the disturbed vs. non-disturbed areas for monitoring location catchments, though it is more complicated in reality. At West Line Creek, about one-third of the catchment area has spoil, which would lead to actual maximum concentrations of 3,900 mg/L from the spoil. However, maximum concentrations are measured in late winter when the contribution from the spoil is probably much greater than from one-third of the catchment area. As a result, maximum pore water concentrations will be less than 3900 mg/L as shown below.

Chemistry of Pore Waters in West Line Creek Dump

Pore water chemistry is being determined as part of the Applied R&D Program work on selenium by squeezing waste rock samples. At West Line Creek, maximum pore water concentrations of about 2000 mg/L have been measured after excluding one anomalous value above this concentration. These pore water concentrations exceed concentrations in the overall West Line Creek drainage, suggesting that West Line Creek is influenced by non-contact dilution and that a solubility control at or exceeding 2,000 mg/L may be supported.

Mineralogical Evidence for Sulphate Minerals in the Elk Valley

SRK (2004) documented the presence of gypsum in weathered pitwalls at EVO though it is not known if this is primary or secondary gypsum.

Mineralogical work by the University of Saskatchewan on the West Line Creek Dump samples has not detected the presence of gypsum, though barium sulphate ($BaSO_4$, barite) has been identified microscopically. SRK (2004) also identified barite at EVO.

Barite is currently being evaluated by the University of Saskatchewan for its role in sulphate solubility control and in sequestering selenium. SRK considers that it is unlikely that barite will be a significant sulphate control because the availability of barium is limited. While barite has a much lower solubility than gypsum, barium is released by weathering of slow-reacting minerals such as feldspars, so that the presence of calcium and magnesium from carbonate mineral dissolution will drive sulphate solubility.

Selenium

A solubility limit for selenium was based on the assumption selenium can co-precipitate with gypsum (Fernández-González et al. 2006). A $C_{s,Se}$ solubility limit concentration of 1.5 mg/L selenium was estimated using the sulphate concentration of 2400 mg/L and a typical Se/SO_4 ratio. The range of Se/SO_4 ratios observed in the valley indicates that this concentration would vary by site.

There is ongoing work evaluating selenium solubility controls, including contact-water selenium concentrations and selenium co-precipitation with sulphate minerals such as gypsum and barite (reference).

No solubility controls were used for nitrate, due to its high solubility relative to concentrations in the Elk Valley.

From monitoring data, the speciation of nitrogen forms (f_{NO_2} , f_{NH_3}) as a function of nitrate was estimated as:

$$C_{NO_2} \text{ (mg N/L)} = 0.0063 \cdot C_{NO_3}$$
$$C_{NH_3} \text{ (mg N/L)} = 0.012 \cdot C_{NO_3}$$

Fixed solubilities of other elements used to calculate overall water chemistry are shown in Table 6. These statistics were calculated based on a consolidated database of water chemistry for operations in the Elk Valley, including field weathering leach-pile experiments at LCO (SRK 2013b).

The resulting chemistry shown in Table 6 is approximately in equilibrium with calcite, giving a partial carbon dioxide pressure of 10%.

The waste rock contact factor ($p_{uncontacted}$) for use in the Submerged Waste Rock Source Term (Section 2.6.1) was assigned a value of 0.5, i.e., 50% of rock is not flushed by meteoric water.

Table 6. Waste Rock Source-Term Element Concentrations

Parameter Type	Element	Units	Based on Monitoring Data to June 2010	
			P_{50}	P_{95}
Concentrations used to adjust $C_{i,j}$	SO_4	mg/L	2400	2400
	Se	mg/L	1.5	1.5
Parameters added to source term at fixed concentration	pH	s.u.	8.2	8.4
	Alkalinity	mgCaCO$_3$/L	330	373
	F	mg/L	0.66	1.2
	Cd	mg/L	0.0011	0.0029
	K	mg/L	2.6	6.5
	Na	mg/L	8.4	15

Source: P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CE003.001_Selenium_Geochemistry\Selenium_Release_Model\2012-06_Loading_Empirical_Report\Other_Element_Scaling\[1CE003.001_Compiled_Results_SJD_ld_20110221_VER02.xlsx]

3.2 Re-Handled Wastes

Load released by re-handling of wastes are provided in Table 7. The 50th and 95th percentiles of shake flask leachate concentrations were used to represent the range in loads for each type of legacy waste. For any parameters not shown in Table 7, load released was determined from the volume of contact water and fixed concentrations shown in Table 6 (legacy waste rock and hot waste) and Table 8 (legacy CCR and tailings).

3.3 Pitwall

The thickness depth (d) was set at 2 m, which is a typical overblast depth for mining in the Elk Valley.

Table 7. Load Released by Re-Handlng of Legacy Wastes (mg/m^3)

Parameter	Historic Tailings		Historic CCR		Historic Waste Rock		Historic Hot waste	
	P50	P95	P50	P95	P50	P95	P50	P95
Ca	85000	130000	33000	65000	16000	23000	220000	1200000
Cd	0.12	0.25	0.4	1.2	0.043	0.11	0.26	5.2
Cl	2000	4400	3400	6000	510	780	5100	7300
F	1700	2300	820	1900	350	550	3100	3500
Mg	34000	83000	11000	26000	6300	8500	100000	400000
Na	1500	4100	840	1200	480	1100	1400	58000
Nitrate (N)	230	600	4500	13000	1500	2700	1000	13000
Se	77	89	22	34	15	31	30	70
SO_4	180000	510000	56000	96000	26000	52000	710000	4400000

Source: P:\01_SITES\Fording_River\1CT017.007_MLARD\400_Water Quality Predictions\412_Predict Loadings\Hisotric_Waste_Flushing_Terms\[Historic_Waste_Flushing_Terms_1CT017.007_rev05_ld_AML.xlsx

3.4 Coal Reject Concentrations

Table 8 provides maximum observed concentrations in seepage from Greenhills Area A CCR Dump. The statistics were calculated based on three samples collected in 2009. These concentrations were used as a fixed concentration source term for coal reject.

Table 8. Coal Reject Fixed Concentrations

Parameter	Units	Value
Alkalinity	mg $CaCO_3$/L	490
Ca	mg/L	340
Cd	mg/L	<0.0003
F	mg/L	0.19
K	mg/L	5.2
Mg	mg/L	190
Na	mg/L	9.8
NH_3	mg N/L	0.14
NO_2	mg N/L	<0.02
NO_3	mg N/L	<0.1
pH	s.u.	7.4
Se	mg/L	0.0087
SO_4	mg/L	1300

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3.5 Co-Disposed CCR and Waste Rock

Table 9 provides release rates for CCR based on humidity cell tests performed on CCR from LCO. CCR release rates are an order of magnitude higher than waste rock, with the finer particle size distribution of CCR likely an important difference. These rates were decreased by a factor of 0.3 to reflect lower site temperatures.

Due to the very small dataset, care must be taken in applying these rates to CCR deposits. If there is a need to evaluate the effect of codisposal on loadings, additional testing should be performed.

Table 9. Codisposed CCR Release Rates

Material	SO_4	Se
	g/m^3/year	mg/m^3/year
CCR	61	33

Source: P:\02_MULTI_SITES\Elk_Valley_Coal_Corp\1CE003.001_Selenium_Geochemistry\Phase_3_Implementation\Laboratory Program\5.Results\HCTs\Outcomes\[Elk Valley KT Outcomes 1CE003.001 mcc REV00.xls]

4 Discussion

4.1 Relationship between Waste Rock Quantity and Selenium Release

The underlying assumption in the method is that chemical loadings of soluble ions generated by weathering of rock are primarily a function of waste rock volume. This assumes that leaching of these ions is not generally controlled by solubility because that would result in loadings being a function of contact water volume and consequently the approximate facility area rather than volume. The basis for this decision was a result of the following observations:

- The observation that selenium concentrations in the Elk River have increased roughly in parallel with the increase in cumulative spoil volume (Figure 1)
- The presence of sulphate concentrations in drainage from relatively undiluted seeps, and baseflow drainage at concentrations lower than required to precipitate gypsum
- The presence of a predictable linkage between rates of leaching observed at small scale and those at full scale (Kennedy et al. 2012)
- From a geochemical perspective, the narrow range in release rates calculated for spoils with volumes ranging over two orders of magnitude

4.2 Effect of Spoil Aging on Release Rates

There are few sites in the Elk Valley that allow the impact of aging to be effectively evaluated because most spoils continue to be active. In the current assessment, LCO WLC and EVO SM1 monitoring sites represent spoils that have had limited or no recent spoiling activity.

The drainage from WLC has not yet shown a decrease in selenium or sulphate concentrations since major spoiling activities ended in 2000 (Figure 102). Nitrate concentrations are decreasing, which is consistent with explosives residuals being leached. Likewise, SM1 has not shown a decrease in concentrations even though monitoring of selenium and sulphate began 20 years after the dump was constructed (Figure 123). It is expected that any decrease would follow an exponential trend, with a relatively rapid initial decrease followed by a flattening decay trend.

Using the average age parameter, only the nitrate release rate decreased with age (Figure 6), which was also observed at WLC. SM1 showed the lowest average selenium release rate in the dataset. SM1 is also the oldest site, and the age of the site is potentially a factor in the low selenium release rate. For example, long-term breakdown of the spoil and reclamation may be allowing sub-oxic conditions to develop in the spoil.

4.3 Calculation of Nitrate Loadings

The equations shown in Table 3 were initially applied to nitrate loading in water quality models developed for the Elk Valley, with $\bar{t}$ calculated based on waste schedules. Due to the exponential form of the equations, when the average age is near one year, nitrate loadings calculated using this equation were found to result in very high and unrealistic nitrate concentrations in waters. Use of these equations was therefore replaced with the published Environment Canada method described by Ferguson and Leask (1988) for operational conditions. Their method was developed based on interpretation of monitoring data in the Elk Valley and uses the powder factor and types of explosives as inputs. The equations have been applied to decay of nitrate concentrations after waste rock placement ceases.

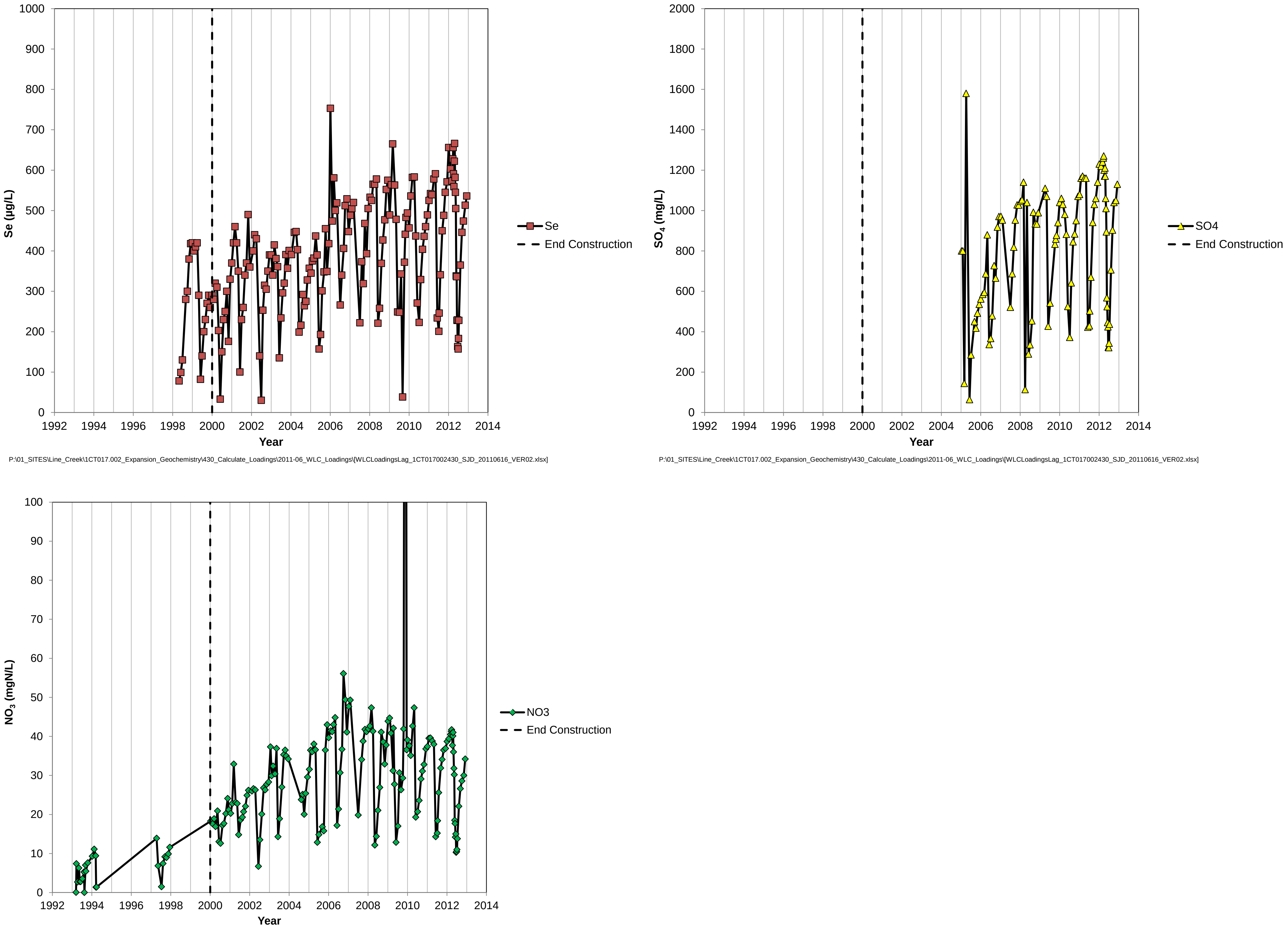

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Figure 12. Drainage Chemistry for WLC

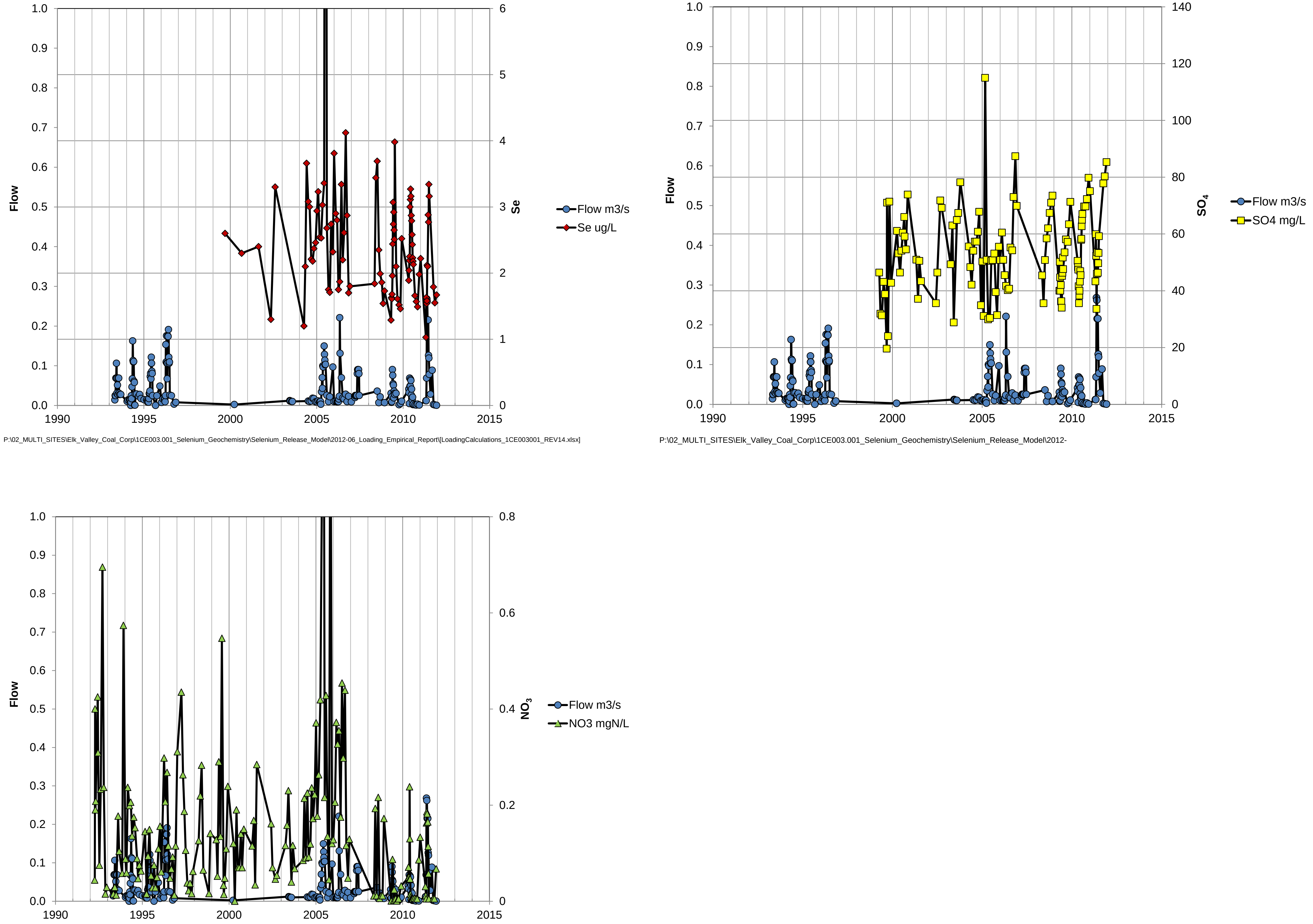

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Figure 13. Drainage Chemistry for SM1.

4.4 Application of Release Rates to the Elk Valley Water Quality Model

As described in Section 2.1, the source-term method was developed to provide a means for predicting average source term water chemistry for future spoils. Application of the average rates in Table 3 and Table 4 and average seasonal distribution of loadings to existing spoils requires the use of calibration factors to match simulated concentrations to historical data. Because the source-term method is based on the range of conditions throughout the valley, calibration factors are inevitably required because rates do vary, albeit over a range that is fairly narrow from a geochemical perspective.

A number of potential explanations for the variability in rates can be hypothesised:

- Measurement accuracy:
  - Completeness of monitoring record
  - Quantification of spoil volumes in catchment areas
  - Delineation of catchment areas
  - Flow measurement methods
- Geochemical factors:
  - Variation in the geochemical characteristics of the host rocks, including variations in absolute concentrations of reactive minerals and ratios of reactive minerals
  - For selenium, effects of processes that can cause attenuation, such as the presence of saturated fills, partially saturated zones in ex-pit spoils, and configuration of spoils affecting oxygen availability, including lift heights, traffic surfaces, and reclamation
  - Depletion of sources of reactive minerals
  - Spoil structure and stability over time (whether spoil failures have occurred)
  - Depletion of explosives residuals
- Hydrologic Factors:
  - Fraction of surface water collected at monitoring locations and loss to groundwater
  - Effect of hydrological variations on leaching

Since the influence of most of these factors cannot currently be quantified, the performance of any future wastes from new mining areas should be evaluated using rates shown in Table 3 and Table 4. As a potential future consideration, the simulation of current spoils receiving ongoing wastes from existing mining areas could be assessed using the rates observed for those spoiling areas, where adequate data are available. The current method of using calibration factors achieves the same objective. The limitation of this approach is that different calibration factors are likely to be needed for sulphate and selenium because there is some variation in ratios as shown in Figure 8.

5 Conclusions

This report summarizes the method used to develop geochemical source terms for sulphate, selenium, nitrate and cadmium from the waste rock spoils, CCR dumps and open pit walls at Teck’s operations in the Elk Valley. The interpretations used to develop the source terms resulted in the following conclusions:

- Release of selenium and sulphate from waste rock spoils can currently be predicted using the cumulative volume of spoil.
- Release of nitrate from waste rock spoils can be predicted using the volume of spoil and the average age of the spoil once waste placement stops. The method does not appear to be appropriate for relatively young operational spoils for which the Ferguson and Leask (1988) has been used.
- Selenium and sulphate release rates calculated on a spoil volume normalized basis vary over less than an order of magnitude.
- Monthly release rates of selenium and sulphate are variable. The highest release is observed during snowmelt conditions and lowest release occurs during the winter.
- Variation in selenium and sulphate release rates can probably be attributed to several factors related to measurement methods, geochemical factors, waste rock dump construction, reclamation methods, and hydrological factors. These factors are not readily quantifiable; and therefore, average rates and their confidence limits are the best representation of performance of historical wastes lacking monitoring data and future wastes.
- Release of cadmium from waste rock spoils should be predicted using a fixed concentration source term.
- Release of selenium, sulphate and cadmium from coal reject dumps should be predicted using fixed concentration source terms.

This report, “Geochemical Source Term Inputs and Methods for Elk Valley Water Quality Planning Model”, was prepared by

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Senior Consultant (Geochemistry)

All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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The opinions expressed in this report have been based on the information available to SRK at the time of preparation. SRK has exercised all due care in reviewing information supplied by others for use on this project. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information, except to the extent that SRK was hired to verify the data.

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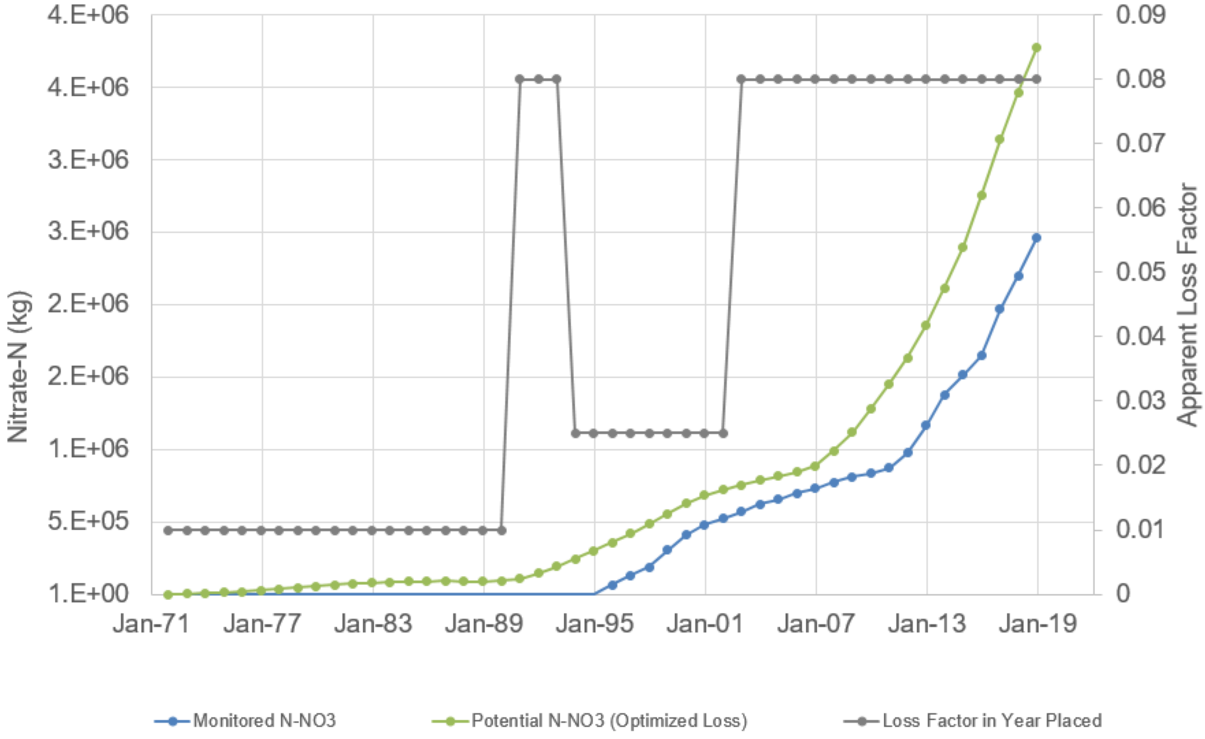
Appendix B – Apparent Loss Factor Estimates



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Appendix C – Apparent Loss Factor Estimates.pptx

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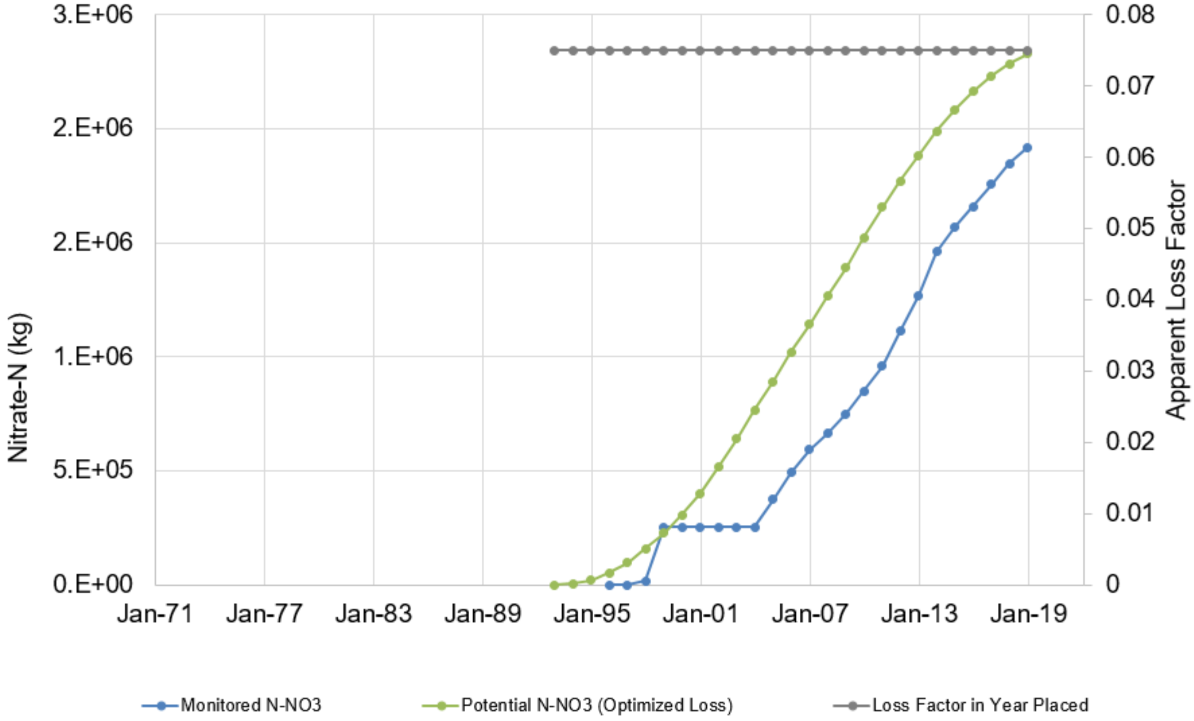
2020 Regional Water Quality Model

2020 RWQM Source Term Update

Clode Creek
Apparent Loss Factor Estimate

Date: March 2021
Approved: MKH
Figure: **B.1**



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2020 RWQM Source Term Update

Henretta Creek
Apparent Loss Factor Estimate

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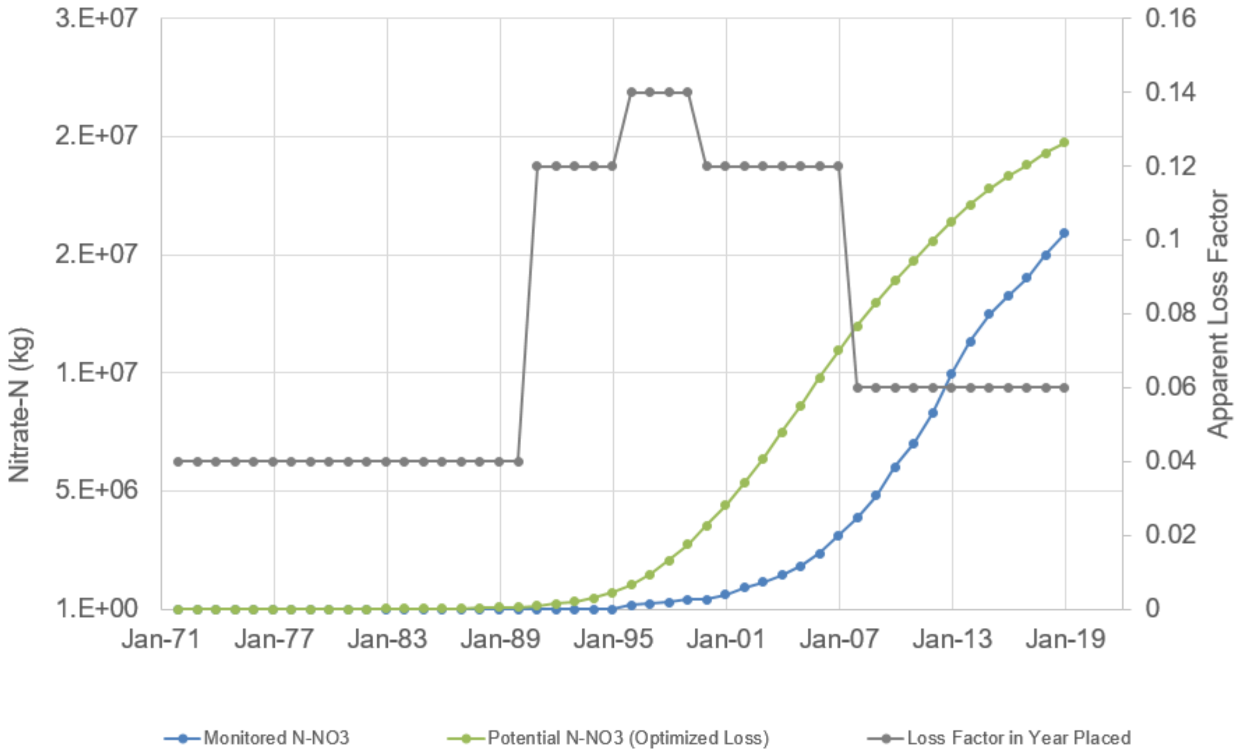
2020 Regional Water Quality Model

Date: March 2021

Approved: MKH

Figure: **B.2**



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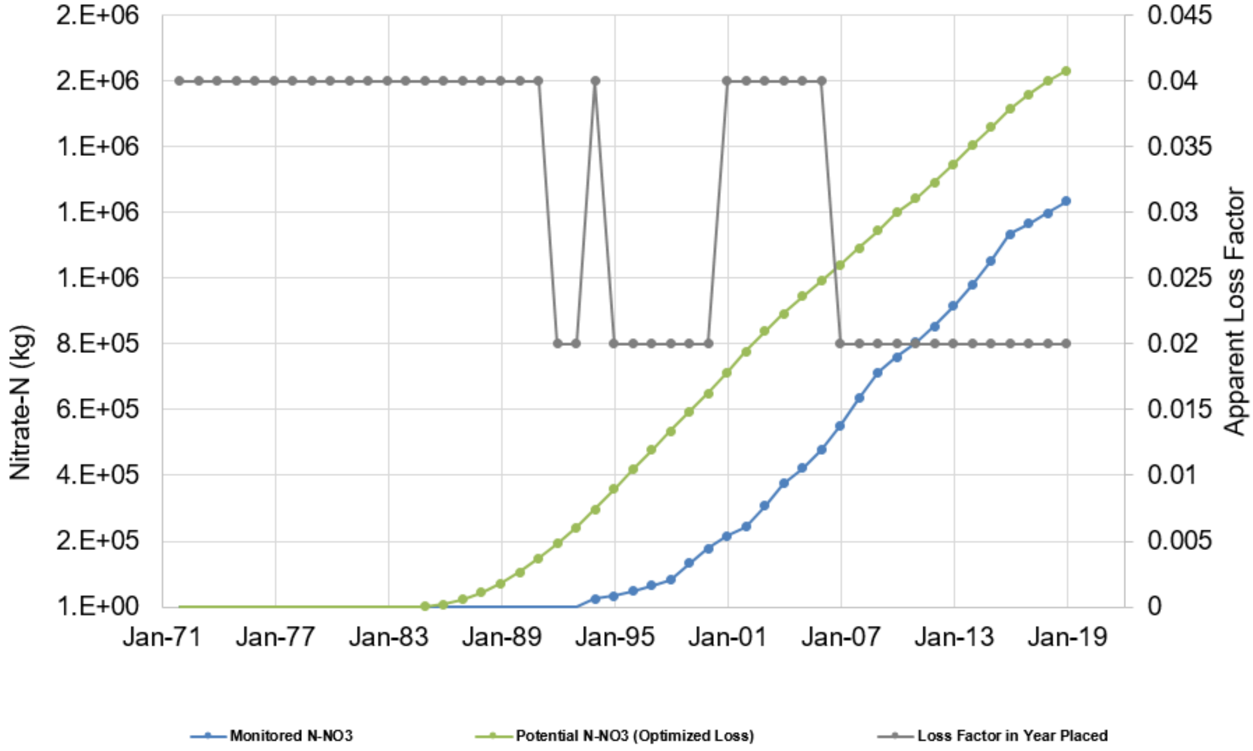

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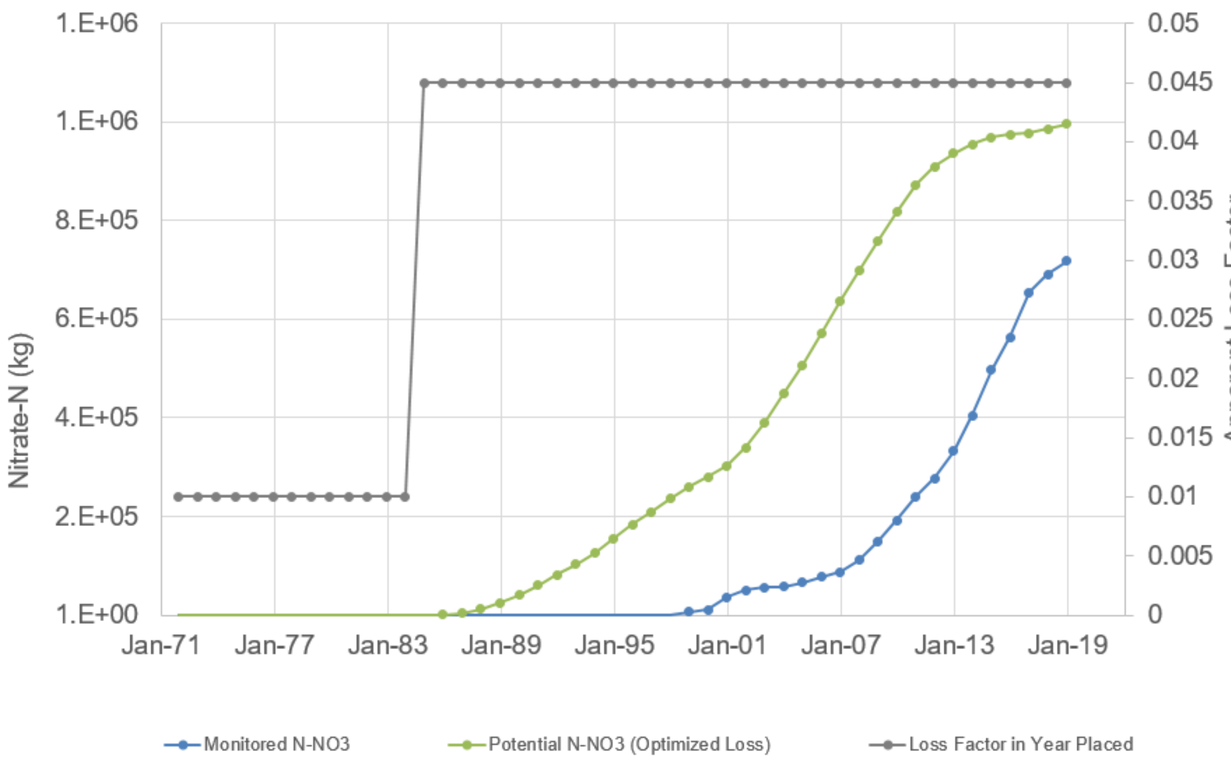
Job No: 1CT017.229 Appendix C – Apparent Loss Factor Estimates.pptx	2020 Regional Water Quality Model	Date: March 2021	Approved: MKH	Figure: **B.4**



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2020 RWQM Source Term Update

Swift Creek
Apparent Loss Factor Estimate

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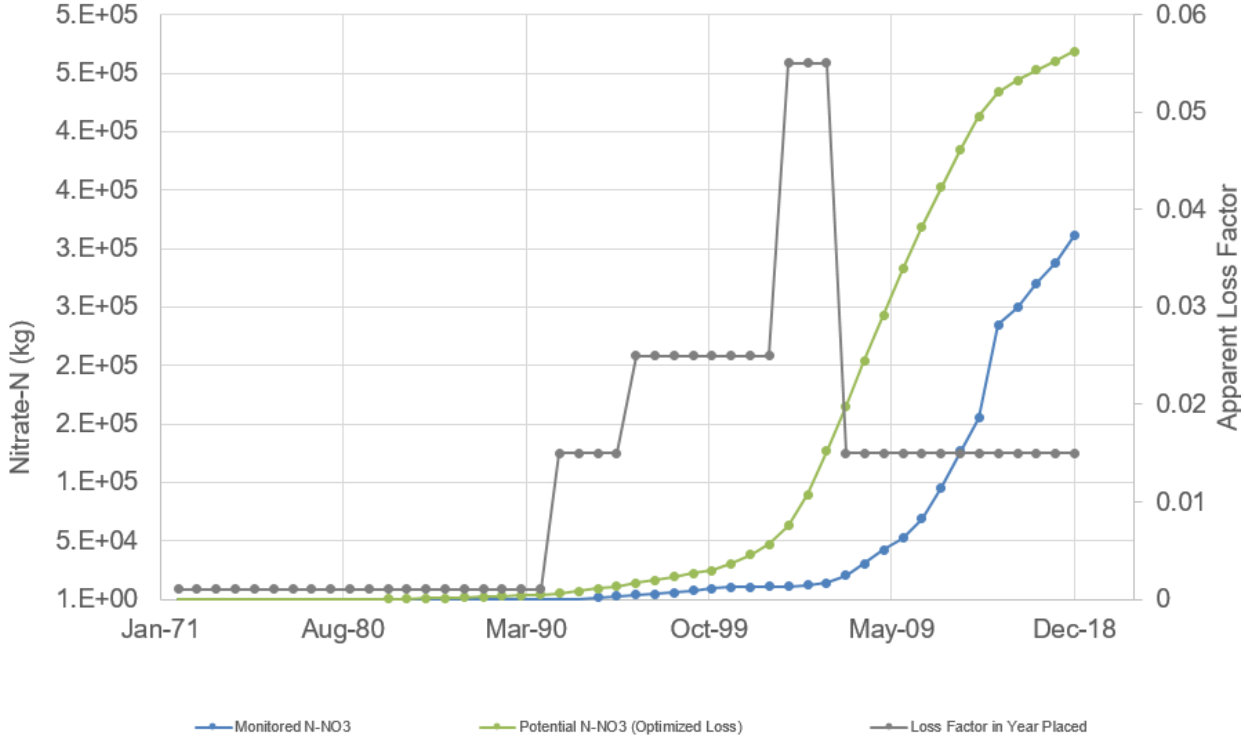
2020 Regional Water Quality Model

Date: March 2021
Approved: MKH
Figure: B.5



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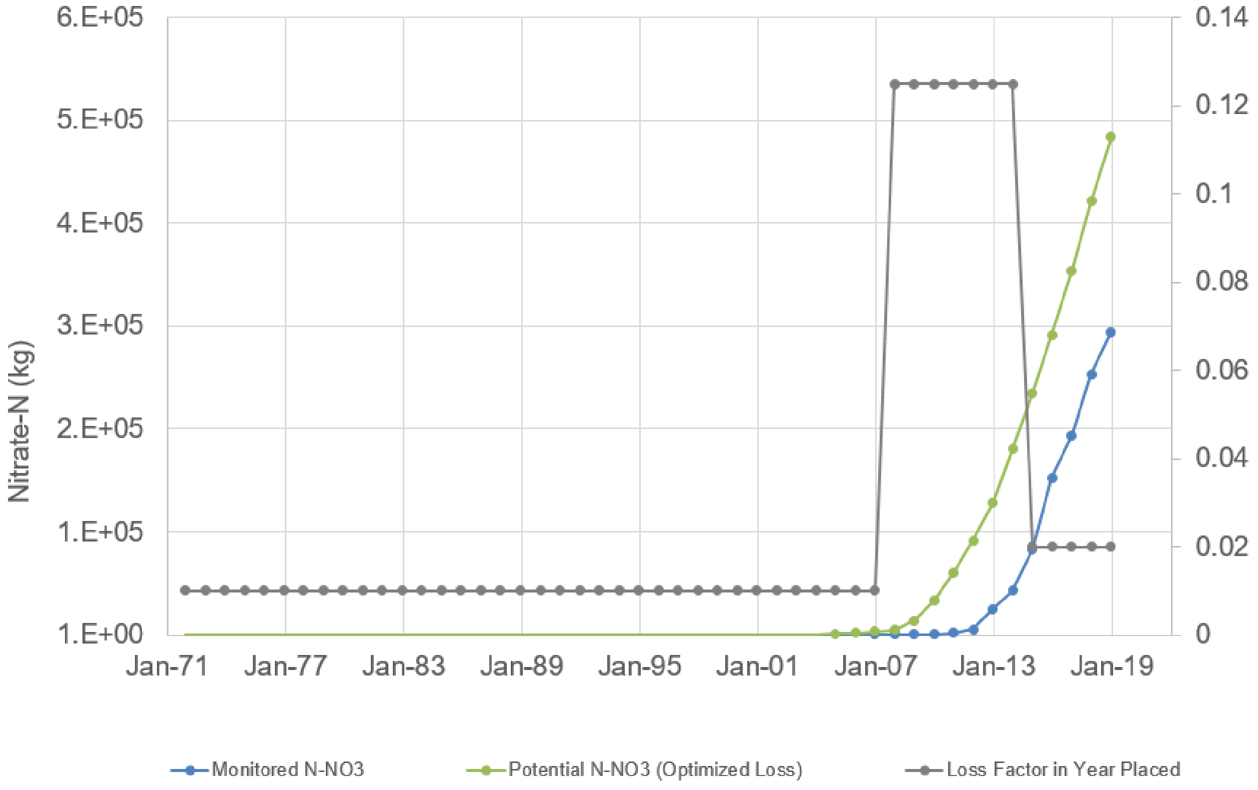
Appendix C – Apparent Loss Factor Estimates.pptx

2020 Regional Water Quality Model

2020 RWQM Source Term Update

Greenhills Creek
Apparent Loss Factor Estimate

Date:	Approved:	Figure:
March 2021	MKH	**B.6**



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Appendix C – Apparent Loss Factor Estimates.pptx

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2020 Regional Water Quality Model

2020 RWQM Source Term Update

Leask Creek
Apparent Loss Factor Estimate

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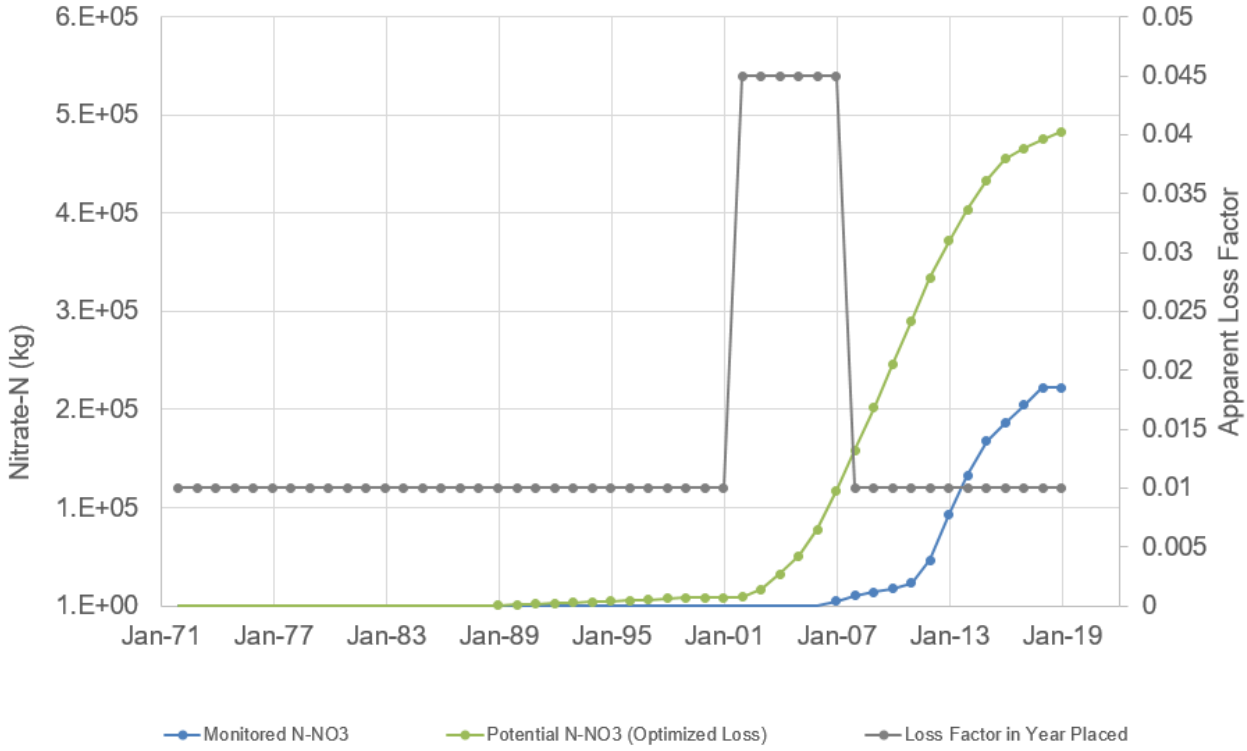
March 2021	MKH	B.7



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2020 RWQM Source Term Update

Thompson Creek
Apparent Loss Factor Estimate

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Appendix C – Apparent Loss Factor Estimates.pptx

2020 Regional Water Quality Model

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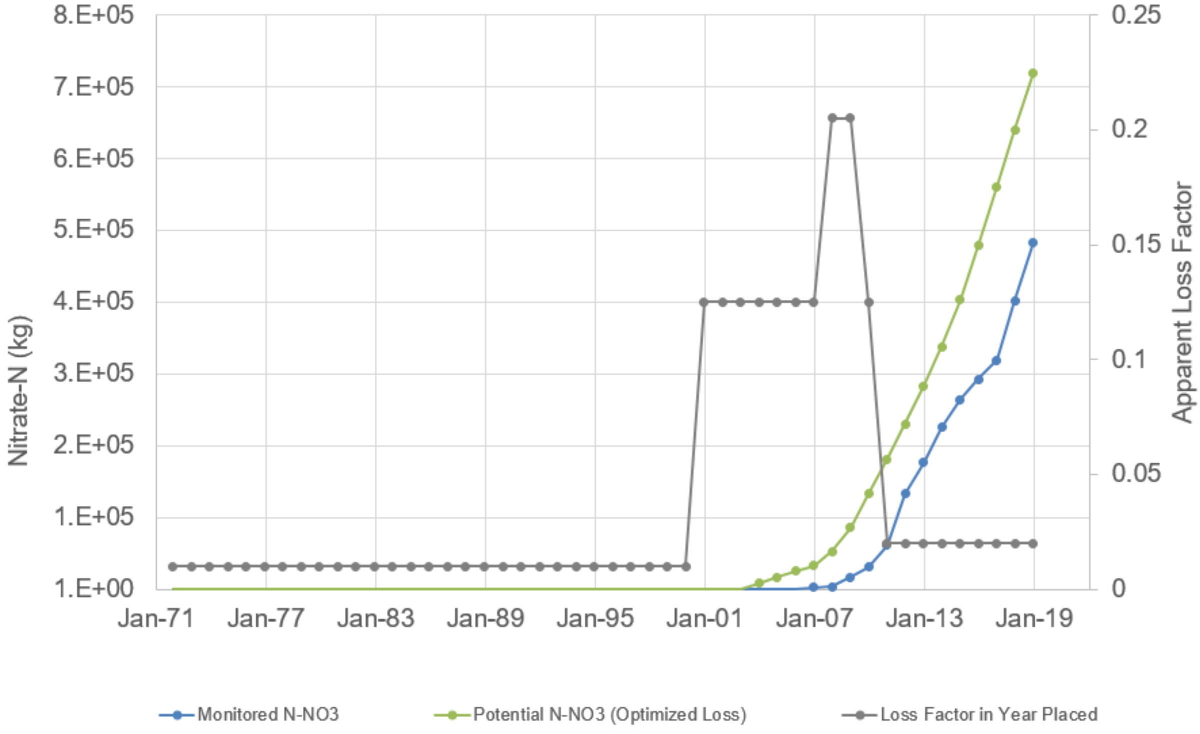

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2020 RWQM Source Term Update

Wolfram Creek
Apparent Loss Factor Estimate

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Appendix C – Apparent Loss Factor Estimates.pptx

2020 Regional Water Quality Model

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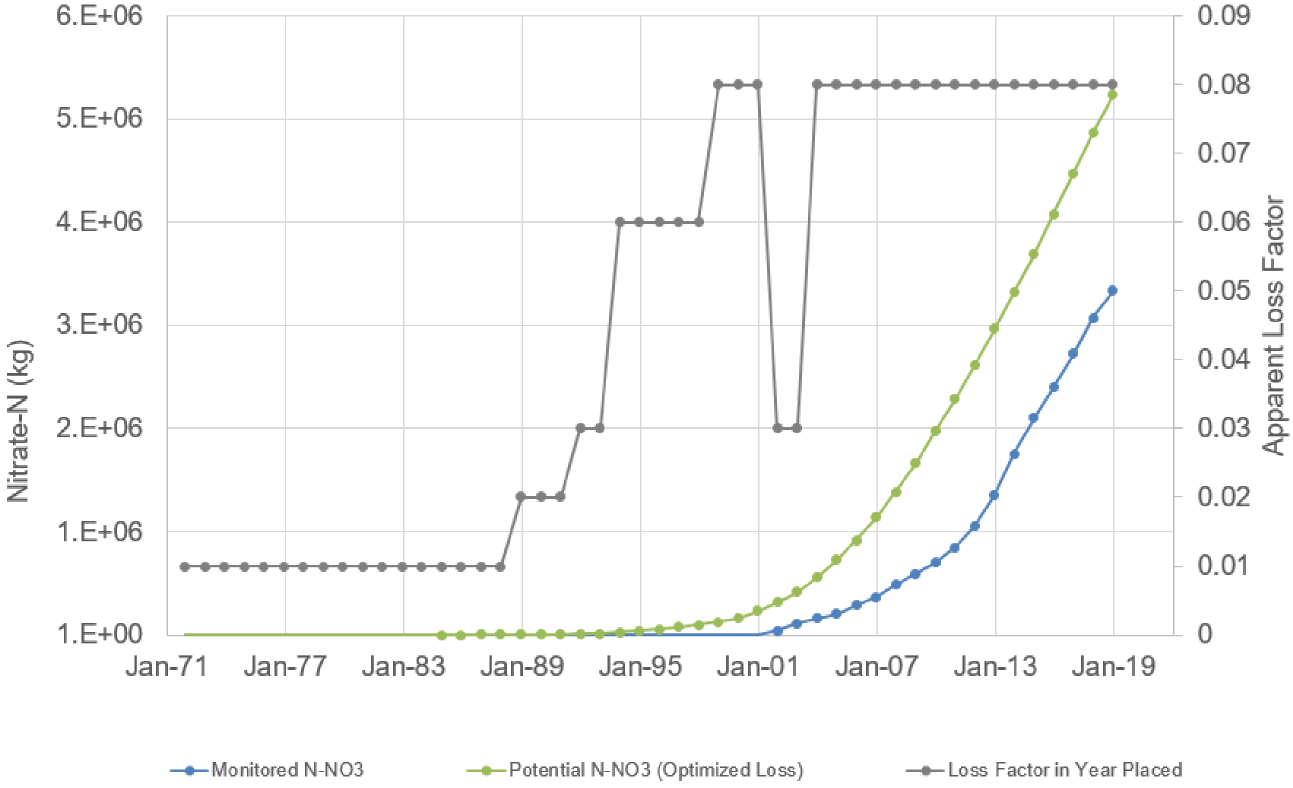

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2020 RWQM Source Term Update

Line Creek Upstream of West Line Creek
Apparent Loss Factor Estimate

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Appendix C – Apparent Loss Factor Estimates.pptx

2020 Regional Water Quality Model

Date: March 2021
Approved: MKH
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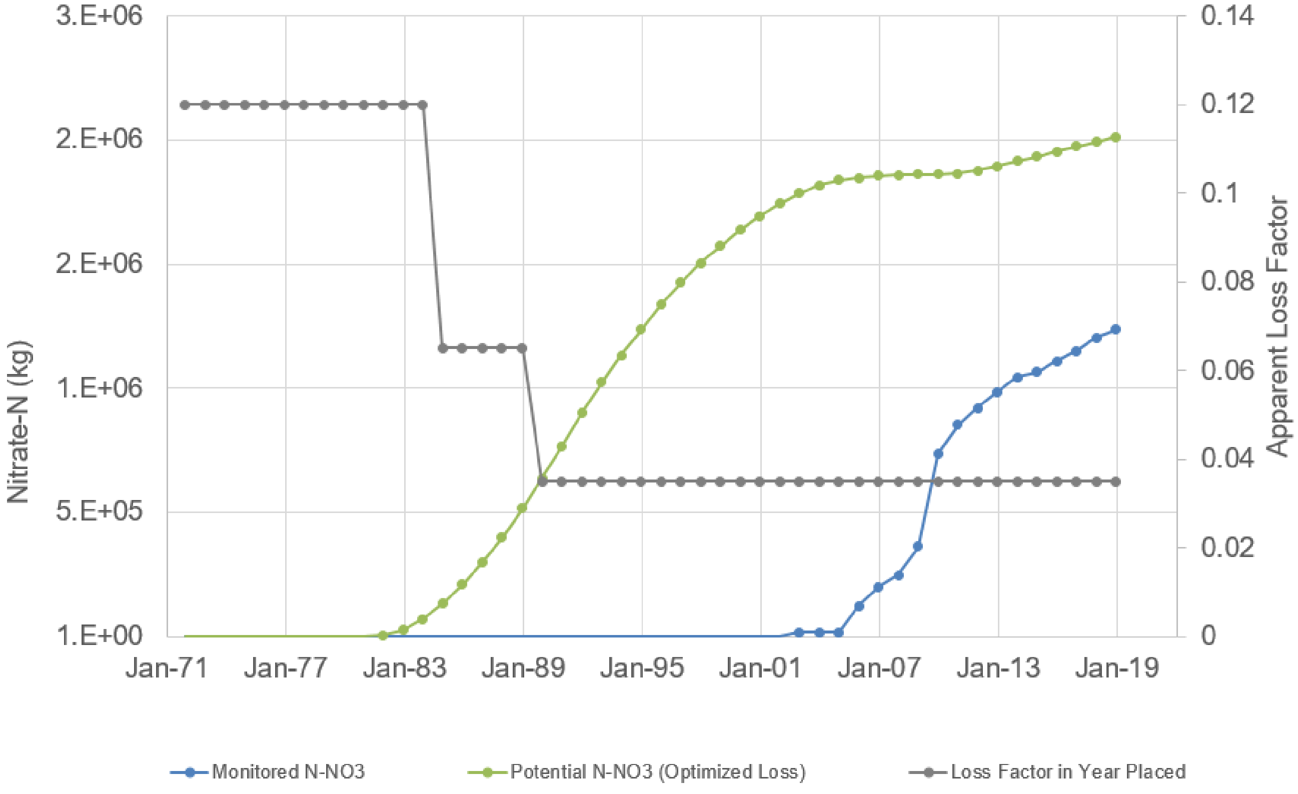

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2020 RWQM Source Term Update

West Line Creek
Apparent Loss Factor Estimate

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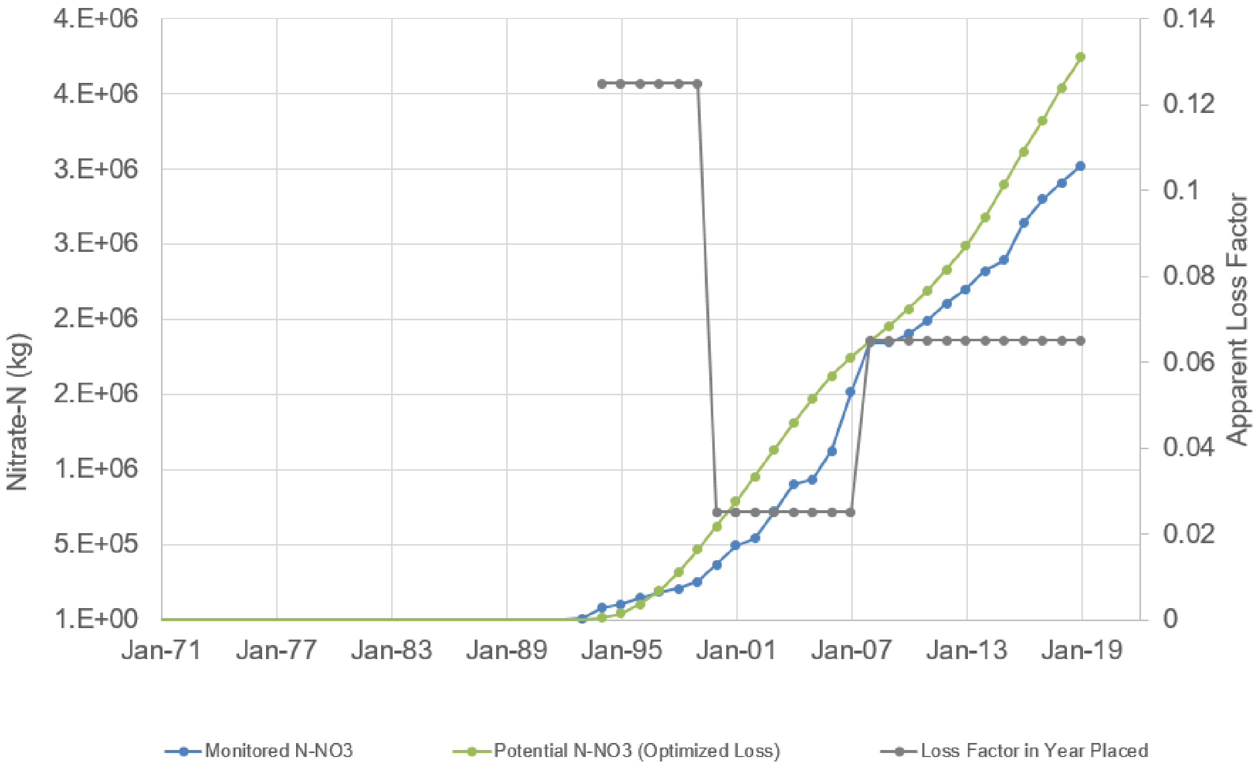
Appendix C – Apparent Loss Factor Estimates.pptx

2020 Regional Water Quality Model

Date: March 2021

Approved: MKH

Figure: **B.11**



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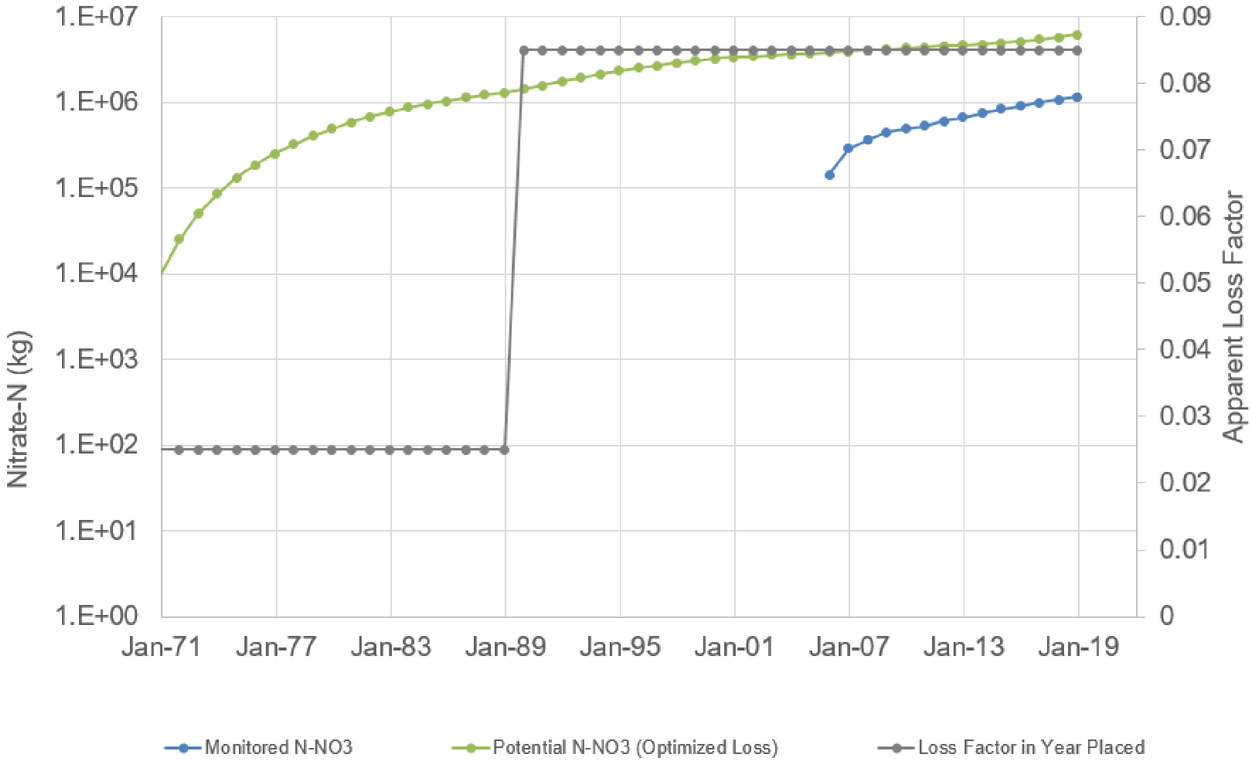
Job No: 1CT017.229 Appendix C – Apparent Loss Factor Estimates.pptx	2020 Regional Water Quality Model	Date: March 2021 · Approved: MKH · Figure: **B.12**



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Appendix C – Apparent Loss Factor Estimates.pptx

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2020 Regional Water Quality Model

2020 RWQM Source Term Update

Erickson Creek
Apparent Loss Factor Estimate

Date: March 2021
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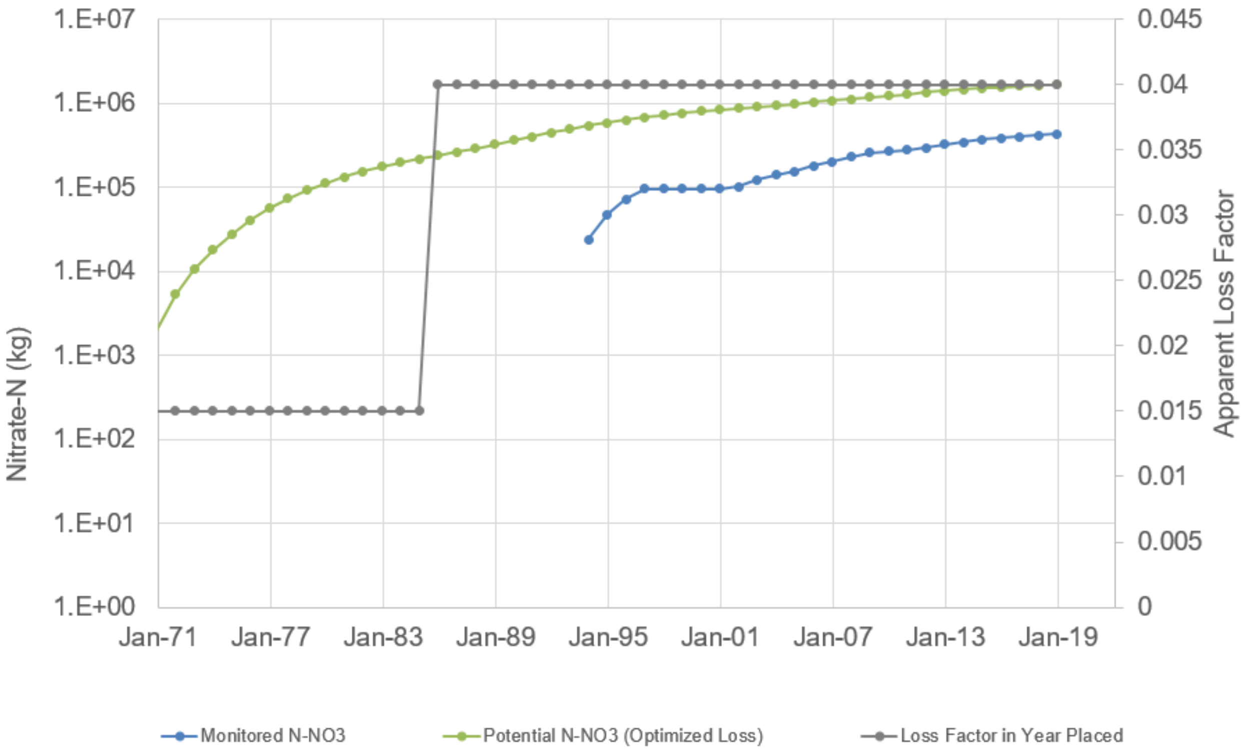
Figure: **B.13**



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2020 RWQM Source Term Update

Elkview Dry and Hamer Creeks
Apparent Loss Factor Estimate

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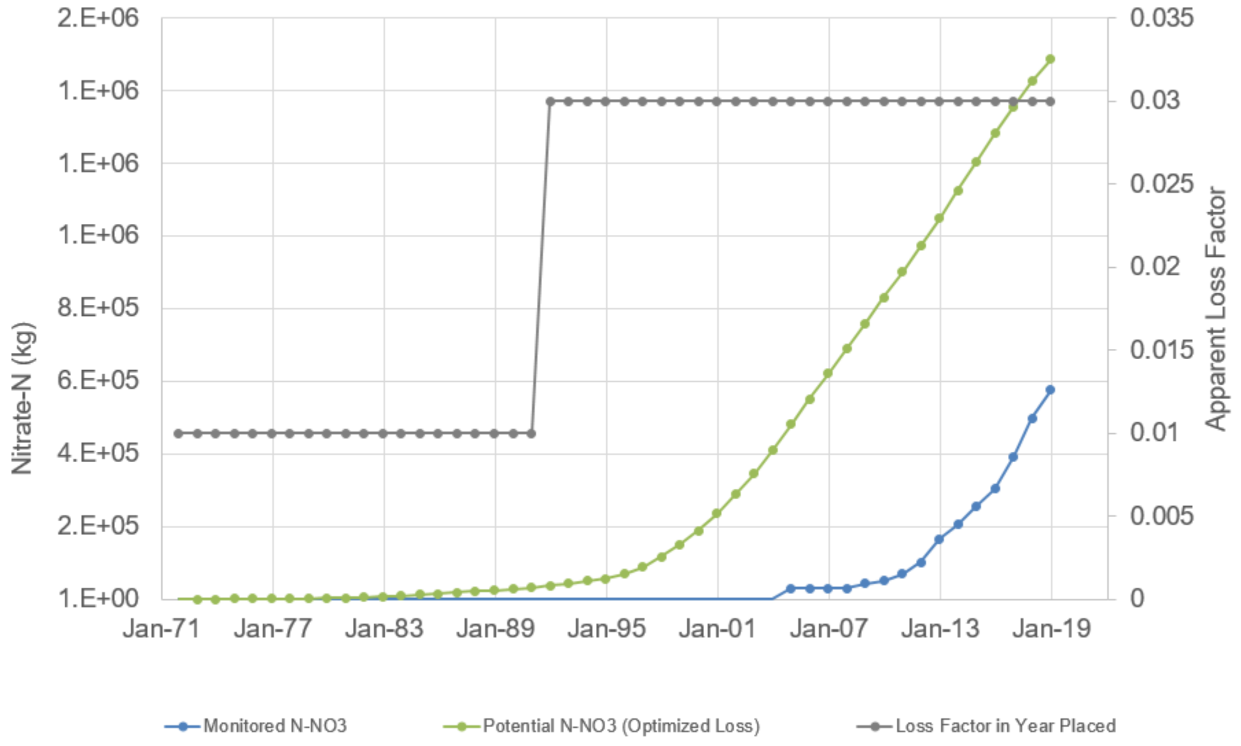
Appendix C – Apparent Loss Factor Estimates.pptx

2020 Regional Water Quality Model

Date: March 2021

Approved: MKH

Figure: B.14



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Appendix C – Apparent Loss Factor Estimates.pptx

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2020 Regional Water Quality Model

2020 RWQM Source Term Update

Corbin Creek
Apparent Loss Factor Estimate

Date: March 2021
Approved: MKH
Figure: **B.15**