Teck

Teck Coal Environmental Office
Bag Service 2000, 421 Pine Avenue
Sparwood, B.C. Canada V0B 2G0

+1 250 425 3331 Tel
www.teck.com

Technical Report Overview

Report: Water Quality Model 2017 Update Overview Report

Overview: This report provides an overview of the first update to the regional water quality model that was developed for the Elk Valley Water Quality Plan. The model is a tool used to simulate how historical, current and future mining activities may affect the concentrations of water quality constituents of interest in the Fording River, the Elk River, tributaries to these rivers located in and around Teck operations, and the Koocanusa Reservoir.

This report was prepared by Teck.

For More Information

If you have questions regarding this report, please:

- Phone toll-free to 1.855.806.6854
- Email **feedbackteckcoal@teck.com**

Future studies will be made available at **teck.com/elkvalley**

2017 Elk Valley Regional Water Quality Model Update – Overview Report

October 2017

Teck

This report has been prepared by:
Teck Coal Ltd.

Jessica Mackie, EP
Lead, Water Quality

This report has been reviewed by:

Kirsten Gillespie, P.Eng.
Manager, Water Modelling

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Description
AM	adaptive management
AMP	Adaptive Management Plan
AWTF	Active Water Treatment Facility
BC	British Columbia
BRE	Baldy Ridge Extension
CMO	Coal Mountain Operations
d/s	downstream
EMA	*Environmental Management Act*
EMPR	BC Ministry of Energy, Mining and Petroleum Resources
EMS	Environmental Management System
ENV	BC Ministry of Environment and Climate Change Strategy
EVO	Elkview Operations
EVWQP	Elk Valley Water Quality Plan
FRO	Fording River Operations
GHO	Greenhills Operations
IIP	Initial Implementation Plan
KNC	Ktunaxa Nation Council
KU	key uncertainties
LCO	Line Creek Operations
MF	Morrissey Formation
MMF	Mist Mountain Formation
MQ	Management Question
P5	5th percentile
P50	50th percentile
P95	95th percentile
RSFMP	Regional Surface Flow Monitoring Program
RWQM	Regional Water Quality Model
R&D	Research & Development
SPO	Site Performance Objective
SRF	saturated rock fills
Teck	Teck Coal Limited
u/s	upstream
WLC	West Line Creek

UNITS

Unit of Measure	Description
%	percent
BCM	bank cubic metre
mg/L	milligrams per litre
µg/L	micrograms per litre

1 Introduction

1.1 Background

Teck Coal Limited (Teck) operates five open-pit steelmaking coal mines in the Elk River watershed in southeastern British Columbia (BC). The individual operations are listed below and shown on Figure 1-1:

- Fording River Operations (FRO)
- Greenhills Operations (GHO)
- Line Creek Operations (LCO)
- Elkview Operations (EVO), and
- Coal Mountain Operations (CMO).

The BC Ministry of Environment issued Ministerial Order No. M113 (the Order), under Section 89 of the *Environmental Management Act* (*EMA*), to Teck in April 2013 which required Teck to develop an Area Based Management Plan called the Elk Valley Water Quality Plan (EVWQP). The Regional Water Quality Model (RWQM) was developed by Teck to examine how activities at its five coal mines in the Elk River watershed could affect water quality in the Elk River and Fording River, as well as in tributaries located in and around each operation. The RWQM was used in 2014 to support the development of the EVWQP. *EMA* Permit Number 107517, Section 10.9, requires Teck to update the RWQM every three years, with the first update due October 31, 2017.

The RWQM is a tool used to simulate how historical, current, and future mining activities will affect the concentrations of water quality constituents of interest in the Fording River, Elk River, tributaries to these rivers (collectively referred to as the Elk Valley) located in and around Teck mine sites, and the Koocanusa Reservoir. The RWQM was used to develop the Initial Implementation Plan (IIP) to meet the Site Performance Objectives (SPOs) and water quality limits defined in *EMA* Permit 107517.

The RWQM estimates concentrations of water quality constituents of interest at selected locations in the Elk Valley. At its core, the RWQM is a water quality mass balance model supported by two key elements, a hydrology model and geochemical source terms. The model has been calibrated and refined using historical information and is used to project future water quality constituent concentrations.

Reporting requirements for the updated RWQM are listed in Section 10.9 of the *EMA* Permit 107517 and in the following operation specific C-Permit amendments issued under the BC *Mines Act*:

- FRO: C-3 Amendment Approving Water Quality and Calcite Mitigation issued November 27, 2014
- FRO: C-3 Amendment Approving Fording River Swift Mine Plan issued December 15, 2015
- GHO: C-137 Amendment Approving Water Quality and Calcite Mitigation issued November 27, 2014
- GHO: C-137 Amendment Approving Cougar Pit Extension issued April 29, 2016
- LCO: C-129 Amendment Approving Water Quality and Calcite Mitigation issued November 27, 2014

- LCO: Permit 106970 issued October 25, 2013, amendment letter issued June 28, 2017 regarding alignment of RWQM update timing with Permit 107517
- EVO: C-2 Amendment Approving Baldy Ridge Extension Project issued December 5, 2016
- EVO: C-2 Amendment Approving Water Quality and Calcite Mitigation issued November 27, 2014, and
- CMO: C-84 Amendment Approving Water Quality and Calcite Mitigation issued November 27, 2014.

The RWQM is used to support water quality management in the Elk Valley. It is used within the Adaptive Management Plan to support evaluations and decision making, and to support various regulatory processes.

The RWQM is used to support the Adaptive Management Plan (AMP) that Teck has developed. The AMP supports meeting the objectives of the EVWQP: to achieve water quality targets including calcite targets, ensure that human health and the environment are protected, and where necessary, restored, and to facilitate continuous improvement of water quality in the Elk Valley. A six stage adaptive management cycle is used in the AMP to provide a framework for water quality management decision making. The RWQM is used in Stage 5 (Evaluation) and Stage 6 (Adjustments) of the AMP as an assessment and planning tool for adaptively managing the planned water quality mitigation measures in the Elk Valley (Teck 2016).

Specifically, the RWQM is used in the AMP to help answer Management Question 1 (MQ1) “Will limits and SPOs be met for selenium, sulphate, nitrate and cadmium” and to support evaluations under Management Question 3 (MQ3) “Are the combinations of methods for controlling selenium, sulphate, nitrate and cadmium included in the implementation plan the most effective?”. For MQ1, the RWQM water quality projections, which include accounting for planned mitigation, are compared to limits and SPOs to answer the question. If water quality projections are above the limits and SPOs, Teck uses this information to inform adjustments under Stage 6 (Adjustments) of the adaptive management cycle. For MQ3, the RWQM water quality projections support evaluations of methods for controlling water quality to inform management decisions and to evaluate changes to planned mitigation if required, and outside of this submission. This 2017 RWQM update submission includes comparison of updated model projections to limits and SPOs based on the existing planned mitigation (e.g. the IIP). Adjustments to the implementation plan, will occur under the AMP and will be advanced in consultation with Ktunaxa Nation Council (KNC) and regulators.

In addition to supporting water quality management in the Elk Valley through the AMP, the RWQM is also used to support regulatory processes. These include:

- Teck’s permit applications, including applications for mine developments as well as mitigation projects
- Development of SPOs and/or limits for Harmer Creek and LCO Dry Creek
- Technical discussions on compliance, for example the nitrate compliance issue at LCO and the pending proposal to adjust the FRO Compliance Point location.

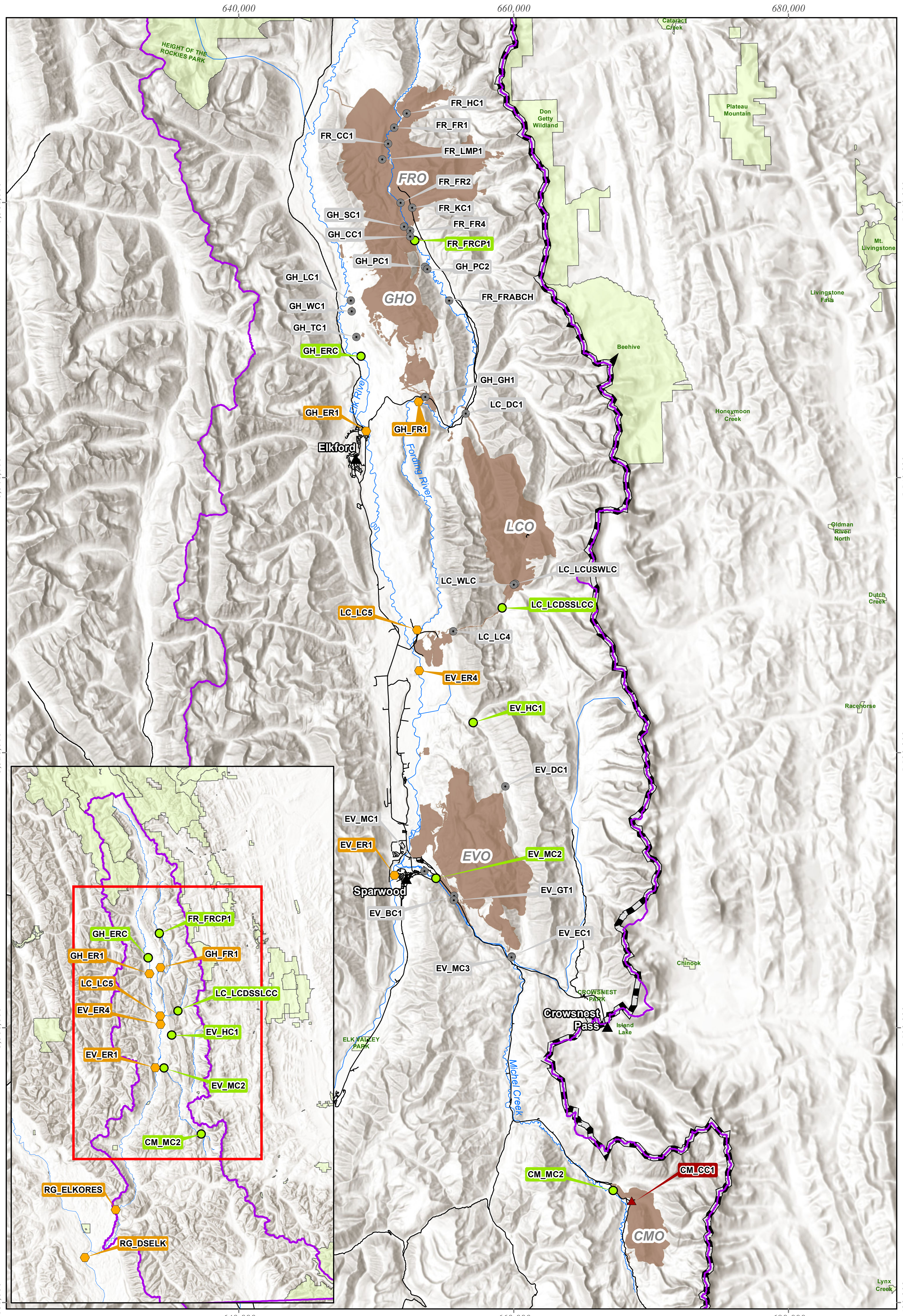


Figure 1-1 Locations of Teck Mining Operations in the Elk Valley and Select Monitoring Locations

Teck

The maps and map data are provided 'as is' without any guarantee, representation, condition or warranty of any kind, either express, implied, or statutory. Teck Resources Limited assumes no liability with respect to any reliance the user places in the maps and map data, and the user assumes the entire risk as to the truth, accuracy, currency, or completeness of the information contained in the maps and map data.

- Ministry Order Stations
- Compliance Stations
- Monitoring Site
- Model Nodes/Monitoring Sites
- Communities
- Rivers
- Teck Coal Mine Operations
- Roads
- Province Boundaries
- Protected Areas
- Elk River Watershed

N

0 1,500 3,000 6,000 Meters

DATE: 10/27/2017	MINE OPERATION: ELK VALLEY OPERATIONS
SCALE: 1:250,000	COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

Document Path: \\teckcominco\CGO\Groups\TCGIS\Data\Projects\WaterQualityStations\WaterQualityLocationsJM1.mxd

1.2 Purpose and Content of Report

The purpose of this document is to provide an overview of the RWQM update, summarize how the submission meets permit requirements, and highlight key changes that were made in the 2017 RWQM. The report includes descriptions of the main components of the RWQM update:

- the conceptual model and the approach taken to represent this numerically;
- the geochemical source terms, focal areas for this update, approach taken, and resulting changes to the geochemical source terms;
- the flow model, focal areas for the update, approach taken, resulting changes and model performance;
- a summary of the site conditions (mine and water management) included in the model;
- the water quality model, focal areas for update, approach and resulting changes, and model performance;
- a summary of the future projections; and
- how this model update supports adaptive management, next steps based on these results, and monitoring recommendations.

This overview report is a summary (at times with direct excerpts) of the following technical reports:

- Annex A: *Geochemical Source Term Methods and Inputs for the 2017 Update of the Elk Valley Regional Water Quality Model* (SRK 2017)
- *2017 Elk Valley Regional Water Quality Model Update – Annex B – Site Conditions* (Teck 2017a)
- *2017 Elk Valley Regional Water Quality Model Update – Annex C – Hydrology Modelling* (Teck 2017b)
- *2017 Elk Valley Regional Water Quality Model Update – Annex D – Water Quality: Model Set-up and Calibration* (Teck 2017c)
- *2017 Elk Valley Regional Water Quality Model Update – Annex E – Water Quality: Future Projections* (Teck 2017d)

The RWQM will be updated on a three-year cycle to continually improve and refine the RWQM, meet permit requirements and to incorporate new information obtained since the previous update. New information incorporated in this update includes feedback from reviewers of the RWQM, information from Teck's Applied Research and Development (R&D) Program, and recent monitoring data.

Teck has received feedback on the RWQM through regulatory processes that utilized the model and meetings in preparation for the 2017 RWQM update. Teck met with representatives of the BC Ministry of Environment and Climate Change Strategy (ENV), BC Ministry of Energy, Mines, and Petroleum Resources (EMPR), and Ktunaxa Nation Council (KNC) in May and July of 2017, in order to provide progress updates and solicit feedback on key changes to model inputs in advance of the October 31, 2017 submission. Through this process, Teck and subject matter experts from SRK Consulting Canada Inc. (SRK) and Golder Associates Ltd. presented the methods incorporated into the updated hydrology modelling, data analysis to date to support update of the geochemical source terms, and framed out the plan to update the RWQM. The specific feedback and how it has been addressed is described in the Hydrology, Geochemistry and Water Quality Methods and Calibration reports. Based on feedback the focal areas for the 2017 RWQM update were to improve the calibration for nitrate, and improve tributary flow modelling and concentration projections.

Monitoring data used in model development has been updated. The 2014 RWQM (EVWQP model) included monitored flow and concentration data to the end of 2012. Data used in the RWQM has been updated to the end of 2016.

Learnings from the Applied R&D Program have been included to inform the RWQM update. These learnings have primarily been used to update the conceptual model for water quality constituent release. The information relied upon is from studies of waste rock hydrology and nitrate transport through spoils (described in Section 2.2 of the *Geochemical Source Term Methods and Inputs for the 2017 Update of the Elk Valley Regional Water Quality Model* (SRK 2017). This is described in the conceptual model below.

1.3 Conceptual Model

1.3.1 Overview

The RWQM is based on the current conceptual model of water quality constituent release and transport in the Elk Valley. The conceptual model is updated over time as Teck continually improves and refines the understanding of the driving mechanisms. The current conceptual model is sumarized below.

Coal is present in the Elk Valley as layers or seams that are interlayered with sandstone, siltstone and mudstone. These surrounding rocks contain sulphide and carbonate minerals, which contain substances such as selenium, sulphate, and cadmium. Accessing coal ore bodies requires blasting and movingthe surrounding non-ore bearing rock (waste rock). These mining activities expose additional surface area to the atmosphere which can enhance the release of these substances.The blasting process also results in the deposition of explosives residue on surrounding rock and pit walls. This residue contains nitrogen compounds; the most abundant of which is nitrate. The subsequent placement of waste rock in spoils faciliates exposure and release of water quality constituents through a series of processes described below.

The waste rock generation and exposure steps involved in the mining process are illustrated in a simplified manner in Step 1 and Step 2 on Figure 1-2. Constituents of interest are mobilized from the waste rock into the receiving environment via infiltrating precipitation, from rainfall or melting snow; as illustrated in Step 3 on Figure 1-2. Runoff from the waste rock spoils discharges to tributary watercourses and reports to the Fording River or the Elk River.

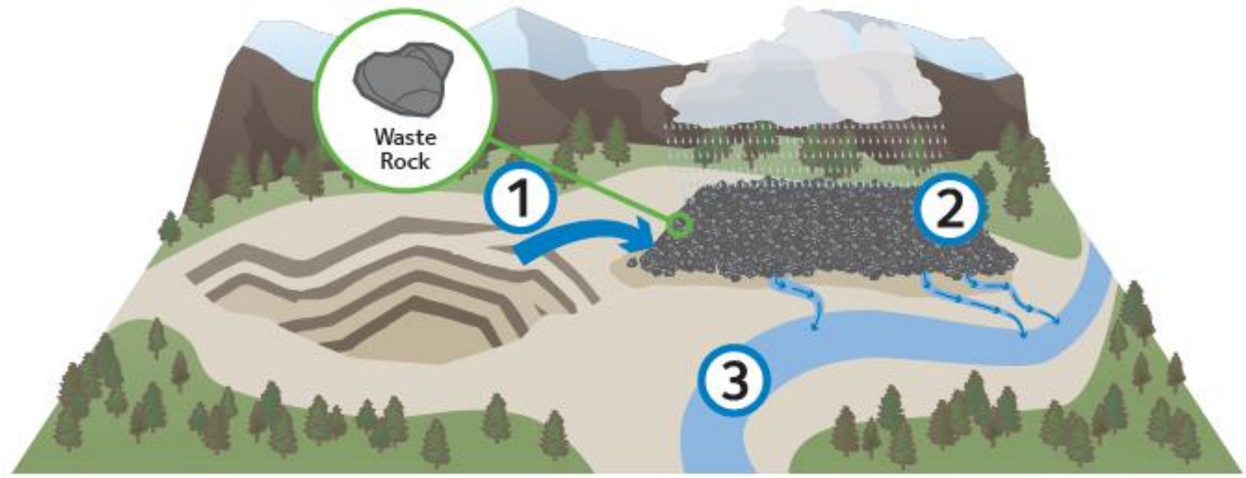


Figure 1-2 Simplified Relationship between Coal Mining and Water Quality (Source: Environmental Monitoring Committee (EMC) 2017)

1.3.2 Conceptual Model for Water Flow Through Waste Rock

The waste rock hydrology conceptual model is linked closely with conceptual models of water quality constituent release. Several field studies and associated publications have been completed and contributed to the understanding of water flow within waste rock. Field studies have been conducted at Teck sites by researchers at the University of Saskatchewan and McMaster University on the subject of waste rock hydrology. Literature on instrumented test dumps completed at the Key Lake Uranium mine (Saskatchewan), the Diavik Diamond mine (North West Territories), and the Antamina metals mine (Peru) has also been reviewed. Observations and learnings from these studies are incorporated into the conceptual model described below. The conceptual model for waste rock hydrology is provided in Appendix A of Annex C - Hydrology Modelling report (Teck 2017b).

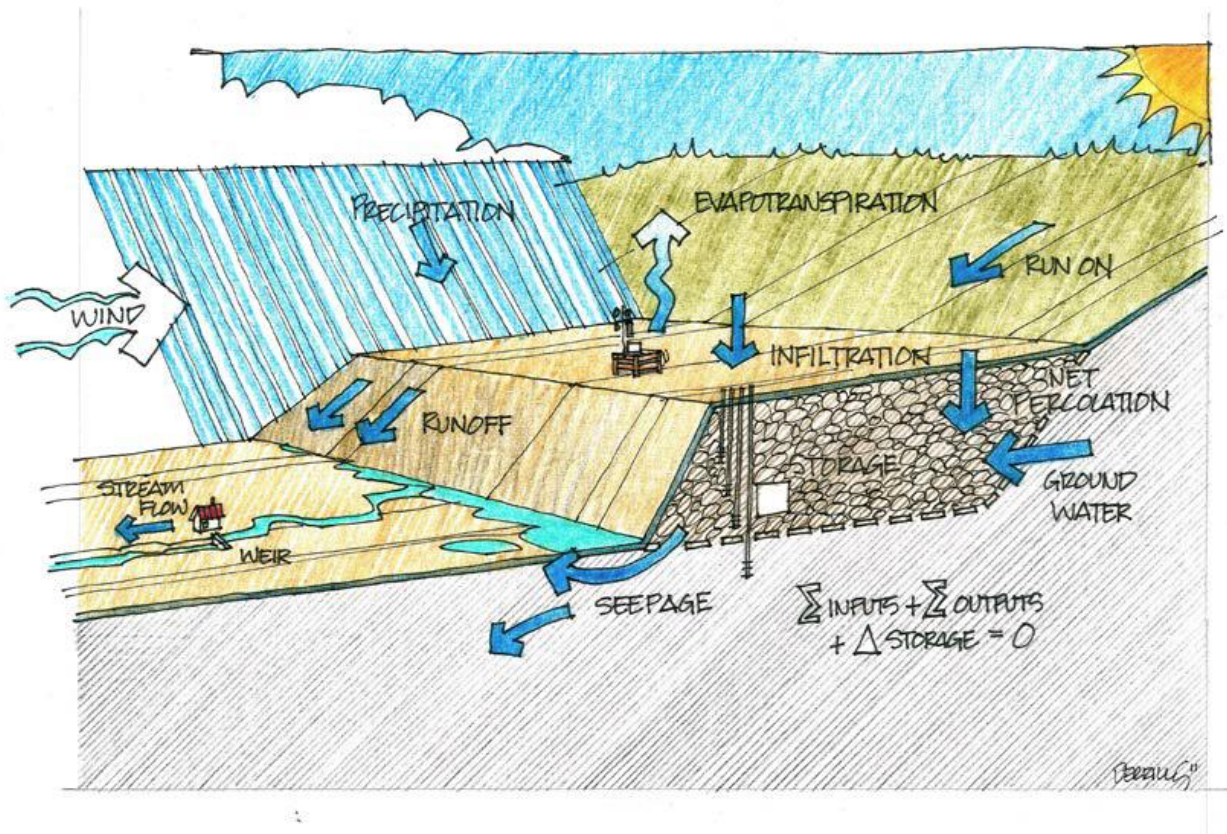


Figure 1-3 Waste Rock Conceptual Water Balance

The conceptual understanding of the water balance of a waste rock dump is illustrated on Figure 1-3. The terms illustrated on Figure 1-3 are highlighted as ***bold italics*** text through this section, as each component is described. Surface ***runoff*** is limited on active waste rock dumps (unreclaimed) due to the porous nature of the media. The primary factor that influences water movement through a waste rock dump is ***infiltration***. ***Infiltration*** rates are primarily influenced by the surface conditions (vegetation cover versus bare rock) and can be influenced seasonally, with infiltration limited during winter conditions. The waste rock dumps are unsaturated although storage occurs in pore spaces. Waste rock is typically placed with very low water content (similar to *in situ* rock water content) and a portion of infiltrating water is typically sequestered by the rock during a period described as “wetting up”. The amount of time required to wet up is dependent on many factors such as dump height, dump construction methods, and climate. ***Net percolation*** is the term used to describe the water that passes through the waste rock dump.

Water flow through the waste rock dumps is highly variable, both spatially and temporally, due to the textural heterogeneity of the waste rock (Nichol et.al. 2005). The textural variability can be influenced by the dump construction methods. The majority of Teck’s waste rock dumps in the Elk Valley are constructed through end dumping, which results in gravity segregation of the dumped materials. Larger particles, such as boulders and cobbles, tend to roll down the dump face and settle at the bottom; whereas smaller sand, gravel, and silt sized particles remain at the top of the dump face. Near surface flow rates can be high during periods of rapid snow melt or intense precipitation, which can influence the development of preferential flow pathways. Waste rock dumps in the Elk Valley are on average 100 m to

200 m thick with some as thick as 300 m. The large thickness of waste rock dumps dampens the effects of episodic recharge events so that at the base of waste rock dumps studied in the Elk Valley, ***net percolation*** is relatively constant throughout the year (Barbour et. al. 2016).

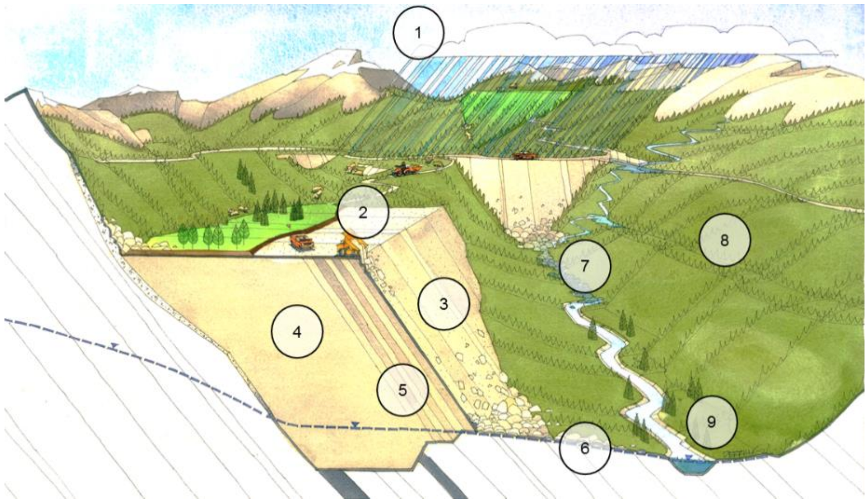
Run-on (run off from up-gradient natural catchment areas) is understood to dominantly flow through the coarse rubble zone at the base of the dump (also referred to as rock drains) and has little interaction with the bulk of the overlying waste rock materials, though some saturation of the base of the dump may occur seasonally during high flow periods (Villeneuve et. al. 2017). Run-on from natural drainage is highly seasonal and this natural drainage, when combined with the ***seepage*** from the overlying waste rock mass can result in strong seasonal variation in the water quality that emerges from the base of the waste rock dumps. ***Groundwater*** flow systems or near surface flow pathways underlying waste rock are conceptually understood on a site-by-site basis. Groundwater discharging into the base of a waste rock dump (along buried creek channels) are likely to flow through the same rock drains as run-on and have little interaction with the overlying mass. ***Seepage*** is often difficult to characterize on its own due to mixing with the run-on and groundwater at points of measurement at the base of the waste rock dump or further downstream at long-term monitoring locations.

The factors presented in the waste rock hydrology conceptual model support the understanding that flow through a waste rock dump is not an instantaneous process, and that there is a hydrologically controlled delay (lag) between the placement of waste rock and the appearance of load in the receiving environment. The length of that lag is dependent up on the waste rock dump specific factors and local climate factors, among others. These concepts, specific to water quality constituent release and transport, are further explained in the following section.

1.3.3 Conceptual Model for Water Quality Constituent Release and Transport

1.3.3.1 Water Quality Constituent Release and Transport in Unsaturated Waste Rock

The conceptual model for water quality constituent release and transport is focused primarily on unsaturated waste rock, building upon the concepts in the conceptual model for waste rock hydrology. The conceptual model for water quality constituent release and transport in unsaturated waste rock is illustrated and described on Figure 1-4.



1	**Net Percolation** • 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. • Run-off from the unsaturated waste rock is negligible
2	**Rock placement and physical conditions** • Waste placement is tracked as bank cubic metres (BCM) of waste placed per year and is a primary factor in source term development. • The method of construction can influence the flowpaths that constituents of interest (CIs) travel to exit the waste piles.
3	**Leaching of explosives residuals contributes inorganic nitrogen (e.g., nitrate) to contact waters** • Leaching of explosives residuals are expected to 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. • The amount of NO_3 present is a function of placed waste rock, powder factor, management practices, wet/dry holes, blast utilization and is present dominantly as NO_3.
4	**Geochemical weathering processes under oxygenated conditions** • Oxidation of pyrite results in release of soluble components of pyrite, mainly sulphate, but also traces of elements including selenium and other metals. • Dissolution of acid-neutralizing minerals and release of soluble components of those minerals, mainly base cations (calcium, magnesium). • Throughout the unsaturated waste rock, it is assumed that pyrite oxidation is not oxygen limited. • There is a strong regional correlation of selenium to sulphate. • The interaction of reactive surfaces (e.g. iron oxides) may attenuate elements, e.g. cadmium, and precipitation of secondary minerals such as gypsum may control sulphate concentrations. • Waste rock may break down over time, exposing new surface areas as a result of compaction, physical weathering etc.
5	**Hydrological processes that may influence release of CIs from waste rock** • There are leaching inefficiencies within the waste piles that are difficult to quantify whereby not all pore spaces are leached by infiltrating waters. This can be influenced by dump height, grain size etc. • When waste rock piles are disturbed (e.g. during rehandling), pore spaces not previously leached may leach. • Travel time through the waste rock pile is believed to be largely a function of lift height and net percolation.
6	**Transport of CIs via seepage, run-off and groundwater pathways** • Water carrying CIs from the dump exit the dump as surface water and groundwater. • Negligible run-off occurs and groundwater pathways are expected to be minimal on a regional scale reporting ultimately to the Elk River. • Where groundwater pathways occur, there is a potential for load bypass at specific monitoring stations and sub-oxic reduction of Se and NO_3.
7	**In-stream precipitation processes** • As seepage with high partial pressure of CO_2 exits the waste rock pile and equilibrates with the atmosphere, calcite becomes supersaturated and precipitates within the streams. Trace metals such as cobalt and cadmium (among others) have been shown to co-precipitate with calcite when this occurs. • The precipitation of calcite is affected by seasonal changes in flow whereby during high flows and spring freshet, streams are diluted and calcite does not precipitate. During this period some trace metals concentrations (e.g. Co) tend to parallel sulphate trends in the receiving environment.
8	**Undisturbed area influences** • Dilution from undisturbed areas varies by drainage and influences the monitoring station flow and water quality. A load is associated with this undisturbed area, and the relative proportion varies by constituent.
9	**Monitoring location and data record** • Source term development requires data for flow and water chemistry. The extent of monitoring record varies across the region. Some stations have robust data sets while others are limited. Recent data (<10 years) tends to be more complete, while older data are sometimes limited.

Figure 1-4 Geochemical Conceptual Model for Unsaturated Waste Rock (modified from source: SRK 2017)

1.3.3.2 Other Mine Sources

Runoff from pit walls, coal rejects, rehandled waste rock, and tailings water discharges contribute to the release of constituents of interest; however, the mass contribution from these sources is low compared to mass released from waste rock sources. The conceptual models for mass release from these sources are described below.

Pit Walls

The conceptual model for water quality constituent release from pit walls is similar to the conceptual model for unsaturated waste rock. There are two notable differences: (1) the volume of reactive rock is much smaller (intact rock with relatively shallow depth of reactive surface), and (2) there is no hydrologic delay anticipated between contact with reactive surfaces and load release (SRK 2017).

Coal Rejects

Coal rejects are composed of coal refuse mixed with fines and are typically stored in small dedicated facilities that are constructed in small lifts and compacted as they are built. Weathering processes in coal rejects are similar to those that affect waste rock; however, oxygen penetration into these piles tends to be limited. Organic carbon is abundant in coal rejects, leading to oxygen-consuming reactions and resultant reducing conditions. Selenium leachate from these facilities may be limited by transformation to chemically reduced forms. Release of other trace elements may be controlled to low levels by the abundance of reactive surface on the coal fines (SRK 2017).

Tailings

The conceptual model for water quality constituent release from tailings ponds is similar to the conceptual model described for coal rejects. Tailings tend to have a higher degree of saturation which further limits oxygen penetration into the materials stored in these facilities. Nitrate and selenium concentrations in seepage samples collected down-gradient from tailings ponds tend to be very low, compared to the concentrations measured in the pond and inflowing sources. This reduction in concentration (due to mass removal) is conceptually understood to result from the presence of sub-oxic zones within the tailings, "*which can lead to microbial reduction of nitrate and selenium, similar processes as those within the saturated zones of the backfilled pits*" (SRK 2017).

Rehandled Waste Rock

Rehandled waste rock is the term used to describe waste rock that is moved from one location to another to accommodate ongoing mine development plans. Previously unflushed waste rock becomes exposed to atmospheric processes and residual nitrate and oxidation products that have accumulated since the waste was originally placed are released. These releases lead to relatively short-term increases in loading in the year it is rehandled. This release is in addition to that which would otherwise occur if the materials were not rehandled.

1.3.3.3 Regional Transport

The conceptual model for the regional transport of constituents of interest from the various mine sources down to the Koocanusa Reservoir is summarized in this section. Loads from mine sources are transported into local tributaries or directly into the main valley-bottom rivers (Elk River, Fording River, or Michel Creek) via seepage or surface discharge. The majority of the discharge travels as surface runoff, with the remaining discharge travelling along shallow, near surface, flow pathways that report to surface. These processes are similar for all operations, with local differences in the partitioning between surface and ground water flow pathways between tributaries. The main valley-bottom rivers are gaining on a watershed basis, which means that groundwater flow paths in the valley bottom sediments are generally localized and report to surface water in close proximity to the operation. Groundwater flow through deep bedrock is negligible compared to flow through overburden and is not considered an important means of mass transport.

Mixing within the mainstem river system occurs due to turbulence induced by the water flowing over bouldery substrate.

1.4 Approach to Model Update

1.4.1 Organization of the Regional Water Quality Model

The RWQM numerically represents this conceptual model. It is based on a mass balance equation such that concentrations at a given location are calculated by adding upstream inputs and dividing by the total flow. Concentrations at a given location in the RWQM were calculated using the following equation:

$$c_x = \frac{\sum_{i=1}^{n} R_{x,i} - S_x}{\sum_{i=1}^{n} q_i}$$

where:

c_x = predicted concentration of constituent '*x*' at a given location (mass per unit volume)

$L_{x,I}$ = mass of constituent *'x'* associated with inflow *'i'* discharging to a given location (mass per unit time)

S_x = mass of constituent '*x*' lost (described more below))

q_i = flow rate of inflow *'i'* (volume per unit time), and

n = number of inflows to the location in question.

Sources in the mass balance equation include waste rock, coal reject, pit walls, tailings discharges and drainage from natural areas. Considered losses (S_x) include instream losses incorporated as part of calibrating the model, and the removal of mass through mitigation (active water treatment). Data used to develop the RWQM and the contributing components are illustrated on Figure 1-5.

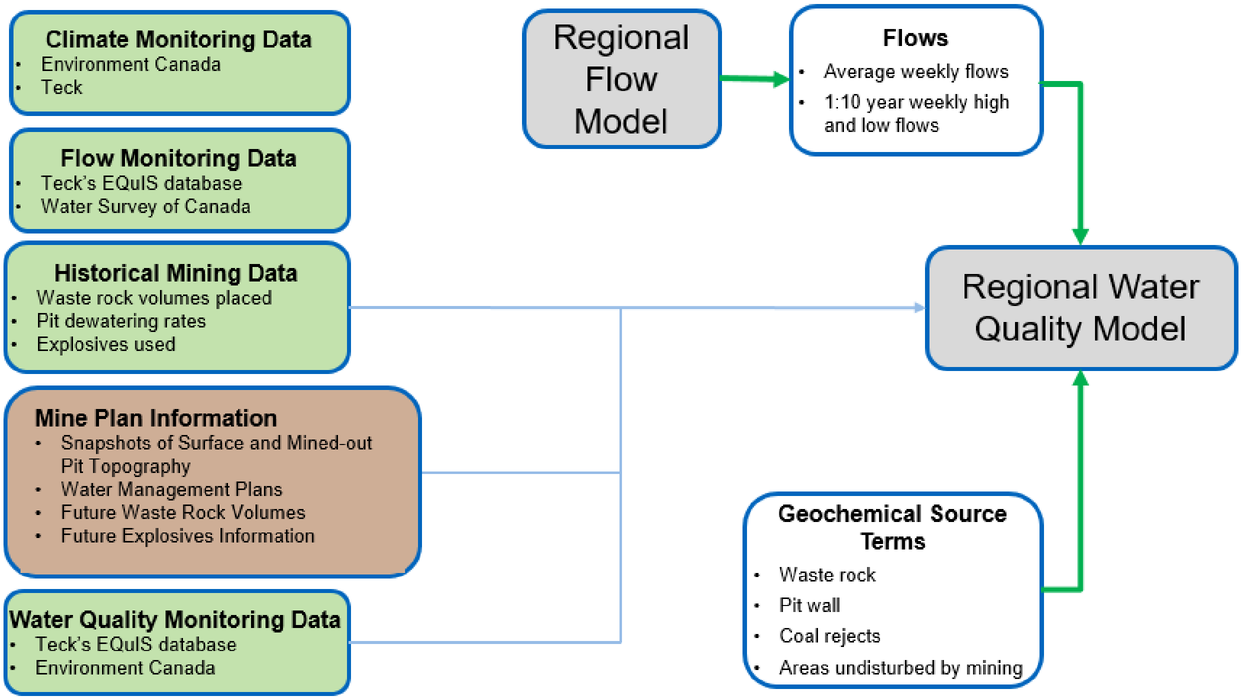


Figure 1-5 Overview of the RWQM Inputs and Components

The RWQM is used to account for the mass of constituents of interest, such as selenium, sulphate, and nitrate, from the source (i.e., waste rock, natural catchment runoff), through the mine affected tributaries, into the Fording River and Elk River, and further downstream into the Koocanusa Reservoir. Waste rock is the largest mine related source of these constituents of interest and has been used in the following conceptualization to demonstrate how the constituents are mobilized and transported from the ground into local waterways. The term "loading" (or "load") is used frequently in this document and is generally defined as the mass of a substance (constituent of interest), such as selenium or sulphate, that is transported in a solution (i.e., runoff from a waste rock dump), over a specified time frame. The concentration is calculated as the sum of the mass of the constituent of interest divided by the volume of water.

The RWQM uses inputs from a Flow Model and geochemical source terms. The Flow Model provides the RWQM inputs specific to flow pathways, flow rates, segregates flows that are influenced by mine sources and those that are unaffected, tracks water that accumulates in reservoirs, such as pits, and combines these flows in a manner that mimics historical and current conditions and projects future conditions. The mass release rates for concentrations of the constituents of interest from the various mine sources were provided in the form of geochemical source terms (source terms). The source terms are provided as release rates or are concentration based. For example, the waste rock source terms for selenium, sulphate, and nitrate are dependent upon the volume of materials present and are provided as release rates, whereas other parameters, such as cadmium and cobalt, do not appear to be influenced by the cumulative volume of waste rock and are provided as concentration based input parameters.

The RWQM is developed by combining the Flow Model with the geochemical source terms and mine plan information, as well as information specific to natural catchment runoff chemistry. Each individual flow in the Flow Model is paired with a representative loading term (source term or natural catchment) and the required calculations and rules (assumptions) are built into the model, which enable it to track all modelled loads, and calculate concentrations at various locations (nodes) throughout the modeled system. The RWQM is a valuable water management and planning assessment tool because of the intricacies built into it and because the inputs and the RWQM itself are based on, and calibrated against, a large database of measured parameters.

The concepts presented thus far were the basis for the EVWQP model and remain the underlying concepts of the 2017 RWQM. The conceptual models for waste rock hydrology and water quality constituent release have evolved since the EVWQP model was developed. These revised concepts have been incorporated into the 2017 RWQM update and are described in the next two sections of this report.

1.4.2 Alteration of the Regional Water Quality Model to Reflect Changes to the Conceptual Model

The updated conceptual model for waste rock hydrology is the main change in the conceptual model for the 2017 RWQM update. The change was primarily addressed in the calculation of geochemical source terms for unsaturated waste rock. Catchment specific release rates and concentration based source terms have been developed for unsaturated waste rock and implemented into the RWQM. The release rates for nitrate, sulphate, and selenium have incorporated a catchment specific lag and loading distribution, which is intended to capture the catchment specific factors that would affect the travel times of water quality constituents from placement of waste rock through to appearance in the receiving environment as well as seasonality. These changes to the 2017 RWQM inputs were further refined through the calibration process.

1.4.3 Calibration Overview for the Updated Regional Water Quality Model

The objective of the calibration process was to match observed seasonal and annual changes in water quality constituent concentrations as accurately as possible. The calibration process included the comparison of model projections for the historical period to measured data and adjustment of the model to more closely match the measured data. This was accomplished through evaluation of model statistics and visual fit to maximize the ability of the model to capture the range and seasonal pattern in the monitoring data. Adjustments occurred in an iterative process within the 2017 RWQM Flow Model (Flow Model) and the water quality model. In the Flow Model, adjustments were made to the data set used for each watershed (the analogue), adjusting the timing and magnitude of the flows, and yield. In the water quality model adjustments were made at the tributary scale to lag times, the magnitude of the loading rate, and the seasonal timing of release at the tributary scale. Adjustments were required in the Fording, Elk and Michel to reduce over prediction.

The goal of the calibration process was to reduce model error and bias, such that simulated concentrations reflected observed patterns, in terms of replicating seasonal variability, the observed range of concentrations over the period of interest and long-term temporal trends (if present).

1.5 Conformance with Permit Requirements

The water quality modelling update and reporting requirements are listed in Table 1-1, along with where the required information can be found in the 2017 RWQM submission.

Table 1-1 Regional Water Quality Model Update Permit Requirements - Table of Concordance

Site	Permit	Requirements	Report that Requirement is Addressed In	Report Section
All	**EMA 107517** (2) **Section 10.9**	**Section 10 (Reporting Requirements) - 10.9 WATER QUALITY MODELLING**		
		The Permittee must update the water quality model and complete a water quality prediction report for each mine site and the Designated Area as a whole to be submitted to the Director by October 31, 2017.	2017 RWQM Update	Full Report
		This report must be updated every 3 years or more frequently as required, based on changes to the mine plan, when observed water quality and water quantity are regularly and significantly different from predicted values, or as otherwise required by the Director in writing. The report must include data collected from the monitoring programs described in Section 9 as well as any other special studies undertaken to investigate water quality in the Designated Area.	Annex A - Geochemical Source Term Methods Annex C - Hydrology Modelling Annex D - Water Quality: Model Set-up and Calibration	Appendix A Appendix B, C, D Appendix B, C
		On a three year cycle, verify and, failing verification, calibrate the Elk Valley Water Quality Planning Model using the most recent three years of water quality data and regional flow data from appropriate (e.g. Environment Canada regional) hydrometric data stations.	Annex C - Hydrology Modelling Annex D - Water Quality: Model Set-up and Calibration	Section 6 Appendix B, C
		The report must provide:		
		i. Current and projected (through the next twenty years) bank cubic meters of waste rock at the mine, detailed by affected drainage.	Annex B - Site Conditions	Full Report
		ii. Hydrology modelling information, detailed by affected drainage.	Annex C - Hydrology Modelling	Section 4
		• Identify the specific hydrology information used in the modeling work	Annex C - Hydrology Modelling	Section 4
		• An evaluation of the relative data accuracy/precision and overall confidence in the data used. The evaluation should consider any relative bias that a station may introduce (e.g. a stations' ability to represent total watershed yield). Documentation must clearly provide a rational for why specific data was selected for use in the model.	Annex C - Hydrology Modelling	Section 6
		iii. Current and predicted concentrations of Order constituents, and other constituents of interest (COIs) as required, in the surface water of affected drainages through the life of the mine based on current model, which incorporates waste rock volumes and local hydrology, compared to BC Water Quality Guidelines or water quality targets for selenium, nitrate, sulphate and cadmium.	Annex E - Water Quality: Future Projections	Section 2

Site	Permit	Requirements	Report that Requirement is Addressed In	Report Section
		iv. A description of the calibration and validation of the flow model and water quality.	Annex C - Hydrology Modelling Annex D - Water Quality: Model Set-up and Calibration	Section 6 Section 5
		v. A sensitivity analysis for variation in flows and potential errors in measured input data.	Annex C - Hydrology Modelling Annex E - Water Quality: Future Projections	Section 2.5 Appendix A
		vi. Data tables and model output in electronic format.	Submitted Excel file	
		vii. A monitoring plan for continued evaluation of ii), iii) and iv) as the mine progresses.	2017 RWQM - Overview Report	Section 7.4
		viii. Refined hydrology, hydrogeology and geochemical source term information (including refinements for cadmium source terms), together with any site specific water balance models and hydrogeology studies;	Annex A - Geochemical Source Term Methods Annex C - Hydrology Modelling	Full Report Full Report
		ix. Changes to the mine plan; and	Annex B - Site Conditions	Full Report
		x. Information and outcomes from research and technology development studies that have been incorporated into the model.	2017 RWQM Update: Overview Report Annex A - Geochemical Source Term Methods	Section 2.2 Section 2.2
All	C-Permits - Note 3 B4 (a)	The Water Quality Model used in the EVWQP shall be updated at a minimum frequency of every three years, or more frequently as required, based on changes in the mine plan and/or when observed water quality and/or water quantity are frequently and significantly difference from predicted values.	2017 RWQM Update	Full Report
All	C-Permits - Note 3 B4 (b)	The Water Quality Model shall be updated to include:		
		• re-calibration and adjustment of the model based on relevant water quality and flow monitoring data to ensure conservatism is maintained	Annex C - Hydrology Modelling Annex D - Water Quality: Model Set-up and Calibration	Section 6 Section 5
		• refined hydrology, hydrogeology and geochemical source-term information (including refinements for cadmium source terms) together with any site-specific water balance models and hydrogeology studies	Annex A - Geochemical Source Term Methods Annex C - Hydrology Modelling	Full Report Full Report

Site	Permit	Requirements	Report that Requirement is Addressed In	Report Section
		• changes to the mine plan	Annex B - Site Conditions	Full Report
		• information and outcomes from research and technology development studies	2017 RWQM Update: Overview Report Annex A - Geochemical Source Term Methods	Section 2.2 Section 2.2
All	C-Permits - Note 3 Sec. B4 (c)	An Updated Water Quality Modelling Report with updated water quality predictions for key locations on the mine site and in the Elk River watershed, shall be submitted to the Chief Inspector by October 31,2017	2017 RWQM Update	Full Report
FRO	C-3 Amendment Fording Swift Mine Plan (15Dec15) Sec. C5 (b)	The water quality model shall be updated every three years with the first model update due October 31, 2017 or more frequently if required based on changes in observed water quality or new information.	2017 RWQM Update	Full Report
FRO	C-3 Amendment Fording Swift Mine Plan (15Dec15) Sec. C5 (c)	Future updates to the water quality model shall include projections of selenium, cadmium, nitrate, and sulphate for the duration of permitted mining activities at Fording River Operations.	Annex E - Water Quality: Future Projections	Full Report
GHO	C-137 Approving Cougar Pit Extension (29Apr16) Sec. C4 (b)	The water quality model shall be updated every three years with the first model update due October 31, 2017 or more frequently if required based on changes in observed water quality or new information.	2017 RWQM Update	Full Report
GHO	C-137 Approving Cougar Pit Extension	Future updates to the water quality model shall include projections of selenium, cadmium, nitrate, and sulphate for the duration of permitted mining activities at Greenhills Operations	Annex E - Water Quality: Future Projections	Full Report

Site	Permit	Requirements	Report that Requirement is Addressed In	Report Section
	(29Apr16) Sec. C4 (c)			
LCO	EMA 106970 Effluent (25Oct13) Section 5.5 Amendment letter issued 28Jun17	During operations, the Permittee must track waste rock placement, water quality and flow monitoring data to enable calibration, updating and refinement of the water quality predictions and model. The Permittee must complete the first water quality prediction report for Line Creek Operations and submit it to the Director, Environmental Protection by March 31, 2014. The water quality model must be formally reviewed and updated every three years thereafter, or more frequently based on changes in observed water quality. [Amendment letter issued June 28, 2017 regarding alignment of water quality model update with Permit 107517 date of October 31, 2017.]	2017 RWQM Update	Full Report
EVO	C-2 Amendment BRE Project (5Dec16) SecC5 (b)	The water quality model shall be updated every three years with the first model update due October 31, 2017 or more frequently if required based on changes in observed water quality or new information.	2017 RWQM Update	Full Report
EVO	C-2 Amendment BRE Project (5Dec16) C 5 (c) Letter BRE Water Quality Predictions (16Dec15)	Future updates to the water quality model shall include projections of selenium, cadmium, nitrate, and sulphate for the duration of permitted mining activities at Elkview Operations. [Letter detailed that life of mine water quality predictions (based on life of mine waste rock inventory) should be provided for currently approved projects (Base Case) as well as reasonably foreseeable proposed projects for the next twenty years (RFD Case).]	Annex E - Water Quality: Future Projections	Full Report

1. RWQM - Elk Valley Regional Water Quality Model; n/a - not applicable
2. Environmental Management Act Permit 107517, revised 5Jun17.
3. Common requirement to the following C-Permits: FRO C-3 Amendment Water Quality and Calcite Mitigation (27Nov14) ; GHO C-137 Amendment Water Quality and Calcite Mitigation (27Nov14) ; LCO C-129 Amendment Water Quality and Calcite Mitigation (27Nov14); EVO C-2 Amendment Water Quality and Calcite Mitigation (27Nov14); CMO C-84 Amendment Water Quality and Calcite Mitigation (27Nov14)

2 Geochemical Source Terms

2.1 Focal Areas and Approach

The geochemical characterization and source term methodology for Teck's Elk Valley operations is summarized below and detailed in the *Geochemical Source Term Methods and Inputs for the 2017 Update of the Elk Valley Regional Water Quality Model* (Annex A; SRK 2017) report. The focus areas of the geochemistry update in support of the 2017 RWQM update were:

- on the conceptual model;
- on catchment specific source terms for subaerial (unsaturated) waste rock, and
- on update of cadmium and cobalt source terms.

The goal was to use recent learnings to improve the calibration for nitrate specifically, and to improve tributary scale projections for all constituents.

The approach was to incorporate learnings from the Applied R&D Program to update the conceptual model for water quality constituent release. This updated conceptual model was applied by adjusting the source term equation for nitrate, and then, since it was a hydraulically driven change, applied the same concepts to selenium and sulphate. The data used to develop the geochemical source terms and how these terms fit into the overall model development framework are illustrated on Figure 2-1.

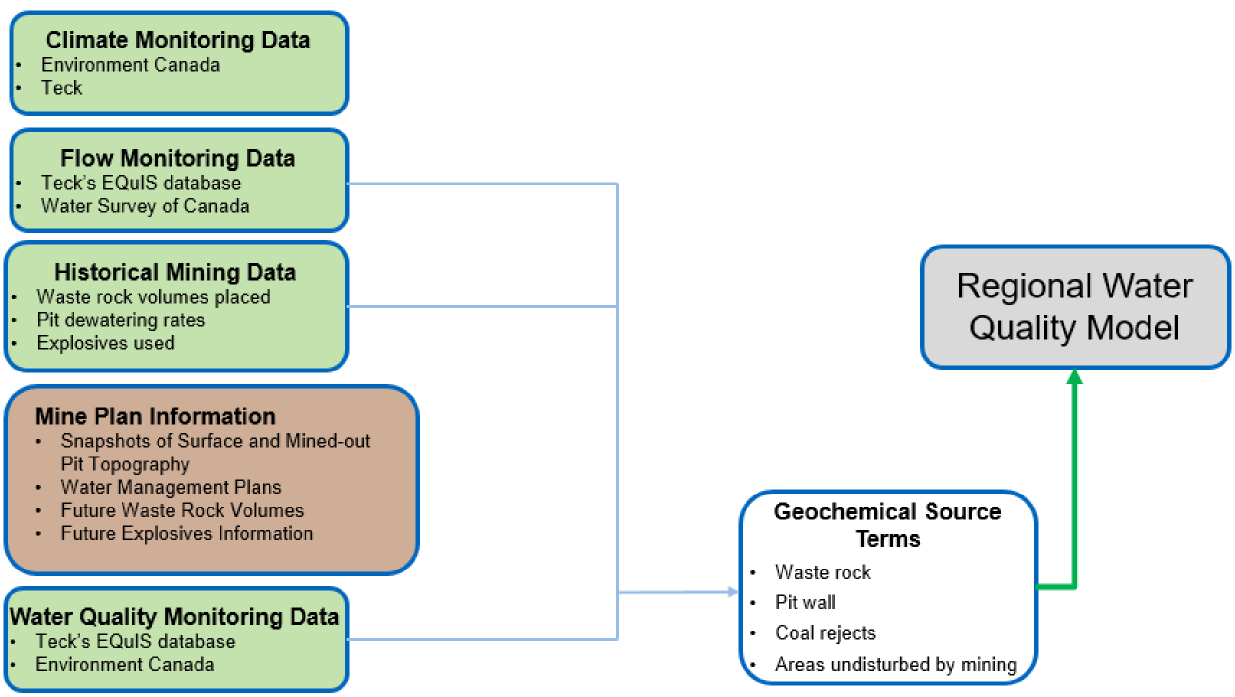


Figure 2-1 Geochemical Source Terms – Input Data and Components

2.2 Resulting Changes to Geochemical Source Terms

The main changes to the source term methods are summarized below:

- The waste rock source terms are now catchment specific, rather than generic, to the affected catchments in the Elk Valley.
- The methods used to fill gaps in the flow and chemistry monitoring databases and subsequent calculated release rates, has been updated to produce an interpolated data set, rather than the stepped data record used to inform previous release rates.
- The methods now incorporate aspects of the conceptual model linked to hydrological factors that result in delay of appearance of loading due to non-instantaneous movement of infiltrating water through the waste rock. Nitrate has been evaluated as an indicator of the hydrologic controlled lag in loading, which has been applied to the calculation of selenium and sulphate release rates.
- The period over which residual nitrate in the unsaturated waste rock is released been updated. This mass is now assumed to be depleted equally over the ten years following placement (10% of the initial load placed removed per year).
- Loading distribution for annual release rates were provided for a weekly timestep (formerly provided for a monthly timestep).
- Solubility constraints for selenium, linked to gypsum precipitation, have been removed.
- The conceptual model specific to calcite precipitation has been refined and used to support the update for the cobalt and cadmium source terms.
- Fixed concentrations for nitrate and selenium were applied to seepage from FRO South Tailings Pond.

The source terms for the backfilled and subaqueous waste rock, rehandled waste rock, pit walls, and coal rejects were not substantially changed in this model update. The methods for the derivation of these source terms and the underlying conceptual models are detailed in SRK (2017) but are not summarized in this overview report.

A summary of the updates to the source terms between the EVWQP model and 2017 RWQM update are provided in Table 2-1. These modifications to the source terms have enhanced the model’s ability to account for the hydrological processes that effect the release and transport of the constituents of interest within a waste rock dump and have accounted for the variation in other factors, such as local climate influences, waste rock dump construction, and minor variation in geochemical processes, between sites.

The greatest change in the geochemical conceptual model that forms the basis for the 2017 RWQM is the revised understanding of the hydrological aspects of unsaturated waste rock, which result in a “*delay in appearance of chemical loading* [of nitrate, selenium, and sulphate] *due to travel time of infiltrating water*” (SRK 2017). The revised concepts were developed by the University of Saskatchewan and “*uses nitrate trends to indicate the delay in loading which was assumed to be a consistent delay for the release of selenium and sulphate*” (SRK 2017). These concepts are expanded upon in Annex A: *Geochemical*

Source Term Methods and Inputs for the 2017 Update of the Elk Valley Regional Water Quality Model (SRK 2017).

These delay concepts have been incorporated into the unsaturated waste rock source terms for nitrate, as well as for selenium and sulphate. The sources of nitrate (residuals from blasting) differ from selenium and sulphate (released due to oxidation of pyrite); however, analysis of the data supports a unified approach to the revision of these source terms. The primary difference is that the nitrate source loading is assumed to be depleted equally over the 10 years following placement (10% of the initial load placed removed per year), whereas the selenium and sulphate release rates remain constant. Gypsum solubility constraints were assessed for sulphate and were incorporated into the RWQM at the first point downstream of the waste rock dumps, effectively removing loads that exceed maximum possible concentrations. Solubility constraints were not applied to selenium in the 2017 RWQM update, which is a change compared to the methods for the EVWQP model.

The incorporation of the catchment specific hydraulic time lag into the source terms for nitrate, selenium, and sulphate has resulted in improved calibration with modelled concentrations more closely matched to measured concentrations and trends over time (summarized in greater detail in Section 5 Water Quality: Model Set-up and Calibration). The incorporation of the time-release component to the nitrate source term has further improved calibration for this water quality constituent, as the model is better able to replicate the gradual increase and decrease in receiving water concentrations. Tributary specific release rates for selenium and sulphate tend to be higher in the 2017 RWQM, which has resulted in improved calibration within the tributaries compared to the EVWQP model.

Table 2-1 Summary of Updates to the Source Terms between EVWQP model and 2017 RWQM Update

Description	2014 EVWQP Model	2017 RWQM
Sources	Waste rock, benched Mist Mountain Formation (MMF) pit walls, re-handled waste rock, coarse coal rejects	Waste rock, MMF and non-MMF benched and unbenched pit walls, re-handled waste rock, coarse coal rejects, and tailings
Spatial representation.	Regional average.	Catchment specific.
Data record available for assessment.	1995 to 2011.	1995 to 2016.
Data interpolation method.	Stepped interpolation between two measured data points whereby missing daily values were assigned the same value as the closest preceding measurement.	Linear interpolation between two measured data points.
Tributaries included.	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.	FRO_HC1, FRO_KC1, FRO_CC1, GHO_CC1, GHO_GH1, GH_LC2, GHO_SC1, GHO_PC1, GHO_TC1, GHO_WC2, LCO_DC1, LCO_WLC, LCO_LCUSWLC, EVO_BC1, EVO_DC1, EVO_HC1, EVO_SM1, EVO_GT1, EVO_EC1, CMO_CC1.
Solubility constraints.	Gypsum solubility limit constrained maximum SO_4 and Se concentrations.	Gypsum solubility limit constrained maximum SO_4 concentration. Control for Se was removed from the model pending further research.

Description	2014 EVWQP Model	2017 RWQM
Assumptions of time related release of NO_3.	NO_3 leaching assumed to report to seepage within a year of placement as per Ferguson and Leask (1988). Leaching rate decreased exponentially as a function of the average age of the waste pile.	NO_3 initial time delay factor incorporated to reflect hydrological factors and influence of waste placement methods. Tributary specific initial time delay estimated from monitoring data and waste placement histories. Leaching rate assumed to spread over finite period of time estimated as 10 years.
Assumptions of time related release of SO_4 and Se.	None applied	Initial leaching delay as derived from NO_3 monitoring record applied to initial release of SO_4 and Se.
Calcite precipitation	Not considered	Used to calculate instream cobalt concentration. Assumes calcite precipitation in months of August through April.
Time step used for load distributions.	Monthly	Weekly
Cadmium concentration	Fixed annual concentrations represented by P50 and P95 for all data available.	Fixed concentrations represented by P5, P50, and P95 for all data available.[a]
Cobalt concentration	Fixed annual concentrations represented by P50 and P95 for all data available.	Fixed seasonal concentrations represented by P5, P50 and P95 for all data available when calcite is precipitating. When calcite is precipitating, calculated from proportion of Morrissey Formation (MF) in waste rock and sulphate.[a]

P5 – 5th percentile, P50 – 50th percentile, P95 – 95th percentile.

3 Site Conditions

Historical mining information and future mine plans, site conditions, and water management activities have been input to the 2017 RWQM update to support the calibration process and projection of future water quality conditions in the Elk Valley. The site conditions are detailed in the *Site Conditions* (Teck 2017a) report provided in Annex B and the permit required documentation specific to the current and projected waste rock volume by drainage and changes to the mine plans for are summarized here.

The mine development plans, through the 20 year planning window, listed in Table 3-1 have been included in the 2017 RWQM update; based on 2016 mine plans.

Table 3-1 Mine Plans Included in 2017 RWQM Update

Operation	Existing or Future Development Project
FRO	Turnbull West, part of Turnbull East
	Eagle 6
	Lake Mountain
	Swift
	Castle
GHO	Cougar South (Historical Cougar North Pit and Phases 3 to 6)

Operation	Existing or Future Development Project
	Cougar North (Phases 7 to 11)
LCO	Mine Service Area Extension, North Line Creek Extension, Burnt Ridge Extension in Phase I
	Burnt Ridge North 1, 2, and 3 Mount Michael 1, 2, 3 in Phase II
EVO	Natal Pit, Baldy Ridge Pit, and Adit Pit
CMO	Coal Mountain

The current and projected waste rock volumes for each operation are summarized in Table 3-2.

Table 3-2 Cumulative Waste Rock Volumes

Operation	EVWQP Waste Rock [million BCM]		2017 RWQM Update Waste Rock [million BCM] [a,b]	
	2013[c]	2034[c]	2016[c]	2037[c]
Fording River [d]	2,674	4,901	2,910	5,336
Greenhills[d]	441	1,507	605	1,431
Line Creek	601	1,411	713	1,386
Elkview	1,444	2,847	1,645	3,140
Coal Mountain	272	893	308	311
Total	**5,432**	**11,559**	**6,181**	**11,604**

(a) Annual waste rock placement by drainage schedules are included in Appendix A of Annex B.

(b) Does not include rehandled waste rock

(c) End of the year (e.g. 12/31/2016)

(d) Waste rock placed in the Swift and Cataract watersheds by both Fording River and Greenhills are listed in this table as part of Fording River.

The changes in mine plans between the EVWQP submission and the 2017 RWQM update are summarized in Table 3-3.

Table 3-3 Changes to Site Conditions between the EVWQP and the 2017 RWQM Update

Theme	EVWQP	2017 RWQM Update
Planning Period	2014 to 2034	2017 to 2037
Pits	FRO: Turnbull South, Eagle 6, Swift GHO: Cougar North Extension, Cougar North, Cougar South LCO: Mount Michael 1, 2 and 3, Burnt Ridge 2, 3 and 4 EVO: Cedar, Baldy Ridge, Natal, Adit CMO: Wheeler, Marten, Marten Ridge	FRO: Turnbull (South, West, East), Eagle 4, Eagle 6, Lake Mountain, Swift GHO: Cougar South (historical Cougar North, Phases 3, 4, 5, 6), Cougar North (Phases 7 to 11) LCO: Phase I: Horseshoe Ridge, Burnt Ridge South, Mine Services Area West, South; Phase II: Mount Michael 1, 2 and 3 pits, Burnt Ridge 1, 2 and 3 EVO: Baldy Ridge, Natal, F2, Adit CMO: 6, 14, 34 and 37
Waste Rock Volumes	Planned waste rock during planning window (2014-2034)	Includes all planned and permitted waste rock within the 20-year planning window (2017-2037), as well as residual permitted waste rock beyond 2037.
Groundwater	Included for FRO (for the Swift Project)	Included for FRO (for the Swift Project), GHO (for the CPX project) and EVO (for Natal pit, Baldy Ridge pits and Cedar pit)

BRE = Baldy Ridge Extension; CPX = Cougar pit Extension.

4 Flow Model

4.1 Model Configuration

The RWQM flow model (Flow Model) was developed to provide the input flow series for the RWQM. The Flow Model has been updated for the 2017 RWQM update in accordance with the EMA Permit 107517 and C-Permit requirements and improvements to the model have been made specific to the Flow Model calibration resulting in corresponding improved confidence in future water quality projections.

The Flow Model was used to generate estimates of historical and future flows for the receiving environment in the Elk Valley (i.e., the Elk River and Fording River) and for tributaries directly affected by historical or future mining activities. Historical flows are used as inputs to the RWQM to support the calibration process under observed conditions. Future flows are estimated for average, low and high flow conditions and used as inputs to the RWQM to determine a corresponding range of water quality projections for the 20-year planning window (i.e., 2017 to 2037).

The Flow Model uses two flow estimation methods to generate historical and future flows: (i) the analogue watershed (representative hydrograph) method; and (ii) the scaling method. The choice of method varies depending on the location where flows are estimated.

A hydrograph is defined as a graphical representation of surface discharge (flow rate) over time and is developed for a specific location in a creek or river. The shape of a hydrograph is influenced by the catchment specific properties that include, but are not limited to, slope, land cover and land use, and local and regional climatic influences. Hydrographs for well-defined watersheds can be used to represent flows in watersheds with similar characteristics that have limited site specific flow data. These are referred to as analogue watersheds. Analogue watersheds in the Flow Model were selected for the following characteristics: well-defined boundaries, one predominant land use (i.e. natural or mine-affected), and a strong historical flow data record. They have similar characteristics to watersheds with limited or no flow data records (called “target watersheds”). The data from each analogue watershed were used to derive one or more “representative hydrographs”. Representative hydrographs were assigned to the natural and mined areas within a target watershed, and flow contributions from each land type were estimated by adjusting the representative hydrograph for differences in drainage area, elevation and timing of freshet. The total flow from the target watershed was estimated by summing the adjusted natural and mined area flow contributions. Flows at a model node were estimated by adding the contributions from upstream watersheds.

The analogue watershed method was applied to ungauged or data limited watersheds where historical and future mining activities have a notable influence on flow. This method was used for the entire Fording River watershed, which includes the entire Fording River Operations (FRO) and Line Creek Operations (LCO), and a portion of Greenhills Operations (GHO). Similarly, flows for the entire Michel Creek watershed were estimated using this method, which includes the entire Coal Mountain Operations (CMO) and a portion of Elkview Operations (EVO). Further, Elk River tributaries affected by current or future mining activities at GHO and EVO were also modelled using the analogue watershed method.

The scaling method for estimating flows consists of using monitored data directly or by pro-rating flows from gauged stations. Pro-ration of flows is a method of adjusting flows based on the area contributing to the point of interest compared to the area contributing to the location where the flows are gauged. The scaling method was used for regional nodes (i.e., Elk River and other Koocanusa Reservoir tributaries), where future mining activities are expected to have a negligible influence on the current flow regime, and where available flow data records are strong and considered to be representative of both historical and future flow conditions. These regional nodes are characterized by relatively large contributing drainage areas, with small mine-affected areas and small projected increases in mine-affected area. For instance, at the Elk River node downstream of Michel Creek, the current mine-affected area is less than 5% of the watershed. For these regional nodes, historical and future flow statistics are derived using data from long-term hydrometric stations, and scaled by watershed area to determine flow at the nodes. This approach was selected for the Elk River and other Koocanusa Reservoir tributaries because it is expected to be more accurate than the analogue watershed approach. The data used to develop the Flow Model and how these terms fit into the overall model development framework are illustrated on Figure 4-1.

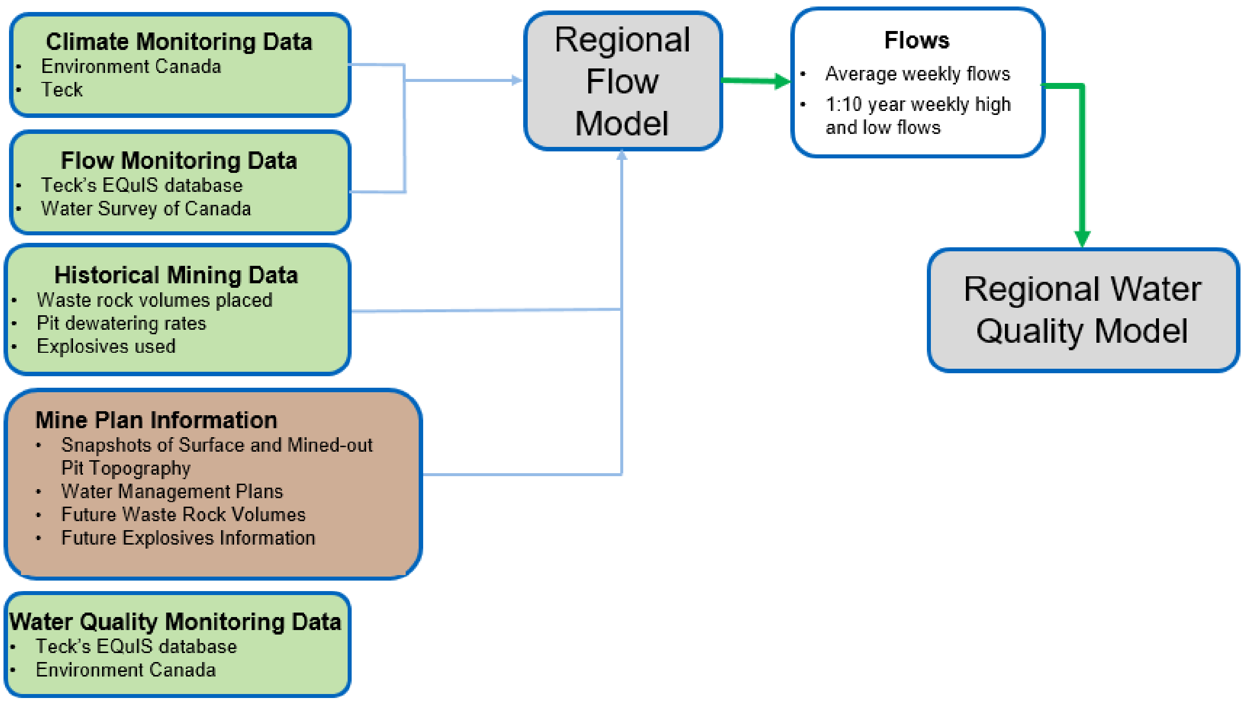


Figure 4-1 Flow Model – Input Data and Components

4.2 Focal Areas and Approach

The Flow Model updates were focused on meeting the EMA Permit 107517 and operation specific C-Permit requirements for the three-year RWQM update and on addressing feedback received from external third-party reviewers, regulators, and the KNC. The 2017 Flow Model update included both changes to the model calculations, as well as updated input data (e.g. mine plans, more recent monitoring data).

Three focal areas of improvement to the Flow Model were identified: (i) spatial variability; (ii) timing and magnitude of freshet flows; and (iii) winter flow estimates. The following improvements were implemented in the 2017 RWQM version of the Flow Model to address these items.

(i) New analogue watersheds were added to the Flow Model and new representative hydrographs were derived. The existing assignment of analogue watersheds was reviewed and refined. These changes improve the Flow Model's ability to represent the observed spatial variability in hydrologic response across the Elk River watershed.

(ii) Input data (i.e., representative hydrographs) used in the Flow Model and the modelling time step were both changed from monthly to weekly. This change resulted in improved accuracy during freshet flows, both in terms of timing and magnitude.

(iii) Baseflow adjustments were applied in the Fording River watershed to improve calibration during low flows.

The 2017 RWQM update also considered internal feedback from Teck to improve the model's applicability for secondary uses such as determining hydrologic effects of planned projects to support environmental assessment or other regulatory permit applications.

The Flow Model update was conducted as follows:

- Step 1: Review and compile available flow and climate data from Environment Canada and Teck stations.
- Step 2: Select analogue watersheds for natural area analogues (watersheds with negligible mining influence) and mine area analogues (watersheds with predominant mining influence).
- Step 3: Derive input hydrographs and statistics.
- Step 4: Complete preliminary evaluations on the monthly vs. weekly time step change, on new analogue assignments, verify yield evaluation relationship, and complete initial model checks.
- Step 5: Update mine plan inputs for the recent historical period (2013 through 2016), for 2016 life-of-mine plan information, and update water management information (historical and planned).
- Step 6: Calibrate and verify model performance. Updated historical flow series by watershed are evaluated based on goodness of fit and graphical methods via a comparison to monitoring data and previous model results. Adjustments are made to the assignments of analog watersheds, freshet timing, yield adjustments and base flow adjustments.
- Step 7: Generate future flow projections by watershed for three flow conditions (average, low, and high).
- Step 8: Generate results for input to water quality model, which include the historical flow series, and future flow projections for the three flow conditions.

The iterative process focuses on Step 5 through Step 8, with model adjustments made based on the model predictions compared to monitoring data and based on feedback from the water quality model calibration process.

4.3 Resulting Changes to the Flow Model

The updates to the Flow Model between the EVWQP model to support the EVWQP and the 2017 RWQM update are provided in Table 4-1 (Source: Table 3-2 of Annex C, Hydrology Model (Teck 2017b).

Table 4-1 Summary of Updates to the Flow Model between the EVWQP model and the 2017 RWQM Update

Description	2014 EVWQP Flow Model	2017 RWQM Update Flow Model
Model Time Step	Monthly	Weekly
Period for Model Calibration	1995 to 2012	1995 to 2016 (2016 data are preliminary)
Period for Deriving Flow Statistics	1995 to 2010 (up to 2012 in some instances)	1995 to 2015 (2016 was not included because available data were preliminary)

Description	2014 EVWQP Flow Model	2017 RWQM Update Flow Model
Watersheds	Fording River (excluding Line Creek) and Michel Creek watersheds. All affected Elk River tributaries at GHO and EVO.	Included additional watersheds at GHO, EVO, and CMO. Increased watershed detail at LCO Phase I (Line Creek).
Water Management Activities	Level of detail appropriate for quantifying regional effects	Increased level of detail all sites (using information gathered for various regulatory applications between 2014 and 2016)
Pit Seepage and Groundwater Flow Changes from Future Mining	Included for FRO (based on modelling completed for the Swift Project)	Included for FRO (based on modelling completed for the Swift Project). Also included for GHO and EVO based on modelling completed for the Cougar Pit Extension (CPX) and Baldy Ridge Extension (BRE) Projects.
Representative Hydrograph for Natural Areas	Based on LCO-Dry Creek for FRO, GHO and LCO Phase 2 Based on Hosmer Creek for EVO, CMO and CMO2	Added new representative hydrographs based on Line Creek (LCO, FRO), LCO Dry Creek (LCO), Harmer Creek (EVO) and updated the EVWQP Model representative hydrographs based on Hosmer Creek (CMO, EVO) and LCO Dry Creek (FRO, GHO).
Representative Hydrograph for Mined Areas	Single representative hydrograph based on Cataract Creek	Single representative hydrograph based on Cataract Creek adjusted to reflect changes in yield from one analogue to another.
Scaling Methods	Elk River nodes, Koocanusa Reservoir tributaries and Line Creek (LCO Phase 1)	Elk River nodes, Koocanusa Reservoir tributaries

4.4 Flow Model Calibration Results

Flow model performance was evaluated through review of the calibration results, including a statistical comparison of model projections to historical monitoring data. Flow Model performance was evaluated using a combination of standard goodness-of-fit statistics (e.g., Nash-Sutcliffe Efficiency) and graphical techniques (e.g., mean flow hydrographs), which are explained in detail in Section 6 of the *2017 Elk Valley Regional Water Quality Model Update – Annex C – Hydrology Modelling* (Teck 2017b).

The performance of the 2017 RWQM Flow Model is consistently better than or comparable to the EVWQP model. The update to simulate weekly flow resulted in the biggest improvement, particularly with respect to the model's ability to replicate spring freshet conditions. The monthly timestep in the previous models resulted in calibration issues for both hydrology and water quality over this same timeframe. The other area of improvement is related to the inclusion of more representative hydrographs (analogue watersheds) and/or refinements to existing ones, resulting in more representative tributary flows. Performance typically ranges from acceptable to very good along the main stem nodes of the Fording River, Line Creek, Michel Creek and the Elk River. Model performance ranges from poor to acceptable in the Fording River tributaries. There are still a few nodes where model performance falls short (e.g., the Elk River tributaries at GHO, and winter flow predictions at some nodes).

The performance of the Flow Model at the regional (main stem) scale is verifiably strong. Flow Model performance was typically rated between "acceptable" and "very good" along the main stem receiving environment nodes of the Fording River, Line Creek, Michel Creek and the Elk River based on the Nash Sutcliffe Efficiency. Confidence in the calibration of the Flow Model for these regional nodes is high. Model performance at all Fording River nodes was improved over the EVWQP model (where comparisons were possible). Similarly, performance at Elk River and Michel Creek nodes was comparable to or better than the EVWQP model.

The performance of the Flow Model at the local (tributary) scale is variable and subject to higher uncertainty, compared to the regional scale. Model performance ranges from “poor” to “acceptable” in the Fording River tributaries, based on the Nash Sutcliffe Efficiency. There are still a few nodes where model performance falls short (e.g., the Elk River tributaries at GHO, and winter flow predictions at some nodes). Model performance can be verified where the local hydrological conditions are well understood and there are sufficient monitoring data to support the evaluation. Poor ratings at data limited nodes indicate a poor match between modelled and monitored data but do not account for the quality of monitored data. At data limited nodes, the quality of monitored data may be affected by data gaps, high infiltration rates (flow bypassing the gauge), measurement accuracy and uncertainties in watershed conditions. A poor rating does not necessarily indicate that the model performance is unacceptable, and should be understood in the context of the watershed, the data available, and the quality of the data. These factors are described in greater detail in the *2017 Elk Valley Regional Water Quality Model Update – Annex C – Hydrology Modelling* (Teck 2017b). The uncertainty introduced by poor model performance is reduced due to feedback during the calibration of the water quality model. For instance, calibration of the Flow Model was adjusted in the lower Fording River tributary watersheds to improve water quality model calibration during winter. Further, the water quality model considers a range of flow scenarios for future projections as a way to account for the potential for errors in input data and to incorporate sensitivity to flow projections in planning. This step helped to eliminate or limit systematic modelling errors that would influence the RWQM performance.

5 Water Quality: Model Set-up and Calibration

5.1 Focal Areas and Approach

The RWQM update was focused on meeting the EMA Permit 107517 and operation specific C-Permit requirements for the three-year RWQM update and on addressing feedback received from external third-party reviewers, regulators, and the KNC. The 2017 RWQM update is inclusive of the changes incorporated into the geochemical source terms and the Flow Model, which are detailed in Section 2 and Section 4, respectively. The focus area of the 2017 RWQM update was initially on modifications to the model structure to accommodate changes in model inputs. The focus then shifted to improving the model calibration (in the tributaries and in the Fording River, Elk River, and Koocanusa Reservoir), with the objective of improving model representation of spatial variability in water quality through the Elk Valley. The approach incorporated the following information:

- three additional years of flow and water quality data into the Flow Model and geochemical source terms;
- improved Flow Model inputs with respect to spatial variability, the timing and magnitude of spring freshet flows, and winter low flow estimates;
- catchment specific geochemical source terms for unsaturated waste rock with weekly loading distributions for water quality constituents provided as release rates (nitrate, selenium, and sulphate).
- catchment specific hydrologic time lag for unsaturated nitrate, selenium, and sulphate waste rock source terms. The nitrate source terms were also updated to include a time-release component to

enable the model to better replicate the gradual increase and decrease in receiving water concentrations for this parameter.

- catchment specific source terms for cadmium and cobalt based on the conceptual understanding that these water quality constituents co-precipitation with calcite.

Similar to the EVWQP model, a flow relationship was incorporated into the RWQM model. The flow relationship is based on observations from measured data that flow and load are positively correlated, that is, as flow increases, annual release rates also increase. This flow relationship was updated for the 2017 RWQM using the additional available data. The supporting analysis and resulting relationship for each water quality constituent is described in SRK (2017).

5.2 Resulting Changes to the Regional Water Quality Model

Key changes to the RWQM are presented in the previous section, as they informed the focus and approach to the model update. These changes, as well as the other changes made since the EVWQP model submission are summarized in Table 5-1.

Table 5-1 Summary of Updates to the RWQM between the EVWQP model and the 2017 RWQM Update

Description	2014 EVWQP Model	2017 RWQM
Model Time Step	• Monthly	• Weekly
Period for Model Calibration	• Nitrate: 2006 to 2012 • Other water quality constituents: 2004 to 2012	• Nitrate: 2006 to 2016 • Other water quality constituents: 2004 to 2016
Planning Period	• 2014 to 2034	• 2017 to 2037
Nitrate release from waste rock	• Nitrate release assumed to start as soon as waste rock placed in spoil • Yearly release rate derived using Ferguson and Leask method combined with an exponential decay curve that considers average waste rock age • Yearly release distributed over 12 months using a common monthly loading distribution that was applied, with few exceptions, to all modelled catchments	• Annual release rate based on estimated nitrate content in explosives residue accompanying each volume of waste rock placed into a spoil • Catchment specific initial lag between waste rock placement and detection of nitrate in the receiving environment, defined using monitoring data • Nitrate residuals assumed to wash out of a given volume of waste rock over a 10-year adjusted leach time • Annual release rates transformed into weekly rates using catchment-specific weekly loading distributions
Selenium and sulphate release from waste rock	• Release begins as soon as waste rock placed in spoil • Applied valley-wide average release rate to each modelled catchment, and then modified as required through calibration • Annual release rate transformed into monthly release rates using a common, valley-wide monthly loading distribution that was applied, with few exceptions, to all modelled catchments	• Catchment-specific initial lag, the same duration as calculated for nitrate, between waste rock placement and detection of selenium or sulphate in the receiving environment • Catchment-specific release rates, which are then modified as required through calibration • Annual release rates transformed into weekly rates using catchment-specific weekly loading distributions
Trace metal release from waste rock	• Common, valley-wide concentration-based source term for cadmium	• Operation-specific source term for cadmium • Catchment- specific source terms for cobalt • Defined largely as a set of monthly concentrations

Description	2014 EVWQP Model	2017 RWQM
	•	•
Water quality constituent release from pit walls	• All pit walls assumed to be of a similar type, with constituent release defined similar to waste rock	• Pit walls divided into five categories to account for influence of Morrissey Formation • Separate release rates developed for each category of pit wall
Constituent release from tailings storage	• Assumed to be the same as coal rejects	• Defined using recently collected monitoring data and modelled concentrations
Instream sinks	• Not considered	• Now included to reflect trends observed in monitored data collected from the Elk River and Fording River.
Retention areas	• A retention area is included in the Erickson Creek catchment to dampen seasonal variability in model projections, thereby better matching monitored information collected from the creek mouth	• Retention areas are included in the Cataract, Porter and Erickson Creek catchments, as well as between EVO Dry Creek and Harmer Creek, to dampen seasonal variation in model projections to dampen seasonal variation in model projections, thereby better matching monitored information
Water quality management incorporated in the model for evaluation	• Active water treatment • Covers • Clean water diversions and conveyance of mine-affected water as a means to support mitigation	• Active water treatment • Clean water diversions and conveyance of mine-affected water as a means to support mitigation • Source control through changes to blasting practices and changes to waste rock placement • Saturated rock fills • Consumptive water use in coal processing • Passive treatment via tailings pond storage

5.3 Model Calibration Process

The first component of model calibration is in the Flow Model. The initial calibration of the RWQM evaluation was conducted once the updated geochemical source terms and mine inputs were built into the model. The calibration was assessed based on the ability of the model to replicate the seasonality and concentration ranges for the measured data over the historical period. The calibration period spanned from 2004 through 2016 for most constituents of interest, and from 2006 through 2016 for nitrate, and covered a range of wet and dry years. The calibration process for water quality constituents with release rates (nitrate, selenium, and sulphate) differs from the process for concentration based source terms (cadmium, cobalt.).

Calibration of nitrate, selenium, and sulphate involved the adjustment of the geochemical release rates for unsaturated waste rock on a catchment specific basis. The performance of the model was repeatedly evaluated through a visual comparison of the simulated to measured data, along with an examination of error and bias. Consideration was given to the fact that the measured data represent water quality for a discreet period, with samples collected weekly or monthly, whereas the model data are representative of one week intervals.

Calibration factors were used to adjust the model inputs, in an iterative fashion, in order to systematically reduce error to make the model as accurate as possible. The model calibration is improved through adjustment of calibration factors that target the assumptions specific to the mass of nitrate assumed in the freshly blasted waste rock (not applied to the selenium and sulphate calibration process), the initial lag, and the weekly release distributions. The Flow Model inputs to the RWQM were reviewed, and adjusted if required, prior to the adjustment of the weekly release distributions. If adjustments to the weekly release distribution were required, adjustments were generally applied to catchments that had limited data or were specific to adjustments around freshet. The timing of load release is very sensitive in the weekly loading distributions and a one week (or more) offset between these rate distributions and the Flow Model onset of freshet can result in residual concentrations spikes or troughs in the RWQM.

Cadmium and cobalt release from unsaturated waste rock is solubility limited and the source terms were provided as monthly catchment specific concentrations. The cobalt source term was provided as a sulphate dependent calculation for the months of May through July, to account for the period that calcite is not precipitating, resulting in higher downstream cobalt concentrations. The initial calibration process for these constituents is similar to those with release rates, and includes a visual comparison of the simulated to measured data. Calibration statistics were not generated as a large number of cobalt monitoring data were non-detectable and it appears as through mining in the Elk Valley is not resulting in increasing concentration trends for these constituents.

The RWQM model maintains a mass balance as it simulates the transport of constituents downstream in the Fording and Elk rivers. The RWQM has shown a consistent and increasing over-estimation of measured selenium and nitrate concentrations with distance downstream in the Fording and Elk rivers, particularly during the winter. Evaluation of monitoring data have also indicated a consistent, historical pattern of selenium and nitrate concentrations that indicates a loss of mass during transport in the Fording and Elk rivers during winter. In order to calibrate the model to reflect monitoring data, an instream sink was added. The loss or removal of mass within a model is referred as a sink. If the mass (amount) of a constituent is removed during instream transport, it is referred to as an instream sink. Incorporating an instream sink within a model is an explicit (transparent) means of representing the instream loss of a constituent as water travels downstream within a river or stream to reduce positive model bias.

The comparison and calibration adjustments to best fit the historical monitoring data and the feedback mechanism between the RWQM, the Flow Model, and geochemical source terms are essential to the calibration process and results in more reliable future water quality projections. The goal of the calibration process was to reduce model error and bias, such that simulated concentrations reflected observed patterns, in terms of replicating seasonal variability, the observed range of concentrations over the period of interest and long-term temporal trends (if present). The calibration was deemed complete when efforts expected on iteration no longer yield appreciable or notable gains in model performance. Calibration results are presented in the Hydrology Modelling report (Annex C; Teck 2017b) and Water Quality: Model Set-up and Calibration report (Annex D; Teck 2017d).

5.4 Model Calibration Results

The performance of the 2017 RWQM is evaluated through review of the calibration results. It is consistently better than, or comparable to, the EVWQP model submitted in 2014. The improved performance is a product of the updates made to the water quality and flow components of the model, and the updated geochemical source terms. In particular, the incorporation of initial lag and adjusted leach time resulted in a step-change improvement in nitrate projections.

Modelled historical concentrations in mine-affected tributaries and in the Fording River and Elk River matched reasonably well with the measured data, in terms of replicating the range of measured concentrations and matching the seasonal, yearly, and longer-term trends. Similar to the Flow Model performance, there are nodes where model performance could be improved. These nodes tend to be for tributaries that have limited datasets for hydrology and/or water quality, or where more complex flow systems may be present that are not adequately characterized and implemented in the model. Recommendations for improvements have been made to address these potential data gaps.

An overview of the 2017 RWQM performance is provided in the following subsections. The model calibration results were assessed via visual comparison to historical monitoring results and through statistical analysis (error and bias). Each is explained below:

- Visual Comparison: The historical concentration time-series and the measured data were plotted and visually compared to assess if simulated results replicated the range of measured concentrations, and matched the seasonal and yearly trends in the measured data.
- Error and Percent Error: Model error was calculated as the average absolute difference between individual simulated and measured data points over the entire calibration period. Error provides an indication of model accuracy, in terms of its ability to simulate a given concentration at a given time. Conversion to percent error allowed comparisons between watercourses with widely differing instream concentrations. The error values are converted into percent error in order to easily compare model accuracy between watercourse with differing concentrations.
- Bias and Relative Bias: Model bias was calculated as the average difference between the individual simulated and measured data points over the entire calibration period. Bias provides an indication of whether simulated data tend to be higher or lower than measured data. Relative bias, similar to percent error, allows for meaningful comparisons between watercourses with differing concentrations.

There is a general over-prediction evident in the early winter 2014 time-frame. The error in the model during this period results from the manner in which the flow relationship is implemented. Flow years are defined as May through April to represent one hydrologic cycle and the average flows in the May 2013 through April 2014 flow year (2013 flow year) were higher relative to the longer-term average. The confounding issue was that the bulk of the flow was recorded in June and the model does not differentiate a high flow event from a high flow year. The 2013 flow year was represented as a high flow year and nitrate, selenium, and sulphate loading from waste rock was correspondingly increased over that entire time frame, resulting in a greater departure from measured concentrations. This type of error is not expected to affect future projections, because those scenarios are built assuming flows are either high or low every week of the year, rather than representing a high flow event (as that which occurred in 2013).

5.4.1 Model Calibration Results for Nitrate

The modelled historical nitrate concentrations for the Fording River, Elk River, and the tributaries matched reasonably well with measured data, in terms of visually replicating the range of measured concentrations and matching the seasonal, yearly, and longer-term trends.

The model performance with respect to its ability to replicate the range of measured nitrate concentrations and match seasonal, yearly, and longer-term trends in the tributaries and the Fording

River and Elk River is summarized in this section. Calibration plots are provided for several tributary model nodes on Figure 5-1 and for several locations within the Fording River and Elk River on Figure 5-2.

The RWQM, like any model, is a simplification of the natural system being represented. Factors contributing to model error for nitrate in particular, include uncertainties in the distribution of blasting residue within the waste rock spoils, and how evenly blasting residue is washed off materials within the spoils. The model assumption is that blasting residuals are evenly distributed and wash off evenly over a 10-year period. In reality, conditions are likely to be more heterogeneous, leading to small scale variability in nitrate release rates and downstream concentrations that are not captured by the model.

The calibration time-series results for the EVWQP model have been included on the graphs on Figure 5-1 and Figure 5-2 as a means for visually assessing the improvements in the calibration between that model and the 2017 RWQM (reference to 2014 RWQM in the graph legends is synonymous with the EVWQP model). The 2017 RWQM results show much better agreement with the measured concentrations at most sites, resulting in notable improvements in several years in the historical period. Graphs for all model nodes are provided in Appendix C1 of Annex D (Teck 2017c).

The ability of the model to replicate seasonal and long-term patterns in observed constituent concentrations for the mine affected tributaries is reflected in the relative bias statistics. The majority of the results for relative bias are between 0.9 and 1.1. The percent error statistics in some tributaries (e.g., Kilmarnock Creek, Cataract Creek, Erickson Creek) were lower, in the order of 15% to 30%. In other tributaries, such as Clode Creek and those discussed below, model error was larger, ranging from 30 to 111%.

In a few tributaries, simulated trends did not follow observed trends as closely. At GHO, this is likely a result of uncertainty in the simulated flows and/or pumping records available from the mine site. These differences did not adversely affect the ability of the model to simulate measured concentrations in the Fording River and Elk River. Similarly, model performance in LCO Dry Creek is not as strong as in other areas. However, spoiling has only recently begun in LCO Dry Creek and there are limited mine-affected data available against which to evaluate model projections.

The 2017 RWQM is able to accurately reflect observed seasonal and longer-term annual trends in nitrate concentrations in both the Fording River and Elk River, as well as simulate the measured range. The model has a tendency to over-predict nitrate concentrations during lower winter flow periods in the lower Fording River and most of the Elk River, when instream concentrations peak. The projections are more accurate than those produced with the EVWQP model, with a lower degree of over-prediction. Error and bias are low with average error ranging from 22% to 44% at compliance and Order Stations.

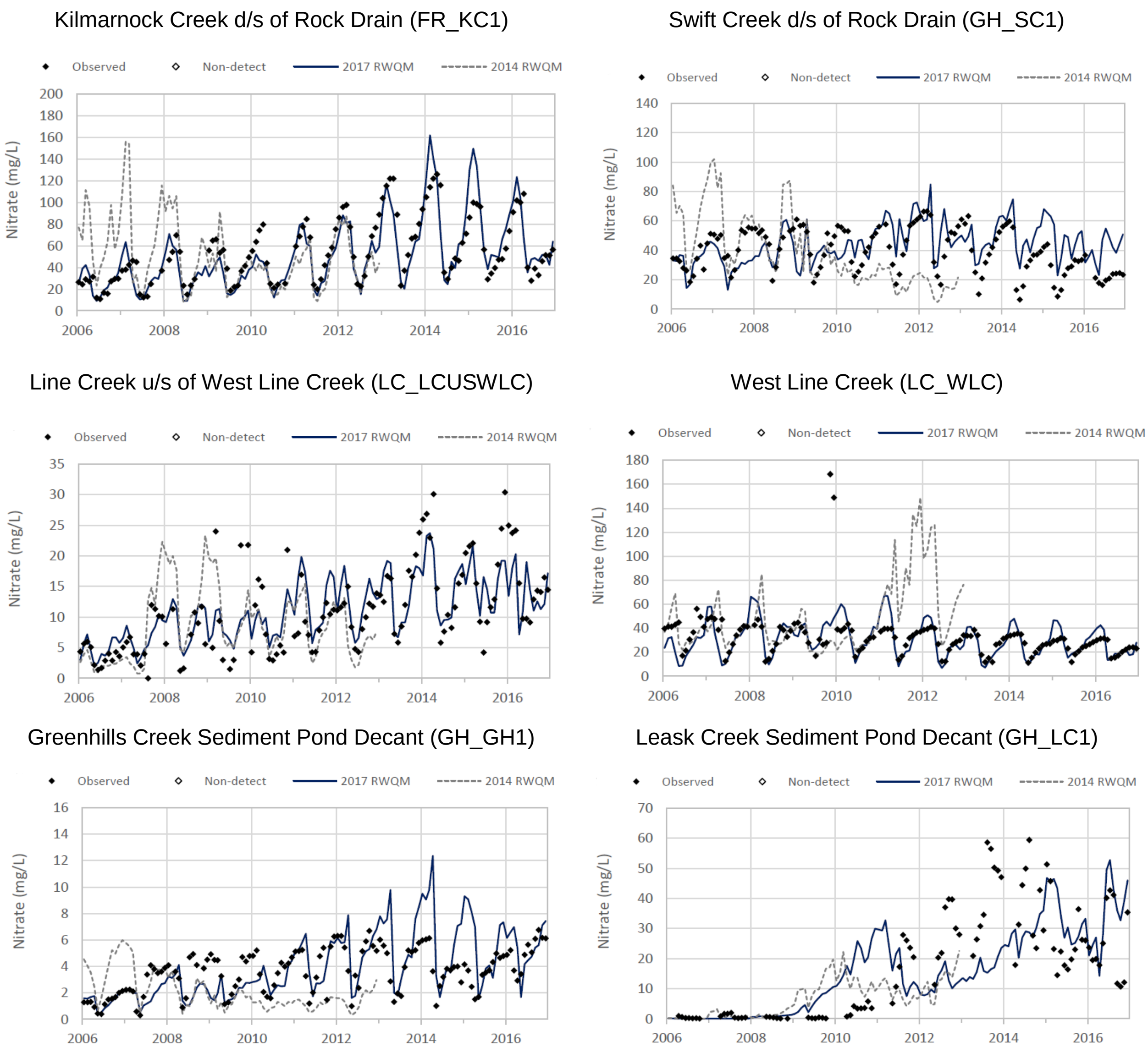


Figure 5-1 Nitrate Calibration Graphs for Kilmarnock Creek, Swift Creek, Line Creek, West Line Creek, Greenhills Creek, and Leask Creek, 2006 through 2016

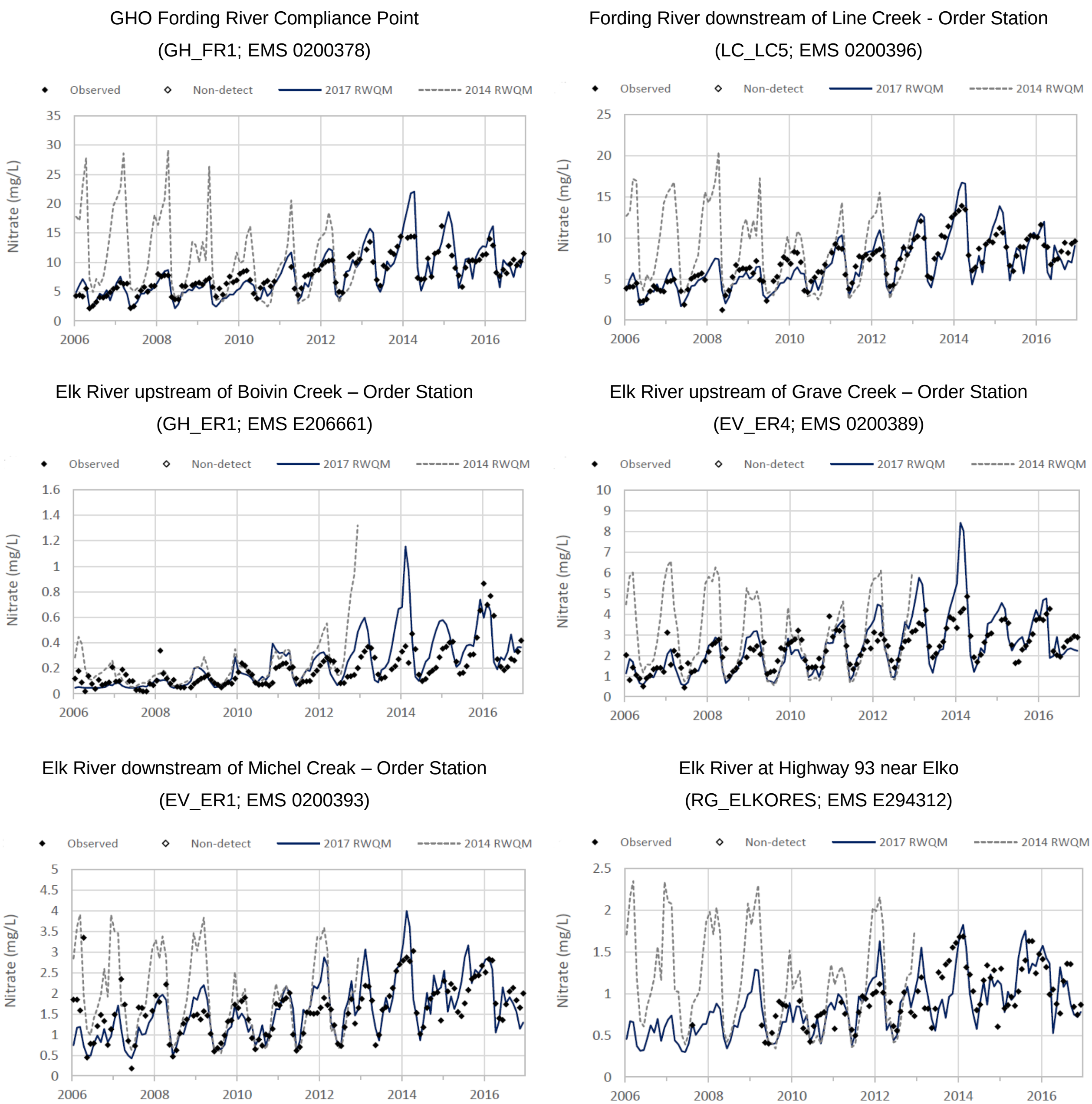


Figure 5-2 Nitrate Calibration Graphs for Locations within the Fording River and Elk River, 2006 through 2016

5.4.2 Model Calibration Results for Selenium

The model performance with respect to its ability to replicate the range of measured selenium concentrations and match seasonal, yearly, and longer-term trends in the tributaries and the Fording River and Elk River is summarized in this section. Calibration plots are provided for several tributary model nodes on Figure 5-3 and for several locations within the Fording River and Elk River on Figure 5-4. The selenium calibration time-series results for the EVWQP model have been included on the graphs on Figure 5-3 and Figure 5-4 as a means for visually assessing the improvements in the calibration between that model and the 2017 RWQM (reference to 2014 RWQM in the graph legends is synonymous with the EVWQP model). The 2017 RWQM results are in better agreement with the measured concentrations at most sites. Graphs for all model nodes are provided in Appendix C2 of Annex D (Teck 2017c).

The ability of the model to replicate seasonal and long-term patterns in observed constituent conditions for the mine affected tributaries is reflected in the relative bias statistics. Relative bias ranges between 0.85 and 1.2 and model error ranges from 14% to 68%. The model performance in simulating selenium levels in mine affected tributaries is improved from the EVWQP model. In a few tributaries at GHO, simulated selenium trends did not follow observed trends as closely, as described for nitrate above.

The 2017 RWQM is able to accurately reflect observed seasonal and longer-term annual trends in selenium concentrations in both the Fording River and Elk River, as well as simulate the measured range. The model maintained a near-neutral bias throughout most of the Fording River and Elk River, with some consistent under prediction in the upper Fording River, downstream of Henretta Creek. Model error in the Fording River ranged from 20 to 35% and in the Elk River, it ranged from 19% to 30%, with some over-prediction of observed winter conditions. This tendency to over-predict is particularly evident in early 2014, and results from the aforementioned item involving application of the flow relationship. Overall, the performance of the 2017 RWQM is comparable to or better than the EVWQP model.

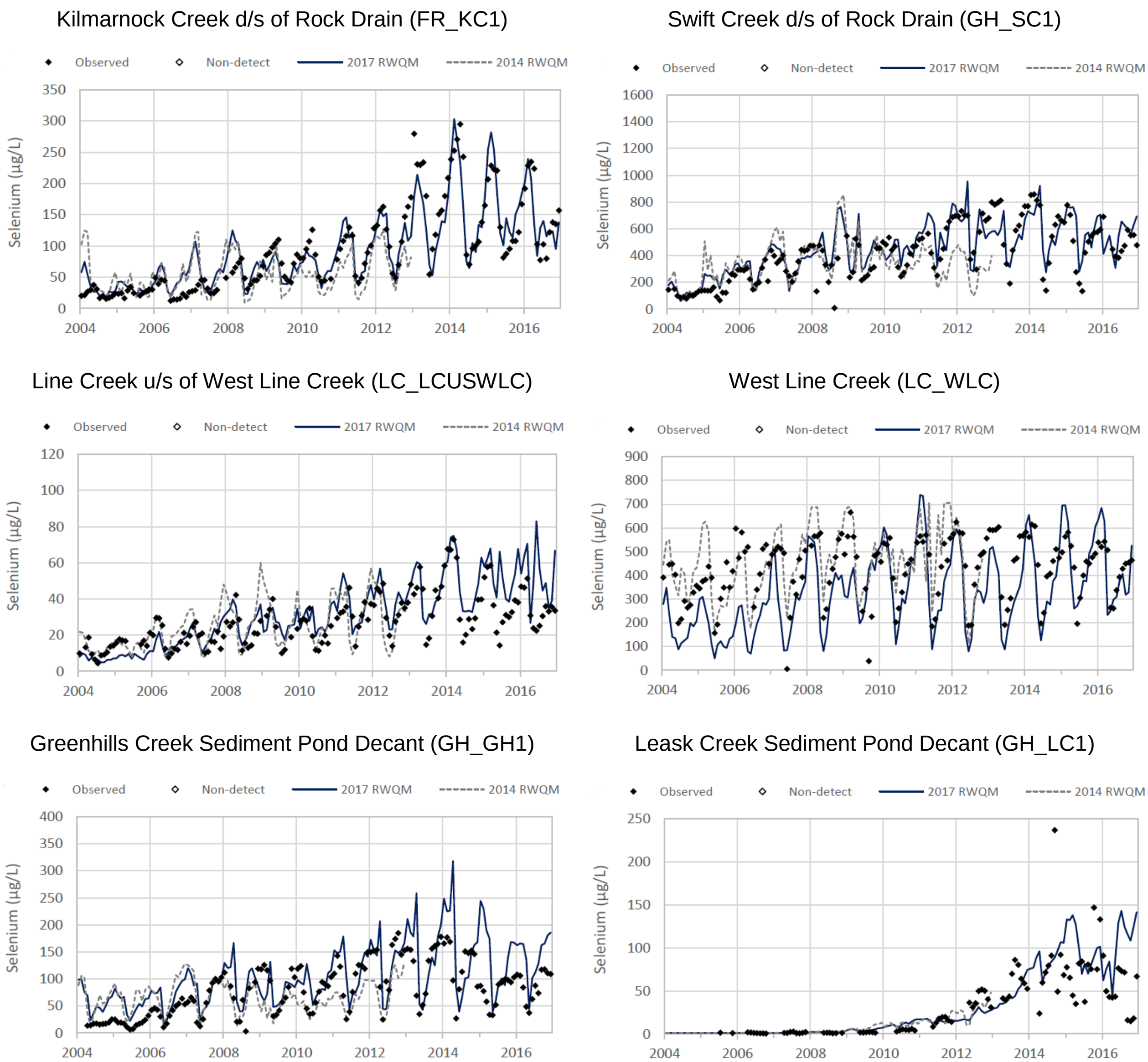


Figure 5-3 Selenium Calibration Graphs for Tributary Locations: Kilmarnock Creek, Swift Creek, Line Creek, West Line Creek, Greenhills Creek, and Leask Creek 2006 through 2016

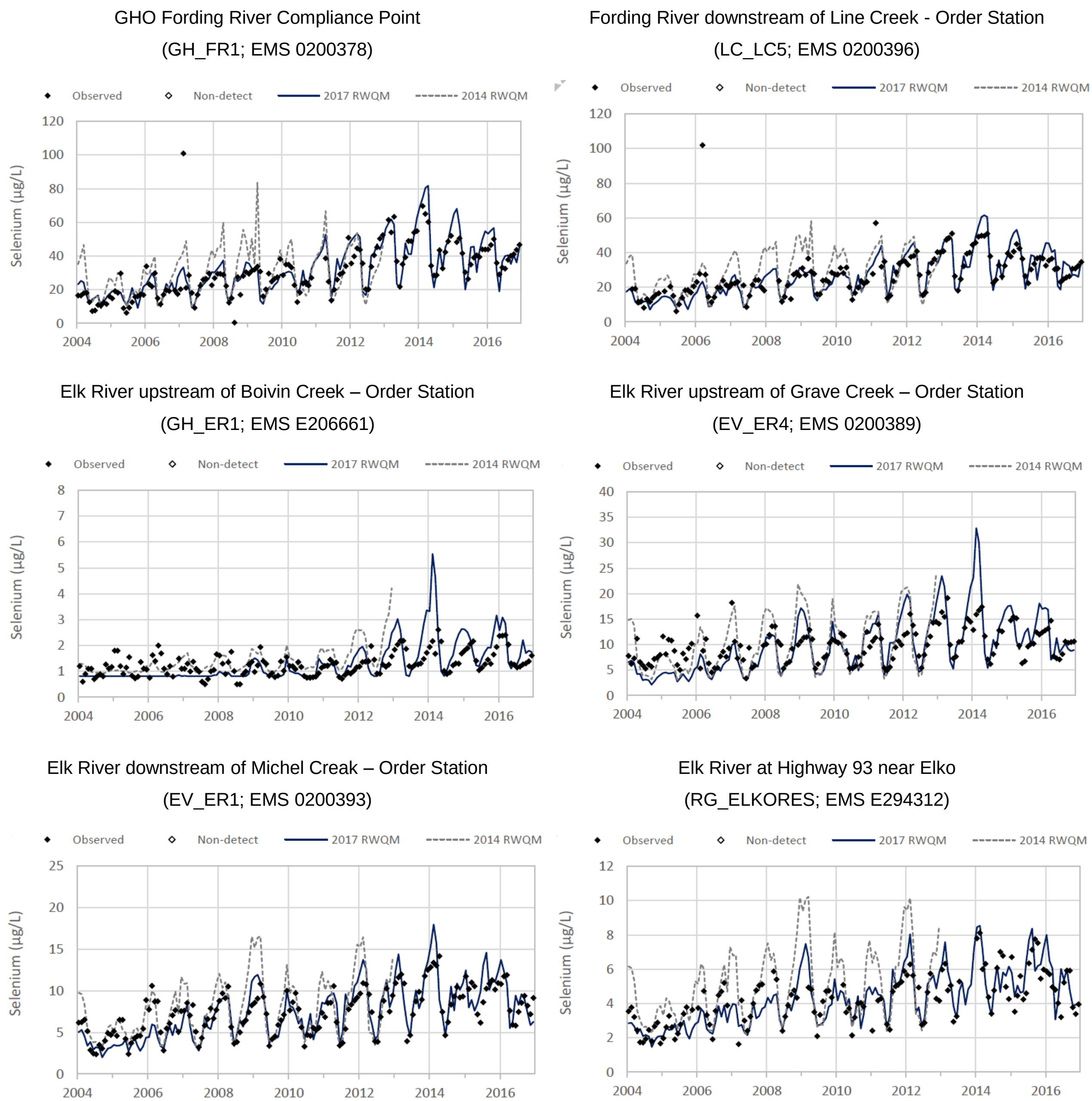


Figure 5-4 Selenium Calibration Graphs for Locations within the Fording River and Elk River, 2006 through 2016

5.4.3 Model Calibration Results for Sulphate

The model performance with respect to its ability to replicate the range of measured sulphate concentrations and match seasonal, yearly, and longer-term trends in the tributaries and the Fording River and Elk River is summarized in this section. Calibration plots are provided for several tributary model nodes on Figure 5-5 and for several locations within the Fording River and Elk River on Figure 5-6. The sulphate calibration time-series results for the EVWQP model have been included on the graphs on

Figure 5-5 and Figure 5-6 as a means for visually assessing the improvements in the calibration between that model and the 2017 RWQM (reference to 2014 RWQM in the graph legends is synonymous with the EVWQP model). The 2017 RWQM results are in better agreement with the measured concentrations at most sites. Graphs for all model nodes are provided in Appendix C3 of Annex D (Teck 2017c).

The ability of the model to replicate seasonal and long-term patterns in observed constituent conditions for the mine affected tributaries is reflected in the relative bias statistics. The majority of the results for relative bias are between 0.9 and 1.1 and model error ranges from 15% to 50%. These statistics generally indicate that RWQM is better able to replicate seasonal and longer-term patterns than individual measured data points. As previously noted, some of the model error stems from the fact that the model outputs are weekly average concentrations, whereas the measured data were collected by grab sampling, which represents an instantaneous concentration at the time of collection.

In several GHO tributaries, including in Leask Creek and Wolfram Creek, simulated trends did not follow the observed trends as closely. A similar pattern was noted for selenium and nitrate, and is likely a result of uncertainty in the simulated flows and/or pumping records available from the mine site. These differences did not detrimentally affect the ability of the model to accurately simulate measured concentrations in the Fording River and Elk River.

The 2017 RWQM is able to accurately reflect observed seasonal and longer-term annual trends in sulphate concentrations in both the Fording River and Elk River, as well as simulate the measured range. The model maintained a near-neutral bias throughout most of the Fording River and Elk River, with some over-prediction of observed in winter low flow conditions in the Elk River. This tendency to over-predict is particularly evident in early 2014, and results from the aforementioned item involving application of the flow relationship. Model error in the Fording River ranged from 17 to 27% and in the Elk River, it ranged from 19% to 24%. Overall, the performance of the 2017 RWQM is comparable to or better than the EVWQP model.

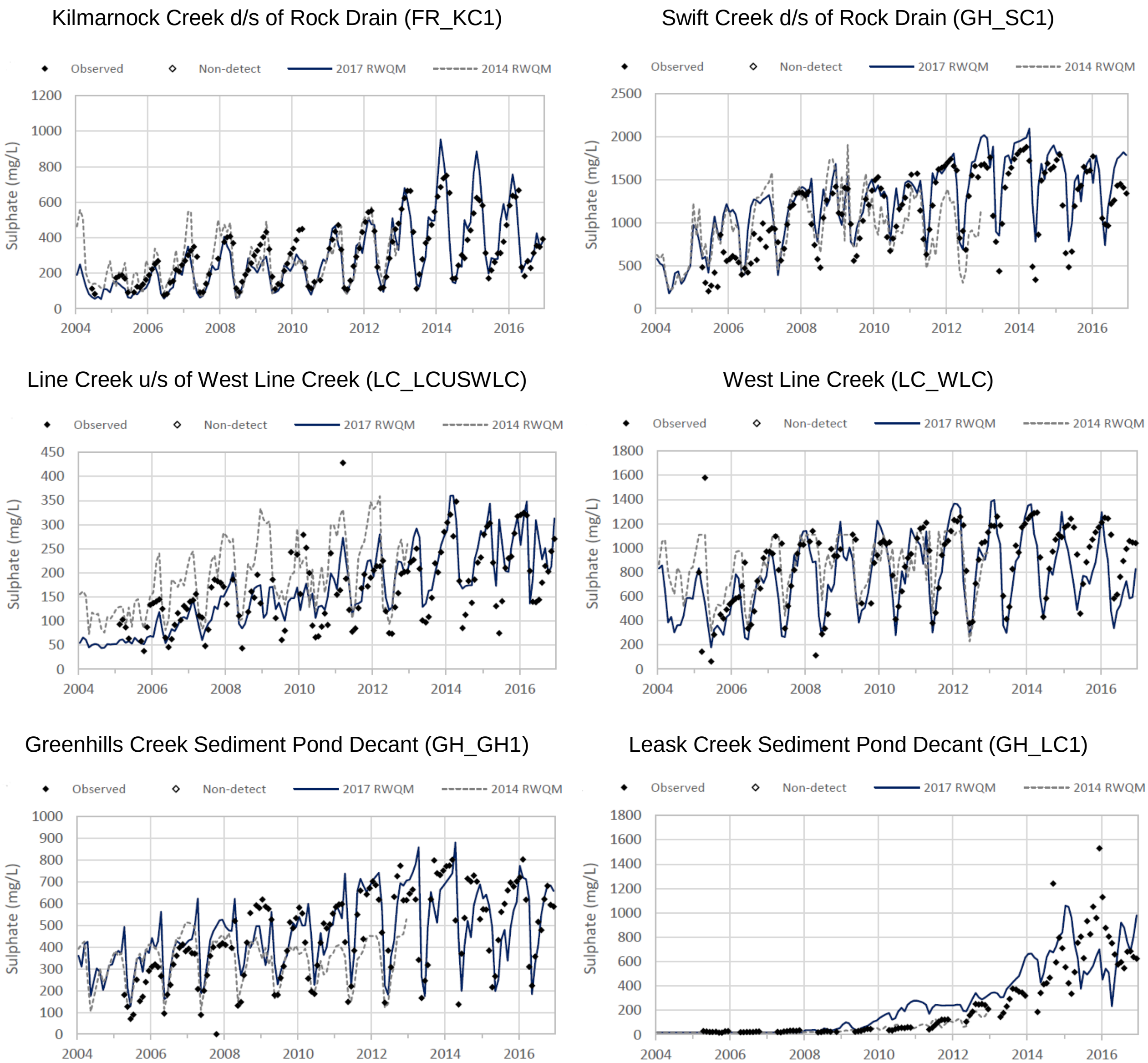


Figure 5-5 Sulphate Calibration Graphs for Tributary Locations: Kilmarnock Creek, Swift Creek, Line Creek, West Line Creek, Greenhills Creek, and Leask Creek 2006 through 2016

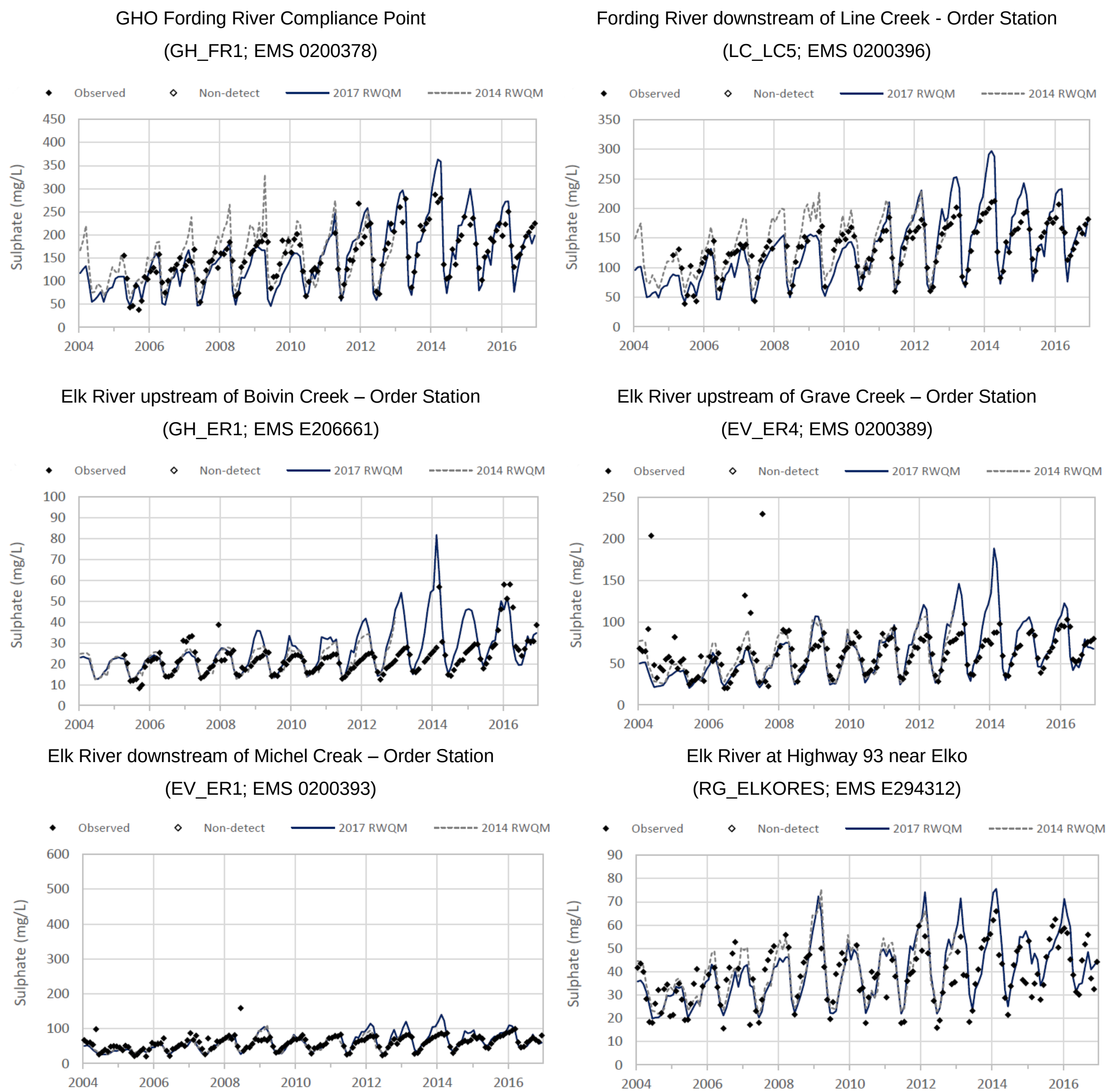


Figure 5-6 Sulphate Calibration Graphs for Locations within the Fording River and Elk River, 2006 through 2016

5.4.4 Model Calibration Results for Other Constituents

The model is set up to project concentrations of cadmium, because it is an Order Constituent, and cobalt, because it has been identified as a constituent of interest in some locations.

The model performance with respect to its ability to replicate the range of measured cadmium concentrations and match seasonal, yearly, and longer-term trends in the tributaries and the Fording River and Elk River is summarized in this section. Model performance with respect to cadmium was mixed. In some mine-affected tributaries, simulated concentrations mirrored the observed range and followed seasonal patterns (Figure 5-17, with additional figures in Appendix D). Performance in West Line

Creek was particularly good, reflecting the use of catchment-specific geochemical source terms. In other tributaries, such as Kilmarnock and Clode creeks, model performance was poor (Figure 5-18), indicating that further refinement of the model for cadmium in specific drainages may be warranted if the model is to be used to inform management decisions at the tributary scale.

In the upper Fording River, simulated concentrations matched reasonable well with observed data, in terms of replicating seasonal patterns and capturing the range of observed concentrations (Figure 5-19). The same was generally true in upper Elk River. Farther downstream, simulated cadmium concentrations consistently over-predicted observed information, suggesting that losses are occurring which are not accounted for in the model.

Simulated cadmium concentrations in the Fording River and Elk River were below SPOs despite the over-prediction; consequently, incorporation of loss terms was not undertaken. Refinement of the model will be considered if required to inform decisions, should projected future concentrations suggest an issue with meeting SPOs in the Elk River or Fording River.

The model performance with respect to its ability to replicate the range of measured cobalt concentrations and match seasonal, yearly, and longer-term trends in the tributaries and the Fording River and Elk River is summarized in this section. In mine-affected tributaries, simulated cobalt concentrations generally reflected the prevailing temporal trend, showing no long-term increase in concentrations over time (see Figure 5-20, with additional plots in Appendix D). The model was, however, limited in its ability to fully replicate seasonal patterns or short-term increases in observed concentrations in most tributaries. Exceptions included Michel Creek, where simulated concentrations encompassed the observed concentrations range and tended to generally follow the observed seasonal pattern. Simulated cobalt concentrations in the Fording River typically encompassed the observed range, and mirrored some of the observed seasonal variation (Figure 5-21, with additional plots in Appendix D). Performance in the Elk River was similar to that described above for mine-affected tributaries. Simulated cobalt concentrations generally reflected the prevailing temporal trend, showing no long-term increase in concentrations over time (see Figure 5-21, with additional plots in Appendix D). Refinement of the model will be considered in specific areas, should projected future concentrations be required to support management decisions.

6 Water Quality: Future Projections

6.1 Introduction

The 2017 RWQM was used to assess how concentrations of nitrate, selenium, sulphate and other constituents may change over time with continuing mine development and implementation of planned water quality mitigation. The IIP, as incorporated in the 2017 RWQM, reflects the EVWQP and Permit 107517 with some adjustments:

- Changes to the forecasted operational date for the Fording River South Active Water Treatment Facility (AWTF) and the Elkview Operations Phase 1 AWTF to reflect their current schedule status and;
- Modelled start dates for remaining treatment facilities shifted from the operational dates in the permit (i.e. the date at which the facility is seeded with biology), to reflect the subsequent

commissioning and ramp-up time (up to 12 months) for a facility to reach its fully effective operating capacity. The IIP and adjustments to the timelines are summarized in Table 6-1.

Teck will undertake an evaluation and adjustment of the implementation plan of water quality mitigation measures following completion of the RWQM update, as discussed in Section 7. The objective of the evaluation and adjustment will be to maintain a plan that will meet SPOs at Order stations and water quality limits at compliance points. This will be documented separately following the framework of Adaptive Management (Teck 2017).

Table 6-1 Configuration of the Initial Implementation Plan in the EVWQP and in the 2017 RWQM Update

Modelled Active Water Treatment Facility	Sources Targeted for Mitigation	Total Water Volume Treated (m^3/d)	Associated Diversions[(a)]	Associated Conveyance of Mine-Influenced Water	Year Fully Effective in the RWQM	
					EVWQP	2017 Update
WLC Phase I	LCO West Line	7,500	–	• Convey Line Creek to mitigation • Discharge to Line Creek	Q2 2014	• 5,500 m^3/d in Q1 2016 • 1,600 m^3/d in Q1 2019
FRO South	GHO Swift, Cataract and FRO Kilmarnock	20,000	Diversion of Upper Kilmarnock watershed and Upper Brownie watershed	• Convey Swift and Cataract and the mine-influenced portion of Kilmarnock to the mitigation • Discharge to the Fording River	Q1 2018	Q4 2021
EVO Phase I	EVO Bodie, Gate, Erickson	30,000	Diversion of Upper Erickson watershed and South Gate Creek	• Convey mine-influenced water from Erickson to mitigation • Discharge to Erickson Creek	Q1 2020	Q2 2022
FRO North Phase I	FRO Clode, North Spoil, Swift Pit	15,000	–	• Convey mine-influenced water to mitigation • Discharge to the Fording River	Q1 2022	Q4 2023
EVO Phase II	EVO Erickson	20,000	–	• Convey mine-influenced water to mitigation • Discharge to Erickson Creek	Q1 2024	Q4 2025
GHO	GHO West Spoil and Greenhills Creek	7,500	–	• Convey mine-influenced water to mitigation • Discharge to Thompson Creek	Q1 2026	Q4 2027
LCO Dry Creek	LCO Dry Creek	7,500	–	• Convey mine-influenced water to mitigation • Discharge to the Fording River	Q1 2028	Q4 2029
FRO North Phase II	FRO Swift Pit	15,000	–	• Convey mine-influenced water to mitigation • Discharge to the Fording River	Q1 2030	Q4 2031

Modelled Active Water Treatment Facility	Sources Targeted for Mitigation	Total Water Volume Treated (m^3/d)	Associated Diversions[a]	Associated Conveyance of Mine-Influenced Water	Year Fully Effective in the RWQM	
					EVWQP	2017 Update
WLC Phase II	LCO Line Creek	7,500	Diversion of Upper Line Creek	• Convey mine-influenced water to mitigation • Discharge to Line Creek	Q1 2032	Q4 2033

Future projections are presented in *2017 Elk Valley Regional Water Quality Model Update: Annex E – Water Quality: Future Projections* (Annex E; Teck 2017d) for the 20 year planning period and include projections with and without accounting for the IIP. 2017 RWQM projections are compared to the 2014 EVWQP projections to show how the projections have changed. Detailed monthly time series plots are provided for the 2017 RWQM under low, average and high flow scenarios.

A summary of the projections is provided below for nitrate, selenium, sulphate, and cadmium and cobalt. Time-series concentration plots for compliance points and Order Stations for these constituents are included in Annex E.

6.2 Projected Nitrate Concentrations

Future nitrate projections compared to SPOs are summarized in this section and are presented below. The model projections for the 2017 RWQM are similar to the EVWQP model projections; however, 2017 RWQM projections are generally higher where there are differences. The comparison focuses on the SPOs because they are the water quality targets that the EVWQP IIP was designed to meet. A comparison of future projected nitrate concentrations to SPOs and water quality limits is provided in Annex E.

Future projected nitrate concentrations in the 2017 RWQM follow a similar decreasing trajectory as the EVWQP projections, corresponding to the gradual disappearance of explosives residuals from waste rock. The incorporation of the updated unsaturated waste rock source terms for nitrate that include a catchment specific initial lag and a time-release (adjusted leach time) component have affected a notable change between the EVWQP model projections and the 2017 RWQM. The adjusted leach time has resulted in projections that tend to be less variable from one year to the next. The period over which nitrate concentrations are projected to increase is further affected by updates to planned waste rock deposition rates.

Following the application of mitigation, maximum monthly nitrate concentrations are projected to meet long-term compliance limits or SPOs throughout the system within the 20 year planning window, although the date at which this occurs varies by location. Projections at LC_LC5, GH_ER1, RG_ELKORES, and RG_DSELK Order Stations remain below SPOs throughout the planning period.

Nitrate concentrations are projected to be seasonally above the SPOs at the Order Stations GH_FR1, EV_ER4, and EV_ER1 in the near term (before the FRO South AWTF is fully effective. The projected concentrations above the SPOs occur during with winter low flow conditions. At GH_FR1, projections above SPOs (highest projected concentration is 4 milligrams per litre (mg/L) above the SPO) occur in December through March in 2020 and 2021 due to the combination of the reduction in the SPO from

20 mg/L to 14 mg/L on December 31, 2019 and the delay in implementing the FRO South AWTF. At EV_ER4, projected concentrations above the SPOs (highest projected concentration is 1.5 mg/L above the SPO) occur from December through March in 2020 and 2021, and December 2021. At EV_ER1, projected concentrations are marginally above the SPO in February and March in 2020 and 2021 (highest projected concentration is 0.2 mg/L above the SPO). Nitrate concentrations at these locations are projected to drop below the SPO upon commencement of full operation of FRO South AWTF. Nitrate projections beginning in 2022 are below SPOs throughout the system.

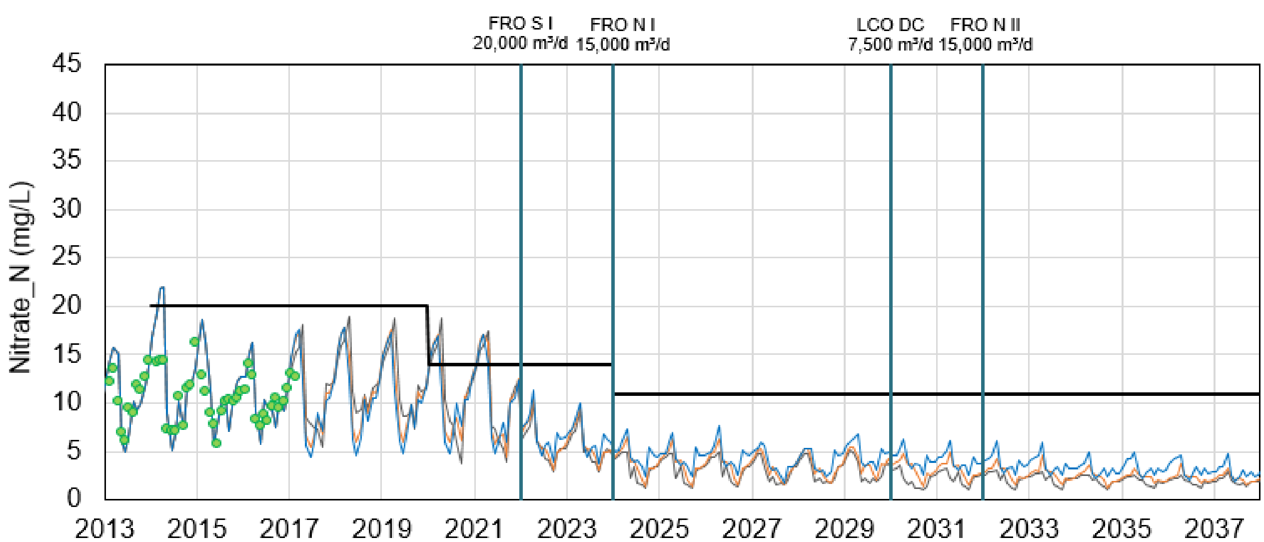
Nitrate projection time-series plots for the Order Stations are provided on Figure 6-1. The plots include monitoring results, and future projections for the three flow scenarios from 2013-2037. The AWTFs that are upstream of each Order Station are also included on each graph.

Figure 6-1 Projected Nitrate Concentrations for the Elk Valley Order Stations

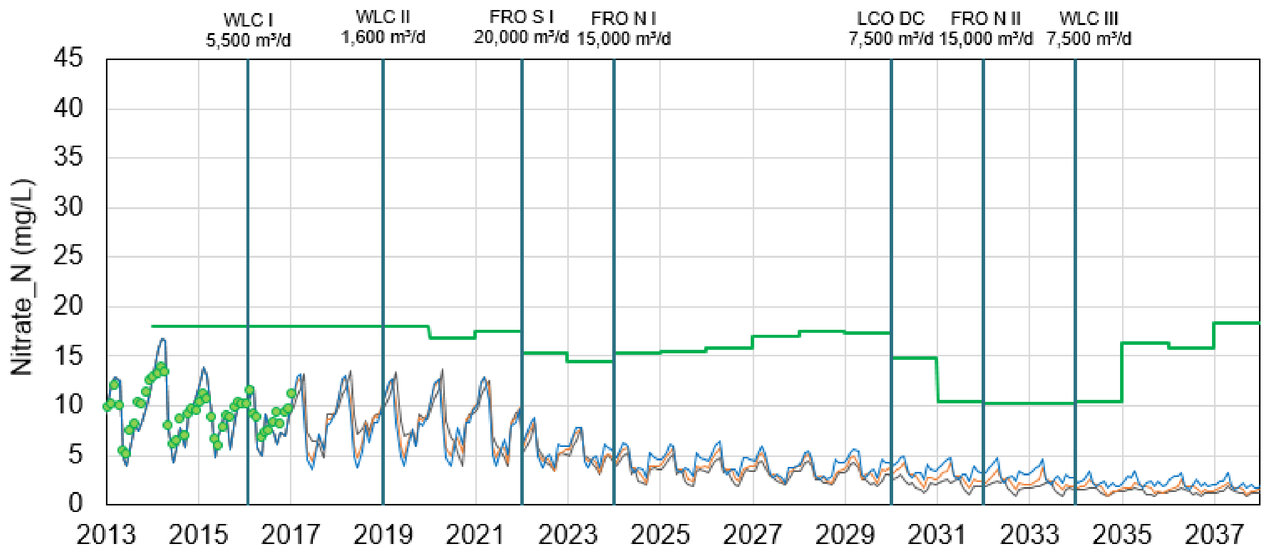
Legend Common to All Plots

- Projected Monthly Average Concentrations under Low Flows
- Projected Monthly Average Concentrations under Average Flows
- Projected Monthly Average Concentrations under High Flows
- Monthly Average Observed Concentrations
- Site Performance Objective

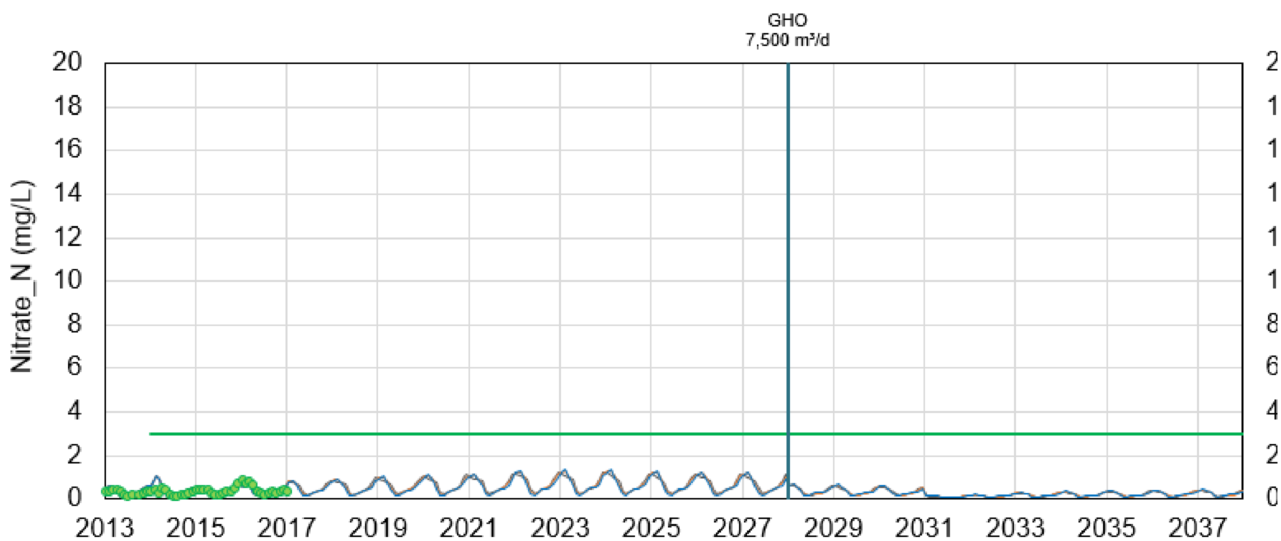
GH_FR1, EMS 0200378 – Fording River downstream of Greenhills Creek



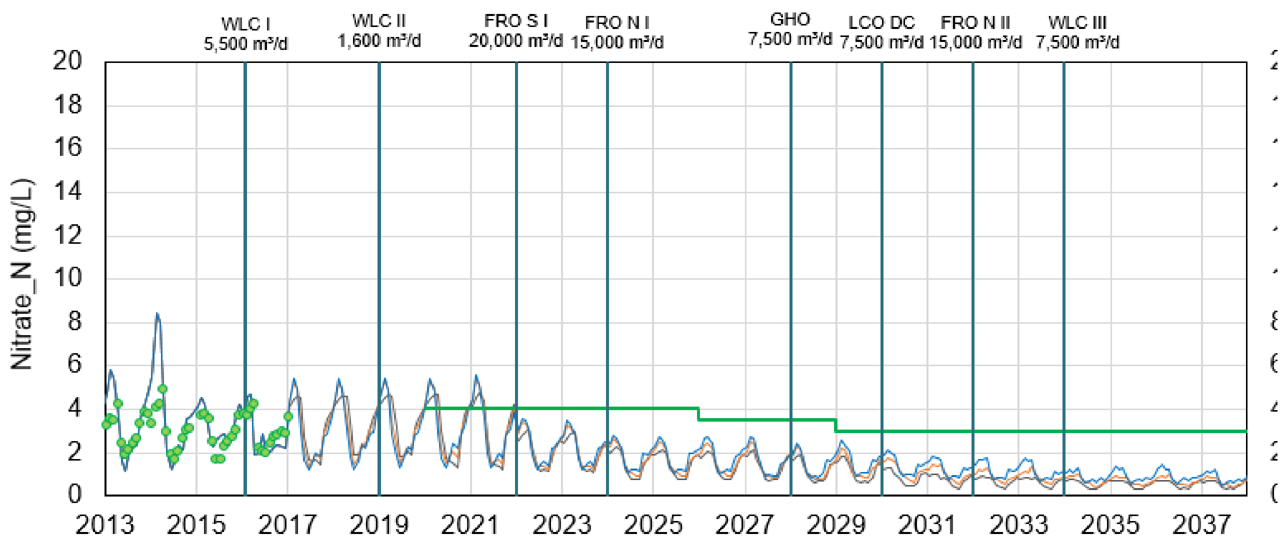
LC_LC5, EMS 200028 – Fording River downstream of Line Creek



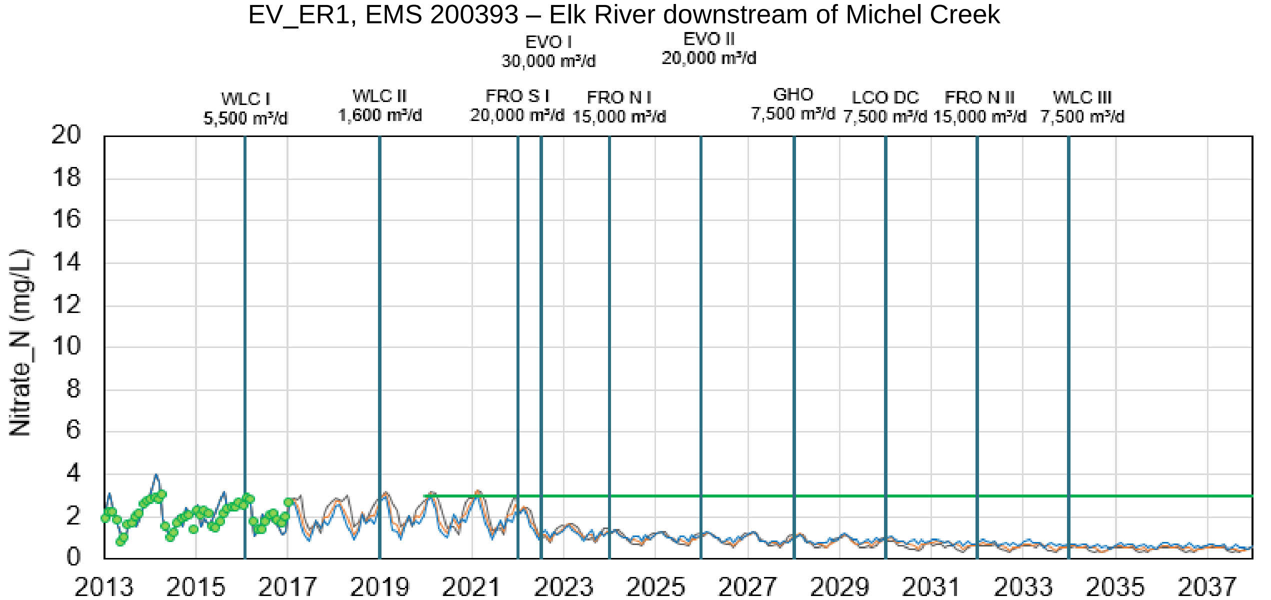
GH_ER1, EMS 206661 – Elk River downstream of Greenhills Operations

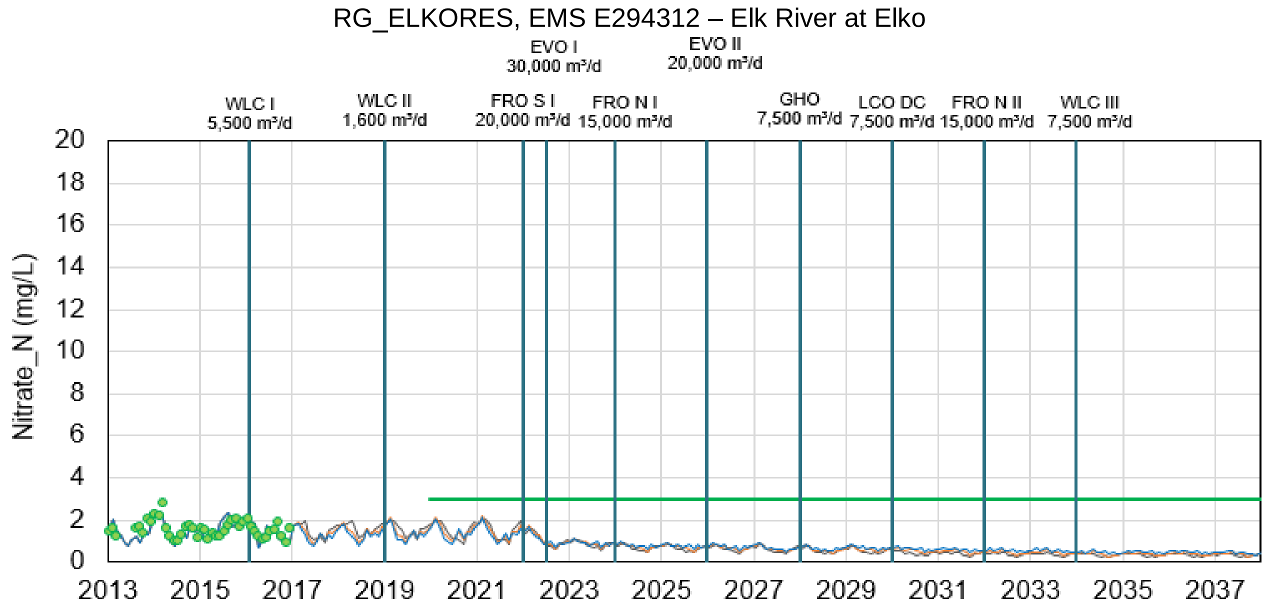


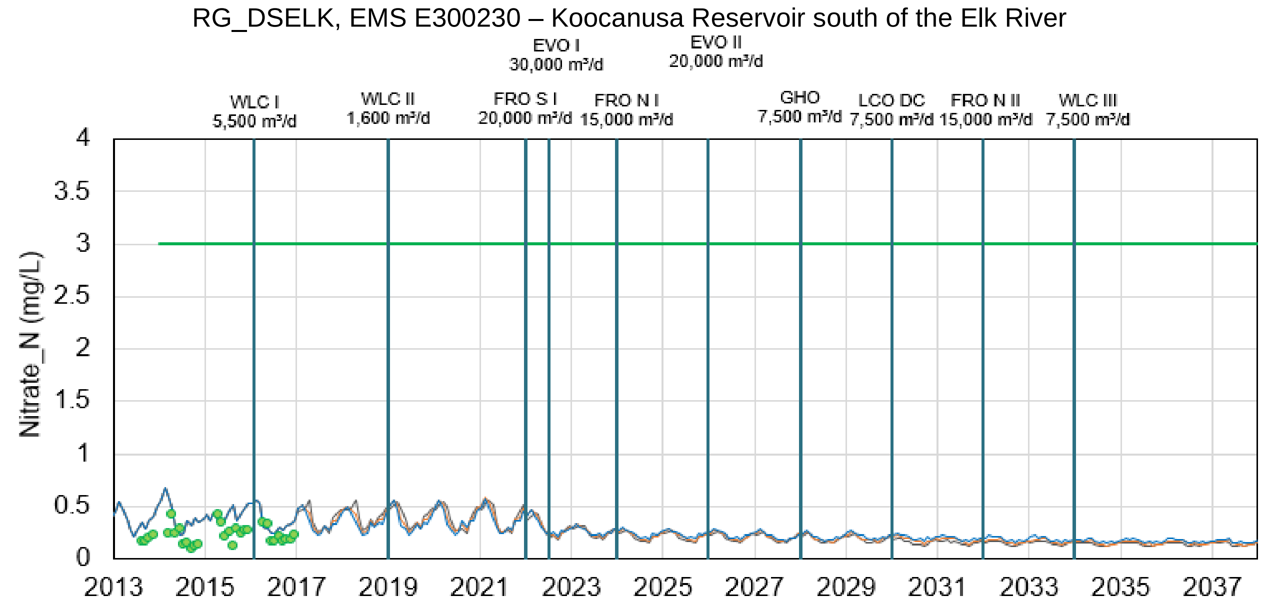
EV_ER4, EMS 0200027 – Elk River downstream of confluence with Fording River



EV_ER1, EMS 200393 – Elk River downstream of Michel Creek







6.3 Projected Selenium Concentrations

Future selenium projections compared to SPOs are summarized in this section and are presented below. The model projections for the 2017 RWQM are similar to the EVWQP model projections; however, 2017 RWQM projections are generally higher where there are differences. The comparison focuses on the SPOs because they are the water quality targets that the EVWQP IIP was designed to meet. A comparison of future projected selenium concentrations to SPOs and water quality limits is provided in Annex E.

Future projected selenium concentration patterns in the 2017 RWQM are similar to the EVWQP projections, with concentrations trending upward over time. Selenium projections are higher in the 2017

RWQM compared to the EVWQP projections, following the application of the mitigation outlined in the IIP. Projected concentrations of selenium are below SPOs at the GH_ER1, EV_ER1, and RG_ELKRES Order Stations throughout the 20 year planning window.

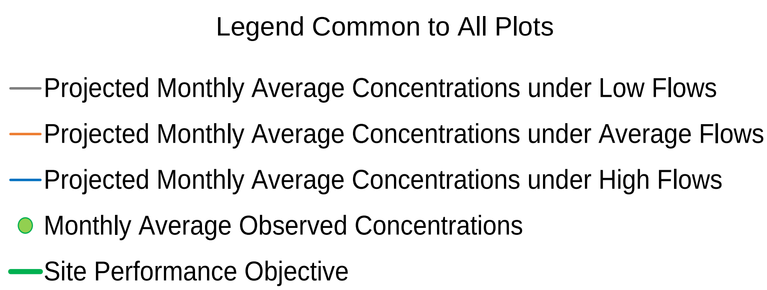
In the near-term (before the FRO South AWTF is fully effective by the end of 2021) selenium concentrations are projected to exceed the SPOs at GH_FR1, LC_LC5, EV_ER4, and RG_DSELK. In the longer term and including mitigation under the IIP, selenium concentrations are projected to seasonally exceed the SPOs at the LC_LC5 and EV_ER4 Order Stations.

The duration and magnitude of the projected selenium SPO exceedances are summarize by Order Station:

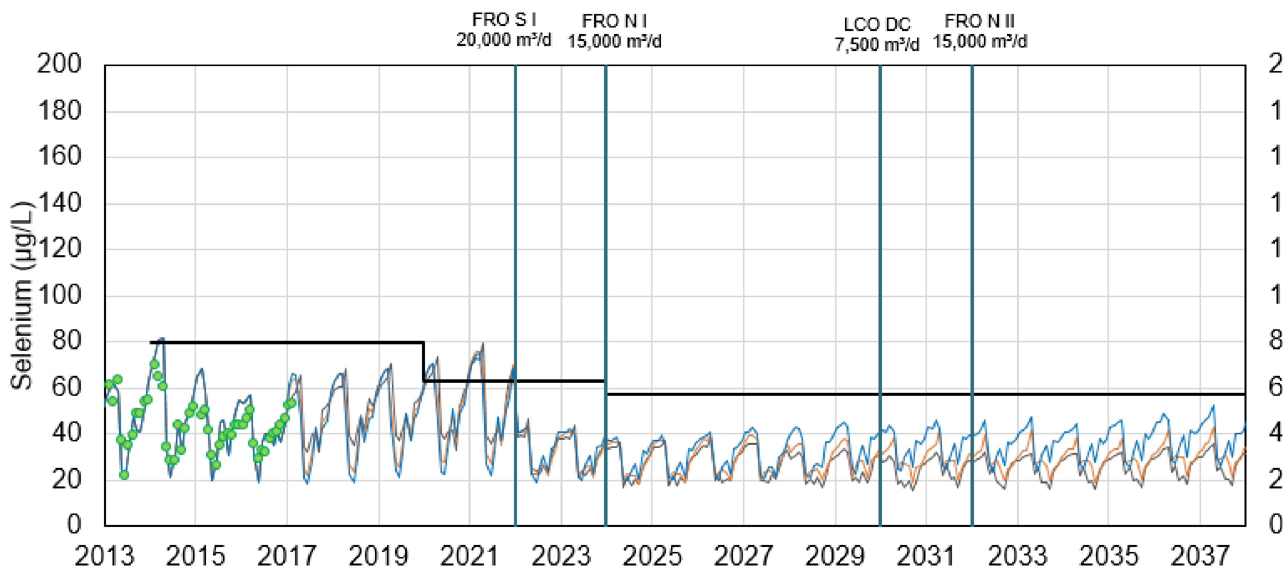
- GH_FR1: projected selenium concentrations are above the SPO (63 micrograms per litre (µg/L)) from December through April in 2020 and 2021 and the highest projected concentration is 16.5 µg/L above the SPO.
- LC_LC5: projected selenium concentrations are above the SPO (51 µg/L) in February and March of 2020 and 2021 and above the long-term SPO (40 µg/L) in February and March in 2027 through 2033, and in 2036 and 2037. The highest projected selenium concentration for the long-term period is 3.6 µg/L above the SPO.
- EV_ER4: projected selenium concentrations are above the SPO (23 µg/L) in February of 2020 and 2021 and above the long-term SPO (19 µg/L) in February in 2027 through 2030 under some flow conditions. The highest projected selenium concentration for the long-term period is 2 µg/L above the SPO.
- RG_DSELK: projected selenium concentrations are above the 2 µg/L SPO in 2018 through the first half of 2022 from December through May and the highest projected concentration is 0.8 µg/L above the SPO. Model bias at this station, as described above, is high, meaning that the model has a tendency to over predict when compared to monitored data at this location.

Selenium projection time-series plots for the Order Stations are provided on Figure 6-2. The plots include monitoring results, and future projections for the three flow scenarios from 2013 through 2037. The AWTFs that are upstream of each Order Station are also included on each graph.

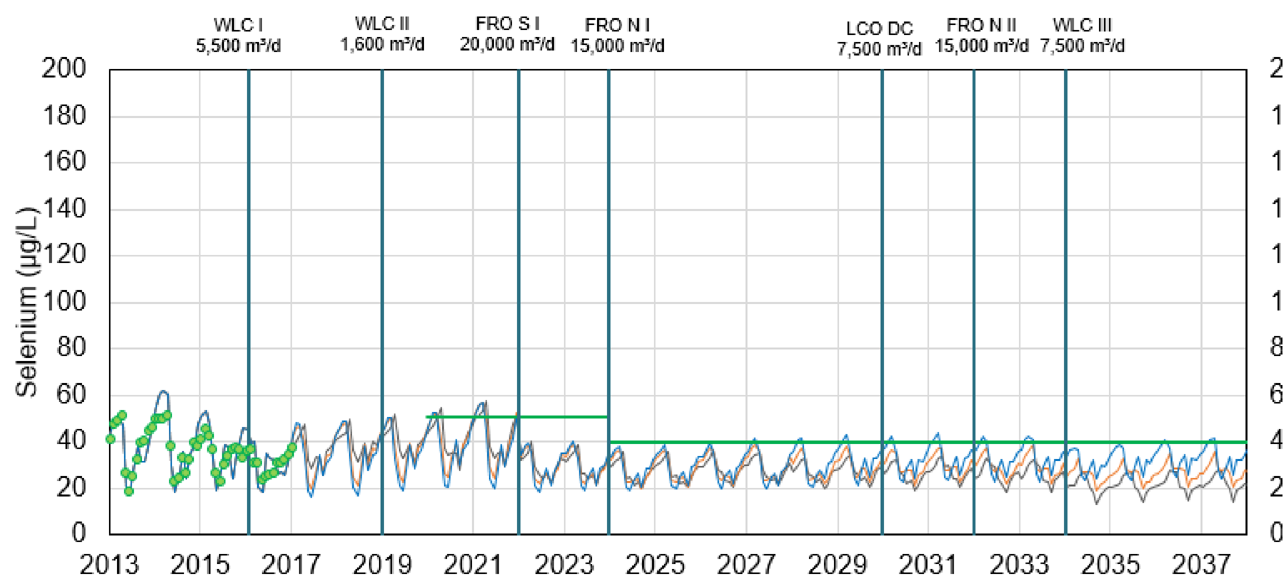
Figure 6-2 Projected Selenium Concentrations for the Elk Valley Order Stations



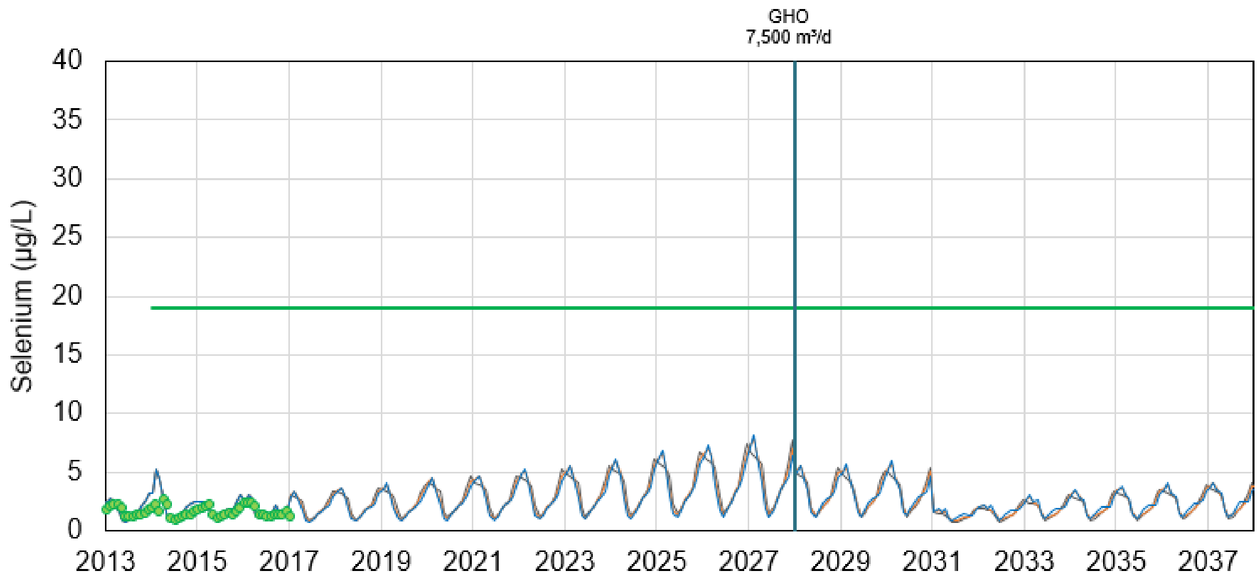
GH_FR1, EMS 0200378 – Fording River downstream of Greenhills Creek



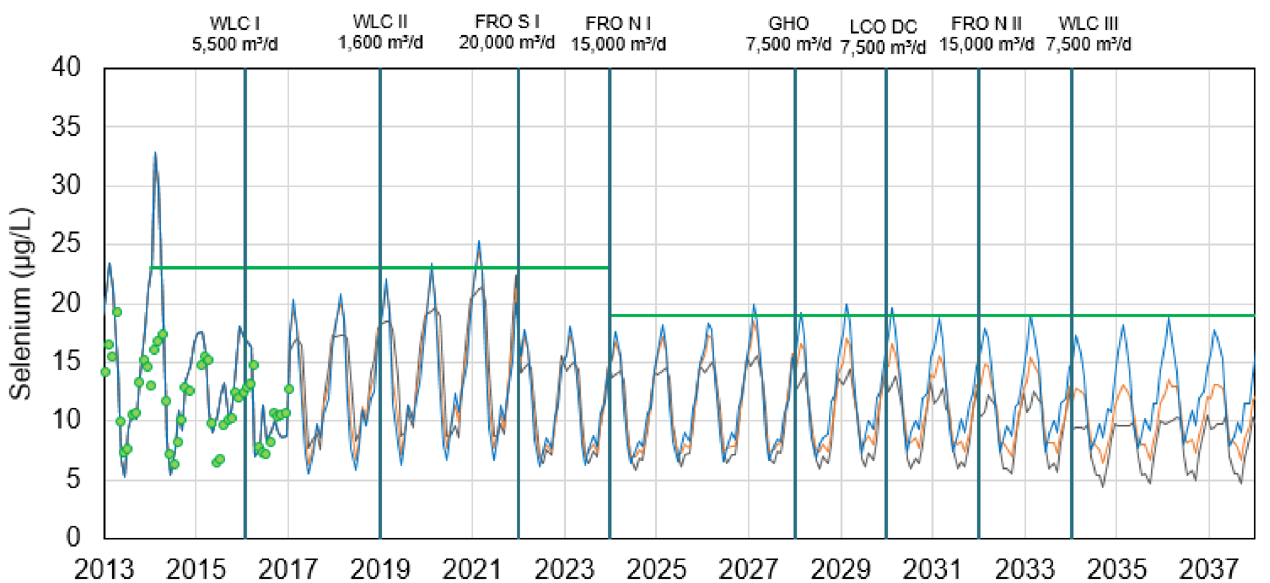
LC_LC5, EMS 200028 – Fording River downstream of Line Creek



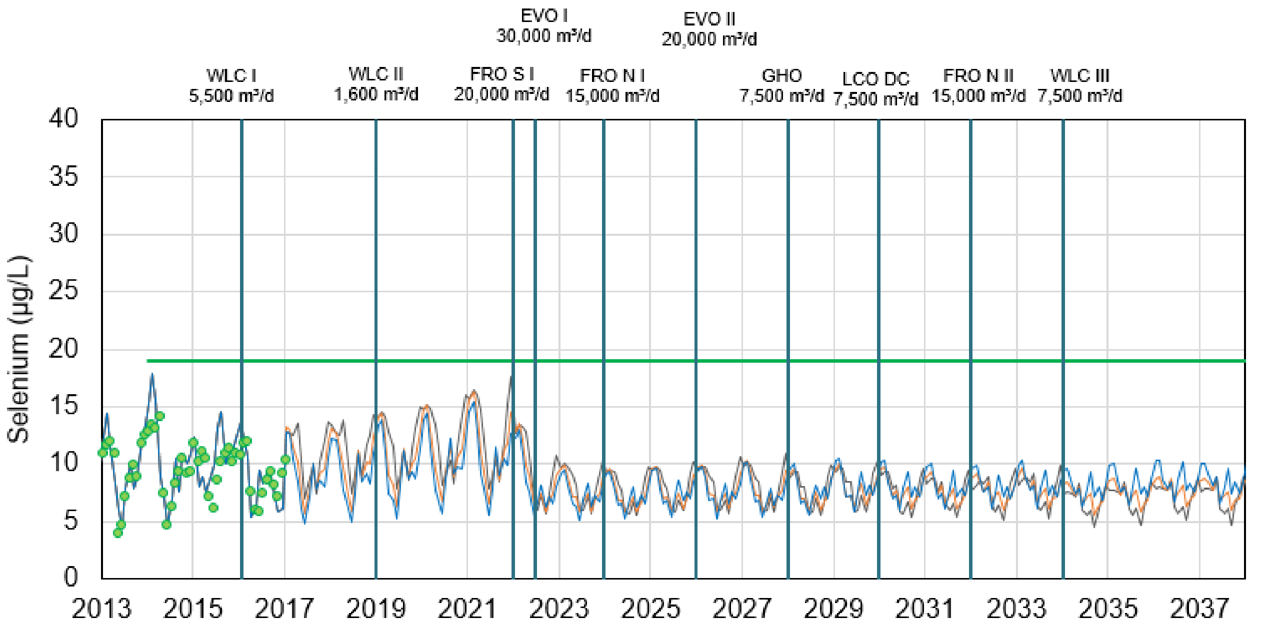
GH_ER1, EMS 206661 – Elk River downstream of Greenhills Operations



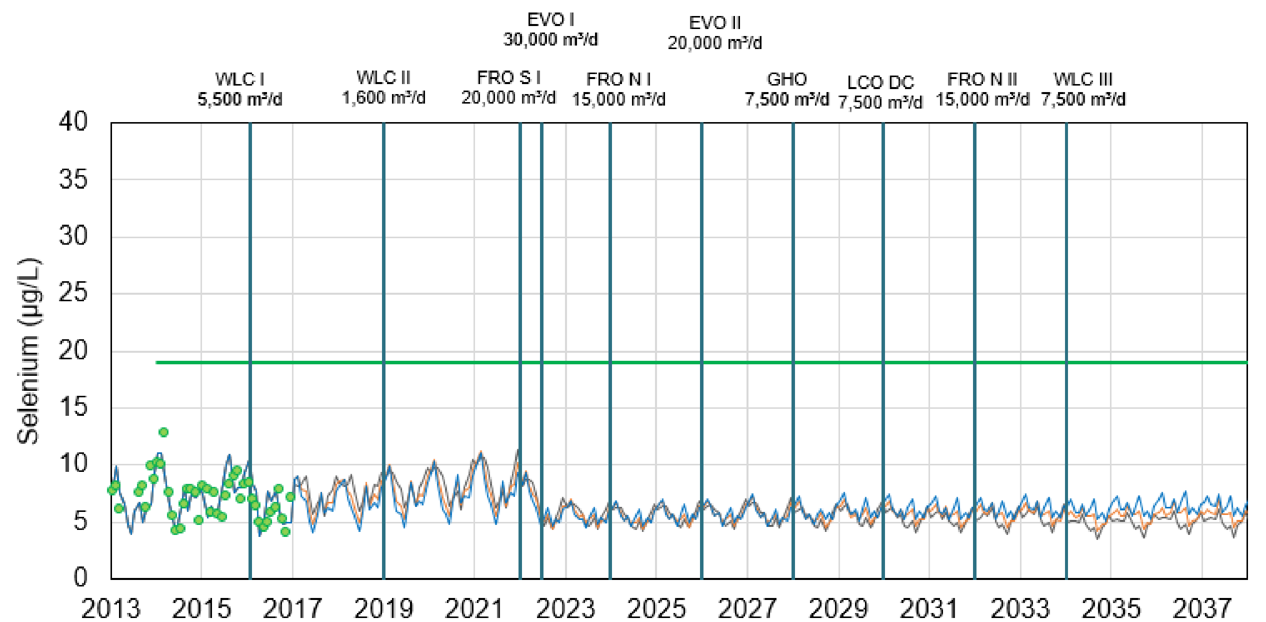
EV_ER4, EMS 0200027 – Elk River downstream of confluence with Fording River

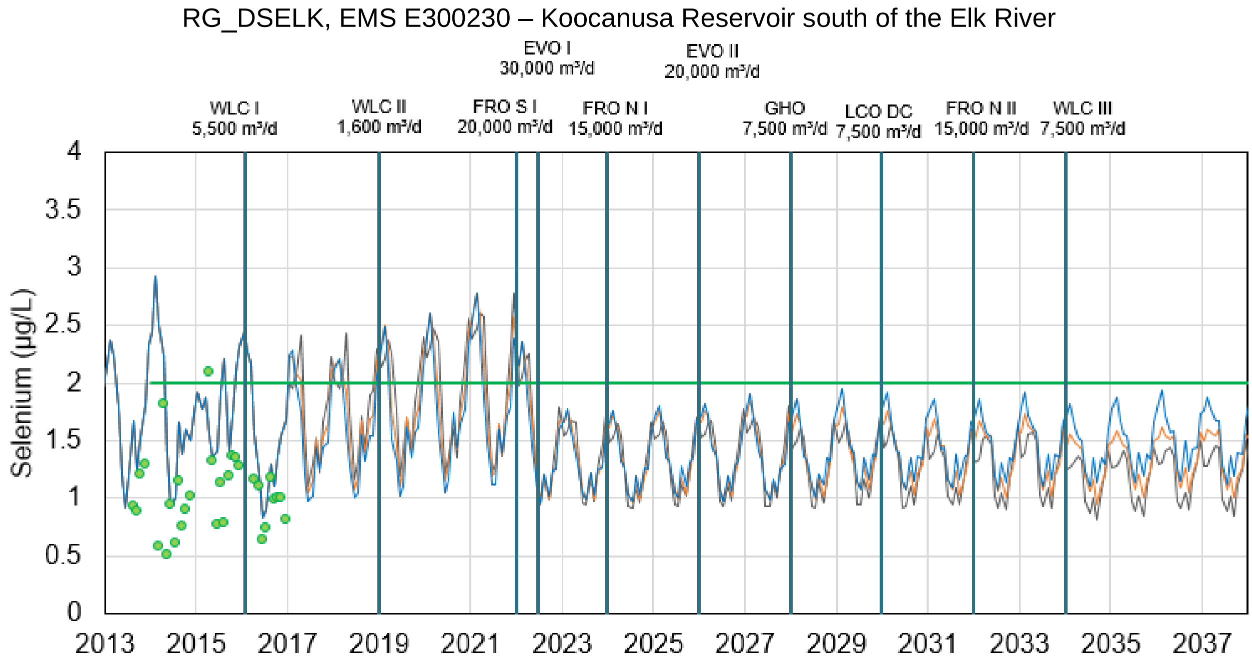


EV_ER1, EMS 200393 – Elk River downstream of Michel Creek



RG_ELKORES, EMS E294312 – Elk River at Elko





6.4 Projected Sulphate Concentrations

Future sulphate projections compared to SPOs are summarized in this section and are presented below. The model projections for the 2017 RWQM are similar to the EVWQP model projections; however, 2017 RWQM projections are generally higher where there are differences. This comparison focuses on the SPOs. A comparison of future projected sulphate concentrations to SPOs and water quality limits is provided in Annex E.

Future projected sulphate concentrations in the 2017 RWQM are similar to the EVWQP projections, with concentrations trending upward over time. Sulphate projections are typically higher in the 2017 RWQM compared to the EVWQP projections, but this difference becomes minimal further down in the watershed with almost no difference between the projections at the RG_ELKORES and RG_DSELK Order Stations. Projected sulphate concentrations remain below the SPOs at GH_ER1, EV_ER4, EV_ER1, RG_ELKORES and RG_DSELK Order Stations throughout the planning period. There are seasonal (low flow) projected sulphate concentrations above the SPOs for GH_FR1 and LC_LC5. The projected sulphate concentrations at GH_FR1 are above the SPO (429 mg/L) in February and March of 2028 and are above the SPO again in 2032 through 2037. The highest projected sulphate concentration at GH_FR1 is 95 mg/L above the SPO. The projected concentrations at LC_LC5 are above the SPO (429 mg/L) in 2036 and 2037 during the months of February and March and the highest projected sulphate concentration is 25 mg/L above the SPO.

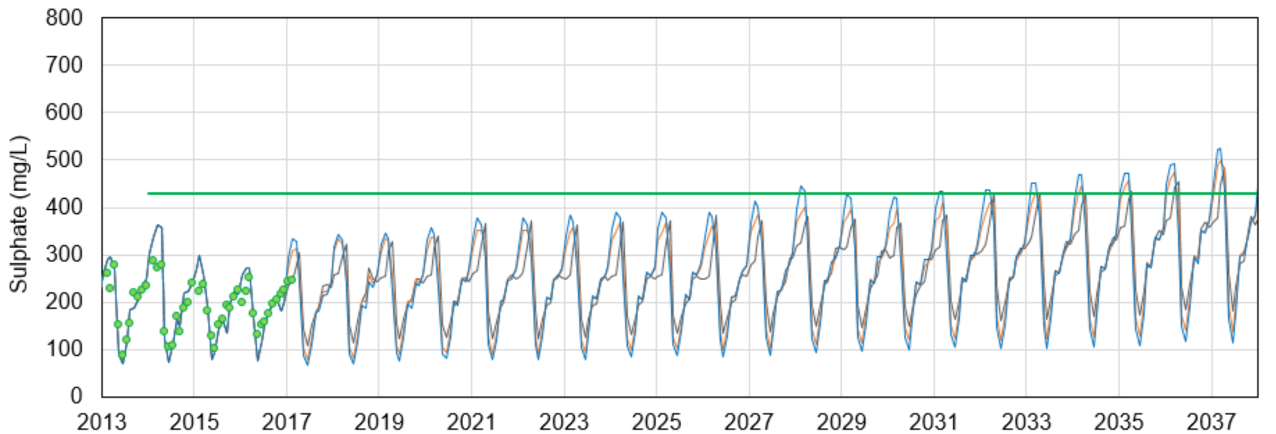
Sulphate projection time-series plots for the Order Stations are provided on Figure 6-3. The plots include monitoring results, and future projections for the three flow scenarios from 2013 through 2037.

Figure 6-3 Projected Sulphate Concentrations for the Elk Valley Order Stations

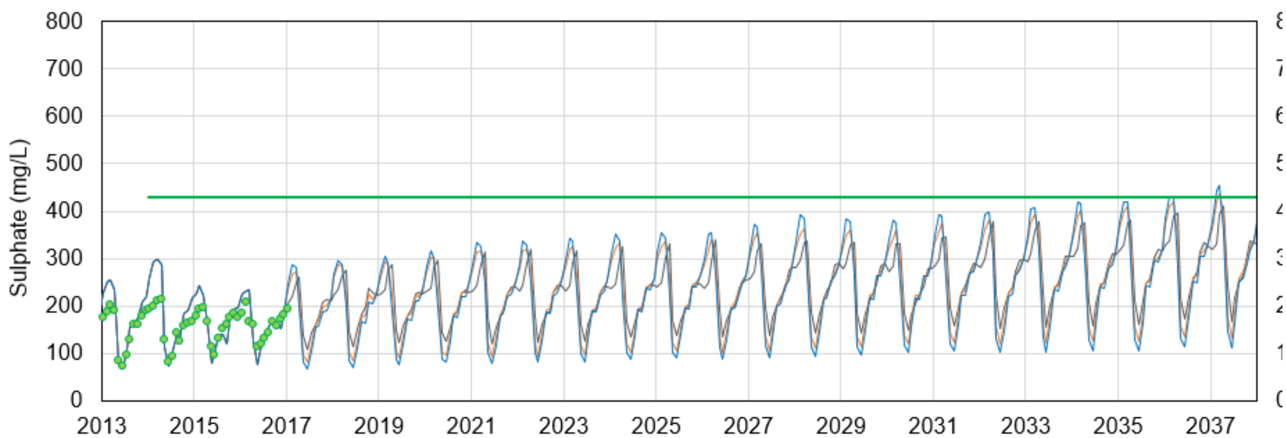
Legend Common to All Plots

- Projected Monthly Average Concentrations under Low Flows
- Projected Monthly Average Concentrations under Average Flows
- Projected Monthly Average Concentrations under High Flows
- Monthly Average Observed Concentrations
- Site Performance Objective

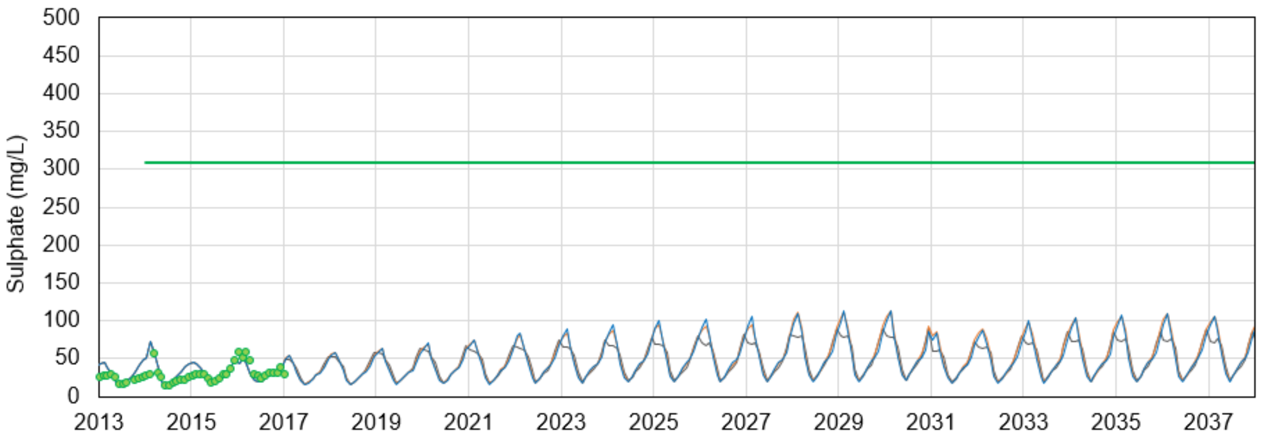
GH_FR1, EMS 0200378 – Fording River downstream of Greenhills Creek



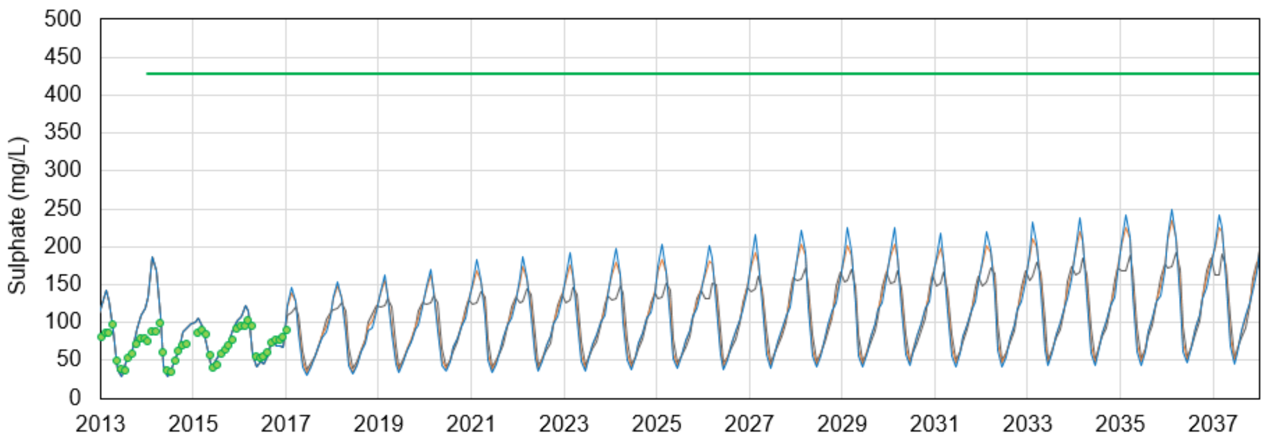
LC_LC5, EMS 200028 – Fording River downstream of Line Creek



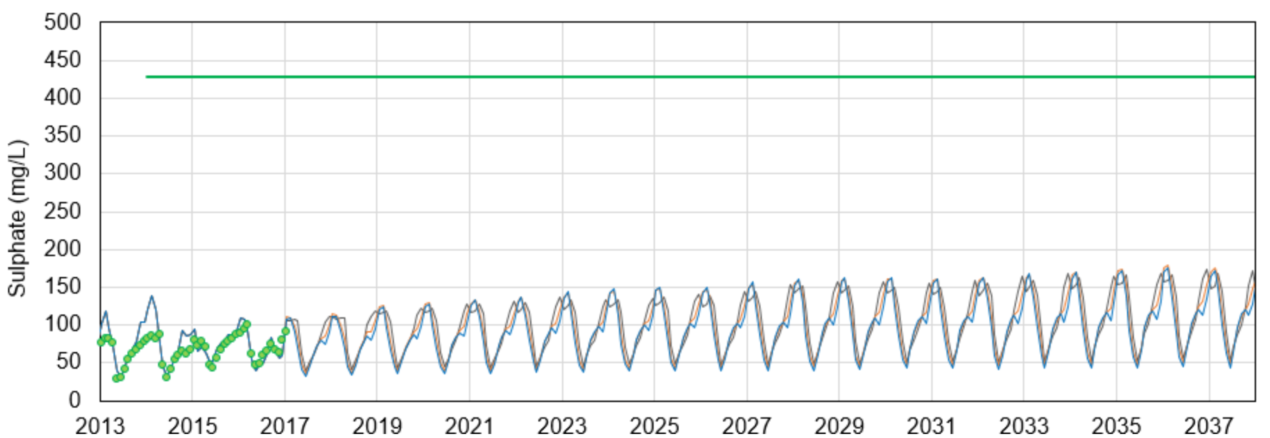
GH_ER1, EMS 206661 – Elk River downstream of Greenhills Operations



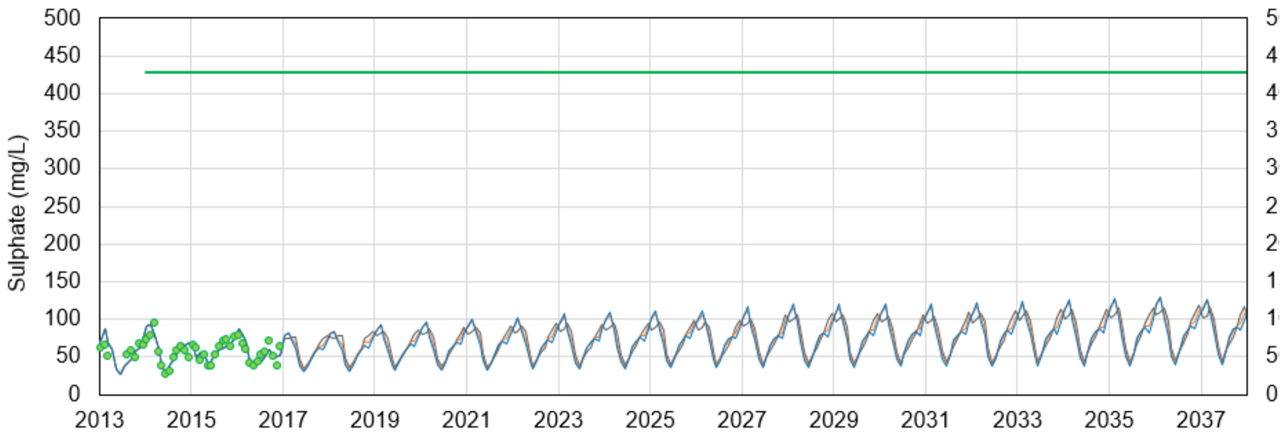
EV_ER4, EMS 0200027 – Elk River downstream of confluence with Fording River



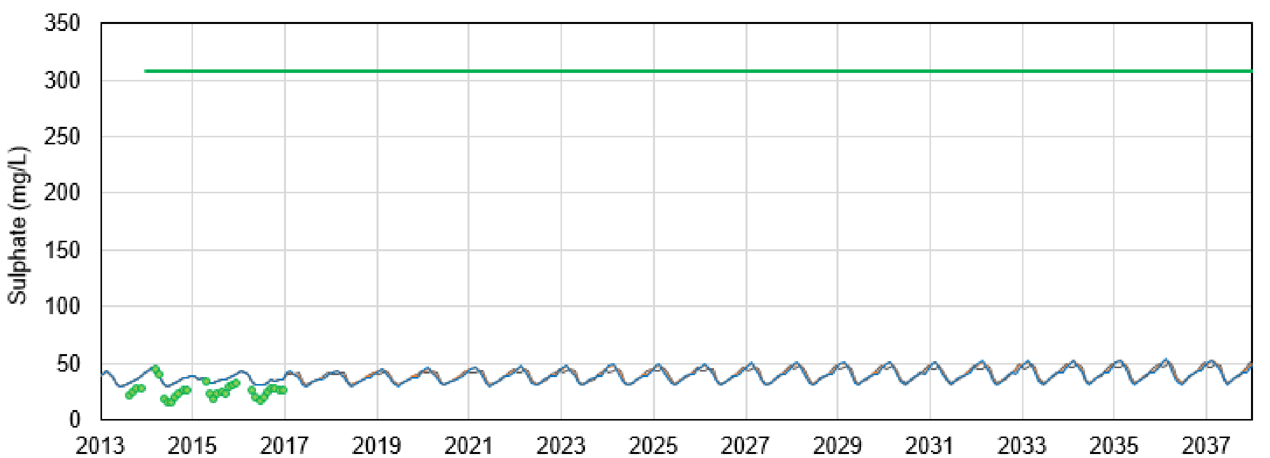
EV_ER1, EMS 200393 – Elk River downstream of Michel Creek



RG_ELKORES, EMS E294312 – Elk River at Elko



RG_DSELK, EMS E300230 – Koocanusa Reservoir south of the Elk River



6.5 Projected Cadmium and Cobalt Concentrations

The future projections developed using the 2017 RWQM are discussed with reference to applicable SPOs (cadmium) and BC water quality guidelines for the protection of aquatic life (cobalt). The mitigation measures included in the IIP do not target cadmium or cobalt concentrations in mine-influenced water. Consequently, only one set of future projections was developed for each constituent, one which included planned mitigation to capture the influence of changes to water management associated with mitigation.

Maximum monthly cadmium concentrations are projected to remain below SPOs at all Order stations, as shown on the figured included in Annex E, Appendix D. Maximum monthly cobalt concentrations are similarly projected to remain below BC water quality guidelines at all Order stations (Annex E, Appendix D). These results indicate that neither cobalt nor cadmium is presently, or projected to be, a regional issue. It may be a local concern as described in Annex E at LCO for cadmium and CMO for cadmium and cobalt.

7 Adaptive Management

7.1 Regional Water Quality Model and the Adaptive Management Plan

Six overarching Management Questions are included in the Adaptive Management Plan (AMP). The AMP includes a description of how each of the Management Questions will be answered, and how the key uncertainties specific to each Management Question will be evaluated and reduced. Section 7 of this RWQM Overview Report summarizes how the adaptive management process will be applied to the RWQM update to answer Management Question 1, “Will water quality limits and SPOs be met for selenium, sulphate, nitrate and cadmium?”, and how key uncertainties (KUs) were addressed through the update.

The AMP includes a six stage Adaptive Management (AM) cycle (Figure 7-1) that will guide the evaluation (Stage 5: Evaluate) and adjustment (Stage 6: Adjustment) to the implementation plan based on the results of the RWQM update. The 2017 (updated) RWQM projections include planned mitigation (i.e., the IIP) that was developed with the 2014 (previous) version of the RWQM, with some differences in future mine plans and a 20-year planning window that ended three years early. Teck plans to apply the AM process on a regular three-year cycle, following completion of the three-year RWQM update, to evaluate and adjust the implementation plan so that future projections will be managed so that water quality limits and SPOs for selenium, sulphate, nitrate and cadmium will be met.

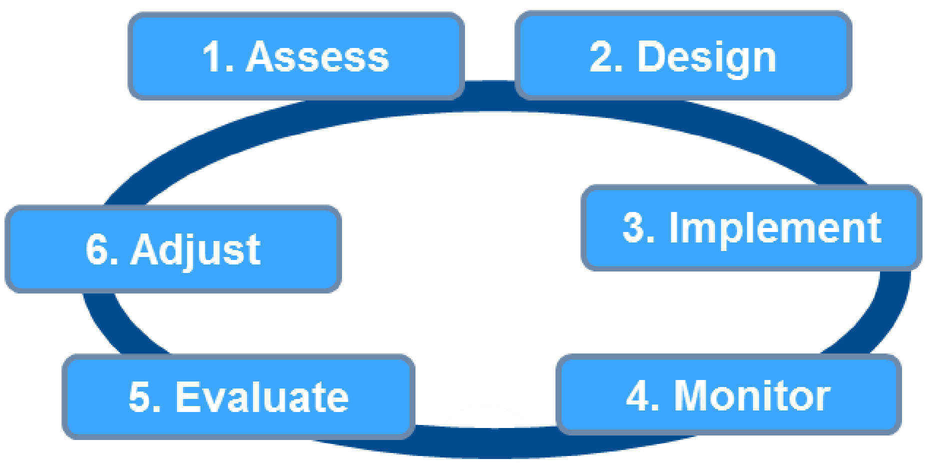


Figure 7-1 The Six Stage Cycle of Adaptive Management

7.2 Management Question 1: Will limits and SPOs be met for selenium, sulphate, nitrate, and cadmium?

Management Question 1 (“Will water quality limits and Site Performance Objectives be met for selenium, sulphate, nitrate and cadmium?”) is evaluated through periodic review of RWQM projections and monitoring data.

The combination of improvements in source-terms, changes to mine plans, delay in implementation of AWTFs and extension of the 20-year planning period, has resulted in updated RWQM projections which do not meet site performance objectives or water quality limits at some locations or timeframes. The implementation plan will need to be evaluated and adjusted so that future RWQM projects will meet limits and SPOs. The objective of the implementation plan evaluation is to maintain a plan that will meet SPOs at Order stations and water quality limits at compliance points. The implementation evaluation will be documented in a separate submission using the Adaptive Management Plan (Teck 2016). This is consistent with working through Stage 6 of the AM cycle, and adjusting to new information from the evaluation Stage.

The following adjustments under Stage 6 of the AM cycle are proposed. Adjustments will be determined in consultation with regulators and KNC.

- Mitigation: Based on model projections above SPOs and limits after 2022, when additional treatment (at FRO and EVO) is operational, Teck will be working with regulators and KNC to evaluate adjustments to the implementation plan. This is expected to involve updating the timing and sizing of mitigation at some locations in the valley to achieve SPOs and limits. This will be done in consultation with ENV, EMPR and KNC and will follow the general steps of:
    - Reviewing and confirming prioritization of mine-influenced streams for water quality management;
    - Reviewing and confirming management options that are sufficiently advanced to be included in the adjusted implementation plan;
    - Considering and incorporating relevant water management learnings to date;
    - Identifying the mitigation required to meet long-term SPOs within the 20 year planning window and;
    - Adjusting the sequence of the identified mitigation to meet short and medium term compliance limits and SPOs, taking into consideration timing constraints (i.e. time required to successfully design, permit, build and ramp-up mitigation to the point at which it is effective).

  These steps are currently being planned in more detail and will be reviewed with regulators and KNC post submission of the RWQM.

- Monitoring: Based on model projections above SPOs in the near term (within five years) at the Order Stations GH_FR1, LC_LC5, EV_ER4 and EV_ER1, a review of monitoring programs to confirm data is available to inform management decisions and evaluations of ecological health monitoring programs will be completed. While projections are expected above the SPOs, they are projected to be similar concentrations to current conditions.
- Nitrate management: Based on near term projected, and in the case of LCO, measured, nitrate concentrations above limits and SPOs, Teck has implemented changes to blasting practices as described in the LCO Compliance Action Plan (Teck 2017e). The projections in the 2017 RWQM update have not yet accounted for the benefits of improved practices. Opportunities such as

operational water management changes that will have benefit within the next five years will continue to be investigated, with a focus on areas where projections are above limits (LCO, FRO).

7.3 Key Uncertainties

7.3.1 Addressing Key Uncertainties in the AMP

The analysis in this report will inform the approach to addressing KUs under MQ1 and MQ3 in the AMP.

Under MQ1, the RWQM update undertook work specifically aimed at reducing KU 1.2 “How will uncertainty in the RWQM be evaluated to assess future achievement of limits and SPOs?”. Key Uncertainty 1.2 is an ongoing continuous improvement component of the three year water quality model update. Key Uncertainty 1.2 identified specific sources of uncertainty:

- uncertainties in modelled tributary flows,
- uncertainty in the geochemical conceptual model and source terms at the tributary scale,
- uncertainty in nitrate source terms,
- uncertainties and variables in the implementation plan, and
- year-to-year variability in flow conditions.

The first three of these were the focus areas of the 2017 RWQM update and were substantially reduced through updated data analysis and resulting changes in the RWQM. Uncertainty reduction associated with these three sources of uncertainty are described below. The last two are residual sources of uncertainties and should be carried forward for reduction in future revisions of the RWQM.

Modelled tributary flows have improved through updates to the flow model. Increasing spatial resolution, the number of analog watersheds, and temporal resolution (to weekly from monthly), had a combined result of improving model performance in tributaries. See additional details in the Hydrology Modelling report.

The geochemical conceptual model was updated through the incorporation of new information from the Applied Research and Development Program. The main change was to incorporate a time component to the release of constituents. The source terms were updated as tributary specific terms.

Nitrate source terms were updated through the incorporation of the changes in geochemical source terms and tributary specific nitrate residual terms. There has been a resulting step change in the accuracy of the nitrate projections.

Through the RWQM update, additional sources of uncertainty related to KU 1.2 have been identified through discussions with the Qualified Professionals who support the development of the model. These will be evaluated in more detail and addressed as part of subsequent updates to the RWQM. They will be part of continually improving the RWQM under KU 1.2. For each newly identified source of uncertainty, a brief description of the uncertainty, the objective for reducing it, and a high-level design for reducing it, is described below:

1) Can operational information, such as pit water monitoring and historical mining activities be used to improve source terms over time?

   Historical mining activity may influence the timing or quantity of constituents released. The specific factors that have the largest influence are uncertain but may include pit dewatering activity and/or spoil development pattern (for example and for further refinement, bottom-up or top-down construction sequence, proximity to water, spoil height over time). In addition, pit dewatering activities are captured in the monitoring data but may not represent long term release rates, introducing bias in calculation of source terms. The objectives of reducing this source of uncertainty are to improve source term calculation through appropriately accounting for pit water management and incorporating relevant factors if identified. This source of uncertainty will be reduced through compilation of historical mining activity information and the evaluation of whether there are other factors influencing release (e.g. spoil height) to improve interpretation of data used to calculate source terms.

2) Can the RWQM be improved in specific catchments where mitigation decisions are required and uncertainty is high?

   Water quality management decisions need to be made at loading sources that have a substantive influence on water quality constituent concentrations at compliance points for each operation. The objective of reducing this source of uncertainty is to improve confidence in decisions through more accurate projections in specific catchments. The sources of uncertainties are mainly site specific and related to flow paths and the quantity and timing of release. This source of uncertainty will be reduced through:

   - Evaluation of which specific drainages require a localized groundwater baseflow module linked to updated geochemical source terms, and development of a module for those drainages.

   - EVO Harmer: Characterization of dominant flow paths and investigate presence of a sink between EVO Dry Creek and Harmer Creek. Source characterization at EVO Harmer Creek: While projections are above the interim limits, the need for additional study of this area has been identified to better characterize the pathway between the source in EVO Dry Creek, and the monitoring station at EV_HC1. This will be required to inform management decisions and establishment of a long term SPO for Harmer Creek.

   - LCO source characterization: Projections for selenium, sulphate, and nitrate are above the limits based on a significant change to the source terms at this location. The projections show a significant increase over the next couple of years that is inconsistent with the current trends in the monitoring data. Design of a study to confirm these results, in parallel to source control efforts will be the first step.

   - GHO West side: Characterize flow and water quality from inflow to the sediment ponds to the Elk River to inform collection and conveyance of water to the planned AWTF.

   - LCO cadmium and CMO cobalt and cadmium: Develop a study plan to improve projections of cadmium and cobalt at CMO, and cadmium at LCO to inform the need to mitigate for these trace metals.

3) How may selenium and sulphate release rates change over time?

   Constituent release rates for parameters other than nitrate are currently assumed to be constant over time. There is uncertainty in the mechanisms associated with the generation and sequestration of constituents in waste rock spoils that could influence the calculation of source terms. The objective of reducing this source of uncertainty is to improve longer term projections of selenium, and sulphate. This source of uncertainty will be reduced through:

   - Continuation of the Applied Research and Development program focused on understanding mineralogical sources and sinks. Targeted research on understanding mechanisms leading to changes in constituent release as waste rock spoils age and to evaluate sequestration of selenium in oxic environments (for example, gypsum).

4) What mechanism (s) are causing the reduction in mass observed between the tributaries and at monitoring stations in the Fording, Elk and Michel?

   Monitoring indicates that the mass of selenium and nitrate is reducing within the Fording and Elk rivers and in Michel Creek. This measured reduction has been incorporated into the model; however, the mechanism(s) are uncertain. This objective of reducing this source of uncertainty is to better understand the mechanism and improve, if required, how this reduction is accounted for in the model. This source of uncertainty will be reduced through additional data analysis and development and execution of a study design to reduce the uncertainty.

Under MQ3, the RWQM is used to provide analysis towards resolving or incorporate the outputs of each of the KUs. The results of the RWQM update provides analysis related to the KUs as described below.

- KU 3.2: "What is the most feasible and effective method, or combination of methods, for source control of nitrate release"? The update to the RWQM includes specific inputs (powder factor and nitrate residual) that can be adjusted to account for the benefits of source control. Teck has ongoing research and development to resolve this KU. This includes a field program to measure the quantity of nitrate available for leaching as a result of the use of a range of blasting products and practices. This information can also be used to refine the geochemical conceptual model for nitrate. This will provide information to support the use of nitrate as a tracer for hydrological processes and understanding of lag and dispersion effects for release of CIs, and the estimation of the benefit of nitrate management measures implemented in the RWQM.

- KU 3.5: Is sulphate treatment required? Based on projections of the RWQM above SPOs at two Order Stations, Teck will be initiating a program to investigate sulphate mitigation suitable for application in the Elk Valley. This involves identifying a sulphate treatment or source control mitigation that could be implemented in the Elk Valley. This would allow Teck to be prepared to implement it at sources in the Fording River Operation, EVO Harmer, and Line Creek Operation as required.

7.4 Monitoring Recommendations

Monitoring programs were reviewed by the geochemistry, hydrology and water quality modelling teams as part of the 2017 RWQM update to identify if additional monitoring would improve modelling in future updates of the RWQM, which resulted in the following recommendations:

1) Regional Surface Flow Monitoring Program (RSFMP):

    a. Identify and implement monitoring at suitable long-term natural analogue watersheds and establish year-round daily or weekly flow monitoring for the Fording River (e.g. Chauncey, Grace Creek), Elk River (e.g tributary on the west side upstream of Greenhills, Grave Creek), Michel Creek (e.g. Fir, Wheeler Creek). This will ensure long term natural data sets are developed for natural analogs. Natural analog datasets are used to estimate the flows from natural areas within tributaries. These natural areas are often larger than the mine influenced areas.

    b. Implement a monitoring program to verify the scaling methods used to estimate flow at the following ungauged Compliance Points and/or Order Stations: GH_FR1, GH_ERC, GH_ER1 and EV_ER1. Proposed Compliance Points should be considered in this program (e.g., FR_FRABCH). This will verify the methods currently used in the model and monitoring programs to estimate flows at mainstem locations.

    c. Consistent with the data use in the RSFMP, collect operational water management data, specifically for pit dewatering activities, (flow and quality) to inform interpretation of monitoring data at discharge points and improve source terms. Currently for example, it is possible that historical pit dewatering increases calculated loads, which are therefore overestimated in cases where pit dewatering is not expected to occur going forward.

    d. Review data collection methods at two specific catchments to confirm accuracy: Cataract Creek, Henretta Creek (winter flows).

2) Regional Surface Water Monitoring Program:

    a. Monitoring of pit dewatering quality and quantity will improve modelling and interpretation of monitoring data to derive source terms.

8 References

Barbour, S. L., Hendry, M. J., & Carey, S. K. 2016. *High-resolution profiling of the stable isotopes of water in unsaturated coal waste rock*. doi:http://dx.doi.org/10.1016/j.jhydrol.2016.01.053

Environmental Monitoring Committee. 2017. Permit 107517 Environmental Monitoring Committee 2017 Public Report.

Ferguson, KD and Leask SM. 1988. *The Export of Nutrients from Surface Coal Mines*. Regional Program Report 87-11. Environment Canada.

Nichol, C., Smith, L., & Beckie, R. (2005). Field-scale experiments of unsaturated flow and solute transport in a hetreogeneous porous medium. Water Resour. Res, 41. doi: http://dx.doi.org/10.1029/2004WR003035

SRK 2014. *Geochemical Source Term Inputs and Methods for the Elk Valley Water Quality Planning Model*. Report prepared for Teck Coal Limited. June 2014.

SRK 2017. *Geochemical Source Term Methods and Inputs for the 2017 Update of the Elk Valley Regional Water Quality Model [Annex A]*. Report prepared for Teck Coal Limited. October 2017.

Teck 2016. Water Quality Adaptive Management Plan for Teck's Coal Operations in the Elk Valley.

Teck 2017a. *2017 Elk Valley Regional Water Quality Model Update – Annex B – Site Conditions*. Prepared for Teck Coal by Golder Associates Ltd, October 2017.

Teck 2017b. *2017 Elk Valley Regional Water Quality Model Update – Annex C – Hydrology Modelling*. Prepared for Teck by Golder Associates Ltd, October 2017.

Teck 2017c. *2017 Elk Valley Regional Water Quality Model Update – Annex D – Water Quality: Model Set-up and Calibration*. Prepared for Teck Coal by Golder Associates Ltd, October 2017.

Teck 2017d. *2017 Elk Valley Regional Water Quality Model Update – Annex E – Water Quality: Future Projections*. Prepared for Teck Coal by Golder Associates Ltd, October 2017.

Teck 2017e. *Compliance Action Plan for Permit 107517 Line Creek Exceedances*. Letter issued by Teck to Ministry of Environment and Climate Change Strategy on September 14, 2017.

Villeneiuve, S.A., Barbour, S.L., Hendry, M.J., Carey, S.K. 2017. *Estimates of water and solute release from a coal waste rock rump in the Elk Valley, British Columbia, Canada* (In draft).