2020 Regional Water Quality Model Update Report

Rev0

March 2021

Teck

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Acronyms and Abbreviations

Acronym or Abbreviation	Description
AET	actual evapotranspiration
AMP	Adaptive Management Plan
AWTF	Active Water Treatment Facility
BC	British Columbia
BRE	Baldy Ridge Extension
BRD	Bodie Rock Drain
CCR	coarse coal rejects
BRN	Burnt Ridge North
CMO	Coal Mountain Operations
CPX	Cougar Pit Extension
EAC	Environmental Assessment Certificate
ECCC	Environment and Climate Change Canada
EMA	*Environmental Management Act*
EMLI	Ministry of Energy, Mines and Low Carbon Innovation
ENV	Ministry of Environment and Climate Change Strategy
EMS	Environmental Monitoring System
EVO	Elkview Operations
EVWQP	Elk Valley Water Quality Plan
FRO	Fording River Operations
GHO	Greenhills Operations
HSR	Horseshoe Ridge
LOM	life of mine
LCO	Line Creek Operations
LRP	Lower Round Prairie
MAE	mean absolute error
MSA	Mine Service Area
MTM	Mount Michael
MOE	BC Ministry of Environment (dating prior to re-organization, 2016 and earlier)
NLC	North Line Creek
NLX	North Line Creek Extension
PET	potential evapotranspiration
FC	Regional Flow Component
RFMP	Regional Flow Monitoring Plan
RMSE	root mean square error
RWDI	Rowan Williams Davies and Irwin
RWQM	Regional Water Quality Model

Acronym or Abbreviation	Description
SRF	saturated rock fills
SRM	Snowmelt Runoff Module
STP	South Tailings Pond
SWE	snow water equivalent
Teck	Teck Coal Limited
TSF	Tailings Storage Facility
UBCWM	University of British Columbia Watershed Model
VMC	volumetric water content
WQC	Water Quality Component
WWT	Wastewater Treatment (FRO climate station ID)

Units

Unit of Measure	Description
%	percent
°C	degrees Celsius
°C/d	degree-days
cm	centimetre
km^2	square kilometre
m	metre
m^3	cubic metre
m^3/day	cubic metres per day
m^3/s	cubic metres per second
mm	millimetre
masl	metres above sea level

GLOSSARY

Term	Similar terms (may or may not be synonymous) and acronyms	Definition
Ablation	*See* Sublimation	The reduction in volume of glacial ice and snow by the combined processes of melting and sublimation.
Active Zone	Soil moisture storage, Evapotranspiration soil layer	The near surface layer, or root zone, wherein water is susceptible to evapotranspiration and other atmospheric exchanges.
Actual evapotranspiration	AET	Amount of water lost through the processes of evaporation and water loss from plants (transpiration).
Analogue watershed	Representative watershed / Reference watershed	A watershed with well-defined watershed boundaries that is dominated by a single land use (i.e., either mine or natural), has a well-documented history of watershed activities and possesses a strong long-term data record that can be used to generate a representative flow series that can be applied to other watersheds of similar land use.
Basal seepage		Used herein to refer to water moving through a waste rock spoil that reports to a groundwater system underlying the waste rock.
Baseflow		The portion of the hydrograph that represents low fall / winter flow, which is typically related to groundwater discharge.
Catchment	Watershed, Drainage, Sub-catchment	See *Watershed*
Catchment lag time	Not to be confused with hydraulic response time or hydraulic lag	The time between peak precipitation and peak discharge from a catchment, regardless of whether water is moving through natural or mine-affected areas.
Conceptual model		A text-based description, often supported by figures or other graphics, that explains the processes that govern the movement of water and/or mass through a system. With respect to the 2020 RWQM Update, the conceptual hydrology model describes the movement of water through waste rock spoils and other mine affected areas in the Elk Valley. The conceptual water quality model describes, in broad terms, the release of selenium, nitrate and sulphate from waste rock spoils and the movement of these constituents through mine-influenced tributaries and through the Fording River and the Elk River.
Constituent inventory		Total mass of a given constituent contained in waste rock spoil.
Deep groundwater recharge	Deep percolation	Water that infiltrates through the root zone and seeps downwards to recharge a lower aquifer. Deep percolation refers to water that does not contribute to interflow or local surface runoff.
Direct precipitation	DP	The total amount of rain and snow that has fallen on an open water surface, which is separate from any external flows that contribute to the total flow.
Dispersion		The outward migration of mass from a center point as that centre point moves through space.
Drainage	Watershed, Sub-catchment	See *Watershed*

GLOSSARY

Term	Similar terms (may or may not be synonymous) and acronyms	Definition
Eddy covariance		A statistical method to determine exchange rates of gases between atmospheric boundary layers.
Empirical		Based on observation rather than theory.
Erlang Value		A positive integer that defines the shape of the Erlang distribution. The Erlang Value is a model input parameter within GoldSim that influences dispersion. The lower the Erlang Value, the higher the rate of dispersion.
Evaporation		The process by which water is changed from the liquid phase to the vapour phase.
Evapotranspiration	ET	Loss of water through the processes of evaporation and transpiration (water loss from plants).
Fetch length	fetch	The horizontal distance over which wave-generating winds blow.
Field Capacity	Soil water retentive capacity; tension water	The amount of water held by tension that is not drained by gravity.
Freshet	Spring freshet	A time of higher than normal flow attributable to the melting snow and ice.
Groundwater bypass	Underflow, Subsurface flow, Valley-bottom flow	The part of total runoff that occurs beneath the ground level at a given location. Term is also used to refer to water flowing through the permeable valley-bottom sediments and gravels that may not be captured in hydrometric monitoring data or collected at an intake location.
Hard mine areas	Pit wall areas	Mine-influenced areas of the catchment that are characterized by relatively impermeable surfaces; typical includes pit walls, roads, buildings, process plant areas and other facilities. Hard mine areas specifically exclude waste rock spoils and coarse coal refuse facilities.
Hydraulic lag	Lag time Not to be confused with hydraulic response time or catchment lag time	Time period between the placement of waste rock in a spoil and the detection of constituents released from that waste rock at the first monitoring station located downstream of the spoil. It is effectively defined by the time it takes a particle of water to travel vertically through a spoil, into the downstream environment and report to the first downstream monitoring station.
Hydraulic response time	Delay time Not to be confused with hydraulic lag or catchment lag time	Time period between infiltration into a spoil and the corresponding release of a comparable amount of water from the base of the spoil. It is effectively defined as the time it takes a pressure wave to propagate through a spoil.
Infiltration		Movement of water from the ground surface into the active zone; can also be used to refer to the movement of water from a watercourse or waterbody into the ground, which provides aquifer recharge
Instream sink		Mass removal mechanism used in the model to achieve a mass balance.

GLOSSARY

Term	Similar terms (may or may not be synonymous) and acronyms	Definition
Interflow		Water that flows in the unsaturated zone between the ground surface and the top of the groundwater table and then discharges back to surface.
Lake evaporation	Evaporation	Evaporation that occurs from a lake surface.
Lapse rate	Temperature gradient; Orographic factor	The rate of change of air temperature relative to a change in elevation.
Leaf area index	LAI	The ratio of leaf area to soil surface area. Leaf area index is correlated to potential and actual evapotranspiration rates.
Macropore flow	Preferential flow; quick flow, quick percolation	The flow of water through non-capillary pores in a waste rock spoil; the presence of which is dependent on the texture and textural variability of the spoil.
Mainstem		The main portion of a watercourse extending continuously upstream from its mouth, but not including any tributary watercourses.
Matrix flow	Slow flow, slow percolation, capillary flow	The flow of water through capillary pores in a waste rock spoil. Typically, the dominant flow path that governs water movement though waste rock spoils.
Mine-influenced	Mine-affected, Disturbed, Mine-contact	Having the characteristic of being somehow affected or altered by mining activity (e.g., mine-affected area of a watershed or a mine-affected water flow).
Natural	Undisturbed, Background	Having the characteristic of being unaffected by mining activity (e.g., undisturbed or natural area of a watershed or a background or natural flow).
Numerical model		A computer-based representation of the conceptual model, with the processes identified in the conceptual model represented mathematically in a computer program thereby allowing for the simulation of flow and or water quality.
Orographic	Elevation-based	Differences related to elevation (specifically in regards to precipitation).
Overburden		The soil (sand, silt, clay or mix thereof) that overlies bedrock and must be removed before mining a mineral deposit.
Particle size distribution	Texture	The property of a granular material, such as waste rock, that describes the relative amount of particles present, according to size.
Percolation	Net Infiltration	The downward movement of water from the active zone into and through underlying porous materials.
Percolation, Net		The percolation rate at the base of a waste rock spoil, after accounting for internal water storage within the spoil due to "wetting up"
Piston flow	Pressure wave	See *Pressure wave*
Porosity	Void space	The percentage of the bulk volume of a rock or soil that is occupied by interstices (minute openings or crevices), whether isolated or connected.

GLOSSARY

Term	Similar terms (may or may not be synonymous) and acronyms	Definition
Potential evapotranspiration	Reference evapotranspiration	The maximum quantity of water capable of being evaporated from the soil and transpired from the vegetation of a specified region in a given time interval under existing climatic conditions and without limiting available surface moisture.
Precipitation		The total amount of rain and snow that falls to the ground, usually expressed in millimetres. Typically used to describe rain and snow fall within a given area, as opposed to that at a specific location (which is referred to as direct precipitation)
Precipitation gradient	Precipitation lapse rate	The rate of change of precipitation relative to a change in altitude.
Preferential flow	Macropore flow, quick flow	See *Macropore Flow*
Pressure wave	Piston flow	The representation of matrix flow whereby water moves at approximately the same rate throughout the spoil caused by a pressure differential through the pores. It is a dampened, piston type, downward displacement of water in a waste rock spoil caused by infiltration at the top of the spoil.
Rainfall		The fall of water to the ground in liquid form.
Retention areas	Reservoirs	Reservoir elements included within the numerical model to dampen seasonal variation in constituent concentrations.
Rock drain		A constructed or naturally formed coarse rubble or gravel corridor along a valley-bottom that is capable of receiving and conveying water flow.
Runoff	Surface runoff, overland flow	The portion of water from rain and snowmelt that flows over land to streams, ponds or other surface waterbodies. It is the portion of water from precipitation that does not infiltrate into the ground or evaporate.
Run-on		Essentially the same as runoff, but referring to water that flows onto a facility, or any piece of land of interest. In the RWQM, often used in the context of run-on flows at the base of a waste rock spoil from an upstream catchment.
Saturated hydraulic conductivity		The ease with which pores of a saturated soil transmit water, represented as the relationship between the flow rate and the hydraulic gradient.
Saturation		The amount of water contained in a granular material relative to the porosity.
Scaling method		The method by which flow statistics derived using data from long-term hydrometric stations are scaled by watershed area to determine flow at ungauged locations of interest.
Shallow groundwater flow	Underflow, interflow, valley-bottom flow	Water traveling near, but below, the ground surface along flow pathways that are relatively short and report to local watercourses / waterbodies, as opposed to water moving through deeper aquifers that typically contain older water moving at much slower rates.

GLOSSARY

Term	Similar terms (may or may not be synonymous) and acronyms	Definition
Snow water equivalent	SWE	The amount of liquid water generated when a given quantity of snow melts.
Snowfall		The fall of water to the ground in solid phase.
Snowmelt		The water that results from melting snow.
Soil moisture		The amount of water contained within a soil in the unsaturated active zone.
Steady state	Equilibrium	State when a system is no longer changing or in flux; conditions have essentially stabilized.
Storage		Water retained as soil moisture or contained in reservoirs, pits, ponds, lakes and wetlands.
Sublimation	See Ablation	The transformation of solid phase (snow or ice) to vapour phase (water vapour), driven by the vapour pressure gradient.
Subsurface flow	Underflow, valley-bottom flow, shallow groundwater flow, groundwater bypass	See *Groundwater bypass*
Surface runoff	Runoff	The flow of water that occurs when excess precipitation or meltwater flows above ground.
Surface water – groundwater partitioning		Division of total watershed flow into surface flow and groundwater water flow components. It is location-specific and related to groundwater bypass.
Toe discharge		Net percolation that reaches the base of a waste rock spoil and travels laterally along the underlying topography and reports as surface discharge.
Tributary scale	Catchment scale	Small to mid-sized catchments, typically representing a drainage area ranging from a few square kilometres to up to 100 km^2, with varying levels of mine disturbance.
Unsaturated zone	Vadose zone	An initial subsurface layer that does not consistently contain or otherwise hold water, by capillary action or otherwise.
Vapour pressure		The pressure exerted by gaseous water in thermodynamic equilibrium with its condensed phases (snow or water) at a given temperature.
Volumetric water content		The ratio of water volume in a granular material to the total bulk volume, which is limited by porosity.
Waste rock spoil		Rock removed during mining and stored in a designated area.
Water balance		The accounting of water movement into and out of a system, generally consisting of: precipitation, atmospheric losses, watershed yield, storage and deep percolation.
Water retentive capacity	Field capacity; tension water	The amount of water held in a type of soil by surface tension that is not drained by gravity.

GLOSSARY

Term	Similar terms (may or may not be synonymous) and acronyms	Definition
Watershed	Catchment, Sub-Catchment, Drainage, Basin	The entire geographical area drained by a river and its tributaries (i.e., an area characterized by all runoff being conveyed to the same outlet). For the purposes of this report, the term 'watershed' is used to describe drainage areas at the valley or broader river scale (i.e., Elk River, Fording River, and Michel Creek). In contrast, the terms 'catchment' and 'sub-catchment' are used to describe drainage areas at the respective tributary scale and sub-tributary scale.
Watershed yield	Basin yield, Total flow, Total runoff; Total watershed yield	Total runoff from a given watershed, including surface runoff and groundwater discharge that appears in the stream, plus groundwater outflow that leaves the basin underground.
Wetting up (wet up)		The required time needed for the depletion of available moisture storage as water continues to percolate through the unsaturated spoil.

1 Introduction

1.1 Background

Teck Coal Limited (Teck) has 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)
- 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 9.9, requires Teck to update the RWQM every three years. The first update was completed on October 31, 2017.

The second update was due October 31, 2020. In September 2020, Teck identified that there would be a delay in the submission of the 2020 RWQM Update. The revised submission date was communicated to be March 19, 2021. The change in submission date was requested to allow time to address issues identified during model calibrations in order to produce an effective tool for future planning and decision making. The issues resulted from changes made to the numerical framework of the RWQM.

The RWQM is a tool used to simulate how historical, current, and future mining activities could 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 Koocanusa Reservoir. It is based on a conceptual model describing constituent release and transport, the elements of which are reflected numerically in the RWQM. The RWQM was used to develop the Initial Implementation Plan (IIP), which was included in the EVWQP, to meet the Site Performance Objectives (SPOs) and compliance limits defined in *EMA* Permit 107517.

In the 2017 RWQM Update, learnings since the submission of the EVWQP informed the conceptual model for constituent release and resulted in the identification and incorporation of an initial time delay between waste rock placement and measurement of constituent mass at the first downstream monitoring station. Learnings also informed updates to the equations used to describe nitrogen leaching and eventual wash out from waste rock. Incorporation of these changes resulted in improved RWQM performance and reliability. Follow-up activity to the 2017 RWQM Update included research and site-specific investigations focused on groundwater pathways linking tributaries to the river mainstems, the potential mechanisms resulting in loss of selenium and nitrate load along these pathways, and changes to constituent release over time. The IIP was also adjusted following the 2017 RWQM Update and documented in the 2019 Implementation Plan Adjustment (IPA) (Teck 2019).

The 2020 RWQM Update is focused on incorporating learnings related to the mechanisms driving constituent release and transport, including the explicit incorporation of groundwater flow pathways and development and implementation of a waste rock hydrology module, as well as a fundamental change to a climate-driven model framework. The shift towards increasing the number of mechanisms included in the model is intended to improve confidence in model performance, projections of future conditions and use in mitigation planning.

Teck indicated prior to the submission of the 2020 RWQM Update that adjustments to the Implementation Plan are required and will be completed as a next step. The model updates do not include any adjustments to the water quality management and mitigation measures outlined in the 2019 IPA. This report is focused on describing the updated tool, which is intended for use in future mitigation planning and water quality assessments.

The RWQM is a mass balance model that consists of four components:

- a flow component used to simulate water flow through the Elk Valley
- geochemical source terms used to define constituent release rates from waste rock and other mine facilities
- mine site information
- a water quality component that uses output from the flow component, mine site information, the geochemical source terms and background water quality monitoring data to estimate constituent concentrations at locations in the Elk Valley

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 9.9 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
- CMO: C-84 Amendment Approving Water Quality and Calcite Mitigation issued November 27, 2014

Section 3.3 contains a list of specific requirements and where they are met in this submission.

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

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 (Evaluate) and Stage 6 (Adjust) of the AMP as an assessment and planning tool for identifying where and how the planned water quality mitigation measures in the Elk Valley may need to be adjusted (Teck 2018).

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, water quality projections developed using the RWQM 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 to the implementation plan under Stage 6 (Adjust) 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.

The 2020 RWQM Update submission is a model methods submission. It details how the model has been updated and changed to reflect new learnings and incorporate feedback collected since the 2017 RWQM Update. This submission describes the changes made and how the updated model performs, with reference to the simulation of historical conditions. This submission also includes projections into the future, based on the updated configuration of the model and the mitigation measures outlined in the 2019 IPA. In addition, as this document is a methods submission, it includes unmitigated future projections in order to identify what has changed and to evaluate how the 2020 RWQM performs in comparison to the 2017 RWQM. Neither the mitigated or unmitigated projections reflect expected future concentrations, because mitigation has not yet been adjusted. As a result, the future projections outlined herein should not be used to assess potential effects to water quality or aquatic health.

Adjustments to the Implementation Plan are underway and will be described in a separate submission; an integrated aquatic effects assessment will be completed, as appropriate, and included in the separate submission. Adjustments to the Implementation Plan have been initiated in response to new learnings around the use and performance of saturated rock fills (SRFs), changes to blast management practices that have been implemented across Teck’s operations, improved understanding of surface water – groundwater partitioning at Kilmarnock Creek and in response to the model updates outlined herein. The next IPA is being developed, consistent with the AMP and permit requirements related to the 3-year model updates. It will be advanced in consultation with Ktunaxa Nation Council (KNC) and regulators.

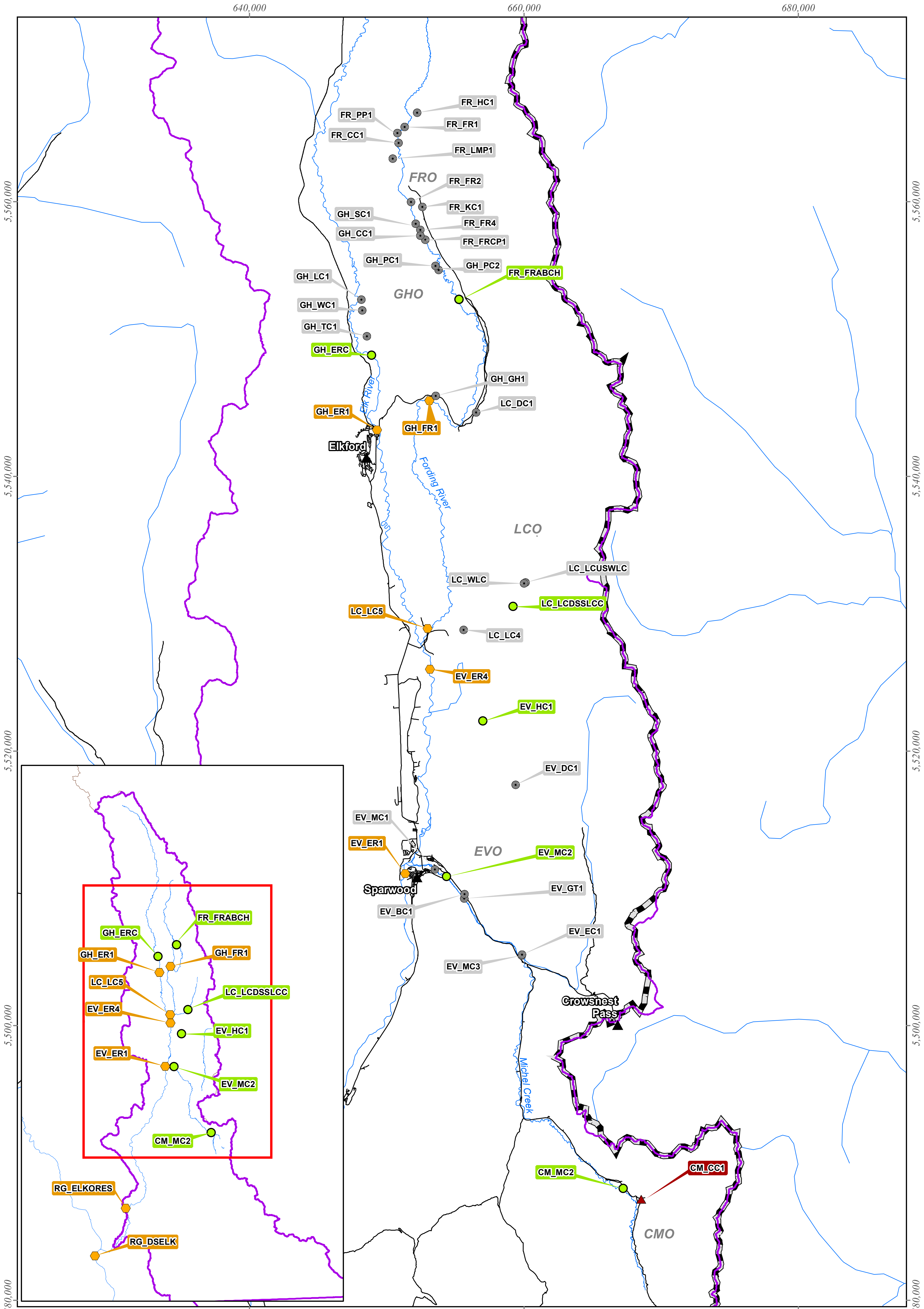


Figure 1-1 Locations of Teck Mining Operations in the Elk Valley and Select Monitoring Locations

[redacted]

The maps [redacted] 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.

Legend:
- 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:	MINE OPERATION:
3/16/2021	ELK VALLEY OPERATIONS
SCALE:	COORDINATE SYSTEM:
1:250,000	NAD 1983 UTM Zone 11N

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

1.2 Purpose and Content of Report

The goal of the 2020 RWQM Update submission is to identify the important changes to source terms, modelling methods, calibration, and the resultant effect to model performance, as they form the basis for a robust tool used to support mitigation planning, permitting and aquatic health assessments. The purpose of this document is to provide an overview of the 2020 RWQM Update, summarize how the submission meets permit requirements, and highlight key changes implemented in the water flow and water quality modelling approaches. The report includes descriptions of the main components of the 2020 RWQM Update, specifically:

- the conceptual model;
- the general approach and updates to the numerical model;
- the geochemical source terms, discussed in terms of focal areas for this update, approach taken, and resulting changes to the geochemical source terms;
- the site conditions;
- the flow component, discussed in terms of focal areas for the update, approach taken, resulting changes and model performance; and
- the water quality component, discussed in terms of focal areas for update, approach and resulting changes, and model performance.

It also includes a discussion of how this model update supports adaptive management and next steps based on these results.

The following supporting documents are included in the submission, as they provide greater detail on the model inputs, methods and results:

- Annex A: Geochemical Source Term Methods and Inputs for the 2020 Update of the Elk Valley Regional Water Quality Model
- Annex B: 2020 RWQM Update: Hydrology Modelling – Set-up, Calibration and Future Projections Report
- Annex C: 2020 RWQM Update: Water Quality Modelling Set-up and Calibration Report – Order Constituents
- Annex D: 2020 RWQM Update: Water Quality - Model Projections Comparison Report

In addition, Appendix A of this report includes a copy of the report entitled *Coal Mountain Operations Water and Load Balance Model 2020 Consolidated Report* (SRK 2021a). This document was not developed as part of the 2020 RWQM Update, but is included as the material contained therein is pertinent to the 2020 RWQM.

2 Conceptual Model

2.1 Overview

The 2020 RWQM is based on an updated and improved conceptual model describing constituent release and transport in the Elk Valley. The conceptual model is updated routinely as Teck continues to improve and refine understanding of the mechanisms driving constituent release and transport.

Coal is present in the Elk Valley as layers or seams that are interlayered with sandstone, siltstone and mudstone. The rock in the surrounding seams contain sulphide and carbonate minerals, which contain constituents such as selenium, sulphate, and cadmium. Accessing coal ore bodies requires blasting and moving the surrounding non-ore bearing rock (waste rock). These mining activities expose rock surfaces to the atmosphere, which can enhance the release of these constituents. The blasting process also results in the deposition of explosives residue on waste rock and pit walls. This residue contains nitrogen compounds; the most abundant of which is nitrate. Waste rock exposure to the atmosphere, which occurs in the pit after blasting and after placement in spoils, results in oxidation of sulphide minerals and subsequent release of constituents. Upon release, constituents move from waste rock spoils into the receiving environment via precipitation that infiltrates into waste rock spoils and flows by gravity to the base of the spoil.

Water from waste rock spoils emerges into surface watercourses or infiltrates into shallow groundwater systems which report to tributary watercourses with natural or mine-influenced headwaters, wherein it mixes with water from non-mine affected areas as it moves downstream, eventually reporting to the larger mainstems of the Fording River and the Elk River. Water flow through tributaries and the larger watersheds is influenced by physiography and climate, as well as exchanges between surface water and groundwater flow paths.

2.2 Conceptual Model for Water Flow Through Waste Rock

Waste rock spoils tend to be heterogeneous, and their hydrological behaviour is complex. Vertical water movement through the waste rock occurs as a result of water infiltrating into waste rock, percolating through the spoils and being release as toe discharge at the base of the spoil, with some water being retained through “wet-up” and/or transient storage (Figure 2-1). The hydrologic response of a waste rock spoil is slower than that of an undisturbed land; they tend to attenuate freshet peaks and result in increased winter baseflow.

Waste rock spoils can have limited or no vegetative cover (depending on reclamation status), resulting in reduced evapotranspiration (ET) rates compared to non-mine affected areas (Birkham et al. 2014, Birkham 2017). Runoff is typically negligible from waste rock, and therefore water that is not lost to evaporation infiltrates into the waste rock.

Infiltrated water that percolates below the influence of ET in the spoil is subject to unsaturated groundwater flow dynamics. Flow pathways through waste rock spoils are variable and can be via capillary pores (matrix or piston flow) as well as non-capillary pores (macropore or preferential flow). Macropore flow pathways can dominate in small, new spoils and in the near surface of older spoils. However, in most spoils, matrix flow pathways tend to dominate (Barbour et al 2016). Transport of constituents is also understood to be primarily driven by flow through the waste rock matrix due to greater residence time and increased contact of water with the fine-grained material (Neuner et. al. 2013).

Wet-up is defined as the time required for a spoil to retain sufficient moisture to support capillary action and the free movement of water from the top of the spoil to its base, with subsequent release to downstream environments. In the Elk Valley, wet up for newly placed waste rock is typically achieved within one or two years of placement (OKC 2018, Barbour et al 2016).

Net percolation is the water available for discharge once it has infiltrated and moved through the waste rock spoil. It emerges as either toe discharge or seepage to an underlying groundwater flow pathway, depending on local geology and topography. It may also be released into rock drains present at the base of the spoil, mixing with runoff from upstream areas passing through the rock drain (i.e., a zone of higher permeability created through the natural segregation of waste rock when end-dumping). Research (e.g., Wellen et al. 2018) indicates that constituent transport is driven by vertical rather than horizontal flow through waste rock, and that flow through waste rock drains contributes little to overall constituent release from waste rock spoils to downstream watercourses and waterbodies.

Although it can take some time for a particle of water to travel vertically from the top of a mature spoil to the bottom of the spoil and into the receiving environment, the time required for a spoil to respond to a change in annual climatic conditions is relatively short. In other words, water flow through a waste rock spoil follows a piston-type pattern, wherein infiltration into the top of a spoil results in a pressure wave that travels relatively quickly through the spoil and pushes older water out from the base of the spoil. Pressure waves move through a spoil in a matter of weeks, compared to the 10+ years in may take a drop of water to travel through a mature spoil.

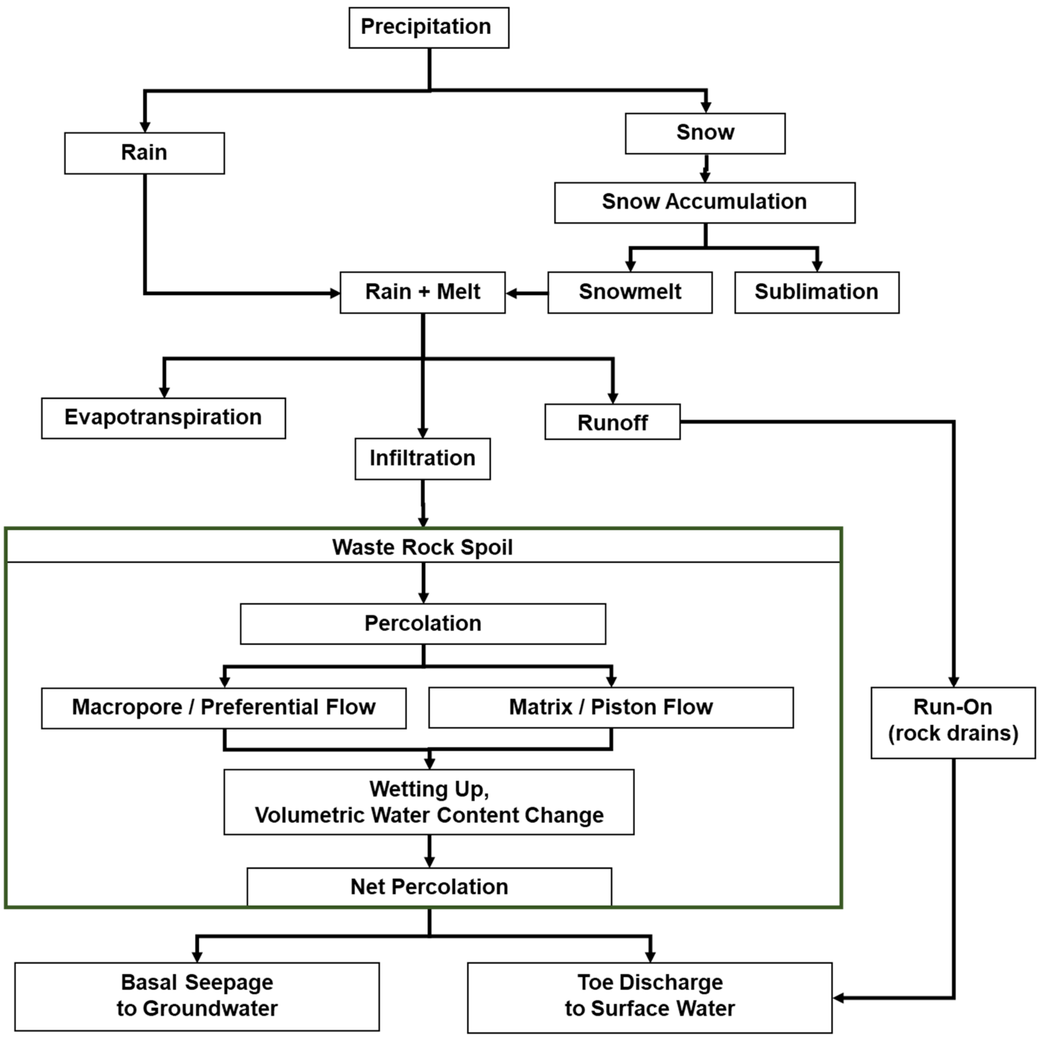
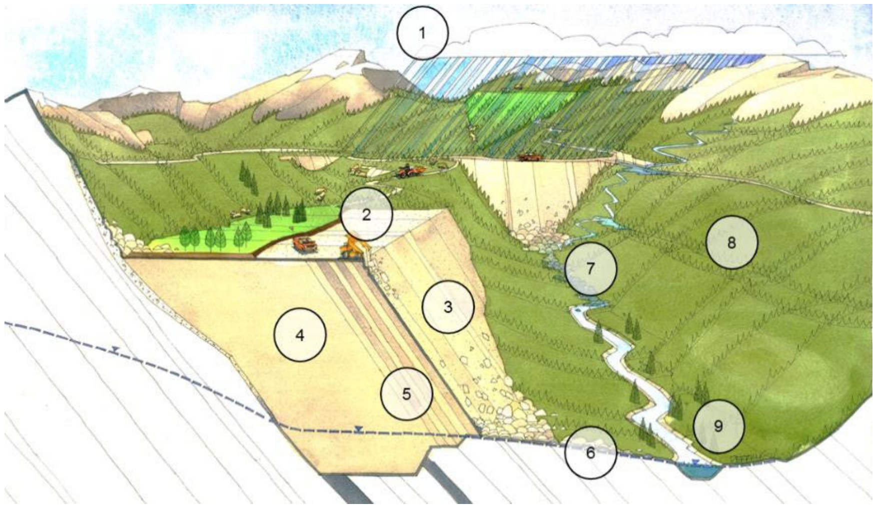


Figure 2-1: Waste Rock Spoil Conceptual Flow Model

2.3 Conceptual Model for Water Quality Constituent Release and Transport

2.3.1 Unsaturated Waste Rock

The conceptual model for water quality constituent release and transport from unsaturated waste rock is illustrated and summarized on Figure 2-2, with greater detail provided in Annex A. As the processes outlined in Figure 2-2 occur, the release of constituents continues until the source material is depleted. Depletion occurs more quickly for nitrate (which is highly soluble and readily available for transport), than for sulphate, selenium and other constituents (which are less soluble and must first be released through oxidation).



1	**Net Percolation** • The amount of water that enters from the surface of the waste rock piles is a function of precipitation and snowmelt minus evaporation, evapotranspiration and sublimation. • Run-off from the unsaturated waste rock is negligible
2	**Rock placement and physical conditions** • Waste rock placement is tracked as bank cubic metres (BCM) placed per year and is a primary factor in source term development. • The method of construction can influence the flow paths that constituents of interest (CIs) travel to exit the waste rock piles.
3	**Leaching of explosives residuals contributes inorganic nitrogen (e.g., nitrate) to contact waters** • Leaching of explosives residuals will diminish with time since a finite amount of explosives are introduced during mining and nitrogen forms are not expected to be generated by rock weathering. • The amount of nitrogen present is a function of placed waste rock, powder factor, management practices, wet/dry holes, blast utilization and is present dominantly as nitrate.
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 cadmium (among others) have been shown to co-precipitate with calcite when this occurs.
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 2-2: Geochemical Conceptual Model for Unsaturated Waste Rock

2.3.2 Other Mine Sources

In addition to waste rock spoils, runoff from pit walls, coal refuse, rehandled waste rock, and seepage from tailings facilities, contribute to the release of constituents; however, constituent contributions from these other sources are low compared to that from waste rock. The conceptual models for constituent release from these sources are described below, with greater detail provided in Annex A.

Pit Walls

The conceptual model for 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.

Coal Refuse

Coal refuse is comprised of finer grained materials (compared to waste rock) that are typically stored in dedicated facilities that are constructed in small lifts and compacted as they are built. Oxygen penetration into coal refuse facilities tends to be limited and organic carbon is abundant, leading to oxygen-consuming reactions and resultant reducing conditions that limit the release of constituents through pyrite oxidation and other similar processes. The release of trace elements may also be controlled to low levels by the abundance of reactive surface areas on the coal fines.

Tailings

The conceptual model for constituent release associated with seepage from tailings facilities is similar to the conceptual model described for coal refuse. Tailings facilities tend to have a higher degree of saturation that 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 lower compared to the concentrations measured in the pond and inflowing sources. As outlined in more detail in Annex A, lower concentrations of nitrate and selenium in tailings seepage result from the presence of sub-oxic to anoxic zones within the tailings. In the presence of labile carbon, these conditions are favourable for microbially mediated reduction of nitrate and selenium, similar to the processes occurring within the saturated zones of backfilled pits.

Rehandled Waste Rock

Rehandled waste rock is the term used to describe waste rock that is moved from one location to another to accommodate mine development. Residual nitrate and oxidation products that have accumulated since the waste was originally placed are released when the waste rock is rehandled. This release is in addition to that which would otherwise occur if the materials were not rehandled and results in a relatively short-term increase in loading following placement.

2.3.3 Regional Transport

Constituents released from mine sources, as well as those contained in runoff from non-mine affected areas, are transported into local tributaries, which drain into the Elk River, the Fording River or Michel Creek. Transport into and along these regional systems occurs primarily via surface flow, with some flow and transport occurring via shallow subsurface flow pathways that report, at a regional level, to surface.

Movement of water and constituent mass along subsurface flow pathways is not always uniform. They can consist of preferential and non-preferential sub-pathways. Although travel along the preferential sub-pathway dominates, the presence of preferential and non-preferential sub-pathways can result in the dispersion of water and constituent mass as they move from mine-influenced tributaries to the river mainstems.

Similarly, within the river mainstems, water movement is not uniform. Differential movement of water (and, by association, mass) occurs due to bank storage and exchange between the water column and the underlying hyporheic zone. It can also result from exchange that occurs between the water column and underlying shallow groundwater flow pathways oriented in a parallel direction to mainstem flow, exchange that occurs as surface water passes through gaining and losing river reaches. The effect of the differential movement is small, insufficient to materially alter mainstem hydrographs, which typically reflect the summation of upstream tributary input. Nevertheless, it can influence instream mixing conditions, particularly during lower flow periods of the year.

Mixing within the mainstem river system occurs primarily through advective dispersion and turbulence induced by the water flowing over rocky substrate. Constituent mass, specifically selenium, nitrate and cadmium, can be removed from the system as it moves downstream through reductive processes (selenium and nitrate), adsorption to bed sediments (cadmium) or other forms of attenuation.

These processes are similar for all operations, with local differences in the partitioning between surface and groundwater flow pathways. Groundwater flow through deep bedrock is understood to be small to negligible.

3 Approach to Model Update and Conformance with Permit Requirements

3.1 Organization of the Regional Water Quality Model

The RWQM numerically represents the conceptual model described in Section 2. It is a mass balance model, and concentrations at a given location are calculated by adding upstream inputs and dividing by the total flow. Sources include waste rock, coal reject, pit walls, tailings facilities and drainage from natural areas. Losses include instream losses incorporated as part of calibrating the model, and the removal of mass through mitigation (e.g., water treatment). Data used as inputs to the RWQM and the contributing components are illustrated on Figure 3-1.

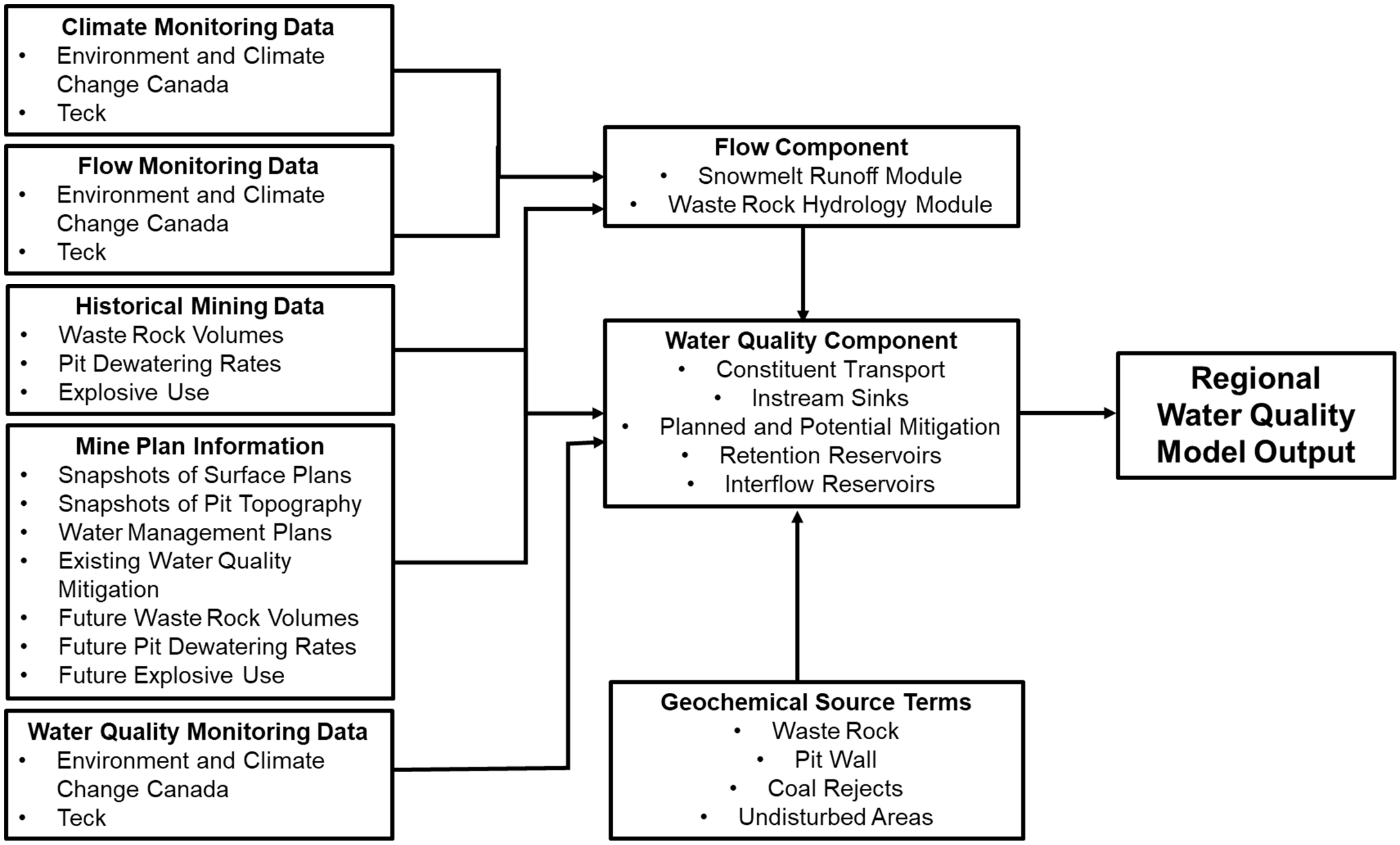


Figure 3-1: Schematic Overview of the RWQM Inputs and Components

The four main components of the 2020 RWQM have not changed from the 2017 RWQM. They consist of:

- a Flow Component (FC) that is used to estimate total water flow in tributary watersheds and in the Fording River and Elk River
- geochemical source terms that identify the mass of nitrate, selenium, sulphate, and other constituents released from waste rock, pit walls and other mine areas (e.g., tailings storage facilities and coal refuse facilities)
- mine site information, including historical mine site data and future permitted mine plans
- a Water Quality Component (WQC) that is used to estimate constituent concentrations in mine features, mine-affected tributaries, the Elk River, the Fording River, Michel Creek and Koocanusa Reservoir.

The four components work in concert to initially identify the amount of water and constituent mass that originates from mine infrastructure, mine facilities and non-mine affected areas. Water flow and mass are then tracked as they move down through the system until they eventually reach Koocanusa Reservoir.

The geochemical source terms are defined either in terms of mass released per unit volume of source material (e.g., mg per bank cubic meter of waste rock) or mass per volume of water draining from the source material (e.g., mg/L). They are used in combination with the mine site information to define rates of mass release from operational areas, historically and into the future. The FC is used to simulate the volume of water generated and released from mine operations and natural areas, including that which may be stored within pits, consumed within mine operations through coal processing or dust suppression, or moving between sub-catchments due to mine water management. This information is input to the WQC, which is used to calculate and track the movement of mass and water through the system, while accounting for the influence of water quality mitigation measures, instream losses and/or attenuation processes and on-going mining activity. Outputs from the RWQM include estimates of flow, constituent mass (or load) and constituent concentrations for numerous modelled locations within the Elk Valley.

Although the components of the RWQM remain the same, and it is still organized in the same manner, the content of each component changes with each model update. An overview of the areas of focus for the 2020 RWQM Update is outlined in Section 3.2, with additional detail provided in Sections 4, 6 and 7 in reference to the geochemical source terms, the FC and the WQC, respectively.

3.2 Objectives and Areas of Focus for the 2020 Update

The main objectives of the 2020 RWQM Update were to:

- incorporate new learnings and data collected since the completion of the 2017 RWQM
- address feedback received from representatives of the BC Ministry of Environment and Climate Change Strategy (ENV), BC Ministry of Energy, Mines, and Low Carbon Innovation (EMLI) and Ktunaxa Nation Council (KNC) since the completion of the 2017 RWQM Update
- address areas of discrepancy identified between modelling projections generated using the 2017 RWQM and monitoring data collected since the last update, specifically with respect to the updated understanding of constituent release from newer waste rock
- reflect changes to explosive management and other changes to mine operations and mine water management

Specific areas of focus for the 2020 RWQM were as follows:

Geochemical Source Terms

- incorporate monitoring data collected since 2016 into the existing Elk Valley geochemistry dataset and update selenium, sulphate and nitrate source terms, as appropriate and required
- update source terms with consideration of historical water management and groundwater information
- update nitrate source terms to account for the use of liners in blast holes and other improvements in the handling and use of explosives
- update the source terms for cadmium to more strongly reflect the linkage between sulphate and cadmium generation, as well as to reflect calculated rates of attenuation
- examine the extent to which selenium and sulphate source terms may change over time in response to the depletion of source minerals and other geochemical processes (e.g., accumulation of iron oxides on waste rock surfaces)

Flow Component

- switch to a climate-driven model framework, thereby eliminating the need for analogue hydrographs
- develop and implement a numerical method to simulate water flow through waste rock spoils
- increase the level of spatial detail included in the FC to allow for a better representation of mine water management and other mine activities
- calibrate the updated model framework using monitoring data collected up to the end of 2019

Water Quality Component

- update the numerical representation of hydraulic lag to account for the quicker release of constituents from new spoils
- apply hydraulic lag and leaching efficiency to constituents released from rehandled materials
- change the model framework to allow for a more dynamic release of constituent mass from waste rock in response to interannual changes to the timing of spring freshet or other variations in climate
- increase the level of spatial detail included in the WQC to allow for a better representation of mine water management and other mine activities
- update the model framework to reflect the changes made to the geochemical source terms
- calibrate the updated model using monitoring data collected up to the end of 2019

The objective of the calibration process, for both the FC and WQC, was to match intra- and interannual patterns observed in measured data as accurately as possible. The calibration process was iterative. It involved model simulation, comparison of model output to recorded data, modification of model methods and model inputs, and evaluation of model performance statistically and visually, with the iterative loop continuing until successive changes to model inputs and/or input parameters did not yield notable improvements to performance.

Following calibration, projections were generated and compared to those of the 2017 RWQM to characterize model performance when looking into the future. The objective of this exercise was to identify to what extent the updates made as part of the 2020 process influence or alter projections of future conditions with reference to those produced using the 2017 RWQM. It was not to assess compliance, which is an activity that will be undertaken as part of the next update to the Implementation Plan.

3.3 Conformance with Permit Requirements

The water quality modelling update and reporting requirements are listed in Table 3-1, along with where the required information can be found in the 2020 RWQM submission.

Table 3-1: 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 9 (Reporting Requirements) - 9.9 WATER QUALITY MODELLING**		
	Section 9.9	The permittee must update the regional 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.	2020 RWQM Update Report	Full Report
		This report must be updated every 3 years starting October 31, 2017, 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 8 as well as any other special studies undertaken to investigate water quality in the Designated Area.	Annex A - Geochemical Source Term Methods Annex B - Hydrology Modelling Annex C - Water Quality: Model Set-up and Calibration 2020 RWQM Update Report	Full Reports Section 5
		On a three-year cycle, verify and, failing verification, calibrate the Elk Valley Regional Water Quality 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 B - Hydrology Modelling Annex C - Water Quality: Model Set-up and Calibration	Section 5, Appendix A Section 2, Appendix B
		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.	2020 RWQM Update Report	Section 5, Appendix B
		ii. Hydrology modelling information, detailed by affected drainage.	Annex B - Hydrology Modelling	Section 4
		iii. Identify the specific hydrology information used in the modeling work	Annex B - Hydrology Modelling	Section 4
		iv. 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 B - Hydrology Modelling	Section 4
		v. Current and predicted concentrations of Parameters of Concern as required, in the surface water of affected drainages through the life of the mine based on current model, which incorporates waste rock	2020 RWQM Update Report	Section 7 and Section 8

Table 3-1: Regional Water Quality Model Update Permit Requirements - Table of Concordance

Site	Permit	Requirements	Report that Requirement is Addressed In	Report Section
		volumes and local hydrology, compared to BC Water Quality Guidelines or water quality targets for selenium, nitrate, sulphate and cadmium.	Annex D - Water Quality: Model Projections Comparison	Section 2
		vi. A description of the calibration and validation of the flow model and water quality.	Annex B - Hydrology Modelling Annex C - Water Quality: Model Set-up and Calibration	Section 5 Section 2
		vii. A sensitivity analysis for variation in flows and potential errors in measured input data.	Annex B - Hydrology Modelling Annex D - Water Quality: Model Projections Comparison	Section 4 and Section 5 Appendix A
		iii. Water quality and water quantity model output in electronic format.	Submitted Excel file	
		ix. A monitoring plan for continued evaluation of ii), iii) and iv) as the mine progresses.	2020 RWQM Update Report	Section 9.4
		x. 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 B- Hydrology Modelling	Full Report Full Report
		xi. Changes to the mine plan; and	2020 RWQM Update Report	Section 5
		xii. Information and outcomes from research and technology development studies that have been incorporated into the model.	2020 RWQM Update Report Annex A - Geochemical Source Term Methods	Section 2.2 Section 4.2
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.	2020 RWQM Update Report	Full Report
All	C-Permits - Note 3	The Water Quality Model shall be updated to include:		

Table 3-1: Regional Water Quality Model Update Permit Requirements - Table of Concordance

Site	Permit	Requirements	Report that Requirement is Addressed In	Report Section
	B4 (b)	• re-calibration and adjustment of the model based on relevant water quality and flow monitoring data to ensure conservatism is maintained	Annex B - Hydrology Modelling Annex C - Water Quality: Model Set-up and Calibration	Section 5 Section 2, Appendix B
		• 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 B - Hydrology Modelling	Full Report Full Report
		• changes to the mine plan	2020 RWQM Update Report	Section 5
		• information and outcomes from research and technology development studies	2020 RWQM Update Report Annex A - Geochemical Source Term Methods	Section 2.2 Section 4.2
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.	2020 RWQM Update Report	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 D- Water Quality: Model Projections Comparison	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.	2020 RWQM Update Report	Full Report
GHO	C-137 Approving Cougar Pit Extension (29Apr16)	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 D - Water Quality: Model Projections Comparison	Full Report

Table 3-1: Regional Water Quality Model Update Permit Requirements - Table of Concordance

Site	Permit	Requirements	Report that Requirement is Addressed In	Report Section
	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.]	2020 RWQM Update Report Model Projections Comparison in Tributaries in the Elk Valley Report	Full Report 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.	2020 RWQM Update Report	Full Report
EVO	C-2 Amendment BRE Project (5Dec16) C 5 (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 Elkview Operations.	Annex D - Water Quality: Model Projections Comparison Model Projections Comparison in Tributaries in the Elk Valley Report	Full Report Full Report

1. RWQM - Elk Valley Regional Water Quality Model; n/a - not applicable
2. *Environmental Management Act* Permit 107517, revised October 2020.
3. Common requirement to the following *Mines Act* 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)

4 Geochemical Source Terms

The geochemical characterization and source term methodology for Teck's Elk Valley operations is summarized below and detailed in Annex A. The focus areas of the geochemistry update in support of the 2020 RWQM update were:

- refinement of geochemical conceptual models
- reducing uncertainty in catchment specific source terms for subaerial (unsaturated) waste rock
- quantifying the soluble mass produced in unsaturated waste rock prior to placement in the spoil
- evaluating longer-term constituent release through quantifying an available constituent inventory and decreases in release rates as mass is depleted
- refinement of attenuation mechanisms, including:
    - in spoil and instream adsorption
    - constituent co-precipitation with calcite
    - attenuation in active and passive saturated rockfills
    - attenuation in tailings ponds
- updating the cadmium source terms
- accounting for changes to nitrogen loads from improved blasting practices (e.g., lining of blast holes)

The data used to develop the geochemical source terms and how these terms fit into the overall model development framework are illustrated on Figure 4-1.

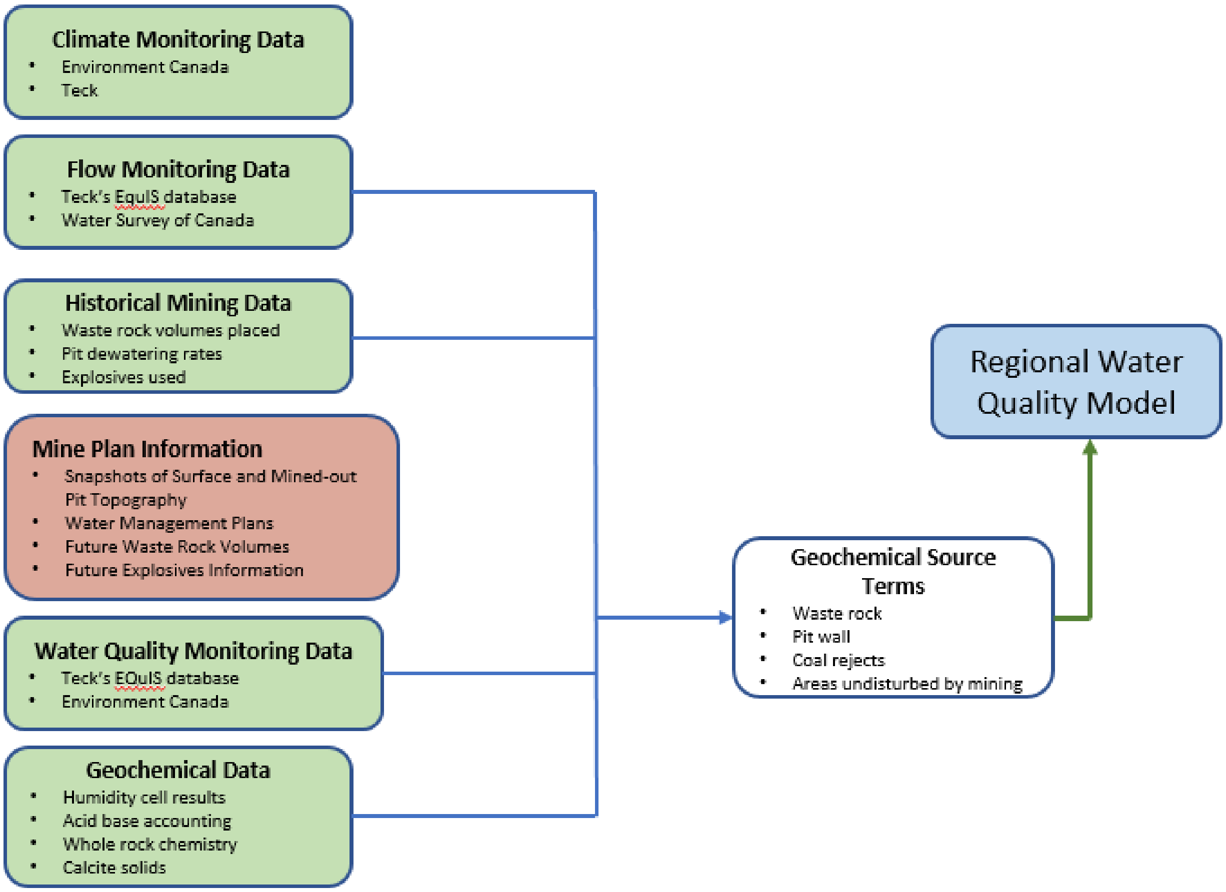


Figure 4-1: Geochemical Source Terms – Input Data and Components

4.1 Resulting Changes to Geochemical Source Terms

The main changes to the 2020 RWQM source terms in comparison to the 2017 RWQM are provided in Table 4-1 and are summarized in the following subsections.

Table 4-1: Summary of Updates to the Source Terms between 2017 RWQM Update and 2020 RWQM Update

Description	2017 RWQM	2020 RWQM
Sources	Waste rock, MMF and non-MMF benched and unbenched pit walls, re-handled waste rock, coarse coal rejects, and tailings	Waste rock, MMF and non-MMF benched and unbenched pit walls, re-handled waste rock, coarse coal rejects, tailings and saturated rock fills
Spatial representation.	Catchment specific	Catchment specific
Data record available for assessment.	1995 to 2016	1995 to 2018

Table 4-1: Summary of Updates to the Source Terms between 2017 RWQM Update and 2020 RWQM Update

Description	2017 RWQM	2020 RWQM
Data interpolation method.	Linear interpolation between two measured data points.	Linear interpolation between two measured data points.
Tributary monitoring locations used in source term development.	FR_HC1, FR_KC1, FR_CC1, GH_CC1, GH_GH1, GH_LC2, GH_SC1, GH_PC1, GH_TC1, GH_WC2, LC_DC1, LC_WLC, LC_LCUSWLC, EV_BC1, EV_GT1, EV_DC1, EV_HC1, EV_SM1, EV_EC1, CM_CC1.	FR_HC1, FR_KC1, FR_CC1, GH_CC1, GH_GH1, GH_LC2, GH_SC1/2, GH_PC1, GH_TC1, GH_WC2, LC_WLC, LC_LCUSWLC, EV_BC1, EV_GT1, EV_DC1, EV_HC1, EV_EC1, CM_CC1. LC_DC1 and EV_SM1 were not carried forward into the 2020 RWQM update as a result of insufficient data to confidently derive source terms for these catchments.
Solubility constraints.	Gypsum solubility limit constrained maximum SO_4 concentration at 2,540 mg/L. Control for Se was removed from the model pending further research.	Sulphate solubility limit updated with additional monitoring data collected between 2016 and 2018. New solubility limit is 2,530 mg/L. Control for Se was also not included in 2020.
Assumptions of time related release of NO_3.	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.	Catchment specific hydraulic lag times updated to account for changes to the unsaturated waste rock source term derivation method (e.g., accounting for groundwater bypass, etc.)
Se and NO_3 release	Release rates based on monitored water quality and flow rates at downstream monitoring locations and waste rock volumes	Release rates based on monitored water quality and flow rates at downstream monitoring locations corrected for: natural catchment runoff, groundwater bypass, site water management activities and site facility drainage (e.g., CCR). Catchment waste rock volumes were reconciled by Teck as part of the 2020 RWQM update. Release rates normalized to average annual flow rates.
Nitrogen release	Historical loss factors carried forward into future water quality predictions	Reduction of loss factors occurring through lining of blast holes included in the 2020 RWQM update.
Assumptions of time related release of SO_4 and Se.	Initial leaching delay as derived from NO_3 monitoring record applied to initial release of SO_4 and Se.	Approach maintained in the 2020 RWQM for existing spoils. In new development areas hydraulicly driven delay is expected to be short initially and increase with spoil height.
Depletion of constituent inventory	Not included	Depletion of available inventory included in the RWQM when spoiling is completed in a tributary. Decrease in release rates assuming a 1st order decay function based on humidity cell data also included as a sensitivity in the RWQM.

Table 4-1: Summary of Updates to the Source Terms between 2017 RWQM Update and 2020 RWQM Update

Description	2017 RWQM	2020 RWQM
Instream Sinks	Calcite precipitation used to calculate instream cobalt concentration. Assumes calcite precipitation in months of August through April. Se and NO_3 sinks also included in RWQM.	Coprecipitation and adsorption of cadmium, cobalt and nickel calculated from the spoil oxidation site to the next downstream monitoring location.
Time step used for load distributions.	Weekly	Calculated in the RWQM (See Table 7-1)
Cadmium concentration	Fixed concentrations represented by P5, P50, and P95 for all data available.[(a)]	Calculated using metal sulphate release rate ratios (MSRRR) observed in HCTs
Tailings Impoundments	Constant nitrate and selenium concentrations assumed in seepage from tailings impoundments	Breakthrough of nitrate and selenium from tailings impoundments included in the 2020 RWQM
Saturated rock fills	R&D work was ongoing and not advanced enough to develop a source term	Pilot scale test results from the F2 and Eagle 4 SRFs used to develop a denitrification and selenium reduction source term for active SRFs. Selenium reduction in passive flows through backfilled pits (termed passive SRFs) also developed based on monitoring results from these facilities

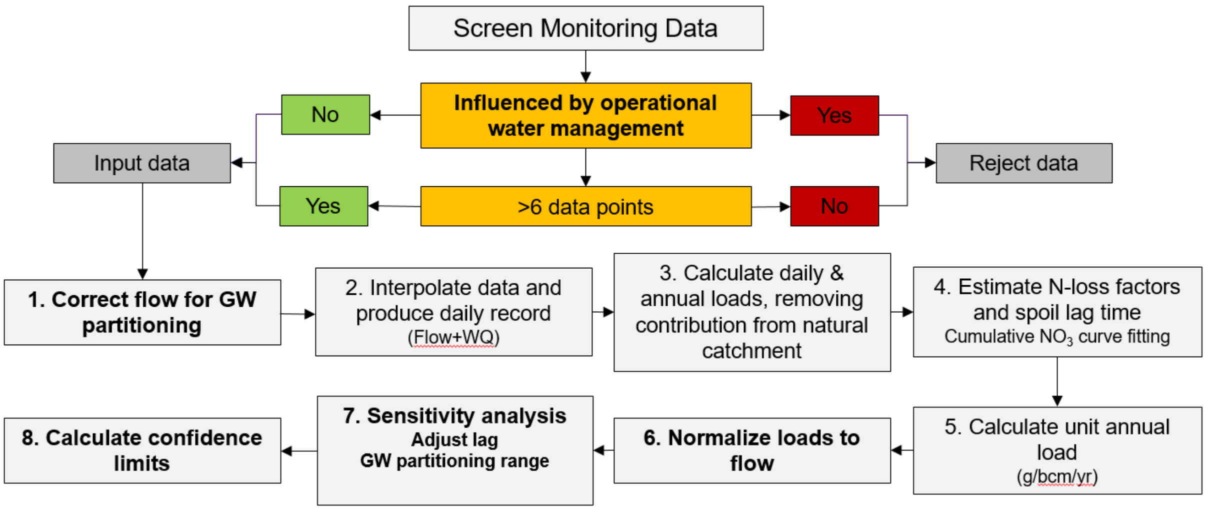
P5 – 5th percentile, P50 – 50th percentile, P95 – 95th percentile.

4.1.1 Unsaturated Waste Rock

The main focus of the 2020 RWQM was on refinement of release rates from unsaturated waste rock as this represents the dominant constituent loading source in the Elk Valley. The overall approach was similar to the SRK (2017) approach. The 2017 approach was modified to constrain uncertainty in tributary-specific release rates to return to the concept of “valley-wide” release rates to reflect the consistent geochemical characteristics of waste rock and the similarities in waste rock dump construction methods. Modifications to the 2017 approach included:

- accounting for groundwater bypass of tributary monitoring stations
- removing natural catchment load
- removing mine water management (e.g., pit dewatering) influences on monitoring data used to calculate constituent release rates
- normalization of empirical annual loads to annual average flow rates
- including sensitivity analysis on hydraulic lag and groundwater bypass estimates

The approach for estimating unsaturated waste rock release rates is presented in Figure 4-2.



Note: Bold text indicates new steps in the 2020 RWQM Update compared to that used in the 2017 RWQM Update.

Figure 4-2: Geochemical Source Terms – Unsaturated Waste Rock Source Term Derivation Method

The source terms developed in 2017 relied on monitoring results downstream of mature spoils that are considered to have reached a "quasi" hydraulic and geochemical equilibrium. Development of the LCO Dry Creek spoil provided an opportunity over the past three years to evaluate release rates from a newer spoil. The learnings from monitoring results in LCO Dry Creek were used to hypothesize that an initial soluble load could result in an increase in initial release rates until oxidative processes within the spoil dominate constituent release or that the hydraulic lag through newer spoils is shorter resulting in rapid flushing of soluble load prior to wet up of the spoil. An evaluation of these two concepts was considered in the update of the unsaturated waste rock source terms as part of the 2020 RWQM update.

In the 2017 RWQM, empirical release rates were assumed to persist in perpetuity. In reality, there is a finite mass in waste rock spoils that will be depleted through time. Depletion of the available inventory was accounted for in the 2020 RWQM and estimates of the potential and available inventories in waste rock spoils were made. It was conservatively assumed that depletion did not commence until waste rock placement was completed in the spoil. A second method to evaluate depletion and decrease in release rates was an evaluation of 1st order decay rates in long-term humidity cell tests from LCO. Test results from these cells indicate release rate decay occurs. However, in the absence of sufficient empirical evidence to quantify this process under ambient conditions at the field scale, depletion through 1st order decay was considered as a sensitivity to the base case in the 2020 RWQM.

Over the past several years Teck has made advancements to reduce nitrogen loadings to the Elk Valley. For example, lining of blast holes to reduce leaching is now common practice. Changes in the nitrogen signal at monitoring locations downstream of spoils has not yet been realized as a result of long hydraulic lag times. A focused study (Annex A) has been conducted to evaluate the efficacy of lined blast holes at reducing nitrogen loads. The learnings from this study have been carried forward into the 2020 RWQM to better constrain future nitrogen species concentrations in tributaries downstream of waste rock spoils and project concentrations accounting for improved blasting practices.

In the 2017 RWQM, cadmium release from unsaturated waste rock was represented as a constant concentration based on observed concentrations at monitoring locations downstream of spoils. In the 2020 RWQM update, release rates of cadmium were correlated to sulphate release rates in humidity cell tests. Metal sulphate release rate ratios (MSRRRs) were derived and subsequently applied to empirically derived sulphate release rates to calculate cadmium release from each of the spoils. The MSRRRs were developed as a function of the percentage of MF.

4.1.2 Tailings Impoundments

Constant selenium and nitrate concentrations were assumed in seepage from tailings impoundments. A similar approach was used in the 2020 RWQM update; however, a more robust evaluation of the monitoring dataset indicated that selenium and nitrate breakthrough can occur from the FRO South Tailings Pond when concentrations are elevated in the supernatant. The tailings source term was further refined as part of the 2020 RWQM update to account for this breakthrough.

4.1.3 Attenuation Mechanisms

Attenuation mechanisms in saturated rock fills (SRFs) were introduced in the 2020 RWQM. Pilot scale testing results of the F2 and Eagle 4 SRFs were used to evaluate denitrification and selenium reduction in active SRFs and develop a source term that can be applied to future active SRFs in the 2020 RWQM. Monitoring results upstream and downstream of passive SRFs, were also used to develop a numerical method for selenium reduction of drainage flowing through mined out pits backfilled with waste rock.

As noted in Section 4.1.1, cadmium source terms were calculated using a laboratory-based MSRRRs. These MSRRRs calculated for each spoil were compared to metal/sulphate concentration ratios at the nearest downstream monitoring location to calculate the percent removal from the oxidation site in the spoil and in the tributary upstream of the monitoring location. The method assumes metals are removed by attenuation processes but sulphate remains (or is conserved) in drainage waters. This approach includes total attenuation occurring from coprecipitation with calcite and adsorption within the spoil and in the tributary upstream of the monitoring location.

4.1.4 Other Source Terms

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 Annex A.

5 Site Conditions

Site conditions considered in the 2020 RWQM Update consisted of historical mine activities and on-going permitted mine development. On-going and future projects included in permitted development are those outlined in Table 5-1. Changes to site conditions relative to the 2017 RWQM are outlined in Table 5-2, and total waste rock volumes considered in the 2020 RWQM Update are summarized in Table 5-3. Tables outlining waste rock volumes by drainage are included in Appendix B.

Table 5-1: On-going and Future Projects in the 2020 RWQM Update

Operation	Permitted Project
Fording River	Eagle 6
	Lake Mountain
	Swift
Greenhills	Phase 3 to 7
Line Creek	Mine Service Area Extension
	North Line Creek Extension
	Burnt Ridge Extension
	Burnt Ridge North 1, 2, and 3
	Mount Michael 1, 2, 3
Elkview	Natal Pit
	Baldy Pit
	Adit Pit

Table 5-2: Changes to Site Conditions between the 2017 and 2020 RWQM Updates

Theme	2017 RWQM	2020 RWQM
Time frame considered	2017 to 2037	2020 to the point when full effects of constituent release from waste rock and pit filling and decanting are accounted for
Mine and water management plans	2016	2019 permitted mine plan
Pits	FRO: Turnbull pit, Eagle 4 pit, Eagle 6 pit, Lake Mountain pit, Swift pit GHO: Cougar North, Phases 3 to 6, Phases 7 to 11 LCO: Phase I: Horseshoe Ridge pit, Burnt Ridge South pit, Mine Services Area West pit, South pit; Phase II: Mount Michael 1, 2 and 3 pits, Burnt Ridge 1, 2 and 3 pits EVO: Baldy Ridge pit, Natal pit, F2 pit CMO: 14 pit, 34 and 37 pits, 6 pit	FRO: Henretta pit, Turnbull pit, Eagle 4 pit, Eagle 6 West pit, Eagle 6 pit, Lake Mountain pit, Lake Pit, Shandley pit, Swift pit, Swift Ben's pit GHO: Phase 3 pit, Phase 4/5 pit, Phase 6 pit, Phase 7 pit LCO: Horseshoe Ridge pit, Burnt Ridge South pit, Mine Services Area West pit, North Line Creek pit, Mine Services Area Extension pit, North Line Creek Extension pit, Burnt Ridge Extension pit, Mount Michael 1, 2 and 3 pits, Burnt Ridge 1, 2 and 3 pits EVO: Cedar pit, Natal West (Phase 1), Natal Phase 2, Baldy Ridge (Phases 1 to 7) pit, Adit Ridge pit, F2 pit, South pit CMO: As per Appendix B
Potential creation of local groundwater sinks due to pit depth	FRO: Swift and Turnbull pits GHO: Phase 3 to 7 EVO: Natal pit, Baldy Ridge pits and Cedar pit	Same as 2017 Update, with information related to Swift and Turnbull pits updated to reflect work done in support of the Turnbull West Project Application.

Table 5-3: Cumulative Waste Rock Volumes Considered in the 2020 RWQM Update

Operation	Waste Rock Volume [million BCM] (a,b)	
	Cumulative through 2018[c]	Cumulative Permitted End of Mining
Fording River [d]	3,036	4,780
Greenhills[d]	808	1,180
Line Creek	798	1,445
Elkview	1,787	3,257
Coal Mountain	311	311
Total	**6,739**	**10,966**

[a] BCM = bank cubic metre.

[b] Does not include rehandled waste rock.

[c] End of the year (e.g., 12/31/2018)

[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.

6 Flow Component

6.1 Focal Areas and Approach

Focal areas for the FC update consisted of:

- switching to a climate-driven model framework, thereby eliminating the need for analogue hydrographs
- developing and implementing a numerical method to simulate water flow through waste rock spoils to improve model performance in mine-influenced tributaries
- increasing the granularity of spatial detail included in the FC to allow for a better representation of mine water management and other mine activities
- The resulting changes (which are summarized in Section 6.2) effectively necessitated a complete overhaul of the FC component and rebuilding the model framework to allow for the simulation of processes such as snow accumulation, snow melt and rainfall – runoff responses in more than 150 sub-catchments across the Elk Valley. The updated model is used to simulate flows throughout the model domain, with model performance being evaluated through comparisons to measured data at locations with longer measured datasets as outlined below in Section 6.3. It continues to be built within the commercially available, general-purpose simulation software platform called GoldSim (GoldSim Technology Group 2014). The approach used to simulate flow in mine-affected tributaries, the Fording River and Line Creek differs from that used to estimate flows in the mainstems of Michel Creek and the Elk River. These differences in approach to the simulation of flow are summarized below and discussed in more detail in Annex B.

6.1.1 Approach to the Simulation of Flow in the Fording River Watershed and Other Mine-influenced Tributaries in the Elk Valley

The simulation of flow in the Fording River watershed and in mine-affected tributaries elsewhere in the Elk Valley is based on the application of a snowmelt runoff modelling (SRM) approach, except for those areas covered by waste rock. SRM is an empirical approach that is designed to simulate daily streamflow for mountainous areas with substantial snow cover and associated snowmelt processes on a seasonal basis. The primary input variables for SRM are air temperature, precipitation, and snow cover area. This information is used, along with other inputs, to track snow accumulation and to compute flow (discharge) as an output. The other inputs include:

- rainfall to runoff coefficients that define the extent to which rainfall translates into runoff
- snowmelt to runoff coefficients that define the extent to which snowmelt translates into runoff
- degree-day factors that define rates of daily snowmelt per degree of temperature change
- recession coefficients that identify the rate of decline in discharge between snowmelt or rainfall events
- lapse rates that specify how temperature and precipitation change with changes to elevation

SRM accounts for the effects of water loss through evaporation, evapotranspiration and sublimation, and translates the remaining water volume arriving as precipitation into runoff taking into consideration the characteristics of each sub-catchment, which are described in terms of the recession coefficients and other inputs outlined above.

Four dominant land types are considered in the FC: (1) natural (non-mine affected), (2) hard surfaces (e.g., roads, pits), (3) coal refuse and (4) waste rock. SRM is used to simulate runoff from the first three land types. It is also used to track precipitation, snow accumulation and snowmelt in waste rock areas, thereby defining infiltration rates into waste rock spoils. However, the simulation of flow from waste rock is accomplished using a newly created waste rock hydrology module.

The waste rock hydrology module is straightforward in its design and consists of a reservoir element. Inflows into the reservoir are equal to the infiltration rates calculated by SRM, and outflows are calculated as a function of the volume of water held in the reservoir, expressed into terms of a percentage per unit time (e.g., 2.5% of the volume of water held within the reservoir will be released each week). The waste rock hydrology module was initially designed and calibrated with a focus on Cataract Creek, a tributary that consists almost entirely of waste rock. It was then incorporated more broadly within the FC and applied and calibrated (as required) to other waste rock areas in the Elk Valley.

The intent of the waste rock hydrology module is to simulate the hydrological response of waste rock spoils to infiltration. It was built to simulate the movement of the pressure wave through the spoil, whereby infiltration into the top of the spoil triggers the release of water from its base (as outlined in Section 2.2). The waste rock hydrology model does not track the movement of individual water particles as they move through the spoil, a process that can take much longer. This element of the waste rock conceptual model is represented in the WQC through the application of hydraulic lag.

Water released from waste rock spoils is directed within the model framework to nearby downstream model nodes, wherein it combines with SRM-calculated flows from the other three land types present within the same sub-catchment. Drainage from individual sub-catchments is tracked and combined at downstream nodes, with instream water volumes accumulating with distance through individual tributaries and the Fording River mainstem. The FC is designed to track total watershed yield (i.e., total flow), dividing the total flow into surface and subsurface components at designated modelling nodes where supported by field data and other field observations.

6.1.2 Approach to the Simulation of Flow in Michel Creek

The approach to modelling flows through the Michel Creek mainstem in the FC of the 2020 RWQM is as follows:

- The FC begins at Michel Creek upstream of Erickson Creek
- Flows at Michel Creek upstream of Erickson Creek are estimated using a ranked regression equation based on recorded streamflow data from the Elk River and Michel Creek following the methods outlined in Annex B.
- Flows downstream of Erickson Creek are calculated by successively adding incoming tributary flows (as estimated using the SRM approach outlined above) to those estimated at Michel Creek upstream of Erickson Creek.

Coal Mountain Operations (CMO) is no longer included in the RWQM; flows and loads from this operation are calculated using the CMO Flow and Load Balance Model (SRK 2021a). Flows from CMO are implicit in the flow estimates developed at Michel Creek upstream of Erickson Creek, so flow information from the CMO Flow and Load Balance Model is not used as an input to the RWQM. Constituent loads released from CMO, as estimated using the CMO Flow and Load Balance Model, are an input to the WQC, as outlined in Annex C.

A ranked regression approach is used to estimate flows in Michel Creek upstream of Erickson Creek to simplify the model framework and avoid applying an SRM approach to the large natural watershed area that sits upstream of this location, flows from which will be unaffected by mining activity.

6.1.3 Approach to the Simulation of Flow in the Elk River

The approach applied to estimating flows in the Elk River mainstem and influent flows from the Bull River and Kootenay River to Koocanusa Reservoir remains unchanged from the 2017 RWQM Update. Flows are estimated using monitored data collected from Environment and Climate Change Canada (ECCC) hydrometric stations. The data are either used directly or scaled based on watershed area to other locations on the Elk River. For example, instream flows in the upper Elk River above the Fording River are estimated using data from the ECCC station on the Elk River at Natal (08NK016). Measured flows from the Fording River are subtracted from the Elk River at Natal dataset, and the resulting information is scaled based on differences in contributing watershed area between the Elk River at Natal and the Elk River at the GHO Elk River Compliance Point (GH_ERC; E300090). This approach is applied for numerical simplicity and because the Elk River watershed is large with only a small proportion of the total watershed area being affected by mining, both historically and into the future.

The same is true of both the Bull River and Kootenay River; hence, the application of a scaling approach to estimate flow from both of these rivers into Koocanusa Reservoir.

6.2 Changes to the Flow Component

Updates and changes to the FC completed as part of the 2020 RWQM Update are summarized in Table 6-1 and illustrated in Figures 6-1 and 6-2.

Table 6-1: Summary of Key Changes to the Flow Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Spatial Scale and Level of Spatial Detail	• Model domain spans from the Elk River upstream of GHO through to the Koocanusa Reservoir, inclusive of Fording River watershed and the reservoir itself • All five operations (FRO, GHO, LCO, EVO and CMO) explicitly represented in the model framework • Model contains a total of 96 individual sub-catchments	• Model domain unchanged • Four of five operations (FRO, GHO, LCO and EVO) explicitly represented in the model framework • CMO no longer included in model framework; flow and loads from CMO defined using outputs from the CMO Water and Load Balance Model • Level of spatial detail increased at each operation; model contains a total of 154 individual sub-catchments
Historical Period Considered in Model Set-up	• 1995 to 2015	• 1970 to 2018, with calibration focused on period from 2004 to 2018
Simulation Time Step	• Weekly	• Daily
Meteorological data	• Not used, except as input to the LCO Dry Creek UBCWM, which was used to generate a representative hydrograph for undisturbed areas in the Fording River watershed	• RWQM is now climate-driven, and no longer relies on representative hydrographs • Precipitation and air temperature data from two representative regional climate stations are applied across the model domain, scaled based on elevation within each individual sub-catchment • Precipitation and air temperature data from several local climate stations considered for comparisons against the modelled data (where available)
Hydrometric data	• Flow data from relevant flow monitoring stations used as an input for analogue catchments and regional (mainstem) stations • Flow data from selected tributary and mainstem monitoring stations used for model performance evaluation	• Flow data from flow monitoring stations on Elk River used as model input • Flow data from tributary and mainstem monitoring stations used for model performance evaluation

Table 6-1: Summary of Key Changes to the Flow Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Waste rock deposition	• Based on available data records for historical actuals (up to 2016 year-end) • Waste rock allocation by drainage	• Based on available data records (up to 2018 year-end) • Checked and adjusted to match current drainage delineations with aerial photography and survey information • Waste rock allocation by drainage
Mine plan information	• 2016 permitted mine plans • 5-year snapshots of surface contours for most areas (i.e., dxf files) • 5-year snapshots of mined-out contours (i.e., dxf files) • Details on sequencing (e.g., status maps)	• 2019 permitted mine plans • 5-year snapshots of surface contours for most areas (i.e., dxf files) • 5-year snapshots of mined-out contours (i.e., dxf files) • Details on sequencing (e.g., status maps)
Water management information	• Water flow diagrams developed through discussions with site water leads to represent best understanding of historical and future water management activities • Existing and planned water management infrastructure data (i.e., shapefiles of alignments of diversions, ditches, rock drains, ponds and pipelines) • Description of tailings water management facilities and wash plant water use • Pit dewatering pumping data and pit pumping plans • Existing water management plans	• Expanded water flow diagrams showing a greater level of on-site detail related to historical and future water management activities • Existing and planned water management infrastructure data (i.e., shapefiles of alignments of diversions, ditches, rock drains, ponds and pipelines) • Description of tailings water management facilities and wash plant water use • Pit dewatering pumping data and pit pumping plans • Existing water management plans • Dust suppression information
Flows from undisturbed (non-mine affected) areas of tributary catchments	• Various analogue catchments were used (e.g., Harmer, Line, LCO Dry, Hosmer) for all	• The Snowmelt Runoff Model (SRM) adopted to model non-mine affected (undisturbed) areas in all sub-catchments

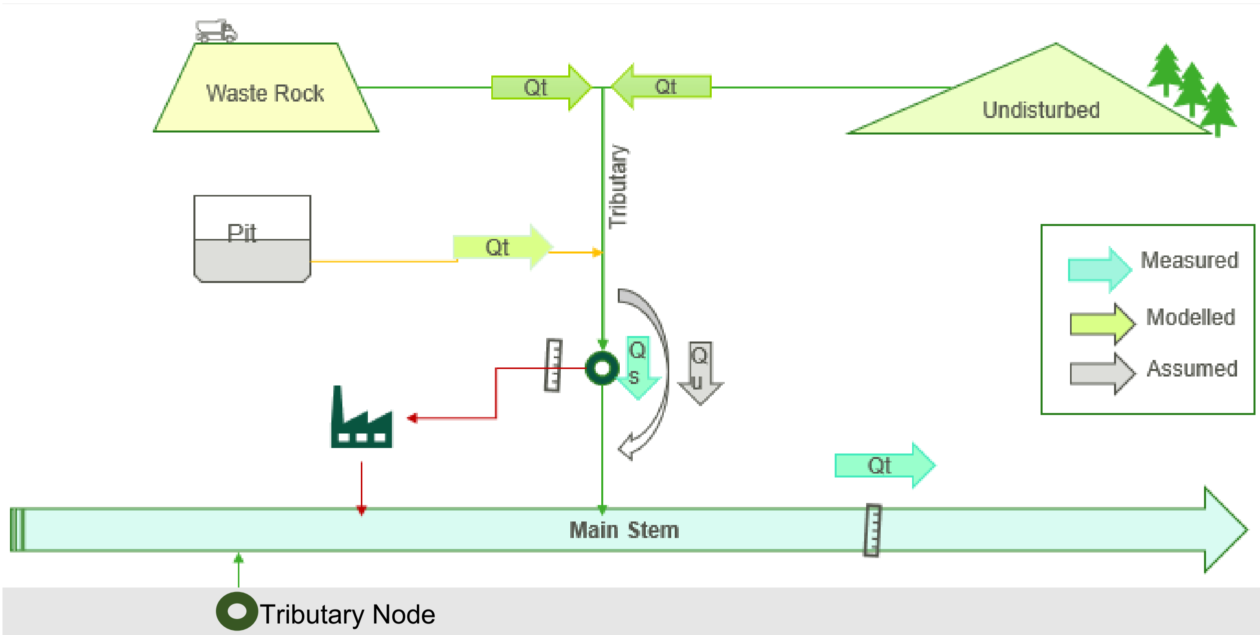
Table 6-1: Summary of Key Changes to the Flow Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Flows from mine-affected (disturbed) areas, excluding waste rock spoils	• Analogue catchment – Cataract Creek (i.e., the same analogue used for waste rock areas was also used for hard mine areas)	• SRM adopted for modelling hard mine surfaces (i.e., pit walls, haul roads, and plant areas) and coarse coal reject spoils, although SRM set-up altered to reflect different characteristics of land types being modelled
Flows from waste rock spoils	• Analogue catchment – Cataract Creek	• Climate-driven waste rock hydrology module developed and implemented for all waste rock spoils
Water stored in flooded, backfilled pits	• Pits modelled to fill up to the decant elevation at varying rates (depending on the flow scenario being modelled) • Submerged waste rock volumes not tracked	• Pits modelled to fill up at rates dictated by climate conditions • For pits where flooding is modelled under future and historical conditions, submerged waste rock volumes estimated for the end-of-mining pit configurations
Mine water management activities represented in the model framework	• Pit pumping • Clean water diversions • Mine water diversions • Consumptive water use in coal processing	• Pit pumping • Clean water diversions • Mine water diversions / pumping • Consumptive water use in coal processing • Use of water for dust suppression
Effects of reclamation	• Not considered	• Long-range reclamation plans included • Evaluated the effects of reclamation by modelling projected decreases in net percolation rates in waste rock spoils
Baseflow changes due to pit seepage	• Pit seepage rates incorporated relative to baseline conditions, using results from project-specific groundwater models that were developed for environmental assessments or permit amendment applications (e.g., Swift, Cougar Pit Extension, Baldy Ridge Extension)	• Methods from the 2017 RWQM retained • Latest available data considered where available

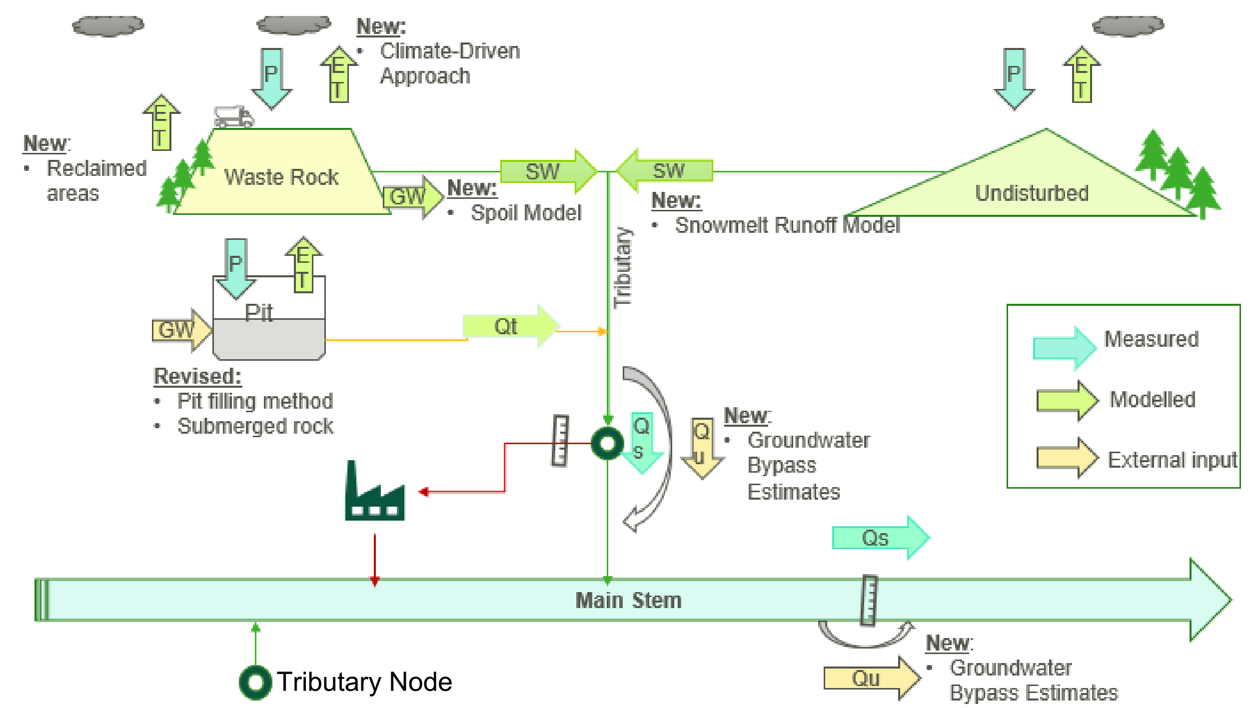
Table 6-1: Summary of Key Changes to the Flow Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Sub-catchment yield (Total flows at tributary nodes)	• Modelled flows are equivalent to total flows	• Modelled flows are equivalent to the total flows • In selected locations, partitioning between surface water and groundwater flows incorporated (see the row titled "Surface water - Groundwater partitioning at nodes")
Flows at mainstem nodes – Michel Creek	• Total flows summed from upstream tributary contributions to Michel Creek	• Scaling method and ranked regression equations used to estimate flows in Michel Creek upstream of Elkview Operations (at EV_MC3), except for CM_MC2. • Flows at CM_MC2 (i.e., Michel Creek CMO compliance point) estimated from the CMO Water and Load Balance Model • Flows at modelling nodes adjacent to and downstream of Elkview Operations calculated as the sum of flow at EV_MC3 plus simulated inputs entering Michel Creek between EV_MC3 and the node in question
Flows at mainstem nodes – Elk River	• Scaling methods or direct data inputs from hydrometric stations for the Elk River nodes	• No fundamental changes to the methods from the 2017 RWQM • Minor adjustments to the scaling equations were made
Surface water - groundwater partitioning at nodes	• Not quantified or considered explicitly during model calibration • Implicitly accounted for in mitigation planning through the use of water availability (defined as the proportion of total catchment flow that is accessible at a given intake)	• Total flow divided into surface water and groundwater components where relevant to model calibration and supported by available field data • Flows were calibrated taking into consideration both measured surface flows and total watershed yield (as required to produce sufficient flow to meet surface and subsurface components)
Future flow projections	• Use of three statistical flow scenarios (average weekly flow, 1-in-10-year weekly low and weekly high flow) • Future flow statistics are based on historical period between 1995 and 2015.	• Estimates of future flow conditions developed using climate data from 2000 to 2019, and running that climate dataset repeatedly through the model framework • Statistics from the resulting dataset generated for comparison to 2017 RWQM output
Water quality management measures	• Not explicitly considered in the FC of the RWQM (only included in the WQC)	• Existing water quality management measures incorporated in the FC • Future mitigation and water quality management measures were not incorporated in the FC.

a) 2017 RWQM



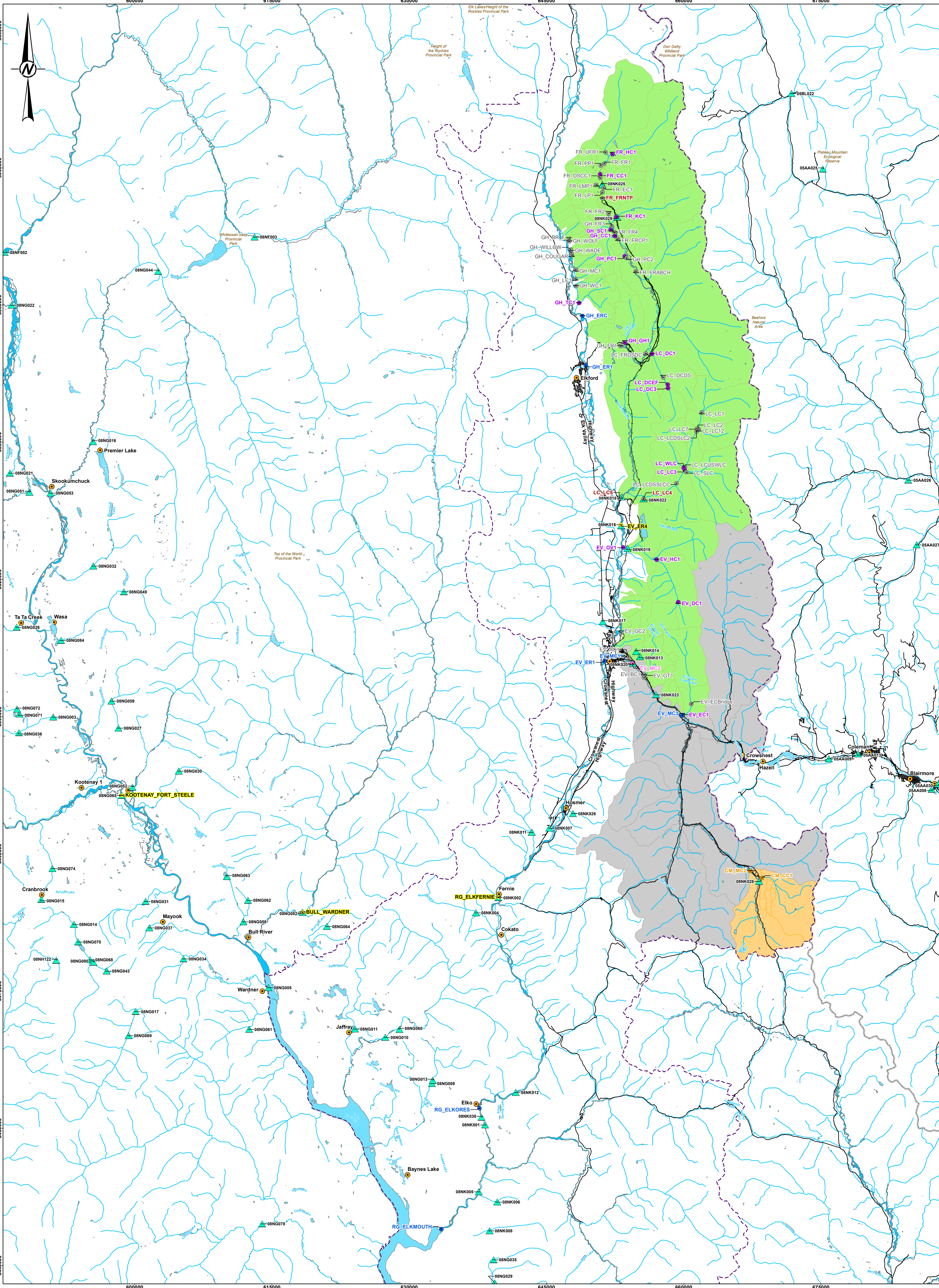
b) 2020 RWQM



Qt = Total Flow; Qs = Surface Flow, Qu = Subsurface Flow, P = Precipitation, ET = Evapotranspiration, GW = Groundwater, SW = Surface Water

Figure 6-1: Flow Component Comparisons: 2017 RWQM (analogue catchment and scaling methods) and 2020 RWQM (climate-driven modules and scaling methods)

PATH: S:\Clients\Teck_Resources\ElkValley\99_PROJ\18111630_Teck_RWQM\40_PROD\0016_HydrologyModellingMethod_2020RWQM\18111630-0016-CS-0001.mxd PRINTED ON: 2021-03-18 AT: 5:25:26 PM



LEGEND

- CITY/TOWN/COMMUNITY
- ENVIRONMENT CANADA HYDROMETRIC STATION
- ROAD
- CANADIAN PACIFIC RAILWAY
- WATERCOURSE
- LAKE
- RIVER
- BRITISH COLUMBIA - ALBERTA PROVINCIAL BOUNDARY
- PROVINCIAL PARK PROVINCIAL PARK
- FIRST NATION RESERVE
- DESIGNATED AREA (ELK VALLEY WATER QUALITY PLAN)
- ELK RIVER WATERSHED BOUNDARY

STATION METHOD

- CALIBRATION
- DIRECT INPUT
- SCALING METHOD
- SCALING METHOD / DIRECT INPUT
- COMPARISONS
- CMO SITE MODEL

WATERSHED METHOD

- DIRECT DATA / RANKED REGRESSION / SCALING METHOD
- SNOWMELT RUNOFF MODEL AND WASTE ROCK HYDROLOGY MODULE METHODS
- CMO SITE MODEL

0 5 10 15 20

1:200,000 KILOMETRES

NOTE(S)

REFERENCE(S)
1. BASE DATA: CANVEC, 2018
2. PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83 COORDINATE SYSTEM: UTM ZONE 11N

CLIENT
TECK COAL LIMITED

CONSULTANT

YYYY-MM-DD	2020-12-01
DESIGNED	PR
PREPARED	PR/RRD
REVIEWED	CG
APPROVED	SK

PROJECT
2020 REGIONAL WATER QUALITY MODEL UPDATE

TITLE
HYDROLOGY MODELLING METHODS IN THE 2020 RWQM

PROJECT NO.	CONTROL	REV.	FIGURE
18111630	0012	0	6-2

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6.3 Calibration Process

The FC of the 2020 RWQM was calibrated following the process depicted in Figure 6-3. Although depicted as a linear process, the review of fit between modelled and recorded data necessitated an iterative process where model performance improvements were made by returning to earlier steps, making adjustments, and repeating the subsequent steps. Model performance was evaluated through the use of statistical fit tests and visual comparisons of inter- and intra-annual trends in the simulated data against the recorded data. The statistical measures used included Nash-Sutcliffe efficiency, modified Nash-Sutcliffe efficiency and root mean square error.

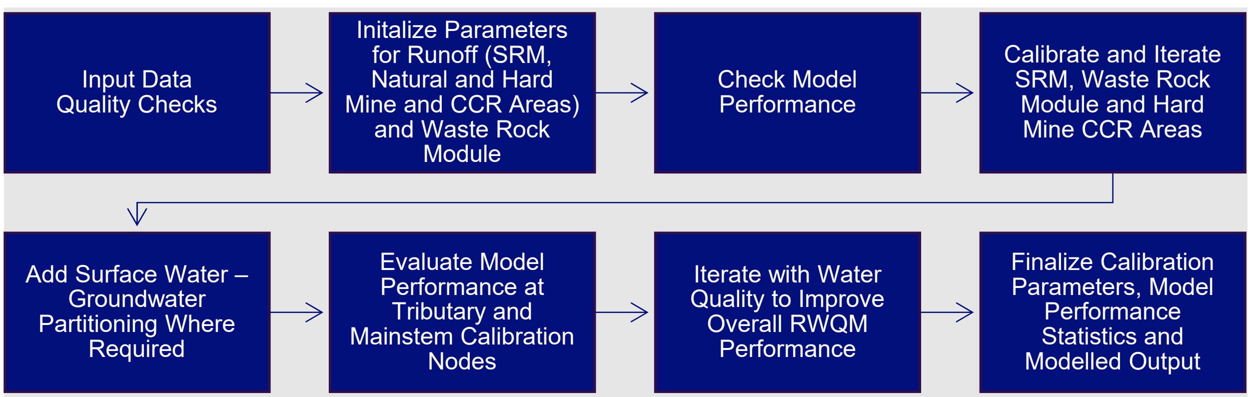


Figure 6-3: Calibration Process for the Flow Component of the 2020 RWQM

6.4 Resulting Performance

The 2020 RWQM is more responsive to variations in climate and topography across the model domain, compared to previous versions of the RWQM, now that it includes more than 150 individual sub-catchments. Waste rock spoil response is also no longer tied to a single analogue hydrograph, which allows for a greater degree of variation between sub-catchments, and the increased spatial resolution included in the model allows for a more detailed representation of on-site water management.

The performance of the FC has improved relative to the 2017 RWQM. In general, the timing of spring freshet is more consistent with the measured flows through most of the model domain, and the shape of the overall hydrograph, from spring freshest through late summer/early fall recession, is better replicated, as outlined in Annex B.

Mainstem performance continues to be strong, with some incremental improvements being achieved in areas where model performance was already good. The performance of the 2020 RWQM is rated from good to very good at most mainstem nodes. In Michel Creek, the statistical fit between model and measured data is equivalent to or better than that achieved with the 2017 RWQM. The use of monitored streamflow data to develop the simulated discharge for the Elk River nodes also results in a strong statistical fit.

Overall, model performance in tributaries has improved relative to that of the 2017 RWQM. Estimated water flows through mine-affected tributaries tend to more closely match measured flows, with reasonable replication of both winter low flows and freshet high flows at most tributary locations. Tributaries with good performance include, for example, West Line Creek, Henretta Creek, Kilmarnock Creek, Harmer Creek and Line Creek, as outlined in Annex B. Accurate replication of measured flows continues to be a challenge in some tributaries, such as Clode Creek and Leask Creek. However, model performance in these latter tributaries is better than that of the 2017 RWQM. Poorer performance in some tributaries does not necessarily indicate that model performance is unacceptable. Poorer performance can reflect knowledge gaps in past water management practices and/or a lack of measured, high quality data against which to evaluate model performance; it should be interpreted and understood in the context of the relative size of the catchment in question and the quality and quantity of measured data available against which to evaluate performance.

7 Water Quality Component: Set-up and Calibration

7.1 Focal Areas and Approach

Focal areas for the WQC update consisted of:

- updating the numerical representation of hydraulic lag to account for the quicker release of constituents from new spoils
- applying hydraulic lag and leaching efficiency to constituents released from rehandled materials
- changing the model framework to allow for a more dynamic release of constituent mass from waste rock spoils in response to interannual changes to the timing of spring freshet or other variations in climate
- calibrating the updated component with a view to improve model performance in mine-influenced tributaries and reduce model overprediction in the river mainstems

The WQC was also updated to reflect the changes made to the FC (such as the increased spatial granularity added to the model framework and the more detailed representation of mine water management), as well as the changes made to the formulation of some of the geochemical source terms (such as that for cadmium).

However, the basic underlying modelling approach for the 2020 RWQM remains unchanged from that of the 2017 RWQM. Constituent mass released from mine facilities and infrastructure continues to be estimated using geochemical source terms derived as outlined in Section 4, with that from non-mine areas defined using monitored data. Constituent mass is tracked within the model framework and moves downstream in correspondence with the movement of flow. Flow inputs are derived using the FC and input directly in the WQC. The WQC maintains upstream to downstream water and mass balances, with flow and mass eventually reporting to Koocanusa Reservoir. The reservoir continues to be modelled as a riverine system, without accounting for water storage or the influence of dam operations on residence times and outflow rates. The WQC is calibrated to historical data and used to generate future projections under a range of flow conditions, taking into consideration on-going mine activity and water quality management actions.

7.2 Changes to the Water Quality Component of the Model

Updates and changes to the WQC completed as part of the 2020 RWQM Update are summarized in Table 7-1.

Table 7-1: Summary of Key Changes to the Water Quality Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Spatial scale and level of spatial detail	• Model domain spans from Elk River upstream of GHO through to Koocanusa Reservoir, inclusive of Fording River watershed and the reservoir itself • All five operations (FRO, GHO, LCO, EVO and CMO) explicitly represented in the model framework • Model contains a total of 96 individual watersheds, sub-watersheds and catchments	• Model domain unchanged • Four of five operations (FRO, GHO, LCO and EVO) explicitly represented in the model framework • CMO no longer included in model framework; flow and loads from CMO defined using outputs from the CMO Water and Load Balance Model (SRK 2021a) • Level of spatial detail increased at each operation; model contains a total of 154 individual watersheds, sub-watersheds and catchments
Historical waste rock deposition	• Based on available data records	• Based on available data records • Checked and adjusted with aerial photography and survey information
Mine water management activities represented in the model framework	• Pit pumping • Clean water diversions • Mine water diversions • Consumptive water use in coal processing	• Pit pumping • Clean water diversions • Mine water diversions / pumping • Consumptive water use in coal processing • Use of water for dust suppression
Period for model calibration	• Nitrate: 2006 to 2016 • Other constituents: 2004 to 2016	• Nitrate: 2006 to 2018 • Other constituents: 2004 to 2018
Hydraulic lag (or Lag time)	• Referred to as “initial lag” • Defined time period between waste rock deposition and detection of released constituents at downstream monitoring station in receiving environment • Fixed, spoil-specific value defined based on measured nitrate concentrations at downstream monitoring station	• Term “initial lag” replaced with “hydraulic lag” (lag time) • Definition is unchanged: defined time period between waste rock deposition and detection of released constituents at downstream monitoring station in receiving environment • Unchanged: defined using measured nitrate concentrations • Fixed, spoil-specific value for older spoils (i.e., those present prior to 2015), including those that continue to receive waste rock • Variable for new spoils, starting at 0 to 1 year and increasing over time to a fixed value based on changing spoil geometry (namely height)

Table 7-1: Summary of Key Changes to the Water Quality Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Leaching efficiency	• Referred to as "adjusted leach time" • Defined as the time period over which soluble constituents wash out of a given volume of waste rock • Defined as a fixed value of 10 years with equal proportion of soluble constituents being release each year	• Term "adjusted leach time" replaced with "leaching efficiency" • Defined as a percent loss per year, rather than a fixed time period • Percent loss per year is defined as 20% for most spoils, with a few exceptions that are outlined in Annex C • Model includes functionality to allow leaching efficiency to vary over time as spoil shape changes
Nitrate release from waste rock	• Annual release rate based on estimated nitrate content in explosives residue accompanying each volume of waste rock placed into a spoil • Nitrate release subject to lag and leaching efficiency • Annual load released transformed into weekly rates using catchment-specific weekly loading distributions	• Same as in 2017, except for change in leaching efficiency outlined above and estimates of explosive residue to account for recent improvements in blasting practices; the latter item was applied taking into consideration when changes to blasting practices occurred and through the addition of a variable input representing how efficient the changes are expected to be at reducing explosive residuals
Selenium and sulphate release from waste rock	• Catchment-specific initial lag between waste rock placement and detection of selenium or sulphate in the receiving environment, with value set to the same duration as calculated for nitrate. • 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	• Release of selenium and sulphate from waste rock consists of two components: initial soluble load and oxidative release • Oxidative release is defined using the same approach as in 2017 • Initial soluble load is the release of an immediately soluble component of selenium and sulphate that arrives with waste rock as it is placed in the spoil. It results from mineral oxidation prior to blasting, during blasting and prior to placement in a spoil. • Initial soluble load is calculated using the same spoil-specific selenium and sulphate release rates as applied to the oxidative component, multiplied by the oxidation time prior to placement in the spoil • Initial soluble load is subject to lag and leaching efficiency, similar to nitrate
Cadmium release from waste rock	• Operation-specific source term for cadmium • Defined largely as a set of monthly concentrations	• Source term is defined based on cadmium to sulphate ratios, which vary based on Morrissey Formation content in each spoil • Released cadmium is then subject to attenuation as it moves through the spoil and through the receiving environment • Tributary-specific attenuation rates are defined on a monthly basis using monitoring data

Table 7-1: Summary of Key Changes to the Water Quality Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Loading distributions	• Annual release rates are transformed into weekly release rates based on catchment-specific weekly loading distributions • Catchment-specific weekly loading distributions defined using historical monitored flows and concentrations • Catchment-specific weekly loading distributions are fixed (i.e., repeat the same 52-week distribution from year to year)	• Annual release rates are transformed into weekly release rates based on how normalized weekly waste rock flows compare to normalized long-term average waste rock flows, rather than being calculated using fixed weekly loading distributions • Allows for a more dynamic response in constituent release from year to year and creates more consistency between constituents
Constituent inventory in waste rock	• Not included	• Total constituent inventory in each waste rock spoil is tracked. Inventory is calculated as a function of mass by weight (e.g., "x" milligrams of selenium per kilogram of waste rock) minus constituent mass released from the spoil over time
Surface water – groundwater partitioning (i.e., at any given location, a portion of the total watershed flow may be travelling through shallow groundwater pathways, with the remaining portion travelling at surface)	• Not considered during model calibration • Implicitly accounted for in mitigation planning through the use of water availability, which defines the proportion of total watershed flow that is accessible at a given intake	• Total flow and load divided into surface water and groundwater components where relevant to model calibration and supported by available field data
Constituent release from pit walls	• Pit walls divided into five categories to account for influence of Morrissey Formation and potential acid generation • Separate release rates developed for each category of pit wall	• Pit walls divided into four categories, rather than five, to simplify data analysis and information transfer • Change involved combining non-PAG, benched sub-Mist Mountain Formation and benched Mist Mountain Formation into single category, referred to as benched Mist Mountain Formation

Table 7-1: Summary of Key Changes to the Water Quality Component Incorporated into the 2020 Regional Water Quality Model

Description	2017 RWQM	2020 RWQM
Rehandle of historical waste materials	• Rehandle of waste materials results in a short-term, immediate release of constituents in addition to that which would otherwise occur if the materials were not rehandled. • The movement of this "extra" load into the receiving environment was not subject to lag or leaching efficiency	• Rehandle of waste materials results in a short-term, immediate release of constituents in addition to that which would otherwise occur if the materials were not rehandled. • The movement of this "extra" load into the receiving environment is subject to lag time and leaching efficiency, with both hydrologic processes being defined by the characteristics of the spoil into which the rehandled material is placed.
Instream sinks for nitrate and selenium	• Included instream sinks between specified monitoring locations in the Elk River and Fording River mainstems • Instream sinks included in model to reflect trends observed in monitored data collected from both rivers, and to maintain a bass balance through the system • Instream sinks applied to nitrate and selenium only	• Continue to be applied to selenium and nitrate, with rates of loss adjusted to reflect updated model calibration
Retention areas	• Retention areas are included in the Cataract Creek, Porter Creek and Erickson Creek catchments, as well as between EVO Dry Creek and Harmer Creek, to dampen seasonal variation in model projections, thereby better matching monitored information	• Retention areas continue to be applied in specific areas to dampen seasonal variation in model projections, thereby better matching monitored information • Retention areas are included in Henretta Creek, Cataract Creek, Eagle Pond, Porter Creek, upper Line Creek, Erickson Creek, EVO Dry Creek and Harmer Creek catchments, as well as in the upper Fording River
Non-preferential flow reservoirs	• Not included	• Non-preferential flow reservoirs have been added to account for the non-uniform nature in which water likely moves along the larger groundwater flow paths connecting Kilmarnock Creek to the Fording River and West Line Creek to Line Creek, which can result in the temporary storage and more gradual release of some of the water moving along these flow paths
Interflow reservoirs	• Not included	• Interflow reservoirs have been added to account for the temporary storage and gradual release of water from adjacent banks and subsurface flow paths that occur along the mainstems of the Elk River, Fording River, Line Creek and Michel Creek

7.3 Calibration Process

Calibration involved simulating historical water quality conditions in the Elk Valley and comparing model output to measured data. The model was then adjusted as required, in an iterative fashion, to achieve a good fit to the measured data. Goodness of fit was evaluated visually and through the use of error and bias statistics. 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 measured range of concentrations over the period of interest and long-term temporal trends (if present). The calibration was deemed complete when efforts expended on iteration no longer yielded appreciable or notable gains in model performance.

The adjustments involved modification of the geochemical source terms and the FC to improve model performance. As previously noted, the flow estimates developed using the FC are independently derived from the geochemical source terms. The process of calibration provided an opportunity to refine both inputs to the WQC to allow for a better match to historical water quality measurements at monitoring locations throughout the Elk Valley.

Changes to the FC included alterations to the waste rock hydrology module (i.e., changes to the drawdown rate). Other changes included modifications to runoff and recession coefficients to improve the replication of measured flows, which then helped to improve the performance of the WQC.

With respect to geochemical source terms, the calibration process started with the values identified as outlined in Section 4. These values were then adjusted, where required, through application of a calibration factor to improve model performance. Waste rock is the largest source of nitrate, selenium, sulphate, and cadmium to the receiving environment, so alterations to the source terms used to numerically represent this release had the largest effect on model performance and were the primary focus for model calibration. The altered values developed through the calibration process were checked against the confidence intervals included with the initial geochemical source terms.

The calibration period spanned from 2004 to 2019 for most constituents, although error and bias statistics were calculated using data from the 2004 to 2018 time period. Measured information from 2019 was not included when generating the calibration statistics, because it was still considered preliminary data at the time the calibration was initiated. The one exception was nitrate; the calibration period for nitrate spanned from 2006 to 2019, coincidental with the availability of explosives use data, with error and bias statistics calculated considering information from 2006 to 2018.

7.4 Resulting Performance

7.4.1 Nitrate

Tributaries

Simulated results in mine-affected tributaries to the Fording River and Elk River matched reasonably well with measured data, in terms of replicating the range of measured concentrations and matching seasonal, yearly, and longer-term trends. Comparisons of model output to monitored data are shown for selected tributaries in Figure 7-1; comparable plots for all modelled tributaries are included in Annex C.

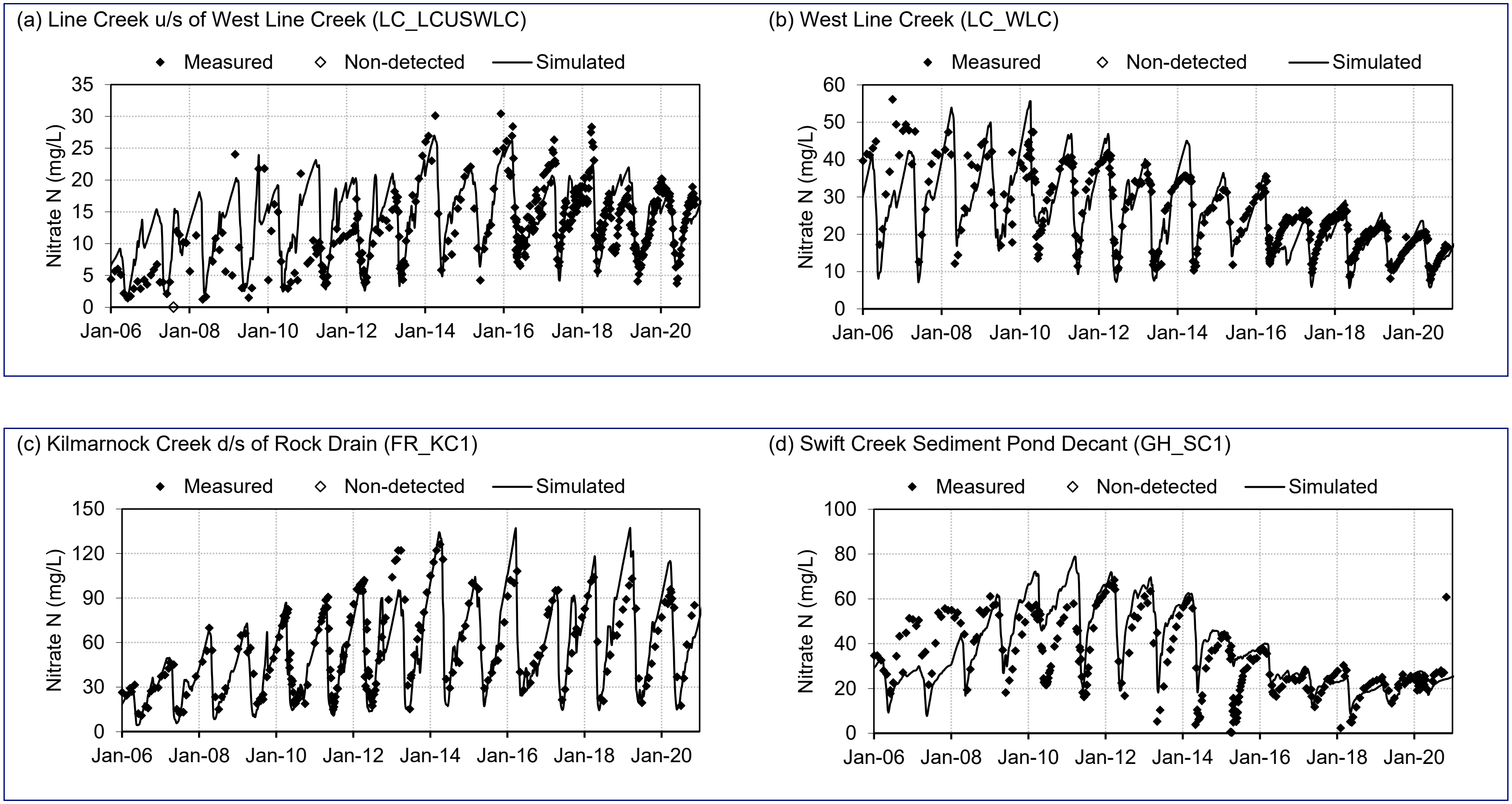
The ability of the model to replicate seasonal and long-term patterns in measured nitrate concentrations is reflected in the relative bias statistics, which range from 0.8 to 1.4. The error statistics in some tributaries (e.g., Kilmarnock Creek, Cataract Creek, Erickson Creek) were also small, in the order of 15 to 30%, comparable to the 20% threshold used in many analytical laboratories to identify split samples as being different from one another. In other tributaries, such as Clode Creek, model error was larger and ranged from 30 to 69%. In a few tributaries at GHO, simulated trends did not follow observed trends as closely throughout the calibration period (Figure 7-2), likely due to uncertainty in the simulated flows and/or pumping records available from the mine site. Nevertheless, model performance overall has improved relative to the 2017 RWQM, including in the GHO tributaries (see Annex C).

The WQC, like any model, is a simplification of the natural system being represented. Factors contributing to model error 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 at a consistent rate over time (e.g., 20% per year). 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.

Values assigned to the calibration factors related to lag time and amount of nitrate residual contained in the waste rock are provided in Annex C. They were reviewed by SRK, and were found to be reasonable given the level of uncertainly inherent in the lag time estimates and site-specific variability in powder factors.

Fording River and Elk River

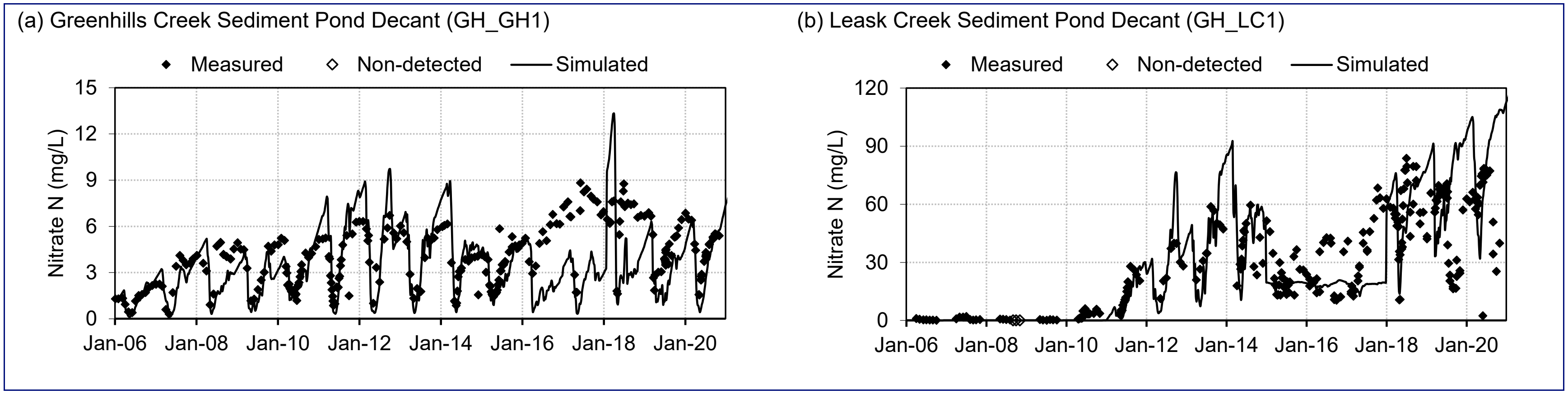
The 2020 RWQM can accurately reflect observed seasonal and longer-term annual trends in nitrate concentrations in both the Fording River and Elk River, as well as simulate the range in measured concentrations (Figure 7-3). The model tends to over-predict nitrate concentrations during lower winter flow periods in the lower Fording River and most of the Elk River, when instream concentrations peak. Model performance overall has improved relative to the 2017 RWQM, with a lower degree of over-prediction and a higher degree of accuracy. Error and bias statistics indicate low bias, and average error ranging from 16% to 44% at compliance points and Order Stations in the Fording River and Elk River (see Annex C for details).



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-1: Modelled and Measured Nitrate Concentrations in Line, West Line, Kilmarnock, and Swift Creeks, 2006-2020



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-2: Modelled and Measured Nitrate Concentrations in Greenhills Creek and Leask Creek, 2006-2020

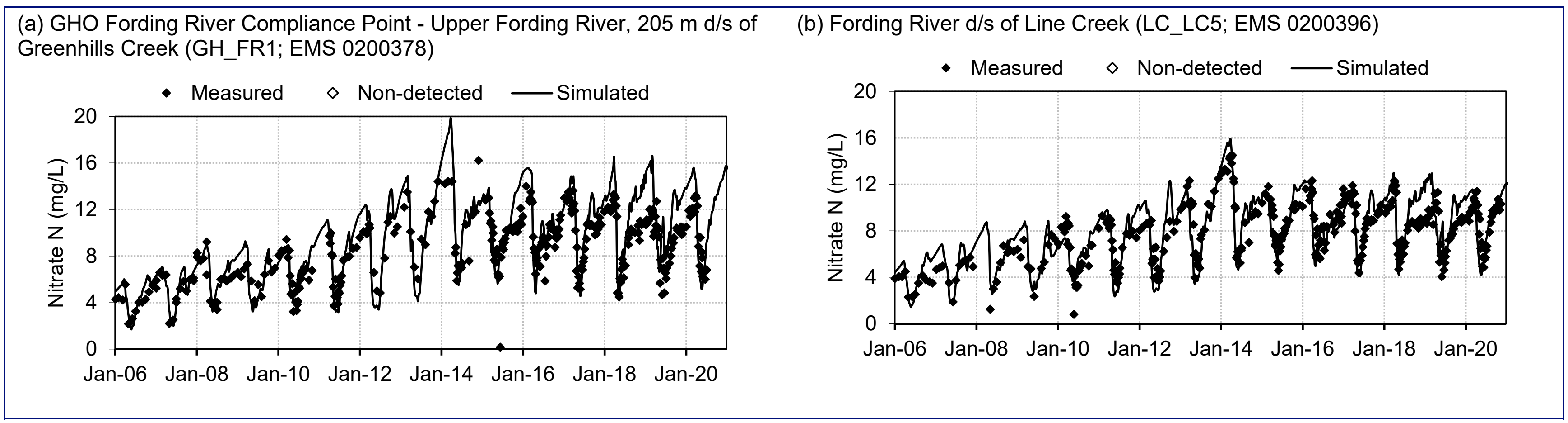
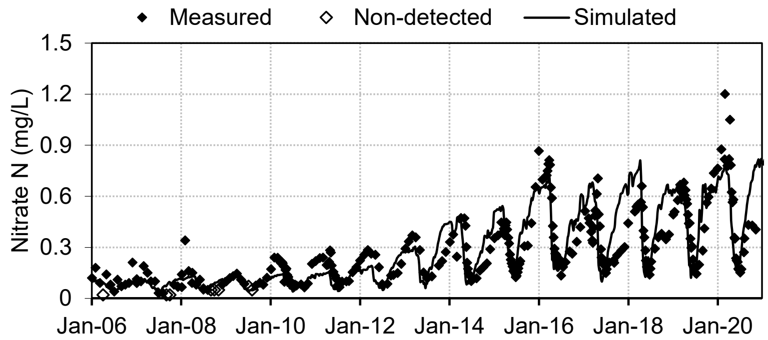
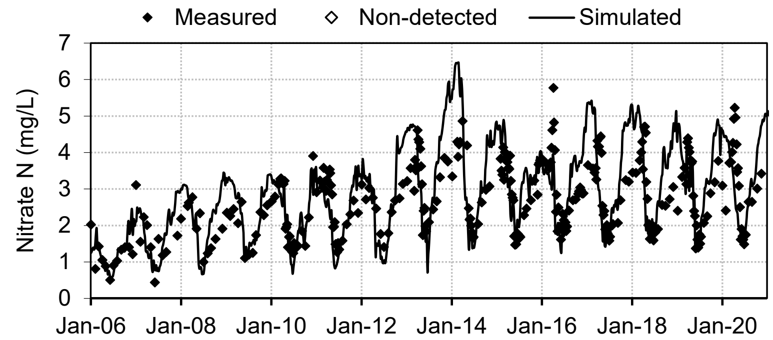


Figure 7-3: Modelled and Measured Nitrate Concentrations in the Fording River and the Elk River, 2006-2020

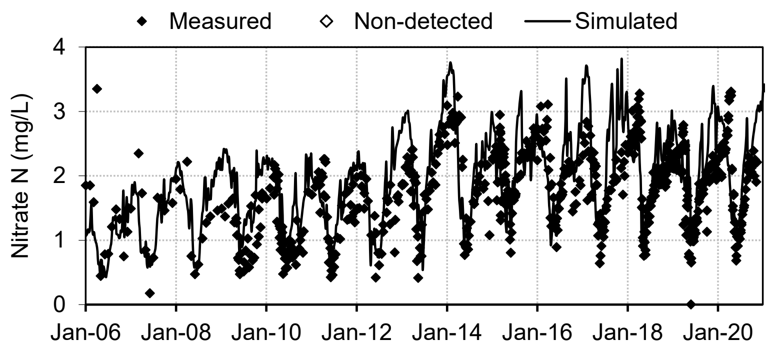
(c) Elk River u/s of Boivin Creek (u/s of Fording River) (GH_ER1; EMS E206661)



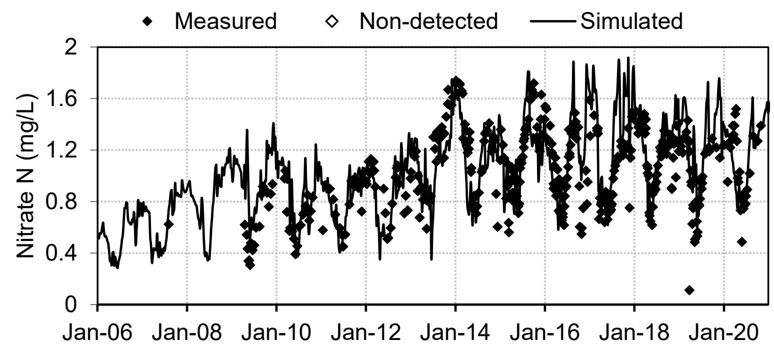
(d) Elk River u/s of Grave Creek (from Fording River to Michel Creek (EV_ER4; EMS 0200389)



(e) Elk River d/s of Michel Creek (EV_ER1; EMS 0200393)



(f) Elk River at Highway 93 near Elko (RG_ELKMOUTH)



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-3: Modelled and Measured Nitrate Concentrations in the Fording River and the Elk River, 2006-2020

7.4.2 Selenium

Tributaries

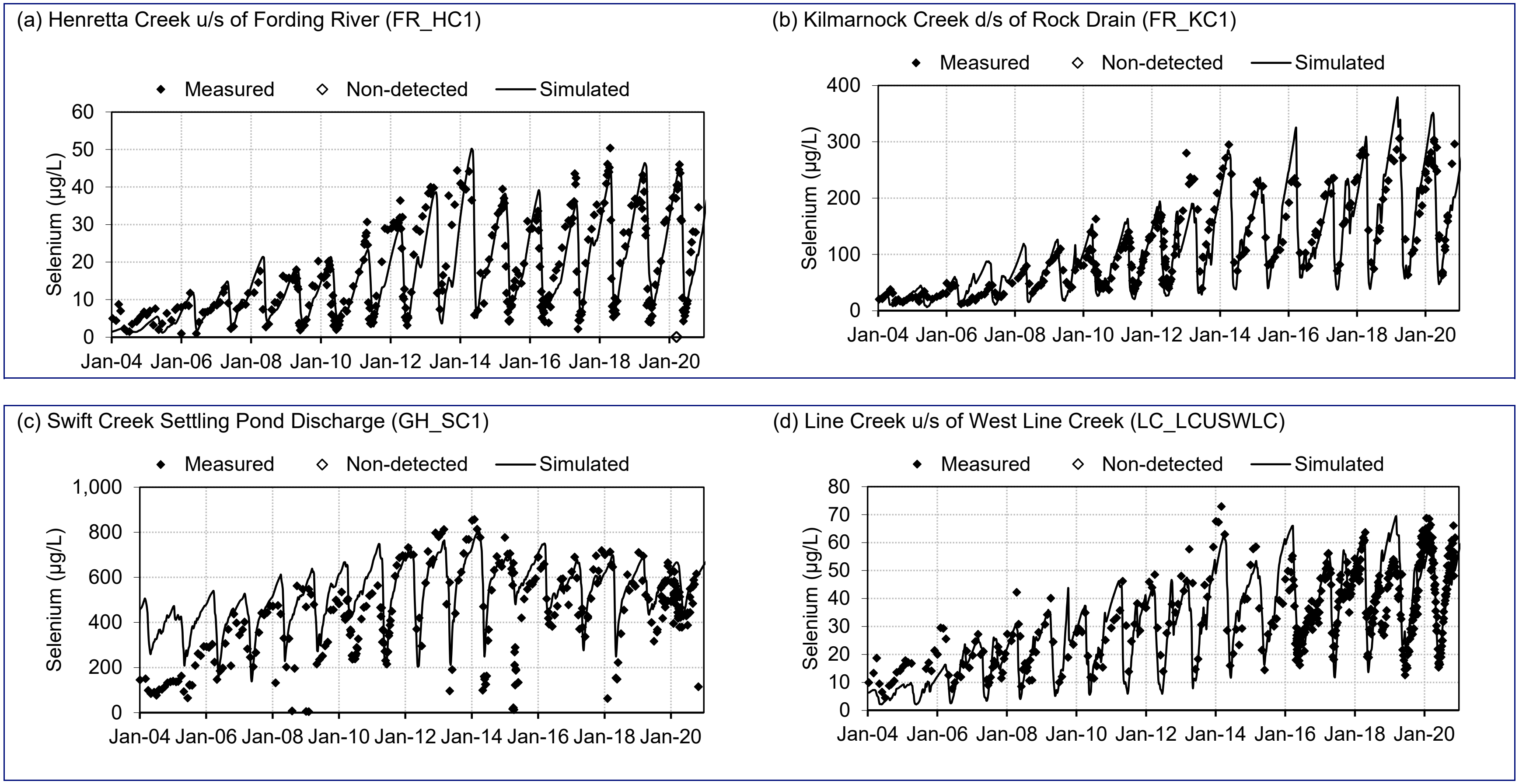
As with nitrate, simulated results produced using the 2020 RWQM for mine-affected tributaries to the Fording River and Elk River matched reasonably well with measured data, in terms of replicating the range of measured concentrations and matching seasonal, yearly, and longer-term trends. Examples of model performance are shown in Figure 7-4, with additional details provided in Annex C. The range of relative bias statistics is between 0.8 and 1.3, with model error ranging from 15 to 56%. The performance of the model in simulating selenium concentrations in mine-affected tributaries is better than that of the 2017 RWQM and supports the model’s intended purpose as a planning and assessment tool. Error in the calibration stems partially from the fact that the model outputs are weekly average concentrations, whereas the measured data are instantaneous concentrations collected through grab sampling. They are, therefore, likely to be more variable than the model output.

In a few tributaries at GHO, the simulated trends did not follow the observed trends as closely throughout the calibration period (Figure 7-5), likely as 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 lower Elk River (Figure 7-6).

Values assigned to the calibration factors applied to the waste rock residing in the local tributaries are provided in Annex C. The resulting calibrated release rates typically fall within or just outside the confidence intervals developed around the average values that were used to initiate the calibration process. Where exceptions occur, they are likely due to differences in the flow data used to generate the geochemical source terms (monitored information) and those used as input in the WQC (output from the FC of the 2020 RWQM).

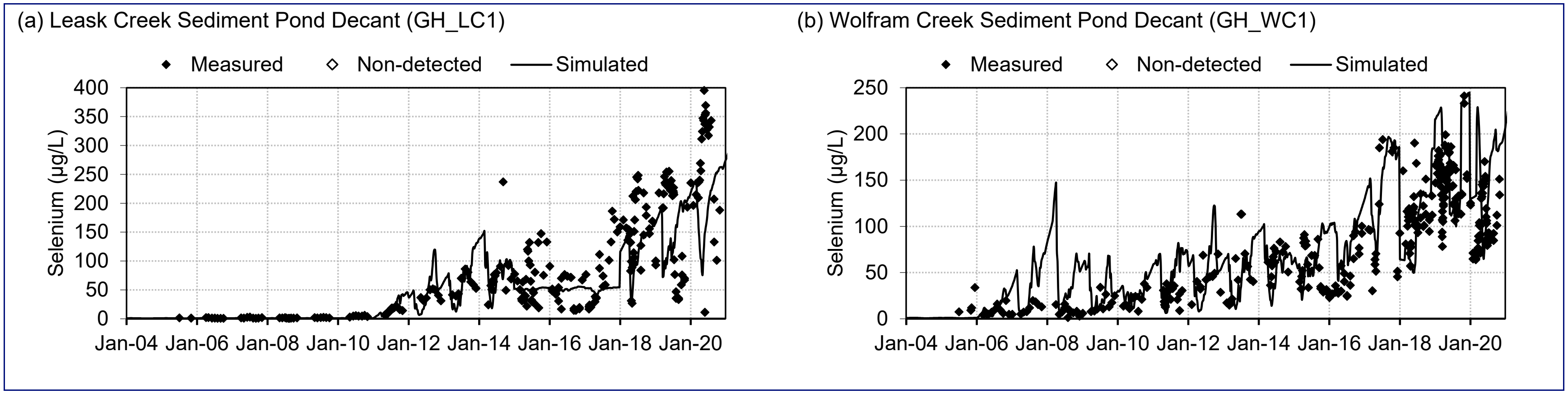
Fording River and Elk River

Simulated results in the Fording River and Elk River matched reasonably well with the range of measured concentrations and seasonal, yearly, and longer-term trends (Figure 7-6). A near- neutral to positive bias was maintained throughout the Fording River and Elk River, as outlined in Annex C. Model error in the Fording River ranged from 14 to 37%; in the Elk River, it ranged from 20% to 45%, with some over-prediction of observed winter conditions. Overall, the performance of the 2020 RWQM is better than to the 2017 RWQM.



Note:
When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-4: Modelled and Measured Selenium Concentrations in Henretta, Kilmarnock, Swift and Line Creeks, 2004-2020



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-5: Modelled and Measured Selenium Concentrations in Leask Creek and Wolfram Creek, 2004-2020

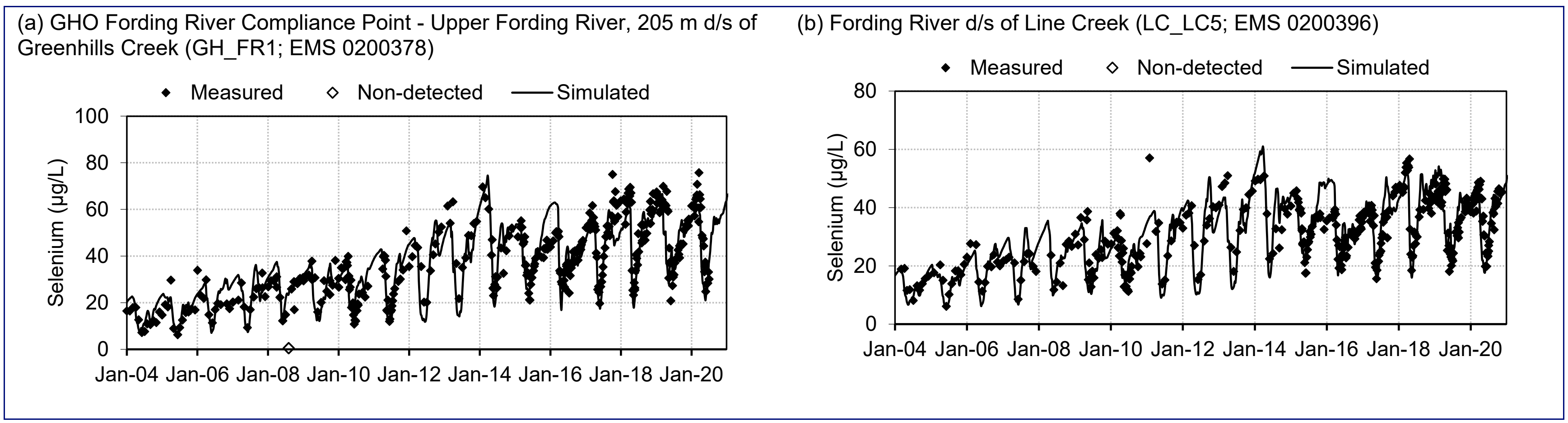
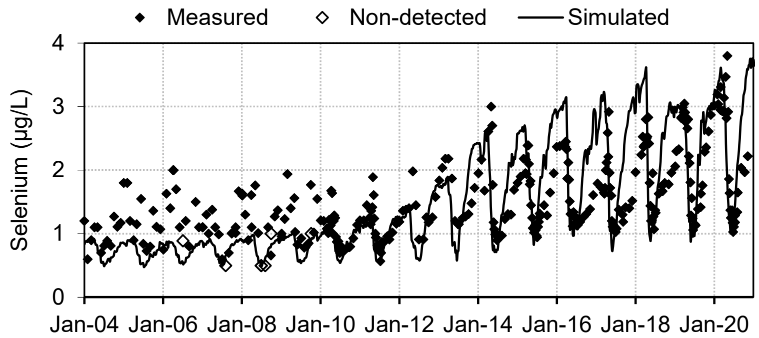
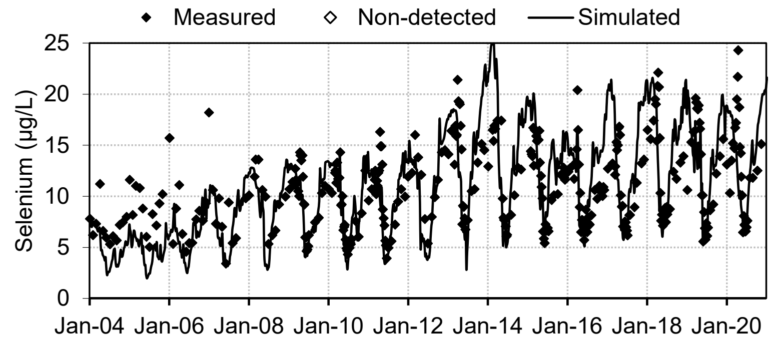


Figure 7-6: Modelled and Measured Selenium Concentrations in the Fording River and the Elk River, 2004-2020

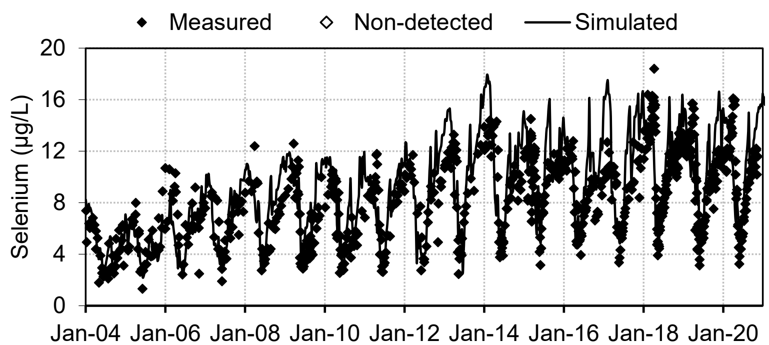
(c) Elk River u/s of Boivin Creek (u/s of Fording River) (GH_ER1; EMS E206661)



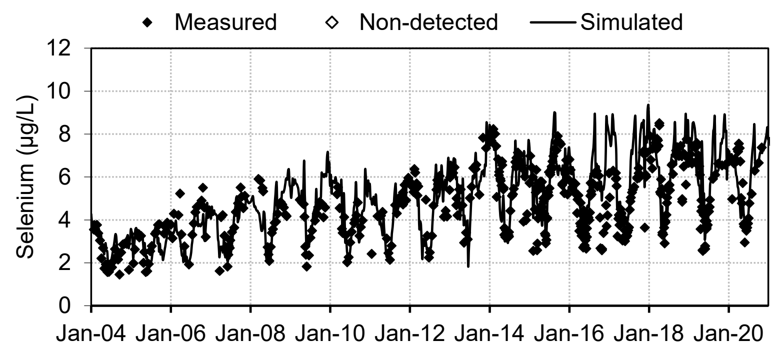
(d) Elk River u/s of Grave Creek (from Fording River to Michel Creek (EV_ER4; EMS 0200389)



(e) Elk River d/s of Michel Creek (EV_ER1; EMS 0200393)



(f) Elk River at Highway 93 near Elko (RG_ELKMOUTH)



Note:
When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-6: Modelled and Measured Selenium Concentrations in the Fording River and the Elk River, 2004-2020

7.4.3 Sulphate

Tributaries

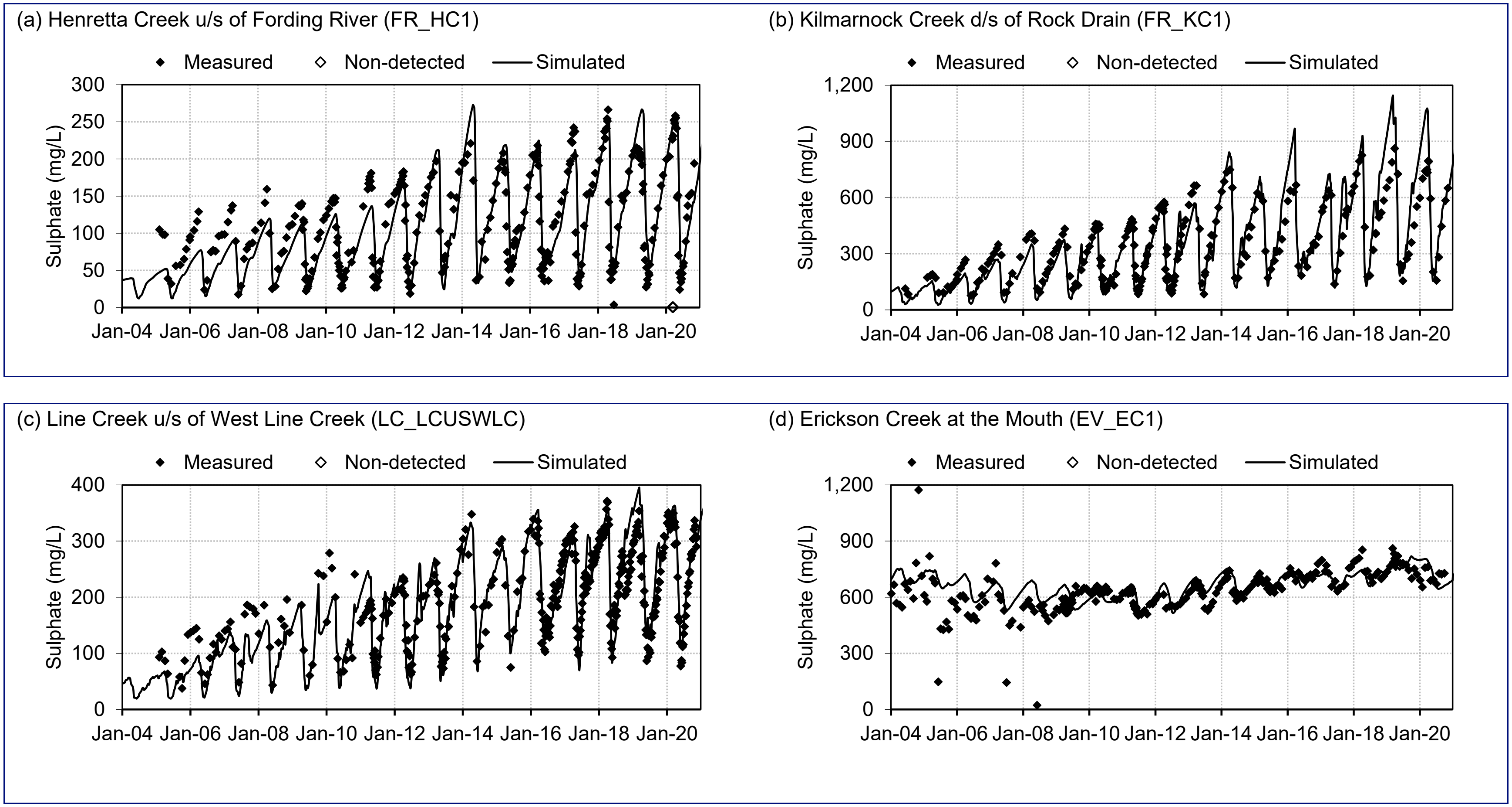
Simulated results in tributaries to the Fording River and Elk River, after calibration, matched reasonably well with measured data in terms of replicating the range of measured concentrations and matching seasonal, yearly, and longer-term trends (Figure 7-7). In several tributaries, including in Leask and Wolfram creeks, simulated trends did not always follow the observed trends (Figure 7-8). 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, and the performance of the 2020 RWQM in these and other tributaries is better than that of the 2017 RWQM, as outlined in Annex C.

Relative bias in the sulphate calibration is typically between 0.8 and 1.2, with error ranging from 10 to 40%. These values indicate that the WQC is better able to replicate seasonal and longer-term patterns than individual observed 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 general, the calibrated sulphate release rates fall within or just outside the confidence intervals developed around the average values that were used to initiate the calibration process. Where exceptions occur, they are likely due to differences in the flow data used to generate the geochemical source terms (monitored information) and those used as input in the WQC (output from the FC).

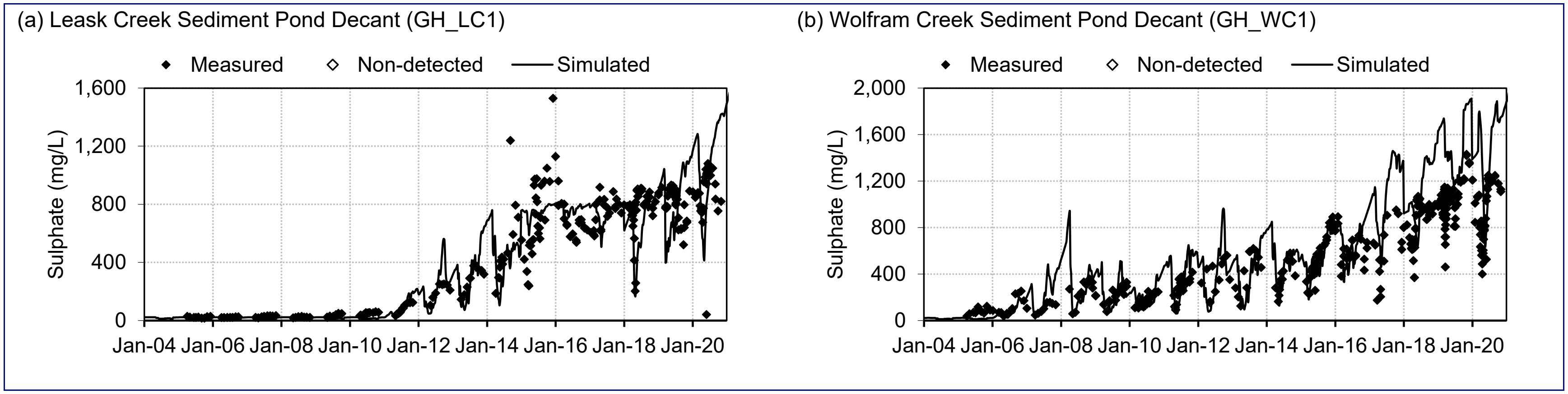
Fording River and Elk River

As with nitrate and selenium, simulated sulphate concentrations in the Fording River and Elk River matched reasonably well with measured data in terms of replicating the range of measured concentrations and matching seasonal, yearly, and longer-term trends (Figure 7-9). Throughout most of the Fording River and Elk River, a positive bias was maintained, with relative bias values ranging from 0.9 to 1.2. Model error in the Fording River ranged from 13 to 25%. In the Elk River, it ranged from 20% to 27%, with some over-prediction of observed winter conditions. Overall, the performance of the 2020 RWQM is better that that of the 2017 RWQM, as outlined in Annex C.



Note:
When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-7: Modelled and Measured Sulphate Concentrations in Henretta, Kilmarnock, Line and Erickson Creeks, 2004-2020



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-8: Modelled and Measured Sulphate Concentrations in Leask Creek and Wolfram Creek, 2004-2020

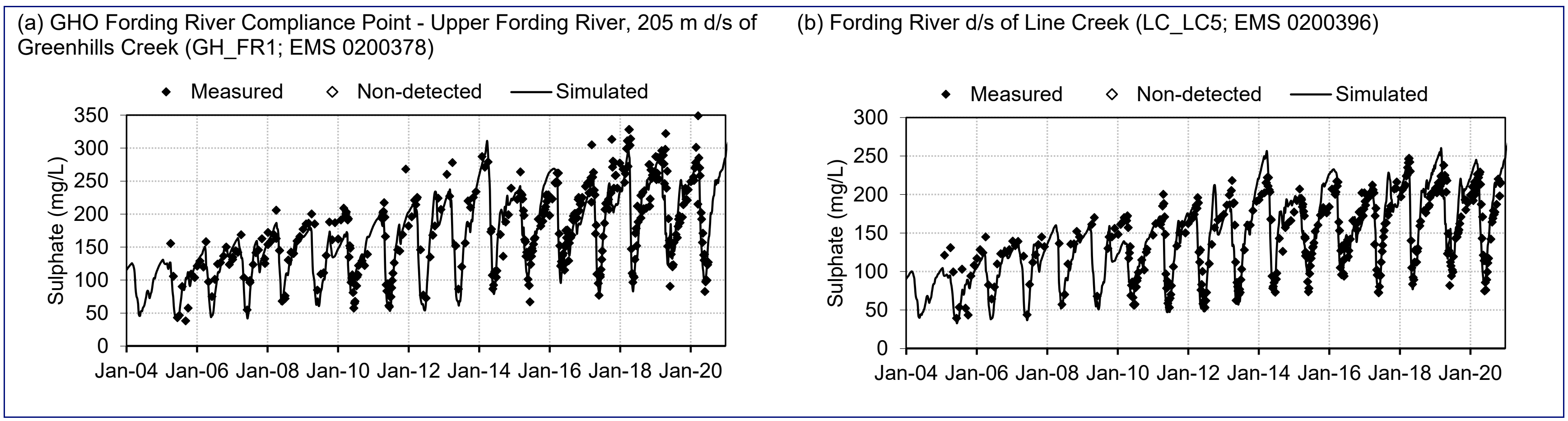
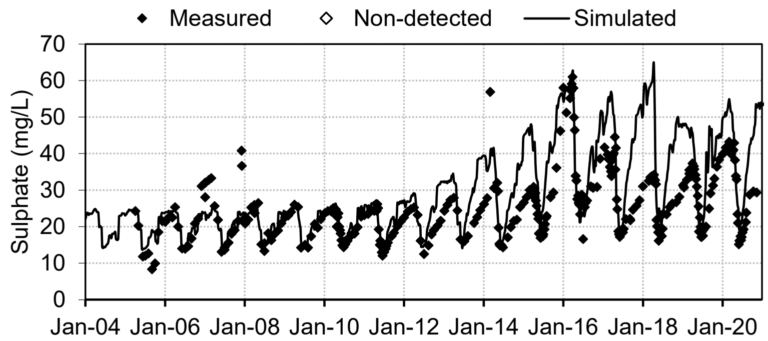
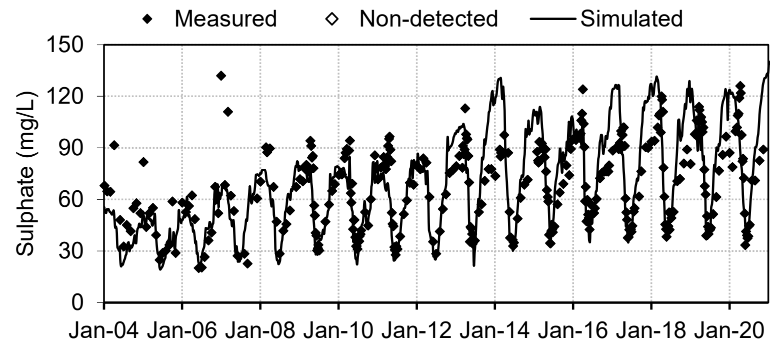


Figure 7-9: Modelled and Measured Sulphate Concentrations in the Fording River and the Elk River, 2004-2020

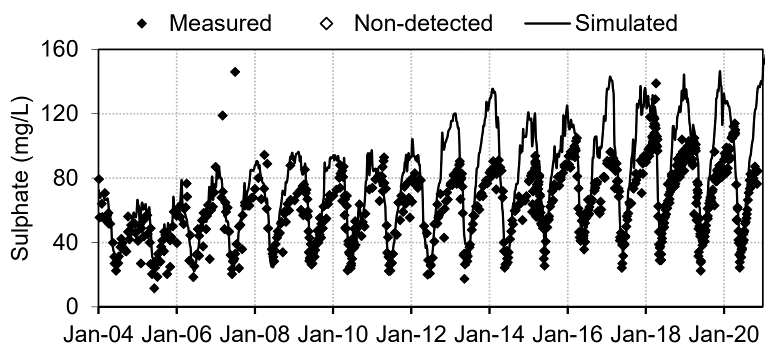
(c) Elk River u/s of Boivin Creek (u/s of Fording River) (GH_ER1; EMS E206661)



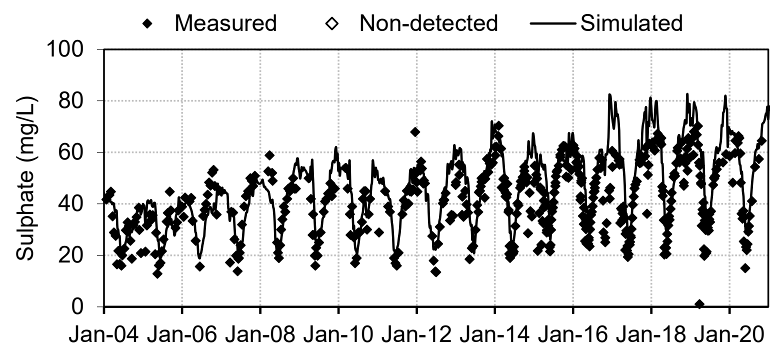
(d) Elk River u/s of Grave Creek (from Fording River to Michel Creek (EV_ER4; EMS 0200389)



(e) Elk River d/s of Michel Creek (EV_ER1; EMS 0200393)



(f) Elk River at Highway 93 near Elko (RG_ELKMOUTH)



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-9: Modelled and Measured Sulphate Concentrations in the Fording River and the Elk River, 2004-2020

7.4.4 Cadmium

Tributaries

Model performance with respect to dissolved cadmium is mixed. In some mine-affected tributaries, simulated concentrations mirrored the observed range and followed seasonal patterns (Figure 7-10). In other tributaries, such as Clode and Leask creeks, model performance was poor (Figure 7-11), 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 related to cadmium.

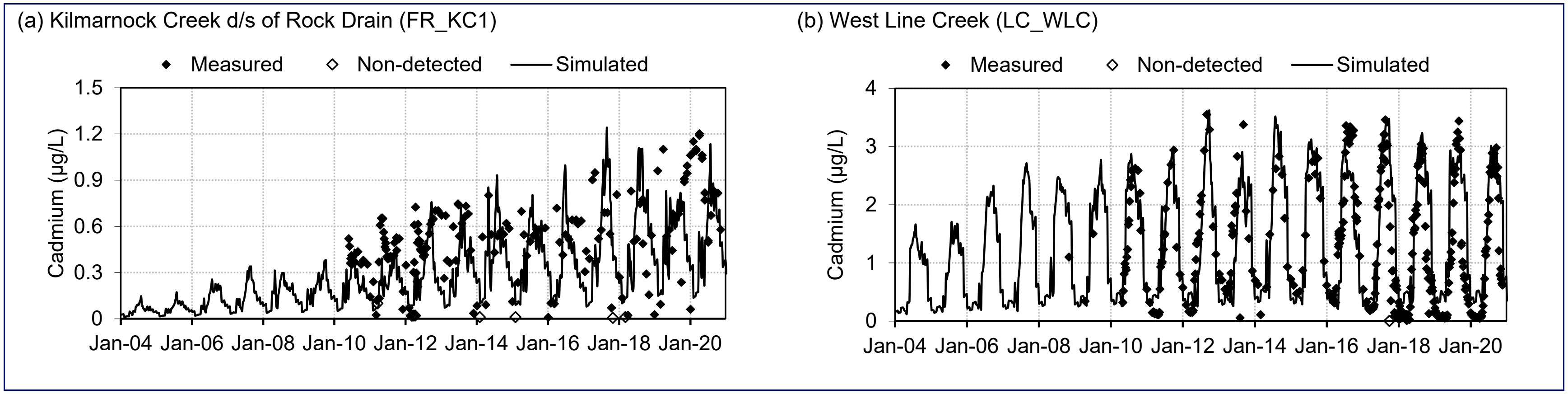
Model calibration for cadmium involved accounting for attenuation between the point of release within spoils and the first downstream modelling nodes, as well as subsequent attenuation along downstream transport pathways, including in the mainstem of Line Creek and the Fording River. The attenuation processes numerically represented in the model likely relate to loss through adsorption to oxyhydroxide minerals (e.g., ferrihydrite), co-precipitation with calcite and adsorption to bed sediment. The degree of attenuation assumed in the model is outlined in Annex C, with the load reduction factors applying year-round.

Relative bias in the cadmium calibration is typically between 0.3 and 1.4, with error ranging from 28 to 102%. These values indicate that the WQC is better able to replicate seasonal and longer-term patterns than individual observed data points. They also indicate that model performance for cadmium is not, in general, as strong as that for selenium, sulphate and nitrate. Nevertheless, the 2020 model updates have resulted in better performance in tributaries relative to that of the 2017 RWQM, as outlined in Annex C.

Fording River and Elk River

Simulated dissolved cadmium concentrations matched reasonably well with measured data in terms of replicating the range of measured concentrations and matching seasonal and yearly trends in the Fording River downstream of Henretta Creek, upstream of Kilmarnock Creek and between Swift and Cataract Creeks (Figure 7-12). Farther downstream, at the GHO Fording River Compliance Point and in the Fording River downstream of Line Creek, and in the Elk River upstream of Grave Creek, simulated cadmium concentrations showed a longer-term, increasing trend that was not observed in the measured data (Figures 7-12 and 7-13). That said, the performance of the 2020 RWQM is better than that of the 2017 RWQM, as outlined in Annex C.

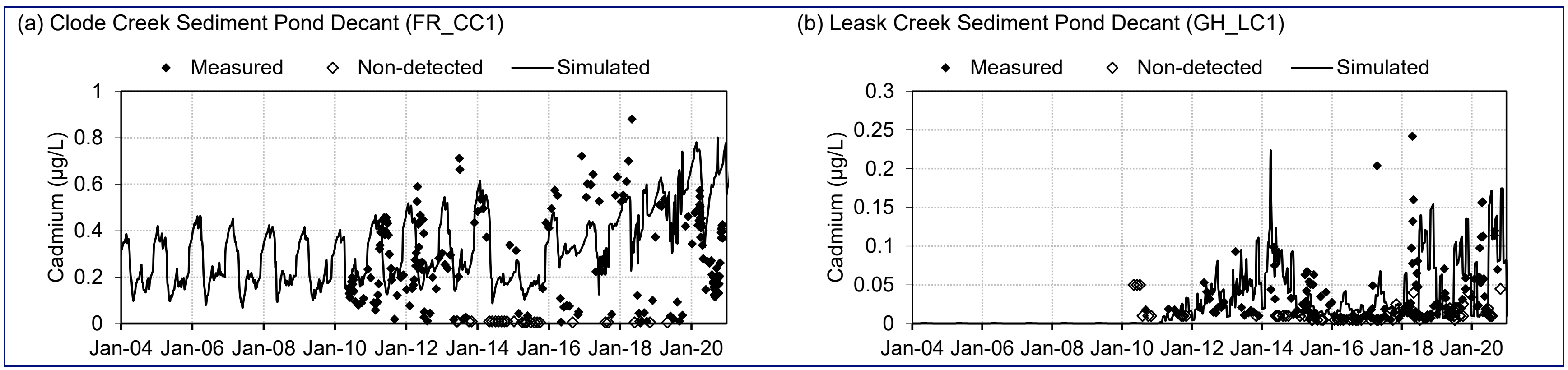
The longer-term, increasing trend is due to the formulation of the geochemical source term used in the model to govern the release of cadmium from waste rock; it explicitly links the release of cadmium to that of sulphate (see Annex A). Thus, if the modelled load of sulphate released from waste rock increases over time, so too does that of cadmium. The increasing trend present in the modelled data suggests that future projections will likely be overestimated and may need to be addressed if cadmium becomes a focus of management action.



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

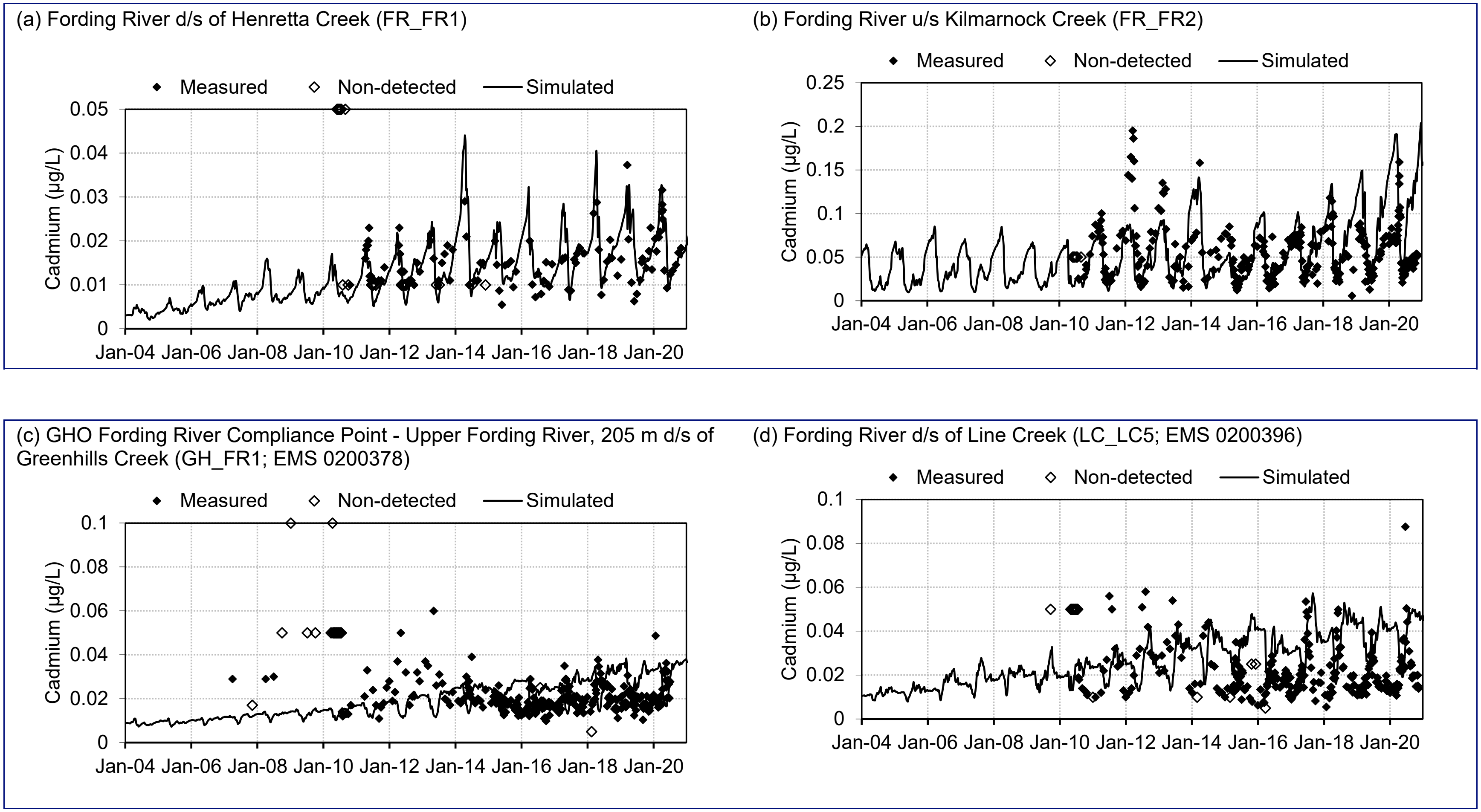
Figure 7-10: Modelled and Measured Dissolved Cadmium Concentrations in Kilmarnock Creek and West Line Creek, 2004-2020



Note:

When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

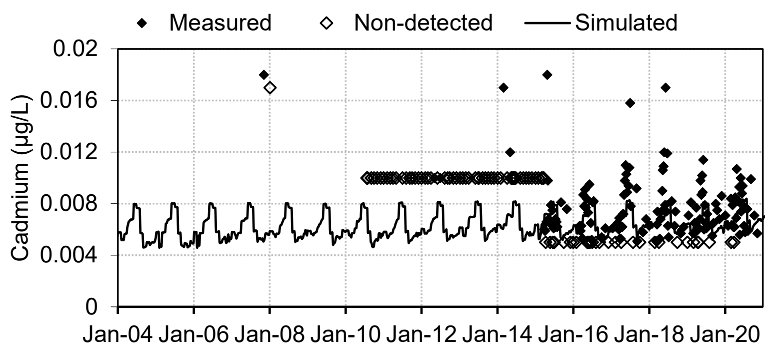
Figure 7-11: Modelled and Measured Dissolved Cadmium Concentrations in Clode Creek and Leask Creek, 2004-2020



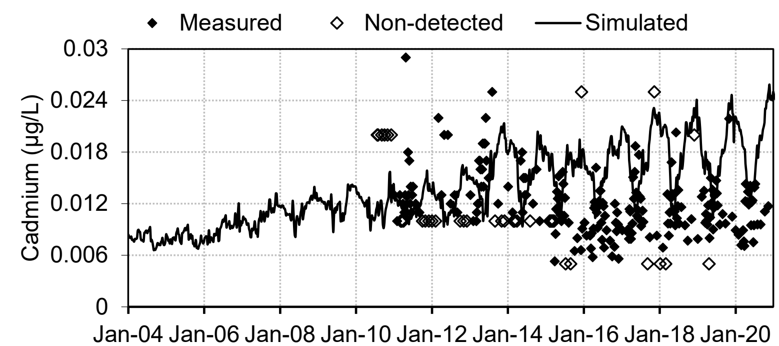
Note:
When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2006 to 2019). When projecting into the future, the WQC uses 20 sets of weekly estimates generated by the FC. In these figures, projected concentrations in 2020 are based on median flow conditions.

Figure 7-12: Modelled and Measured Dissolved Cadmium Concentrations in the Fording River, 2004-2020

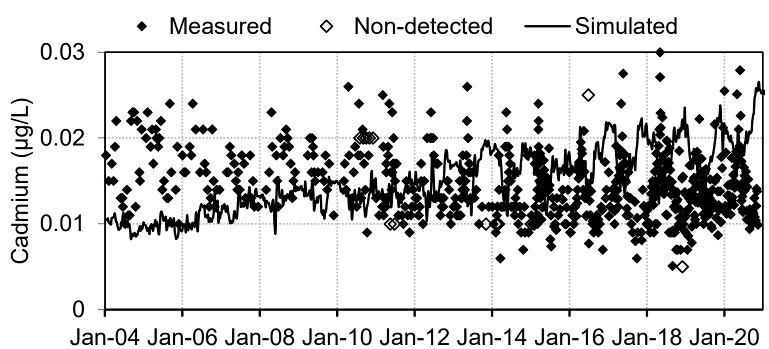
(e) Elk River u/s of Boivin Creek (u/s of Fording River) (GH_ER1; EMS E206661)



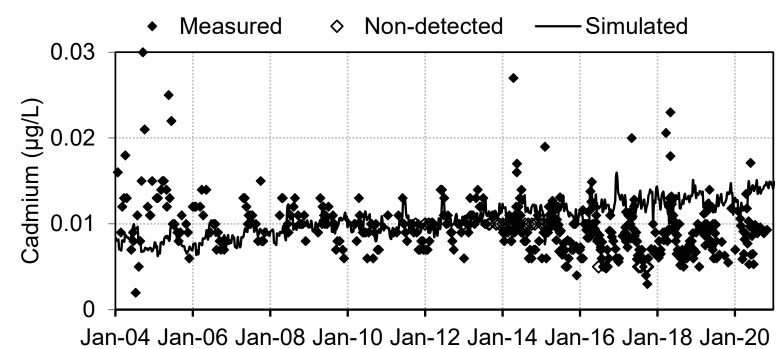
(f) Elk River u/s of Grave Creek (from Fording River to Michel Creek (EV_ER4; EMS 0200389)



(g) Elk River d/s of Michel Creek (EV_ER1; EMS 0200393)



(h) Elk River at Highway 93 near Elko (RG_ELKMOUTH)



Note:
When simulating historical conditions, the WQC uses the weekly flow estimates output by the FC for the corresponding historical period (i.e., 2004 to 2019). When projecting into the future, the WQC uses three sets of weekly estimates generated by the FC (i.e., median, 90th and 10th percentiles). In these figures, projected concentrations in 2020 are based on median flows.

Figure 7-13: Modelled and Measured Dissolved Cadmium Concentrations in the Elk River, 2004-2020

8 Water Quality Component: Model Projections Comparison

8.1 Introduction

The 2020 RWQM Update submission is a model methods submission, outlining how the model has been updated and changed to reflect new learnings and incorporate feedback collected since the 2017 RWQM Update. It is not a compliance evaluation. Consequently, projections are discussed with reference to those produced using the 2017 RWQM to identify what has changed and to evaluate how the 2020 RWQM performs in comparison to the 2017 RWQM. The projections are not reflective of the in-stream performance Teck intends to achieve. Adjustments to the implementation plan are underway and will be described in a separate submission. Adjustments to the implementation plan have been initiated in response to new learnings around the use and performance of saturated rock fills (SRFs), changes to blast management practices that have been implemented across Teck's operations, improved understanding of surface water – groundwater partitioning at Kilmarnock Creek and in response to the model updates outlined herein. The next IPA is being developed under the AMP and will be advanced in consultation with KNC and regulators.

8.2 Approach

The 2017 RWQM produces estimates of instream flow based on analogue hydrographs. Future projections developed using that version of the RWQM are based on three flow conditions: low, average or high flows.

The 2020 RWQM model is climate-driven, and future projections are developed using climate information from 2000 to 2019. The climate information is run repeatedly through the model, so that each year in the future simulation period experiences climate conditions equivalent to those recorded from 2000 to 2019. This approach results in 20 individual estimates of flow and constituent concentration for each week of each future year. The individual weekly estimates are used to calculate temporally-connected monthly and annual average concentrations within each realization. The resulting monthly and annual average datasets are summarized by calculating median (P50), 10th percentile (P10) and 90th percentile (P90) values across the 20 realizations for each future month and each future year.

A potential benefit to the configuration of the 2020 RWQM is that the influences of climate and, in turn, flow on instream water quality are easier to connect (i.e., it is easier to identify the climate conditions that trigger a given projected response in instream water quality). In contrast, flow statistics are input into the 2017 RWQM to assess how variations in climate (and hence flow) may influence future water quality conditions, which makes it more challenging to create direct linkages between given climate patterns (as experienced in a given year) and projected instream water quality responses. Both approaches are effective at developing projections of potential future instream water quality; the 2020 RWQM simply offers an easier mechanism by which to move back and forth between projections of instream water quality response and the climate conditions that drive them.

Future projections of instream water quality are outlined below with a focus on projected median monthly average concentrations derived using the 2020 RWQM compared to those developed by the 2017 RWQM under average conditions. Mitigation for both sets of model projections are based the

2019 IPA. How future projections developed with the 2020 RWQM may vary in response to the following is also outlined below:

- variations in climate
- changes to blasting assumptions
- changes to selenium and sulphate release rates

8.3 Comparison of Model Projections

Model results are presented using a common figure format, which is as follows:

- The x-axis runs from the start of 2004 (for selenium, sulphate, and cadmium) or 2006 (for nitrate) to the end of 2053. The start date corresponds to the start of the calibration period for the 2020 RWQM. The end date (2053) corresponds to the modelled time period at which all permitted waste rock has been deposited and the lag associated with that rock has passed (i.e., all of the waste rock is contributing selenium and sulphate load).
- Projected P50 monthly average concentrations produced using the 2020 RWQM are shown as a solid blue line.
- Projected monthly average concentrations produced using the 2017 RWQM under average flow conditions are shown as a solid grey line.
- Projected annual average concentrations produced using the 2020 RWQM and 2017 RWQM are shown as dashed blue and grey lines, respectively.
- Measured monthly average and annual average concentrations are shown as light green points and dark green points, respectively.
- Modelled information shown prior to 2020 that was generated using the 2020 RWQM was developed based on calibrated flows. Those shown thereafter were developed using multiple climate realizations, as described in Section 8.2.
- Modelled information shown prior to 2017 that was generated using the 2017 RWQM was developed based on calibrated flows. Those shown thereafter were developed using average flow projections.
- Compliance limits are shown in figures as a solid black line and SPOs are shown as a solid green line.

The information described in the bullets above is reflected in the following legend that applies to the figures below:

—— Projected P_{50} Monthly Average Concentrations from the 2020 RWQM
- - - Projected P_{50} Annual Average Concentrations from the 2020 RWQM
—— Projected Monthly Average Concentrations for Average Flows from the 2017 RWQM
- - - Projected Annual Average Concentrations for Average Flows from the 2017 RWQM
● Monthly Average Measured Concentrations
● Annual Average Measured Concentrations
—— Site Performance Objective
—— Limit

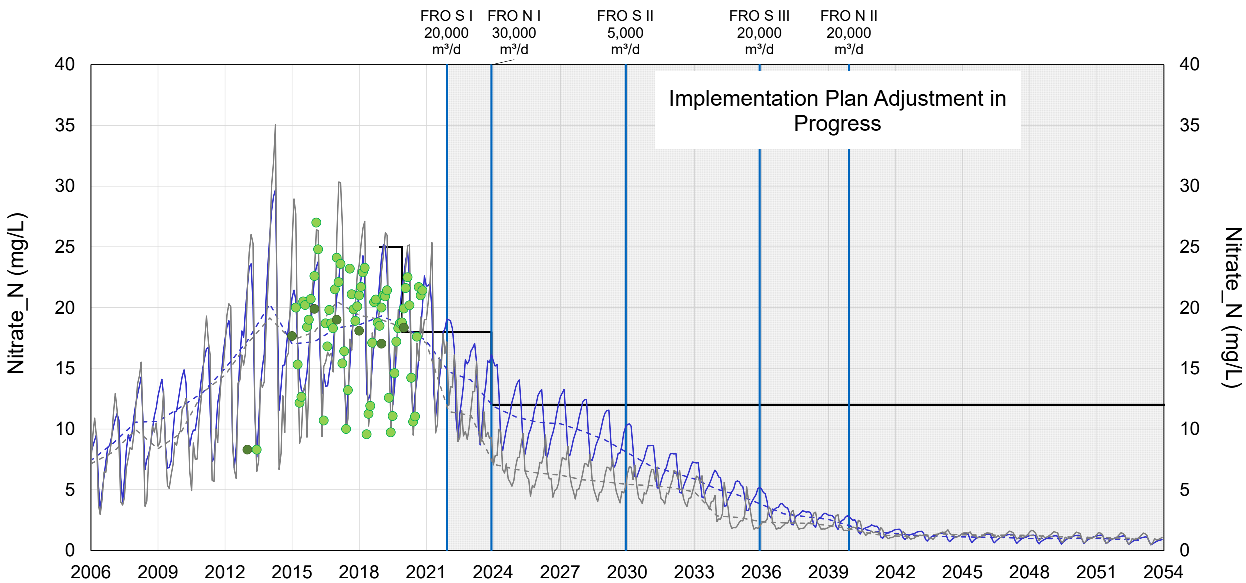
As with any model, input assumptions and projections of future conditions involve uncertainty. Model assumptions are discussed in Annex C

8.3.1 Nitrate

Projected nitrate concentrations developed using the 2020 RWQM followed similar trends to those developed using the 2017 RWQM (Figure 8-1, with additional figures in Annex D). In both cases, projected concentrations declined over time in response to leaching of nitrate from waste rock. The projected rate of leaching is slower in the 2020 RWQM than in the 2017 RWQM because of an update to the method used to simulate nitrate leaching, as discussed in Annex C. New spoils also contribute nitrate load to downstream systems within a shorter timeframe than assumed in the 2017 RWQM. The effects of slower leaching rates and the quicker response of new spoils were offset to some extent by the incorporation of updated blasting practices starting in 2017, namely the use of liners to limit the loss of explosives prior to blasting (as described in Teck [2021]).

In the Fording River above Chauncey Creek, projected nitrate concentrations produced using the 2020 RWQM are also influenced by the release of treated water from the Fording River Operations Active Water Treatment Facility - South (FRO AWTF-S) to Kilmarnock Creek (rather than the Fording River mainstem) and the subsequent movement of this water along subsurface flow paths to the Fording River. Travel times along these subsurface flow paths have been estimated to be in the order of 1 to 6 years (see Annex C for details). Thus, the benefits of treatment achieved by the FRO AWTF-S were projected by the 2020 RWQM to take some time to fully materialize in the Fording River. This outcome is being taken into consideration as work on the next IPA progresses.

(a) FRO Compliance Point (Fording River, 100 m u/s of Chauncey Creek) (FR_FRABCH; E223753)



(b) Fording River downstream of Line Creek (LC_LC5; 0200028)

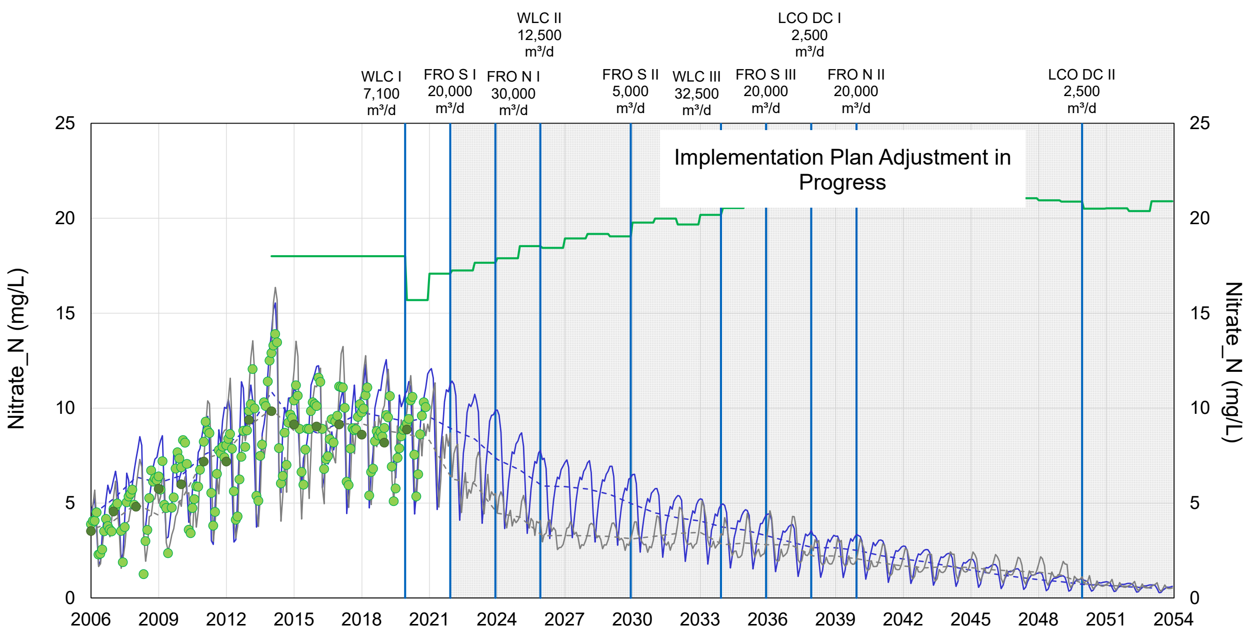
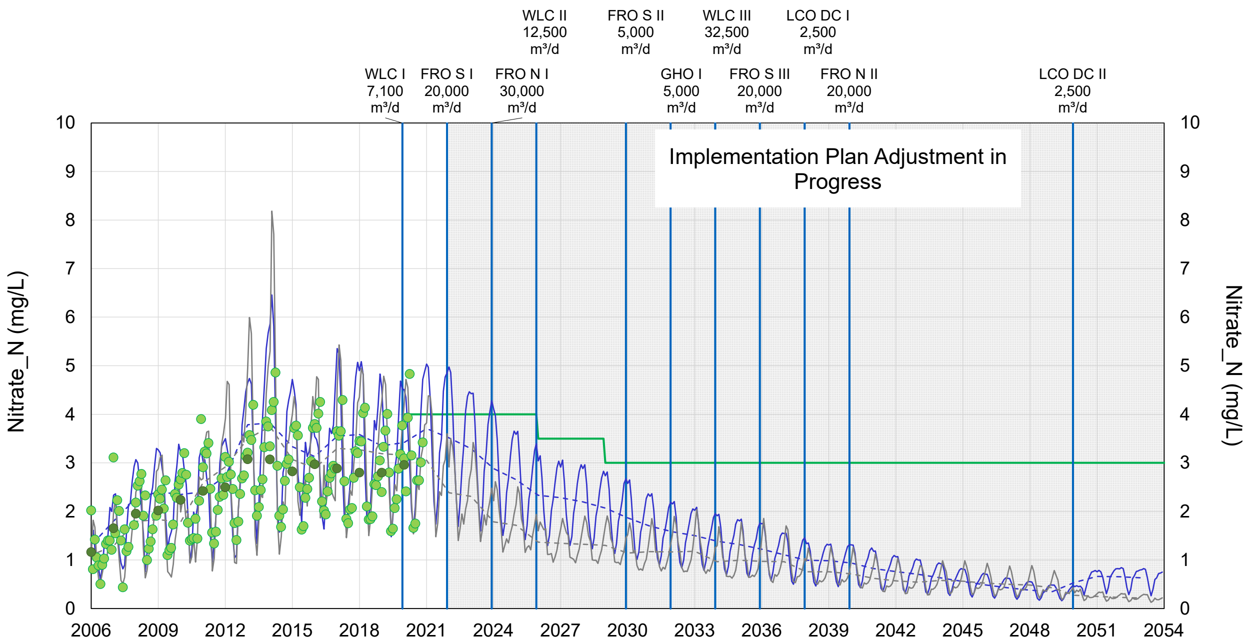


Figure 8-1 Projected Concentrations of Nitrate at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2006-2053

(c) Elk River upstream of Grave Creek (EV_ER4; 0200027)



(d) Elk River downstream of Michel Creek (EV_ER1; 0200393)

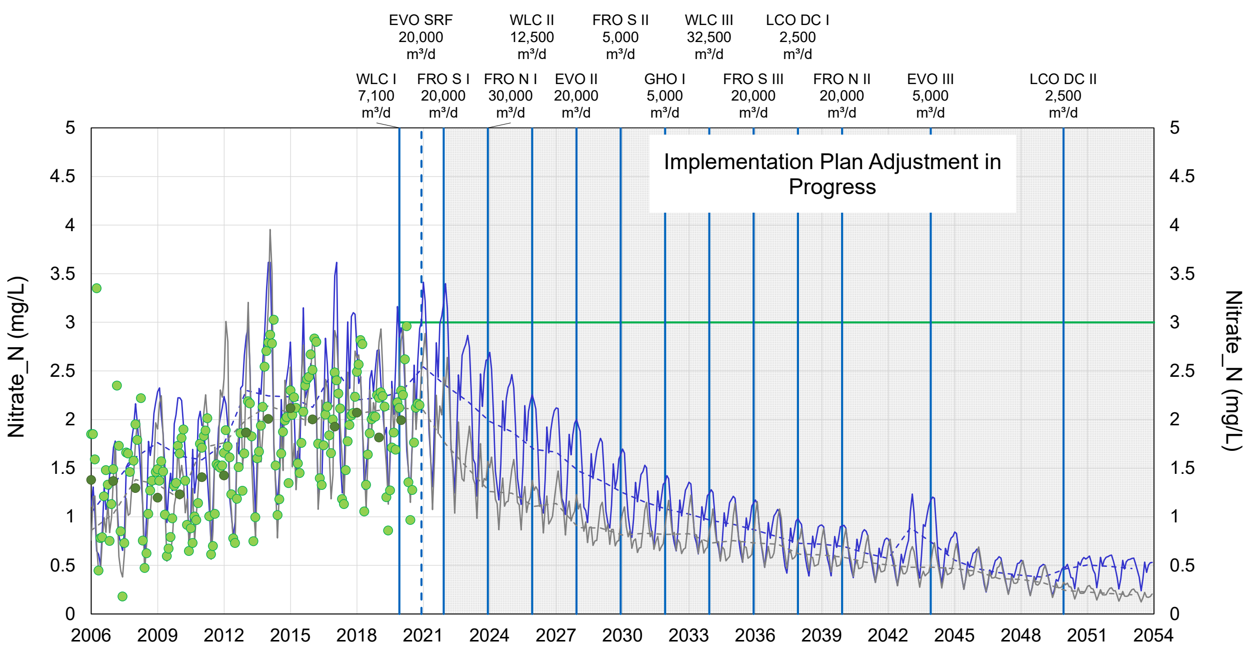


Figure 8-1 Projected Concentrations of Nitrate at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2006-2053

8.3.2 Selenium

In general, projected selenium concentrations produced using the 2020 RWQM were higher than those developed using the 2017 RWQM (Figure 8-2, with additional plots included in Annex D). Differences in the selenium projections are largely attributable to three changes to the RWQM:

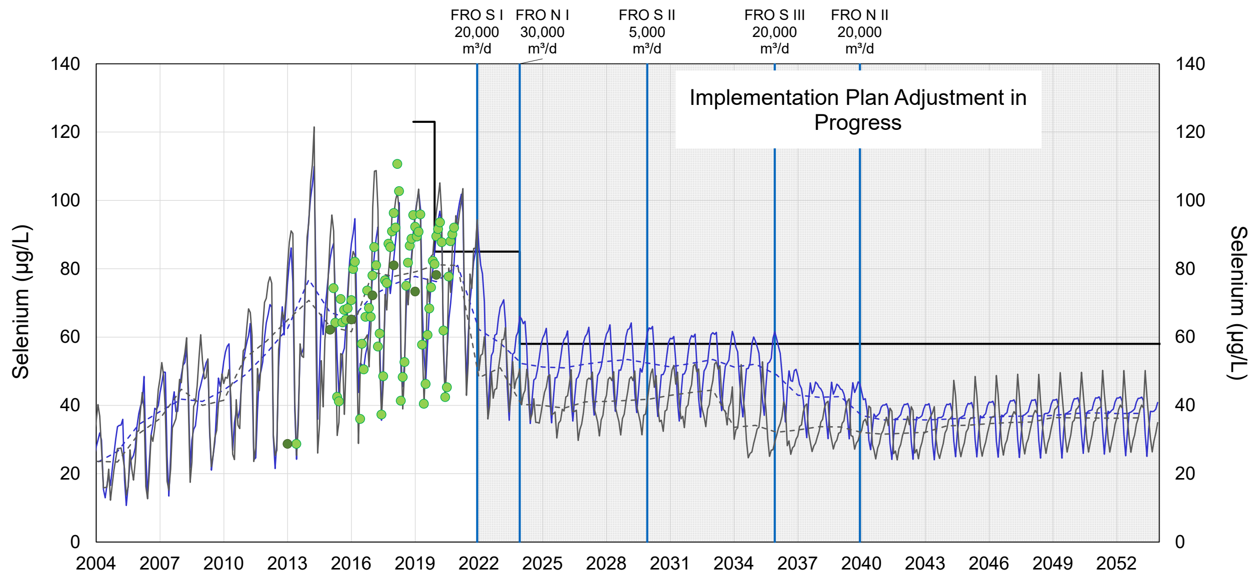
- explicit consideration of surface water – groundwater partitioning at tributary monitoring stations
- incorporation of variable hydraulic lag as it applies to new waste rock spoils, along with the presence of the immediately available initial soluble load
- updated methods to simulate waste rock flow

Explicit consideration of surface water – groundwater partitioning results in higher estimates of total yield in some tributaries, compared to those generated using only surface measured flow data (as was done in the 2017 RWQM Update). In most mine-influenced tributaries, constituent concentrations are similar to those in surface water, based on the evaluation of site-specific groundwater monitoring data. The similarly in constituent concentrations between surface and groundwater indicates that the constituent load released from waste rock mixes with the total yield (i.e., total flow) from a tributary catchment. Thus, as estimates of total yield increase, so must the estimated release rates from waste rock to replicate measured concentrations. Higher release rates produce higher estimates of future loading as more waste rock is added into tributary catchments, which can lead to higher than previously projected concentrations in the receiving environment.

Through the evaluation of the data collected from LCO Dry Creek and from monitoring locations downstream of the FRO North Spoil, it was determined that new spoils release constituent mass more quickly than previously assumed in the 2017 RWQM. In reflection of this new learning, a variable lag for new spoils was incorporated into the 2020 RWQM, whereby hydraulic lag times are initially short (i.e., 1 to 2 years) and increase over time as the spoils expand. The 2020 RWQM was also updated to account for the presence of initial soluble load that is created through pyrite oxidation occurring in newly blasted waste rock prior to placement in a spoil. Shorter hydraulic lag and the presence of initial soluble load result in constituent mass being released more quickly than previous estimated using the 2017 RWQM, which can result in higher constituent concentrations in the receiving environment sooner than would have previously been expected.

Water movement through waste rock is now modelled explicitly, and the methods used result in more of the total yield from waste rock being released in fall and winter and less in spring (see Annex B for details). In other words, in the 2020 RWQM, the dampening effect of waste rock spoils on the annual hydrograph is more pronounced than estimated using the 2017 RWQM, an effect supported by more recent flow data collected from Cataract Creek (see Annex B). This shift produces a commensurate change to the proportions of water in the river mainstems that originate from spoil areas versus non-mine affected areas, with a larger proportion of the fall and winter flow consisting of water originating from spoil areas; the larger proportion of mine-influenced water under lower flow conditions can result in higher projected selenium concentrations during those times of year, in comparison to projected concentrations developed using the 2017 RWQM.

(a) FRO Compliance Point (Fording River, 100 m u/s of Chauncey Creek) (FR_FRABCH; E223753)



(b) Fording River downstream of Line Creek (LC_LC5; 0200028)

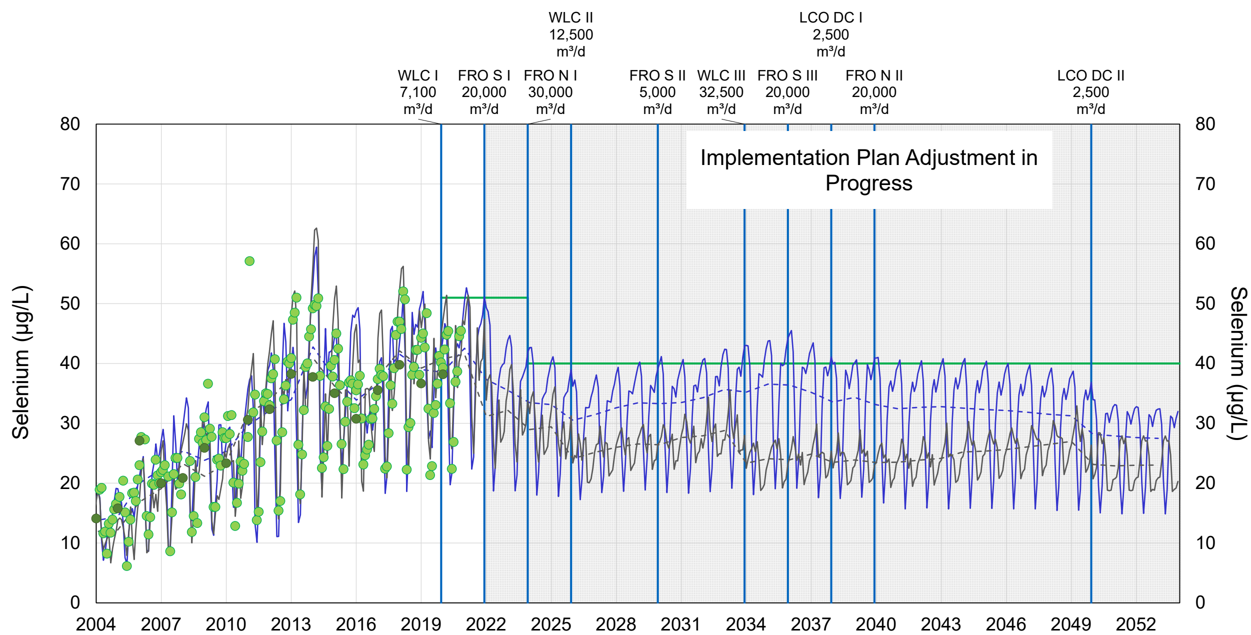
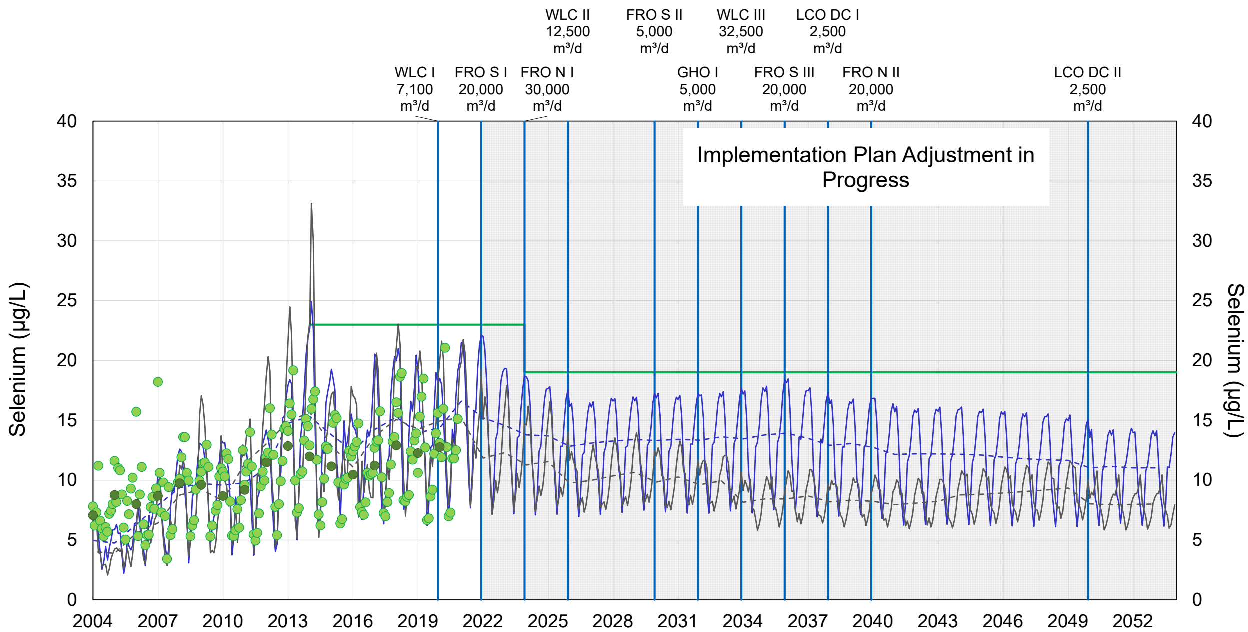


Figure 8.2 Projected Concentrations of Selenium at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2004-2053

(c) Elk River upstream of Grave Creek (EV_ER4; 0200027)



(d) Elk River downstream of Michel Creek (EV_ER1; 0200393)

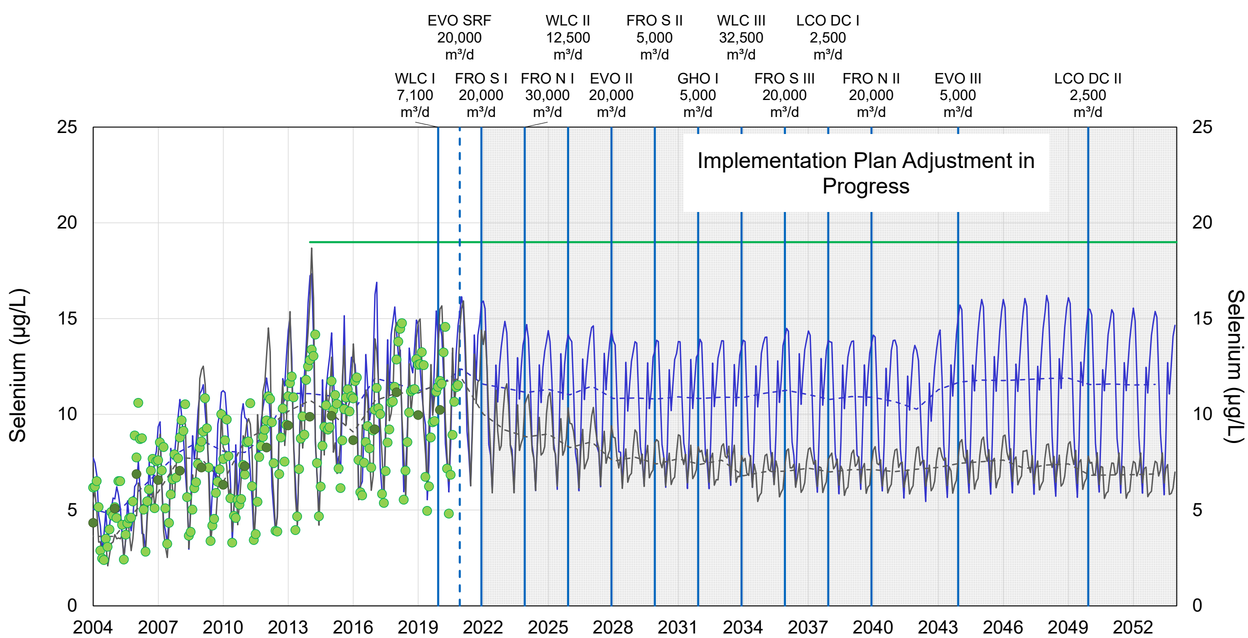


Figure 8-2 Projected Concentrations of Selenium at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2004-2053

The change to the methods used to simulate waste rock flow has a larger influence on the future projections than the incorporation of variable lag or consideration of surface water – groundwater partitioning, because it applies to all spoils. The other two updates are either spoil or catchment-specific, with a smaller influence on the overall system.

The above-noted changes affect selenium, sulphate and nitrate. However, their influence on projected nitrate concentrations is muted by the loss of nitrate from waste rock over time.

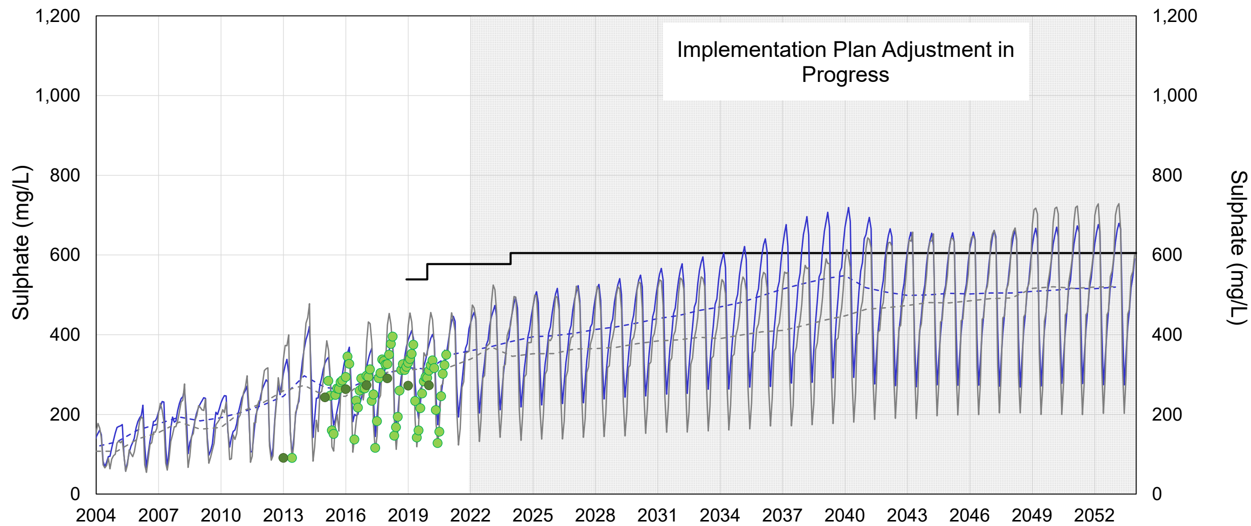
The mitigation included in the 2019 IPA was designed around the understanding that capturing and treating fall and winter flow volumes is an effective means to lower selenium concentrations in the receiving environment, but that additional gains were achieved through the treatment of early spring flow volumes. Thus, additional capacity is added over time to capture more and more of the initial spring flow when concentrations are projected (with the 2017 RWQM) to increase in mine-influenced water faster than runoff from non-mining areas is being generated.

Results produced using the 2020 RWQM continue to indicate that treating fall and winter flow volumes is an effective means to lower selenium concentrations in the receiving environment. However, due to the increased dampening of the annual hydrograph projected by the 2020 RWQM, the focus of subsequent phases of treatment may need to shift. To that end, mitigation planning will focus on maximizing the benefits of treatment facility operation through adjustments to timing and magnitude of facility inputs that is based on an optimized assessment of available sources that includes the collection of groundwater in catchments that are currently targeted for treatment.

8.3.3 Sulphate

As with selenium, projected sulphate concentrations produced using the 2020 RWQM tended to be higher than those produced using the 2017 RWQM (Figure 8-3, with additional plots included in Annex D). Factors contributing to the projected differences are the same as those outlined above for selenium, with the change to the methods used to simulate waste rock flows and accounting for surface water – groundwater partitioning being the primary drivers. The potential for these differences to influence the timing of sulphate treatment is being evaluated as work progresses on the next IPA.

(a) FRO Compliance Point (Fording River, 100 m u/s of Chauncey Creek) (FR_FRABCH; E223753)



(b) Fording River downstream of Line Creek (LC_LC5; 0200028)

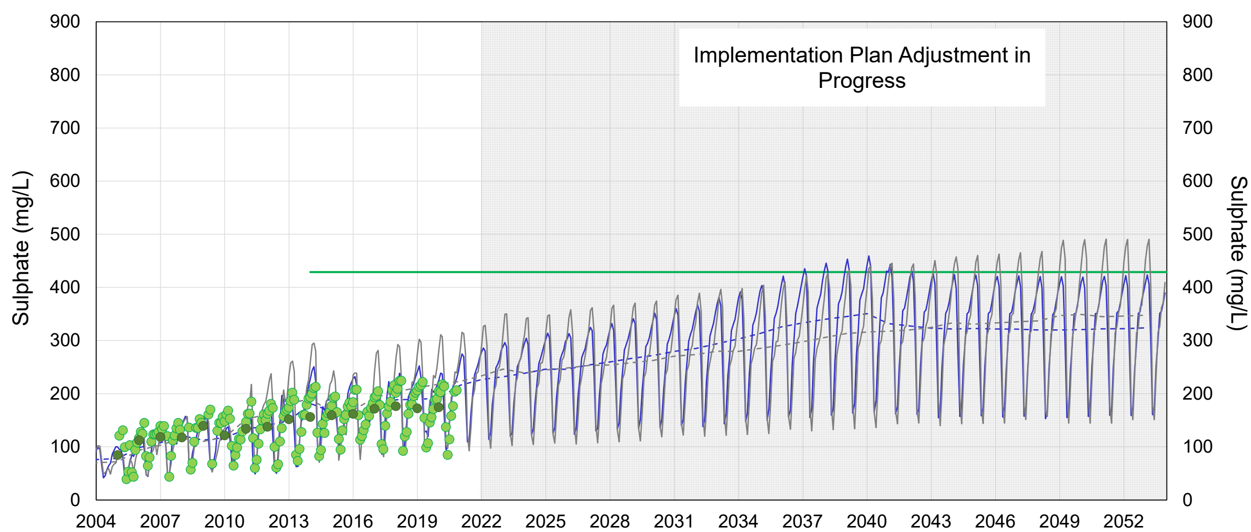
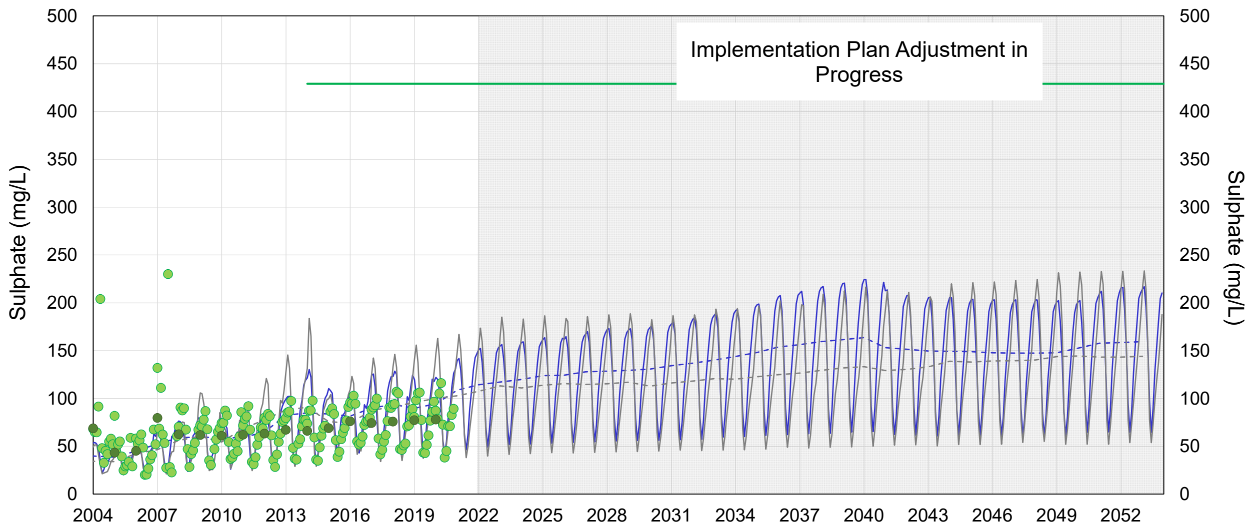


Figure 8-3 Projected Concentrations of Sulphate at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2004-2053

(c) Elk River upstream of Grave Creek (EV_ER4; 0200027)



(d) Elk River downstream of Michel Creek (EV_ER1; 0200393)

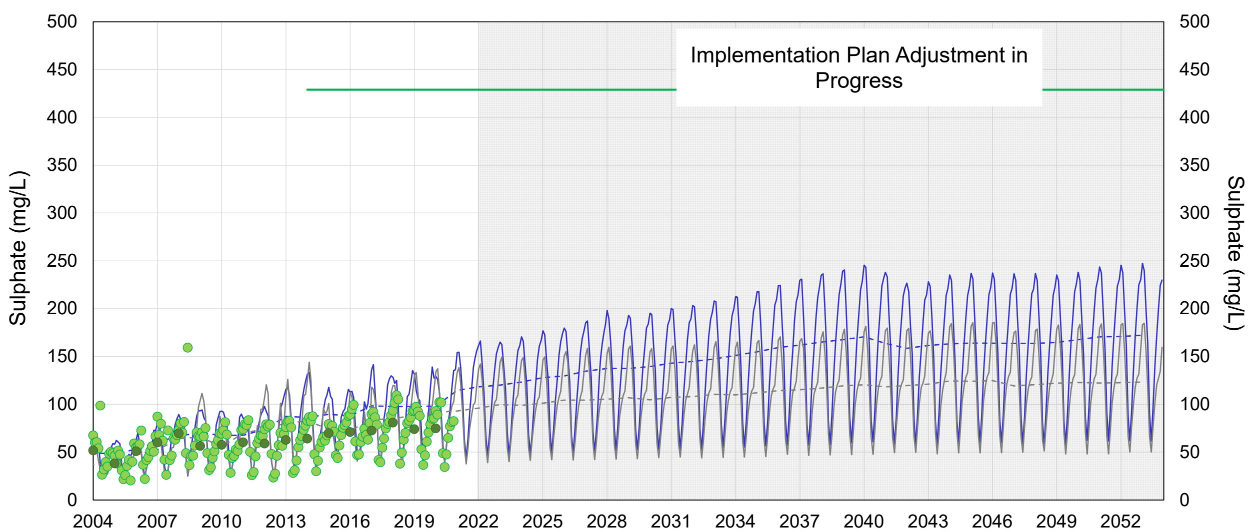


Figure 8-3 Projected Concentrations of Sulphate at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2004-2053

8.3.4 Cadmium

At most locations, projected dissolved cadmium concentrations produced using the 2020 RWQM were similar to or lower than those produced using the 2017 RWQM (Figure 8-4, with additional figures in Annex D). In the 2020 RWQM, cadmium production in waste rock spoils is linked to that of sulphate, and it is subject to the same bulk transport mechanisms. However, the 2020 RWQM also accounts for cadmium attenuation in and downstream of waste rock spoils. While the former process is implicitly accounted for in the 2017 RWQM (to some extent), the latter is not, and it more than offset changes to cadmium concentrations related to those factors outlined above with respect to selenium and sulphate (e.g., accounting for surface water – groundwater partitioning and increased waste rock flows in fall and winter).

The link in the 2020 RWQM between cadmium and sulphate production in waste rock spoils produced an increasing trend in projected cadmium concentrations that is not present in the monitored data. The presence of this trend suggests that cadmium projections developed with the 2020 RWQM are likely overestimates and should be considered with this limitation in mind.

(a) FRO Compliance Point (Fording River, 100 m u/s of Chauncey Creek) (FR_FRABCH; E223753)

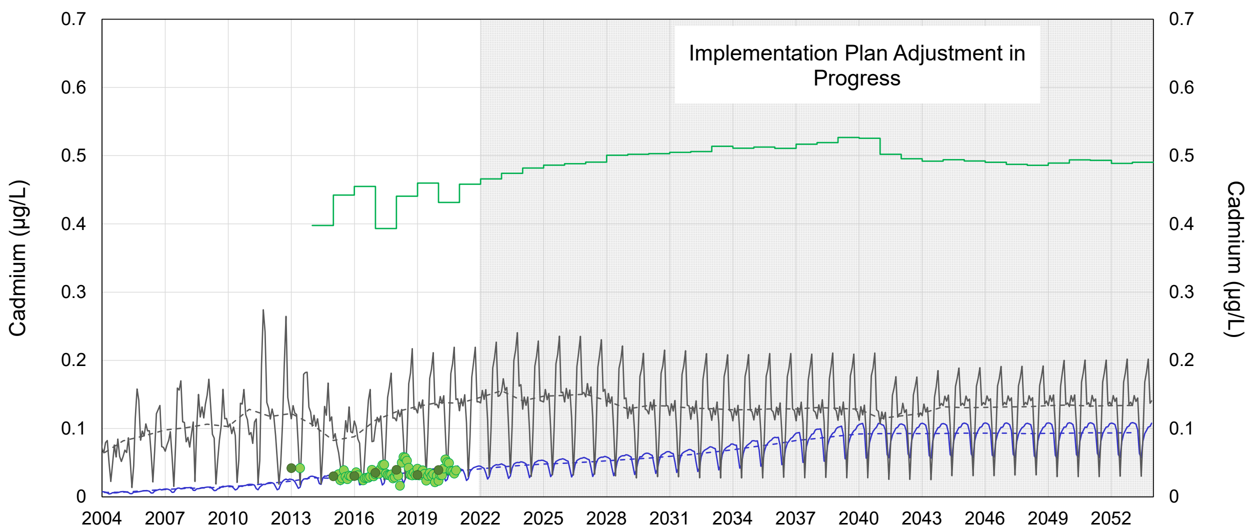
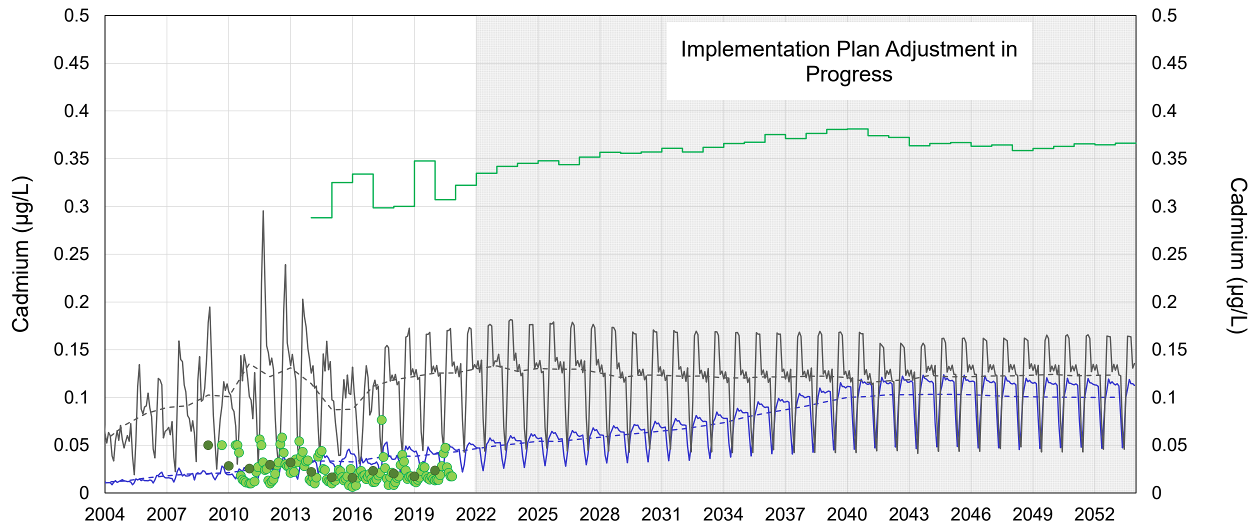


Figure 8-4 Projected Concentrations of Dissolved Cadmium at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2004-2053

(b) Fording River downstream of Line Creek (LC_LC5; 0200028)



(c) Elk River upstream of Grave Creek (EV_ER4; 0200027)

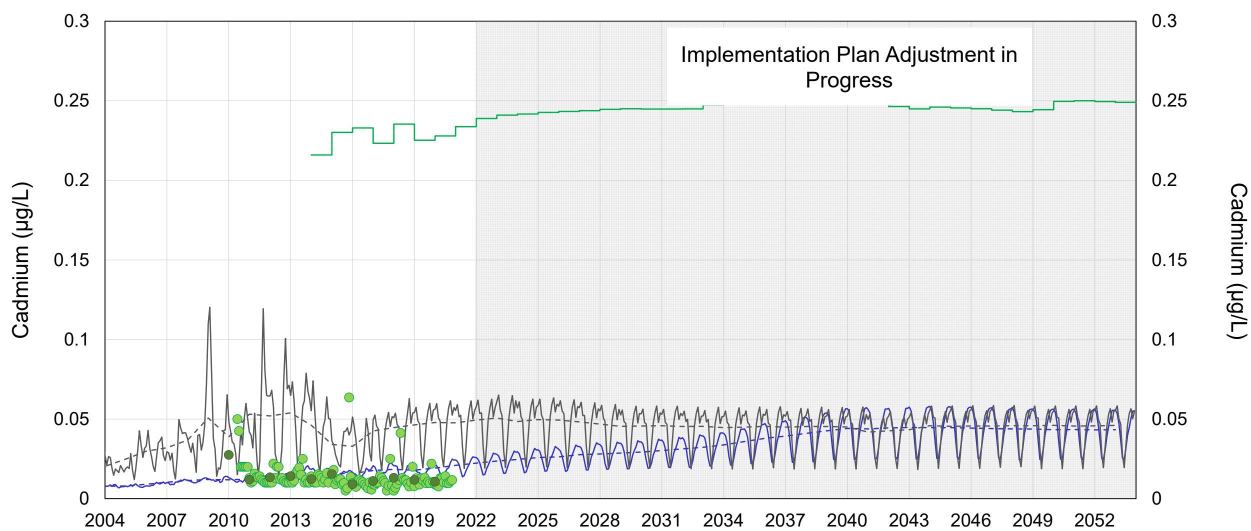


Figure 8-4 Projected Concentrations of Dissolved Cadmium at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2004-2053

(d) Elk River downstream of Michel Creek (EV_ER1; 0200393)

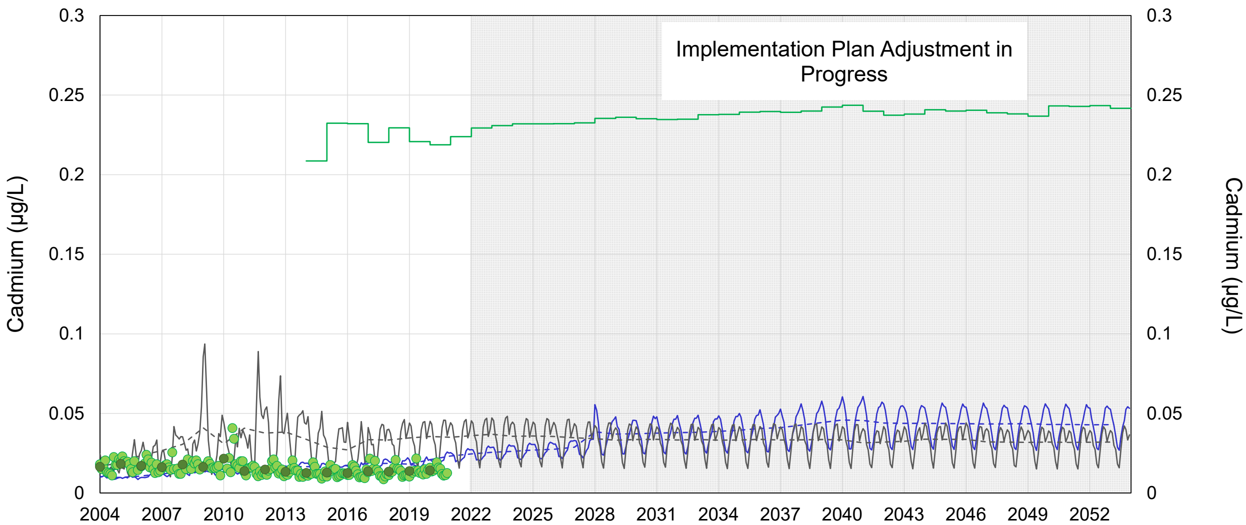


Figure 8-4 Projected Concentrations of Dissolved Cadmium at Two Locations in Each of the Fording River and Elk River Mainstems With Consideration of Mitigation, 2004-2053

8.4 Sensitivity Analysis

8.4.1 Variations in Climate

The 2020 RWQM is climate-driven, and future projections are developed using climate information from 2000 to 2019, as noted in Section 8.2. The climate information is run repeatedly through the model, so that each year in the future simulation period experiences climate conditions equivalent to those recorded from 2000 to 2019. This approach results in 20 individual estimates of flow and constituent concentration for each week of each future year. The individual weekly estimates are used to calculate temporally-connected monthly and annual average concentrations within each realization. The resulting monthly and annual average datasets are summarized by calculating median (P50), 10th percentile (P10) and 90th percentile (P90) values across the 20 realizations for each future month and each future year.

The sensitivity of future projections to variations in climate was evaluated by comparing P50, P10 and P90 results at the following mainstem locations:

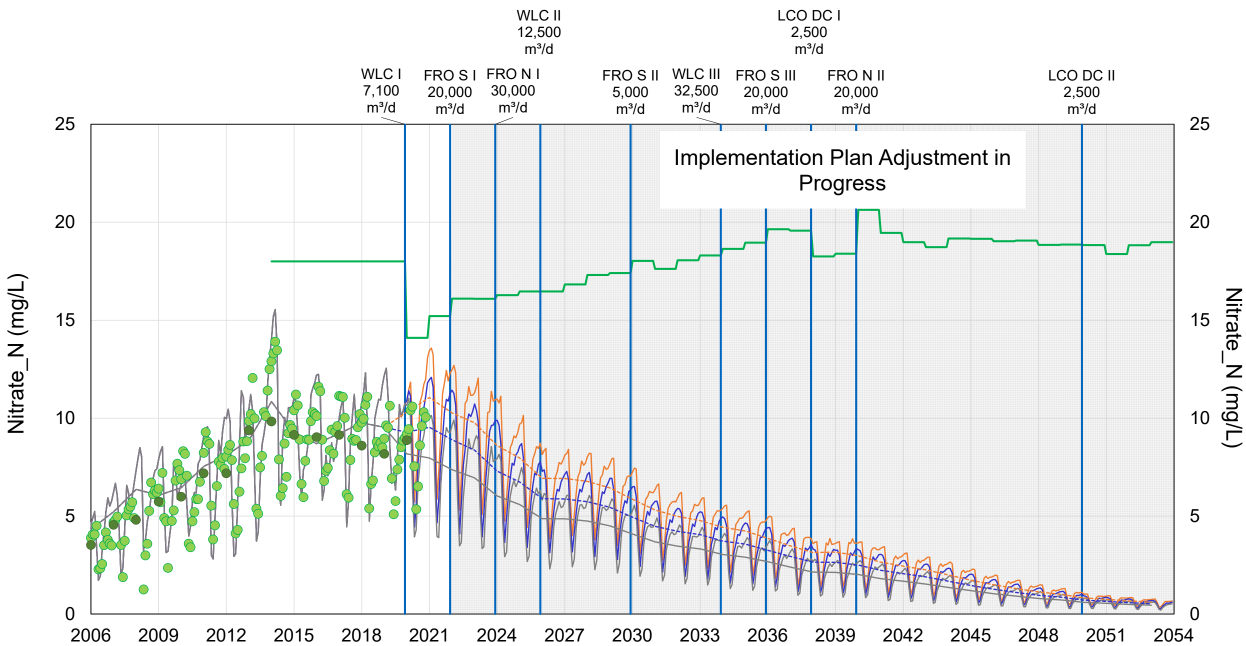
- Fording River downstream of Line Creek (LC_LC5; 0200028)
- Elk River upstream of Grave Creek (EV_ER4; 0200027)
- Elk River downstream of Michel Creek (EV_ER1; 0200393)

Although consistent downward trends were present in all three projected nitrate timeseries across all three locations (Figure 8-5), differences between projected P50 versus P90 or P10 nitrate concentrations were variable over the future simulation period. They were typically larger towards the start of the future simulation period, diminishing over time as projected P50, P90 and P10 concentrations moved towards a common endpoint, reflective of the leaching and gradual disappearance of nitrate source material.

Differences between projected peak monthly average P50 and P90 selenium concentrations were in the order of 8 to 24% across all three locations (Figure 8-6). Differences between projected peak monthly average P50 and P10 selenium concentrations across all three locations were typically higher, in the order of 12 to 25%.

Differences between projected peak monthly average P50 and P90 sulphate concentrations were in the order of 9 to 21%, as were those between projected peak monthly average P50 and P10 sulphate concentrations across all three locations (Figure 8-7). The influence of climate on future projected water quality will be taken into consideration as the IPA is updated.

(a) Fording River downstream of Line Creek (LC_LC5; 0200028)



(b) Elk River upstream of Grave Creek (EV_ER4; 0200027)

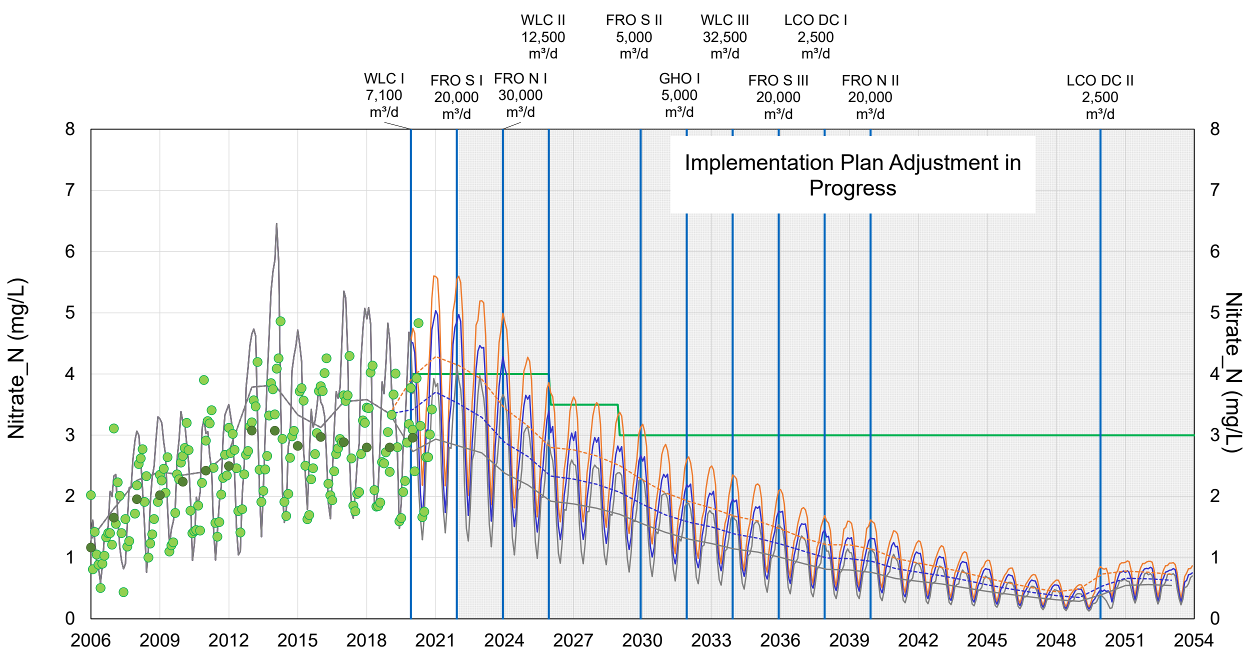
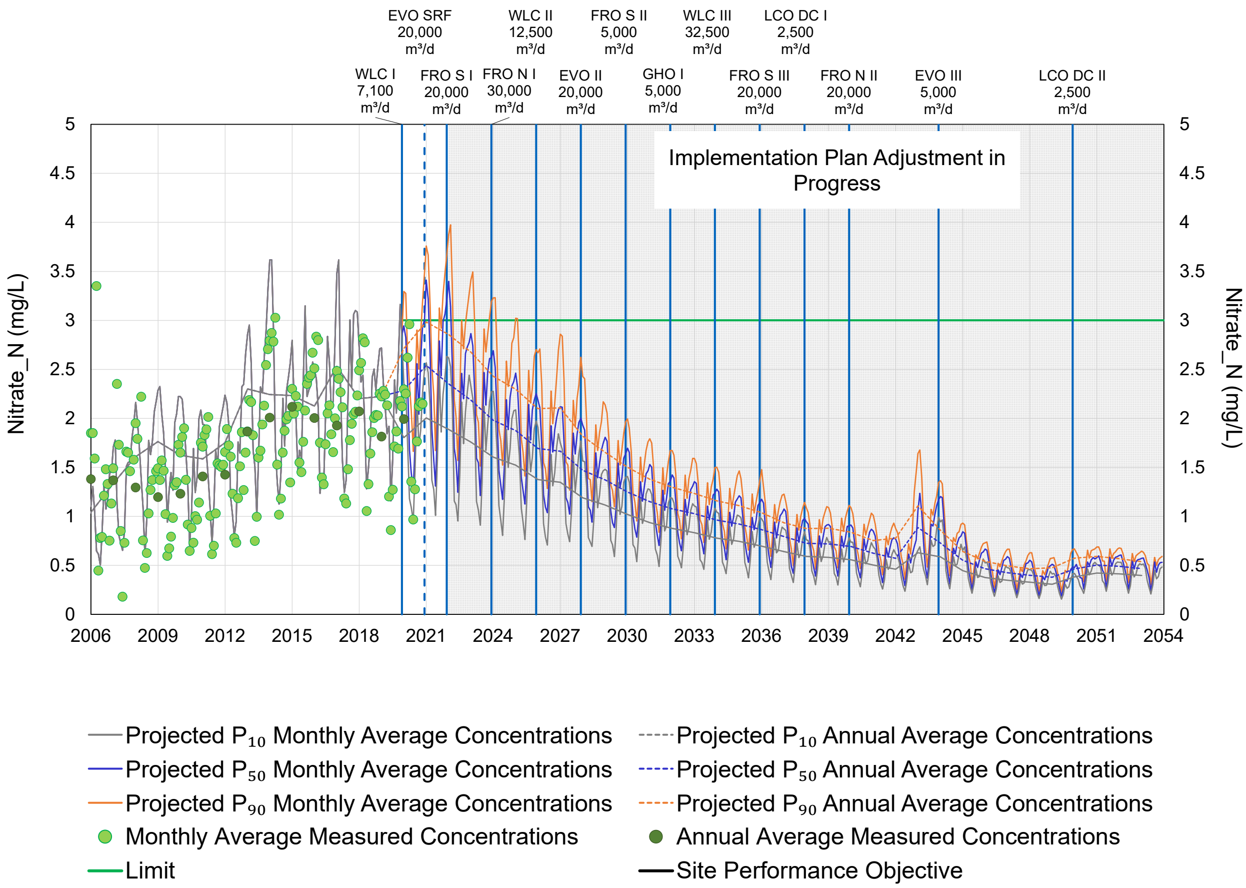


Figure 8-5 Projected Concentrations of Nitrate in the Fording River Downstream of Line Creek and in the Elk River Upstream of Grave Creek and Downstream of Michel Creek under Variable Climate Conditions, 2006-2053

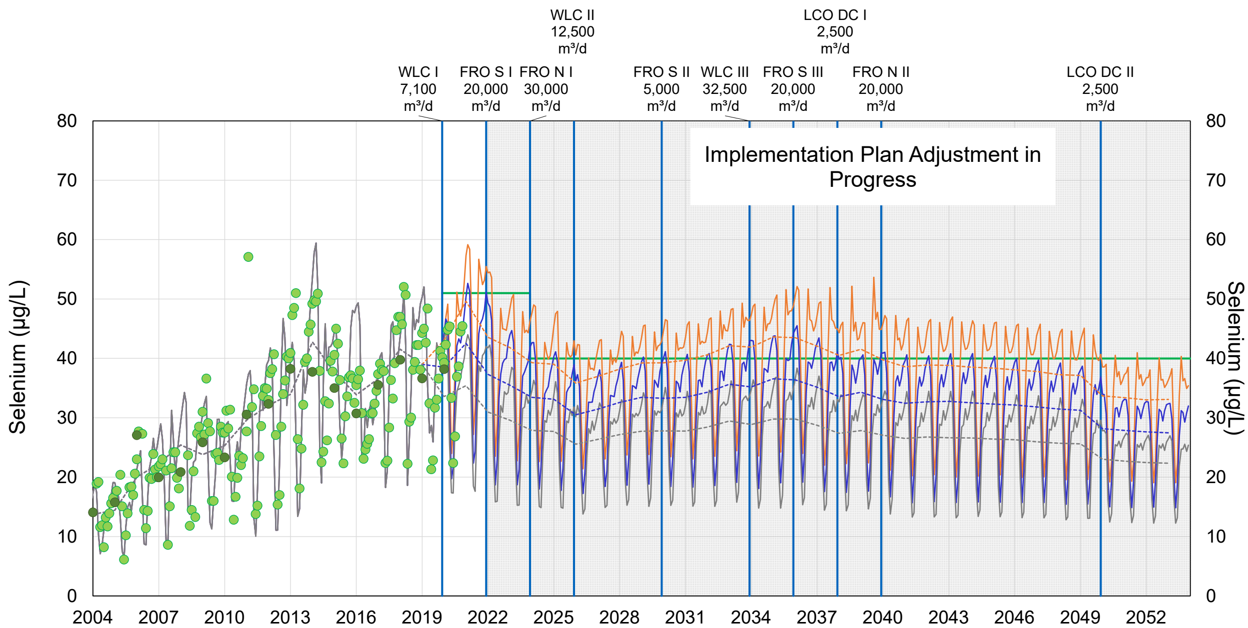
(c) Elk River downstream of Michel Creek (EV_ER1; 0200393)



Note: Simulated concentrations from 2004 to 2019 were generated using measured climate data; projected concentrations from 2020 onward were generated using climate data from 2000 to 2019, run repeatedly through the model.

Figure 8-5 Projected Concentrations of Nitrate in the Fording River Downstream of Line Creek and in the Elk River Upstream of Grave Creek and Downstream of Michel Creek under Variable Climate Conditions, 2006-2053

(a) Fording River downstream of Line Creek (LC_LC5; 0200028)



(b) Elk River upstream of Grave Creek (EV_ER4; 0200027)

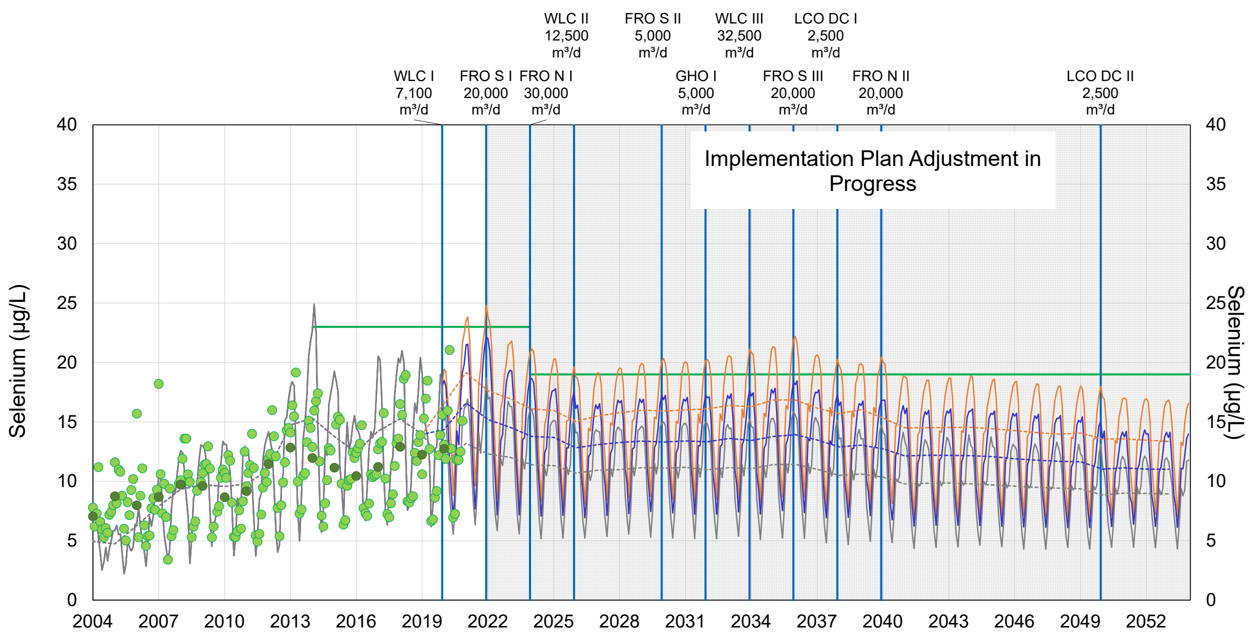
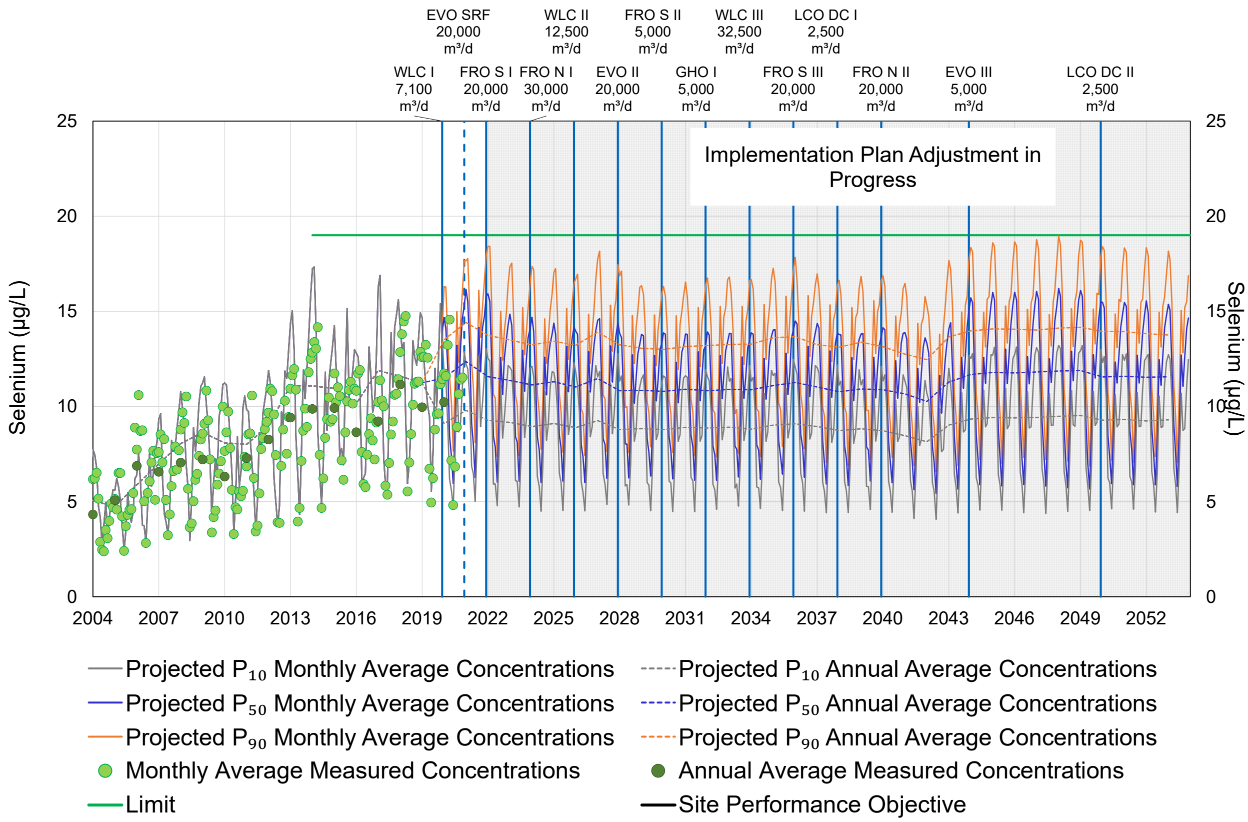


Figure 8-6 Projected Concentrations of Selenium in the Fording River Downstream of Line Creek and in the Elk River Upstream of Grave Creek and Downstream of Michel Creek under Variable Climate Conditions, 2004-2053

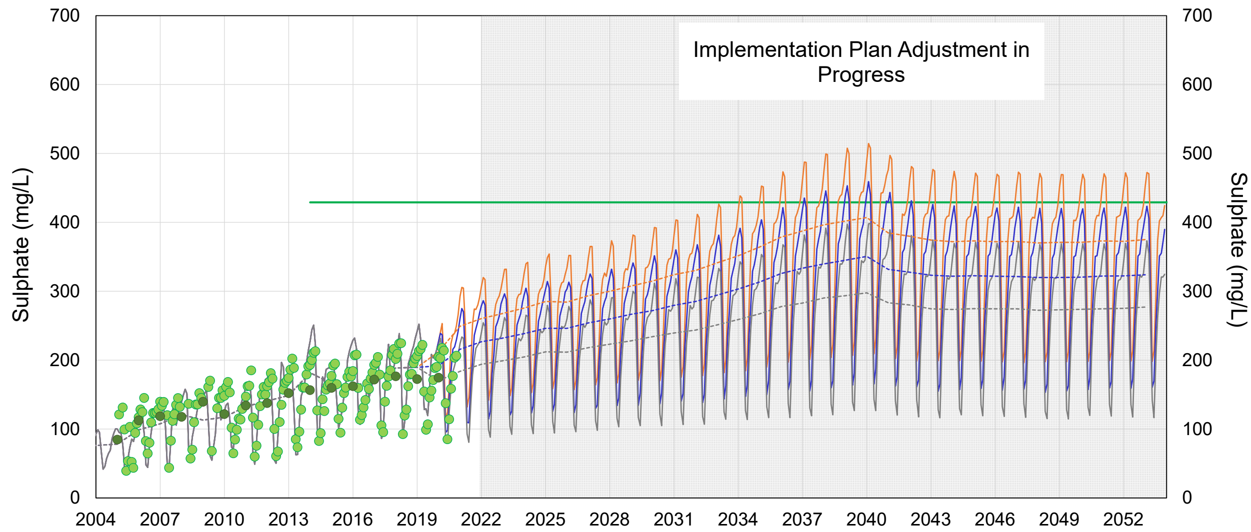
(c) Elk River downstream of Michel Creek (EV_ER1; 0200393)



Note: Simulated concentrations from 2004 to 2019 were generated using measured climate data; projected concentrations from 2020 onward were generated using climate data from 2000 to 2019, run repeatedly through the model.

Figure 8-6 Projected Concentrations of Selenium in the Fording River Downstream of Line Creek and in the Elk River Upstream of Grave Creek and Downstream of Michel Creek under Variable Climate Conditions, 2004-2053

(a) Fording River downstream of Line Creek (LC_LC5; 0200028)



(b) Elk River upstream of Grave Creek (EV_ER4; 0200027)

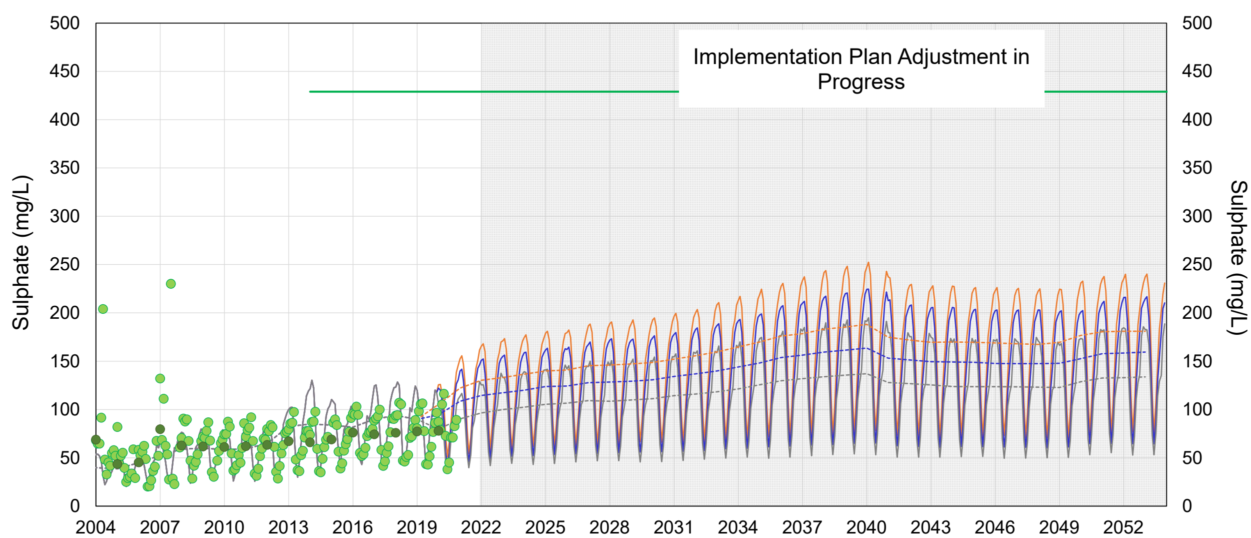
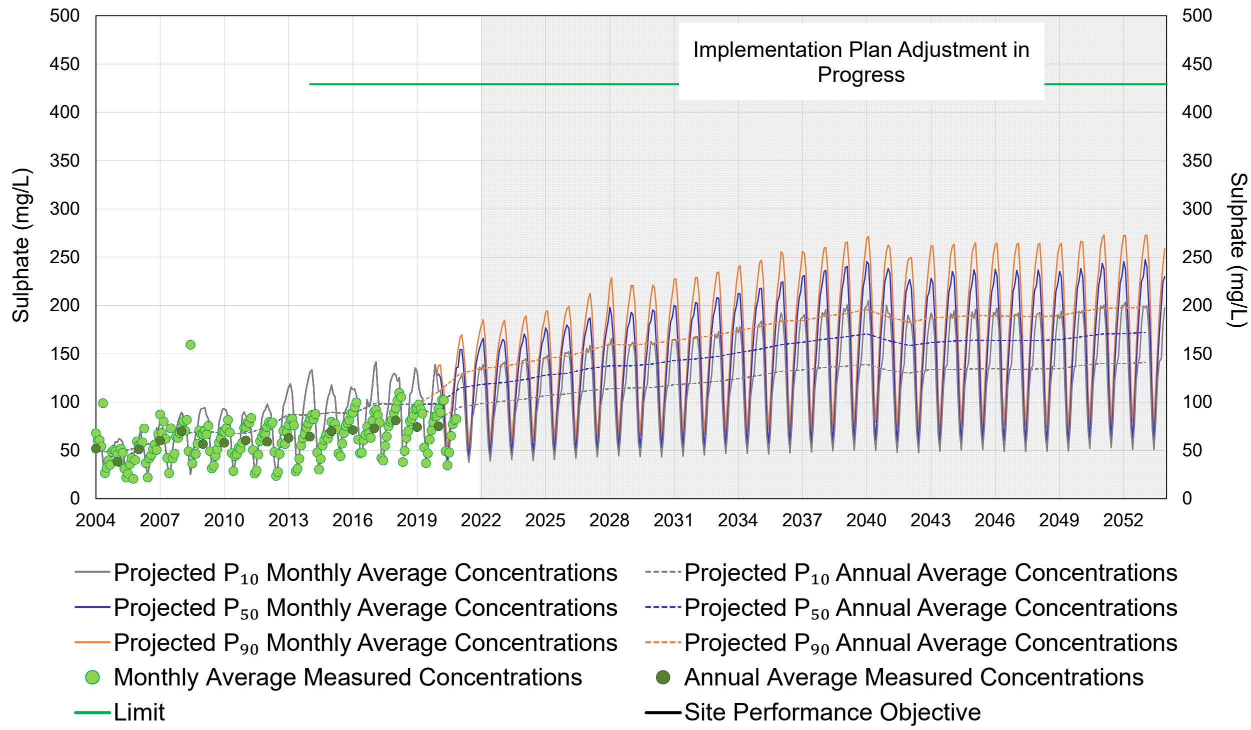


Figure 8-7 Projected Concentrations of Sulphate in the Fording River Downstream of Line Creek and in the Elk River Upstream of Grave Creek and Downstream of Michel Creek under Variable Climate Conditions, 2004-2053

(c) Elk River downstream of Michel Creek (EV_ER1; 0200393)



Note: Simulated concentrations from 2004 to 2019 were generated using measured climate data; projected concentrations from 2020 onward were generated using climate data from 2000 to 2019, run repeatedly through the model.

Figure 8-7 Projected Concentrations of Sulphate in the Fording River Downstream of Line Creek and in the Elk River Upstream of Grave Creek and Downstream of Michel Creek under Variable Climate Conditions, 2004-2053

8.4.2 Changes to Model Inputs Related to Blasting

Lining of blast holes began in 2017 at Teck's operations in the Elk Valley, the purpose of which is to limit the loss of explosives prior to blasting. Limiting the loss of explosives reduces the amount of explosive residual associated with freshly blasted waste rock, which, in turn, reduces the release of nitrate from waste rock spoils.

The 2020 RWQM accounts for the use of liners, as per the methods outlined in Annex C. From 2017 onward, liners are assumed to be present in some proportion of blast holes as defined by historical loading information and mine plans. Their effectiveness at preventing the loss of explosives prior to blasting is modelled as 50%, a value informed by field investigations (see Annex A for details). A sensitivity analysis was undertaken to understand how changes to this value affect projected concentrations of nitrate. Values considered in the analysis were 0% (no loss prevention), 20% (a lower degree of loss prevention), and 90% (a higher degree of loss prevention more closely aligned with Teck's goals). This analysis was conducted with a focus on the following locations:

- Kilmarnock Creek downstream of the Rock Drain (FR_KC1; 0200252)
- GHO Fording River Compliance Point (GH_FR1; 0200378)

The former location was selected, because the waste rock spoil in Kilmarnock Creek is one of the largest sources of nitrate amongst spoils in the Elk Valley; it is also an established spoil, which continues to receive waste rock. Thus, model projections for this location can be used to identify how the use of liners from 2017 onward may influence nitrate leaching from older spoils.

The latter location was selected, because it is situated downstream of older established spoils and more recently established newer spoils, where changes to blasting practices are expected to have a more immediate effect on nitrate leaching. Thus, projections at the GHO Fording River Compliance Point provide insight into the potential net effect of how changes to blasting practices may potentially affect future nitrate concentrations in the receiving environment.

This sensitivity analysis was conducted using P50 flows, rather than running the WQC through 20 complete realizations for each alteration to the assumption around liner effectiveness. This approach was adopted for computational simplicity and to speed the execution of the analysis.

Projected nitrate concentrations in Kilmarnock Creek, assuming liner effectiveness of 0% and 20%, were similar to or higher than those with a liner effectiveness of 50% (Figure 8-8). The overall downward trajectory remained unchanged, but projected annual peak concentrations were up to 4.9 mg/L (or 37%) higher than those projected to occur with a liner effectiveness of 50%. When liner effectiveness was increased from 50% to 90%, projected monthly average nitrated concentrations were in the order of 3.9 mg/L (or 29%) lower than those projected to occur with a liner effectiveness of 50%. In all cases, the differences were most apparent between 2031 and 2036, after projected nitrate concentrations had appreciably declined from those recently measured.

At the GHO Fording River Compliance Point, the influence of liner effectiveness was more apparent, at least in terms of relative change. With a liner effectiveness of 0%, projected monthly average nitrate concentrations were up to 2.5 mg/L (or 52%) higher than those generated assuming a liner effectiveness of 50% (Figure 8-8). With a liner effectiveness of 90%, projected monthly average nitrate concentrations were in the order of 2.0 mg/L (or 40%) lower than those generated assuming a liner effectiveness of 50%. In both cases, the differences were apparent over a larger proportion of the simulation period.

(a) Kilmarnock Creek downstream of the Rock Drain (FR_KC1; 0200252)

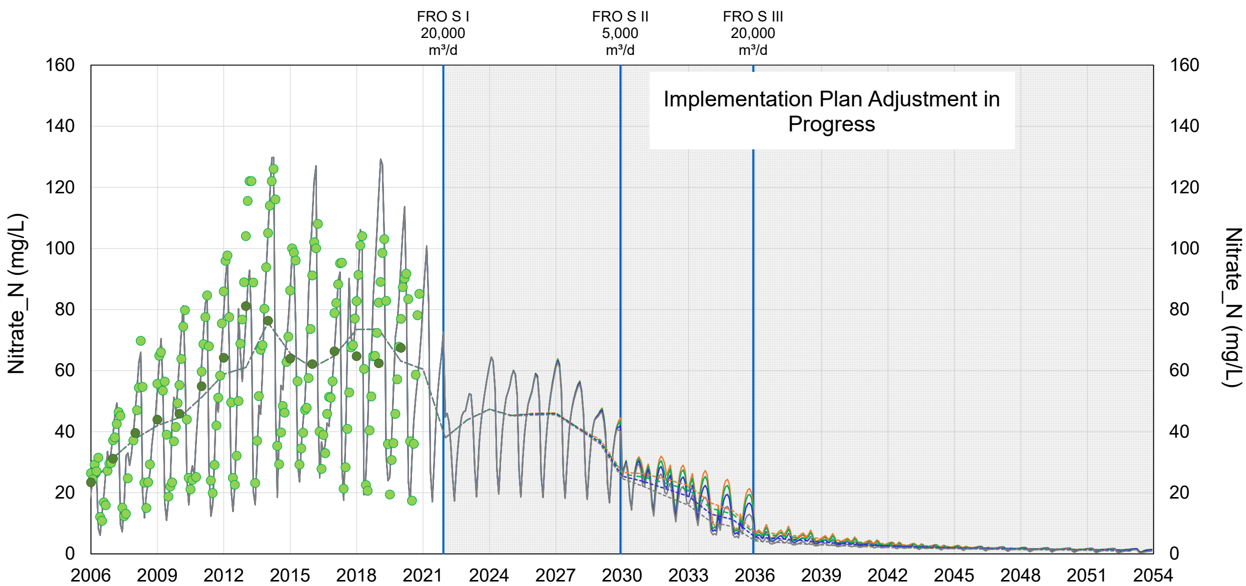
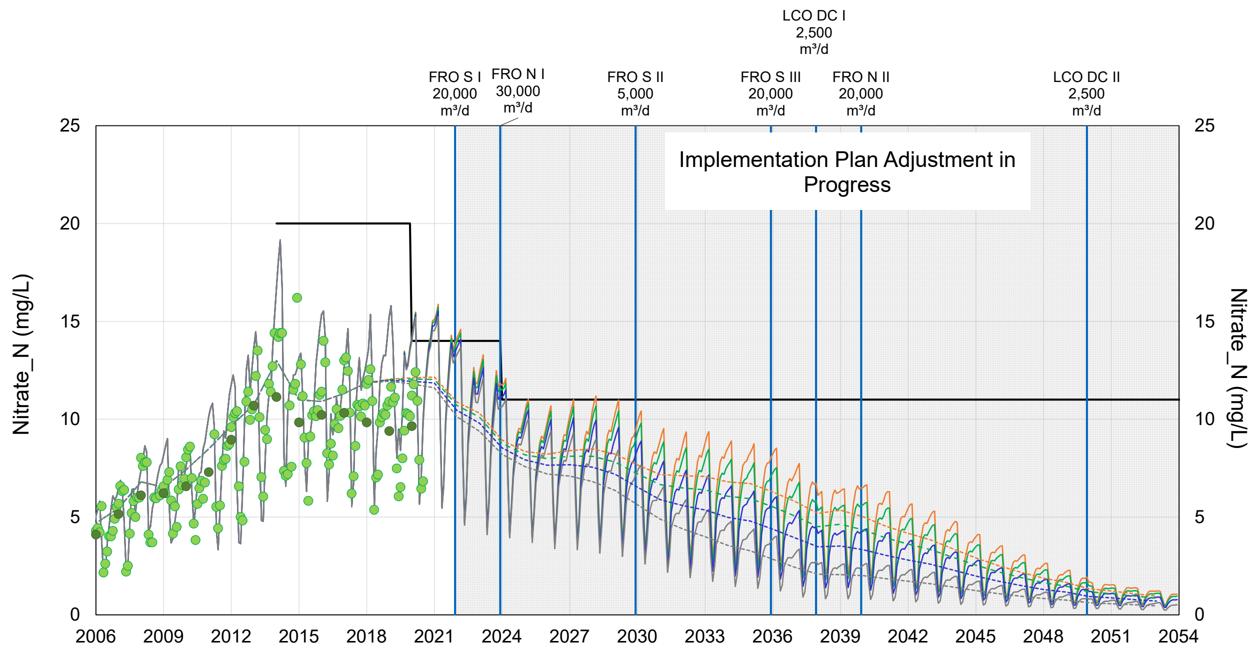


Figure 8-8 Projected Concentrations of Nitrate in Kilmarnock Creek downstream of the Rock Drain and at the GHO Fording River Compliance Point Assuming Different Rates of Liner Effectiveness, 2004-2053

(b) GHO Fording River Compliance Point (GH_FR1; 0200378)



Note: Simulated concentrations from 2004 to 2019 were generated using measured climate data; projected concentrations from 2020 onward were generated using P50 flows.

Projected Monthly Average Concentrations - Liner Effectiveness 0%
Projected Annual Average Concentrations - Liner Effectiveness 0%
Projected Monthly Average Concentrations - Liner Effectiveness 20%
Projected Annual Average Concentrations - Liner Effectiveness 20%
Projected Monthly Average Concentrations - Liner Effectiveness 50%
Projected Annual Average Concentrations - Liner Effectiveness 50%
Projected Monthly Average Concentrations - Liner Effectiveness 90%
Projected Annual Average Concentrations - Liner Effectiveness 90%
Monthly Average Monitored Concentrations
Annual Average Monitored Concentrations
Site Performance Objective
Limit

Figure 8-8 Projected Concentrations of Nitrate in Kilmarnock Creek downstream of the Rock Drain and at the GHO Fording River Compliance Point Assuming Different Rates of Liner Effectiveness, 2004-2053

8.4.3 Changes to Model Inputs Related to Selenium and Sulphate Release Rates

Results from longer-term humidity cell tests indicate that selenium and sulphate release rates from waste rock decline over time as sulphide minerals are depleted, as discussed in Annex A. The decline tends to follow first order decay kinetics. The 2020 RWQM includes functionality to maintain selenium and sulphate release rates unchanged over the entire simulation period or to allow the release rates to decline over time, on a sub-catchment by sub-catchment basis, once spoiling in a given area has effectively stopped. The 2020 RWQM has been calibrated and future projections generated assuming no decline in selenium and sulphate release rates over time.

A sensitivity analysis was undertaken to identify how future projections could change with consideration of decay. Three rates of decay were evaluated. They are referred to as Decay Rate 1, 2 and 3, and are defined as outlined in Annex A. This evaluation was conducted with a focus on West Line Creek, with decay set to start January 1, 2000.

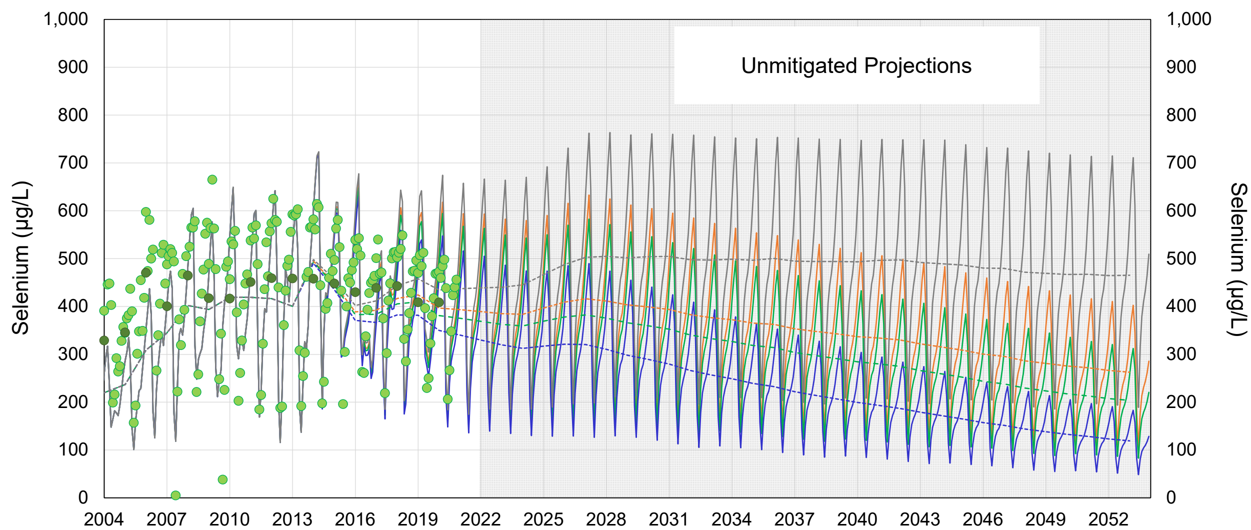
West Line Creek is a waste-rock dominated catchment, wherein spoiling was largely finished by the end of 1999. More specifically, approximately 90% of the 214 million BCM of waste rock currently residing in West Line Creek was placed into this catchment by December 31, 1999. The hydraulic lag in this catchment has been estimated at 14 years. Thus, if changes in selenium and sulphate release are occurring, their influence should be reflected in the monitoring data collected from this catchment after the bulk of the waste rock has been placed and the hydraulic lag has passed (i.e., from 2014 onward), which provides a point of reference from which to interpret the results of the sensitivity analysis.

This sensitivity analysis, similar to that conducted on liner effectiveness, was conducted using P50 flows, rather than running the WQC through 20 complete realizations for each alteration to the assumption around liner effectiveness.

Application of first order decay to sulphate and selenium release rates resulted in lower projected concentrations of both constituents in West Line Creek towards the end of the 2004 to 2019 model calibration period and through the future simulation period (Figures 8-9 and 8-10). Overall model performance for selenium improved with the application of the decay function. Peak modelled monthly average selenium concentrations typically matched peak measured monthly average concentrations more closely from 2015 through 2019 with the application of decay (Figure 8-9). A greater level of improvement was achieved with Decay Rate 3, compared to that achieved with the other two rates. Modelled and measured annual average selenium concentrations tended to match more closely when Decay Rate 1 was applied, because it resulted in less underprediction of monthly average freshet concentrations compared to that which occurred when applying Decay Rate 3 to 2. That said, conditions during freshet are not those that typically drive mitigation planning or assessment of potential effects.

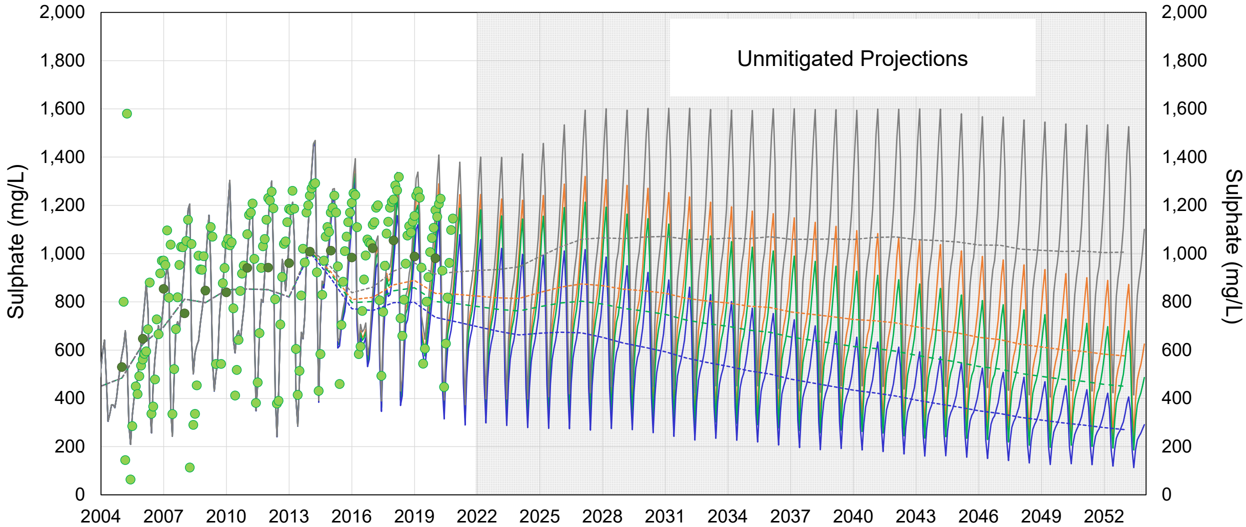
Improvements in model performance were also apparent for sulphate when the decay functionality was applied, although they were less pronounced than those observed with selenium (Figure 8-10). Peak modelled monthly average sulphate concentrations tended to match peak measured monthly average concentrations more closely from 2015 through 2019 with the application of the decay function. However, application of decay did not improve the ability of the model to replicate annual average sulphate concentrations.

Taken together, these results would suggest that further exploration and application of decay is warranted, with a focus on completed or nearly completed spoils.



Note: Simulated concentrations from 2004 to 2019 were generated using measured climate data; projected concentrations from 2020 onward were generated using P50 flows.

Figure 8-9 Projected Concentrations of Selenium in West Line Creek With and Without Consideration of First Order Decay in Selenium Release Rates, 2004-2053



Note: Simulated concentrations from 2004 to 2019 were generated using measured climate data; projected concentrations from 2020 onward were generated using P50 flows.

- Projected Monthly Average Concentrations - No Decay
- Projected Monthly Average Concentrations - Decay Rate 1
- Projected Monthly Average Concentrations - Decay Rate 2
- Projected Monthly Average Concentrations - Decay Rate 3
- Monthly Average Monitored Concentrations
- Projected Annual Average Concentrations - No Decay
- Projected Annual Average Concentrations - Decay Rate 1
- Projected Annual Average Concentrations - Decay Rate 2
- Projected Annual Average Concentrations - Decay Rate 3
- Annual Average Monitored Concentrations

Figure 8-10 Projected Concentrations of Sulphate in West Line Creek With and Without Consideration of First Order Decay in Sulphate Release Rates, 2004-2053

9 Adaptive Management

9.1 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. The AMP includes a six stage Adaptive Management (AM) cycle (Figure 9-1) that will be used to guide updates to the 2019 IPA. Outlined below is a description of how the RWQM will be used 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.

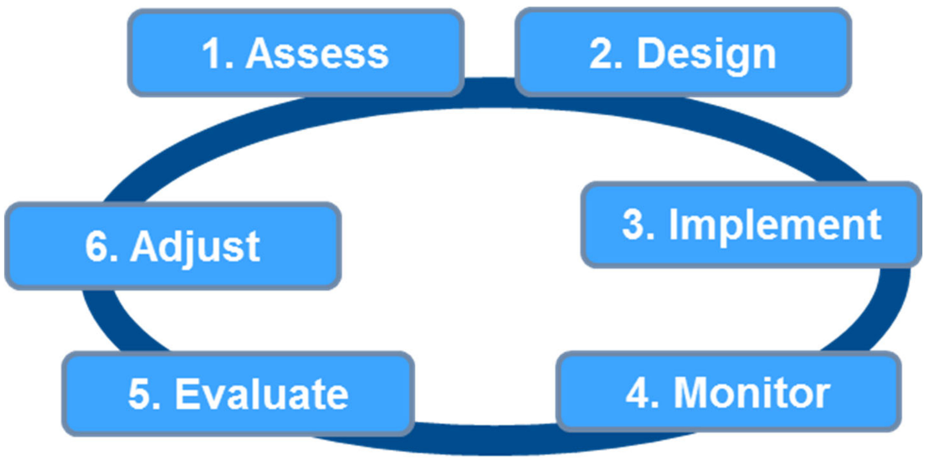


Figure 9-1: The Six Stage Cycle of Adaptive Management

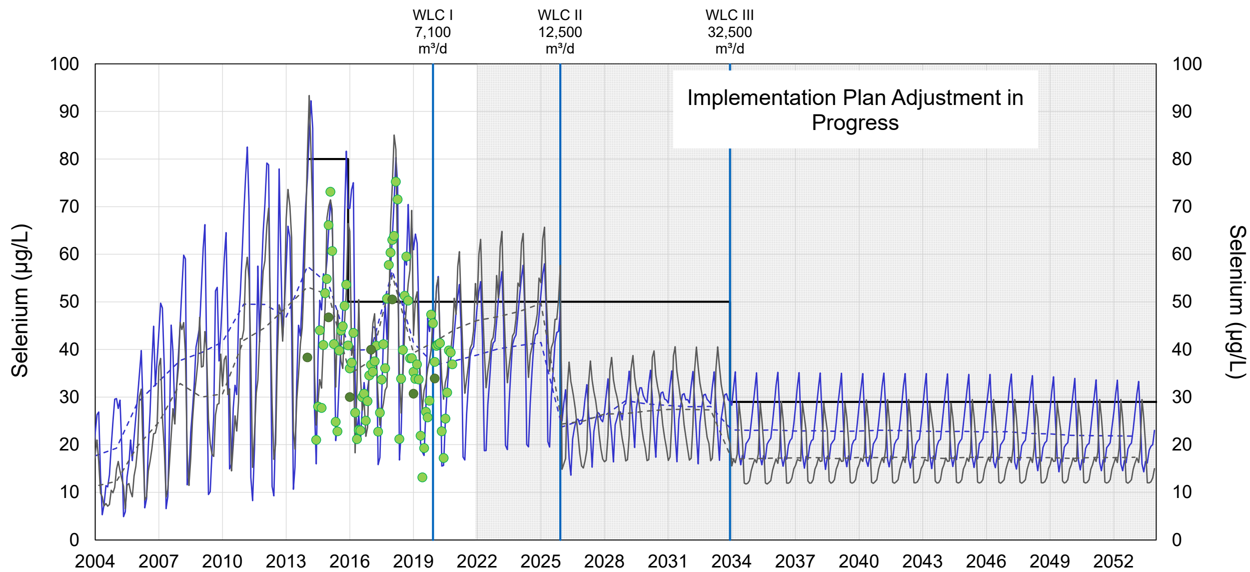
9.2 Management Question 1: Will limits and SPOs be met for selenium, sulphate, nitrate, and cadmium?

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 the move to a climate-driven (vs. analogue hydrograph) approach to hydrology modelling, refined source terms and incorporation of updated groundwater information has contributed to updated RWQM projections that reflect new learnings since the 2017 RWQM and 2019 IPA. These learnings are incorporated into the calibration and projections. The projections have been evaluated, and it has been identified that there are locations and seasons where projected concentrations are above SPOs or compliance limits. This finding indicates a need to adjust mitigation. The next step towards the next IPA is the submission of the 2020 RWQM update (this submission), allowing for the appropriate review of the updated tool, which is consistent with Stage 5 (Evaluate) of the Adaptive Management cycle. Updates to the IPA will be documented in a separate submission. This approach is consistent with working through Stage 6 of the Adaptive Management cycle and adjusting to new information from the Evaluation Stage.

Planning assumptions that will be incorporated in the next IPA will be reviewed in consultation with ENV, EMLI and KNC. Expected adjustments include, but are not limited to, changes to the sources targeted for treatment and/or updates the timing, sizing and location of selected mitigation measures, as well as the type of technology employed. An example of the type of adjustments that will be evaluated in the next IPA is shown on Figure 9-2. In this example, the tributary sources that are directed to treatment at Line Creek have been adjusted to prioritized groundwater collection at West Line Creek over collection of additional surface water in Line Creek. While there is still uncertainty associated with current estimates of groundwater bypassing the West Line Creek intake structure, this adjustment in the model results in increased load removal and improvements in projected water quality at the LCO Compliance Point with a decreased overall treatment capacity.. A review of where these types of adjustments may improve projected water quality will be completed for the next IPA.

(a) Based on 2019 IPA



(b) With Modification to 2019 IPA

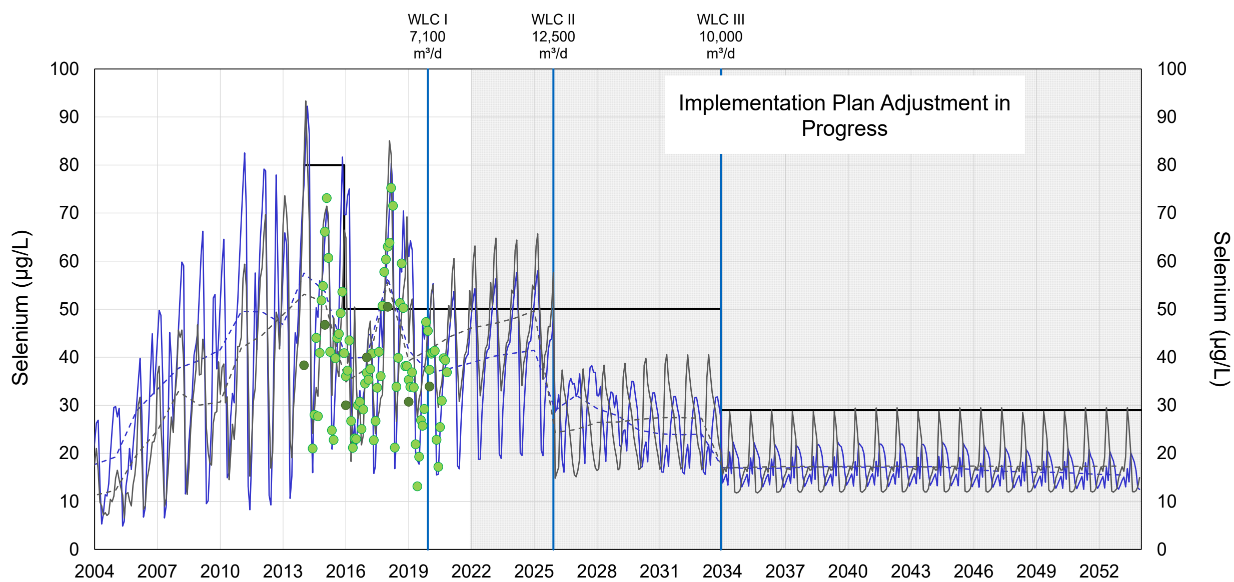


Figure 9-2: Example of Potential Adjustments in the Next IPA: Collection and Treatment of Groundwater at Line Creek Operation starting in 2026.

9.3 Key Uncertainties

Under Management Question 1, 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 (KU) 1.2 is an ongoing continuous improvement component of the three-year water quality model update, with the following four underlying uncertainties (UU):

UU1.2.1. Can operational information be used to improve source terms?

UU 1.2.2. Can the RWQM be improved in specific catchments where mitigation decisions are required and uncertainty is high?

UU 1.2.3. How may selenium and sulphate release rates change over time?

UU 1.2.4. What mechanisms are causing the reduction in mass observed between tributaries and at monitoring stations in the main stems?

Reduction of these uncertainties was a focus for the 2020 RWQM Update. The following section describes how each underlying uncertainty was reduced through work completed prior to and through the 2020 RWQM update well as remaining uncertainties that will be the focal areas leading up to the next update of the RWQM.

UU1.2.1. Can operational information be used to improve source terms?

The historical waste rock distribution by drainage at each operation was reassessed in 2019 using the updated drainage boundaries and available survey information. This has resulted in updates to the distribution of waste volumes by drainage particularly in areas where interpretations of drainage boundaries have changed or where mining has affected historical drainage boundaries. These revised volumes have been used in the 2020 RWQM.

Historical water management information was also reviewed and considered in the calculation of geochemical source terms as well as during calibration of the RWQM.

There is remaining uncertainty on the effects of spoil geometry, dump chronology and dumping method on downstream water quality. Identifying these relationships will support improvements in future iterations of the RWQM.

UU 1.2.2. Can the RWQM be improved in specific catchments where mitigation decisions are required and uncertainty is high?

Catchment specific groundwater investigations have been completed in tributaries that are expected to be targeted for treatment. This has resulted in a refined understanding of groundwater/ surface water partitioning at relevant flow and water quality monitoring stations. This information was used to inform source term development and model calibration and will be used to inform potential groundwater collection requirements through the next implementation plan adjustment under management Management Question 3. Annex A and Annex B contain additional details on how this information was used in the development of source terms and in the FC of the 2020 RWQM, respectively.

A catchment-specific water quality investigation was completed in LCO Dry Creek. Key learnings from this work include an improved understanding of the importance of fast (or preferential) flow paths in new spoils and identification of an initial soluble component of load, both of which result in the appearance of load downstream of a new spoil sooner than what was represented in the 2017 RWQM. These concepts are being incorporated numerically into the 2020 RWQM Update to improve the representation of the effects of first several years of development in new areas on downstream water quality.

As a result of the work described above, as well as the move to a more mechanistic, climate-driven model and increased spatial resolution, modelled tributary flows and water quality calibration have improved and uncertainty has been reduced.

There is remaining uncertainty related to closing the water balance in some catchments in the Elk Valley. Work is planned under MQ1 to better understand climate variability across catchments to reduce this uncertainty and support future refinements of the RWQM. Water balance uncertainty will also continue to be reduced through local groundwater investigations to support mitigation decision making under AMP Management Question 3 (Are the combinations of methods for controlling selenium, nitrate, sulphate and cadmium included in the implementation plan the most effective for meeting limits and site performance objectives?)

There is also remaining uncertainty related to attenuation of cadmium in new spoils and how this will change over time as the spoil grows and matures. This will continue to be investigated through review of monitoring data and revisions to the conceptual model to support future refinements to the RWQM.

UU 1.2.3. How may selenium and sulphate release rates change over time?

The conceptual model of constituent release was refined in 2019 through review of existing information, literature and consultation with geochemistry and hydrology experts. Several mechanisms were identified that may affect the rate of release of selenium and sulphate over time:

- Reduction in inventory of selenium and sulphate in Elk Valley waste rock due the weathering and release over time. There is a finite mass of selenium and sulphate and this will be depleted over time as this mass is exhausted. Of this inventory, only a portion of it is expected to be available to be oxidized from reactive surfaces and transported out of the spoil.
- Decrease in oxidation rates over time. Results of ten years of humidity cell testing on waste rock from Line Creek Operations show decreasing loading of sulphate and selenium over time (Figure 9-3). Results from these humidity cell tests have been used to estimate the decay expected in sulphate and selenium release rates, information that has been incorporated into the 2020 RWQM. The humidity cell test results are discussed in more detail in Annex A.

Field scale data sets at West Line Creek support a decreasing release rate of selenium and sulphate with time (Section 8.4), but require further investigation. Teck’s R&D group will be pursuing detailed modelling and monitoring programs to reduce the outstanding uncertainties associated the mechanisms and rates of decay at field scale

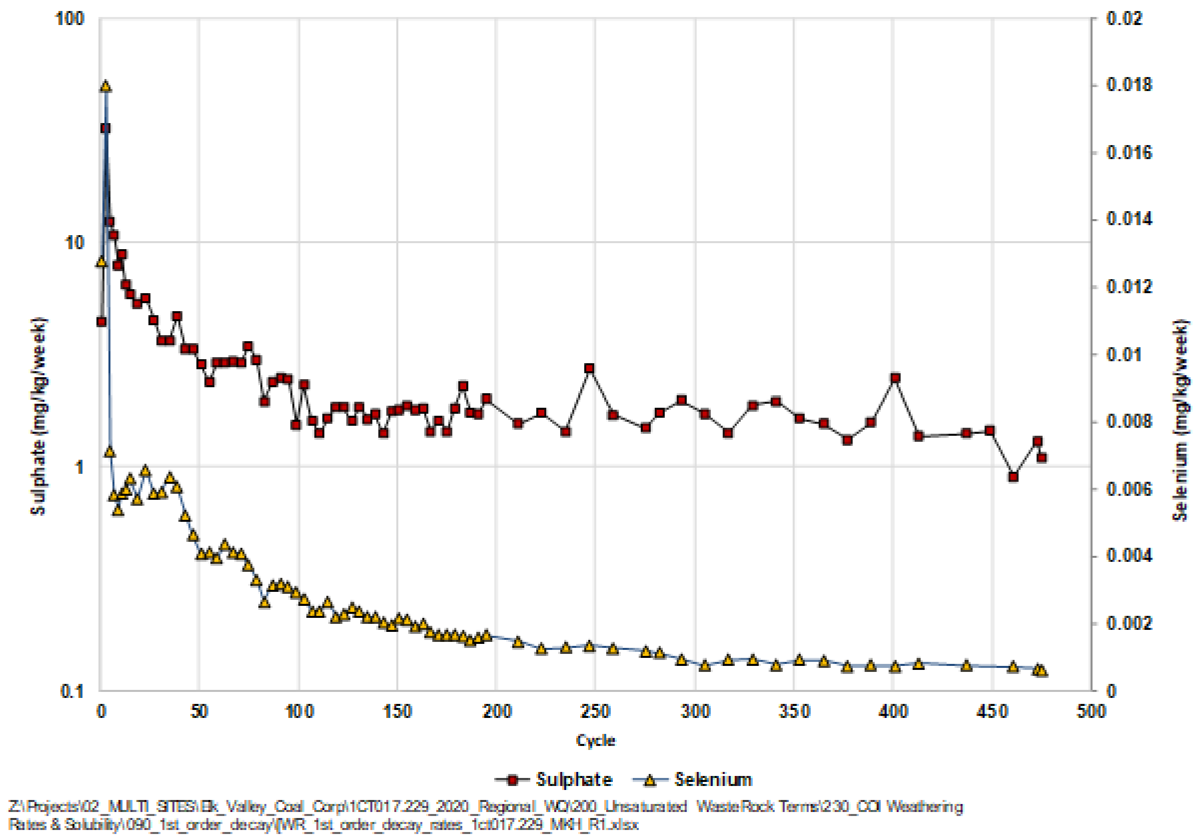


Figure 9-3: Selenium and Sulphate Release Rates for Humidity Cell (LCO HC-19) on Blasted Rock from Line Creek Operations

UU 1.2.4. What mechanisms are causing the mass imbalance between tributaries and at monitoring stations in the main stems?

This underlying uncertainty has been reduced and refined through work on the Mass Balance Investigation (SNC 2021, SRK 2021b) and through the 2020 RWQM Update to recognize that the mass imbalance identified between tributary and mainstem monitoring locations has both a component of mass reduction as well as a component of mass delay. This is currently represented in the RWQM using two model features, which are required to reflect measured patterns in the Elk River and Fording River (instream sinks and interflow reservoirs). The Mass Balance Investigation will continue to reduce this uncertainty to work towards a better understanding of the mechanisms of the mass reduction and delay through targeted monitoring investigations.

9.4 Monitoring Recommendations

Recommendations for continued improvement of the regional flow monitoring program are as per KWL (2020). They include the following:

- review and updated as necessary existing flow monitoring procedures and protocols to reflect relevant standard and confirm compliance with goals for the regional program
- improve the frequency of monitoring at stations where deficiencies have been noted, such as those in Grave Creek (i.e., EV_GV3, EV_GV1), Harmer Creek (i.e., EV_HC6), Thompson Creek (i.e., GH_TC2) and South Line Creek (i.e., LC_SLC)
- continue to work to achieve desired levels of data accuracy and associated data grades
- continue to maintain records of hydrometric station changes, upgrades or new station establishment

In addition to these flow monitoring recommendations, a review and gap analysis of the existing climate and meteorological monitoring program will be undertaken, with the goal of identifying areas for improvement in terms of supporting future updates to the RWQM and the accuracy of the climate data used to drive the model. Specific areas of consideration for the review include:

- spatial coverage of the existing monitoring network, including variability in elevations represented
- consistency in parameters being recorded at each monitoring station, and confirmation that key data requirements of the RWQM are being measured
- confirmation of alignment between actions being undertaken and overall goals of the climate and meteorological monitoring program, in terms of supporting both local and regional initiatives

Recommendations for water quality and source term development include:

- continue to document mine water management activities, including pit pumping
- continue to monitor flows and constituent concentrations downstream of waste rock spoils, for the purposes of continuing to improve the simulation of flow and constituent release from waste rock
- continue to collect information as part of existing mass balance investigations to support the inclusion of sinks in the RWQM
- periodic review and audit of water quality sampling procedures, particularly those applied to larger creeks and rivers, to confirm that sample results are representative of full mix conditions.

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Appendix A

Coal Mountain Operations Water and Load Balance Model 2020 Consolidated Report

Teck

Coal Mountain Operations Water and Load Balance Model 2020 Consolidated Report

Prepared for

Teck Coal Ltd. – Coal Mountain Operations

Prepared by

srk consulting

SRK Consulting (Canada) Inc.
1CT017.260
February 2021

Coal Mountain Operations
Water and Load Balance Model
2020 Consolidated Report

February 2021

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Project No: 1CT017.260

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srk consulting

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Appendices

1 Introductions

1.1 Purpose of Report

SRK Consulting Canada Inc. (SRK) was retained by Teck Coal Ltd. To produce a consolidated report describing the successive revisions to the existing water and load balance model for Coal Mountain Operation (CMO).

The CMO model was originally built-in phases, has undergone two comprehensive reviews and has been used for multiple applications. For each application, the model has been refined to better resolve a particular area of investigation. However, each application is described in separate memos or reports. The purpose of this report is to provide an overview of the model's current configuration, and summarize the conceptual model, model framework, inputs, and calibration, and provides projections for select water quality parameters.

The CMO mine site is located within the Elk Valley region, approximately 30 km southeast of Sparwood and 30 km east of Fernie. Mining activity at CMO began in 1908 with small, underground mines and has continued intermittently as open pit operations with various owners. CMO currently is in Care and Maintenance and has no planned mining activities.

The layout of this document is as follows:

- Section 1 - An overview of earlier model revisions and objectives for the current model revision.
- Section 2 - An overview of site water management.
- Section 3 - Details of the modeling framework.
- Section 4 – A summary of the model inputs including climate inputs, hydrological inputs, water storage and management and water quality inputs.
- Section 5 - A description of the model evaluation, including QA/QC measures, calibration and identified limitations.
- Section 6 - Model results including projections of key water quality parameters at receiving environment nodes.
- Section 6 - A summary.

1.2 Previous Work

The versions of the model as it was developed and refined over time are described in the sections below.

1.2.1 Water Balance (2014)

SRK was retained by CMO to create a site wide water balance model to serve as a tool to address and plan for current and future water management improvements through the evaluation of various water management scenarios, including a range of hydrological conditions (SRK 2014a). The main inputs to the site water balance model were climate data and mine plan information. The model used the Martinec and Rango Snowmelt Runoff Model (SRM) to simulate flows associated with all key water management facilities at the site. Through an iterative calibration process, specific input parameters were developed that allowed the model to closely match historical measured flows at key points at the site. Several features were incorporated in the model to reflect varying conditions and operating plans over time and allow for the projection of future flows and water storage quantities under various climate scenarios. The site water balance model provided the framework on which the load balance model was built.

1.2.2 Load Balance (2015)

The load balance model (SRK 2015a) integrated key findings from previous work, including a water quality data review (SRK 2014b) and Geochemical Characterization Plan (SRK 2015b), and is built upon the site wide water balance model (SRK 2014a). The load balance calculates loading rates by applying load inputs to the flows calculated in the water balance, and generates water quality projections at CMO monitoring locations, with a focus on Corbin Creek and Michel Creek downstream of operations.

1.2.3 2016 Comprehensive Model Revision

The water and load balance model configuration was revised to reflect a proposed change in pit dewatering for 34 Pit (SRK 2016a). The model was used to support site decision making and regulatory notification requirements.

The objectives of the revised water and load balance model were to:

- Improve the existing model so that it can be used to project water quality and assist with water management decisions.
- Provide updated water quality projections that meet the CMO Reclamation Permit C-84 requirement identified in Section C. 1, which states that “An interim closure plan, incorporating the ML/ARD management plan and water quality predictions shall be submitted to the Chief Inspector by December 31, 2016”.

1.2.4 2019 Comprehensive Model Revision

The purpose of the 2019 comprehensive revision was to address areas of refinement identified in the Integrated Water Management Plan (Teck 2017) and to provide a robust tool that can be used to make future water management decisions. Specific goals of the 2019 model revision were the following:

- Update data inputs with new monitoring data collected since the last model revision and with new mechanisms identified that affect estimates of water quality or quantity in the model.
- Update model to reflect water management planned for Care and Maintenance.
- Improve congruency with Regional Water Quality Model (Teck 2017).
- Provide a Base Case against which water management and mitigation options, developed for this project, can be compared to in the future.

1.2.5 Ongoing Model Refinement

The CMO Water and Load Balance model is used on an ongoing basis for both internal and external water quality assessment. Applications regularly lead to model updates when changes to water management are made and when new monitoring data are available. Descriptions of model modifications made since the last comprehensive model review have been included in this report.

2 Water Management Overview

Key water management facilities at CMO are shown on Figure 2-1. Currently, all mine influenced water is collected and managed through a network of ditches, rock drains, ponds, sumps and pits. Existing water management infrastructure at CMO is outlined in the sections below. Additional details on components of CMO's water management infrastructure can be found in the CMO Integrated Water Management Plan (IWMP) (Teck 2017). The most recent revision of the IWMP was submitted December 22, 2017. As per Section 7 of the IWMP, the plan is reviewed annually until site conditions are considered static and then every three years after that, with updates completed as required. Results of the IWMP annual review is reported in the CMO Annual Reclamation Report, which is required annually by March 31.

2.1 Ditches

2.1.1 Clean Water Diversions

Water collection ditches at CMO are used to collect and convey mine influenced water. CMO has limited opportunity for clean water diversions (with the exception of the Scrubby Creek clean water diversion) because the site is located along the watershed divide between Michel Creek and Corbin Creek.

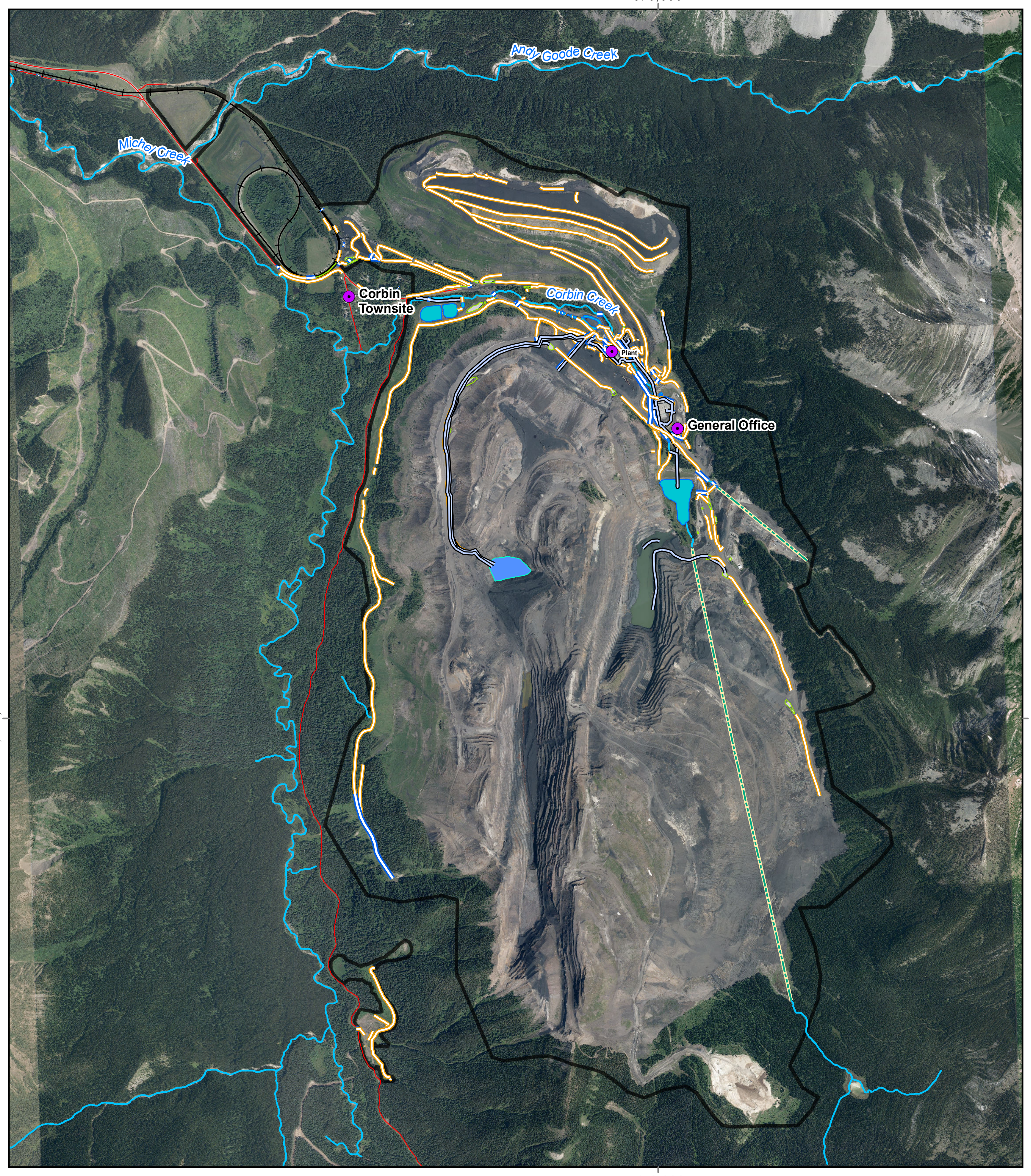
2.1.2 Contact Water Ditches

There are two main contact water collection ditches: the West Ditch and North Ditch.

The West Ditch captures all surface and shallow groundwater flows from the west side of the mine below the west haul road, including water from the dormant West Spoils. This flow is largely local runoff water and generally has low TSS. Water conveyed by the West Ditch reports to the Main Settling Ponds.

The North Ditch also reports to the Main Settling Ponds. The North Ditch collects water from the base of the east and west haul roads, runoff from the upper portion of the Middle-Mountain Refuse Spoil, the14 Pit Horizontal Drains, dewatering from 34 Pit and the processing, shop and administration areas. Mine water intercepted from the processing, shop and administration areas flows into the North ditch via the 'Horseshoe' and 'Step' Ponds. Historically, a third ditch was located to the south-east of the mine, above the Seven Pit Ponds. The Seven Pit Sedimentation Ponds (SPSP) were commissioned to settle suspended solids in runoff from the slope adjacent to the south end of the historic 7 Pit. The pond system consisted of diversion berms and channels routing water from Kovack, Niven, Kuta, and Peach creeks into three interconnected ponds forming the SPSP. In 2017, the SPSP were decommissioned, and natural drainages for Kovack, Niven and Kuta creeks were re-established.

670,000



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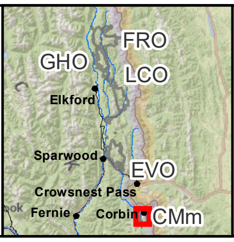

Water Management Features & Infrastructure

Culvert	End Pit Lake	Railway
Ditch	Settling Pond	Paved Road
Rock Drain	Sump	C-84 Permit
Water Pipeline	Stream	

N

0 187.5 375 750 Meters

DATE: 2/11/2021	MINE: Coal Mountain
SCALE: 1:30,000	COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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2.2 Rock Drains

Rock drains are zones of coarse, durable rock capable of transmitting streamflow through a spoil with minimal impedance. CMO has constructed two rock drains on site in Pengelly and Corbin Creeks.

2.2.1 Pengelly Creek Rock Drain

Pengelly Creek is an ephemeral watercourse that typically only flows during spring freshet or during other significant rain events. A section of Pengelly Creek was rocked in by depositing Pengelly spoils overtop of the watercourse, creating the Pengelly Creek Rock Drain (PCRD). The PCRD is approximately 700 m long. Water from the PCRD flows into Corbin Creek approximately 200 m downstream of Corbin Pond.

The Pengelly Creek discharge is managed under EMA Permit 4750 conditions. A sump, a series of ditches, and a sluice gate were installed near the rock drain outlet. The sluice gate was designed to allow for the diversion of potential sediment laden water to the Corbin Pond if sedimentation was required. However, the sluice gate must not be operated since CMO is not authorized under EMA Permit 4750 or the Pengelly Creek Conditional Water License (License number 113668) to divert water from Pengelly Creek to Corbin Pond.

2.2.2 Corbin Creek Rock Drain

Corbin Creek flows through the Corbin Creek Rock Drain (CCRD), which was constructed from spoil material. The CCRD is approximately 2,700 m long. The CCRD receives water from two unimpacted catchment upstream including the Corbin Creek headwaters, and an unimpacted catchment to the southeast of CMO. The CCRD also receives water that infiltrates through the overlying East Spoils. The Corbin Creek Rock Drain discharges into Corbin Pond.

2.3 Ponds

CMO has two settling pond facilities used for the collection of contact water for treatment by sedimentation: Corbin Pond and the Main Settling Ponds. Both settling ponds are permitted and managed under the conditions laid out in PE4570.

2.3.1 Corbin Pond

Corbin Creek and runoff from other unimpacted upstream catchments, infiltration through the overlying East Spoils, runoff from the East Access Road and pumped water from 6 Pit report to Corbin Pond. The Corbin Pond is for impounded by an earthen dam (Corbin Dam). The dam is approximately 265 m long, 18 m high (at its highest point) with a crest width of approximately 6 m. The spillway from the dam is entirely passive, with no gates or other machinery to control pond water elevations. The primary functions of the pond are to provide water for dust and fire control and to settle out solids prior to being discharged to the receiving environment. During operations, the pond had also been used as a reservoir for process water. Total reservoir area is approximately 30,742 m^2 when at the spillway's invert elevation, with a reservoir capacity of approximately 136,000 m^3.

2.3.2 Main Ponds

The Main Ponds are a two-pond system that is located in the north-west corner of CMO. The Main Ponds are comprised of the west pond (primary pond) and the east pond (secondary pond) and collect water from the west and north areas of the CMO property. The West and North Interceptor Ditches both discharge into these ponds.

Much of the sediment that is transported to this system is via the North Ditch; therefore, a series of sumps and small ponds have been constructed along the North Ditch system to assist with settling out solids. In addition, CMO has a permanent flocculant station on the North Ditch, located just upstream of the Main Ponds, that is activated when incoming sediment loads increase. Periodic sediment removal from the ponds is required to increase water retention time and allow settling out of smaller sized particles (e.g., clays and silts) prior to discharging.

Decant from the Main Ponds flows through a short, constructed channel before it converges with Corbin Creek.

2.4 Sumps

2.4.1 Sowchuck and Hotel Infiltration Sumps

Two infiltration sumps are located on either side of CMO's main access road to infiltrate runoff.

1. The Sowchuck infiltration sump collects runoff and direct precipitation from the lower area of Middle Mountain coal refuse spoil at the north end of CMO.
2. The Hotel Sumps collect and infiltrate runoff from the main access road below the Horseshoe ponds.

These sumps need to be maintained and monitored regularly during freshet to ensure inflow does not exceed their holding/infiltration capacity.

2.4.2 Loadout Infiltration Sumps

Runoff in the area of the Coal Loadout Facility is diverted to the Loadout Infiltration Ponds. This system is composed of an infiltration pond and rail loop ditch. A gated culvert under the Corbin Road prevents direct surface water discharge to Michel Creek.

2.4.3 Maintenance Infiltration Sumps

Wash water effluent from the Maintenance Building flows through an oil/water separator which then flows into the Maintenance Infiltration Sumps. Although these sumps receive significantly reduced inflows during Care and Maintenance, they are maintained and monitored regularly to ensure proper function.

2.5 Pits

There are four pits at CMO: 6 Pit, 14 Pit, 34 Pit and 37 Pit. Pit dewatering practices at CMO direct water to established/permitted mining contact water collection systems. Water management for each pit is described below.

2.5.1 6 Pit

Mining started in 6 Pit in 2006 and ceased in November 2018. 6 Pit receives runoff from the local waste rock spoils, pit wall runoff, groundwater inflow and direct precipitation. Outflows include evaporation and pumping.

Pumping from 6 Pit was initiated in April 2016 to manage excess water in the pit and mitigate the potential for water flow through the East Spoils, which could affect the spoil’s geotechnical stability. By early 2017, 6 Pit had deepened to a point where the preferential decant changed to the NW corner of 6 Pit upstream of the Corbin Dam. In April 2017, a high-wall instability was identified on the west side of 6 Pit, which could lead to a wall failure.

The preferred water management strategy is to maintain 6 Pit empty of water. If safe to do so, water will be pumped from 6 Pit to the Corbin Creek rock drain and flow to the Corbin Pond. Once the outcome of the 6 Pit west wall becomes certain, it will be possible to better evaluate backfill opportunities and long-term water conveyance. Due to the continuing displacement of 6 Pit west wall, backfilling and the design and installation of water conveyance features are currently not feasible.

CMO responded by updating the pit pumping plan for 6 Pit in which active pumping is still the preferred management option. However, due to the uncertain high wall stability, this pumping plan also includes all the information required to support the passive decant of 6 Pit water into Corbin Pond and the action, mitigation and monitoring plans in the event that the pit wall fails.

The updated CMO 2019 6 Pit Pumping Plan Version 2 was submitted to EMPR on September 18, 2019. EMPR determined that an amendment to the Mines Act C-84 was not required and the pit pumping plan could proceed as proposed. ENV amended Permit 4750 on December 6, 2019 and included the passive discharge from 6 Pit to the Corbin Sedimentation Pond. FLNRO approved the Short-Term Use Water License application for 6 Pit in accordance with the 6 Pit Pumping Plan- 2019 Update Version 2 on January 22, 2020.

2.5.2 14 Pit

Mining in 14 Pit is complete and backfilling of the pit with waste rock was completed in 2013, mostly from 34 Pit (2009 to 2013). 14 Pit is flooded with water. Water within the backfilled 14 Pit is discharged to the Horseshoe Ponds (North Ditch) through a nine-inch horizontal drainpipe. This drainage system will remain in place through C&M. Flow rates are anticipated to be in the range of 10 to 70 L/s.

2.5.3 37 Pit

Mining in 37 Pit concluded in October 2016. Water sources reporting to 37 Pit include groundwater, catchment runoff and pit wall runoff. Geochemical characterization of 37 Pit indicates that PAG rock from the west side of the pit is the likely source of acidity observed in water that accumulates in 37 Pit. This water was actively treated in 2013 and is now discharged to the mined out 34 Pit where it mixes with neutral water. Backfilling 37 Pit was a strategy used to manage potential acidification of the pit walls during closure.

Coal refuse from processing both CMO and the Elkview Operations (EVO) coal at the CMO plant was placed primarily in CMO's 37 Pit starting in March 2018. 37 Pit has been backfilled with the following material:

- Re-handled coal refuse from Middle Mountain at CMO (116,000 BCM placed in late 2017/early 2018).
- Re-handled CMO waste rock sourced from 34 Pit backfill (213,000 BCM placed starting in late 2017 and used to increase stability of refuse and allow for pit access).
- Coal refuse from processing a combination of EVO and CMO coal at the CMO processing plant (placed starting in March 2018 and ongoing – expected to be 645,000 BCM as of December 31, 2018).

37 Pit water drains by gravity via subsurface pathways (i.e., through backfilled material) to 34 Pit.

2.5.4 34 Pit

In addition to excess water from 37 Pit, 34 Pit also receives runoff from local waste rock spoils, pit wall runoff, runoff from waste rock backfill within 34 Pit, groundwater inflow and direct precipitation. Outflows from 34 Pit include evaporation, and active pumping to maintain the water level below the natural decant level.

In spring 2016, stability concerns with the West Spoils to the west of 34 Pit were identified that could lead to a potential spoil failure affecting the Flathead Forest Service Road and potentially Michel Creek. This instability would occur in the event that water overtops and decants from 34 Pit and flows to the northwest through the West Spoils.

CMO currently controls the water level in 34 Pit with pumping to a sump downstream of the 14 Pit horizontal drain discharge, eventually flowing to the North ditch. 34 Pit is pumped at a rate synchronized to seasonal flow variation in Michel Creek at monitoring location CM_MC2, targeting a pump rate at approximately 5% of CM_MC2 flow up to the maximum allowable rate (150 L/s) during higher flow months (April to November). Pumping rates are also dependant on thresholds established within the West Spoils Geotechnical TARP (Teck 2020). Pumping may exceed 5 % of the Michel Creek flow to prevent 34 Pit from reaching its passive decant elevation.

CMO is conducting a stability assessment for various sections of the West Spoils to determine long term stability. If the results of the stability assessment are favorable and no major mitigations are required, pumping would cease, and water would be allowed to flow through the west spoils throughout Care and Maintenance and in to closure.

3 Description of Model

3.1 Model Framework

3.1.1 Conceptual Model

The objective for the water and load balance model is to mechanistically model the water management system at CMO. The conceptual model to estimate water quality is made up of various mechanisms that influence water quality. Some inputs to these mechanisms are developed empirically. Hydrological, geochemical and operational processes that influence water quality and quantity on site are represented in the model and calibrated to existing monitoring data. The model is used to make future projections to evaluate factors that affect water management at CMO. This information is then used to make decisions on the design and operation of the water management system.

The water balance uses a climate-based approach. The project area was divided such that each catchment had a unique combination of flow path and source term. Daily precipitation, either historical daily time series data or daily precipitation timeseries generated by a stochastic climate generator (WGEN) for the projection period, based on statistics on the long-term climate data series. Daily precipitation was applied to each catchment area to generate an estimated flow volume. A runoff coefficient based on land use type was then applied to this volume to account for a proportional loss of water to evapotranspiration and to groundwater.

The load balance is based on a mass balance approach. The load balance calculates loading rates by assigning concentrations (source terms) to the flows calculated in the water balance and generates water quality projections for both onsite and downstream locations. The source terms are applied either as concentrations in water, or as mass added directly to the flows.

All primary facilities at the site are incorporated in the model, including the pits, waste rock areas, refuse areas, rock drains, sedimentation ponds, contact water ditches and sumps. Flows are simulated from the upper, natural catchments of Coal Mountain, through the operational facilities, to the receiving environment downstream of operations. Model elements representing facilities and their respective element IDs, and how water moves between facilities as implemented within the CMO water and load balance model are shown in the flow diagram in Figure 3-1.

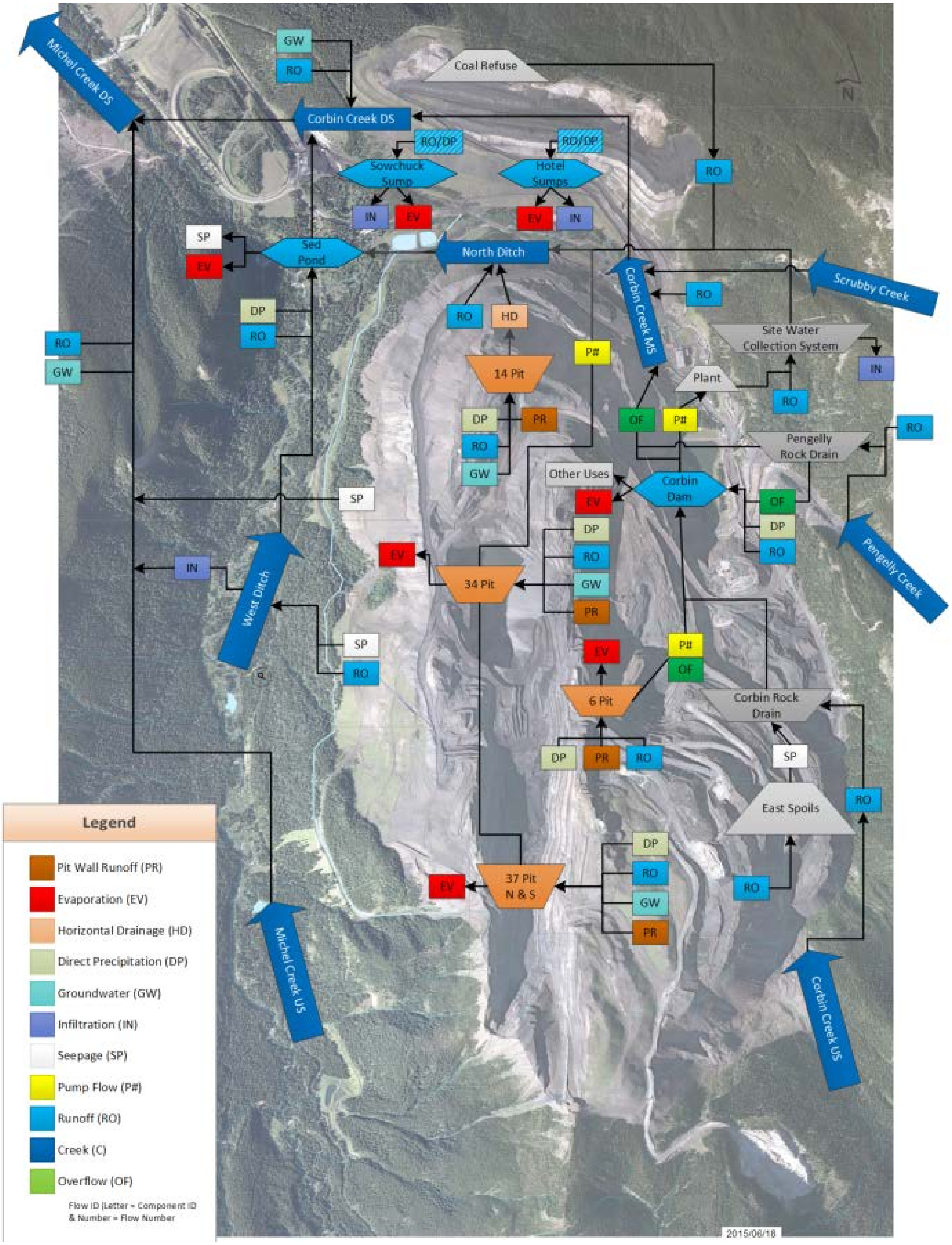

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Figure 3-1: CMO Model Flow Diagram

Mechanisms that are represented in the model include:

- Flows from natural catchments were simulated using a Snowmelt Runoff Model with daily precipitation and temperature as inputs, and runoff coefficient by land type.
- Model controls for water management during operations, and Care and Maintenance, as described in Section 2 including:
  - Routing of contact water to water management facilities (e.g. North and West ditches, Corbin Dam).
  - Active pumping from 6 Pit and 34.
- Loading rates for an initial flush from waste rock rehandled during reclamation activities is scaled on a volumetric basis, based on an empirically derived source term.
- Loading rates from 37 Pit backfill of toll processed coal from EVO.
- Loading rates for all other parameters are assumed to be a result of continual weathering and release. Loading rates for all other parameters are calculated empirically from monitoring data and are incorporated in the model as fixed concentrations.
- Attenuation of selenium is estimated using an attenuation factor. The implementation of this mechanism is unchanged from the originally developed model (described in Section 3.3.5).
- Co-precipitation with calcite of divalent metals is modelled for cobalt, cadmium and zinc based on a flow threshold.
- In addition, scenarios for several water quality management options can be selected, including:
  - Nickel and cobalt water treatment (6 water treatment configurations).
  - Diversion of unimpacted catchments upstream of the CCRD.
  - Water quality assessment of 6 Pit wall failure.

3.1.2 Model Platform and Version

The CMO water and load balance model was developed using GoldSim and is currently updated for use in Version 12.1.1. GoldSim is a dynamic system modeling software package that includes a probabilistic modelling component that uses a Monte Carlo method to vary hydrological inputs to estimate a range of potential future conditions based on the probability distribution function of the input parameters.

3.1.3 Timescale

The CMO model is run on a daily time step. Results are provided as monthly averages. Permit limits are applied for the average of all samples collected in a calendar month. Therefore, the selection of model output as monthly average projections is considered adequate to inform water management decisions.

The current model revision is set up to run from June 2013 to December 2028. This provides a calibration period from June 2013 to December 2019, and 10 year predictive period for Care and Maintenance from January 2020 to January 2030.

3.1.4 Projection Modes

The model has the capability to be run using deterministic and stochastic simulations.

Stochastic simulations use variable inputs based on the probability distribution function of the input to generate a range of results for the water balance to simulate natural climate variability. The stochastic component of the model is within the climate generator. Two modes are available for generating climate: a WGEN module or a re-sampled historical climate record.

1. The WGEN module stochastically generates daily precipitation, and minimum and maximum air temperature based on monthly statistics from an extended climate time series developed for CMO.
2. The re-sampled historical record uses measured precipitation and temperature. The climate year applied in the model is selected using a stochastic element and changes for each calendar year.

The daily weather generator outputs (precipitation and air temperature) are used to develop subsequent hydrological calculations such as estimates of flows and snow storage.

The water model can be run stochastically for multiple iterations to estimate a range of projections of potential flow conditions. This approach produces a range of results for a variable sequence of wet and dry years. The model has also been built to run deterministically to produce appropriate flows for use in projecting various flow conditions, including the 1 in 50 dry year and 1 in 100 wet year hydrological conditions.

3.1.5 Dashboards

Dashboards were created to serve as a user interface. Dashboards allow model inputs to be viewed and/or revised, modeling scenarios to be varied, model results to be viewed and results generated.

The following main dashboards were created for modifying and running the model.

- Main (Master) Dashboard, which contains the following links:
  - About This Model - Provides to a description of the model.
  - Model Inputs - Multiple dashboards are accessed from within the Inputs dashboard. All model inputs are located in the Inputs container within the Main Model. Only key inputs that are likely to be manipulated by the user can be viewed and/or modified from the *Inputs* dashboards.
  - Model Results - Multiple dashboards are accessed from within the *Results* dashboard.
  - Go to Main Model - Links to the main model.

– Model Sources - Links to numerical list of sources used in the model.

3.2 Water Balance Inputs

The overall approach to estimating runoff in the water balance model is shown in Figure 3-1.

Climate inputs to the water balance include either measured daily precipitation and temperature time series for the historical period or synthetic daily precipitation and temperature timeseries for the predictive period. Orographic adjustments to account for elevations differences on site and surrounding catchments were applied to the daily precipitation and temperature timeseries. The adjusted temperature and precipitation timeseries then formed the input to the Snowmelt Runoff Model, which produces a unit yield that can be used to calculate flows for each catchment area in the model. Components of the approach are described in more detail in the following subsections.

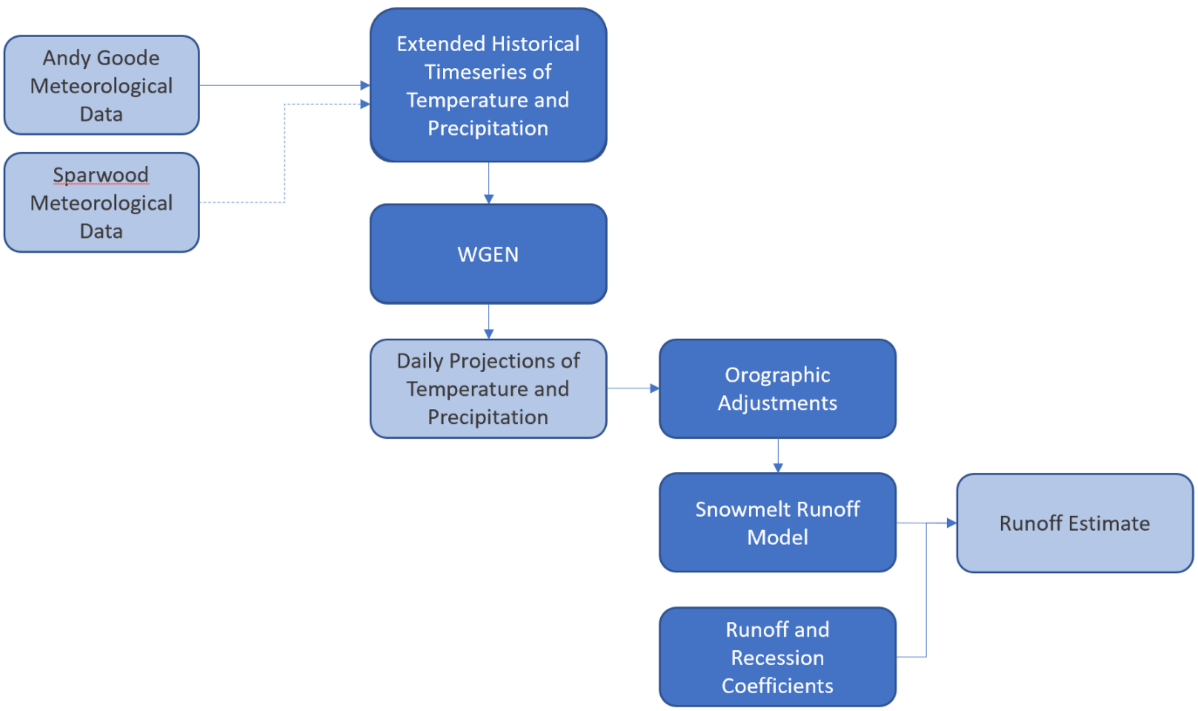

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Figure 3-2: Hydrology Approach for CMO Water Balance Model

3.2.1 Climate Inputs

Records of daily precipitation and mean daily temperature, along with statistics of meteorological parameters were required for input to the water balance model for two key conditions:

- Historical conditions – Available measured climate data are applied when a model start date prior to the current date is selected (primarily for the purposes of model calibration) .

- Predictive conditions – Includes a number of options for running the model under varying hydrological conditions during a timeframe specified by the user.

A climate analysis was conducted to develop the necessary inputs, which included the generation of the following key components:

- Extended climate record was generated to simulate historical conditions, for predictive modeling where the long-term historical record is projected into the future, and to derive the inputs required for the SRM and WGEN models.
- Frequency analysis of to estimate the annual total precipitation for a number of return periods, including average, wet and dry return periods (1:100 wet and 1:100 dry).
- WGEN module which generates daily values of maximum and minimum temperatures, precipitation and solar radiation based on statistics of historical weather data. The module is designed to preserve the correlation between variables (e.g., the probability of a wet day after a wet day), and the seasonal characteristics in actual weather data for the modeled location.
- Mean monthly evaporation.
- Inputs for the GoldSim SRM, based on the WinSRM, which is designed to simulate and forecast daily streamflow in mountain basins where snowmelt is a major runoff factor.

Where deterministic hydrological conditions are applied in the model such as average, wet, and dry return periods, annual total precipitations are based on a water year based of September 1 to August 31. Using a water year is more practical from a hydrological perspective when dealing with a site with significant freshet flows. In the water balance model, starting the model in September, when there is typically no significant snowpack at the site, eliminates the need to estimate the initial snowpack.

Timeseries were created for each of the deterministic hydrological conditions consisting of daily total precipitation and average temperature. For average hydrological conditions, a frequency analysis was completed for precipitation for each month, and the average of each month was combined to create the climate timeseries. For 1 in 100 wet and dry years, a daily record was generated from the WGEN module.

A detailed description of the development of the climate inputs is included in Appendix A.

3.2.2 Catchment Delineations

For modelling purposes, the project area and its surroundings were divided into catchments based on 2012 LIDAR data (Figure 3-2). Catchment delineations were based on maps of existing surface infrastructure and mined out topography. Disturbed catchments were divided such that each sub-catchment had a unique combination of flow path and land use type.

The model is set up to allow catchment areas to change with time and interpolate between values entered for each time period, however no changes to CMO catchments are currently anticipated.

Where a catchment area delineation includes a pond area, the pond area is calculated separately and subtracted from the surrounding catchment. This includes the following ponds: Sediment Ponds, Corbin Dam, Seven Pit Settling Ponds, Hotel Sumps, Sowchuck Sump, and Open Pits 6, 14, 37 and 34. Where available, the pond areas are estimated by looking up the area from an area-elevation lookup table for the facility, where the elevation is calculated from the predicted volume and volume-elevation lookup table for the facility.

The average elevation of each catchment was calculated as part of the delineation work. The catchment elevations are applied in the orographic corrections of temperature and precipitation, which are based on the elevation gradient between the reference climate station and catchment area modeled. The average elevation for the entire site is currently modeled as a whole.

One of the following land use types is defined for each catchment:

1. Natural.
2. Pit wall.
3. Waste rock/disturbed.

The land use types are used to drive the runoff coefficients applied in the SRM model.

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!080_Deliverables\Water Balance Model Report\040_Figures\ Figure 4-1 2015 - CMO Catchments.pptx

Figure 3-3: CMO Water Balance Catchment Areas Map

3.2.3 Orographic Adjustments

Climate data output from WGEN is considered as the baseline condition for future climate at the Andy Goode weather station. Precipitation is transposed to the mean catchment elevation using an orographic adjustment for input in the SRM module and the pond snowmelt module.

The orographic correction for precipitation from the UBC Watershed Model (UBCWM) was applied (Quick 1975), which uses the elevation gradient between the reference climate station and the area modeled and an orographic factor, as shown below:

$$Adjusted\ Precipitation = Reference\ Precipitation * (1 + a2)^{\Delta\, elev/100}$$

Where a2 = precipitation gradient (%)

Δ elev = difference in elevation between catchment and reference climate station

The elevation of the Andy Goode station, 1509 m, was provided by Teck. An orographic factor of 10% was applied for transposing total precipitation from the reference climate station to the elevation of the area modeled, which was based on observations made at other sites and calibration of the SRM model.

3.2.4 Snowmelt Runoff Model (SRM)

A detailed discussion of the SRM model is included in Appendix A. The GoldSim SRM model follows the logic of the WinSRM model (Martinec et al, 2008). It is designed to simulate and forecast daily streamflow in mountain basins where snowmelt is a major factor in estimating runoff. The primary inputs to the model include precipitation, temperature, contributing catchment areas, mean catchment elevations, and the elevation of the reference climate station. The model includes a number of parameters that can be adjusted as part of the model calibration, including snowmelt parameters, recession coefficients and runoff coefficients.

The GoldSim SRM model was used to generate runoff at the CMO site. The water produced from snowmelt and rainfall is computed daily, superimposed on the calculated recession flow, and transformed into daily discharge from the basin according to the following equation:

$$Q_{n+1} = [C_{Sn} * a_n(T_n + \Delta T_n) * S_n + C_{Rn} * P_n] * \frac{A * 1000}{86400} * (1 - k_{n-1}) + Q_n * k_{n+1}$$

Where *Q* is the average daily discharge, in m³/s,

C is a runoff coefficient expressing losses as a ratio of runoff to precipitation, with C_S referring to snowmelt and C_R referring to rain.

a is a degree-day factor (cm/˚C·d) indicating the snowmelt depth resulting from 1 degree-day.

T is the number of degree-days (˚C·d).

ΔT is the adjustment to temperature lapse rate.

S is the ratio of snow covered area to total area.

P is the precipitation contributing to runoff (cm).

k is the recession coefficient.

A is the area of the basin.

Following an initial model calibration, it was revealed that runoff could not be generated for the individual site catchments using the parameters derived through the model calibration as these parameters appeared to be specific to the catchment size. Modifications to the model inputs and the adoption of a hydrograph for the entire site based on the average elevation of the areas modeled. A second calibration exercise was carried out using the entire site catchment area and average elevation.

3.2.5 Pond Snowmelt Model

A simple temperature index snowmelt model is included in the CMO Water and Load Balance model to accumulate snowfall over the winter and release it to the ponds in the spring based on the methodologies outlined in "*Guidelines to Extreme Flood Analysis*", by Alberta Transportation & Civil Engineering Division, November 2004 (Alberta Transportation 2004).

Total precipitation is adjusted for the elevation of each of the ponds modeled using the orographic adjustment described in Section 3.2.3. Adjusted total precipitation is divided between rainfall and snowfall based on the temperature at the site as follows:

$$Total\ Precipitation\ occurs\ as\ Rainfall\ if\ Temperature\ at\ Base\ > 0℃$$

$$Total\ Precipitation\ occurs\ as\ Snowfall\ if\ Temperature\ at\ Base\ \leq 0℃$$

Any precipitation falling as rainfall is assumed to be released immediately. Snowmelt is assumed to occur when the temperature is above the threshold temperature. The index temperature in this case is taken as the mean daily temperature at the reference climate station. The snowmelt rate is calculated as follows:

$$Snowmelt\ Rate\ (mm/d) = (Mean\ Temperature - Threshold\ Temperature) \times Melt\ Factor$$

Where, $Melt\ Factor = 4\ \frac{mm}{C} \times\ day$.The threshold temperature from the SRM model (0.55 °C) was selected from the guideline document (Alberta Transportation 2004).

The total precipitation released to the ponds is the sum of the rainfall and snowmelt:

$$Precipitation\ Released\ Rate = Rainfall\ Rate + Snowmelt\ Rate$$

3.2.6 Recession Coefficients

Generally speaking, the majority of natural flows are attenuated. For example, precipitation is attenuated as it flows through a catchment to a stream. More significant attenuation occurs in some mine affected features, for example as water flows through a waste rock dump. Attenuation of flows associated with runoff is simulated in the CMO model within the SRM model. Recession coefficients are applied to flows from the Waste Rock Dump, Corbin Rock Drain and Pengelly Rock Drain as a simple method of simulating hydrologic processes that attenuate these flows.

The recession coefficients are applied such that the outflow from a reservoir, referred to as the withdrawal rate in GoldSim, is proportional to the volume in the reservoir:

$$Withdrawal\ Rate = (1 - Recession\ Coefficient\ k) \times Reservoir\ Volume$$

Where k is in units of day^{-1}

The larger the recession coefficient, the more attenuation it provides and vice versa. The values currently applied in the model are shown in Table 3-1.

Table 3-1: Recession Coefficients (K Factors) Used in Model

Reservoir	k Factor (day^{-1})
Waste Rock Dump	0.99
Corbin Rock Drain	0.9
Pengelly Rock Drain	0.9

Z:\01_SITES\Coal Mountain\1CT017.260 CMO RWQM Transfer\05_Consolidate WLBM Report\ModelVersion_ConsolidatedReport\ Coal Mountain WLBM_1CT017.198_v25_CCM_CAJ.gsm

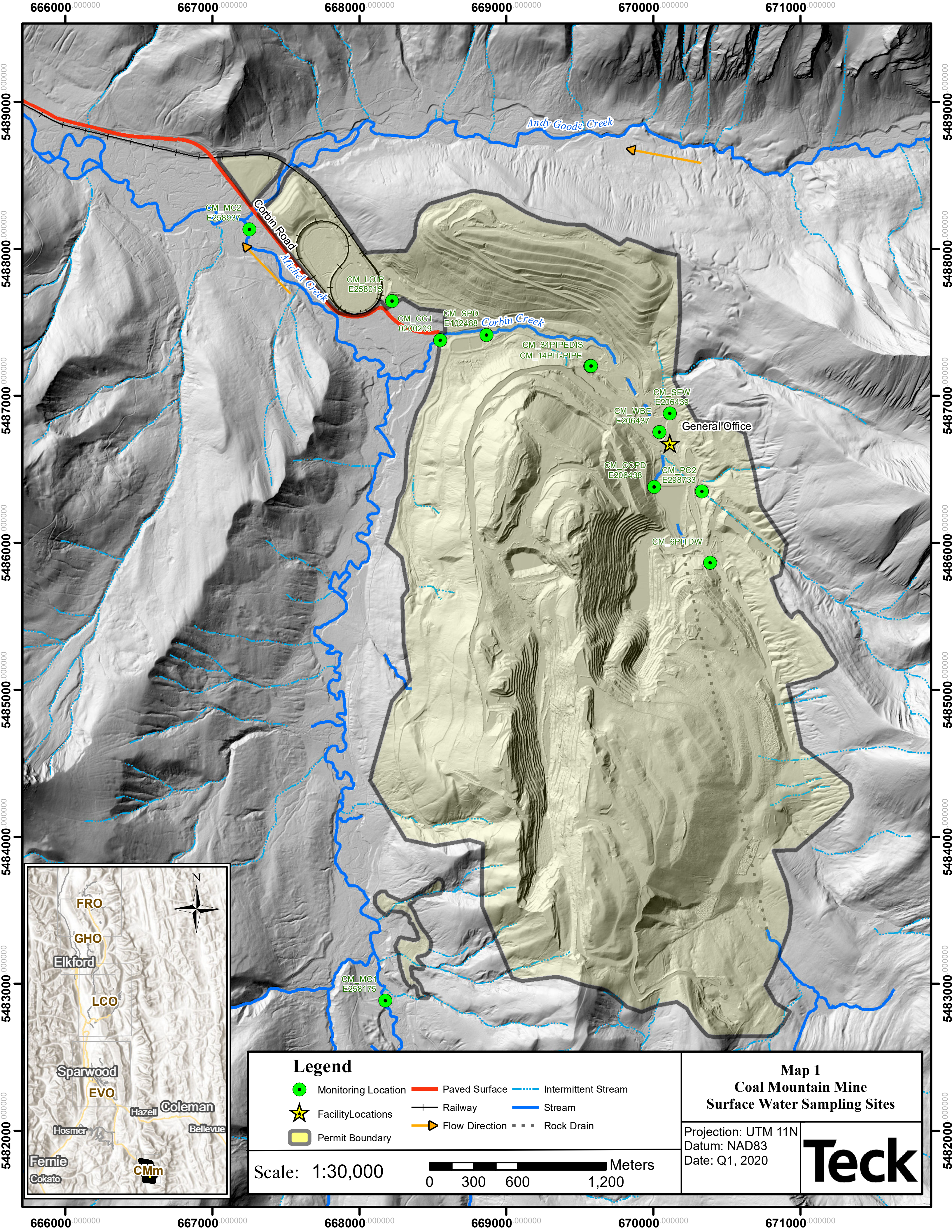
3.2.7 Stream Flows and Water Levels

Flow monitoring data is included in the model primarily for the purposes of model calibration. The flow monitoring stations are shown on Figure 3-3. Table 3-2 provides a summary of the data included in the model. Water level data for 34 Pit is also used for calibration and is collected daily.

Table 3-2: Flow Monitoring Data Included in Model

Station ID	Monitoring Location	Parameter
CM_CC1	Corbin Creek near confluence with Michel Creek	Average daily flow from continuous level
CM_MC1	Michel Creek upstream of operations	Average daily flow from continuous level
CM_MC2	Michel Creek downstream of operations	Instantaneous flow
CM_CCPD	Decant discharge from Corbin Pond	Instantaneous flow
CM_CCRD	Corbin Rock Drain outlet	Instantaneous flow
CM_ND2	North Ditch at flocculent station	Instantaneous flow
CM_SPD	Decant discharge from Main Ponds	Instantaneous flow
CM_SPSP	Decant discharge from Seven Pit Ponds	Instantaneous flow
CM_WD	West Ditch at flocculent station	Instantaneous flow
CM_PC2	Pengelly Rock Drain outlet	Instantaneous flow

Source: Compiled in text.



Map 1
Coal Mountain Mine
Surface Water Sampling Sites
Legend
Monitoring Location
FacilityLocations
Permit Boundary
Paved Surface
Railway
Flow Direction
Intermittent Stream
Stream
Rock Drain
Scale: 1:30,000
0 300 600 1,200 Meters
Projection: UTM 11N
Datum: NAD83
Date: Q1, 2020
Teck
Andy Goode Creek
Corbin Road
Michel Creek
Corbin Creek
General Office
CM_MC2 E258937
CM_LO1P E258015
CM_CC1 0200209
CM_SPD E102488
CM_34PIPEDIS
CM_14PIT-PIPE
CM_SEW E206439
CM_WBE E206437
CM_CCPD E206438
CM_PC2 E298733
CM_6PITDW
CM_MC1 E258175
FRO
GHO
Elkford
LCO
Sparwood
EVO
Hazell
Coleman
Hosmer
Bellevue
Fernie
Cokato
CMm
N
666000
667000
668000
669000
670000
671000
5489000
5488000
5487000
5486000
5485000
5484000
5483000
5482000

3.2.8 Pond Inputs

The volume-elevation curve for Corbin Dam is shown on Figure 3-4 (provided by Teck). The curve is based on a bathymetric survey conducted in 2012. Although the survey indicated some sediment accumulation in 2012 (approximately 18,000 m^3), the curve provided by Teck is applied in the model as if the pond is empty, and the volume of sediment estimated from the survey is added to the pond at the start of the model. This results in a slight under-prediction of the available capacity in the Corbin Dam as the sediment volume is essentially accounted for more than once. The sediment volume accumulated is low when compared to the total capacity of the dam to the spillway invert (approximately 15% of the capacity), therefore, this assumption is not expected to have a significant effect on the results.

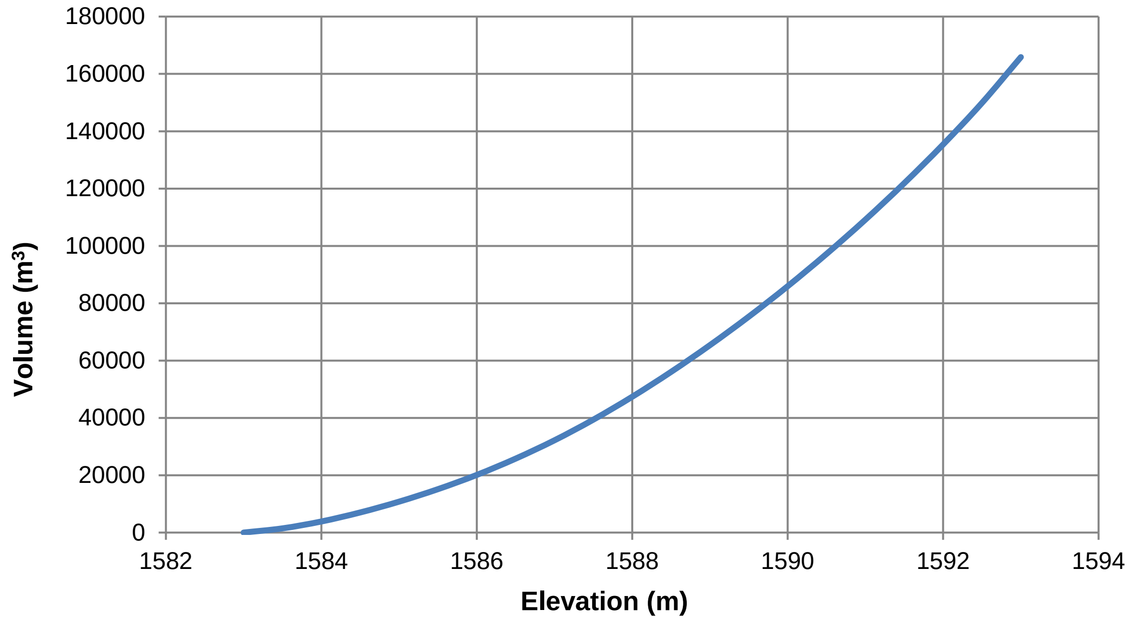


Figure 3-5: Volume-Elevation Curve for Corbin Dam

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\ Vol-Elev\Pit and Pond volume elevation curves _kpw4.xlsx

The volume elevation-curve for the Main Sedimentation Ponds is shown on Figure 3-5. This includes both the East and West Ponds. This curve was projected by SRK based on the curves generated from bathymetric surveys conducted in 2008 and 2012 provided by Teck. It was necessary to project an empty pond as the volume of accumulated sediment in 2012 was estimated to be close to 68,000 m^3, which is nearly five times the maximum capacity shown for the stage storage curve generated from the 2012 survey (approximately 15,000 m^3). The empty curve was projected back based on the reduction in volume between 2008 and 2012, assuming the same rate of sediment inflow occurred going back to 2001, at which time the sediment accumulation records indicate the ponds were empty. The initial volume of sediment estimated from the bathymetric surveys is added to the projected empty pond at the start of the model

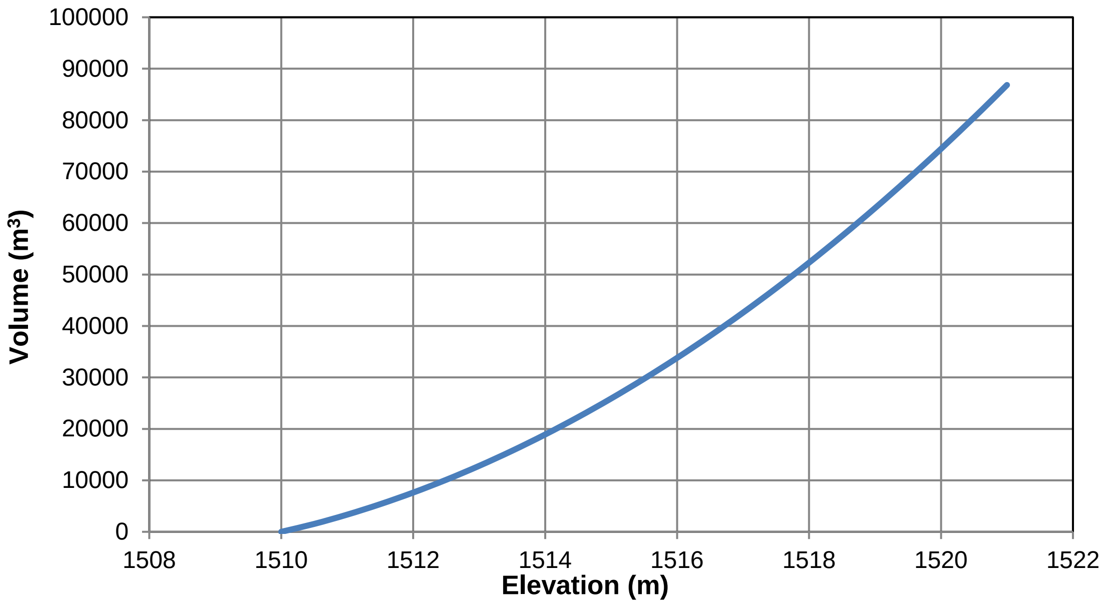


Figure 3-6: Volume-Elevation Curve for Sediment Ponds

Sources: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\ Vol-Elev\Volume elevation curves _kpw3.xlsx (#19) and Bathymetry Data- Sediment accumulation.xlsx (#22)

The elevation and volume limits applied in the model for the ponds are shown in Table 3-3. The maximum capacities are calculated by the model from the volume-elevation lookup tables.

Table 3-3: Elevation and Volume Limits for Ponds

Pond	Spill Elevation (m)	Maximum Capacity (m^3)
Corbin Dam	1591.4	119,344
Main Sedimentation Ponds	1520.7	83,021

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\GoldSim Modelling\Water Balance\Rev 04 February 2014\ Coal Mountain WBM_1CT008_038_20130809_DRAFT_REV04.gsm

The initial volume is calculated by the model based on the input and the volume-elevation data.

Seepage from the ponds is unknown. It is assumed that 5% of the volume of the Main Sedimentation Ponds leaves the ponds as seepage, and report to a sink. No seepage was simulated from the Corbin Dam as it is lined with geotextile and it was assumed that any seepage and excess water from the spillway report to the same location, downstream of the spillway.

The annual sediment flux for each pond was estimated from the bathymetric survey information provided, summarized in Sediment cleanout is simulated using a limit on sediment as a percentage of the pond capacities, which automatically triggers sediment cleanout when the limit is reached. A limit of 95% of the pond capacity is currently set for both the Corbin Dam and Main Sedimentation Ponds.

Table 3-4. The average inflow over the period surveyed, 6355 m^3/year, was applied for the Main Sedimentation Ponds. For Corbin Dam, the value applied, 9150 m^3/year, assumes the sediment estimated in 2012 accumulated over a two-year period. These same volumes of sediment are assumed to enter the ponds each year between April 01 and July 31 of each year. Sediment cleanout is simulated using a limit on sediment as a percentage of the pond capacities, which automatically triggers sediment cleanout when the limit is reached. A limit of 95% of the pond capacity is currently set for both the Corbin Dam and Main Sedimentation Ponds.

Table 3-4: Sediment Inflow Rates for Sediment Ponds and Corbin Dam

	Sediment Inflow (m^3/year)		
Period	**Main Sedimentation Ponds West**	**Main Sedimentation Ponds East**	**Corbin Pond**
2000-2008	3434.9	1480.8	NA
2008-2010	875.5	447.5	NA
2010-2012	11338	1487.5	9149.5
Average	**5216**	**1139**	**9150**

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\ Vol-Elev\Bathymetry Data-Sediment Accumulation.xlsx (#22)

3.2.9 Sumps

The Sowchuck and Hotel Sumps are simulated in the model. The Hotel Sumps include two sumps, which are modeled as one single sump. Other sumps at the mine site are modeled as part of the Site Water Collection System. Inputs for the Sowchuck and Hotel Sumps are provided Table 3-5.

Table 3-5: Inputs for Sowchuck and Hotel Sumps

Parameter	Units	Sowchuck Sump	Hotel Sumps
Spill Elevation	m	1520	1526
Calculated Maximum Capacity	m^3	2070	1671
Bottom Elevation	m	1517	1523
Bottom Area, A	m^2	395	278
Thickness of Wetting Front, t	m	1	1
Coefficient of Permeability, k	m/s	6×10^{-5}	6×10^{-5}

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\GoldSim Modelling\Water Balance\Rev 04 February 2014\ Coal Mountain WBM_1CT008_038_20130809_DRAFT_REV04.gsm

The sumps are designed for retention and infiltration of water into the ground. The infiltration rates were estimated using Darcy's Law, based on methodologies presented in *"A Design Manual for Sizing Infiltration Ponds"*, by the Washington State Department of Transportation (Massman 2003):

$$Infiltration = k\ i\ A$$

Where, $k = Coefficient\ of\ Permeability$

$$i = Hydraulic\ Gradient\ \left(t + \frac{d}{t}\right)$$

$$A = Bottom\ Area$$

$$t = Thickness\ of\ wetting\ front\ beneath\ pond$$

$$d = Pond\ depth$$

The areas at the base of the sumps were estimated from topographical information. The pond depths are calculated in the model. The thickness of the wetting front was selected such that the hydraulic gradient varies between 1 and 1.5. Hydraulic gradients typically start out at a value significantly greater than 1, and approach 1 relatively quickly in comparison to the duration of the event as the wetting front moves downward. For very short infiltration events or fine-grained soils, a gradient of 1.5 may be justified. The coefficient of permeability was selected such that overflows are simulated from the Sowchuck Sump every few years, based on observations from Teck staff. A moderate permeability was selected, and the value was modified to achieve the desired results for the Sowchuck Sump.

The same parameters were applied to the Hotel Sumps, however, the resulting infiltration rate for the Hotel Sumps is greater than the inflows, therefore, water is not retained in the Hotel Sumps.

Infiltration from both the Hotel and Sowchuck Sumps is modeled as reporting to a sink.

3.2.10 Pits

The volume-elevation data were provided by Teck, and the associated areas were calculated by SRK based on the average end area method.

The volume-elevation curve data for Pit 6 is shown on Figure 3-6 and is based on the ultimate pit configuration based on the 2013 LOM.

The volume-elevation curve for Pit 14 is shown on Figure 3-7, with the ultimate and backfilled pit configurations.

The volume-elevation curve for Pit 34 is shown on Figure 3-8, with the ultimate and backfilled pit configurations based on the 2013 LOM and modified to account for backfill volume.

The volume-elevation curve for Pit 37 is shown on Figure 3-9 and is based on the pit configuration at the time the original water balance model was built (2014).

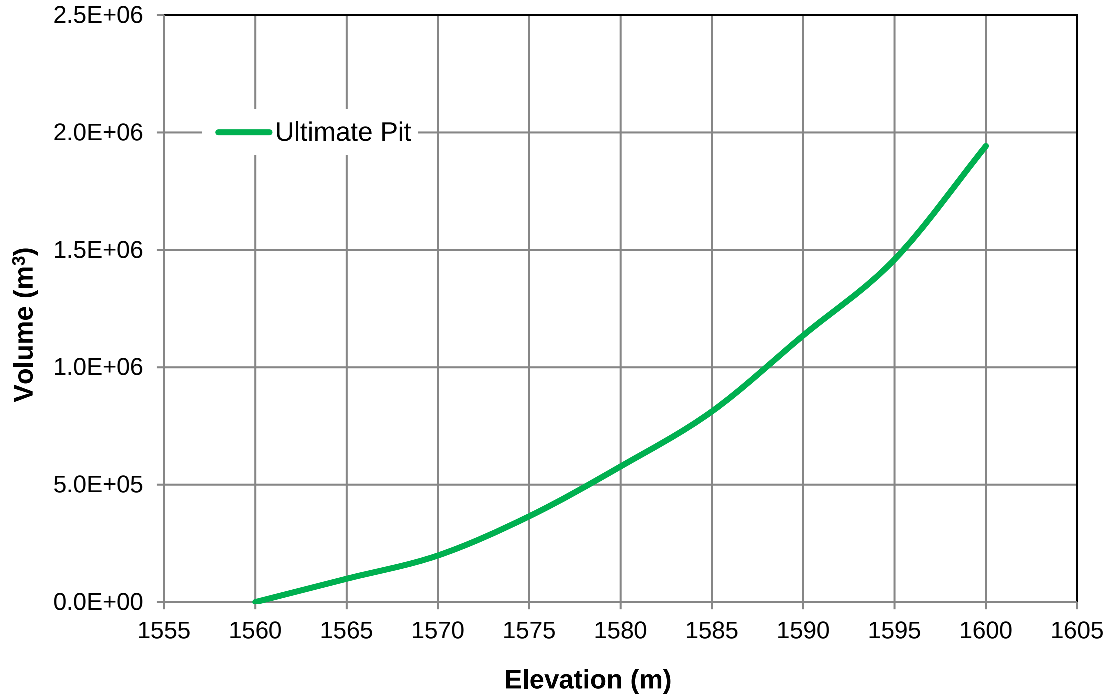


Figure 3-7: Pit 6 Volume-Elevation Curve

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\GoldSim Modelling\WB Inputs\Vol-Elev\37 and 6 Pit end of mine life volume- elevation curves_kpw.xlsx

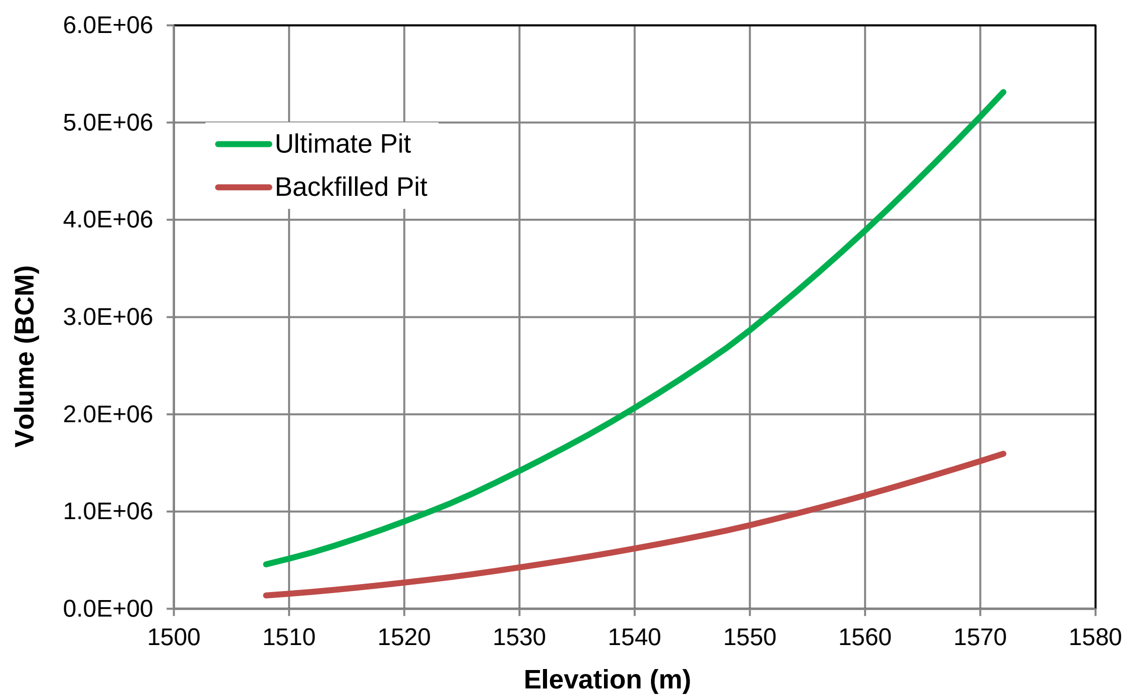


Figure 3-8: Pit 14 Volume-Elevation Curve – Ultimate and Backfilled Pits

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\GoldSim Modelling\WB Inputs\Vol-Elev\Pit and Pond volume elevation curves _kpw4.xlsx

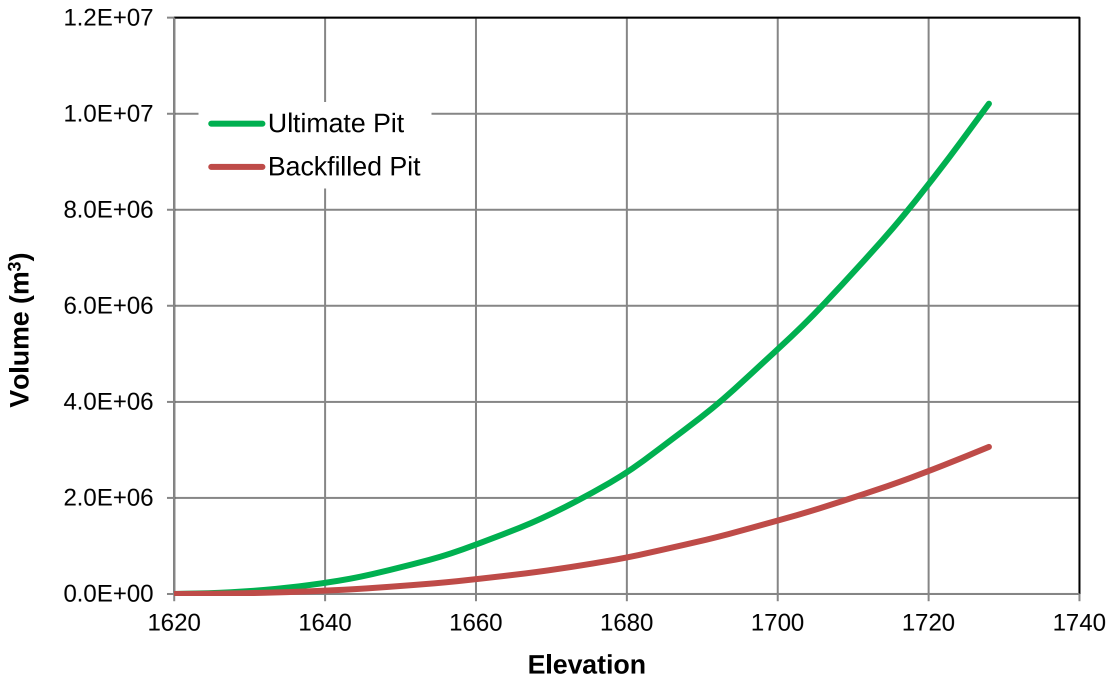


Figure 3-9: Pit 34 Volume-Elevation Curve

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\GoldSim Modelling\WB Inputs\Vol-Elev\Pit and Pond volume elevation curves _kpw4.xlsx

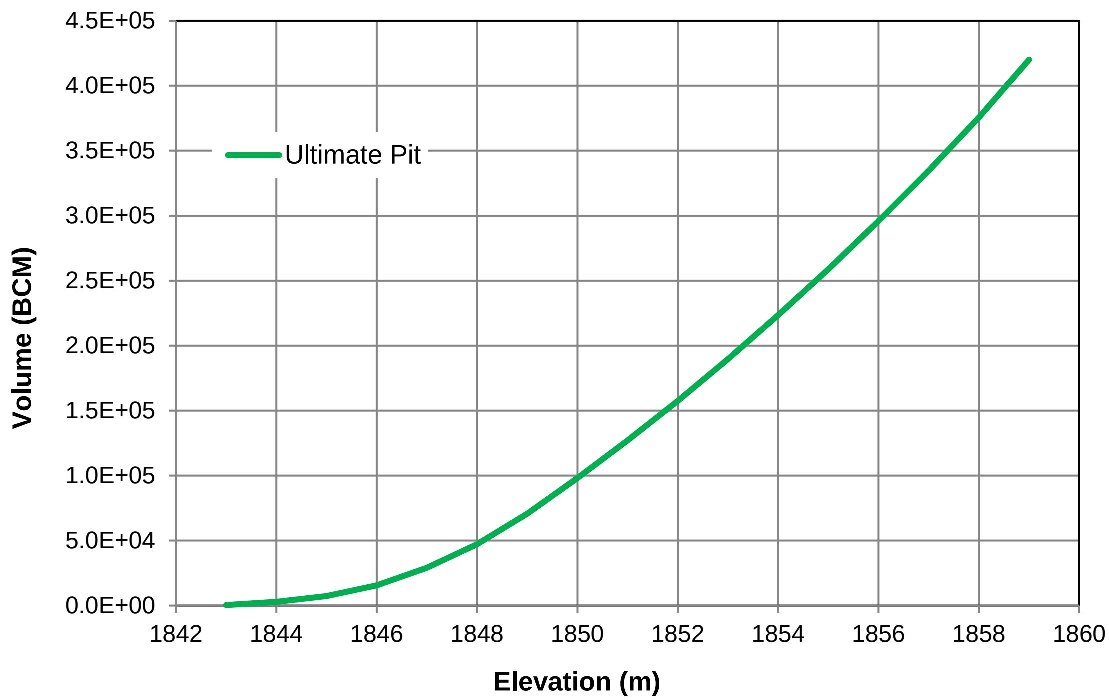


Figure 3-10: Pit 37 Volume-Elevation Curve

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\GoldSim Modelling\WB Inputs\Vol-Elev\37 Volumes_kpw.xlsx

For pits backfilled with waste rock, a porosity of 30% was assumed to account for water stored in the void spaces of the waste rock. The volume-elevation curves are modified such that the volume available for water storage is decreased by 70% where the pit is filled with submerged waste rock. The backfill configurations applied in the model are provided in Table 3-6.

Table 3-6: Pit Backfill Configurations Applied in Model

Open Pit	Description
Pit 6	No backfill
Pit 14	Complete backfill with waste rock, completed in 2013 (model starts with backfill complete)
Pit 34	Partial backfill with waste rock, completed in 2016
Pit 37	Complete backfill with combination of waste rock and coal rejects

Sources: Compiled in text.

The spill points for each pit were provided by Teck and are shown in Table 3-7. The spill point for Pit 14 is the elevation at which water is assumed to flow to the underground workings. The associated maximum storage volumes are calculated in the model.

Table 3-7: Pit Spill Points and Ultimate Capacities

Open Pit	Spill Point Elevation (m)
Pit 6	1596
Pit 14	1560
Pit 34	1729
Pit 37	1859

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3.2.11 Groundwater Inflows

Groundwater inflows assumptions are applied to Pits 14, 34 and 37, with the groundwater inflows scaled to the size of the pits, as shown on Table 3-8.

Table 3-8: Assumed Groundwater Inflows to Pits

Open Pit	Assumed Groundwater Inflow (m^3/s)
Pit 14	0.002
Pit 34	0.002
Pit 37	0.0063

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Groundwater inflow rates to 6 Pit were updated to be consistent with the increased inflow observed as the pit was deepened, and the pumping data. Groundwater inflow rates were assumed based on the timeseries presented in Table 3-9.

Table 3-9: Assumed Groundwater Inflow Rates to 6 Pit

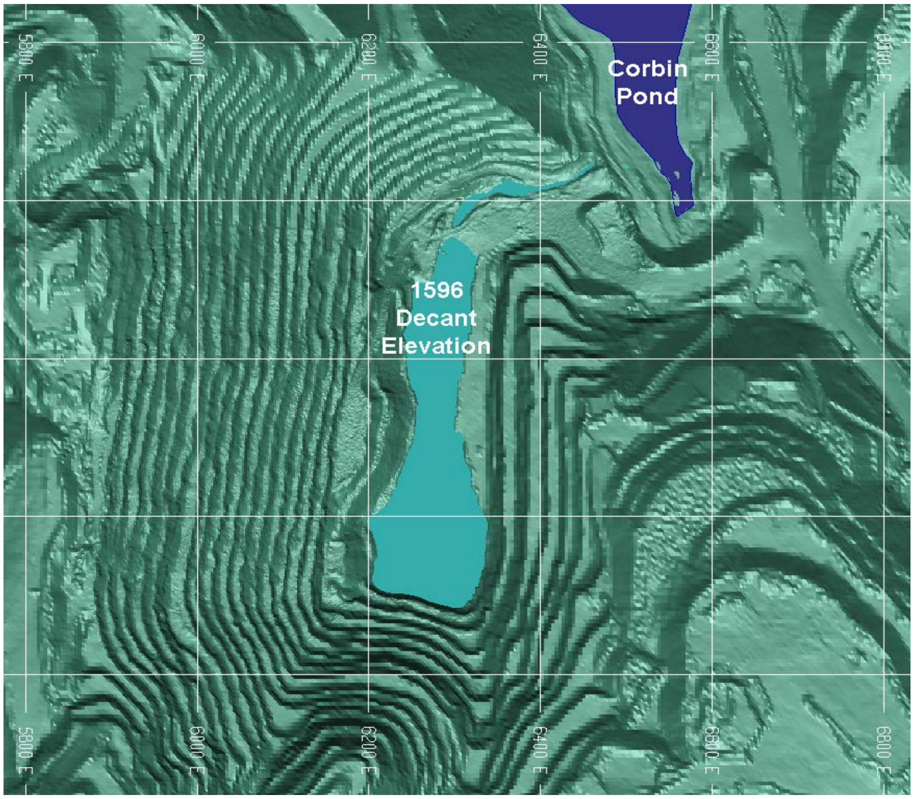
Date	Groundwater Inflow Rate	Comment
Prior to April 2016	0.0001 m^3/s	Before April 2016 little or no groundwater inflows to 6 Pit had been observed.
April 2016 to October 2017	0.001 m^3/s	In April 2016, pumping from 6 Pit began due to an increase in water reporting to the pit, including groundwater. Pump rates applied during this period determined the assumed groundwater inflow rate.
October 2017 onwards	0.004 m^3/s	Increased pumping rates were required in late 2017 and 2018 to accommodate increased groundwater inflow. Increased groundwater inflow is hypothesized to be a result of deepening the pit, which resulted in both the interception of more groundwater, and ability to better capture surface runoff.

Source: compiled in text.

3.2.12 Pit Dewatering

Mining has deepened and changed the configuration of 6 Pit from a slope cut style pit to a basin in which water can be retained. The storage-elevation curve for 6 Pit was updated to reflect the current topography. Pumping is assumed to cease, and the pit allowed to fill in 2023 to an anticipated decant elevation of 1596 m (Figure 3-10).

The model uses measured pumping rates from the pit from March 2016 to December 2018, after which the pumping rate is set to 1200 m^3/day. An additional pumping constraint in the model are the projected inflows to 6 Pit. In model projections, water is pumped from the pit up to the amount of water stored in and/or flowing into the pit in a given time step. Inflows to 6 Pit include local catchment runoff, pit wall runoff and groundwater inflow.



Source: Teck.

Figure 3-11: 6 Pit Topography with Projected Decant Elevation

34 Pit water is pumped to the North Ditch and is discharged into an armored sump immediately downstream of the 14 Pit Horizontal Drain discharge. The North Ditch flows to the Main Sedimentation Ponds, which discharge to Corbin Creek. 34 Pit is pumped at a rate of 5% of projected flow in Michel Creek at CM_MC2 up to the maximum allowable rate (150 L/s), only during higher flow months (April to November).

3.2.13 Pit 14 Horizontal Drains

Horizontal drains were installed in Pit 14 in September 2011 to drain water from the pit into the North Ditch. This was done to maintain the pit water level below the elevation where water would drain to the underground workings (1560 m), and reduce hydrostatic pressure developed once the pit was backfilled. The upper drain is reported to be crushed and it is assumed that water cannot flow through it.

The lower horizontal drain has an outlet higher than inlet, with a gradient between 1-2%. Due to the uphill flow gradient, it is assumed that water can only flow through the horizontal drain when the water elevation in the pit is above the outlet invert. Hence a function in the model is included that allows flow to commence when Pit 14 water levels are greater than 1545 m. The flow capacity of the drain has been set to an assumed value of 0.13 m^3/s.

3.2.14 Conveyances

The conveyances modeled include the: West Ditch, North Ditch, Pengelly Rock Drain, Corbin Rock Drain and Site Water Collection System.

North and West Ditches

Maximum flow and volume capacities were calculated for the North and West Ditches. These are applied to the reservoirs used to model the ditches by limiting the outflows to the flow capacities, and the maximum storage to the volume capacities. The parameters used to calculate the flow and volume capacities are provided in Table 3-10.

Table 3-10: North and West Ditch Specifications

Measurement	North Ditch	West Ditch
Base Width (m)	3.8	0.0
Side Slope Left (H:V)	0.51	0.32
Side Slope Right (H:V)	0.50	0.30
Depth (m)	0.98	3.2
Channel Slope (m/m)	1%	9.3%
Manning's n	0.07	0.07
Area of Flow (m^2)	4.2	3.1
Average Velocity (m/s)	1.3	2.6
Flow Capacity (m^3/s)	**5.3**	**8.3**
Ditch Length (m)	755	1243
Volume Capacity (m^3)	**3200**	**3900**

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\Flowsheets\Coal_Mtn_WTB_Data_Inputs_ML_VM_rev6.xlsx

Notes:

1. Manning's n is assumed an excavated channel, not maintained with possible vegetation growth.

2. The base width of 0 for the West Ditch assumes the ditch section is triangular.

Flow rates were calculated using Manning's Open Channel flow equation. Cross-sectional measurements were taken from LIDAR data from seven sections along the North Ditch and six sections along the West Ditch. The flowrates across each section were calculated for both ditches, and the lowest flowrates obtained across any two sections were used for the capacities of the ditches. The volume capacity of each ditch was calculated by multiplying the length of the ditch by the area calculated for the sections of the ditch that resulted in the most conservative (i.e. lowest) flowrate.

Infiltration from the ditches is unknown and is estimated in the model as 5% of the inflows to the ditches. Infiltration from the West Ditch is assumed to report to Michel Creek downstream of operations. North Ditch infiltration is modeled as reporting to a sink.

Corbin and Pengelly Rock Drains

The Corbin Rock Drain conveys water from Corbin Creek and the overlying East Spoils. The Pengelly Rock Drain conveys water from Pengelly Creek and the overlying Pengelly Spoils. The flows out of the rock drains are attenuated using recession coefficients, as described in Section 3.2.6.

Design information regarding the rock drains is not available. Two reports were reviewed that discussed the theoretical performance and proposed design of the Corbin Rock Drain: 1) *Rock Drain Behaviour at Byron Creek Collieries Sedimentation Pond* (Claridge 1987); and 2) *Geotechnical Study for East Waste Dump* (Piteau 1984). The geotechnical study for the East Waste Dump (Piteau 1984) recommended that the rock drain beneath the East Dump (referred to as the *Waste Rock Dump* in the model) be designed to convey at least the 1-in-200 year return period daily flood flow from Corbin Creek, estimated to be 8.8 m^3/sec (see Table 1 of Piteau 1984). This capacity was selected for the capacity of the Corbin Rock Drain.

The parameters for the Pengelly Rock Drain are unknown. A placeholder value of 8 m^3/s has been applied for the flow capacity of the Pengelly Rock Drain.

Maximum volume capacities have not been applied to either the Corbin or Pengelly Rock Drains (i.e. no upper bounds used in the reservoirs).

Site Water Collection System (SWCS)

The Site Water Collection System includes the network of drains, ditches, culverts and ponds that convey mine influenced water throughout the site to the North Ditch. This includes the Horseshoe Ponds and Step Ponds. The system is simulated as a single unit in the CMO model. Infiltration from all the components in the Site Water Collection System is modeled collectively, assuming 15% of the inflows infiltrate into the ground. Infiltration from the Site Water Collection System is routed to a sink.

3.3 Load Balance Inputs

CMO has a modified Conceptual Geochemical Model (CGM) compared to other sites in the Elk Valley. Modifications to CMO's CGM are described by SRK (2015) and provided in Section 3.3.1.

Geochemical source terms were developed for waste rock in spoils and backfills, coal refuse and pit walls. This includes loading rates based on waste rock volume for nitrate, sulphate and selenium and fixed concentrations for other parameters assuming solubility control by basic pHs. Source term concentrations were derived based on water quality monitoring data collected at CMO. These source terms are described in the following sections.

Loadings and concentrations are calculated for each facility within the GoldSim Contaminant Transport module using mixing cells. Mixing cells are a GoldSim element that solves simultaneous differential equations to calculate loads and concentrations. Mixing cells were created for key facilities. The volumes in the mixing cells are linked to the associated reservoirs in the water balance, and the loads are tracked within the mixing cells.

Load calculations are included for the following water quality parameters: SO_4, NO_3, Al, As, Ba, Be, B, Ca, Cd, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Mo, Na, Ni, Se, Ag, Tl, U, Zn. Parameters were assumed to act conservatively, with the exception of sulphate and selenium – solubility constraints were set for sulphate and selenium, and selenium in 14 Pit and 34 Pit was assumed to be attenuated (Section 3.3.5).

Inflow loading rates are generated for each corresponding inflow in the water balance.

Source terms defined as concentrations are incorporated in the load balance by assigning the water quality to inflows from the corresponding sub-catchment as follows:

$$Inflow\ Loading\ Rate = Inflow \times Source\ Term\ Concentration$$

Source terms defined as loading rates by waste rock volume are incorporated in the model by assigning the loading rate to the waste rock volume at a given facility, as shown in the equation below. As the waste rock volume increases, loading rates are applied to the additional waste rock volume, and the calculated loading increases accordingly.

$$Inflow\ Loading\ Rate = Load\ per\ Unit\ Volume \times Waste\ Rock\ Volume$$

3.3.1 Conceptual Geochemical Models

The dominant waste management facilities at the site and those expected to contribute the majority of chemical loadings are the waste rock dumps. Other sources include the coal refuse disposal facility on Middle Mountain and pit walls. Tailings are not generated separately at CMO but are instead combined with coarse plant refuse and disposed as dry stacked coal refuse in a dedicated facility. Source term inputs to the load balance model were derived in the context of CGMs for each of the waste management facilities at the site.

Waste Rock

The CGM for waste rock in the Elk Valley at Teck's other coal mining operations is well developed and consolidated as part of submissions for the Elk Valley Water Quality Plan (EVWQP) (SRK 2017). The EVWQP CGM is based on the following:

- The dominant waste rock source is the Mist Mountain Formation (MMF).
- The MMF has low potential to generate acid and therefore weathers to yield contact waters with pHs between 7 and 9.
- Oxidation of pyrite in the waste rock yields sulphate and selenium at a rate that has been correlated to the total volume of waste rock in the spoils. The rate is determined on a valley-wide basis and is used to calculate resulting concentrations based on the amount of waste rock and infiltrating water.
- Nitrate release occurs at a rate that is proportional to the mass of waste rock added in a year calculated using the method of Ferguson and Leask (1988). This generic method was developed based on monitoring data from the Elk Valley, but it does not consider recent

site specific explosives recipes and handling, which CMO believes will reduce leaching of explosives residuals. The concentration is calculated from this mass and the infiltrating water volume.

- Concentrations of trace element parameters speciated in solution as positively charged ions (for example, Cd and Zn) are assumed to be present at fixed concentrations regardless of waste rock quantity due to the limiting effects of processes that attenuate these ions, such as adsorption, ion exchange and co-precipitation.

CMO has a modified CGM acknowledging that the Morrissey Formation (MF) and Fernie Formation (which are both stratigraphically below the MMF) are mined due to the complexly folded geological structures. Experience at CMO and other Teck operations in the Elk Valley show that the upper of the two members of the MF (the Moose Mountain Member, MMM) has acid rock drainage (ARD) potential. The lower Weary Ridge Member and the Fernie Formation have low ARD potential. The potentially ARD generating (PAG) MMM has been shown to generate acid within weeks or months of exposure to atmospheric oxygen (SRK 2015).

The true thickness of the PAG layer is approximately 20 m, but folding results in localized areas of greater thickness. Historical mining records indicate that the proportion of PAG rock in spoils deposited to the west of the mined area is probably negligible, whereas all other spoils probably have around 7% PAG rock (SRK 2015).

The modified CGM for waste rock at CMO therefore incorporates the following features:

- Site-specific release rates for sulphate and selenium (SRK 2014d).
- The same nitrate source term concept as the other Elk Valley Operations.
- On balance, waste rock is non-PAG due to both the presence of acid-consuming minerals in the non-PAG waste rock components and the proportion of PAG waste rock.
- Historical disposal conditions have resulted in net non-acidic leaching conditions as shown by decades of pHs exceeding 7 in drainage from spoils containing PAG rock. Future acidification is not expected based on the fact that the PAG rock generates acid soon after exposure and acidity appears to be fully neutralized (SRK 2015).
- Due to the non-acidic weathering conditions, the overall assumption is that concentrations of elements occurring as positively charged ions are leached at fixed concentrations regardless of rock mass.
- The presence of MF waste rock appears to result in accelerated cobalt leaching (SRK 2015); however, the resulting cobalt concentration is fixed regardless of total waste rock mass due to solubility control at basic pHs.

Waste Rock in Backfills

The two main influences of backfill conditions are:

- Rock below the water table in the backfill does not oxidize due to low oxygen conditions.
- Selenium is attenuated provided residence times for pore waters in the saturated zone exceed about one year (e.g. Bianchin et al. 2013).

Coal Refuse

Consistent with coal refuse (CR) and CCR at other operations in the Elk Valley, coal refuse at CMO is non-PAG. The CGM for CR piles is that internal oxygen concentrations are lower than atmospheric due to consumption by oxidation of carbonaceous materials. This results in leachable weathering products being generated from a “rind” of the disposal area. For a given facility, concentrations are assumed to be fixed, but loadings increase in proportion to increased contact water volumes as the footprint increases.

Pit Walls

Pit walls are assumed to function as thin waste rock dumps due to the presence of talus material and the blast shattered zone.

3.3.2 Source Term Concentrations Based on Monitoring Data

Source terms were derived for the stations shown in Table 3-11 which were selected because they have geochemically distinct waters as described in SRK 2014b. Four of the stations are background stations representing water quality upstream of CMO.

The source terms were derived from data collected as part of CMO’s surface water monitoring programs from January 1995 to July 2014. The source terms for Michel Creek at CM_MC1 and Corbin Headwater at CM_CCHW were updated based on new monitoring data in April and June 2020, respectively. Monitoring data were used in calculating mean and 95th percentile concentrations that were used as source terms for each station. When results were below analytical limits of detection (LODs), the LOD values were used in the calculations.

Table 3-11: Source Terms Development from Water Quality Monitoring Programs

Station ID	Description	UTM Coordinates		Year(s) of Data Collection	Location(s) Applied
		Easting	Northing		
CM_PC2	Pengelly Creek Rock Drain	670331	5486350	2008 to 2014	All flows contributing to rock drain discharge
14PIT-PIPE	14 Pit Rock Drain	669559	5487213	2011 to 2014	Used for comparison against predicted results only
CM_CCRD	Corbin Creek Rock Drain	670196	5486003	1999 to 2014	All flows contributing to rock drain discharge
CM_CCPD	Discharge from Corbin Pond	670007	5486382	1995 to 2020	Used for comparison against predicted results only
CM_MM1	Middle Mountain (Coarse Coal Refuse)	669942	5487017	2010 to 2014	All Coal Refuse flows, all catchments reporting to Sowchuck and Hotel Sumps
CM_SPSP	7 Pit Ponds	668344	5483057	2004 to 2012	All flows reporting to 7 Pit Ponds
37PITWELL	37 Pit Well	669232	5484456	2014	
CM_MC1	Background Michel Creek	668171	5482893	1995 to 2020	Runoff from Catchments C10b, C22, C22c, C23, C24 and C24b
CM_PC1	Background Pengelly Creek	670864	5485906	2008 to 2014	Runoff from Catchments C13, C15, C15b
CM_CCHW	Background Corbin Creek	671125	5482488	2001 to 2020	All flows contributing to rock drain discharge

Source: compiled in text based off of SRK 2015a.

East and West Spoils

Source terms for long term weathering in the East and West spoils were based on seepage data collected up to June 2018 (Table 3-12).

The distribution of sulphate concentrations in seepage samples from the West Spoils was bimodal with a distinct subset that was more concentrated. These samples with higher concentrations are indicative of seepage that has been affected by waste rock. Data from stations with at least one sample with sulphate concentrations above 900 mg/L were used to develop the source term for contact water from the West Spoils. This included all samples from stations: CM_NS1, CM_WD11, CM_WD12, CM_WD13, CM_WD14, CM_WD15, CM_WD16, CM_WD17, CM_WD18 and CM_WD19. Expected and upper-case source terms were developed based on mean and 95th percentile statistics of this subset of the available data.

The East Spoils source term was based on the 95th percentile for the whole dataset, which included stations: CM_6PLOS, CM_CS1, CM_CS6, CM_CS8 and CM_NS2.

The source term for runoff from the East Spoils that reports to the Corbin Creek Rock Drain at CM_CCRD was updated in June 2020 based on back calculating the difference in loading from the natural catchment areas (where the CM_CCHW source term is applied) and the monitored loading at the outlet of the CM_CCRD, which represents the runoff from both impacted and unimpacted catchments.

Table 3-12: Source Terms Development from Seepage Monitoring Programs

Station ID	Description	Year(s) of Data Collection	Locations Applied
East spoils	Seepage monitoring data collected from various East Spoils locations	2014 to 2018	Runoff from Catchments C3b, C8, C0b, C11, C16b, C18, C18b and C26b, and 14 Pit and 34 Pit backfill
West spoils	Seepage monitoring data collected from various West Spoils locations	2014 to 2018	Runoff from Catchments C2, C10, C16c and C22b

Source: compiled in text based off of SRK 2015a.

Coal Refuse

Coal refuse at CMO is non-PAG, which is consistent with coal refuse (CR) and CCR at other operations in the Elk Valley. The CGM for CR piles is that internal oxygen concentrations are lower than atmospheric due to consumption by oxidation of carbonaceous materials. This results in leachable weathering products being generated from a “rind” of the disposal area. For a given facility, concentrations are assumed to be fixed, but loadings increase in proportion to increased contact water volumes as the footprint increases.

The Coal Refuse term was calculated using monitoring data from the Middle Mountain road ditch (station CM_MM1). The range was based on the mean to 95th percentile.

Pit Walls

Pit walls are assumed to function as thin waste rock dumps due to the presence of talus material and the blast shattered zone.

Pit wall terms were calculated for those walls in 6 Pit and 37 Pit that remain exposed and will not be covered by backfill or water. The wall terms were calculated as a single concentration representing a combination of the exposed rock types. The term was originally calculated for 6 Pit walls and applied to 37 Pit assuming similar geological composition.

The term was calculated as follows:

- Humidity cell data were used to obtain weathering rates in mg/kg/week on a rock-type basis.
- These rates were used to calculate release under field conditions using a composite scaling factor of 0.01 to represent lower site temperatures and reduced particle surface area (updated by SRK 2018).
- The field release rate was used to calculate total release on a per m^2 basis assuming a bench rubble thickness of 2 m.
- Concentrations were calculated based on wall infiltration of 842 mm/year (90% of total precipitation).
- Predicted chemistry for each rock type was then mixed in proportion to the pit wall composition.

It was found from this calculation that overall pit water chemistry (i.e., that reports to the sumps) would be acidic due to the influence of acidic components of the MF. Based on this finding, attenuation of metals by formation of iron and aluminum hydroxide precipitates was not expected to occur, and the calculated concentrations obtained from the mass balance calculation were not adjusted for secondary mineral precipitation effects. A range of predicted concentrations was calculated by using average and maximum humidity cell rates.

Final concentrations obtained by this method were compared to observed concentrations in acidic 37 Pit water. Concentrations were found to align within an order of magnitude. For example, 37 Pit yielded average iron concentrations of 23 mg/L compared to 58 mg/L obtained by calculation.

Source terms for 6 Pit were evaluated based on their ability to project peak concentrations and seasonal fluctuations of 6 Pit water quality (SRK 2019). Dissolved concentrations of water quality parameters in 6 Pit have remained relatively constant since December 2017. Water quality in 6 Pit has higher sodium and chloride, which are not observed in other water on site and not replicated by the pit wall source terms originally developed for application in the model.

To best represent 6 Pit water quality, and to assess the effect of pumping 6 Pit water to the Corbin Creek rock drain, the 95th percentile for the whole dataset from 6 Pit water samples was used as the updated source term for pit wall and local catchment runoff.

The source term for influent groundwater was updated based on water quality data collected from the 6 Pit deep well. A most likely case source term and an upper-case source term were developed based on average and 95th percentile of the whole dataset, respectively.

3.3.3 Initial Mass

Initial masses of constituents are included in the load balance model for Corbin Dam, 14 Pit, 34 Pit and main sedimentation ponds. The masses are based on measured chemistry and initial volumes at these locations.

3.3.4 Selenium and Sulphate Release Rates

Oxidation of pyrite in the waste rock mobilizes sulphate and selenium at a rate that has been correlated to the total volume of waste rock in the spoils. The rate is determined on a valley-wide basis and is used to calculate direct loading of sulphate and selenium by assigning the loading rate to the cumulative volume of newly placed waste rock volume within a given facility (i.e., waste placed after the model initiation date – waste placed prior to model initiation is represented by source terms based on seepage data). As the waste rock volume increases, loading rates are applied to the additional waste rock volume. The calculated loading rate is equal to the release rate times the volume of waste rock.

Loading rates for newly placed waste rock and loadings rates representing long term weathering for sulphate and selenium are added together in the model to calculate the time dependent loading rate as new waste rock is added to the spoils.

Loading rates for selenium and sulphate had been developed for the Regional Water Quality Model (RWQM) (SRK 2014) and revised in the most recent update to the RWQM (SRK 2017). In the 2017 update, tributary specific annual release rates were calculated from historical monitoring data and records of waste rock placement. The local CMO model applied annual release rates for the 95% upper confidence limit provided in 2017, scaled as per the monthly distribution published in the earlier methodology.

A two-year time adjustment was applied to loadings from newly placed rock in spoils to replicate the lag between when waste is placed to when the signature of the new waste on water quality is expected to be observed at downstream monitoring stations (SRK 2017).

3.3.5 Selenium Attenuation in 14 Pit and 34 Pit

Additionally, selenium is attenuated provided residence times for pore waters in the saturated zone exceed about one year (e.g. Bianchin et al. 2013). The attenuation effect is calculated from the mass balance of the selenium flux entering the backfill $[Se]_{in}$:

$$[Se]_{out} = k[Se]_{in}$$

The value of k was set based on the calibration with 14 Pit drainage water. Since residence times in 14 Pit are expected to be the same in the future, continuing attenuation is expected. A similar attenuation effect was assumed for 34 Pit backfill below the flood level based on the assumption that residence times is similar.

3.3.6 Blasting Residues

Nitrogen compounds are introduced into the waste rock as residuals from blasting agent, which is ammonium nitrate and fuel oil. Nitrate is the main residual, which is flushed from the waste over a period of time. Flushing rates for nitrate were developed for the RWQM (SRK 2017). The methods for rate development from the RWQM were incorporated in the CMO local water and load balance model.

To develop the nitrate source term for the CMO water and load balance model, records of the volume of waste rock placed and the quantities of explosives used were replicated as for the RWQM (SRK 2017). The proportion of explosives not combusted (residual nitrogen) was calculated for CMO using historical waste placement data. In addition, SRK (2017) estimated the lag time to release by evaluating the cumulative nitrate load and concentration trends monitored at CMO over time, and the relation to CMO's waste placement history. The nitrate loadings were applied after an initial lag time of 2 years (SRK 2017). The weekly distributions for nitrate release determined by SRK (2017) was applied to annual nitrate loading rates.

The annual nitrate as N load released to each catchment is calculated using the following equation (SRK 2017):

$$N(n,t) = \frac{V(n) \cdot P_f(n) \cdot f_N \cdot f_R}{t_{AL}}$$

The following inputs were applied in the model:

- V is the waste rock volume. A timeseries for historical waste rock volumes placed by catchment was provided by CMO.
- P_f is the powder factor. A timeseries for historical power factor was provided by CMO.
- F_n is the amount of nitrogen in ANFO and emulsion blends, which is assumed to be 35% by weight.
- f_R is the loss factor = 4.3% for CMO.
- t_{AL} is the average leach rate for nitrate. A 10-year leach time was applied, as recommended by SRK (2017).

3.3.7 Geochemical Constraints

In addition to fixed source term concentrations for the majority of elements to reflect pH controls, concentration solubility limits for sulphate and selenium were built into the model to be applied throughout the load balance when the calculated concentrations exceeded these concentrations:

- Sulphate: Gypsum constrained solubility limit of 2,400 mg/L.
- Selenium: Gypsum constrained solubility limit (co-precipitation with gypsum) of 1.5 mg/L. Although this mechanism is built into the model, no selenium concentrations above 1.5 mg/L are either measured or projected to occur and therefore this mechanism is not employed in model projections.

3.3.8 Calcite for Trace Metals

Cadmium originates from oxidation of sphalerite (ZnS) which contains trace levels of cadmium. (SRK 2017). Therefore, zinc and cadmium release rates are correlated.

Waters emerging from waste disposal areas are over-saturated with respect to calcite which results in secondary calcite precipitation in streams receiving contact waters (SRK 2014c). An important consequence of calcite precipitation is that it removes trace elements from the water column to varying degrees. Divalent cations such as cadmium, cobalt, copper, manganese, nickel and zinc are most readily co-precipitated with calcite by substitution of the calcium ion. Trace element co-precipitation in calcite has a moderating influence on water quality which varies by season. Lowest metal concentrations are apparent during low flows when calcite is precipitating whereas seasonally highest concentrations occur during highest flows.

In the 2016 model update, the co-precipitation of cobalt with calcite was added to the model based on equations developed by SRK (2015b) to predict cobalt concentrations. The projected cobalt concentrations were based on empirical relationships that relate seasonal cobalt concentrations to sulphate concentration and the proportion of waste rock from the Morrissey Formation within the upstream runoff area.

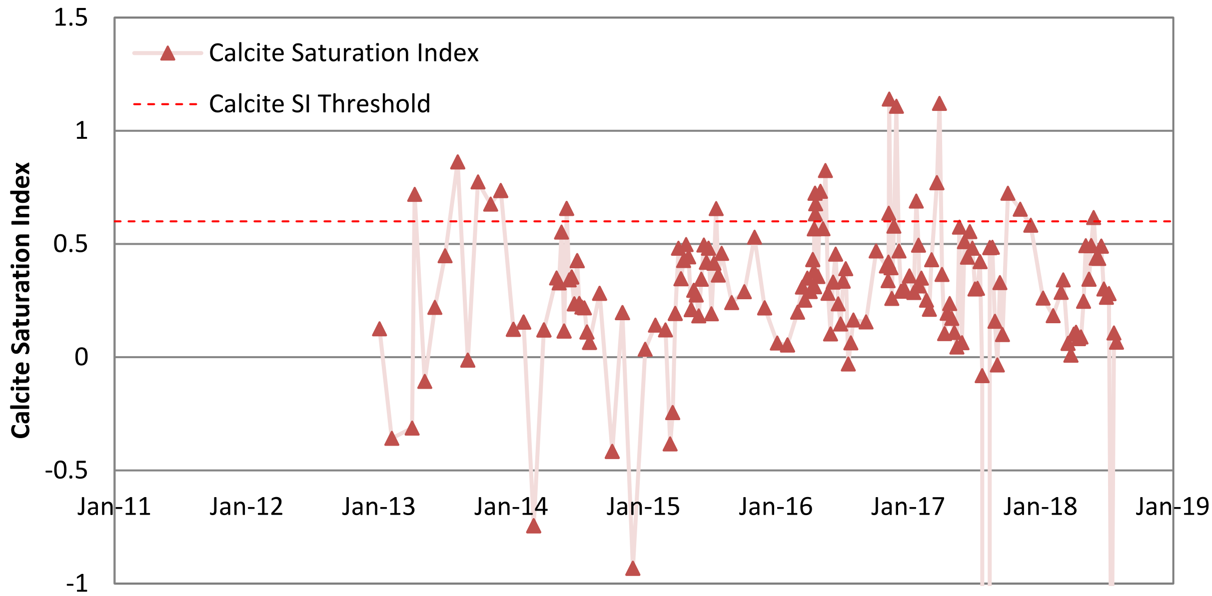
The model was further revised to include sequestration of cadmium and zinc by calcite co-precipitation. The methodology applied for the Regional Water Quality Model (RWQM) was adapted for application at CMO.

In the 2017 RWQM, the cadmium source term is empirically represented by determining the higher range of cadmium concentrations (50th and 95th percentile) indicated by monitoring data grouped according to periods when calcite is anticipated to be precipitating and not precipitating. The period when calcite is not precipitating is indicated by calcite saturation indices less than 0.6 which has been determined as the threshold below which calcite no longer precipitates (SRK 2014b).

The geochemical model PhreeqC (Parkhurst and Appelo, 2013) was used to assess calcite saturation in Corbin Creek. Measured concentrations, field pH, and field temperature were inputs to the geochemical model. Calcite was oversaturated in water samples collected from Corbin Creek since January 2013 and did not vary seasonally (Figure 3-11). This result suggests that calcite is rarely under-saturated in Corbin Creek, and that fluctuations in metal concentrations may be a result of the other factors limiting the sequestration through co-precipitation with calcite (i.e., insufficient time to form, limited capacity). Higher flow could reduce the residence time in the creek system and reduce time calcite has to precipitate. Also, the model does not limit the capacity of cobalt removal through co-precipitation, whereas in reality this mechanism does have limited capacity.

Higher concentrations of cadmium and zinc are observed when the flow rate in Corbin Creek is high (Figure 3-12). A load attenuation factor accounting for sequestration was applied to both cadmium and zinc during low flow periods (*i.e.,* flow < 0.085 m^3/s). During high flow periods, no attenuation factor was applied to these parameters; instead, concentrations of zinc and cadmium were projected based on conservative mass balance.

The timing of cobalt sequestration by calcite was also based on a flow threshold. For cobalt, the flow threshold of 0.145 m^3/s provided the best calibration with monitoring data.



Source: Z:\01_SITES\Coal Mountain\1CT017.192_CMO_Ni_Co_Treatment_Eval\PhreeqcModeling\ InputDataCMO_1CT017-192_Rev01_MCN.xlsx

Figure 3-12: Saturation Index for Calcite in Corbin Creek at CM_CC1

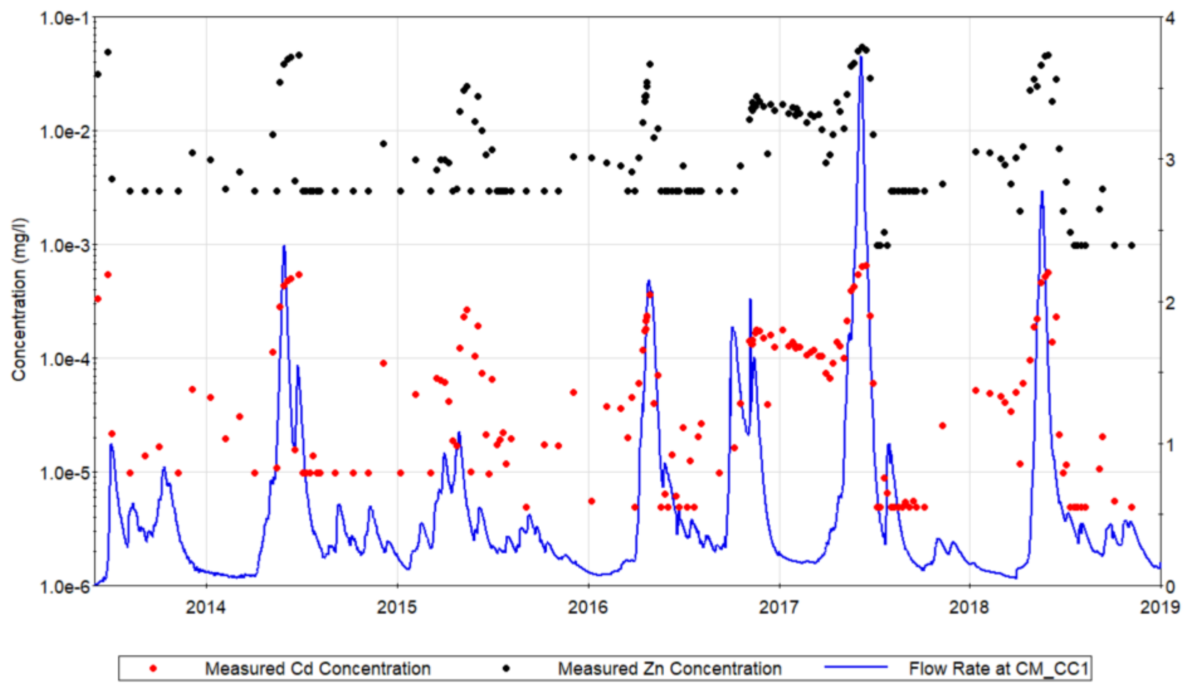


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Figure 3-13: Flow Rate and Dissolved Cadmium and Zinc Concentrations in Corbin Creek at MC_CC1

3.3.9 37 Pit Backfill

As of the end of 2018, the total backfill volume to 37 Pit was 975,000 BCM, as described in Section 2.5.3.

SRK's experience in the Elk Valley is that coal refuse and coarse coal refuse are non-PAG and have geochemical characteristics that are generally stable. SRK (2004) showed that coarse coal refuse (CCR) samples contained less than 0.1% sulphur as sulphide. SRK (2015b) compiled data on CCR characteristics for a number of sources from Teck coal mines in the Elk Valley and concluded that sulphide sulphur content was less than 0.1% and ARD potential was negligible.

Six ABA samples of EVO coal refuse were submitted for analysis in April 2018. Preliminary assessment of results indicate that EVO coal processed at CMO has similar geochemical characteristics (i.e., low content of sulphur as sulphide, and non-PAG) as plant refuse at other Teck sites (pers. comm. Stephen Day). Detailed interpretation of geochemical characteristics of these EVO coal refuse samples, along with confirmatory samples, will be reported in CMO's annual ML/ARD Management report.

The water and load balance model assumed an initial flush based on the volume of re-handled waste rock and plant refuse material, and a fixed concentration source term representative of long-term runoff quality. Initial flush rates for waste rock and coal refuse, and long-term runoff quality of coal refuse, provided by geochemical characterization studies at other mines in the Elk Valley, namely Fording River and Greenhills operations, were assumed to be applicable to backfill material for 37 Pit.

The initial flush for re-handled plant refuse and waste rock reflects weathering products that accumulated through time since the waste was originally deposited. The source terms for flushing are based on geochemical characterization at the Fording River Operations (SRK, 2014) of flushed loads from individual re-handled legacy wastes, including one source term for waste rock and another source term for coarse coal refuse.

The long-term runoff quality for coal refuse is based on Greenhills Operation Area A CCR drainage chemistry (SRK 2009). This source term was compared with newly collected seepage data from the Middle Mountain refuse facility at CMO. Water quality from the two sources were similar, although Area A CCR drainage had higher concentrations for some parameters. Area A CCR drainage chemistry is conservatively used as a proxy for long-term runoff quality for coal plant refuse in 37 Pit. The same source term is applied for refuse placed directly from the plant for CMO coal processing and EVO coal processing.

Source terms were applied in the model for the initial flush, which is estimated on a volumetric basis of re-handled material, and for the long-term runoff quality, which is based on a fixed concentration (SRK 2018). The initial flush from re-handled material is assumed to occur for one year starting when it is placed.

3.3.10 Rehandle in the East Spoils

Concentrations of several parameters have increased in the discharge from Corbin Pond (CM_CCPD) starting in early 2017. This trend was observed in sulphate, parameters associated with the flush of blasting residues (nitrate, ammonia, and nitrite) and parameters associated with metal leaching (boron, calcium, cobalt, lithium, magnesium, manganese, molybdenum, nickel, potassium, selenium, sodium and hardness).

A review of factors that affect water quality in Corbin Creek was undertaken to identify the mechanism responsible for increasing water quality trends (SRK 2019). Starting in 2016 and continuing through most of 2017, historically spoiled waste material at the northeast corner of 6 Pit was removed and placed in the southern and southeastern portion of the East Spoils. Re-handled waste rock will produce an initial flush as weathering products that have accumulated since the waste was originally deposited are disturbed and exposed to meteoric water.

The water and load balance model was updated to include an initial flush to the Corbin Creek rock drain from the placement of 8,760,000 BCM of the re-handled historical spoils from 6 Pit and placed in the East Spoils. Initial flush source terms are estimated based on the volume of the re-handled material. The source term for the initial flush from re-handled waste rock was based on a geochemical characterization at the Fording River Operations (SRK, 2014) where flushed loads from individual re-handled legacy wastes, including waste rock, have been quantified. This source term is likely conservative, as rehandle is likely not as old as the sampled material from Fording River Operations, and so has not weathered to the same degree.

Placement of re-handled waste rock was assumed to begin mid-2016 and throughout 2017. The initial flush source term is applied at a constant rate for one year after the rehandled waste is placed, with a two-year time adjustment similar to that applied to nitrate loading rates for from newly placed rock. Initial flush source terms are estimated based on the volume of the re-handled material. Loadings from the initial flush were added to water in the Corbin Creek rock drain modelling node. Other loading sources reporting to this node include background catchment inflow to the rock drain and long-term seepage from the East Spoils.

Since the 6 Pit historically spoiled waste material was relocated, additional re-sloping has been completed in the East Spoils as part of the CMO reclamation efforts. The volume of waste rock re-sloped between January 1, 2018 to December 31, 2019 was added to the model. Prior to 2018, progressive reclamation efforts were focused on areas outside of the East Spoils.

3.3.11 Total Metals

Upstream of Corbin Creek, model projections for metals are for the dissolved fraction. Total metals are accounted for by estimating a load associated with the suspended fraction and adding that to the load in the dissolved fraction. The load in the suspended fraction was calculated by multiplying the average total suspended solids (TSS) concentration at CM_CC1 by the monthly average TSS concentrations from the Main Sedimentation Pond. Total metal concentrations were estimated at CM_CC1 and are reflected in water quality projections at CM_MC2.

3.3.12 Measured Water Quality

Time series of sampling data were extracted from the CMO EQuIS database for locations downstream of CMO on Corbin Creek (CM_CC1) and Michel Creek (CM_MC2), and discharges from Corbin Creek Rock Drain, Corbin Dam, 14 Pit pipe and Sediment (Main) Ponds. Data from 2010 to 2020 were entered in the model. Only records where the data was available for all parameters modelled were used. Monitoring data were compared to projected results from the load balance model for the purposes of model calibration.

4 Model Evaluation

The purpose of the CMO Water and Load Balance model is as a robust tool for making future water management decisions. For this reason, QA/QC and calibration of the model were a focus area of model development. The following sections describe evaluation of the CMO load balance model performance.

4.1 Model QA/QC

The water quality prediction model was reviewed. The review process included the following steps:

1. Checking that data sources are documented.
2. Verification that storages, inflows, and outflows are correctly located and allocated to the right source and sink.
3. Cross checking of flows to ensure they are not duplicated or missed.
4. Checking of status elements and mine dates to ensure the timing of events is accurate according to the current mine plan.
5. Verification of WBM functions and expressions to ensure they are working as intended.
6. Balances on individual water management facilities were verified by ensuring the inflows and storage of a facility is balanced by the outflows, and that no unaccounted flow (or sinks) are in the model.
7. For the calibration period, predictions were evaluated through comparison to monitoring data.
8. Using professional judgement and experience to evaluate if results reflect the understanding of the project and model inputs.
9. Documentation of quality control procedure and results.

4.2 Model Calibration

The model has undergone significant revisions in both 2016 and 2019, at which time full model re-calibrations were completed on water quality predictions. For interim applications, model validation was performed using newly collected data.

The following sections present the results of the model calibration. The model calibration period was from June 2013 to December 2019. Predictions for the following nodes were compared to measured flow and water quality data collected by CMO:

- 37 Pit, 34 Pit and 6 Pit.
- Corbin Creek Dam.
- Main Sedimentation Ponds.

- Corbin and Michel creeks.

Calibration results are organized by water quantity, including water level, pump rates and flow rates, and water quality, including predictions for selected parameters. Calibration results are evaluated quantitatively or qualitatively, or a combination thereof.

4.2.1 Water Quantity

34 Pit Water Level

Measured water level data for 34 Pit were used to calibrate predicted water levels (Figure 4-1). Predicted water level in 34 Pit during filling in 2014 is well matched to measured data. The predicted water level generally fluctuates in sync with the measured water level, implying processes that influence water quantity in 34 Pit are adequately characterized in the model. However, the magnitudes of the oscillations were not well replicated between mid-2016 and mid 2019, suggesting that the sensitivity of water level to influences (including modelled inflow or measured pumping rates) has not always been well replicated.

In early 2017 the water level was predicted to drop quickly while measured data does not show this event. The pumping data applied in the model influences the rate of water level decrease. Since mid-2019, measured and predicted water levels correlated well.

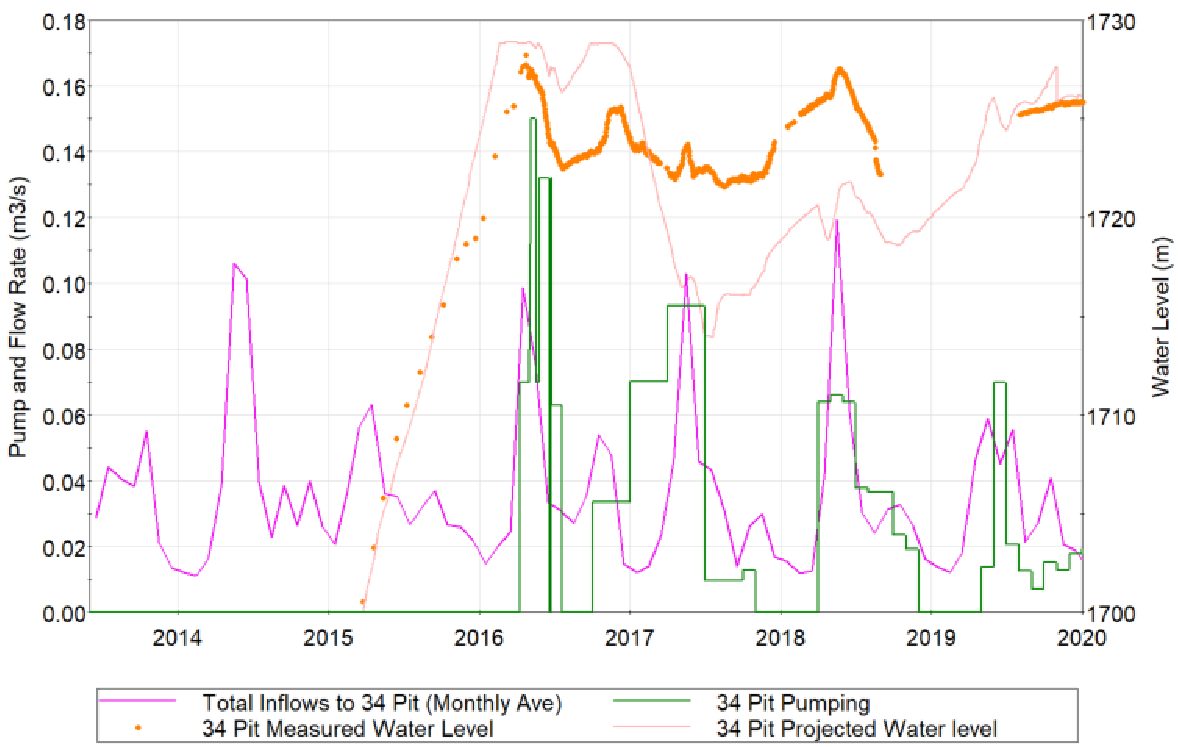

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Figure 4-1: Measured and Predicted Water Level in 34 Pit

Mine Discharges

Comparisons of predicted and measured discharge rates from the following mine facilities were evaluated:

- Main Sedimentation Ponds (CM_SPD).
- Corbin Dam (CM_CCPD).

The accuracy of modelled flows was evaluated using the Nash-Sutcliffe Efficiency (NSE) statistic:

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_m^t - Q_0^t)^2}{\sum_{t=1}^{T}(Q_0^t - \overline{Q_0})^2}$$

Where Q_m^t is the modelled quantity at time *t*, Q_0^t is the measured flow, and $\overline{Q_0}$ is the average measured flow. NSE values between 0.5 and 0.65 indicates a ‘good’ fit for simulated to measured stream flow data (Ritter, 2013; Moriasi et al., 2007). Daily predicted flow rates were used for this evaluation.

Figure 4-2 and Figure 4-3 present the comparison of modelled and measured discharge rates for the above stations. Daily and monthly average discharge rates are presented along side measured discharge rates.

The modelled hydrograph and timing of peak discharge rates correlate well with measured data at both mine discharge points. Predicted discharge rates capture the overall range of measured discharge rates, except for some freshet flows. Monthly average peak flows in 2017 and 2018 from both discharge points were slightly underpredicted.

Predicted flows at CM_CCPD (NSE = 0.63) were considered good fits with measured flows.

At CM_SPD, the NSE was calculated to be 0.44. The NSE is based on squared differences between observed and predicted flows and it is more sensitive to peak flows (higher magnitudes) than low flow conditions (lower magnitudes). Daily peak flows in 2017 and 2018 were not well captured by model predictions. However, the base flow periods are more sensitive to impacts from loading contributions than peak flows. Ensuring accurate representation of base flows allows for appropriate assessment of potential environmental impacts to receiving waters.

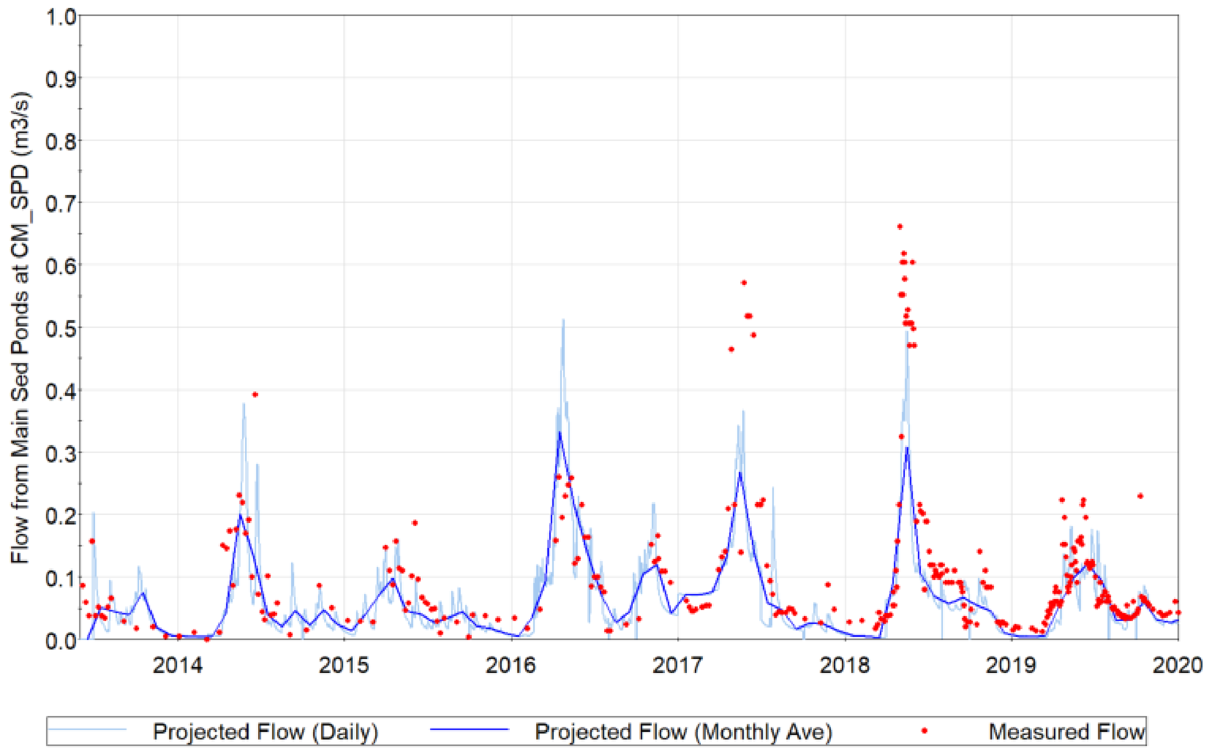

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Figure 4-2: Measured and Predicted Discharge Rate from the Man Sedimentation Ponds (CM_SPD)

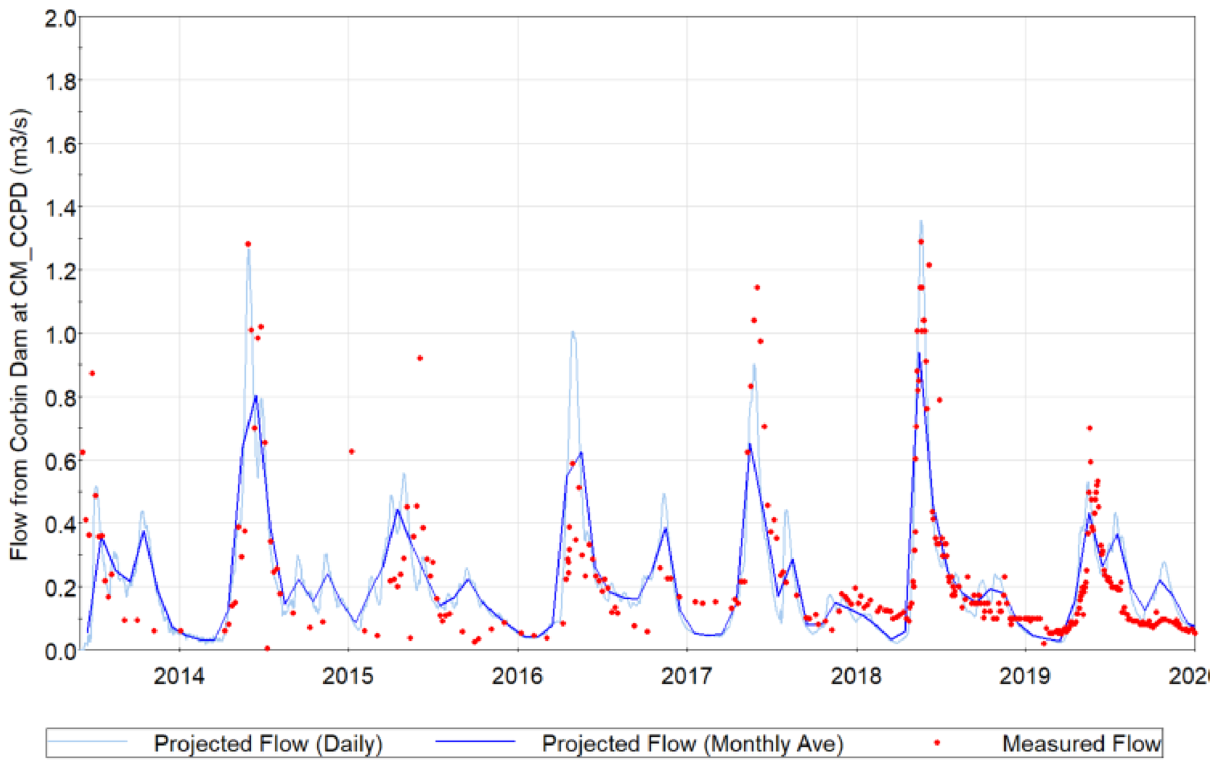

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Figure 4-3: Measured and Predicted Discharge Rate from Corbin Dam (CM_CCPD)

Stream Flows

Comparisons of predicted and measured flow rates in the following creeks were evaluated:

- Corbin Creek at CM_CC1.
- Michel Creek at CM_MC2.

Figure 4-4 and Figure 4-5 present the comparison of modelled and measured stream flows for the above stations. Monthly average discharge rates are presented with measured discharge rates.

Flow in Corbin Creek is dominantly made up of discharge from Corbin Dam, and to a lesser extent, Main Sedimentation Ponds. A suitable calibration in Corbin Creek is reflective of the good fit between modelled and measured flows at upstream locations.

The predicted flow in Michel Creek reflects the hydrograph and timing of peak runoff in measured data for this location. Additionally, modelled base flows are consistent with measured low flows during winter months, when concentrations of most water quality parameters are most sensitive to changes in loading.

Predicted flows at both CM_CC1 (NSE = 0.74) and CM_MC2 (NSE = 0.57) were considered good fits with measured flows.

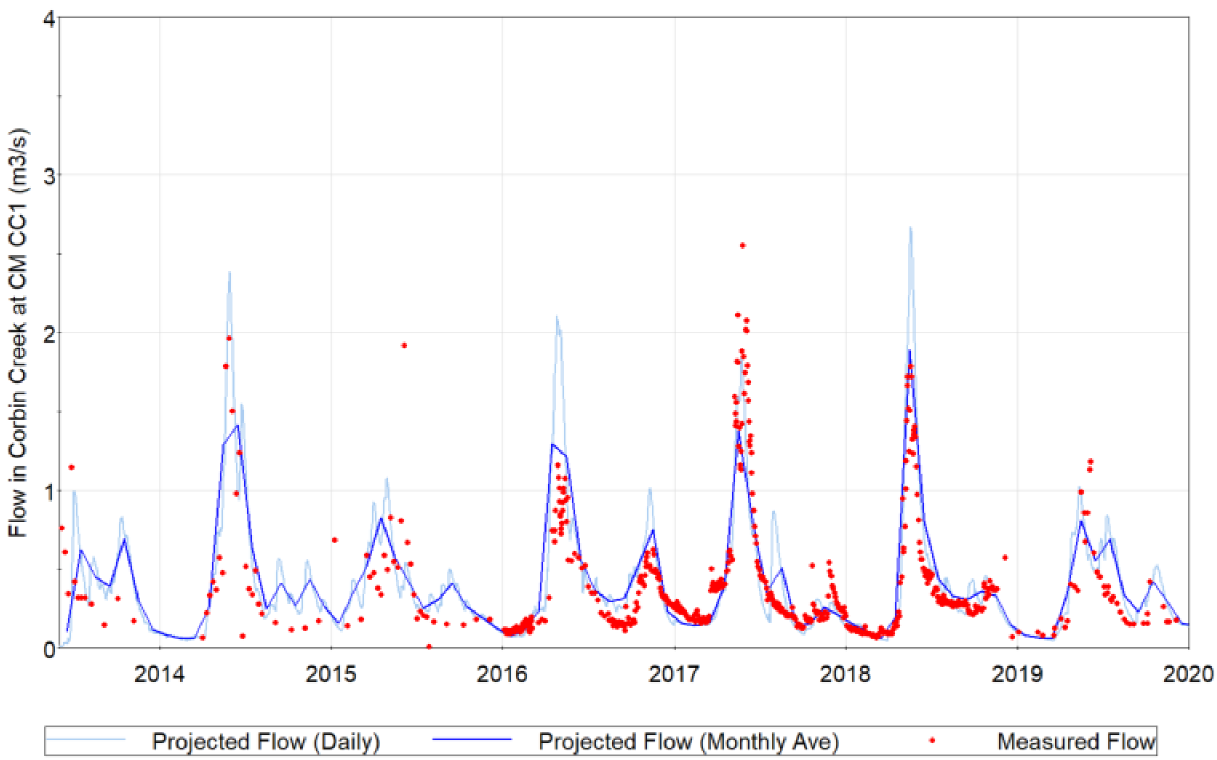

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Figure 4-4: Measured and Predicted Flow Rate in Corbin Creek at CM_CC1

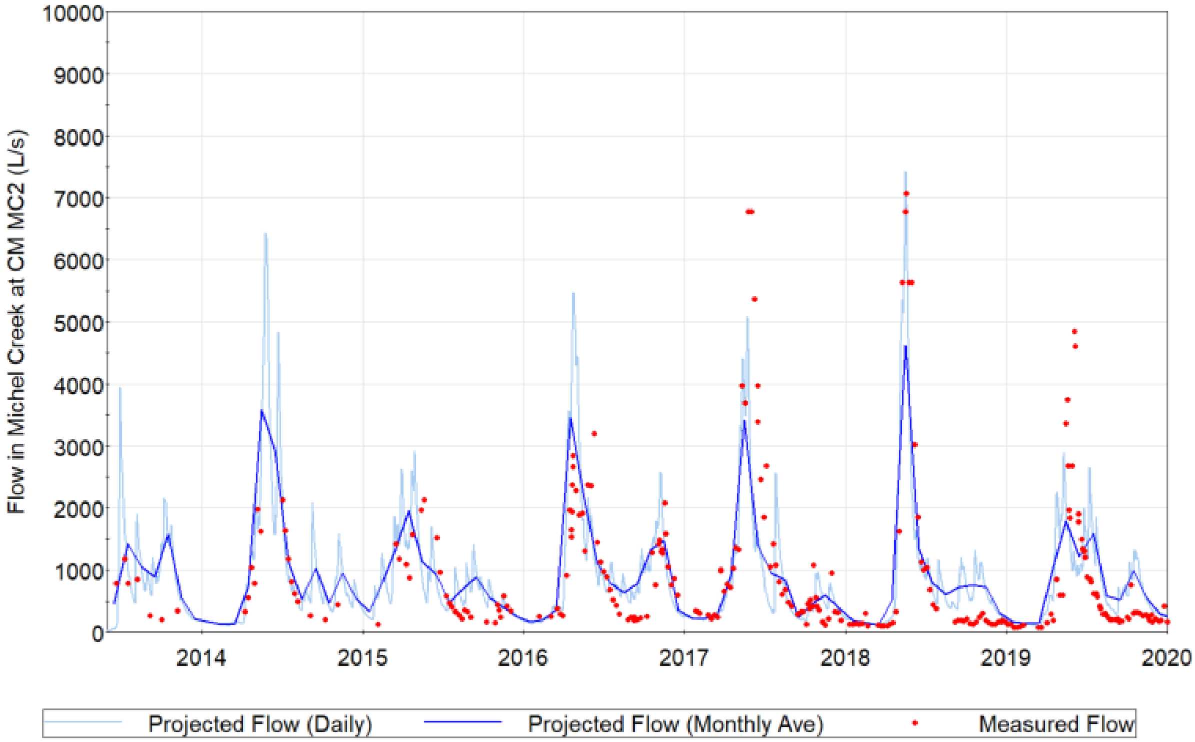

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Figure 4-5: Measured and Predicted Flow Rate in Michel Creek at CM_MC2

4.2.2 Water Quality

The load balance was calibrated by updating inputs and mechanisms as described in Section 3 and adjusting various assumed inputs to the water and load balance, such that model predictions match measured data.

The water quality calibration focuses on parameters that are expected to be mobile and act geochemically conservatively (i.e., sulphate and nitrate), but also includes a discussion of parameters that are influenced by mechanisms applied in the model (e.g., selenium at Corbin Dam (CM_CCPD), cadmium in Corbin Creek at CM_CC1). In all calibration plots, the average case source terms were used for model predictions. Calibration plots and discussion for specific locations are included below. In addition to receiving environment locations including CM_CC1 and CM_MC2, upstream nodes including 37 Pit, 34 Pit and 6 Pit are discussed because the goodness of fit at upstream locations directly impacts the ability of the model to calibrate at downstream locations. In addition, understanding mechanisms influencing water quality at upstream nodes informs water management decisions at these locations.

Calibration plots for all predicted parameters at CM_CC1 and CM_MC2 are presented in Appendix B.

37 Pit

Calibration plots for sulphate and nitrate concentrations in 37 Pit are presented in Figure 4-6 and Figure 4-7, respectively. Calibration for sulphate and nitrate in 37 Pit captures the range of concentrations for these parameters measured in the limited dataset.

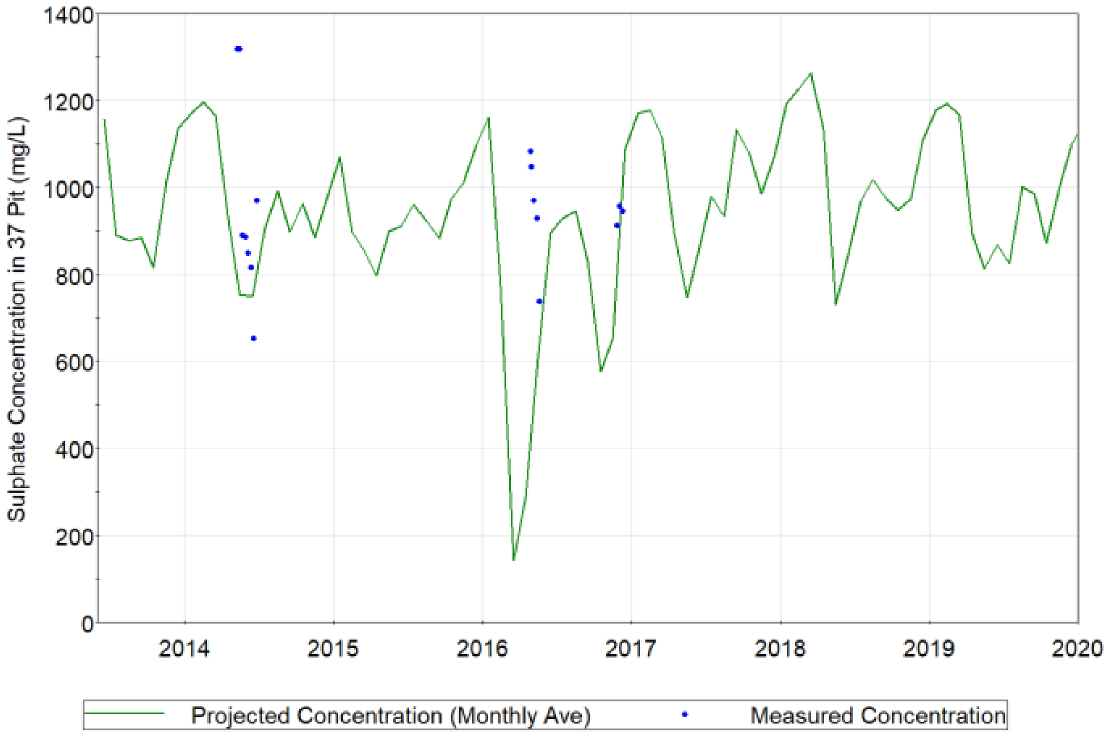

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Figure 4-6: Measured and Projected Sulphate Concentration in 37 Pit

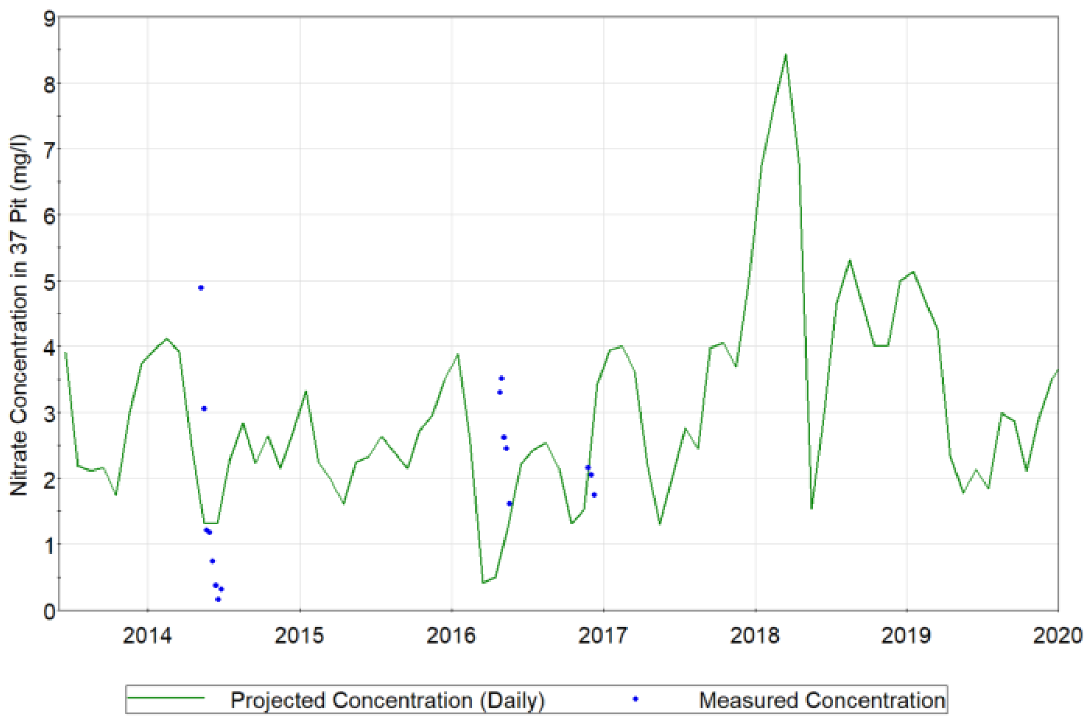

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Figure 4-7: Measured and Projected Nitrate Concentration in 37 Pit

34 Pit

Calibration plots for sulphate, nitrate and total cobalt concentrations in 34 Pit are presented in Figure 4-8, Figure 4-9 and Figure 4-10, respectively. 34 Pit contains a large volume of water (approximately 2.5 Mm^3), and therefore water quality parameter concentrations remain relatively constant (no seasonal variability). Calibration for sulphate and nitrate in 34 Pit captures the order of magnitude of concentrations for these parameters measured in the limited dataset.

Recently, the measured concentration of sulphate and cobalt in 34 Pit have decreased but projections show no change. The reason for this discrepancy is undetermined. However, the model projections remain conservatively high.

Measured concentrations of nitrate in 34 Pit have also recently decreased. The decreasing trend in nitrate concentrations projected after 2015 is a result of historical flushing of blast residues from backfilled waste rock leaving the system (discussed in Section 3.3.6). The initial concentration of nitrate was used to calibrate the nitrate projections. Due to a lack of data prior to 2015, validating the early portion of this trend is not possible.

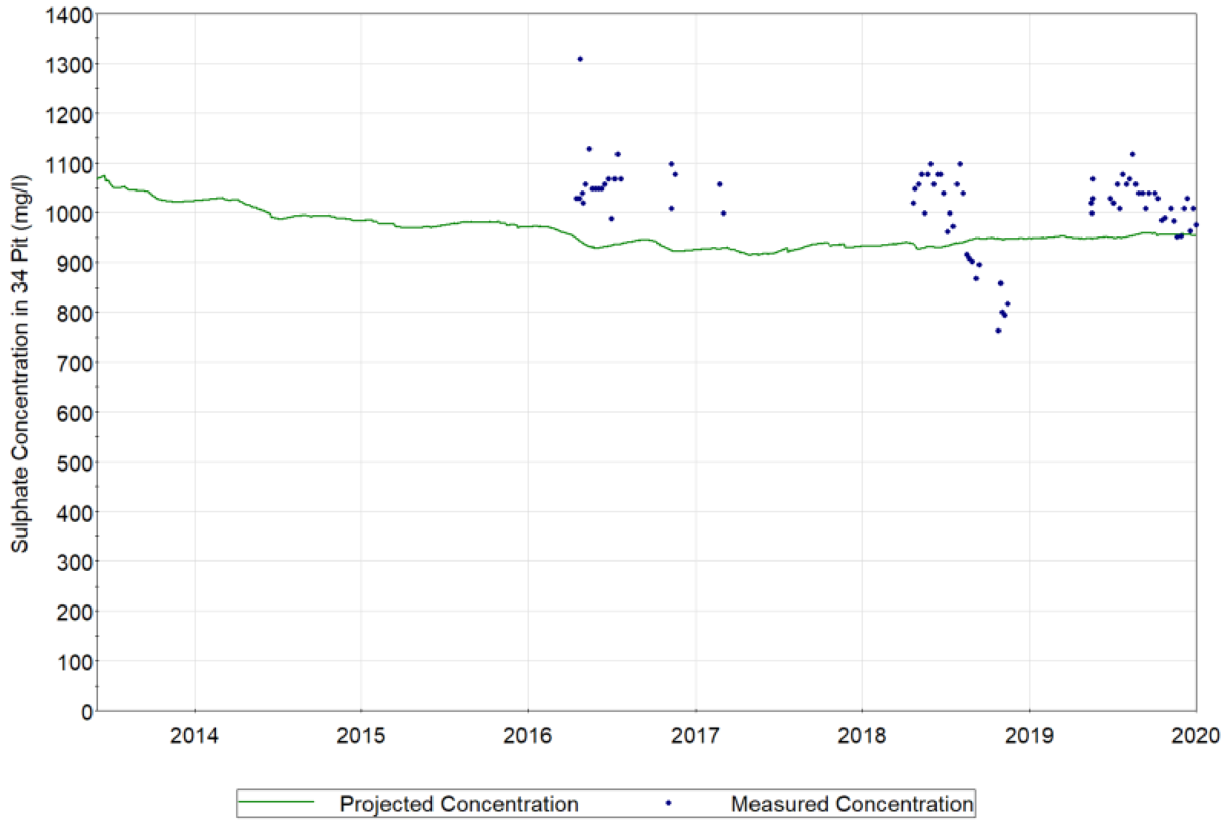

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Figure 4-8: Measured and Projected Sulphate Concentration in 34 Pit

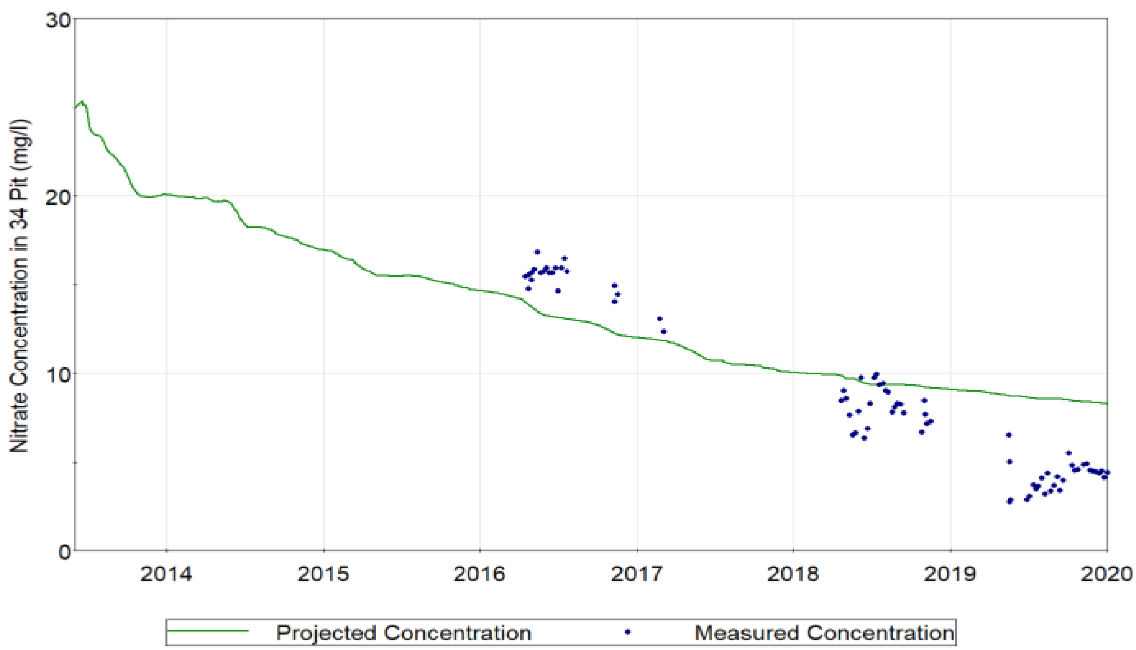

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Figure 4-9: Measured and Projected Nitrate Concentration in 34 Pit

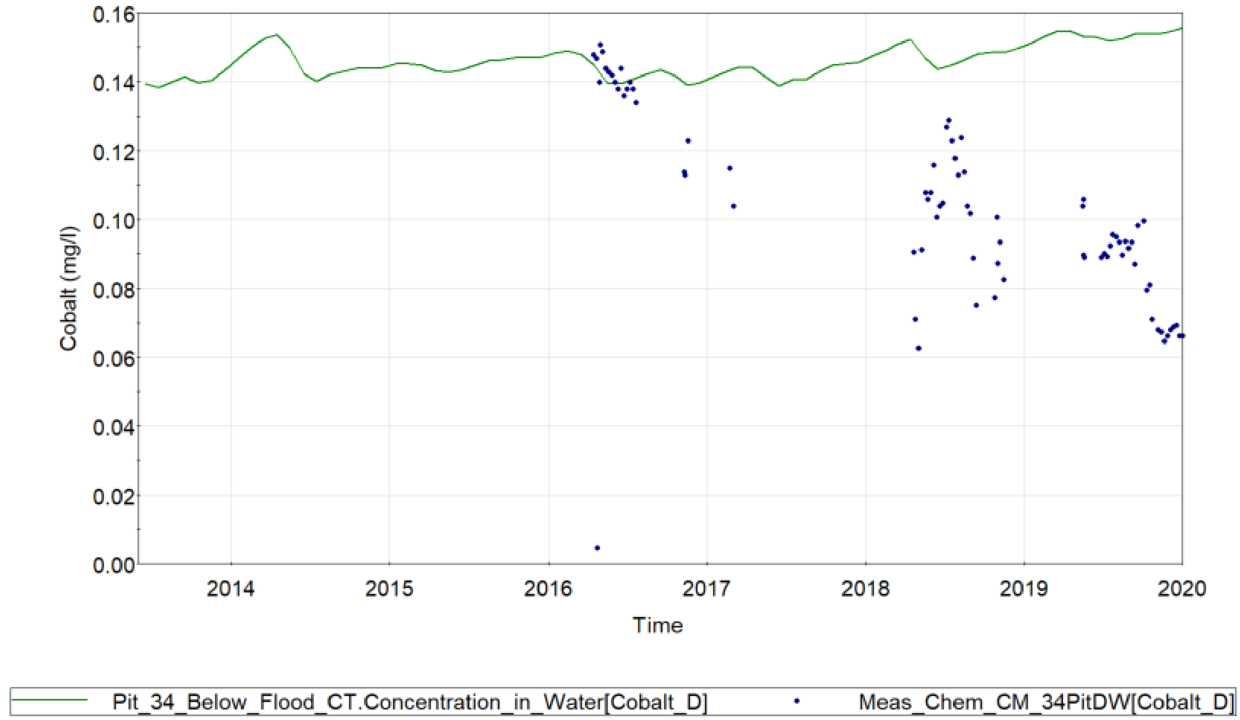

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Figure 4-10: Measured and Projected Cobalt Concentration in 34 Pit

6 Pit

Plots of measured vs. projected concentrations of sulphate, nitrate and sodium in 6 Pit are presented in Figure 4-11, Figure 4-12 and Figure 4-13, respectively.

Projected trends of sulphate and nitrate are similar. From the beginning of the model run in June 2013 to early 2016, no specific groundwater inflow was observed in 6 Pit. This observation is included the model. All loadings to 6 Pit during that time fluctuate with runoff (i.e., runoff from pit walls and local runoff increase proportionally). This results in no projected seasonality in water quality concentrations. Starting in 2016, groundwater inflow rates were assumed to increase as described in Table 3-9, resulting in an increase in seasonal fluctuations of projected sulphate and nitrate concentrations which generally match measured concentrations in magnitude and timing of peaks. Projected sulphate and nitrate concentrations in 6 Pit are conservatively high compared to measured data.

Sodium concentrations are highlighted because of a spike in sodium observed in measured data in the Corbin Dam. Projected sodium concentrations are conservatively high, and range between approximately 100 and 200 mg/L.

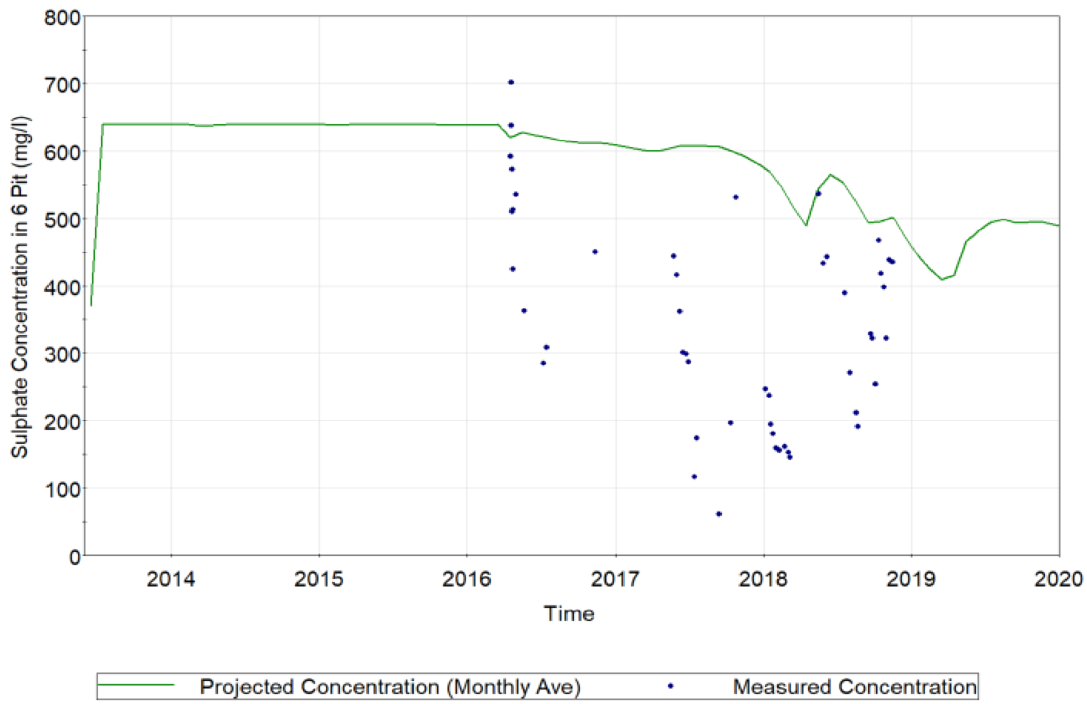

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Figure 4-11: Measured and Projected Sulphate Concentration in 6 Pit

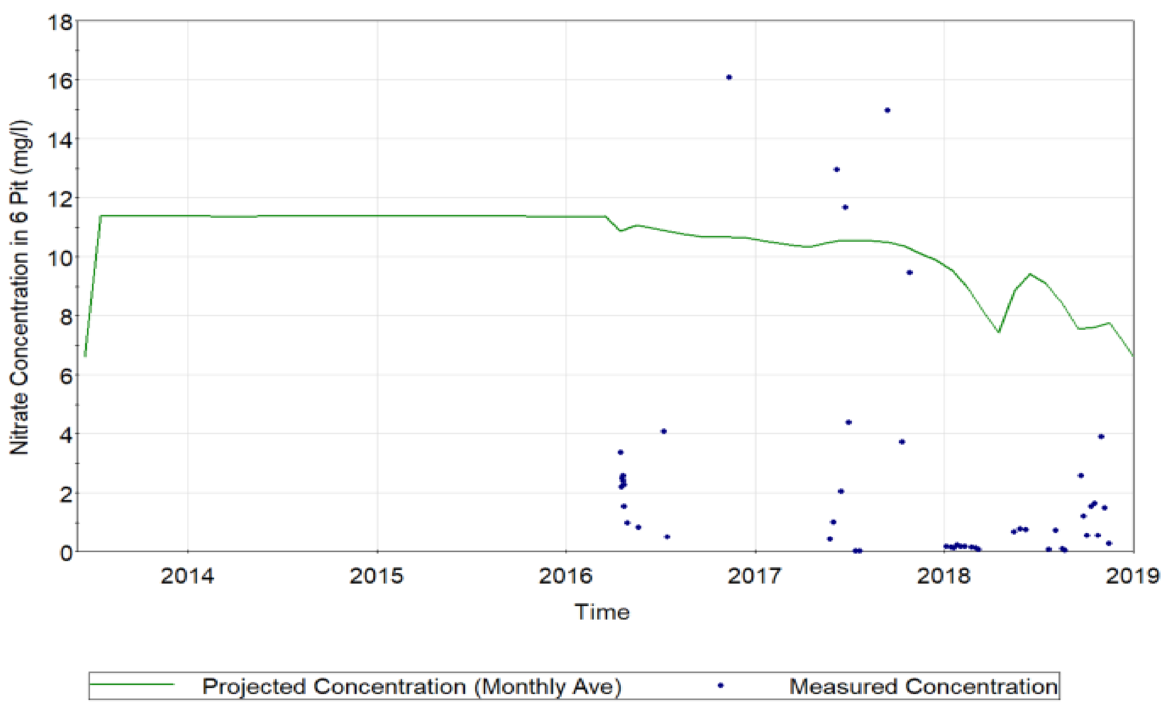

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Figure 4-12: Measured and Projected Nitrate Concentration in 6 Pit

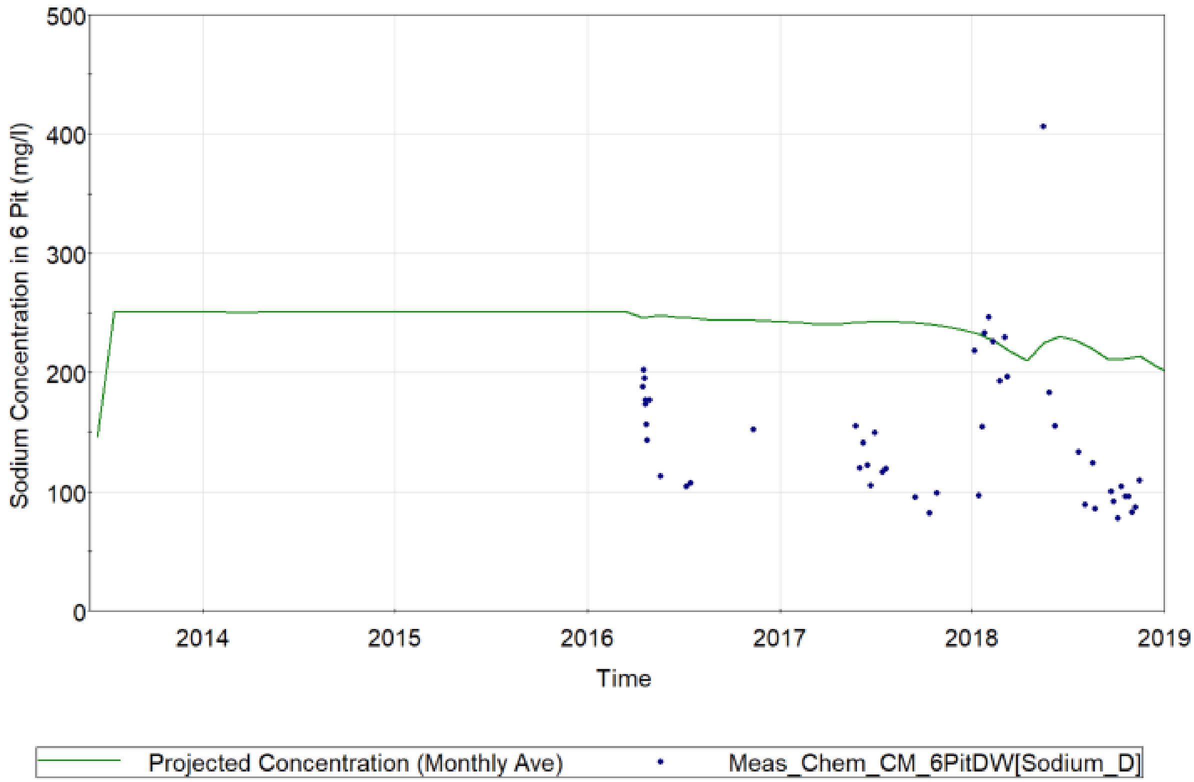

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Figure 4-13: Measured and Projected Sodium Concentration in 6 Pit

Corbin Dam

Calibration plots for sulphate, nitrate, selenium and sodium concentrations in Corbin Dam at CM_CCPD are presented in Figure 4-14 through Figure 4-17. These parameters calibrate adequately: the range of concentrations and the timing of peaks correlate well with measured data, with the exception of late 2017/early 2018.

For many parameters, peaks in predicted concentrations in late 2017 and early 2018 are related to the newly adopted source term for the East Spoils as described in Section 3.3.10. Runoff from the East Spoils reports to the Corbin Creek Rock Drain, and then to Corbin Dam. Runoff flow rates are projected on a daily timestep, which are based on measured precipitation and temperatures during the calibration period. The loading rate from upstream node CM_CCRD is based on coupling projected flows with fixed concentration source terms representing each water quality type (i.e., natural runoff from unimpacted catchment and contact water runoff from through the waste rock) which vary on a monthly basis. The monthly source term concentrations are fixed and do not account for changes in flow regimes that may occur due to an early or late freshet. The peak concentrations observed in many parameters in late 2017/early 2018 are a result of flow regimes not matching with source term inputs.

Projected selenium concentrations in 2018 were over estimated. This coincides with the greatest release rate from rehandled material in the model as well as low flow in the Corbin Creek Rock Drain. The source term applied for the initial flush from rehandled waste rock is the best proxy available, but the data is based on rehandle samples from Fording River Operations waste rock, which has differing geochemistry and has been exposed to weathering for longer. Uncertainty in the timing with respect to both lag time and duration of flushing also exists in model projections.

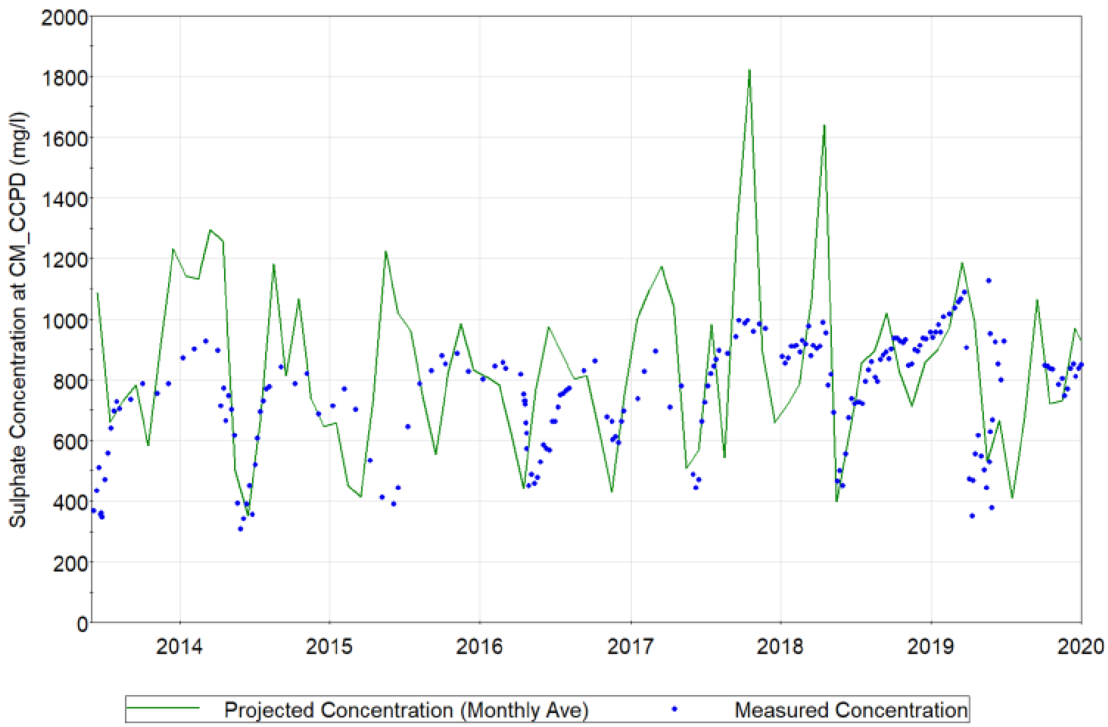

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Figure 4-14: Measured and Projected Sulphate Concentration in Corbin Dam at CM_CCPD

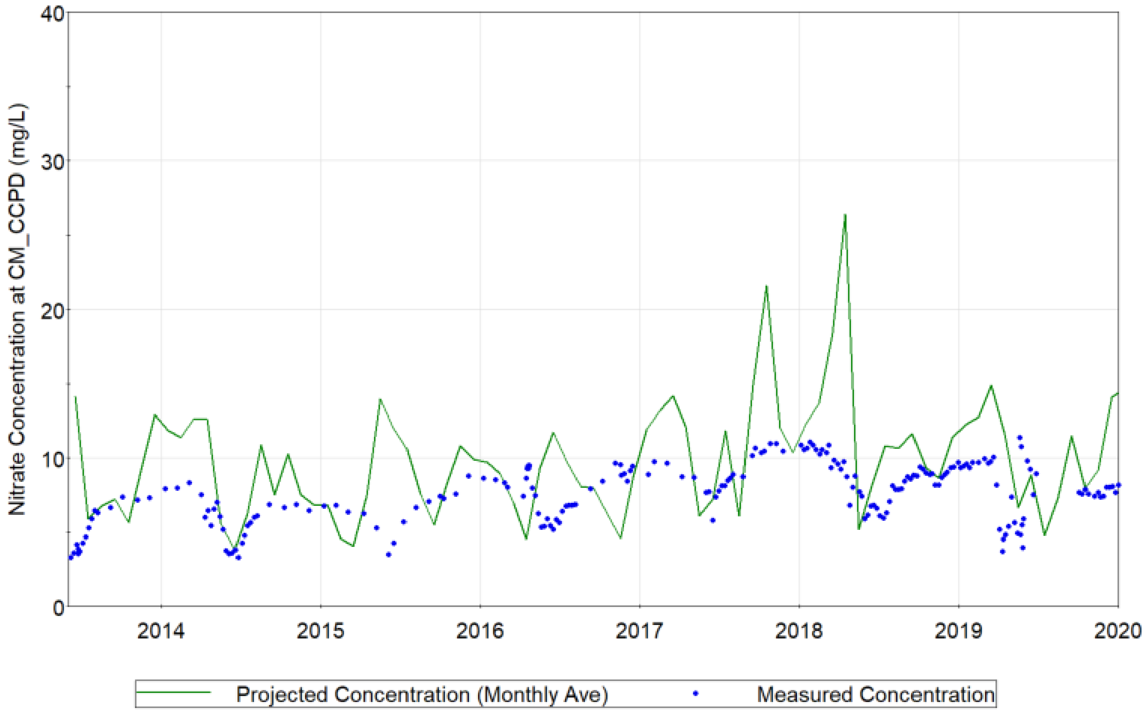

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Figure 4-15: Measured and Projected Nitrate Concentration in Corbin Dam at CM_CCPD

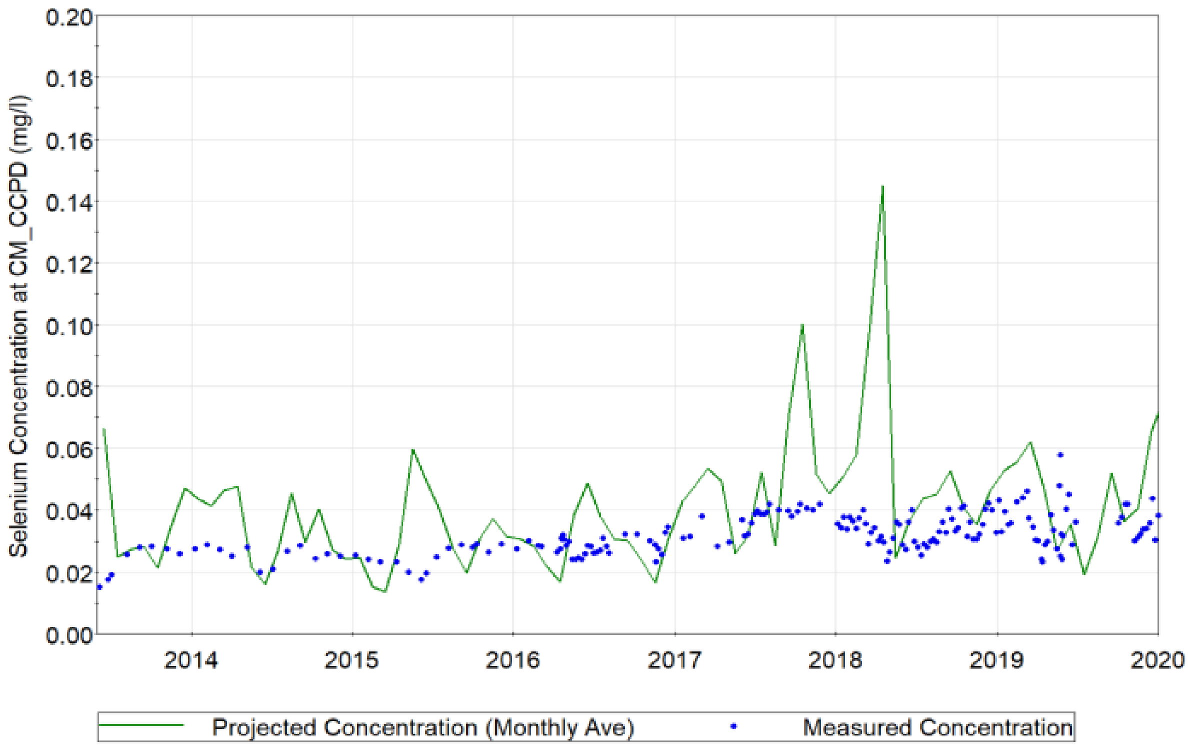

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Figure 4-16: Measured and Projected Selenium Concentration in Corbin Dam at CM_CCPD

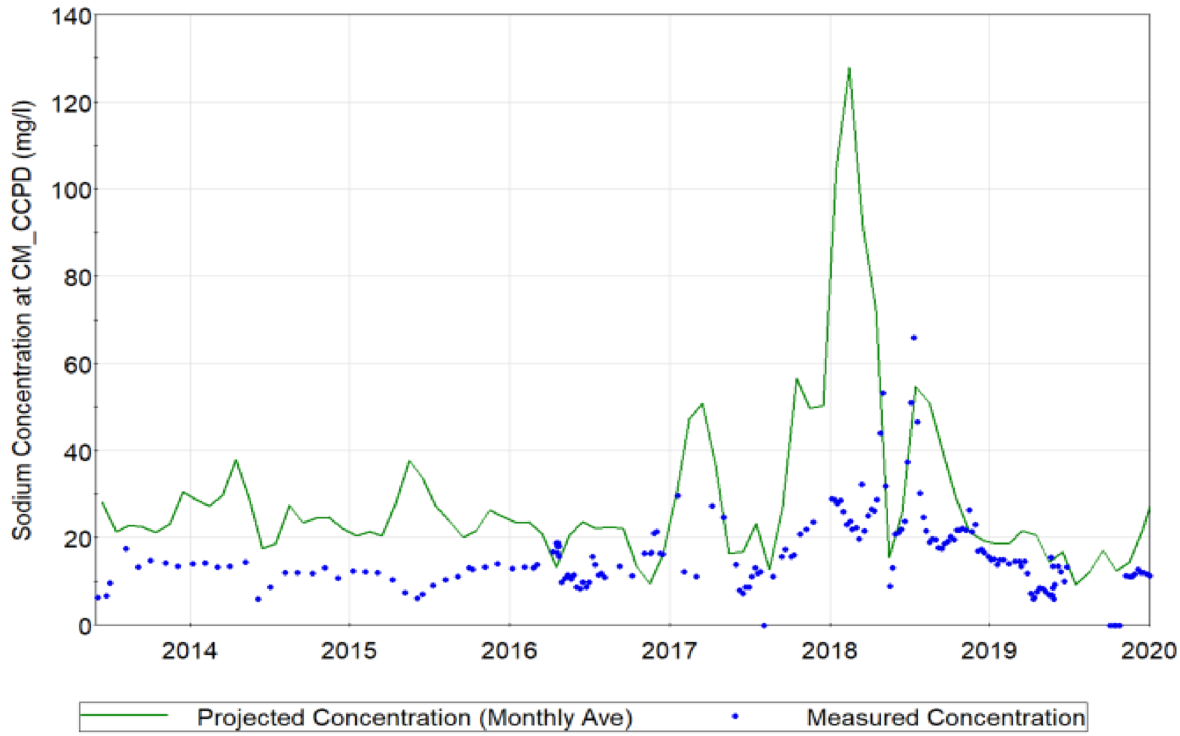

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Figure 4-17: Measured and Projected Sodium Concentration in Corbin Dam at CM_CCPD

Main Sedimentation Ponds

Calibration plots for sulphate and nitrate concentrations in the Main Sedimentation Ponds at CM_SPD are presented in Figure 4-18 and Figure 4-19, respectively. Calibration for sulphate at CM_SPD captures the range of measured concentrations, though seasonality is not well replicated.

Projected nitrate concentrations in the Main Sedimentation Pond (CM_SPD) do not correlate well with measured concentrations. For the majority of the calibration period, nitrate is under predicted at CM_SPD, with measured concentrations decreasing in 2019 and matching well with model projections. Poor calibration at this location indicates that a mechanism that influences nitrate concentration at CM_SPD is not well characterized and/or represented in the model. A similar trend has been observed in 14 Pit (Figure 4-20), but has not been captured in the mechanisms projecting nitrate concentrations at this location.

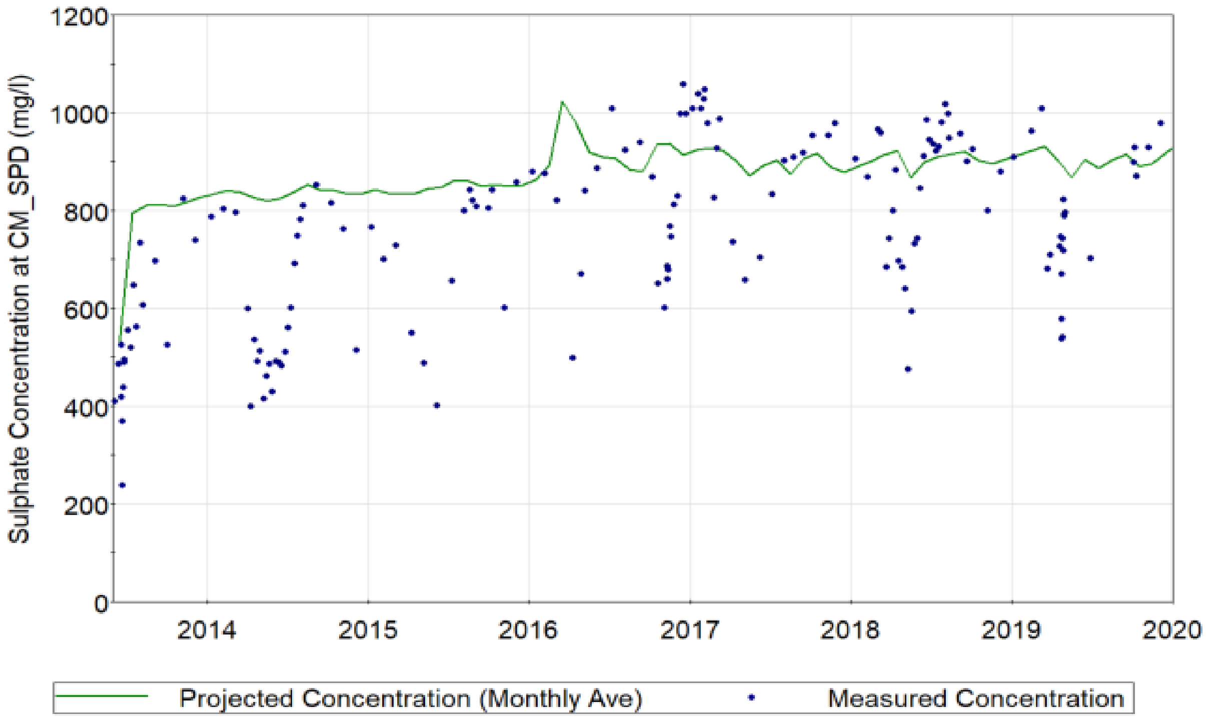

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Figure 4-18: Measured and Projected Sulphate Concentration in the Main Sedimentation Ponds (CM_SPD)

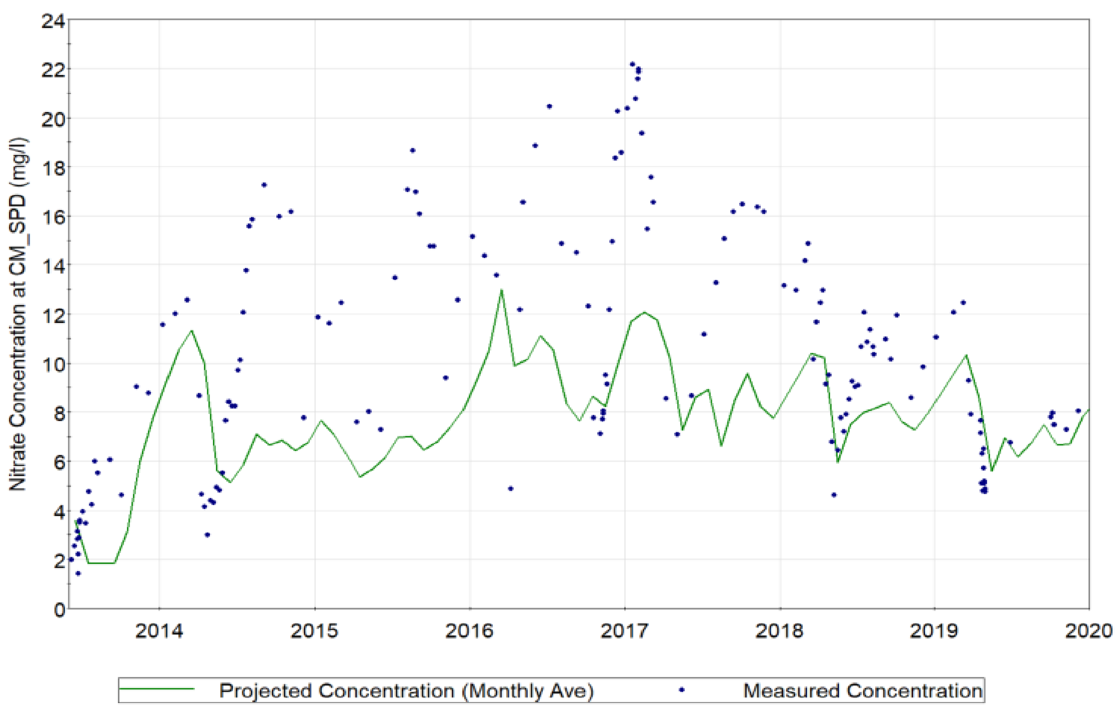

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Figure 4-19: Measured and Projected Nitrate Concentration in the Main Sedimentation Ponds (CM_SPD)

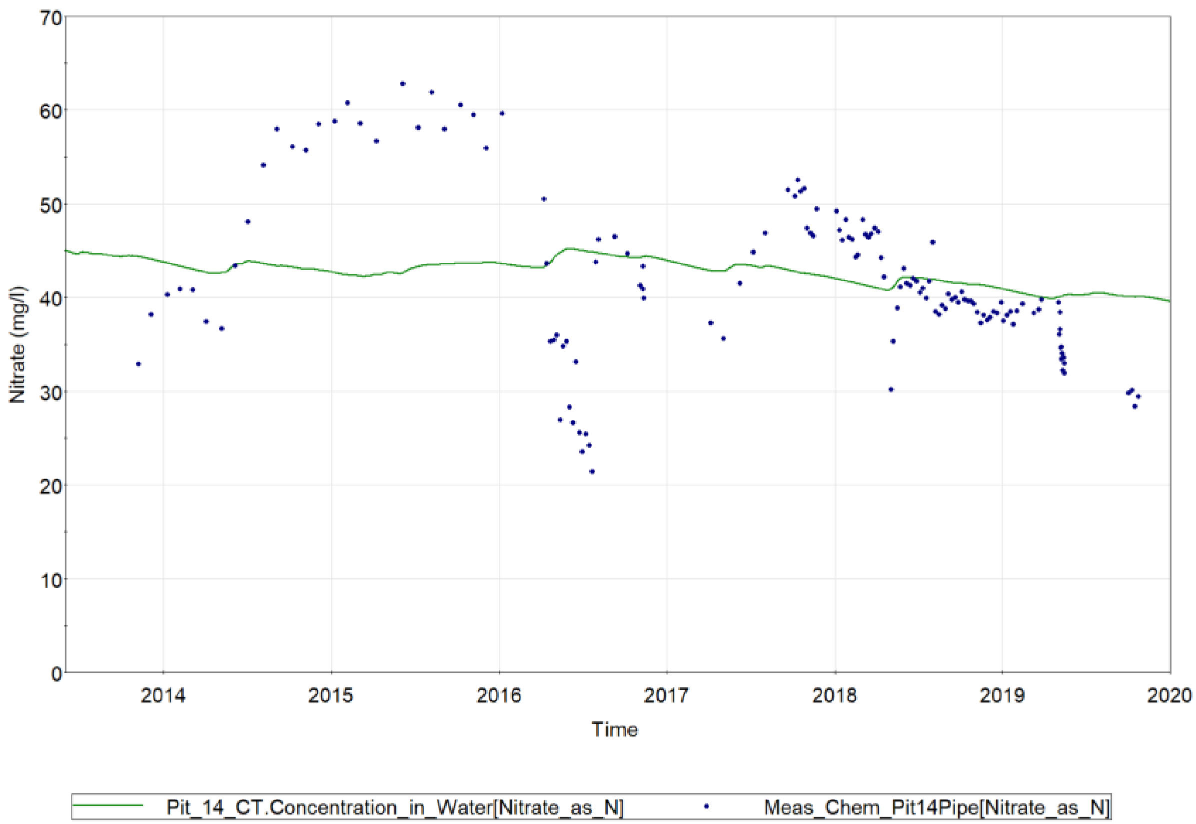

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Figure 4-20: Measured and Projected Nitrate Concentration in 14 Pit

Corbin Creek

Calibration in Corbin Creek at CM_CC1 is discussed by parameter.

- Sulphate (Figure 4-21): Projected sulphate concentrations capture the range of concentrations, and the timing and magnitude of peak concentrations in measured data.
- Nitrate (Figure 4-22): Nitrate concentrations at CM_CC1 are under-predicted during 2016 and 2017 but match well through most of 2018 and 2019. This node receives water from the Main Sedimentation Ponds, and the under-prediction of nitrate at this location is likely a result of the poor calibration at the upstream node.
- Dissolved Cadmium (Figure 4-23): Projections of dissolved cadmium concentrations are governed by calcite co-precipitation represented in the model by the application of attenuation coefficient applied during low flow conditions. The magnitude and timing of projected peak concentrations correlate well with measured data.
- Total Cobalt (Figure 4-24): Projections of total cobalt are also governed by calcite co-precipitation replicated in the model by an empirical equation relating cobalt concentration to project sulphate and Morrissey Formation content of upstream waste rock, which reduces

cobalt removal during the high flow season. The magnitude and timing of projected peak concentrations correlate well with measured data except for 2019 when changes to the 34 Pit Pump plan were made. 34 Pit is a large source of cobalt on site and pumping from 34 Pit now targets 5% of flows within Michel Creek at CM_MC2. This change in pumping strategy has allowed cobalt concentrations to remain low in the receiving environment and suggests that flow rate is not the only factor contributing to the presence/absence of calcite sequestration.

- Calcite saturation (the exceedance of which leads to precipitation), kinetics (a long enough residence time for calcite to form), and capacity for sequestration all likely play a role in the degree of cobalt sequestration that occurs. The modelled calcite sequestration mechanism takes into account both saturation and kinetics and is calibrated using a flow threshold. Developing this mechanism in the model has been an iterative process. As new data is available, this mechanism has been refined. Poor validation of new data collected in 2019 suggests that additional refinement of the modelled mechanism, perhaps to reflect a capacity limit for calcite, and additional calibration would be needed to capture 2019 concentrations.
- Total Nickel (Figure 4-25): Predicted concentrations at CM_CC1 reproduce most of the seasonality of the observed concentrations. Peaks in concentration at CM_CC1 observed after freshet, between June and July, in 2016, 2017 and 2018 are not projected by the model. These peaks are observed only after 34 Pit pumping begins in 2016. Outside of these periods, the model conservatively over-projects nickel concentrations at CM_CC1. No attenuation mechanism for nickel during periods of over-projection was applied in the model for calibration.
- Total Zinc (Figure 4-26): Predictions of total zinc concentrations are also governed by the attenuation coefficient applied during low flow conditions. The magnitude and timing of peak concentrations also correlate well with measured data.

Michel Creek

Calibration plots for sulphate and nitrate concentrations in Michel Creek at CM_MC2 are presented in Figure 4-27 and Figure 4-28, respectively. Calibration for sulphate and nitrate (and for all other parameters) at CM_MC2 reflect the quality of calibration at CM_CC1. For sulphate and nitrate, projected concentrations capture the range of concentrations, and the timing and magnitude of peak concentrations. Appendix A provides calibration plots for all parameters.

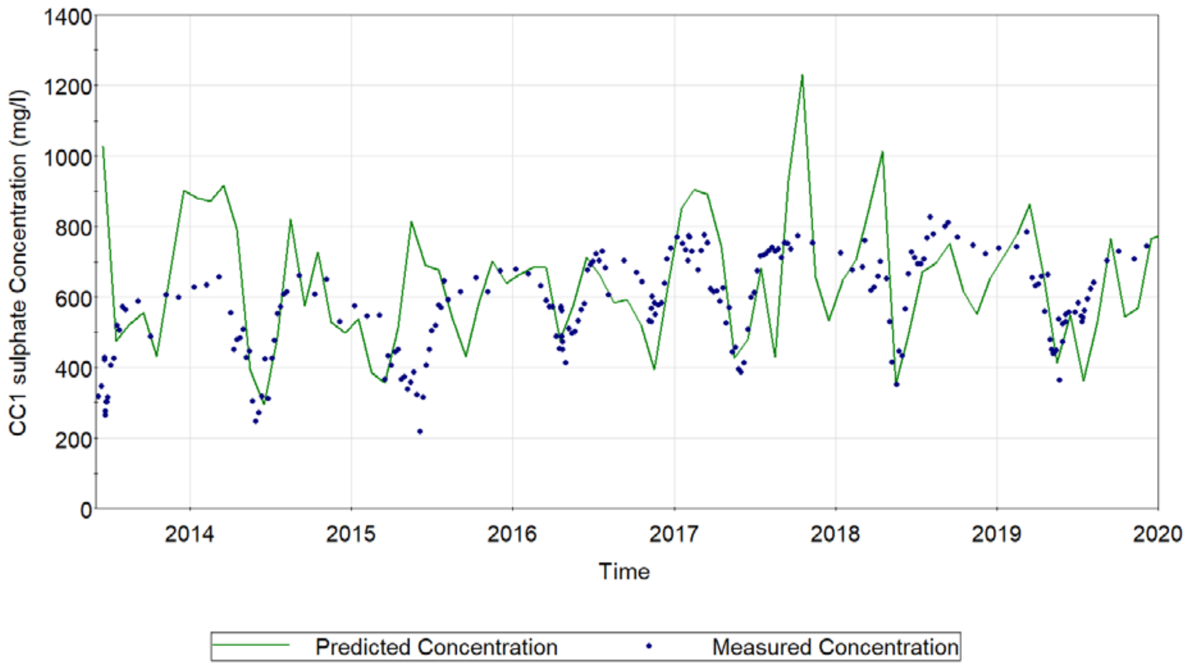

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Figure 4-21: Measured and Projected Sulphate Concentration in Corbin Creek at CM_CC1

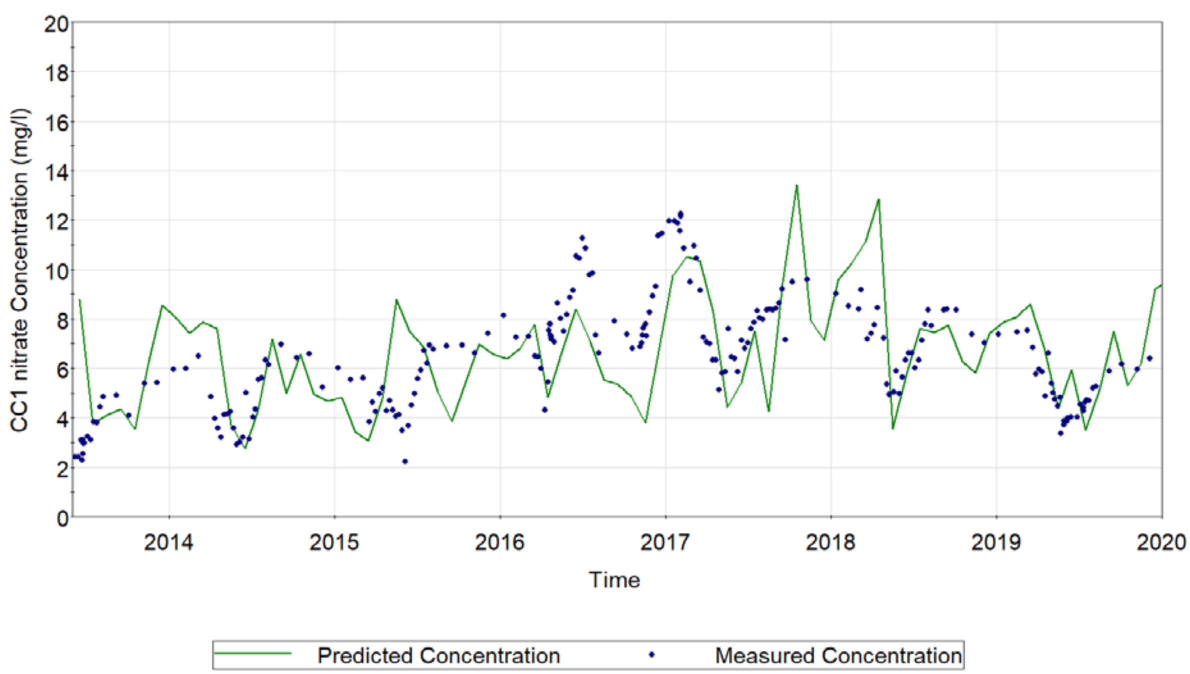

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Figure 4-22: Measured and Projected Nitrate Concentration in Corbin Creek at CM_CC1

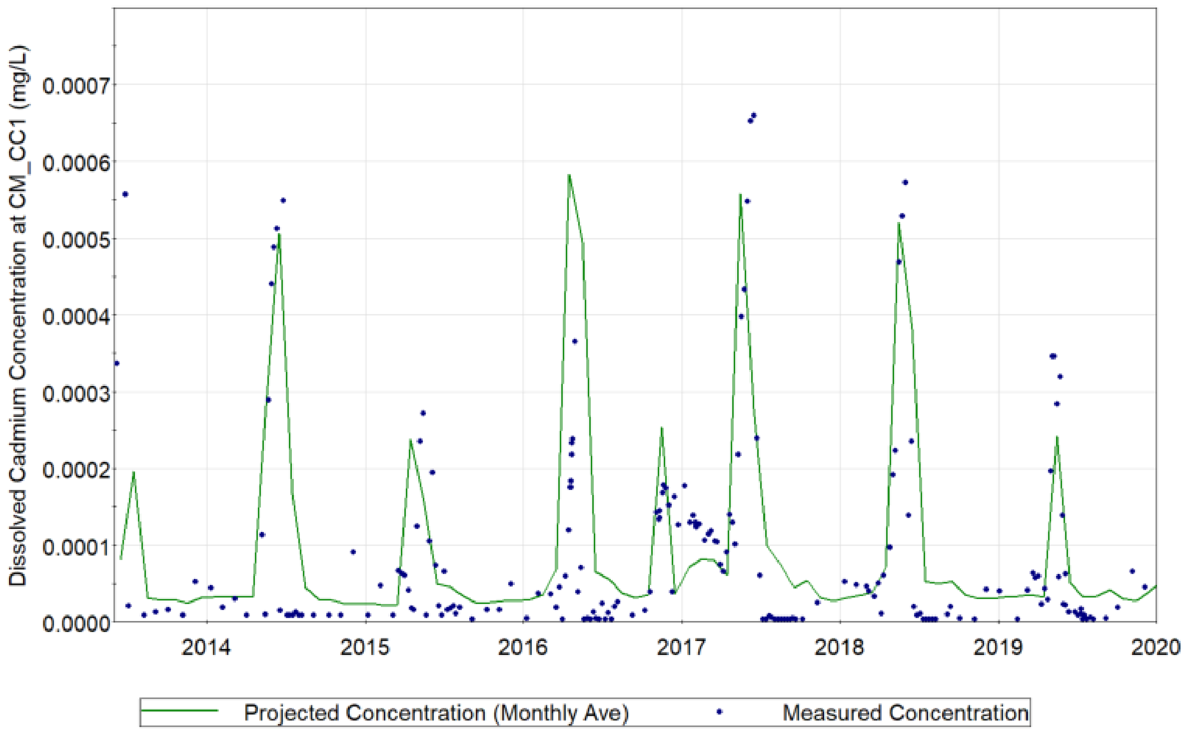

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Figure 4-23: Measured and Projected Dissolved Cadmium Concentration in Corbin Creek at CM_CC1

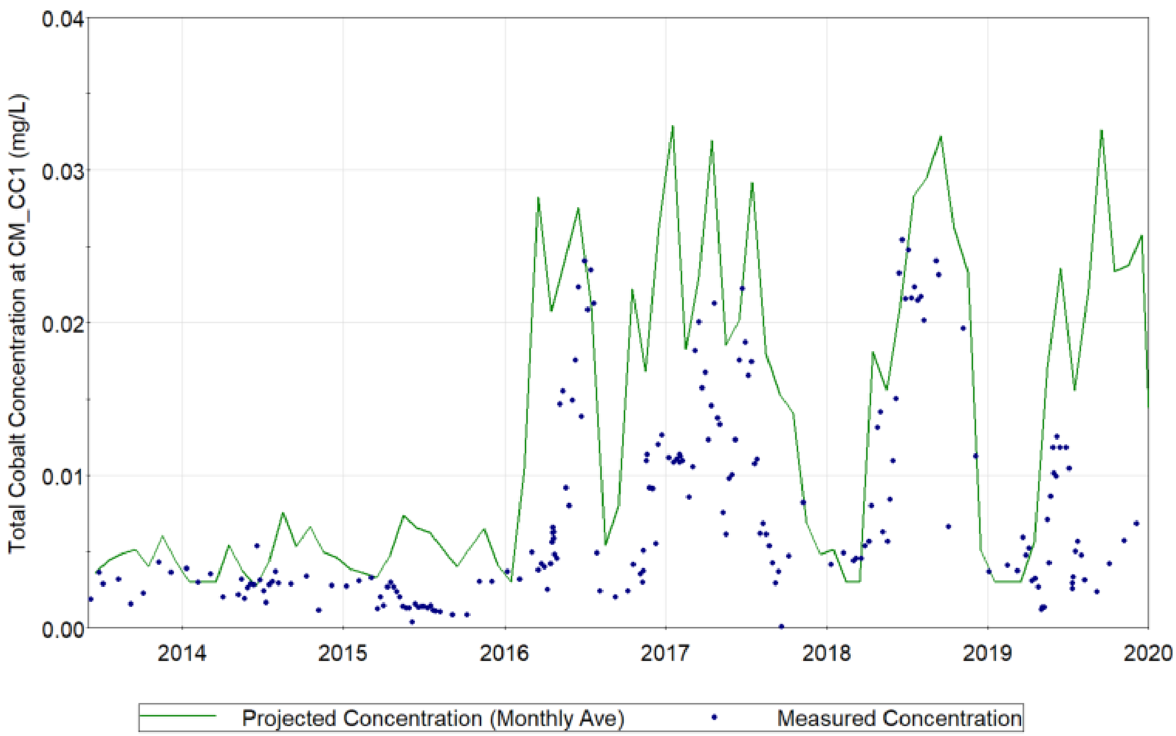

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Figure 4-24: Measured and Projected Total Cobalt Concentration in Corbin Creek at CM_CC1

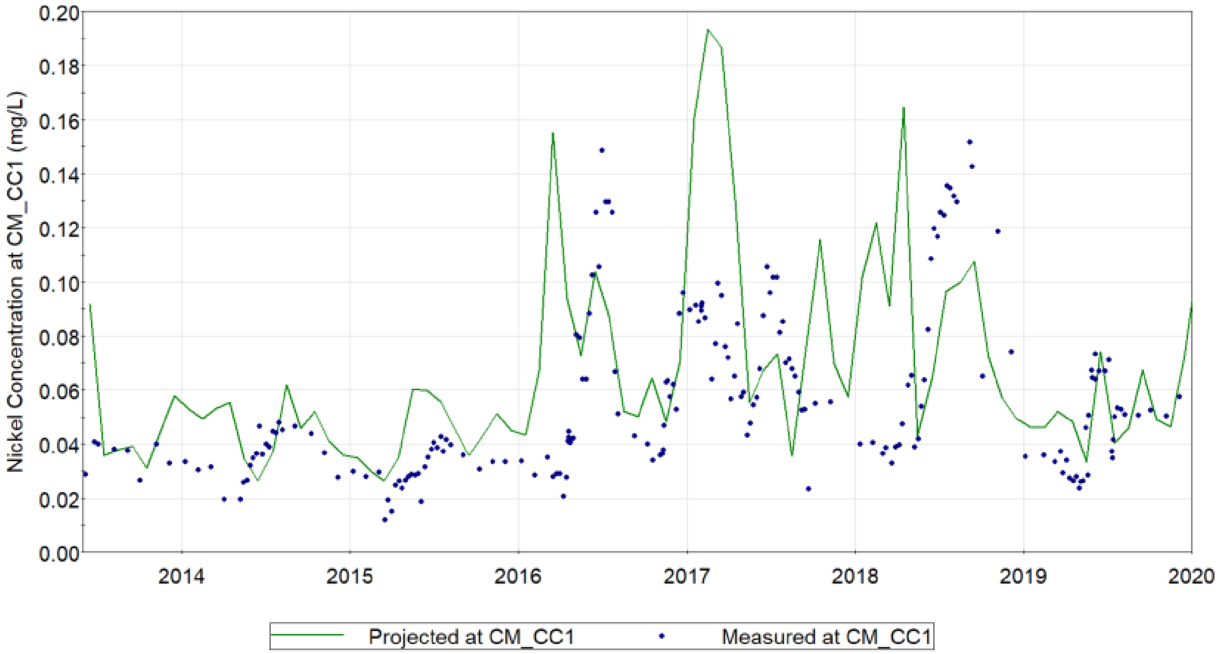

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Figure 4-25: Measured and Projected Total Nickel Concentration in Corbin Creek at CM_CC1

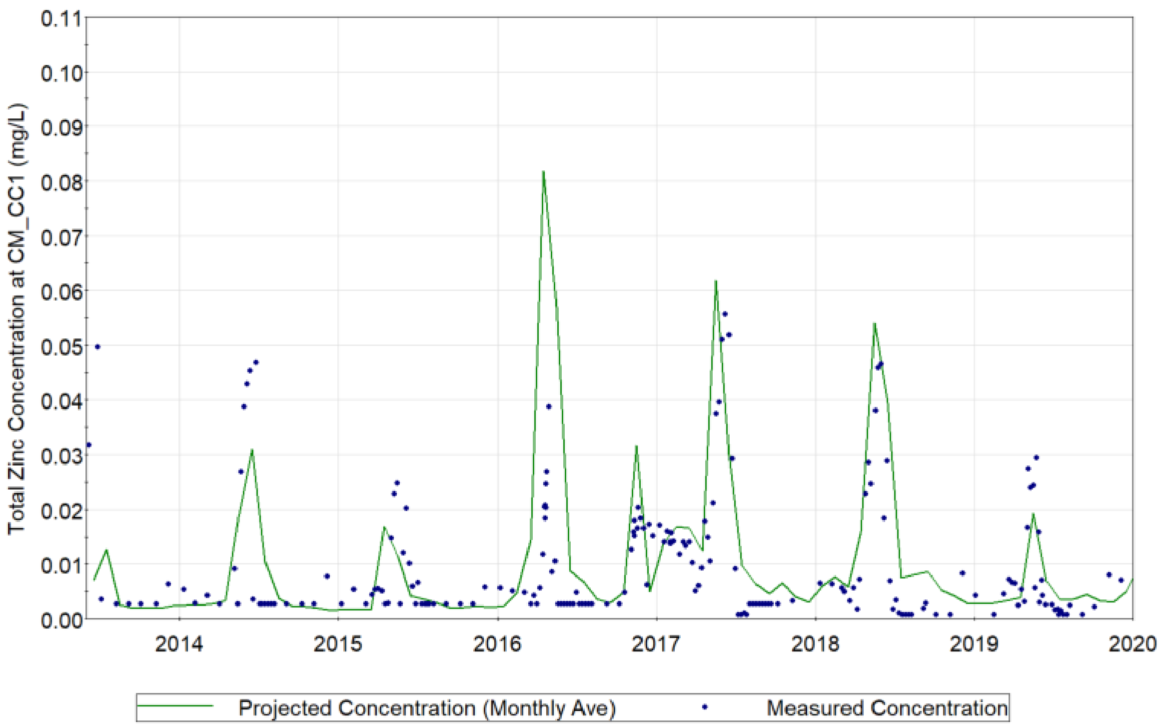

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Figure 4-26: Measured and Projected Total Zinc Concentration in Corbin Creek at CM_CC1

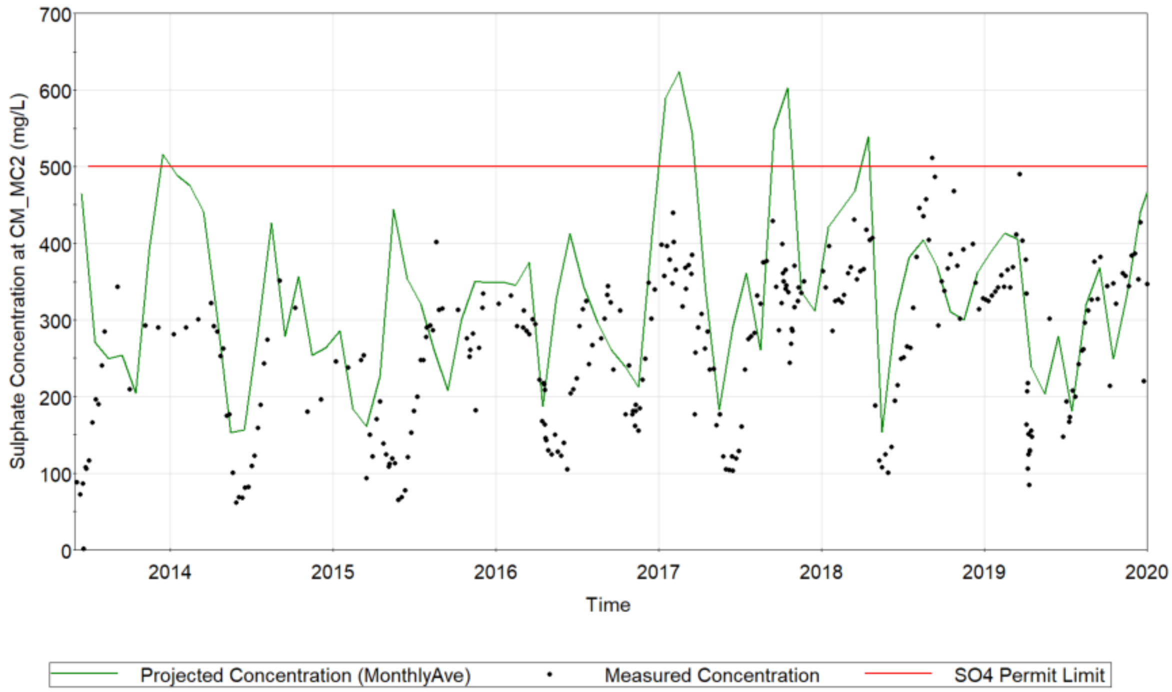

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Figure 4-27: Measured and Projected Sulphate Concentration in Michel Creek at CM_MC2

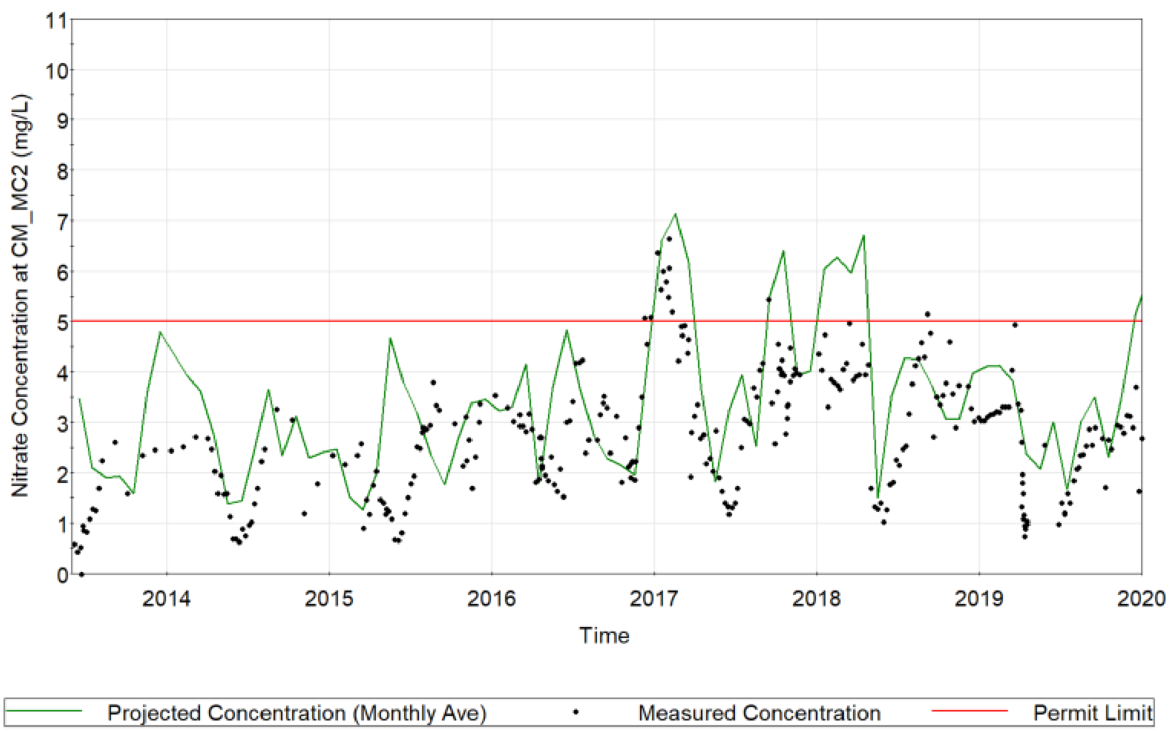

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Figure 4-28 Measured and Projected Nitrate Concentration in Michel Creek at CM_MC2

4.3 Limitations

Limitations of the surface water quality prediction model are as follows:

- Creation of an operational GoldSim model requires a number of assumptions to be made. This includes, but is not limited to, recession coefficients, catchment delineations, flow directions, seepage, groundwater and infiltration rates, spill points and operational controls. While all efforts are made to ensure these assumptions are substantiated, in some cases, lack of data requires that assumptions be made.
- Simulation of attenuation through the Corbin Creek Rock Drain has been made assuming a flow attenuation. The flow mechanisms through drains and dumps are complex. The methodology currently applied is a simplification of the mechanisms involved in these types of flows.
- Differing approaches were used to account for calcite co-precipitation of cobalt compared to other metals. An in-depth analysis was applied to account for cobalt co-precipitation and its relationship to sulphate concentration and Morissey Formation within waste rock was completed by SRK (2015b). Non-attenuated concentrations of cadmium and zinc were estimated using mass balance. An update to the application of this mechanism for cobalt may allow for changes in 34 Pit pumping to be reflected in the projected cobalt concentration.
- Projected nitrate concentrations in 14 Pit and the Main Sedimentation Pond (CM_SPD) do not correlate well with measured concentrations. Poor calibration at these locations indicate that a mechanism that influences nitrate concentration is not well characterized and/or represented in the model.

5 Model Results

Water quality projection results are presented for sulphate, nitrate, dissolved cadmium, and total selenium, which have concentration-based compliance limits for the CMO Michel Creek Compliance Point (CM_MC2) as identified in Permit 107517. Permit limits are presented with the projection results for reference but are not discussed. Measured data collected up to June 2020 is also included.

The model was run to 2030, which extends just beyond the 10-year anticipated Care and Maintenance period. Water quality projections were made using the historical climate series and running it forward in time to illustrate the variability that can be expected due to climate. The discussion below presents projections for the base case (best estimate) source terms only in order to discuss trends anticipated for each parameter.

5.1 Sulphate

Projected sulphate concentrations through Care and Maintenance for CM_MC2 are presented in Figure 5-1.

Measured sulphate concentrations in Michel Creek varied seasonally between 86 and 491 mg/L in 2019. Monthly average measured concentrations remained around the permit limits of 500 mg/L depending primarily on the hydrological conditions modeled. The permit limit of 500 mg/L is the limit for the average of all samples collected in a calendar month.

Sulphate concentrations in the receiving environment are influenced by pit pumping. 6 Pit water, which has a sulphate concentration of approximately 300 mg/L, dilutes sulphate concentrations in Corbin Creek and Michel Creek. Provided pumping from 34 Pit, with a sulphate concentration of approximately 1000 mg/L, is limited to approximately 5% of flow in Michel Creek, 34 Pit is projected to have limited influence of downstream water quality.

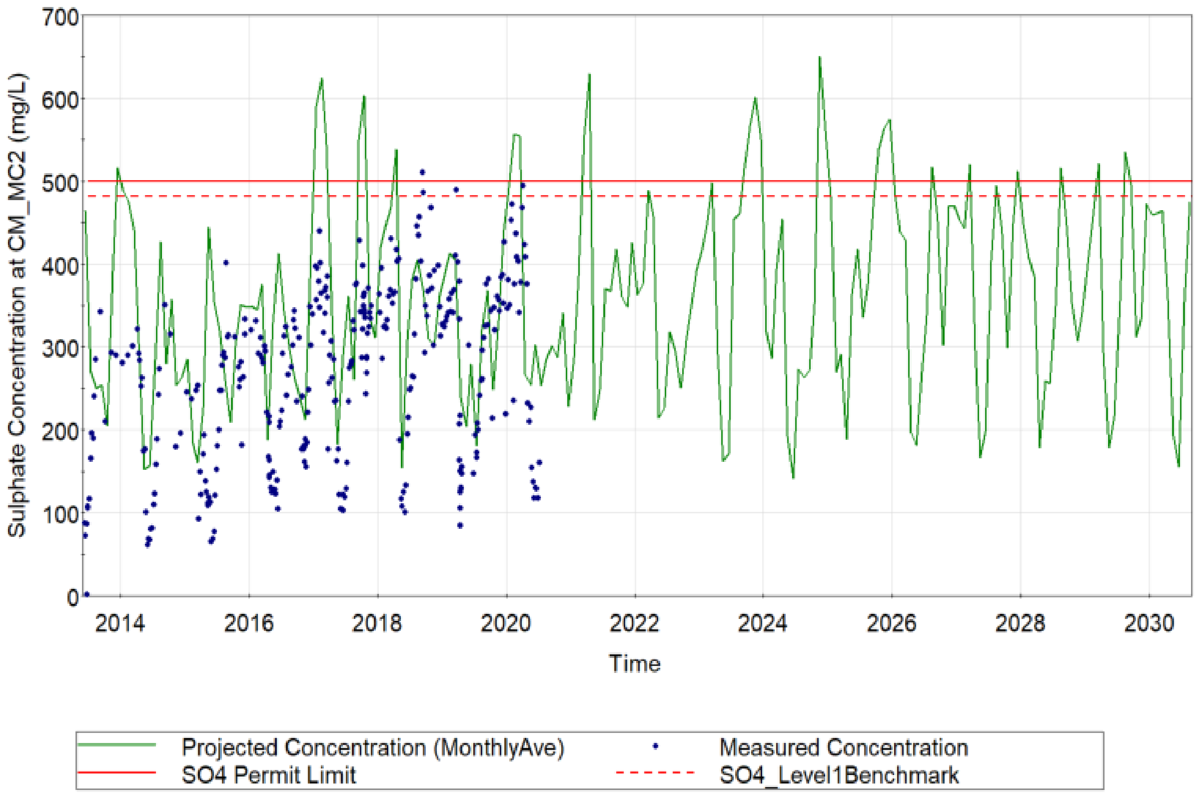

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Figure 5-1: **Measured and Projected Sulphate Concentrations in Michel Creek at CM_MC2**

5.2 Nitrate

Projected nitrate concentrations for CM_MC2 are presented in Figure 5-2.

Measured nitrate concentrations in Michel Creek varied seasonally between approximately 0.75 and 4.9 mg/L in 2019. Nitrate concentrations at CM_MC2 exceeded the permit limit of 5 mg/L for several weeks in early 2017 during pumping from 34 Pit. Isolated samples that measured above 5 mg/L in late 2017 and in 2018 remained below the permit limits, which are limits for the average of all samples collected in a calendar month at the sample location.

In Care and Maintenance, flushed nitrate loadings from blasting residue are expected to decrease over time. Nitrate concentrations in Michel Creek are projected to remain below the permit limit.

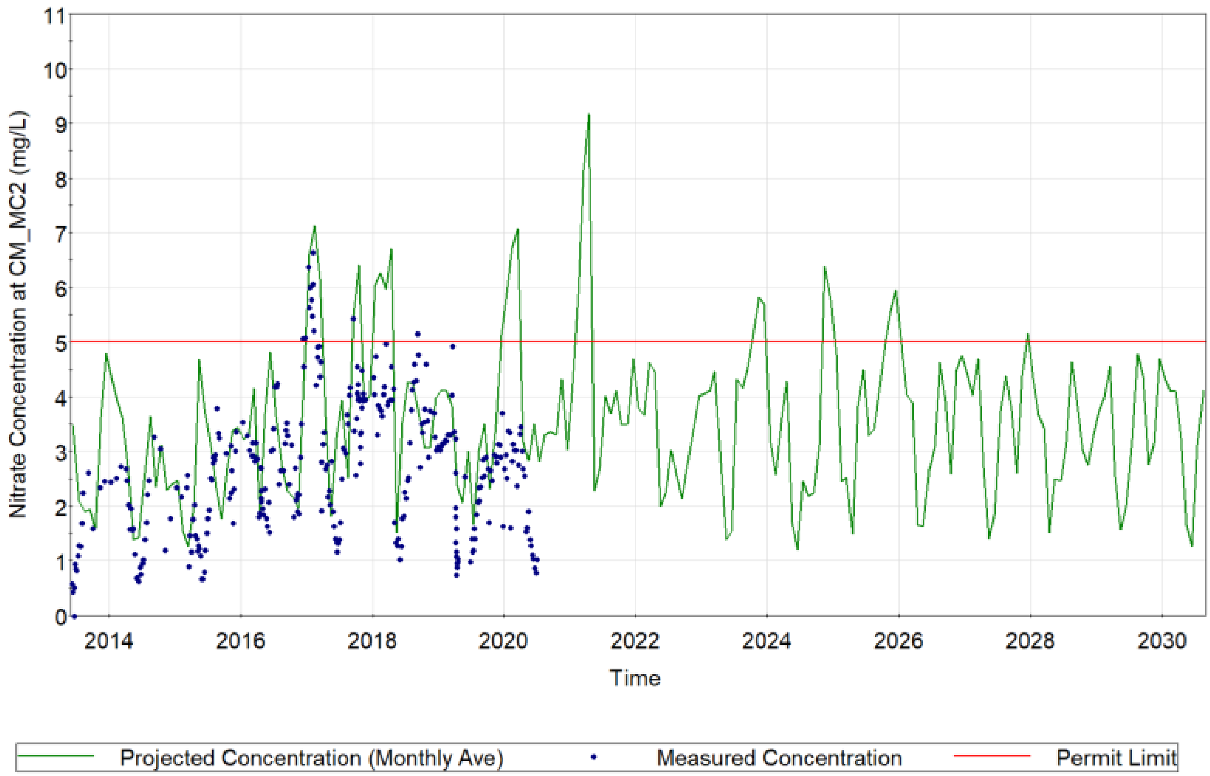

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Figure 5-2: Measured and Projected Nitrate Concentrations in Michel Creek at CM_MC2

5.3 Dissolved Cadmium

Projected dissolved cadmium concentrations for CM_MC2 are presented in Figure 5-3.

Measured dissolved cadmium concentrations in Michel Creek peak during high flow conditions, reaching 0.00012 mg/L in 2017.

Dissolved cadmium concentrations are projected to peak during freshet when calcite sequestration is not occurring. A similar pattern to what has been observed in the past with freshet peaks approaching the permit limit is possible, however projected peak concentrations are conservatively high compared to measured data. Future variable hydrological conditions tend to result in higher projected peak concentrations however, no mechanism exists to expect higher cadmium in future.

5.4 Total Selenium

Projected total selenium concentrations for CM_MC2 are presented in Figure 5-4.

Measured total selenium concentrations in Michel Creek vary seasonally between approximately 0.0030 and 0.013 mg/L. In February 2018, a peak concentration of 0.031 mg/L was projected as a result of flushing of waste rock material relocated from 6 Pit to the East Spoils. However, this peak was not realized.

In 2021, a peak concentration of 0.053 mg/L is projected due to re-sloping for reclamation purposes in the East Spoils. However, uncertainty exist in both the timing and the source terms applied for this projection. The source term applied for the initial flush from rehandled waste rock is the best proxy available, but the data is for Fording River Operations waste rock which has differing geochemistry.

After the initial flush of rehandled material, a similar pattern to what has been observed in the past is projected with total selenium concentrations below the permit limit of 0.019 mg/L in Michel Creek at the compliance location.

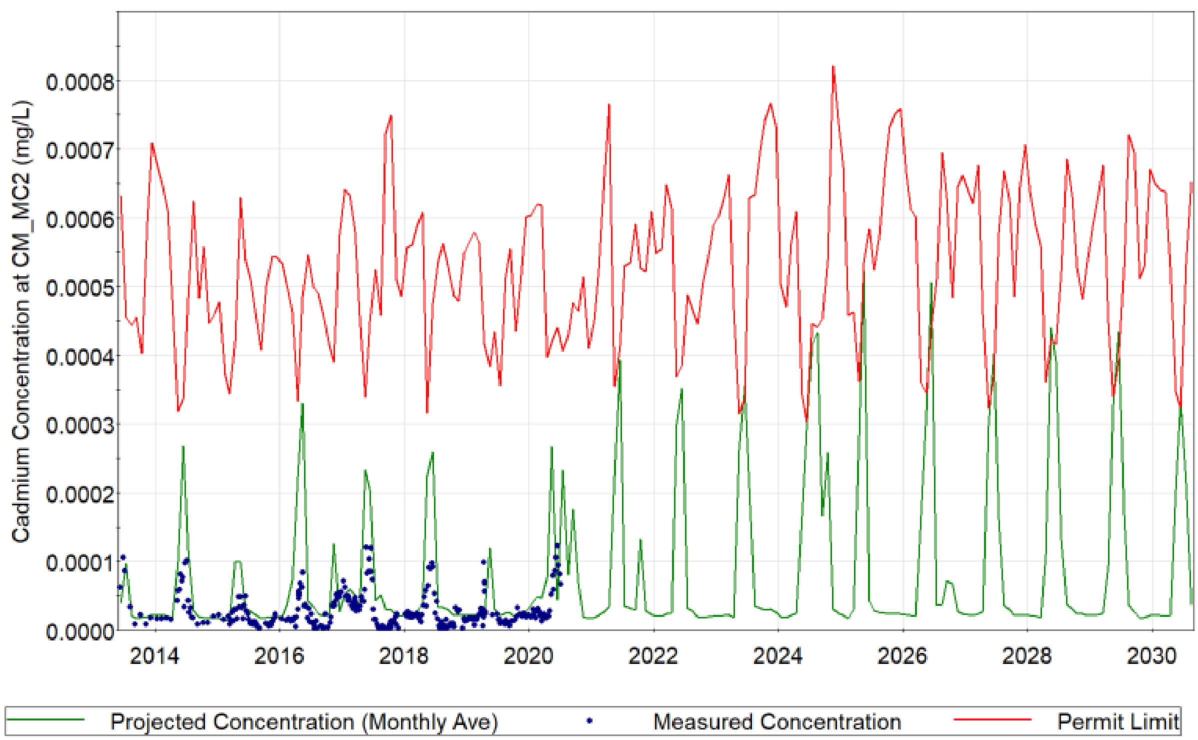

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Figure 5-3: Measured and Projected Dissolved Cadmium Concentrations in Michel Creek at CM_MC2

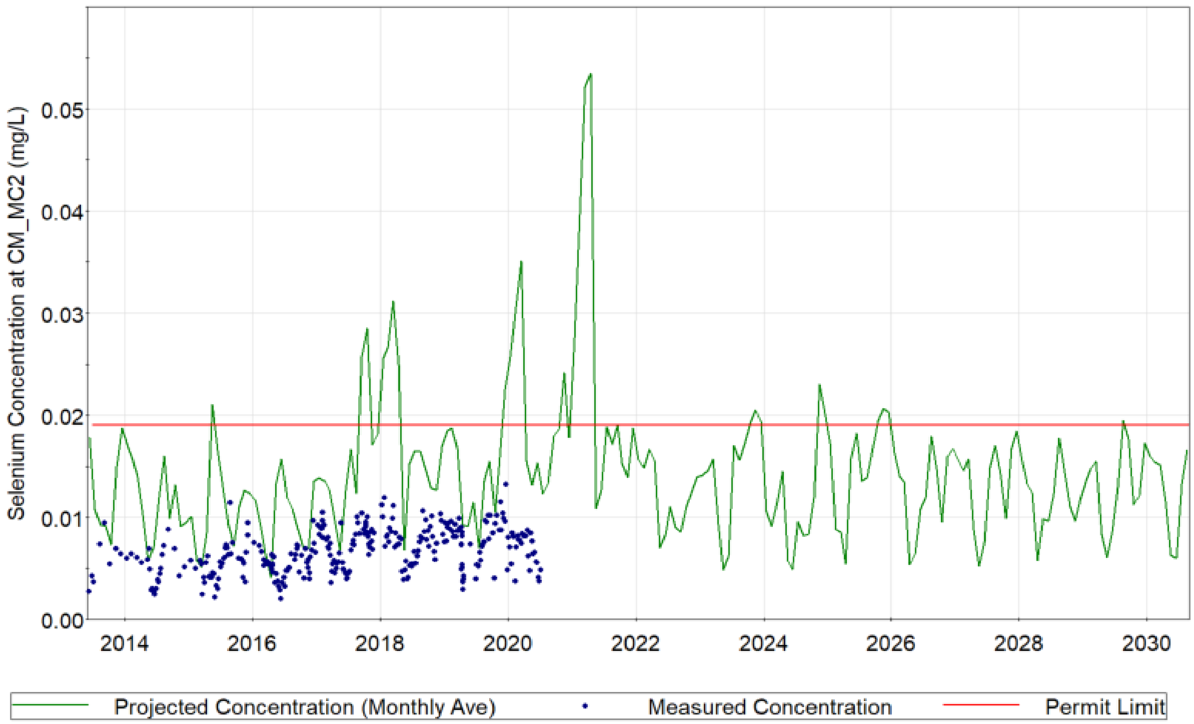

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Figure 5-4: Measured and Projected Total Selenium Concentrations in Michel Creek at CM_MC2

6 Summary

SRK was retained by Teck Coal Ltd. to develop the CMO water and load balance model which has been a robust tool used to inform future water management decisions. This report is a consolidated report describing the successive revisions to the existing water and load balance model for CMO.

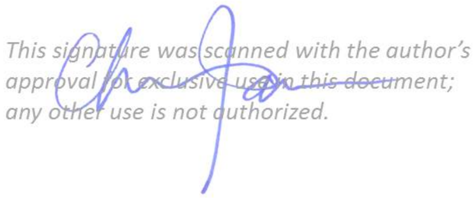
CMO currently has no planned mining activities and is formally in Care and Maintenance for a period of 10 years. During Care and Maintenance, most of the current facilities will remain in place. Mechanisms that are represented in the model include:

- Flows from natural catchments were simulated using a Snowmelt Runoff Model with daily precipitation and temperature as inputs, and runoff coefficient by land type.
- Model controls for water management during operations, and Care and Maintenance, including routing of contact water to water management facilities (e.g. North and West ditches, Corbin Dam) and active pumping from 6 Pit and 34.
- Loading rates for an initial flush from waste rock rehandled during reclamation activities is scaled on a volumetric basis, based on an empirically derived source term.
- Loading rates from 37 Pit backfill of toll processed coal from EVO.
- Loading rates for all other parameters are assumed to be a result of continual weathering and release. Loading rates for all other parameters are calculated empirically from monitoring data and are incorporated in the model as fixed concentrations.
- Attenuation of selenium is estimated using an attenuation factor. The implementation of this mechanism is unchanged from the originally developed model (SRK 2015a).
- Co-precipitation with calcite of divalent metals is modelled for cobalt, cadmium and zinc based on a flow threshold.
- In addition, scenarios for several water management options can be selected.

The purpose of the CMO Water and Load Balance model is as a robust tool for making future water management decisions. For this reason, QA/QC and calibration of the model were a focus area of model development. A combination of quantitative and qualitative evaluations were completed to evaluate the model validation and recalibration. Generally, flows validated well with Nash Sutcliffe Efficiency values exceeding 0.5 for all stations evaluated, except CM_SPD. Water quality predictions are also in good agreement with respect to range of measured concentrations, timing, and magnitude of seasonal concentration fluctuations.

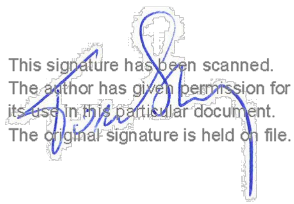
Monitoring continues at CMO according to the requirements outlined in the Environmental Management Act permits 4750 and 107517. New data will be used to validate the current calibration or potentially re-calibrate future model revisions.

This report, Coal Mountain Operations Water and Load Balance Model 2020 Consolidated Report, was prepared by



Christina James, MASc
Principal Consultant

and reviewed by



Tom Sharp, PhD, PEng
Principal Consultant

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

7 References

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Appendix A – Climate Analysis

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Memo

To:	File	**Client:**	Teck Metals Ltd.
From:	Victor Munoz, SRK Samantha Barnes, SRK	**Project No:**	1CT008.038
Cc:	Kathleen Willman, SRK	**Date:**	September 29, 2014
Subject:	Coal Mountain Water Balance Model – Climate Analysis		

1 Introduction

A hydrological analysis was conducted to develop the necessary hydrological inputs for the CMO water balance model. This included the generation of the following key components, which are discussed in the following sections:

- Extended climate record on a daily time step
- Frequency analysis of annual precipitation for various return periods
- WGEN model to predict daily precipitation and temperature and to estimate the daily precipitation values for the wet and dry return periods (1:100 wet and 1:100 dry)
- Mean monthly evaporation
- Inputs for the GoldSim Snowmelt Runoff Model (SRM)[1] to estimate runoff

2 Climate Inputs

2.1 Required Climate Inputs

Records of daily precipitation and mean daily temperature, along with statistics of meteorological parameters were required for input to the water balance model for two key conditions:

- Historical conditions – available measured climate data is applied when a model start date prior to the current date is selected (primarily for the purposes of model calibration)
- Predictive conditions – includes a number of options for running the model under varying hydrological conditions during a timeframe specified by the user:
    1. Average Year – average annual precipitation year

[1] The GoldSim Snowmelt Runoff Model (SRM) is based on the WinSRM model, which is designed to simulate and forecast daily streamflow in mountain basins where snowmelt is a major runoff factor. The model is available on the GoldSim wiki site.

2. 1 in 100 Year Wet – 1 in 100-year annual wet precipitation year
3. 1 in 100 Year Dry – 1 in 100-year annual dry precipitation year
4. Manual Climate – user-specified input climate record
5. Historical Record – historical site record projected into the future
6. WGEN[2] Model – results from the Weather Generation (WGEN) model

An extended climate record was generated to simulate historical conditions, for predictive modeling where the long-term historical record is projected into the future, and to derive the inputs required for the SRM and WGEN models.

The request for proposal (Teck 2013) contained the following three scenarios for predictive climate conditions: 1) average annual precipitation conditions, 2) a "wet-year" defined as the 1 in 100-year annual precipitation conditions, and 3) an extreme condition "event" to be defined based on dam hazard classification. Pursuant to meetings with Teck, the extreme condition was eliminated and a number of options were added including a dry year, manual climate, historical record and WGEN modeling.

2.2 Climate Stations Evaluated

The climate stations evaluated to generate the required precipitation and temperature input records for the water balance model are shown on Figure C2-1. The station details are provided in Table C2-1. The stations evaluated to generate evaporation parameters are discussed in Section 3.

There are two key stations at the site location that provided the primary source of data:

- Corbin station – located northeast of the mine site, directly adjacent to the northern coal refuse stockpile, active from 1977 to 1993
- Andy Good station – currently located northwest of the mine site, active from 2011 to present

The remaining stations were used to patch and/or extend the above site records.

2.3 Selection of Water Year

Where annual totals were calculated in this analysis, a water year was selected over a calendar year, as this is more practical from a hydrological perspective when dealing with a site with significant freshet flows. The water year is based on September 1 to August 31. Although water years often begin on October 1, the month of September was selected as the start of the water year for the CMO project to be consistent with the water balance model and the work done by Golder Associates on other Teck Coal water balance models. In the water balance model, starting the model in September, when there is typically no significant snowpack at the site, eliminates the need to estimate the initial snowpack. Therefore, it is recommended, although not required, that the model be started in September.

[2] WGEN = Weather Generation Model, available on GoldSim's wiki site

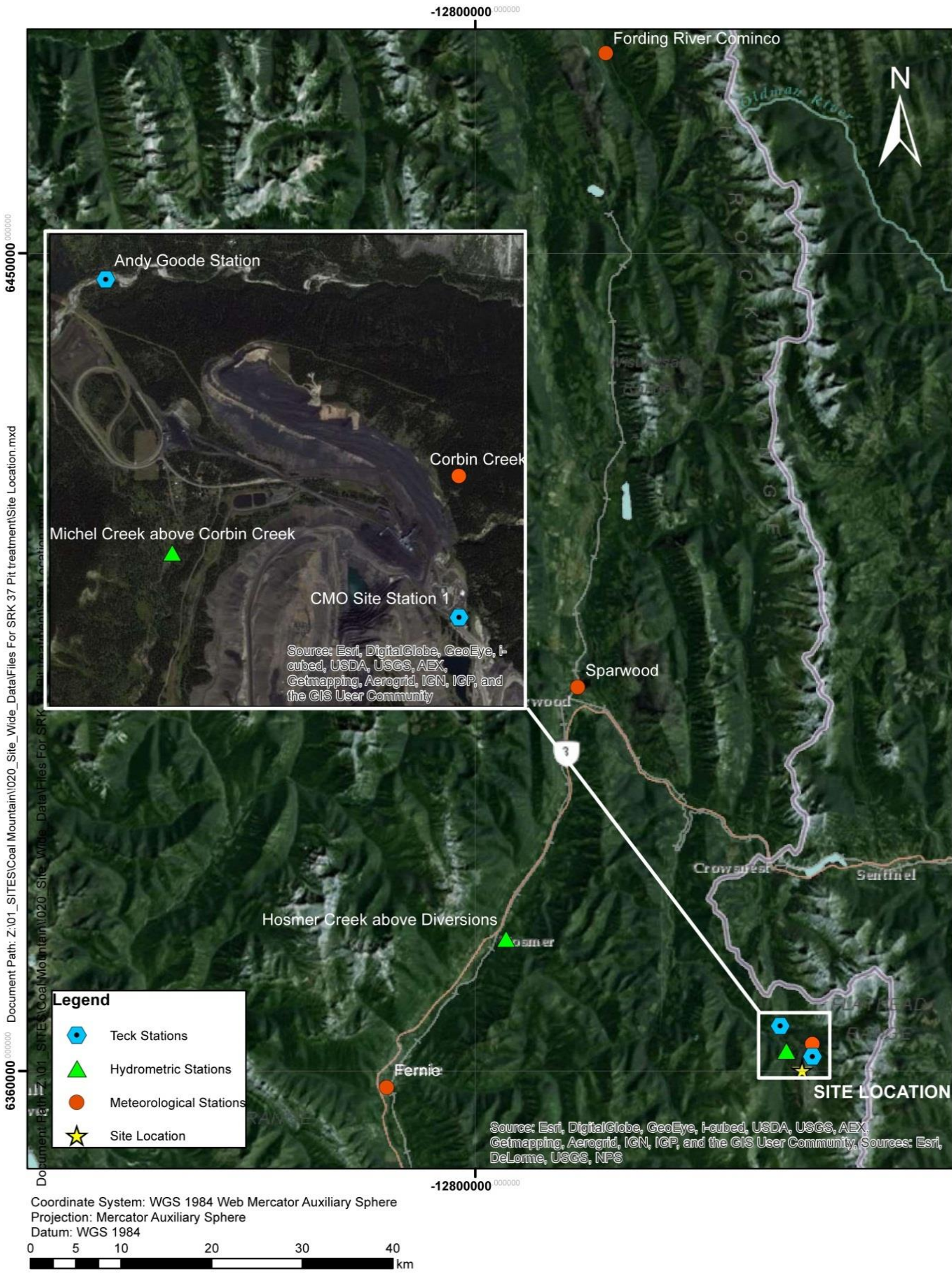


Figure C2-1: Climate and Hydrometric Station Location Map

Source: L:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!080_Deliverables\Hydrology Report\040_Figures\figure 1_Met and Hydromet stations.jpg

Table C2-1: Summary of Stations included in the Climate Analysis

Station Name	Station ID	Source[1]	Elevation (m)	Catchment Area (km²)	Period of Record			Data Type
					First Year	Last Year	Total Years[2]	
Precipitation								
Corbin	1151915	EC	1572	-	1977	1993	5	daily
Sparwood	1157630	EC	1138	-	1980	2013	29	daily
Andy Goode	-	Teck	1509	-	2011	2013	2	daily
Fernie	1152850	EC	1001	-	1913	2013	77	daily
Temperature								
Corbin	1151915	EC	1572	-	1977	1993	5	daily
CMO Site Station 1	-	Teck	1600 (assumed)	-	2005	2010	5	daily
Sparwood	1157630	EC	1138	-	1980	2013	29	daily
Fording River Cominco	1152899	EC	1585	-	1970	2013	27	daily

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Precip\MAP_mastersheet_SB_VM_R7.xlsx

Notes: 1. Climate data sources include Environment Canada (EC) and Teck
2. Total years of record is equivalent to the number of complete years with no more than five missing records in a month

2.4 Available Site Data

When modeling historical conditions, the model applies data from the existing climate station at the site when available (Andy Goode) and data from a station previously installed near the site (Corbin) when modeling dates prior to the installation of the current site station. These stations are discussed below.

2.4.1 Corbin Station

The Corbin station is a historical climate station located near the site that is no longer active (see Figure C2-1). Data from this station was used to create the historical record for the site (which can be applied for modeling past conditions or projected into the future), for the frequency analysis, to generate inputs to the WGEN model and to calibrate the SRM model.

The daily record spans from June 1977 to July 1993, but consisted of a significant number of data gaps. The record was patched and extended to 2013 using transposed data from nearby stations based on correlations between coincident temperature and precipitation, as discussed in Section 2.5.

2.4.2 CMO Site Station 1 and Andy Goode Station

Teck provided records from two climate stations located at the site. The first station (referred to in Table C2-1 and Figure C2-1 as CMO Site Station 1), which is no longer active, provided hourly observations of a large number of climatic parameters from September 2005 to March 2010. The only information available from Teck on this station is that it was a Davis Instruments installation. Precipitation was measured as rainfall only. Precipitation data from this station was not used in the model as it did not measure total precipitation (i.e., rainfall + snowfall), which is required for the water balance model. Temperature data from this station was used to patch the long-term record.

A second station, the Andy Goode station[3], was installed at the site and began recording data on October 3, 2011. There is a data gap between the old and new stations between March 2010 and October 2011, during which time no site climate data measurements are available.

The Andy Goode station is currently active and located northwest of the mine site (see Figure C2-1). The station records hourly observations of wind direction/speed, temperature, snow depth and total precipitation. Although Teck provided the climate records for this station from October 3, 2011, the first complete daily record of precipitation was only available from November 10, 2011. Accordingly, this record was used in the model starting on this later date when coincident temperature and precipitation were available. The snow depth measurements could not be used in the precipitation analysis as they were recorded as values of 0 or 1 (Teck has informed SRK that this is a result of the data exporting process).

2.5 Generation of Extended Site Climate Record

2.5.1 Temperature

The Corbin station (EC 2013) was used as the base for generating the extended climate record for temperature (average, minimum and maximum daily temperatures). Data gaps were observed in the temperature record for the Corbin station. Three different stations were selected to patch the Corbin record, listed in the following order of priority (see Figure C2-1 for station locations): CMO Site Station 1, Sparwood and Fording River.

Since the Corbin temperature data was recorded at the site, no corrections to the temperature data from this record were made. For patching and/or extending the Corbin record using the Sparwood and Fording River stations (EC 2013), corrections were based on relationships derived from scatter plots of average daily temperatures at the station used to patch the data and CMO Station 1. These relationships were established for both the maximum and minimum temperature records. The relationships used to transform temperatures at the reference station to equivalent temperatures at the CMO site are presented in Table C2-2.

The extended site temperature record for average, minimum and maximum temperatures is provided on a monthly average basis in Tables C-1 through C-3 in Attachment 1.

Table C2-2: Expressions for Transposing Temperatures to CMO Site

Climate Station	Relationship to CMO Site Station 1
Sparwood	0.938 x Sparwood - 1.502
Fording River	0.929 x Fording River + 1.781
Sparwood CS	0.944 x Sparwood CS - 1.327

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Temperature\Temperature_mastersheet_SB_VM_Rev3.xlsx

[3] This station measures precipitation with an Ott Pluvio2 precipitation gauge, wind with a RM Young 05103 wind monitor and temperature with a CSI 109 temperature probe

2.5.2 Precipitation

At the onset of the project, the Sparwood station (EC 2013) was proposed as the station to patch and/or extend the Corbin record, however it contained several data gaps within its record. As a result, the nearby Fernie station was used as a secondary station to fill in the gaps in the Corbin record where data from the Sparwood station was not available. The station locations are shown in Figure C2-1.

Correction factors were generated for Sparwood and Fernie, which were then applied to estimate the equivalent precipitation at the Corbin station. These factors were calculated through linear regression of the cumulative precipitation at Corbin versus the cumulative precipitation at the Sparwood and Fernie stations. The cumulative precipitation at each station was compared using the same time steps, where all the data gaps (i.e., missing time steps) in the Corbin record were removed from the cumulative Fernie and Sparwood records.

Two relationships were derived by plotting the cumulative Corbin data against the cumulative Sparwood and Fernie data. A line of best fit was determined for each scatter plot, resulting in a factor of 1.5143 for the Sparwood data and 0.7660 for the Fernie data. The regression indices for the lines of best fit were 0.9989 and 0.9980 for Sparwood and Fernie, respectively.

The Sparwood precipitation data was selected as the primary source to fill in data gaps and extend the Corbin record, while the Fernie data was used when Sparwood data was missing. The final result was a complete Corbin precipitation record from 1977 to 2013. The derived correction factors can continue to be applied to the Sparwood and Fernie precipitation data in order to estimate the equivalent precipitation at the mine site in the future. The patched and extended record is provided on a monthly average basis in Table C-4 in Attachment 1.

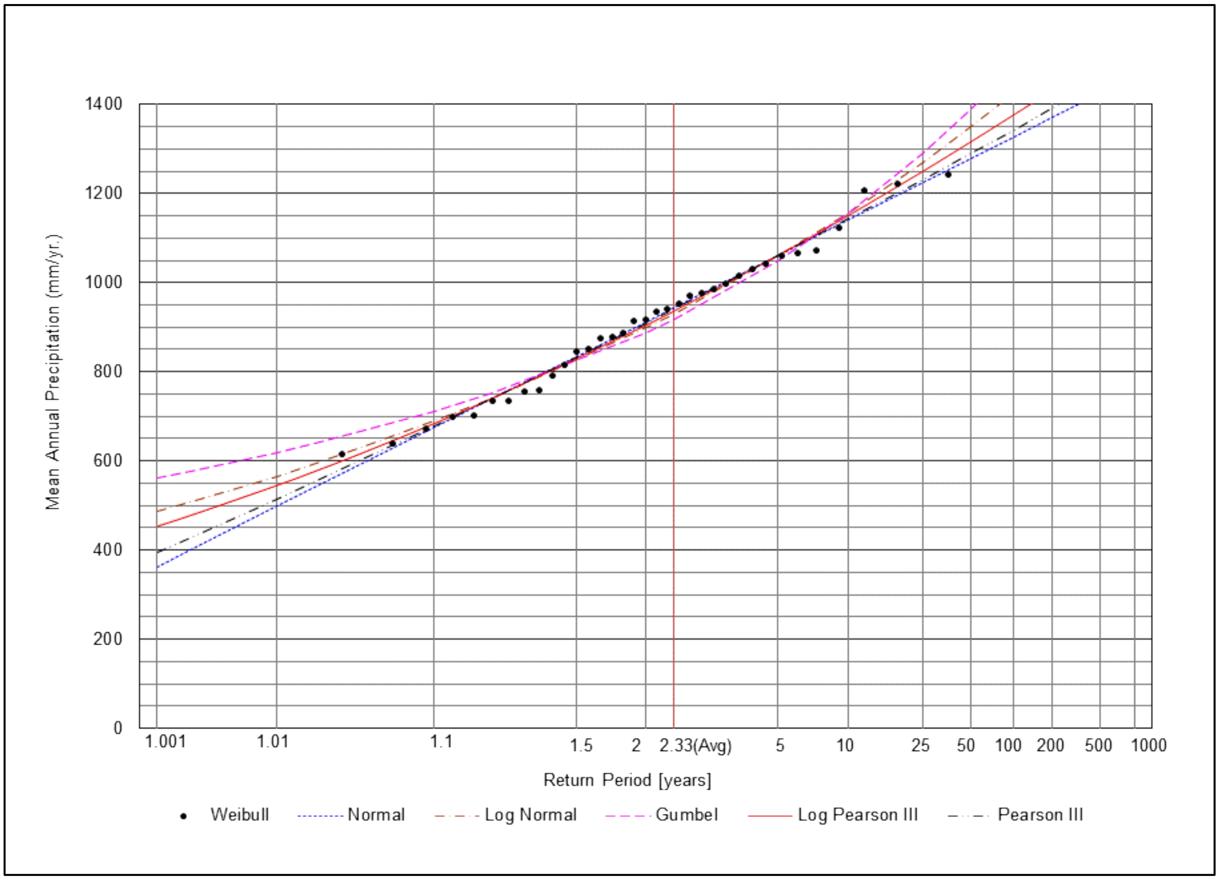
2.6 Frequency Analysis

A frequency analysis was conducted to estimate the annual total precipitation for a number of return periods, including average, wet and dry years. This analysis was conducted using REGBAY software on the patched and extended Corbin precipitation record from 1977 to 2013, which includes transposed data from nearby stations. Ideally, the analysis would have been based on the original Corbin record alone. However, as the analysis uses annual totals only, the inclusion of the transposed regional data essentially doubles the record length, which improves the confidence in the results of the frequency analysis.

The water year, as described in Section 2.3, was incorporated in calculating the total annual precipitation, from September through August, resulting in a total of 37 years of record for the frequency analysis.

Figure C2-2 shows the total precipitation for various return periods, based on six distributions. Table C2-3 presents the annual total precipitation for each return period, based on the Log Pearson III distribution, which resulted in the best correlation with the historical data points. The key outputs from the frequency analysis for the water balance model are the following total precipitation amounts:

- Average Year = 936 mm
- 1 in 100 Wet Year = 1376 mm
- 1 in 100 Dry Year = 545 mm



Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Precip\Frequency Analysis_Pp_VM_Rev2.xlsx

Figure C2-2: Distribution of Annual Precipitation for Various Return Periods

Table C2-3: Frequency Analysis of Annual Precipitation for the CMO Site

Hydrological Condition	Return Period	Total Precipitation (mm/year)
Dry Year	100	545
	25	621
	10	684
	5	741
Wet Year	2	904
	2.33 (Avg.)	936
	5	1062
	10	1150
	25	1249
	50	1315
	100	1376

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Precip\Frequency Analysis_Pp_VM_Rev2.xlsx

2.7 Solar Radiation

Solar radiation inputs were required for the WGEN model. An existing historical solar radiation record was not available for the Corbin station or nearby area. In order to generate the required regional parameters, solar radiation was estimated using values provided in the WGEN Manual (C.W. Richardson, 1984) for the Great Falls station in Montana. This information was complemented with national U.S. isohyet diagrams and was calibrated using a theoretical method for estimating solar radiation. This method generates a regional solar radiation record based on the Julian day and the latitude of the site (Beckham, 1980), using the following equations:

The maximum daylight hour is calculated using Equation 1:

$$N = \frac{24}{\pi}\,\omega_s \qquad \text{Eq. (1)}$$

Where ω_s is the sunset hour angle (in radians), given by Equation 2:

$$\omega_s = \arccos(-tan\varphi tan\delta) \qquad \text{Eq. (2)}$$

Where φ is the latitude of the site, and δ is the solar declination (in radians), given by Equation 3:

$$\delta = 0.4093\sin(\frac{2\pi}{365}J - 1.405) \qquad \text{Eq. (3)}$$

And where J is the Julian day number, starting at 1, and continuing until 365.

This provided a set of solar radiation parameters for the regional solar radiation at the mine site.

2.8 WGEN Model

2.8.1 Model Description

The WGEN (Weather Generation) GoldSim model is available on the GoldSim wiki site. It follows the logic of the 1980s Fortran WGEN model, which is a weather simulation model developed by Richardson at the USDA-ARS Grassland, Soil and Water Research Laboratory (C.W. Richardson, 1984). It generates daily values of maximum and minimum temperatures, precipitation and solar radiation based on monthly and annual statistics. Precipitation is modeled as a two-state Markov process[4]. Maximum and minimum temperature and solar radiation are auto-correlated, cross-correlated and conditioned on precipitation.

Although solar radiation data are not applied directly in the water balance model, this data is required in the calibration stage of the WGEN model. The model is designed to preserve the dependence in time, the correlation between variables, and the seasonal characteristics in actual weather data for the modeled location.

The generation of the synthetic weather records depends on various parameters, which are determined based on historical weather data, and are listed as follows:

- Precipitation:
  - P_i (W/W) = Probability of a wet day *i* given a wet day on *i-1*
  - P_i (W/D) = Probability of a wet day *i* given a dry day on *i-1*
  - α, and β are distribution factors for shape and scale of the rainfall distribution, respectively
  - Monthly mean precipitation values for wet days (inches)
  - Monthly standard deviation for precipitation on wet days (inches)
- Maximum Temperature (Same for Solar Radiation):
  - u_wet, u_dry = Annual mean maximum temperature for wet and dry days, respectively (F)
  - C_wet, C_dry = Annual amplitude of maximum temperature for wet and dry days, respectively (K)
  - CV_wet, CV_dry = Mean coefficient of variation for wet and dry days, respectively
  - C_CV_wet, C_CV_dry = Annual amplitude of coefficient of variation for wet and dry days, respectively
- Minimum Temperature:
  - u = Annual mean minimum temperature (F)
  - C = Annual amplitude of minimum temperature (K)

[4] Markov process is a random process whose future states solely depend on the present state.

– u_CV = Mean coefficient of variation for daily minimum temperature

– C_CV = Annual amplitude of coefficient of variation for minimum temperature

The precipitation parameters summarized above were calculated from the corrected and expanded Corbin record, while the temperature and solar radiation variables required additional analyses.

2.8.2 Summary of WGEN Parameters

The resulting parameters, summarized in Table C2-4 and Table C2-5, were input in the WGEN model and the model was run for a one-year period for 1000 realizations. The precipitation and temperature values predicted from the WGEN model were compared against the historical record to verify that the model was accurately replicating the type of climate conditions observed in the historical record.

Table C2-4: Summary of WGEN Input Parameters

Description	Parameter	Unit	Maximum Temperature	Minimum Temperature	Solar Radiation
Annual mean for wet days	u_wet	-	44.00	27.417	271.6
Annual mean for dry days	u_dry	-	47.15		385.0
Annual Amplitude for wet days	C_wet	-	13.51	10.176	176.5
Annual Amplitude for dry days	C_dry	-	14.81		258.0
Mean coefficient of variation for wet days	CV_wet	F	0.0171	0.01810	-0.430
Mean coefficient of variation for dry days	CV_dry	F	0.0177		-0.260
Annual Amplitude of coefficient of variation for wet days	C_CV_wet	K	-0.0054	-0.00881	0.040
Annual Amplitude of coefficient of variation for dry days	C_CV_dry	K	-0.0053		0.080

Source: \\VAN-SVR0\Projects\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Precip\WGEN_SB_rev5_ML_VM.xlsx

Table C2-5: Monthly WGEN Precipitation Parameters

Month	Probability of a Wet Day given a Dry Day P(W/D)	Probability of a Wet Day given a Wet Day P(W/W)	Mean Precipitation on Wet days (in)	Standard Deviation Precipitation on Wet days (in)
Jan	0.301	0.640	0.237	0.283
Feb	0.243	0.558	0.246	0.300
Mar	0.289	0.592	0.233	0.278
Apr	0.277	0.534	0.215	0.261
May	0.310	0.624	0.246	0.343
Jun	0.387	0.613	0.253	0.319
Jul	0.260	0.461	0.238	0.262
Aug	0.218	0.540	0.217	0.234
Sep	0.221	0.558	0.257	0.334
Oct	0.237	0.584	0.260	0.321
Nov	0.309	0.664	0.288	0.396
Dec	0.333	0.594	0.244	0.294

Source: \\VAN-SVR0\Projects\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Precip\WGEN_SB_rev4_ML_VM.xlsx

The total annual precipitation was calculated for each realization, and these values were compared against the results of the frequency analysis. The total annual precipitation from the WGEN model appeared to be consistent with the frequency analysis for the wet years. However, this was not the case for the dryer years. The lowest total annual precipitation produced from the 1000 iterations of the WGEN model was approximately 590 mm, whereas the frequency analysis indicated that the 1 in 100 dry year would result in a lower total annual precipitation of 545 mm. Based on the frequency analysis, we would expect to see total annual precipitation values close to 545 mm once every 100 iterations and values lower than this on a less frequent basis, which was not the case. The inputs to the WGEN model were reviewed and re-analyzed, however, it was not possible to produce outputs from the WGEN model for the dry years that were consistent with the frequency analysis. Since the Coal Mountain mine has a positive water balance, the dry year conditions would not be the critical conditions to replicate in the water balance model.

The WGEN model was incorporated into the site-wide water balance model. It can be applied in both deterministic and probabilistic simulations. In deterministic simulations, it generates future precipitation and temperature for a length of time specified by the user for one iteration using mean values for its stochastic elements. For probabilistic simulations, it generates predicted precipitation and temperature for a length of time specified by the user for one or more realizations with random sampling of stochastic elements.

2.9 Daily Records for Required Return Periods

Daily records were required for the water balance model for the average, 1:100 wet and 1:100 dry years. The daily record for the average year was extracted from the historical Corbin station record. Based on the frequency analysis, the mean precipitation for the site is 936 mm. The Corbin record was reviewed (1977 to 1993) for a water year with total annual precipitation close to this value. The water year 1981 to1982 was selected, which has a total annual precipitation of 915 mm.

For the 1:100 wet and dry years, the annual precipitation totals estimated from the frequency analysis were not observed in the historical record. In order to generate daily records for these return periods, the results of the 1000 iterations of the WGEN model were used. The annual precipitation totals (water years) for each iteration were reviewed and years with totals close to the values estimated from the frequency analysis for the 1 in 100 wet and dry years were extracted.

There were multiple years in the WGEN results that approximated the 1 in 100 wet year annual total from the frequency analysis, and one of these records was randomly chosen for the input in the water balance. The annual total precipitation (water year) for the record selected was 1377 mm, which is nearly identical to the estimate from the frequency analysis of 1376 mm.

As discussed in Section 2.8.2, there were no annual precipitation totals from the WGEN results that were as low as the 1 in 100 year estimated from the frequency analysis. Consequently, the driest year from the WGEN results was selected to represent the 1 in 100 dry year in the water balance model. This represents an annual total of 592 mm of precipitation, which is slightly higher than the value of 545 mm estimated from the frequency analysis.

3 Evaporation

Lake evaporation was calculated using the software WREVAP, which was developed by Environment Canada's National Hydrology Research Institute (Morton et al, 1985). The model inputs were air temperature, dew point temperature, and bright sunshine hours. A total of eight stations were modeled in WREVAP, and data from three additional stations were extracted from the Canadian 1971-2000 Climate Normals (EC, 2001). All stations are shown on Figure C3-1. The results from the WREVAP modeling provided monthly and annual lake evaporation values for each station. Table C3-1 presents the annual lake evaporation for each station, along with station information.

Table C3-1: Summary of Stations Used in Evaporation Analysis

Station Name	Source	Elevation [masl]	Latitude [degrees]	Annual Lake Evaporation (mm)
Old Glory Mountain	WREVAP	2347	49.2	642.1
Revelstoke	WREVAP	405	51.0	634.1
Castlegar A	WREVAP	495	49.3	745.3
Kimberly A	WREVAP	914	49.7	755.3
Cranbrook A	WREVAP	939	49.6	789.0

Station Name	Source	Elevation [masl]	Latitude [degrees]	Annual Lake Evaporation (mm)
Kelowna	WREVAP	430	50.0	756.7
Lethbridge	WREVAP	910	49.7	806.4
Penticton	WREVAP	344	49.5	788.0
Castlegar BHCPA DAM	EC Climate Normals, 1971-2000	435	49.3	609.9
Whiskey GAP	EC Climate Normals, 1971-2000	1300	49.0	802.7
Duncan Lake Dam	EC Climate Normals, 1971-2000	549	50.2	420.7

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Evaporation\Evaporation_WREVAP_outputs_3.xlsx

Figure C3-2 presents the monthly distribution of lake evaporation for each of the 11 climate stations, as well as the average distribution. The monthly lake evaporation values for all stations evaluated were similar. The averages of the results were selected for modeling the mine site. Table C3-2 presents the average monthly lake evaporation applied to the mine site, along with the annual total. These values are applied in the model to water ponds when the temperature at the site is great than 0°C.

Table C3-2: Annual and Monthly Distribution of Lake Evaporation for CMO

Month	Evaporation [mm]
January	3.6
February	8.6
March	31.1
April	67.2
May	115
June	132
July	153
August	128
September	73.3
October	34.4
November	7.2
December	0.5
Annual Total	**754**

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Evaporation\Evaporation_WREVAP_outputs_3.xlsx

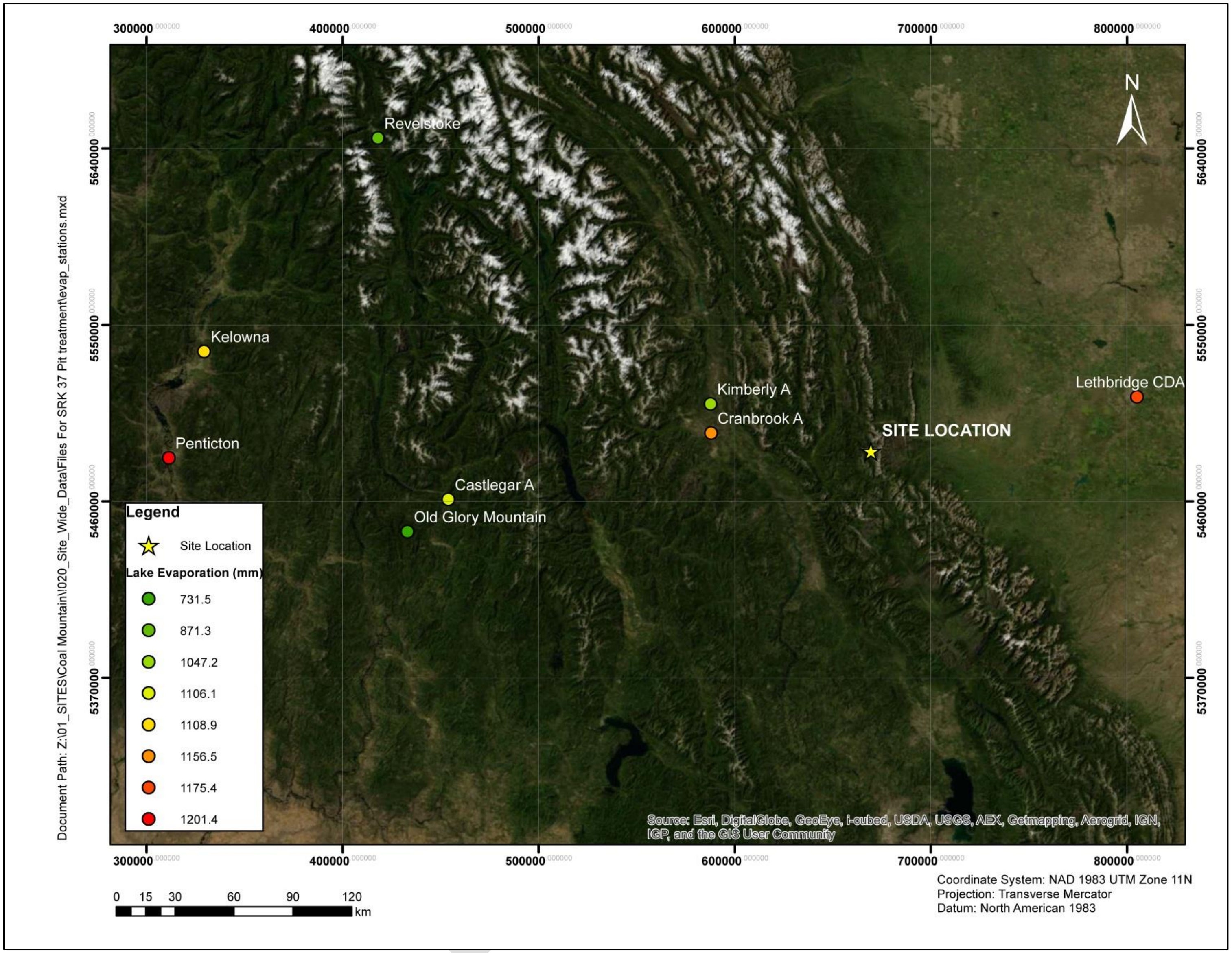
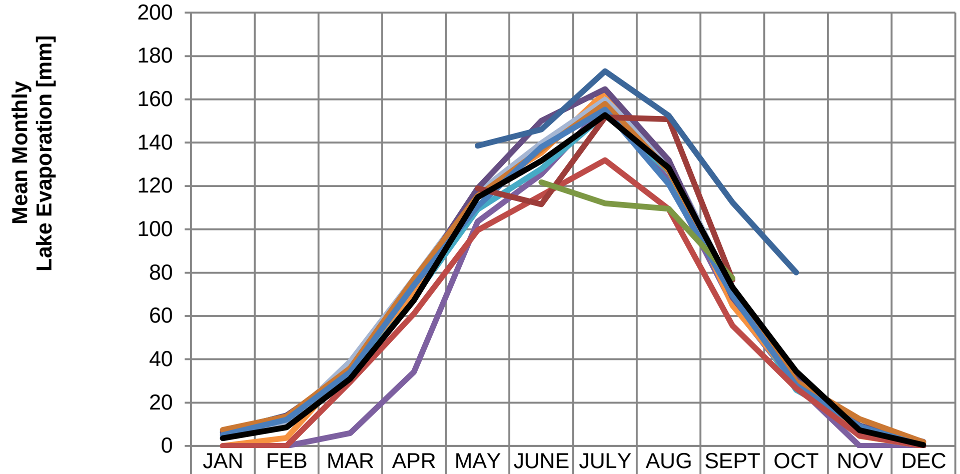


Figure C3-1: Evaporation Station Location Map

Source: L:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!080_Deliverables\Hydrology Report\040_Figures\figure 2_Evap stations.jpg



	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Old Glory Mountain (WREVAP)	0	0	6	34	104	126	157	123	65	28	0	0
Castlegar A (WREVAP)	7	14	33	69	109	128	153	127	70	26	10	0
Kimberly A (WREVAP)	0	4	36	71	117	135	163	130	65	30	5	0
Cranbrook A (WREVAP)	4	11	39	77	117	140	160	131	72	30	8	0
Lethbridge CDA (WREVAP)	6	14	35	74	119	150	165	132	69	32	9	2
Penticton (WREVAP)	7	14	36	77	115	137	158	127	73	30	12	2
Kelowna (WREVAP)	5	12	34	74	111	138	155	121	69	28	9	0
Revelstoke (WREVAP)	0	0	30	61	100	116	132	109	56	27	5	0
Castlegar BCHPA Dam (Canadian Climate Normals 1951-1980)					119	112	152	151	77			
Whiskey GAP (Canadian Climate Normals 1951-1980)					139	146	173	153	112	80		
Duncan Lake Dam (Canadian Climate Normals 1951-1980)						122	112	110	78			
Average	3.6	8.6	31.1	67.2	114.9	131.7	152.7	128.4	73.3	34.4	7.2	0.5

Month

Figure C3-2: Monthly Lake Evaporation

Source: Z:\01_SITES\Coal Mountain\1CT008.038_Site Wide Water Balance\!020_Project_Data\010_SRK\WB Inputs\Hydrology\Evaporation\Evaporation_WREVAP_outputs_3.xlsx

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Appendix B – Water Quality Calibration Plots

FIGURE A1

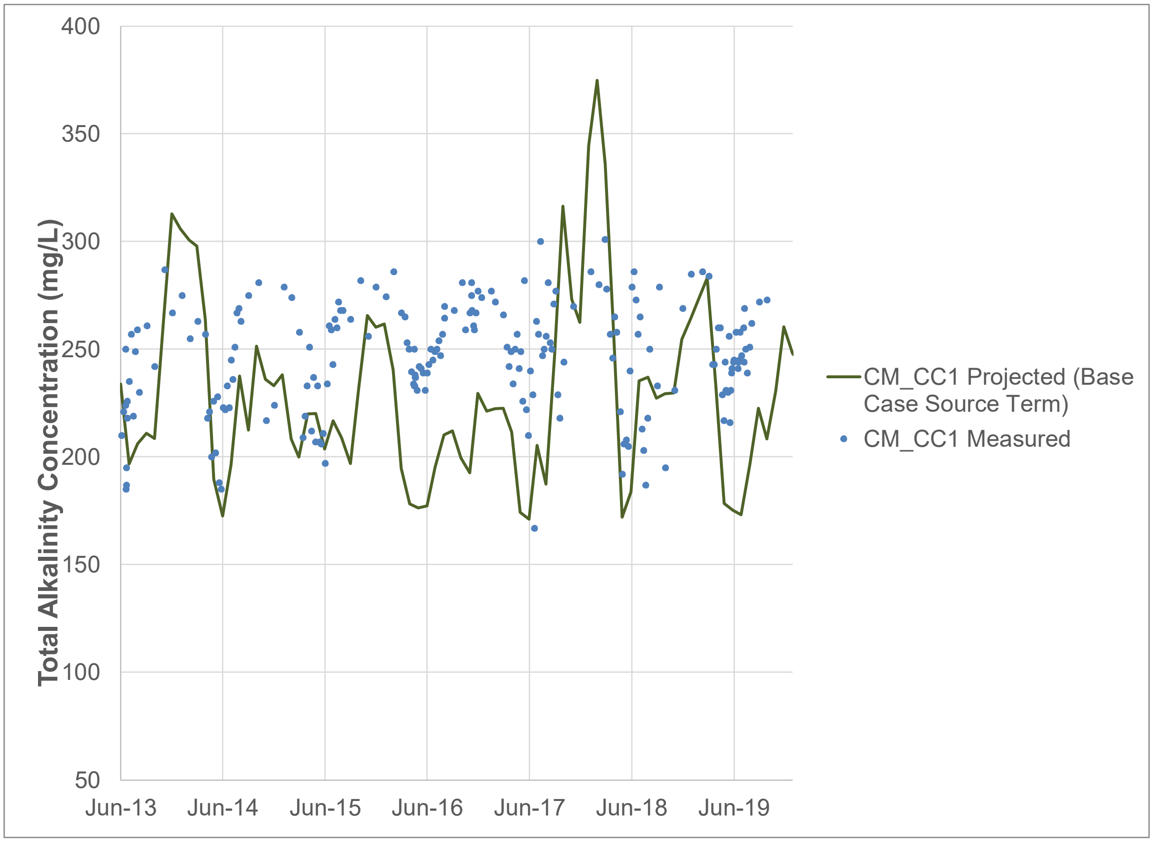

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FIGURE A2

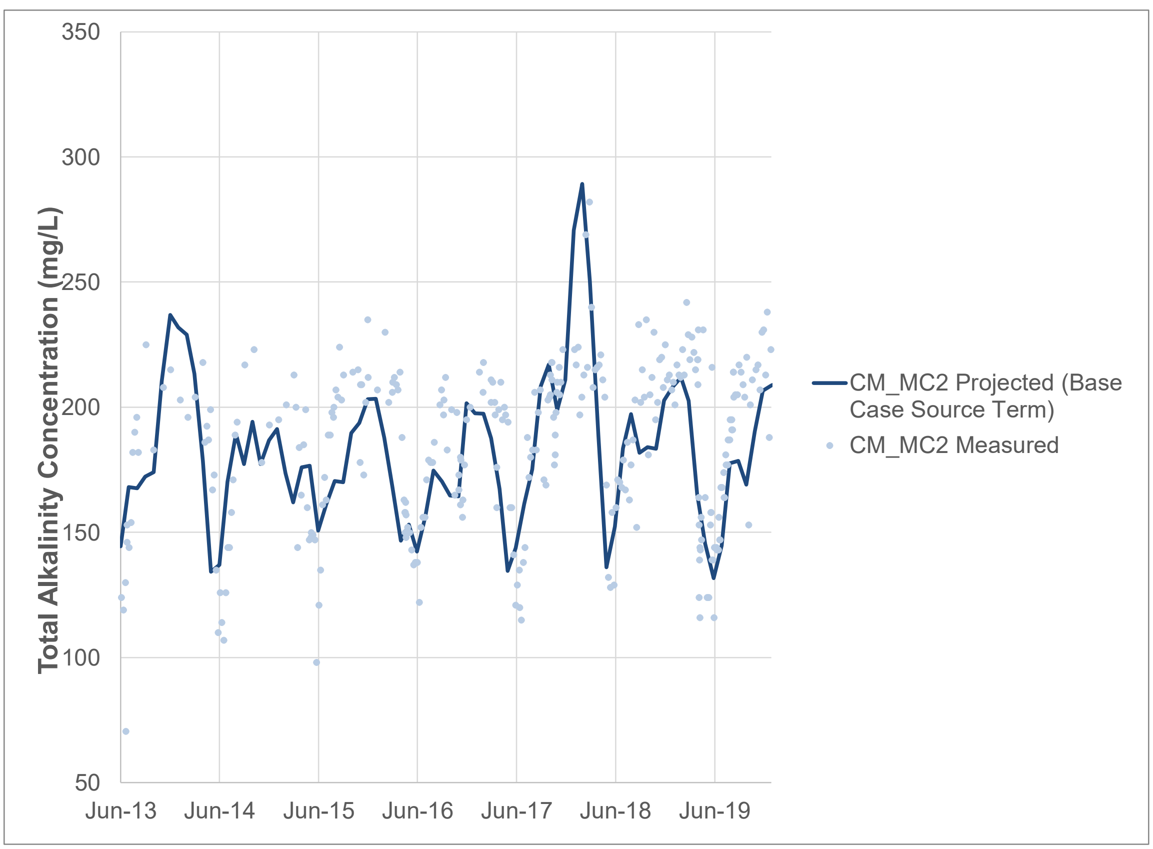

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FIGURE A3

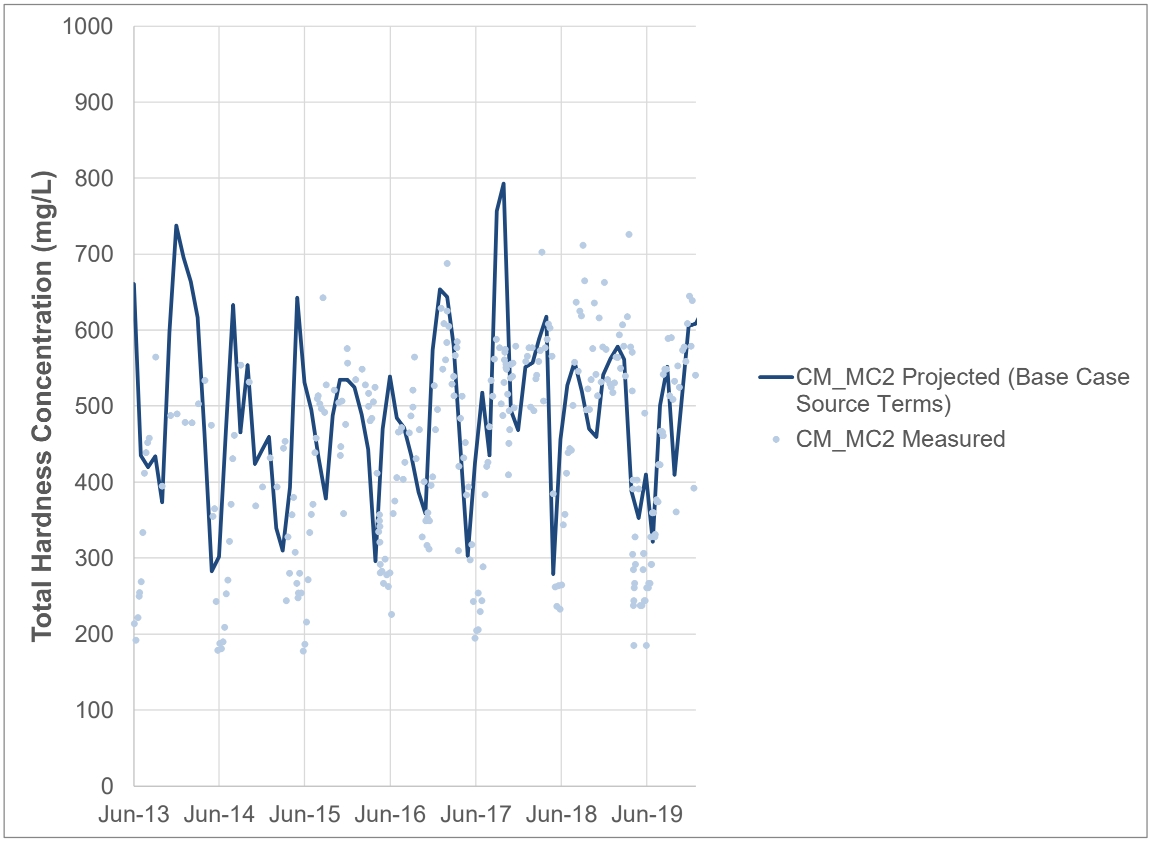

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FIGURE A4

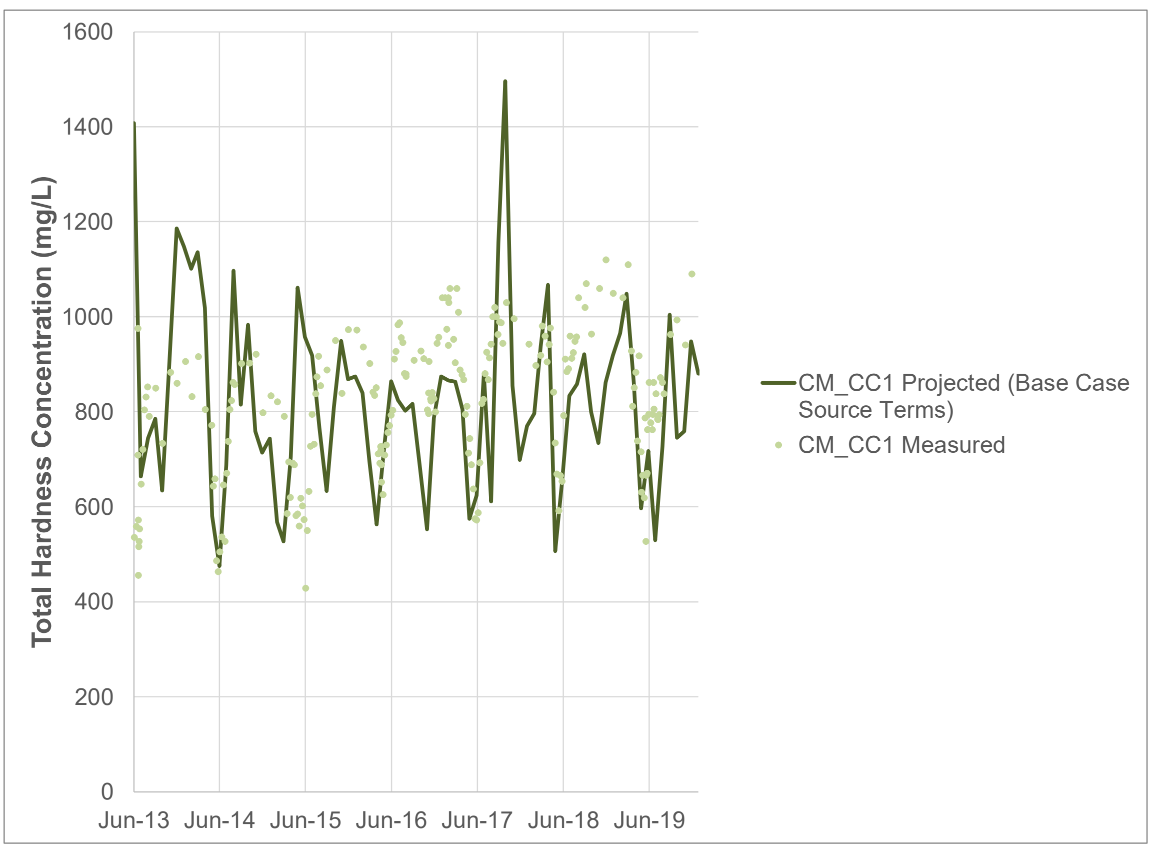

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FIGURE A5

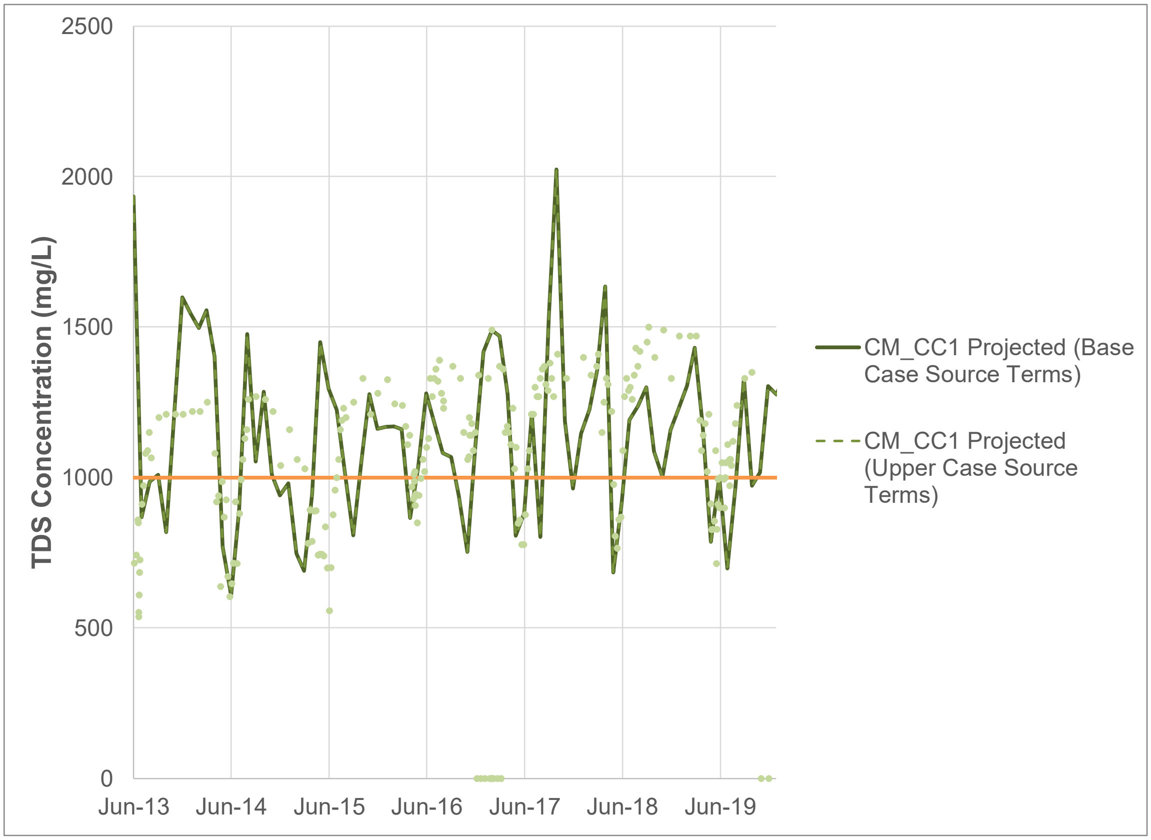

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FIGURE A6

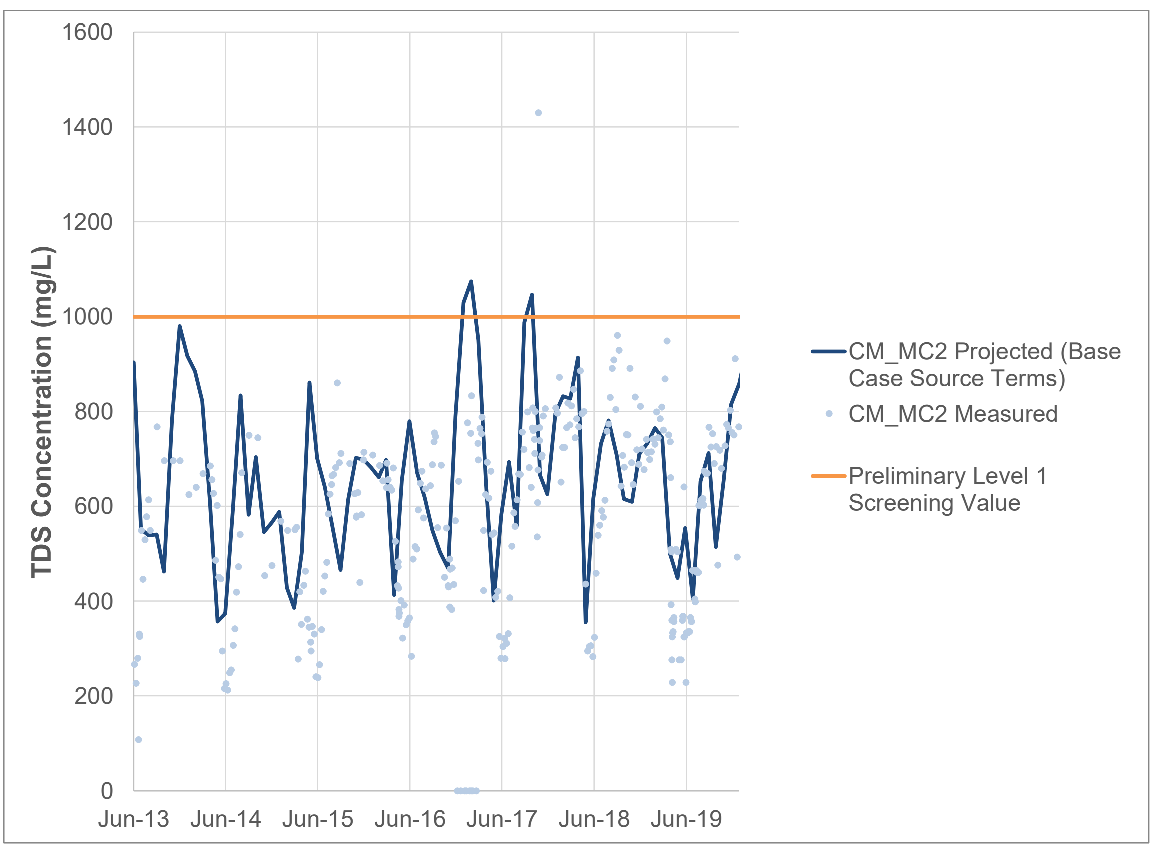

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FIGURE A7

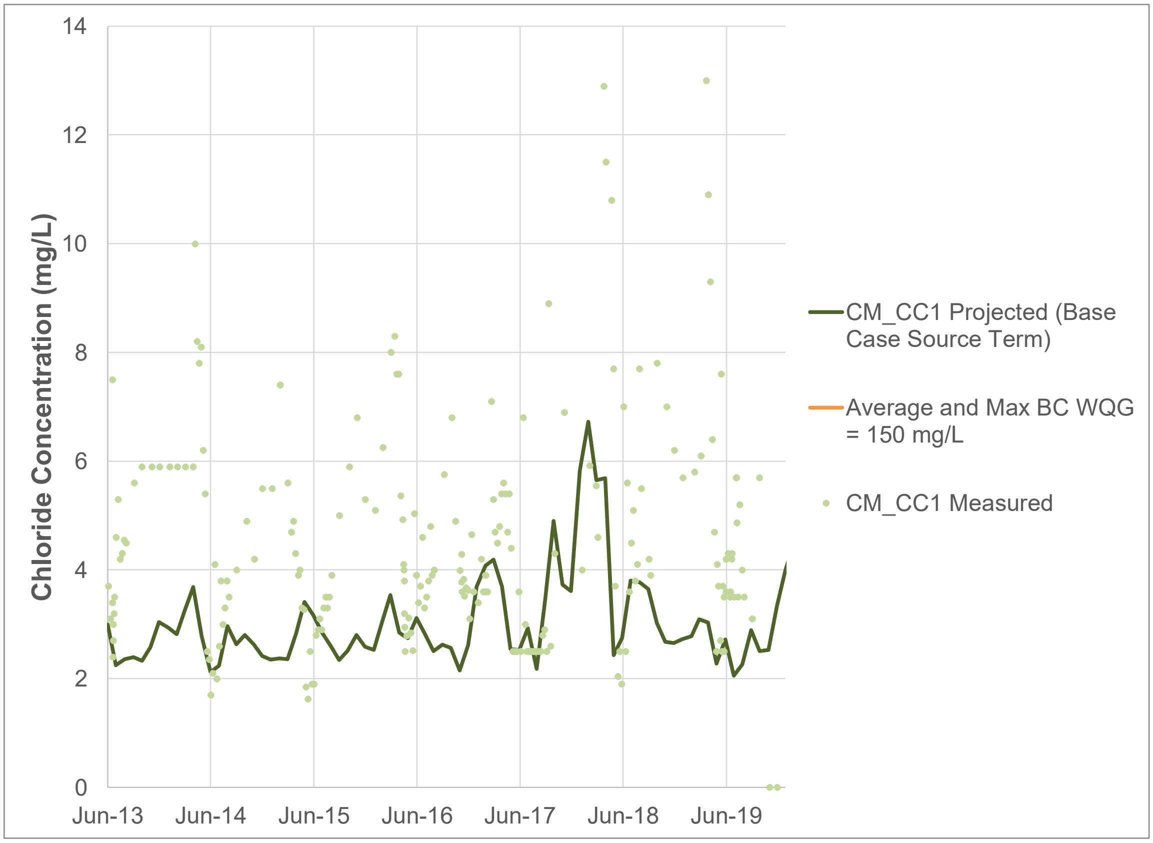

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FIGURE A8

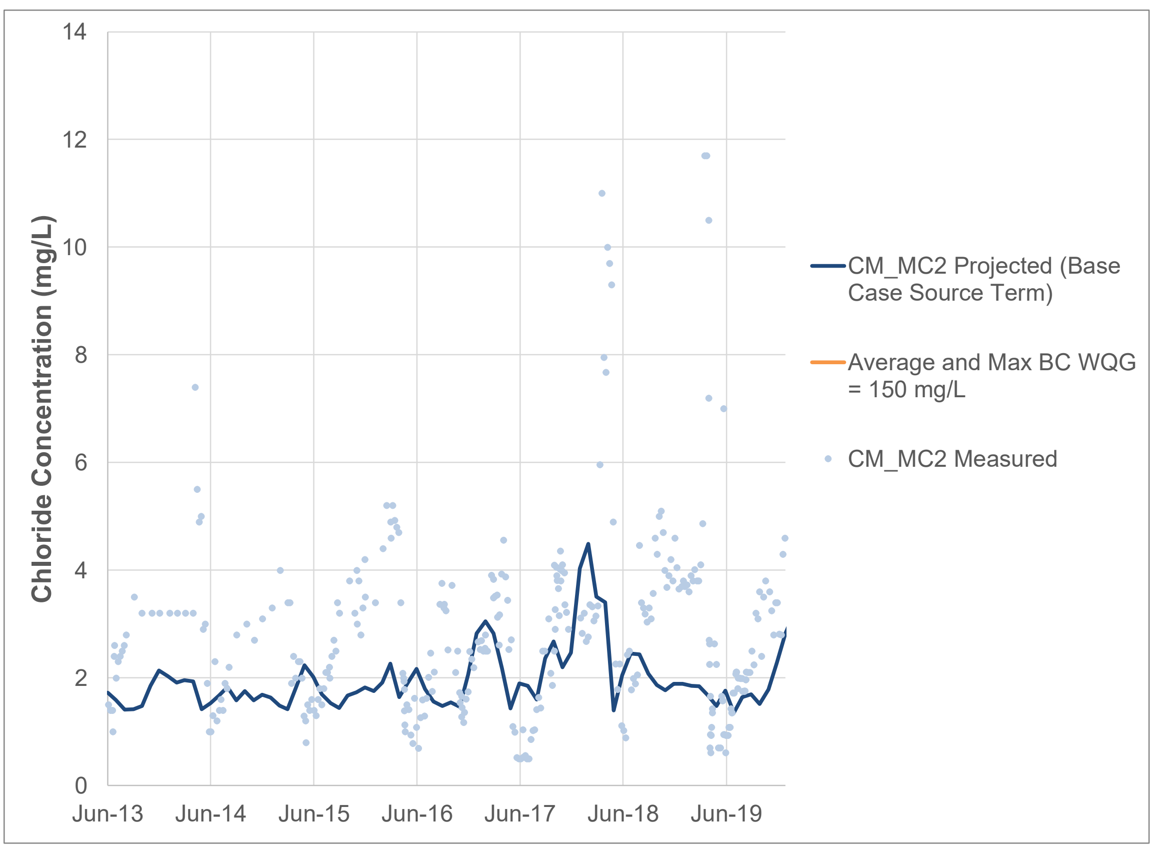

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FIGURE A9

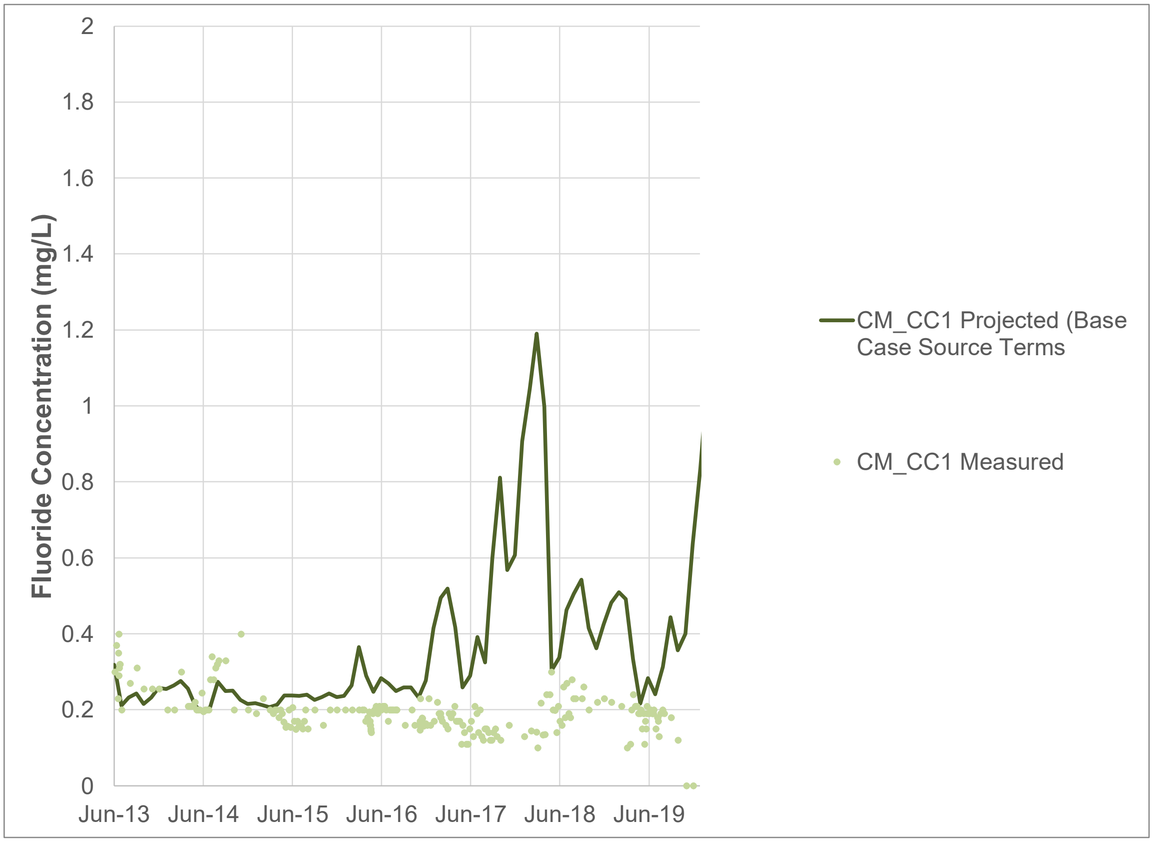

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FIGURE A10

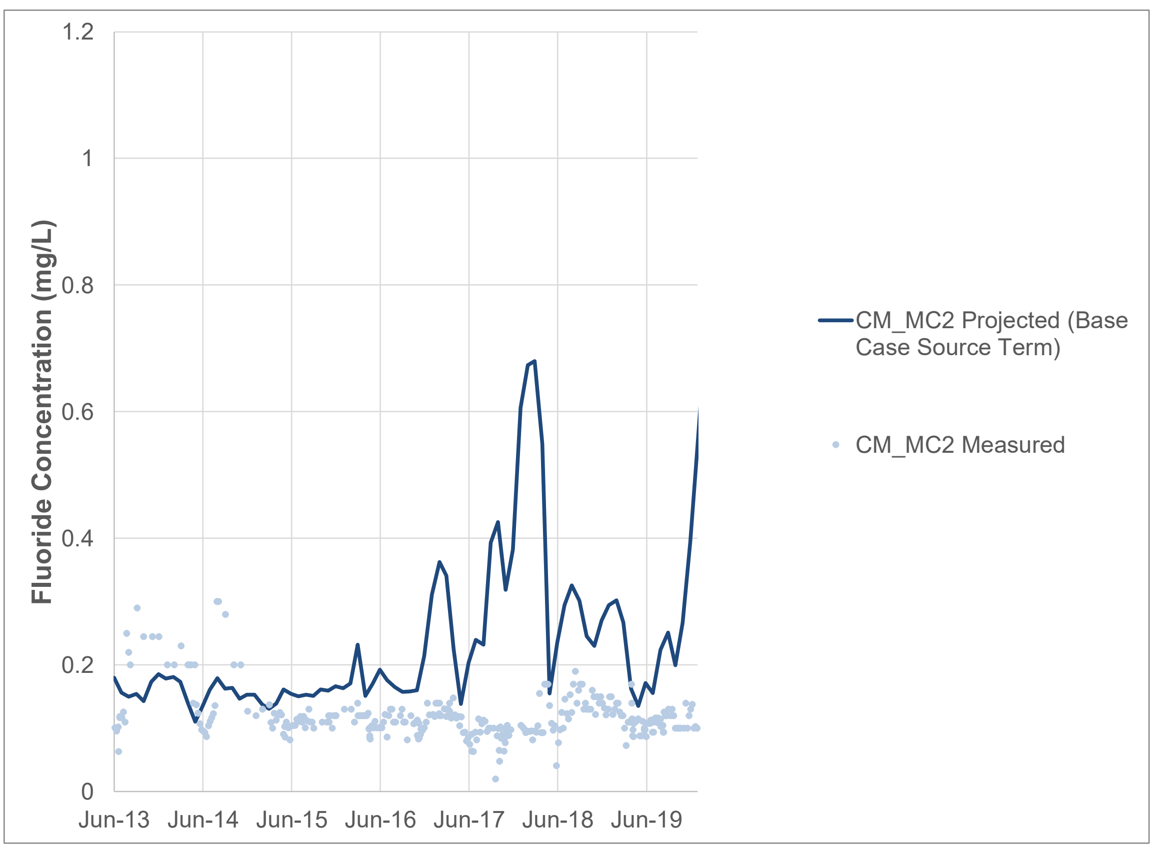

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FIGURE A11

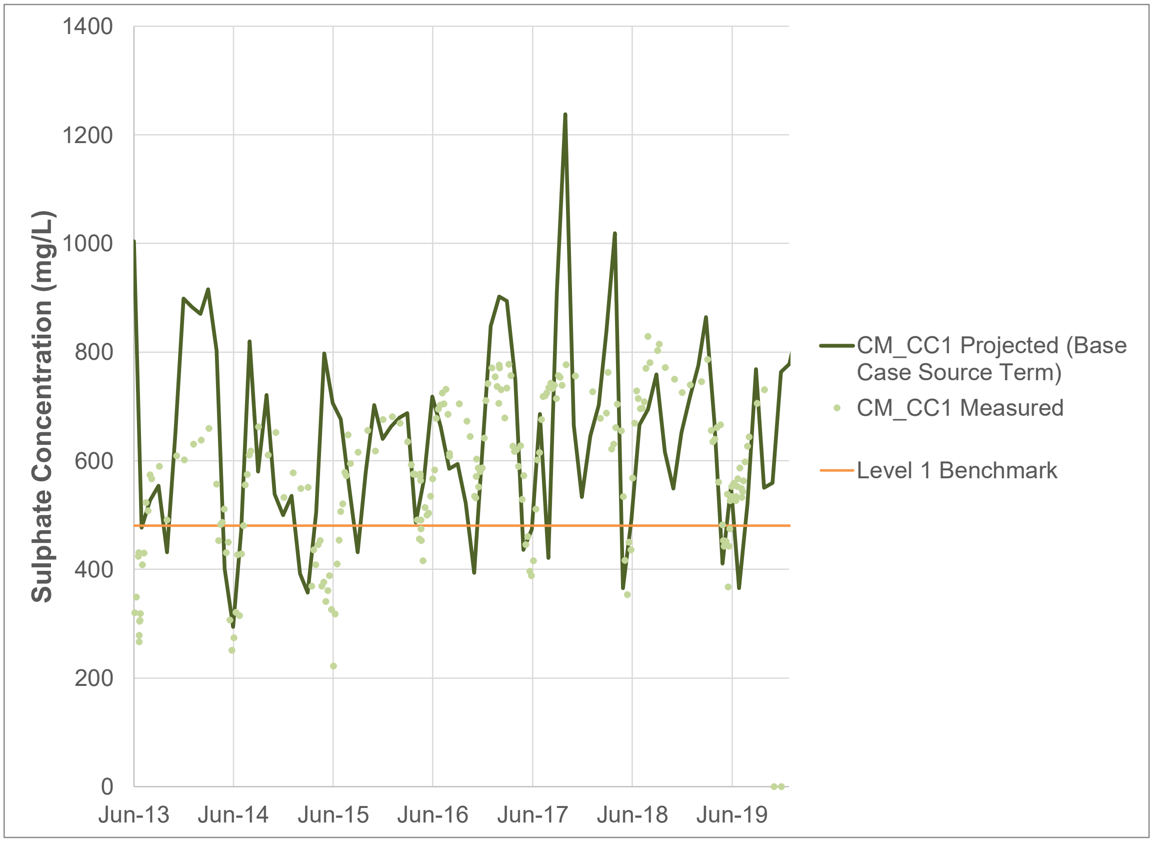

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FIGURE A12

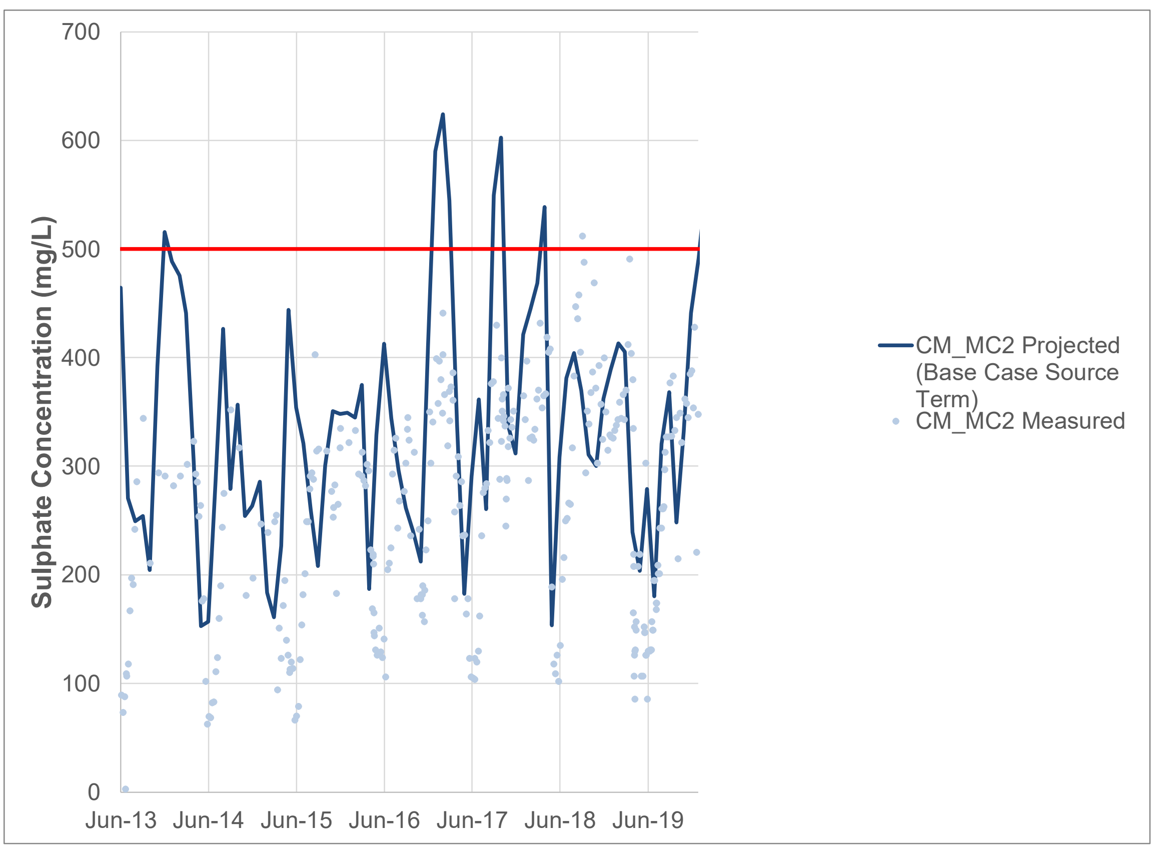

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FIGURE A13

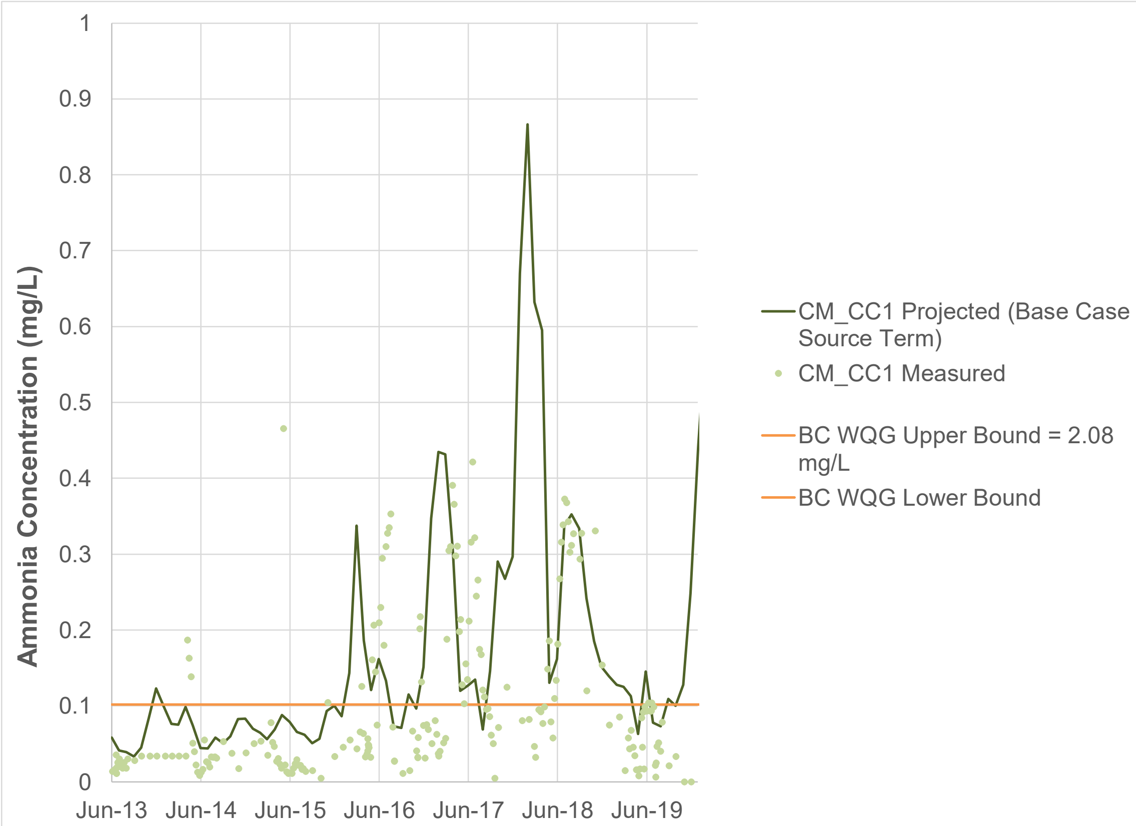

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FIGURE A14

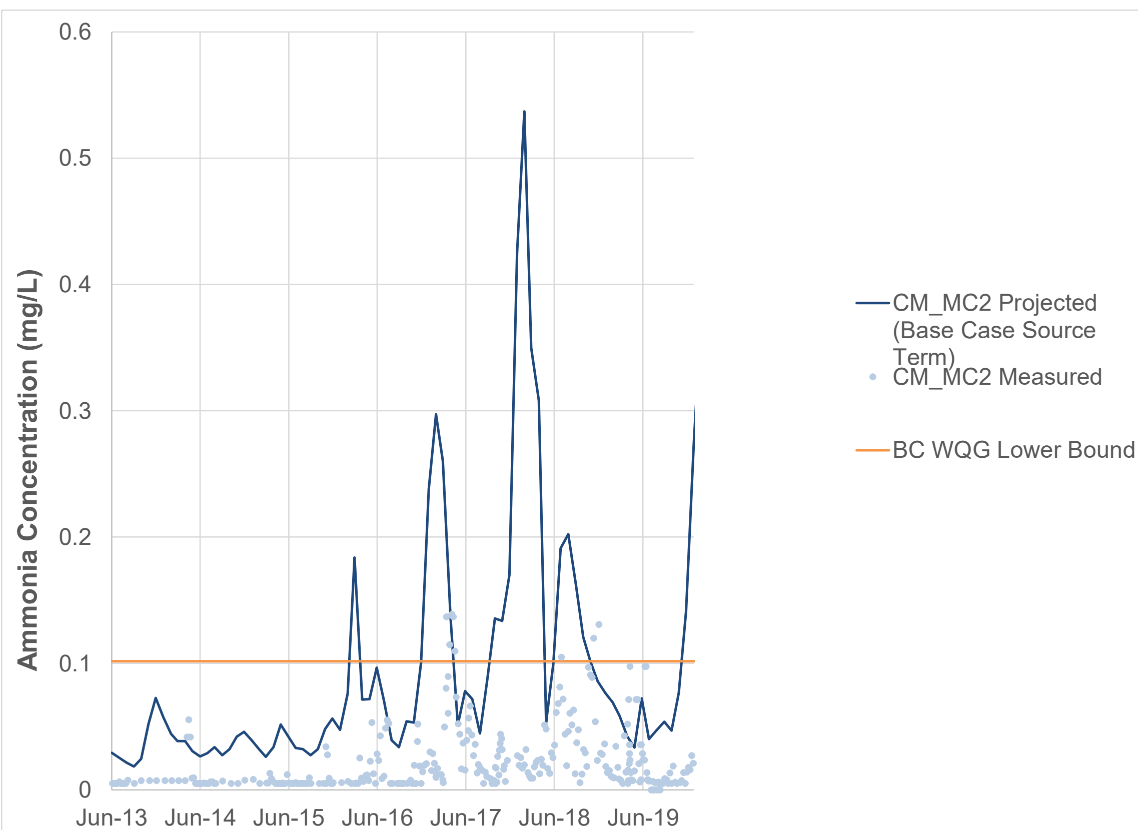

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FIGURE A15

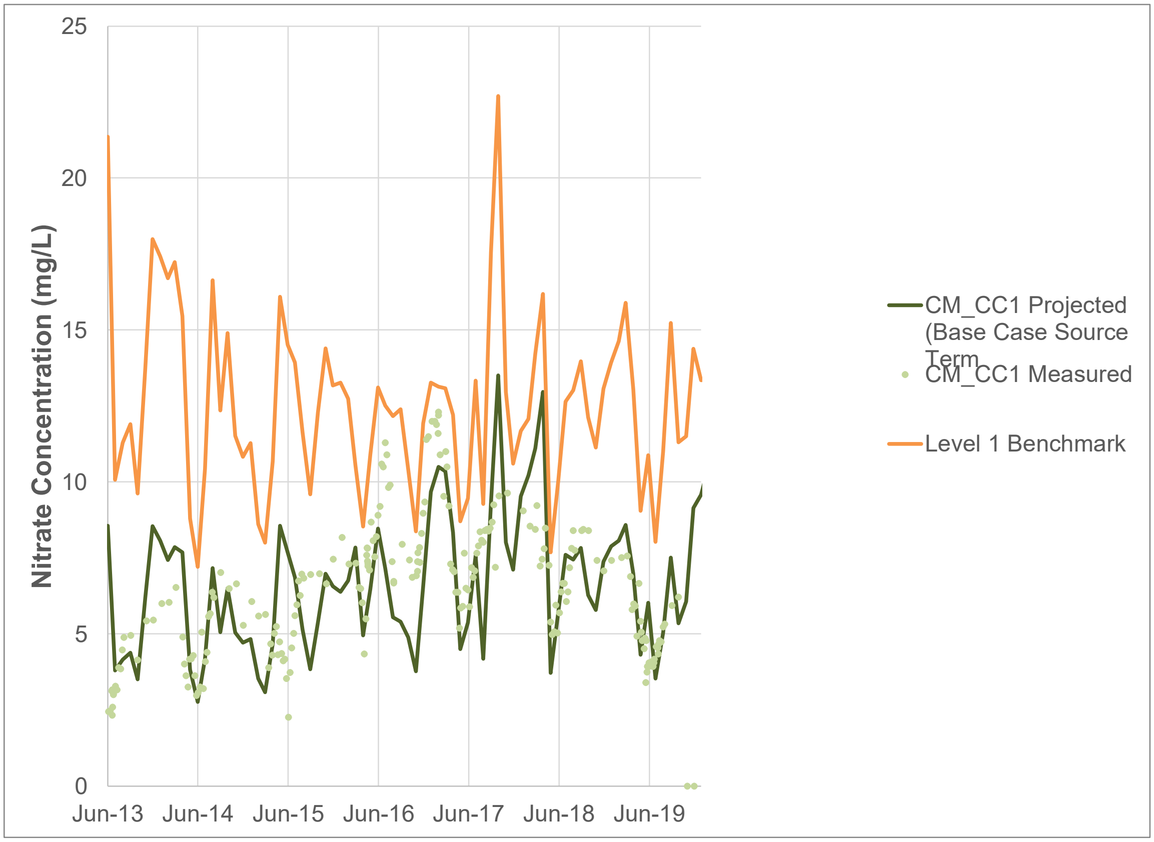

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FIGURE A16

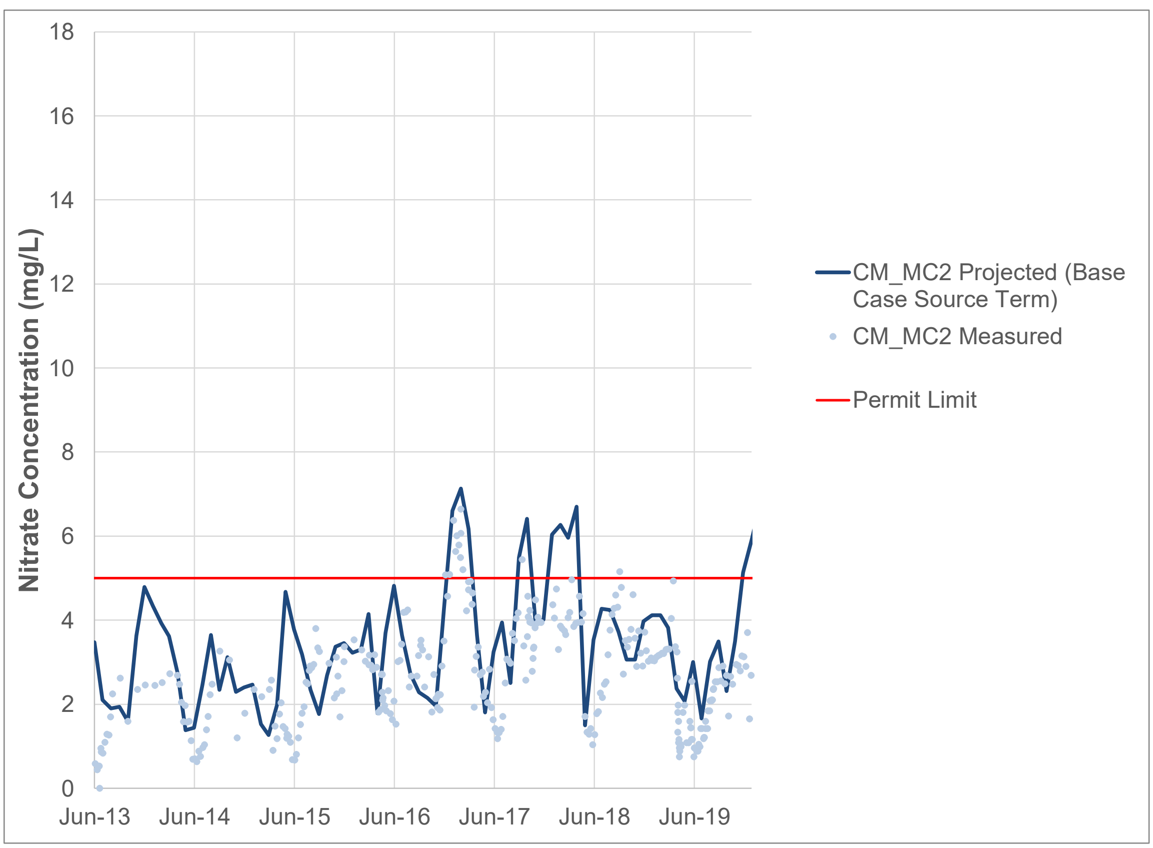

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FIGURE A17

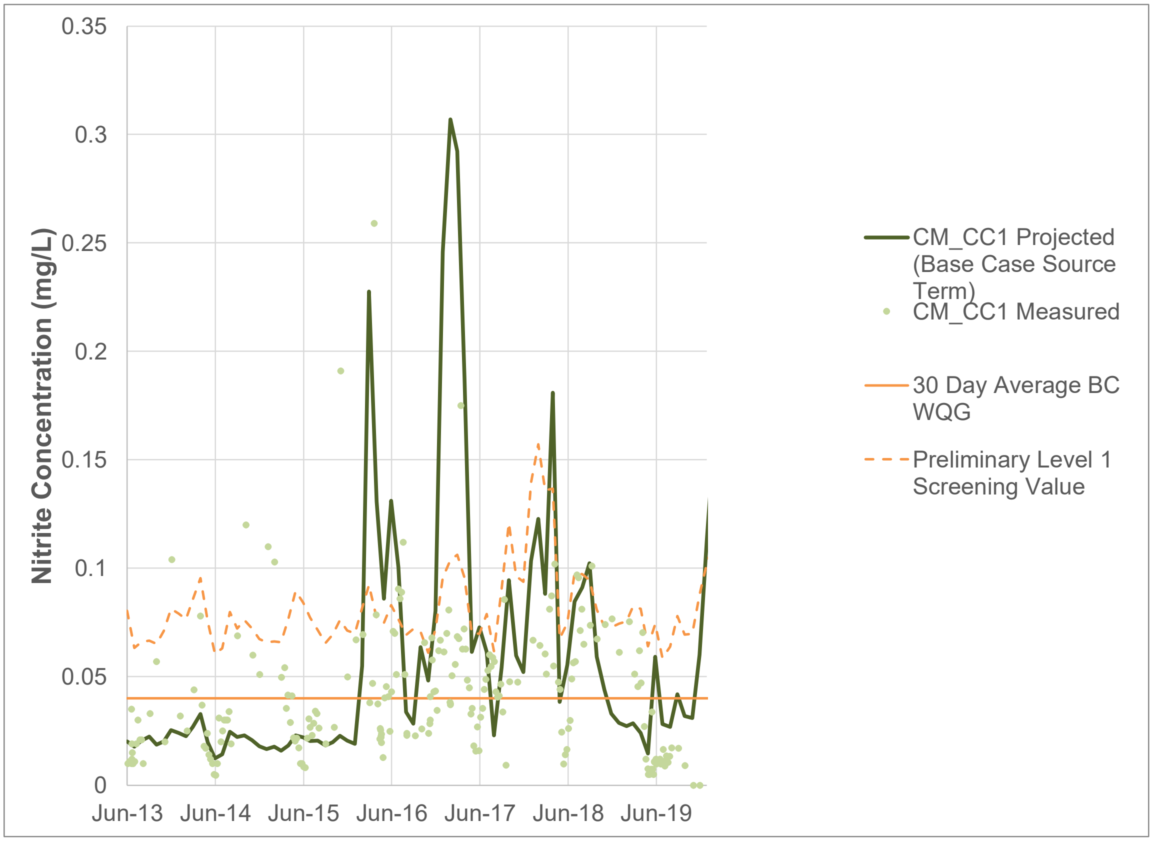

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FIGURE A18

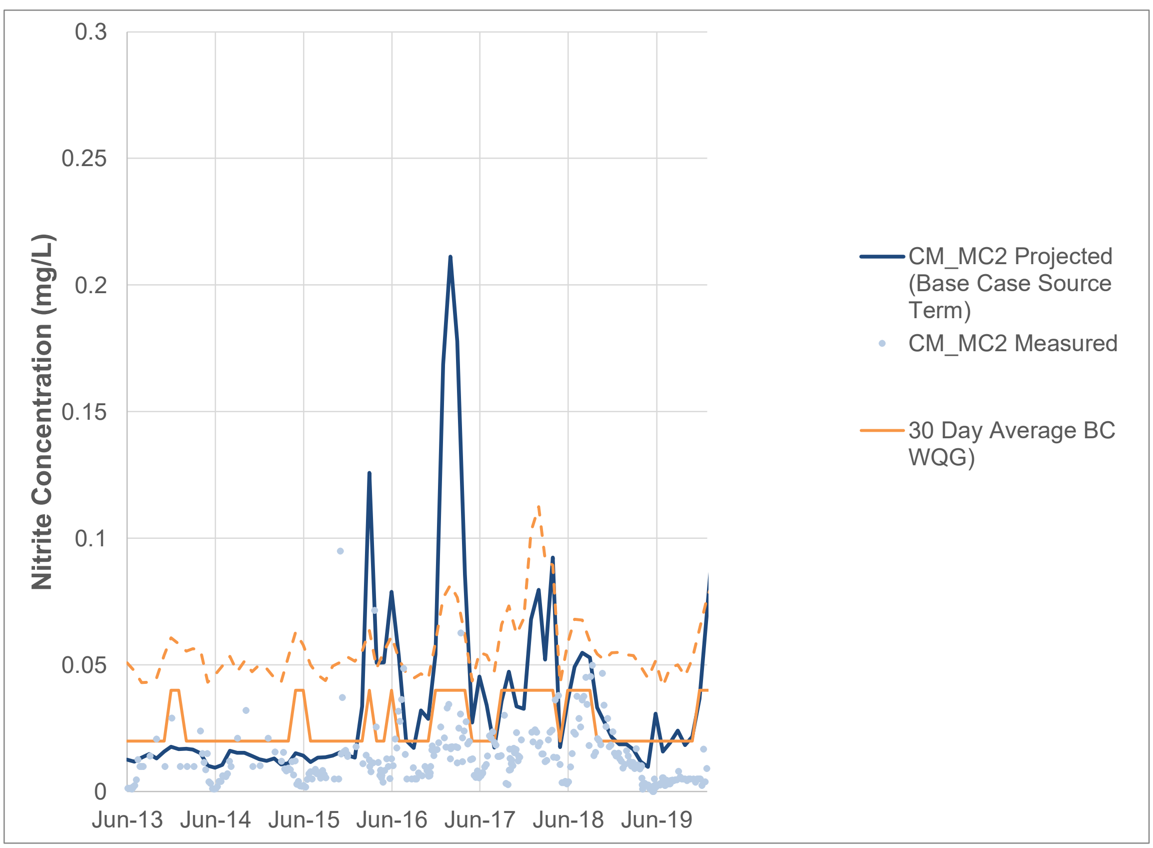

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FIGURE A19

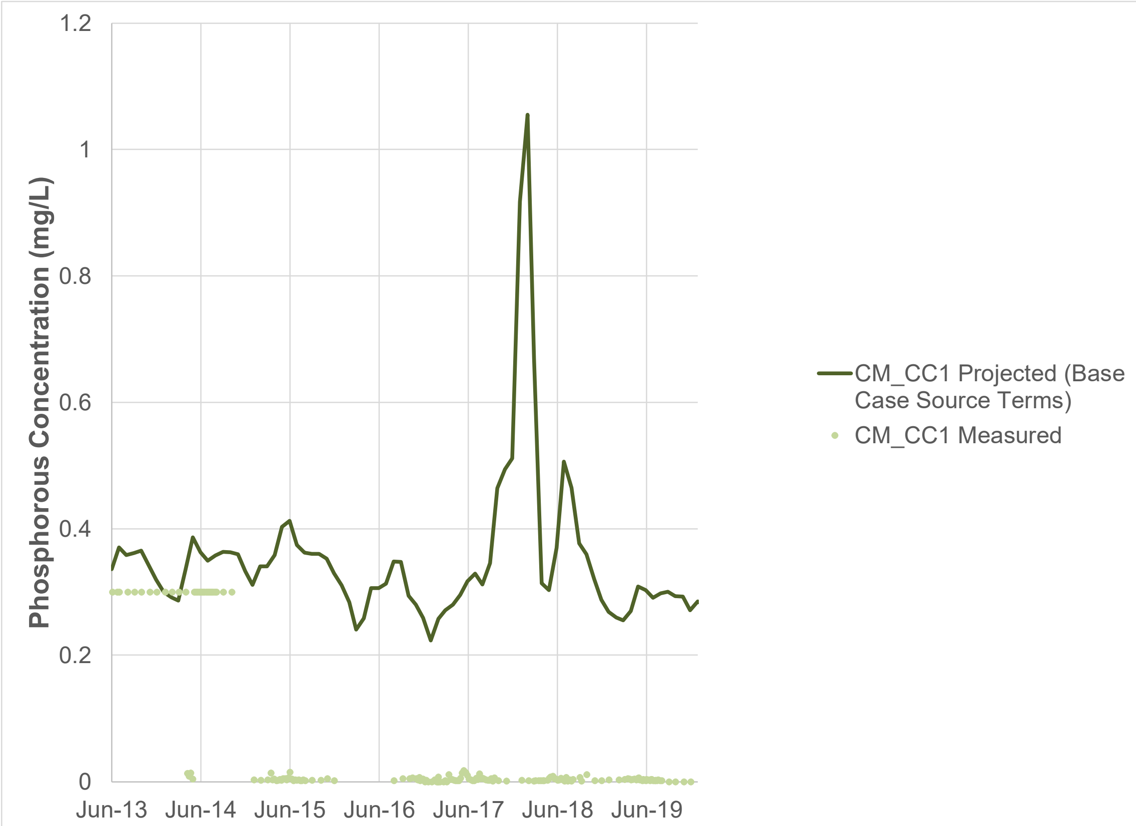

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FIGURE A20

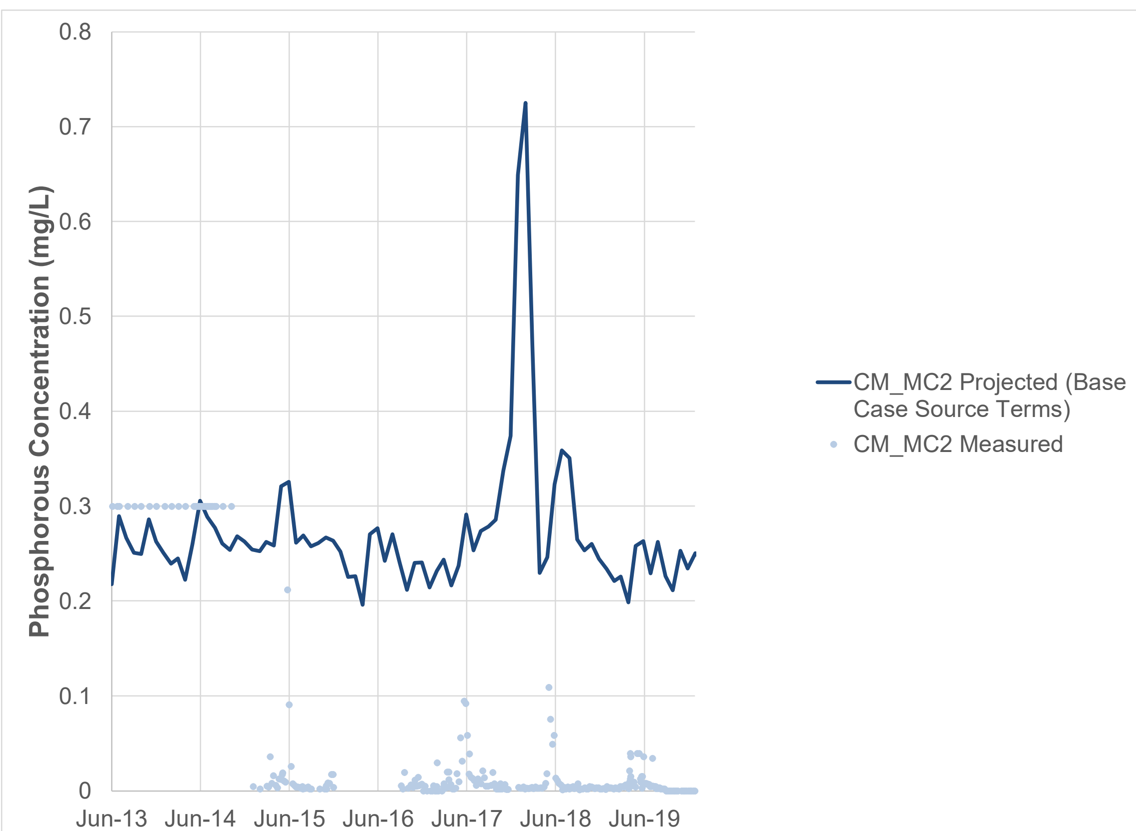

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FIGURE A21

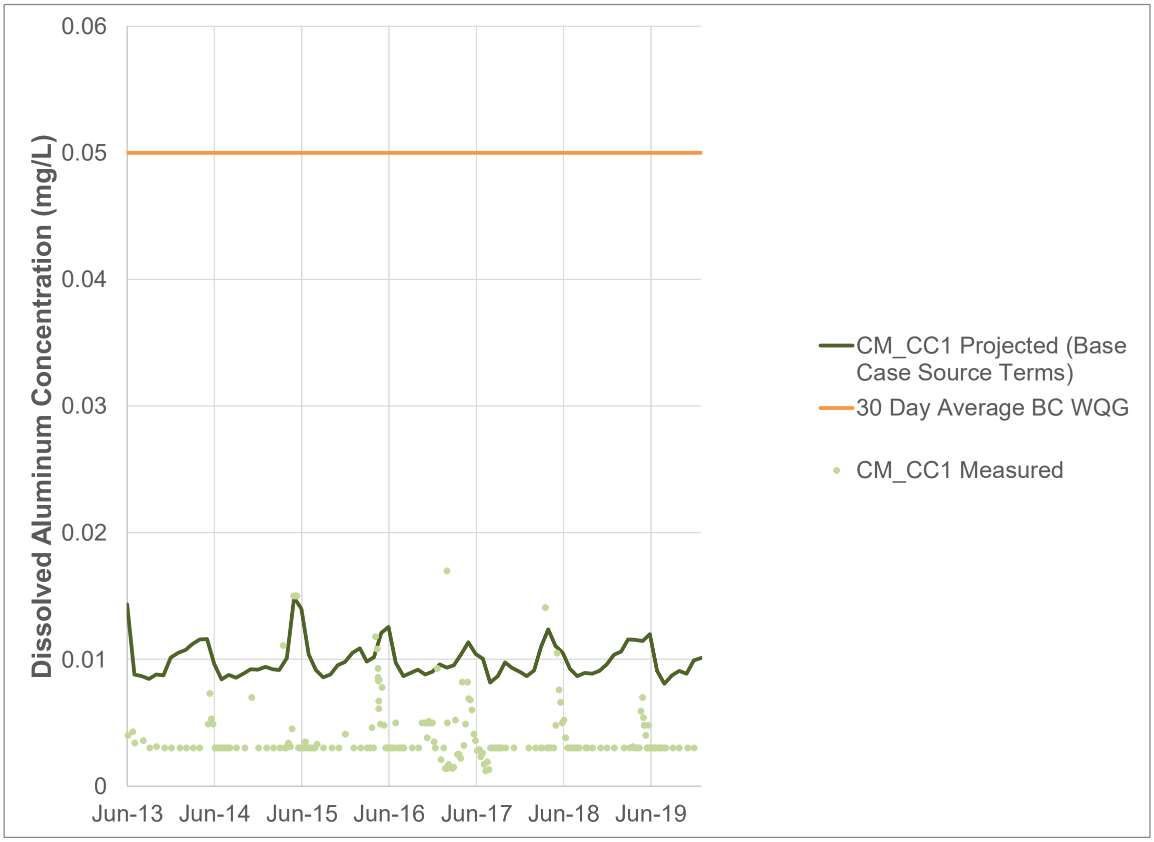

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FIGURE A22

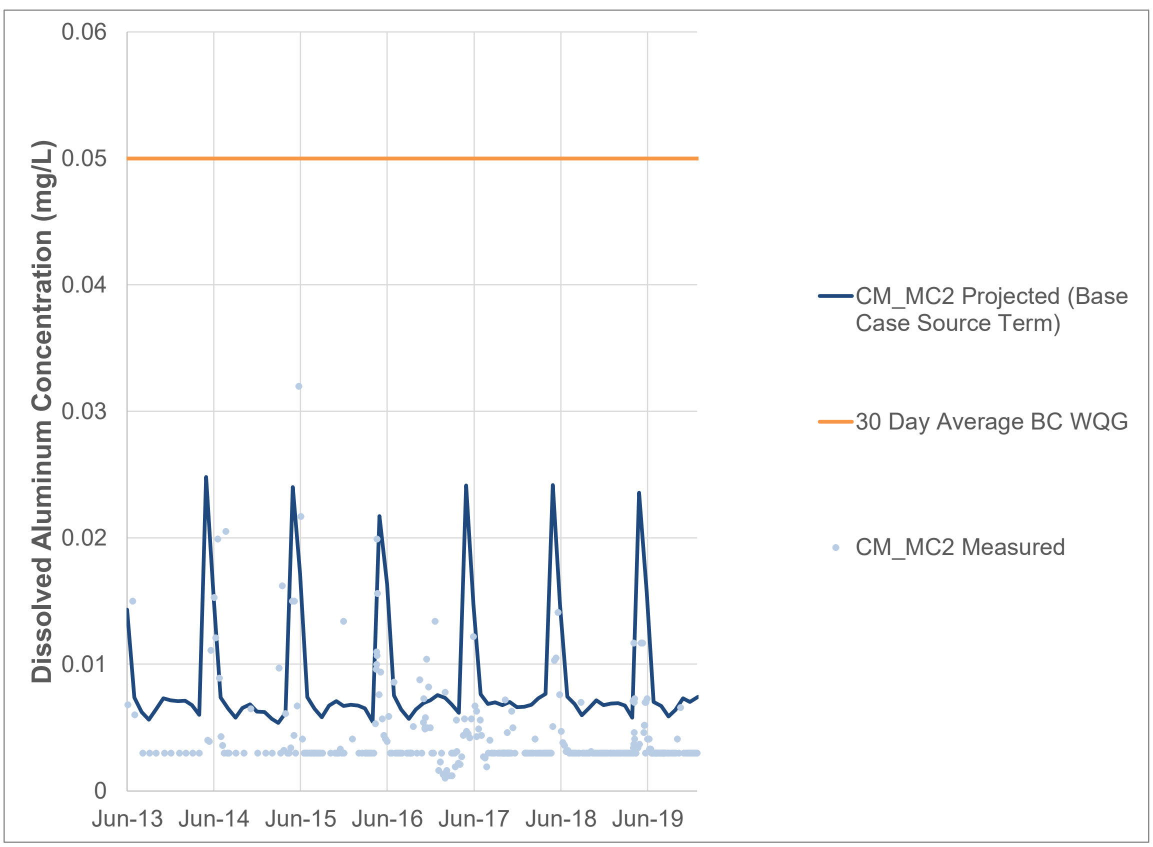

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FIGURE A23

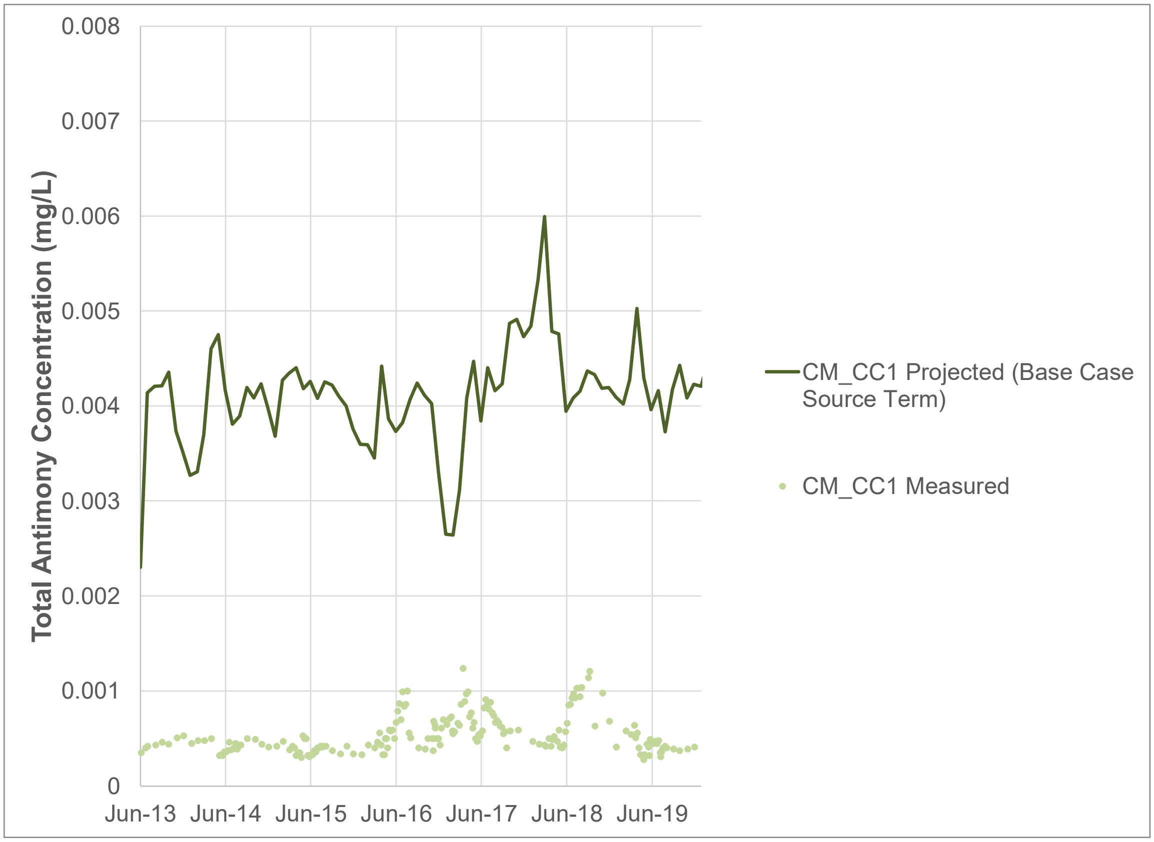

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FIGURE A24

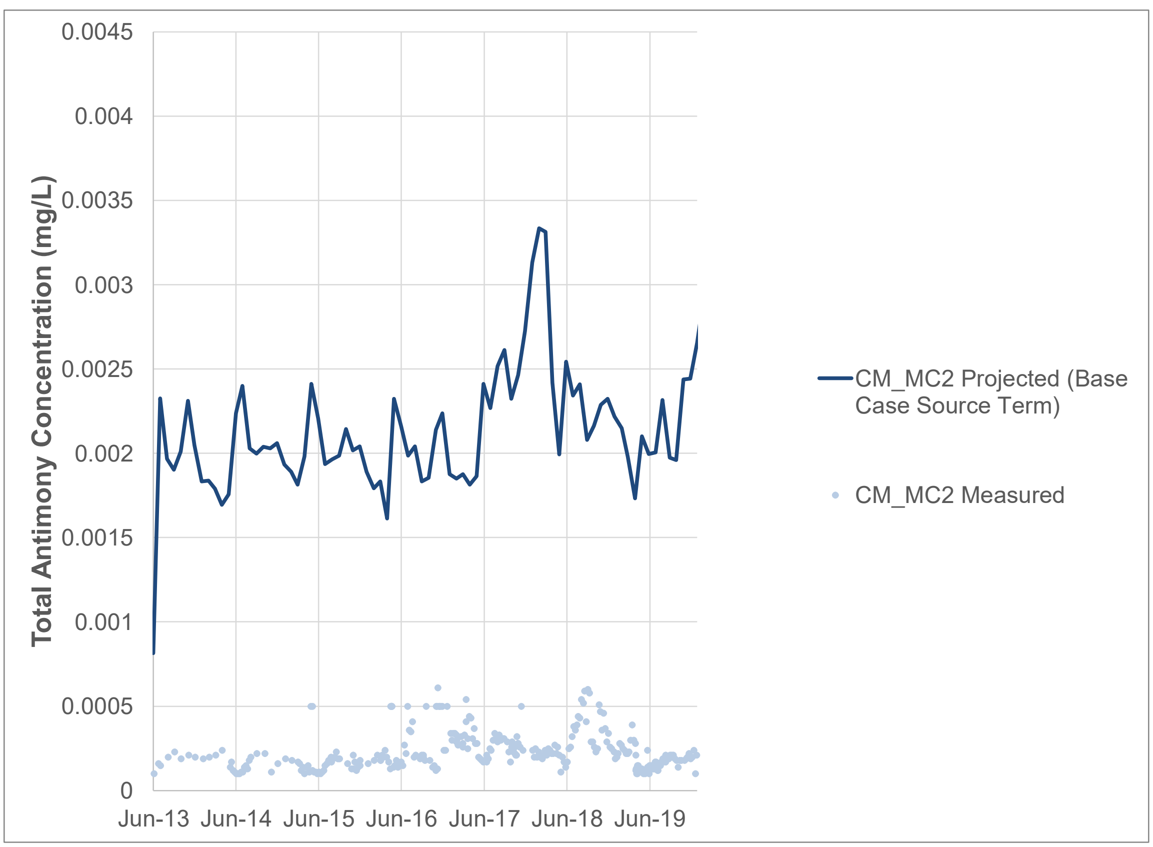

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FIGURE A25

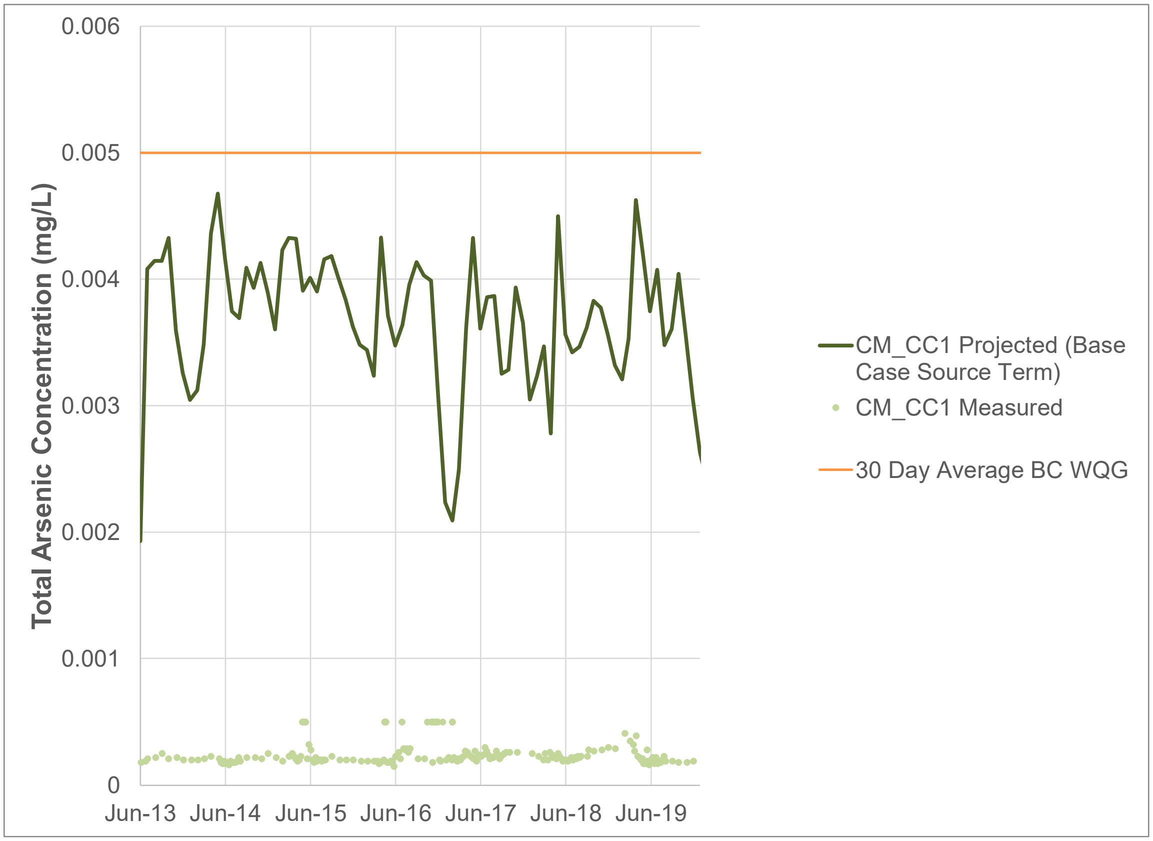

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FIGURE A26

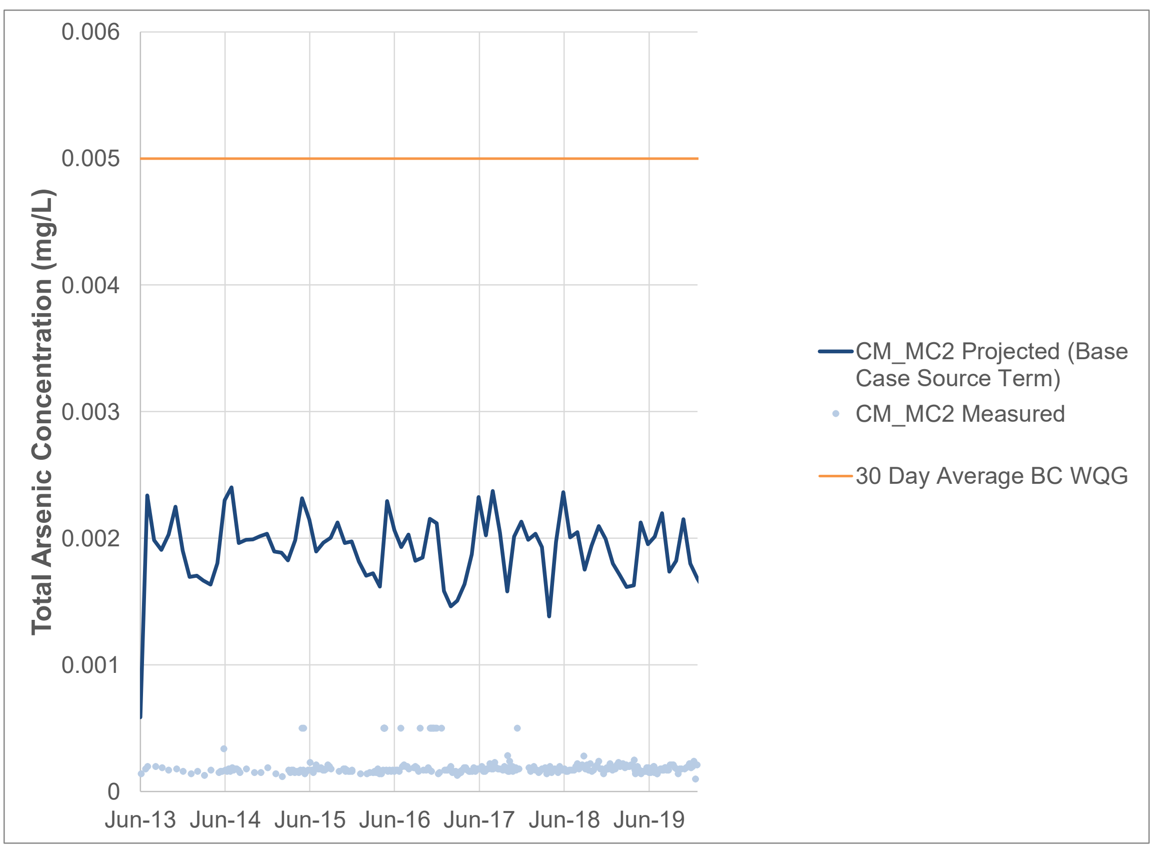

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FIGURE A27

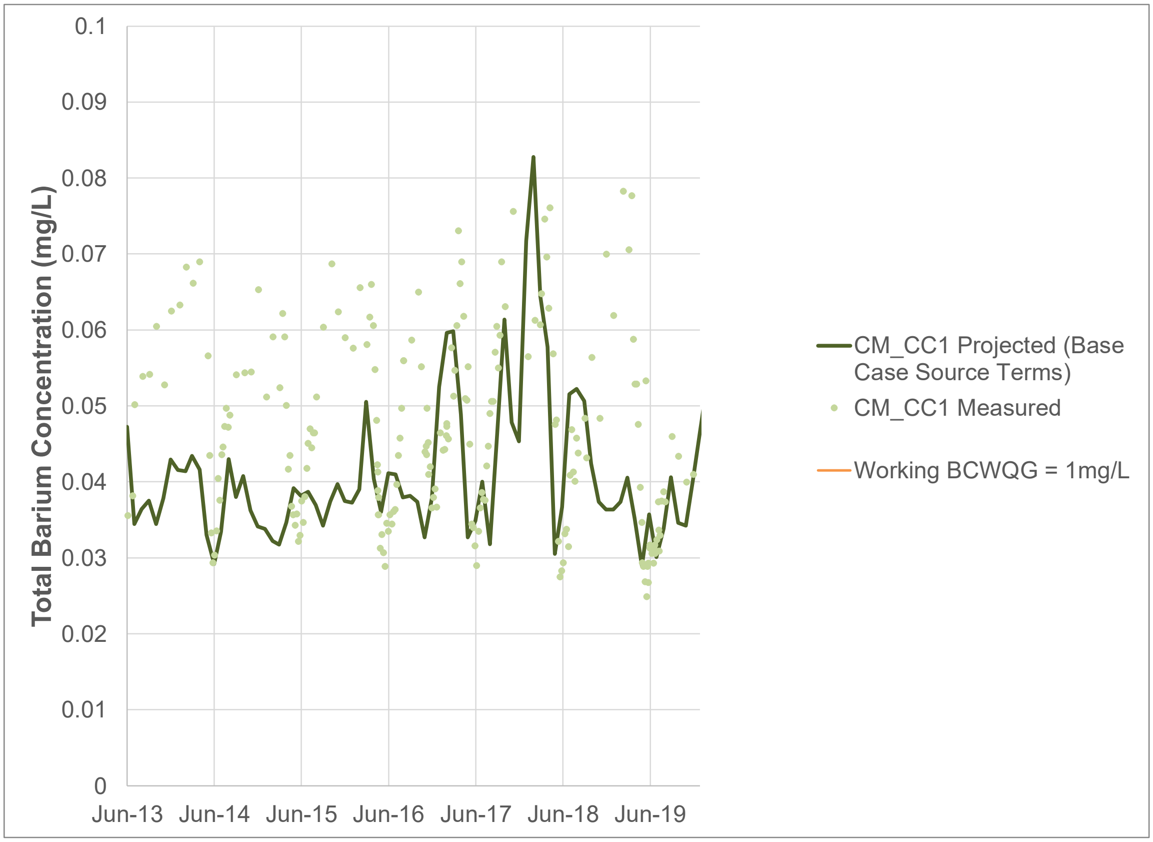

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FIGURE A28

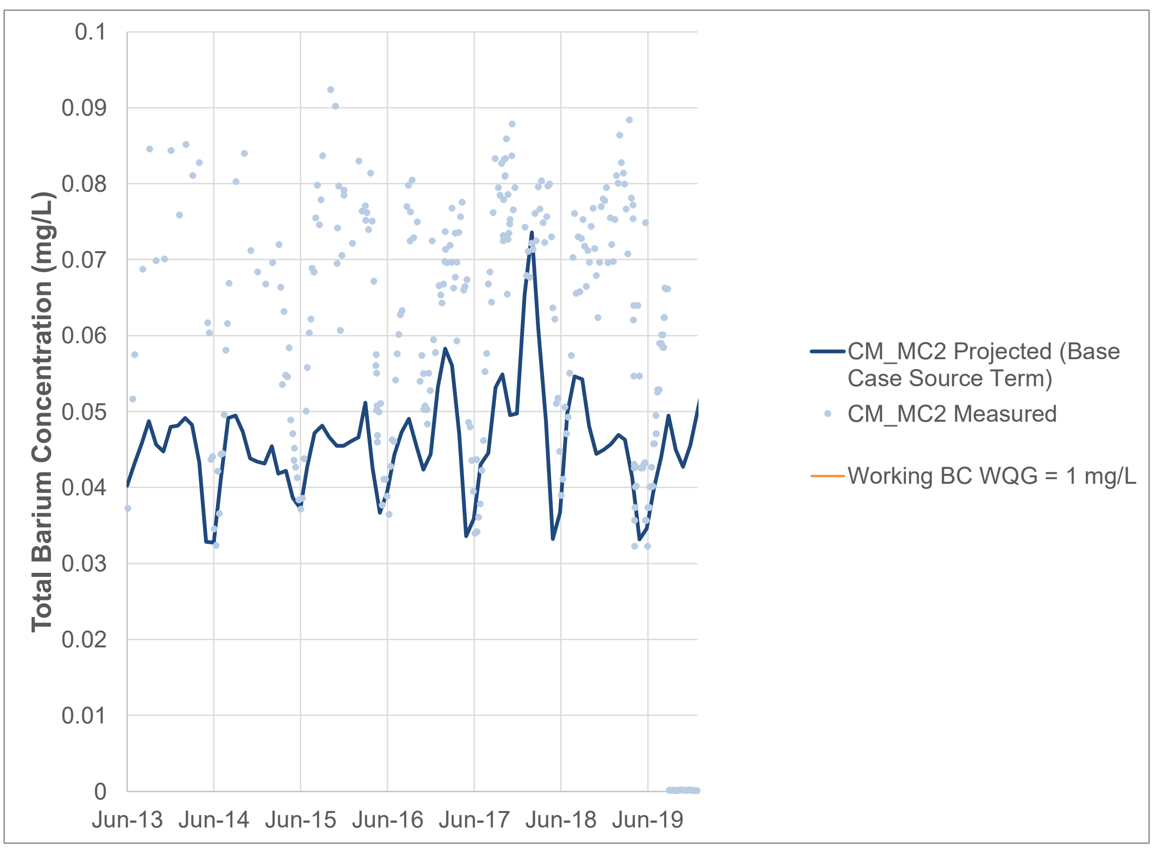

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FIGURE A29

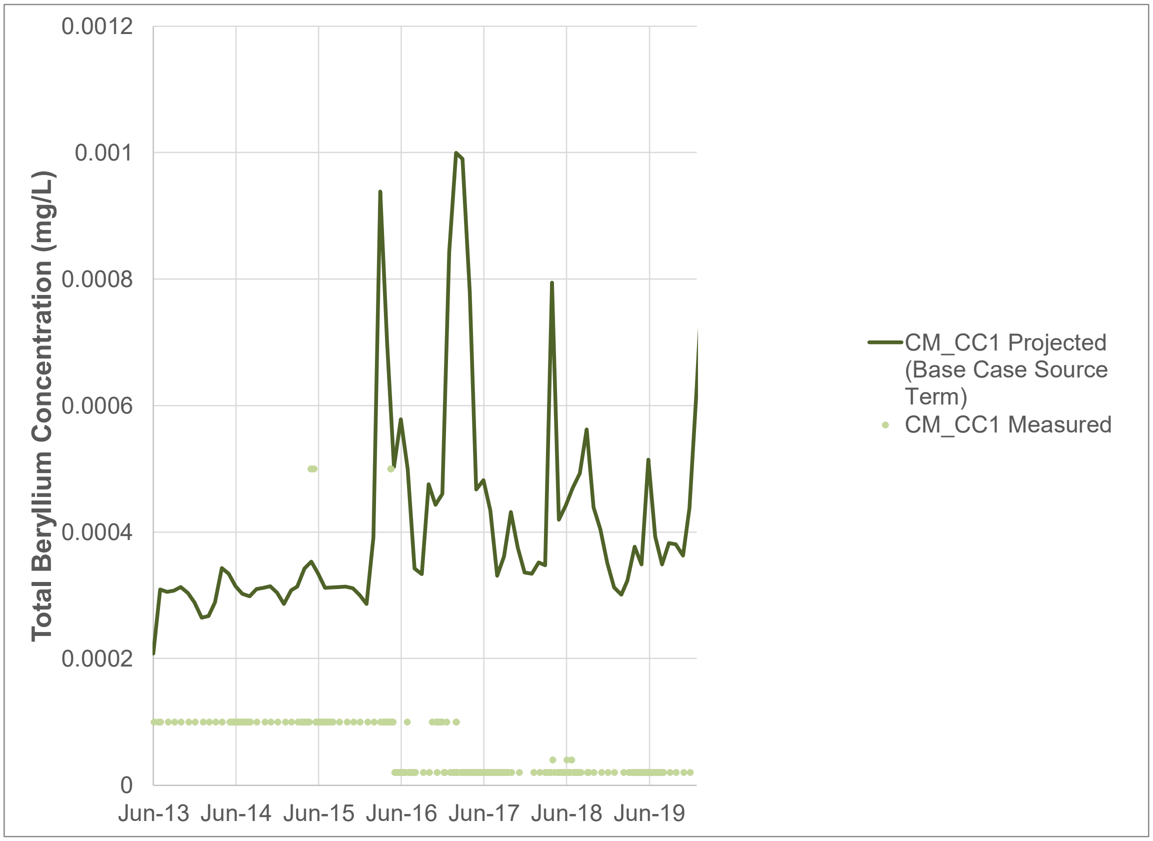

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FIGURE A30

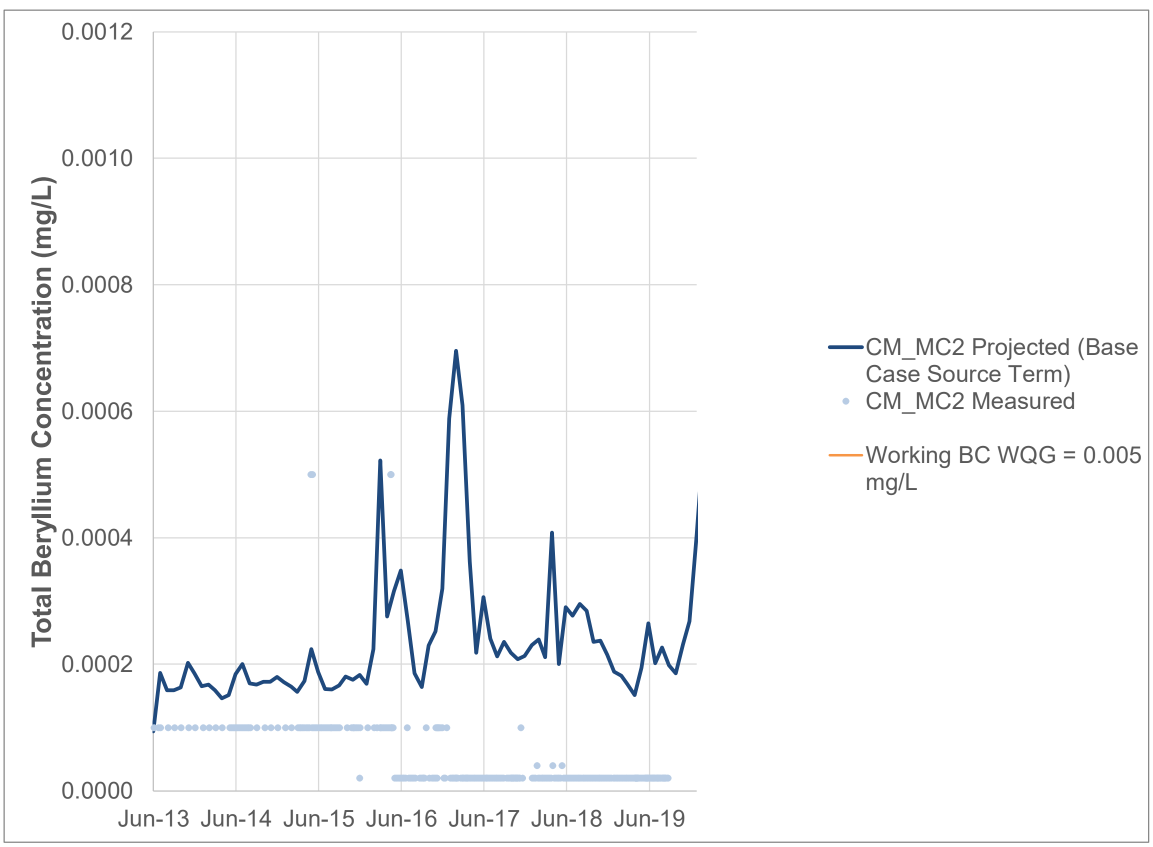

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FIGURE A31

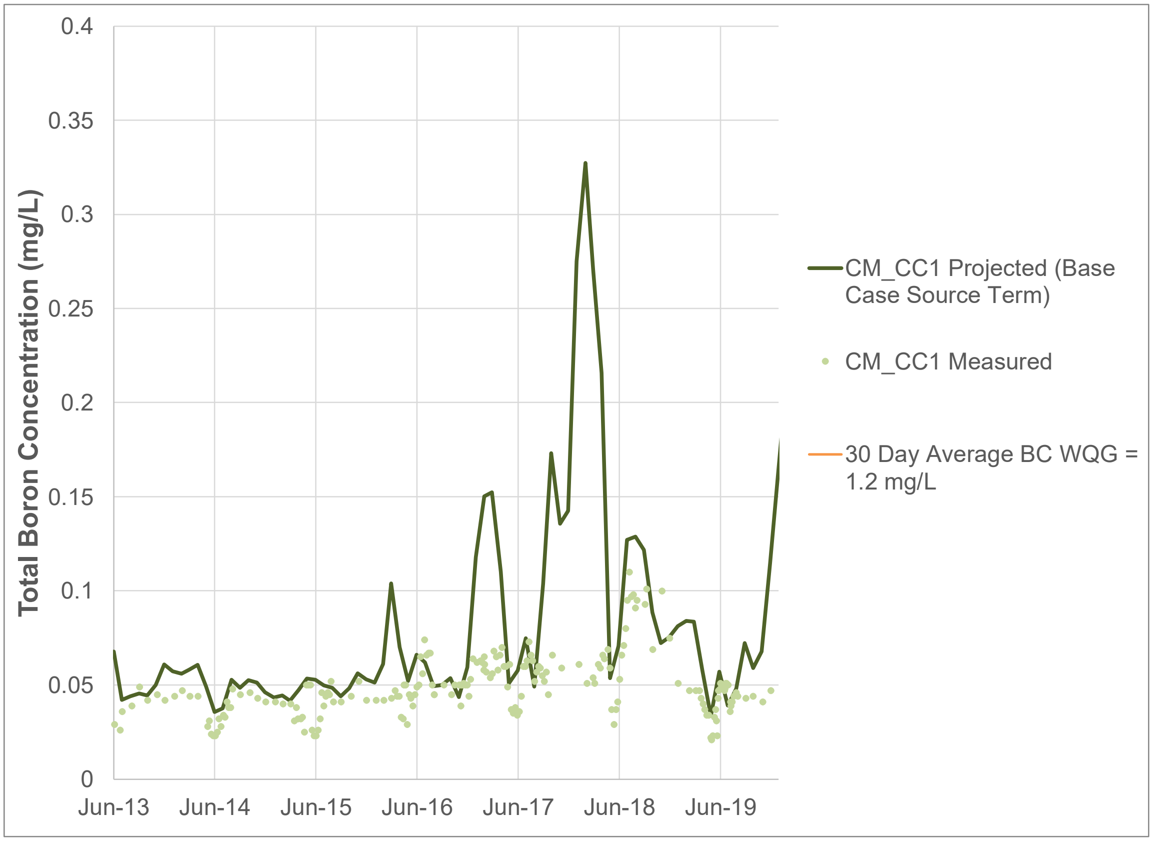

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FIGURE A32

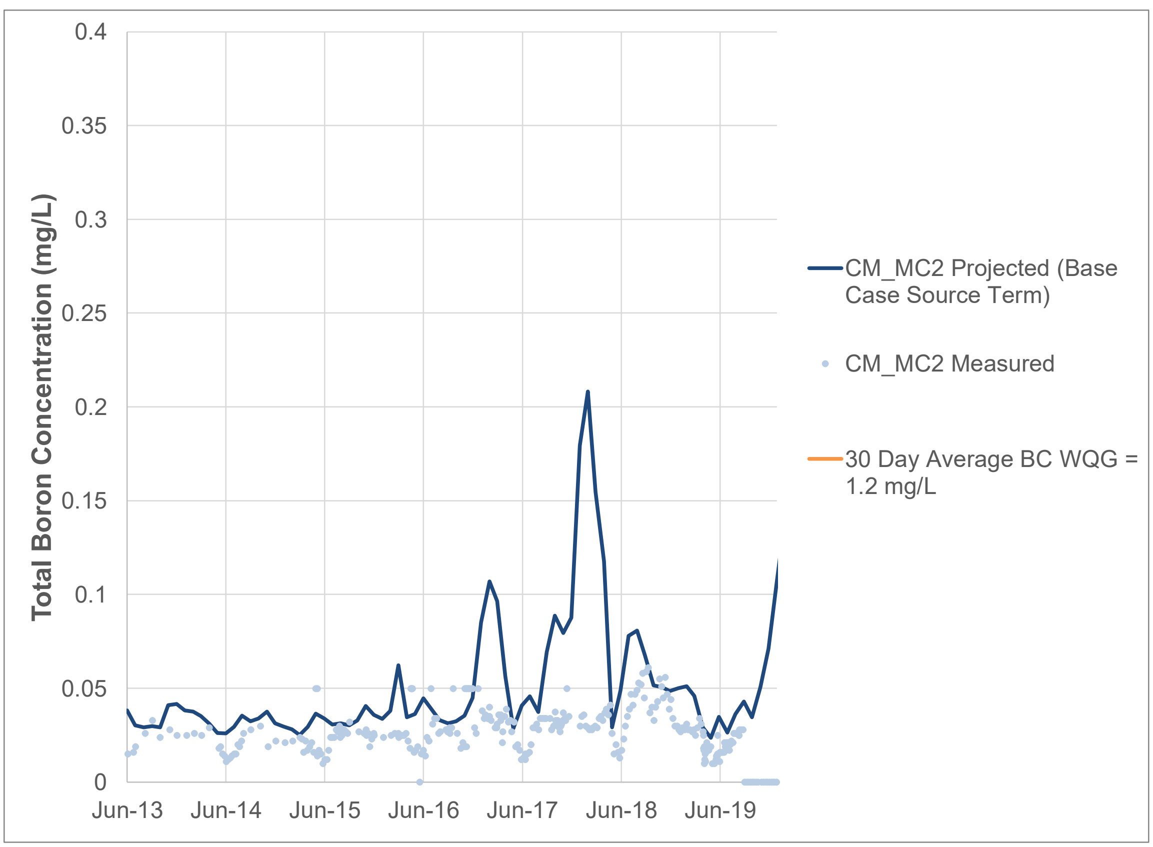

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FIGURE A33

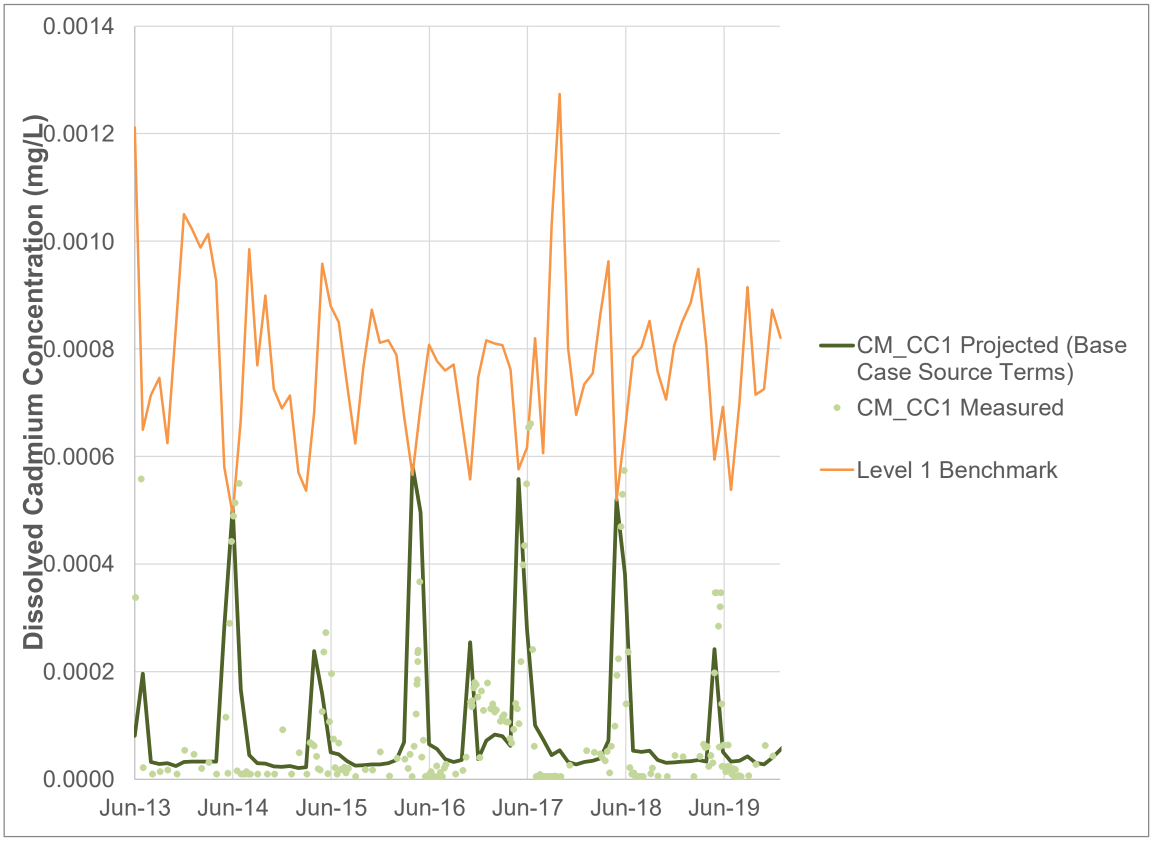

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FIGURE A34

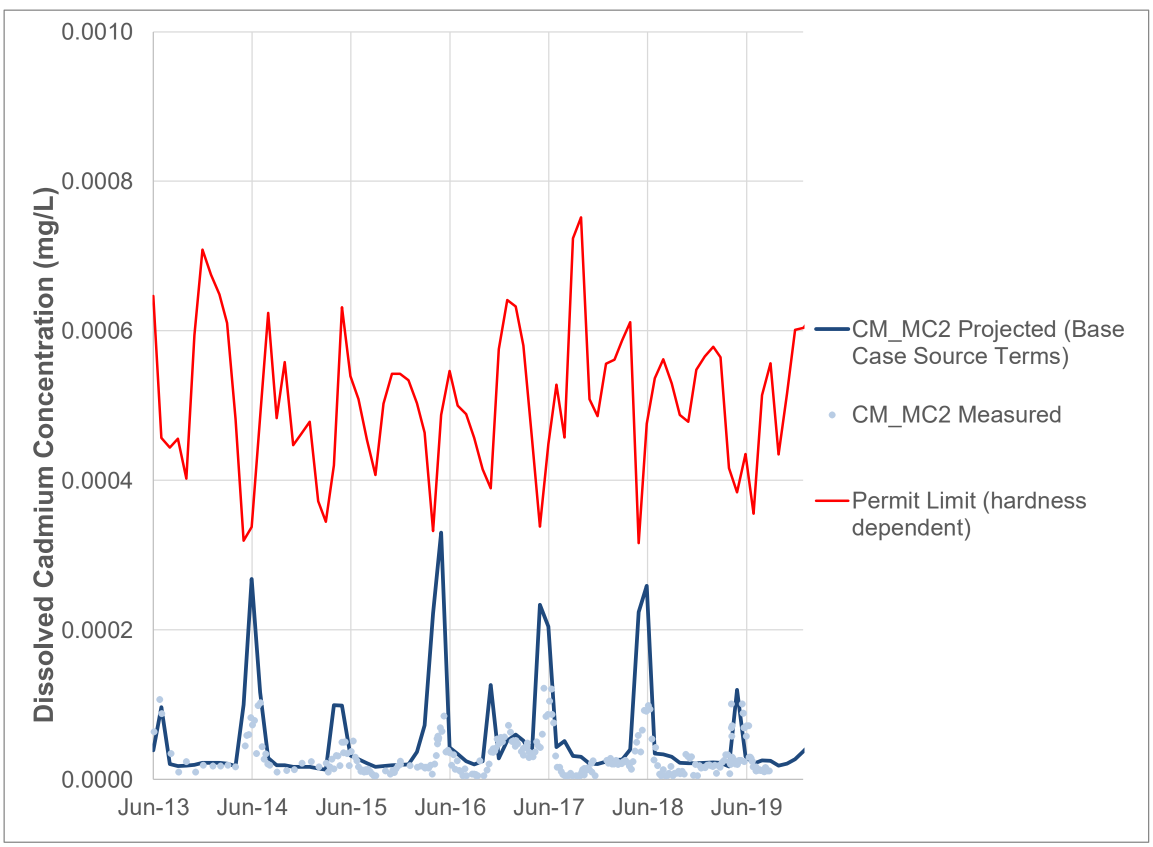

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FIGURE A35

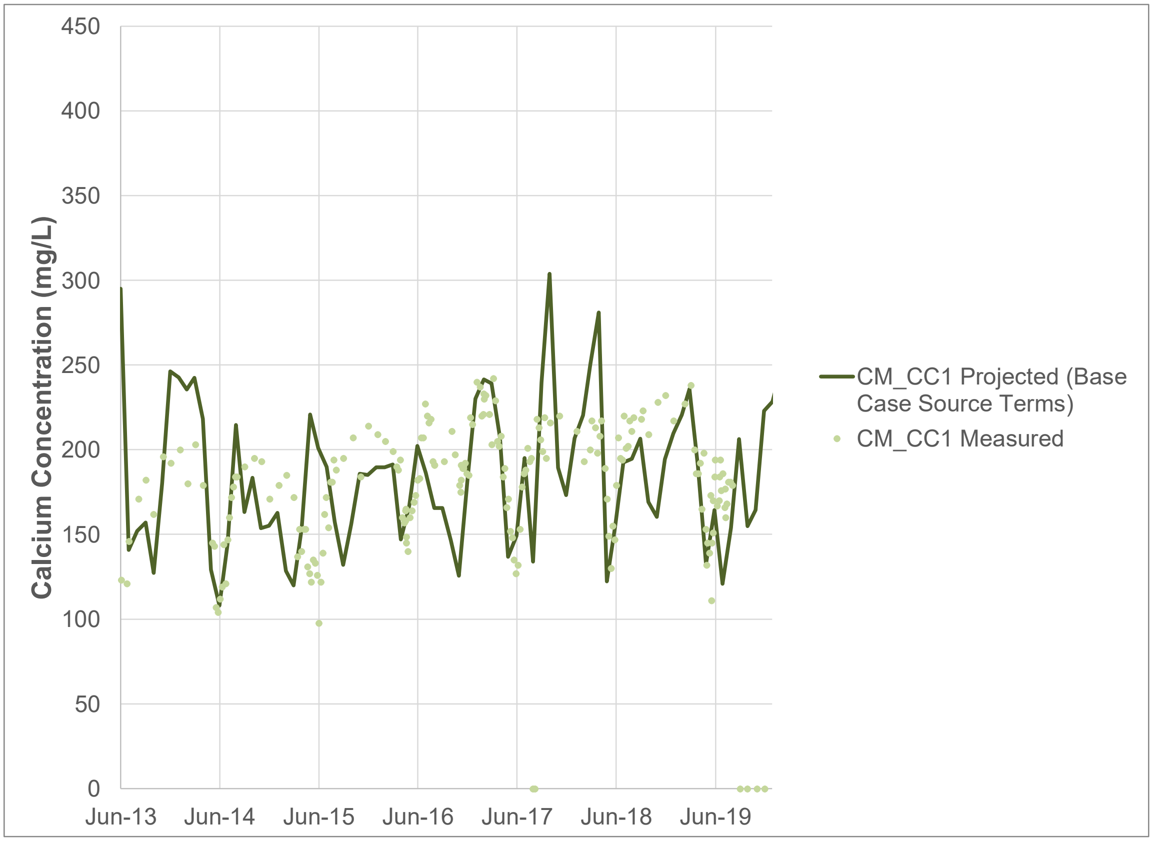

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FIGURE A36

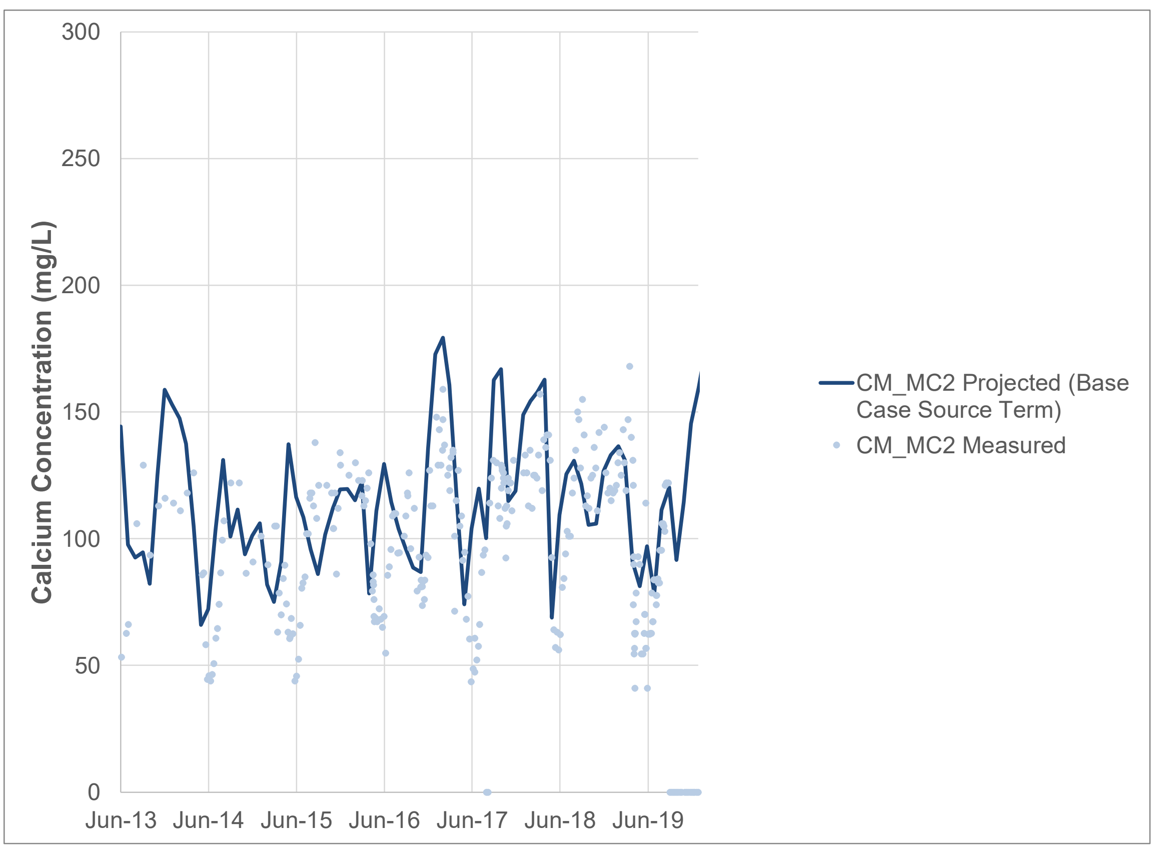

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FIGURE A37

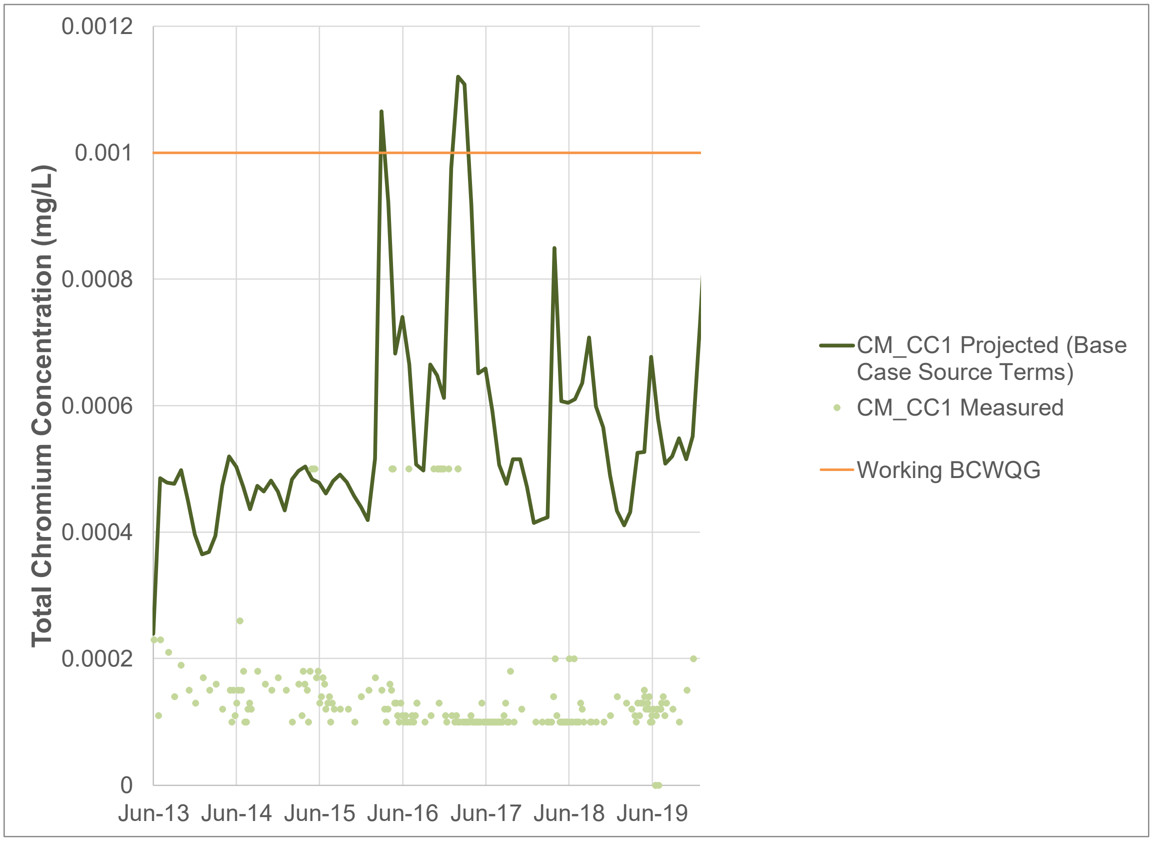

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FIGURE A38

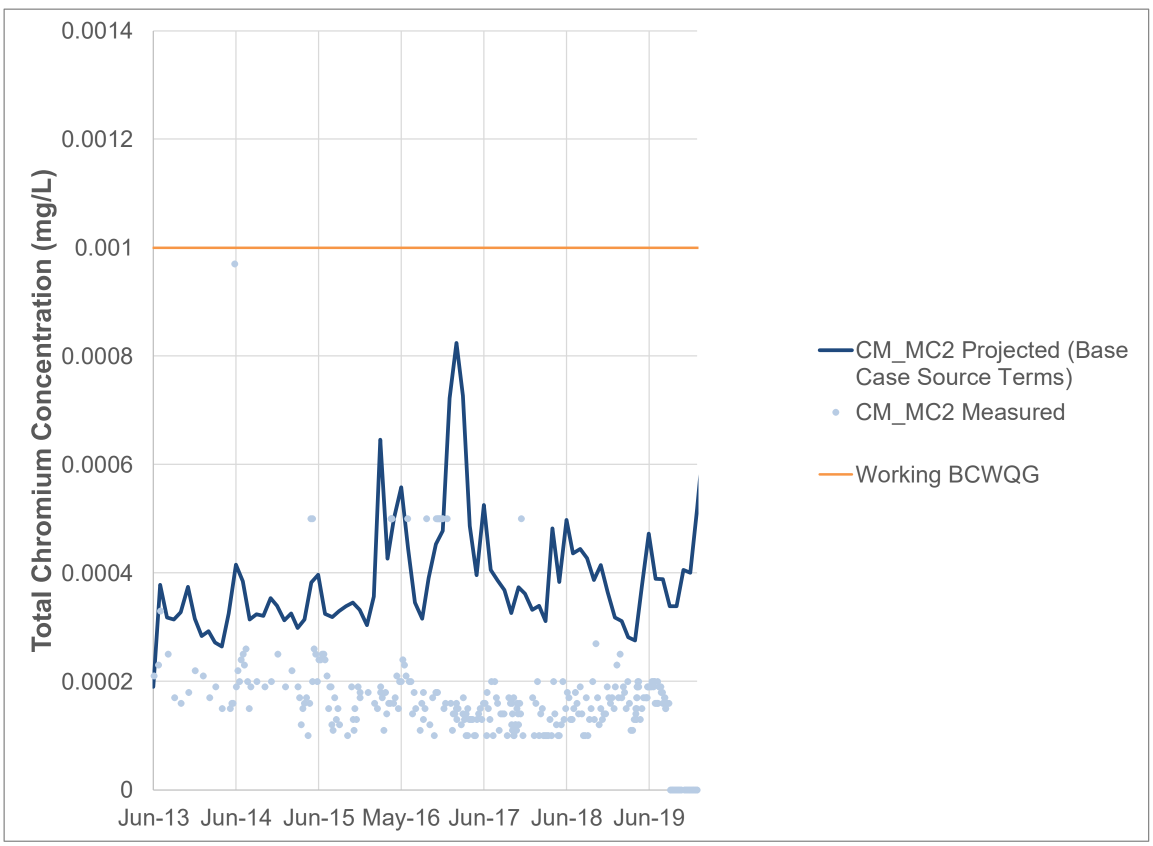

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FIGURE A39

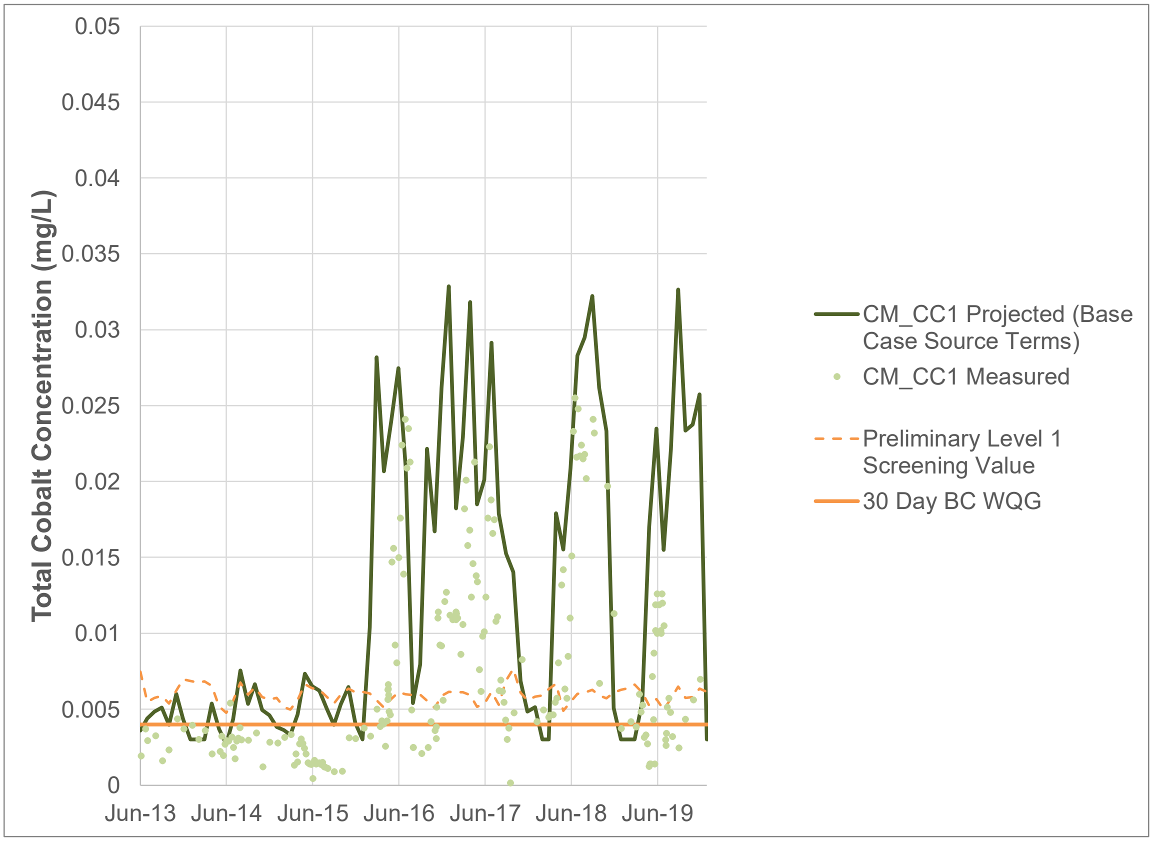

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FIGURE A40

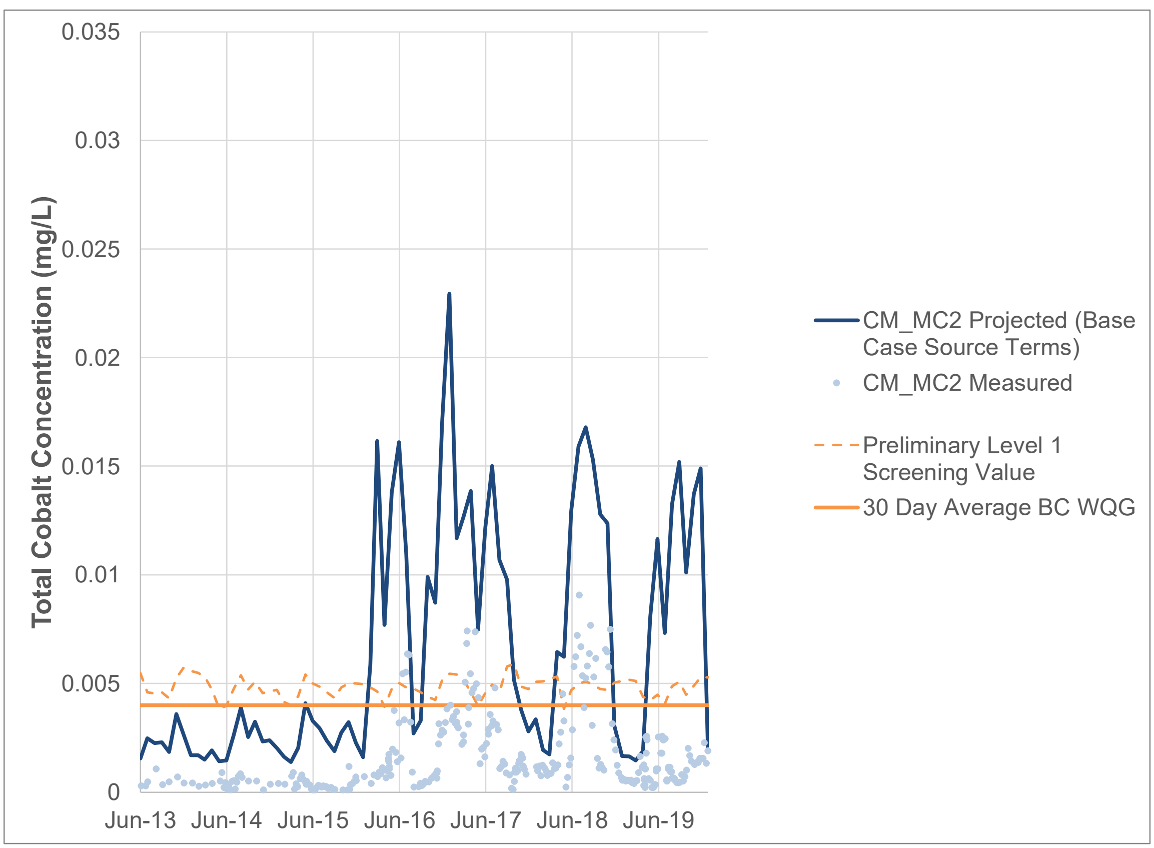

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FIGURE A41

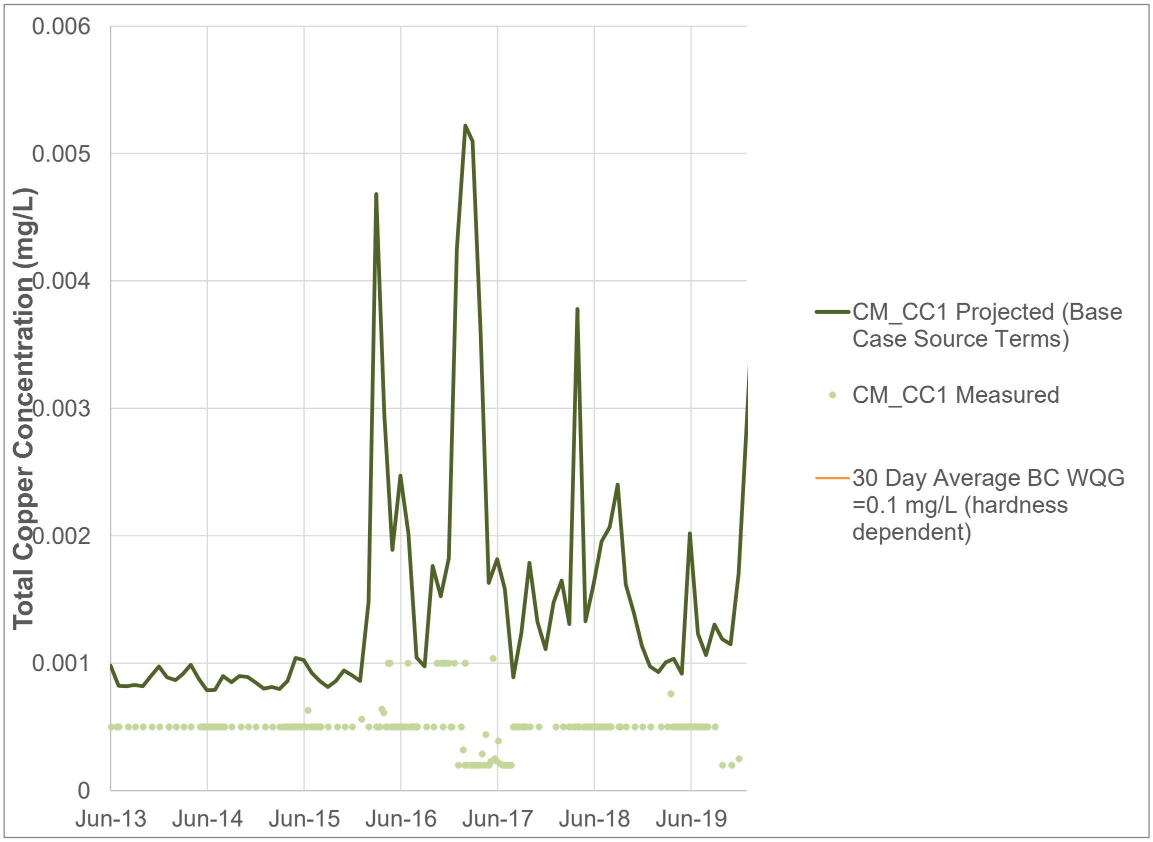

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FIGURE A42

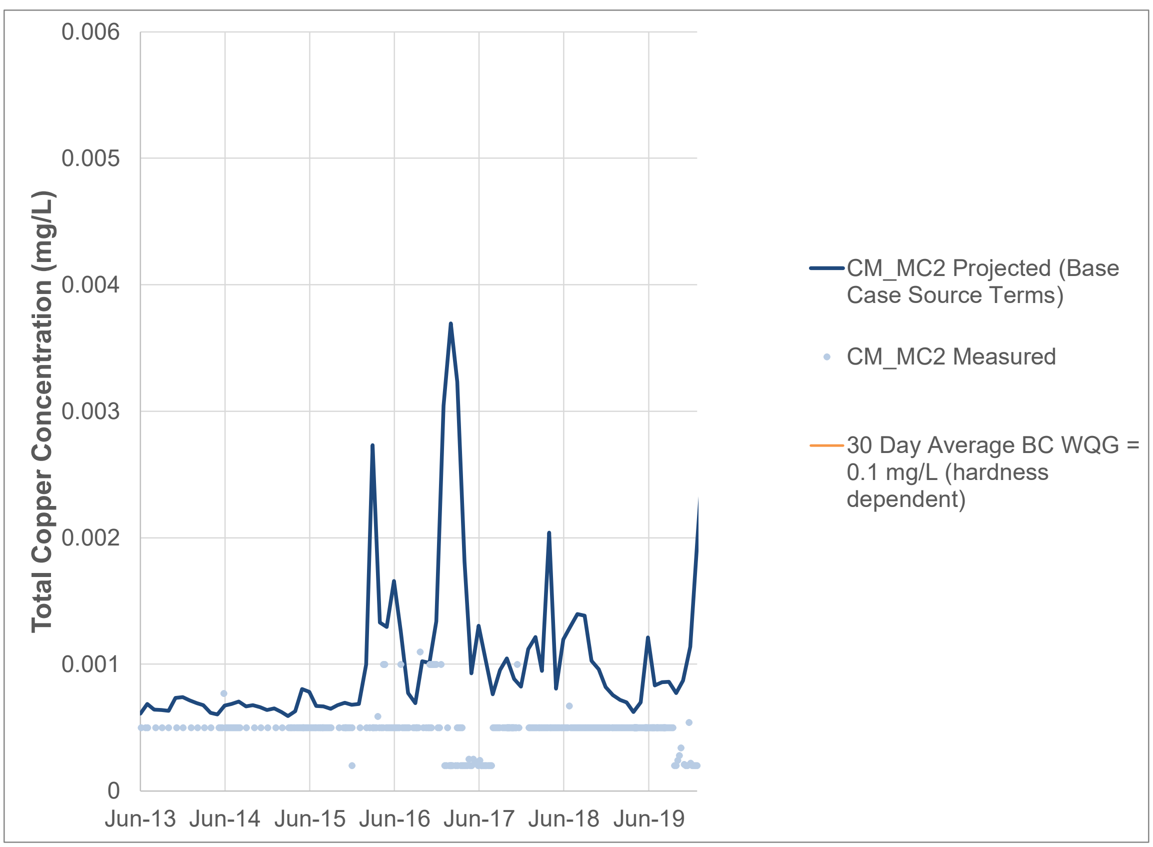

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FIGURE A43

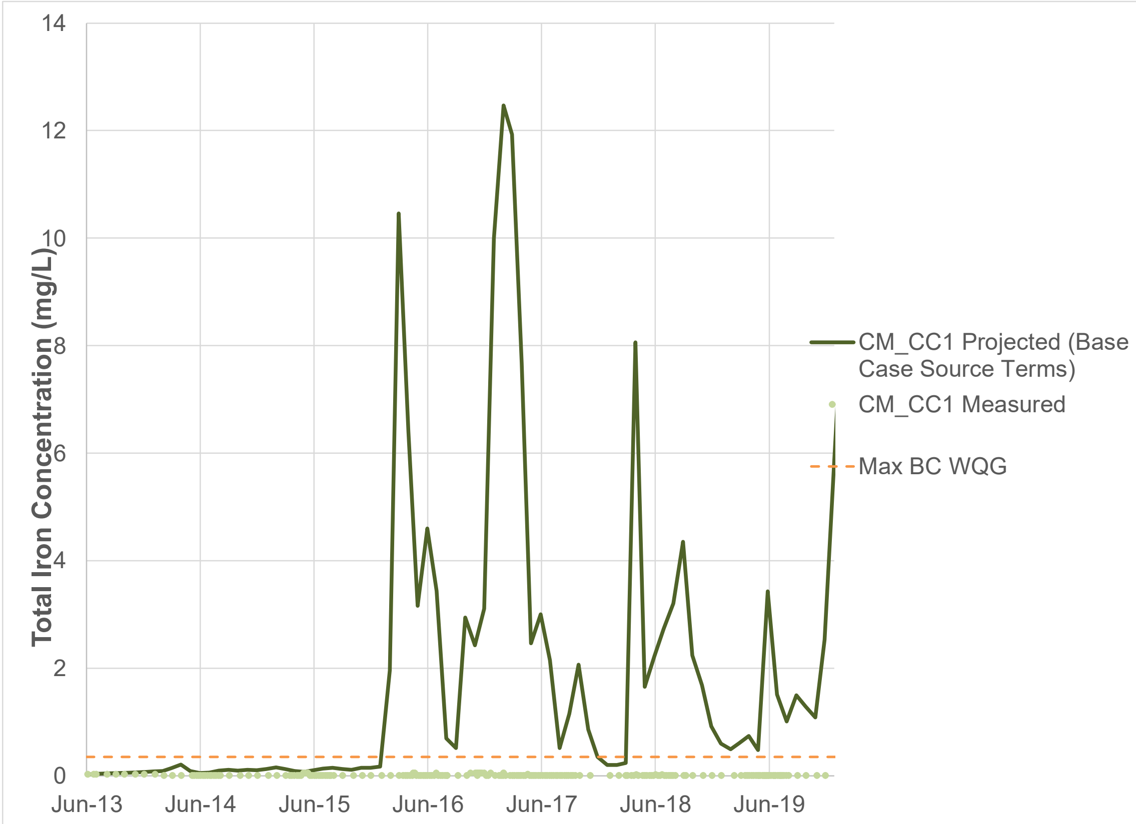

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FIGURE A44

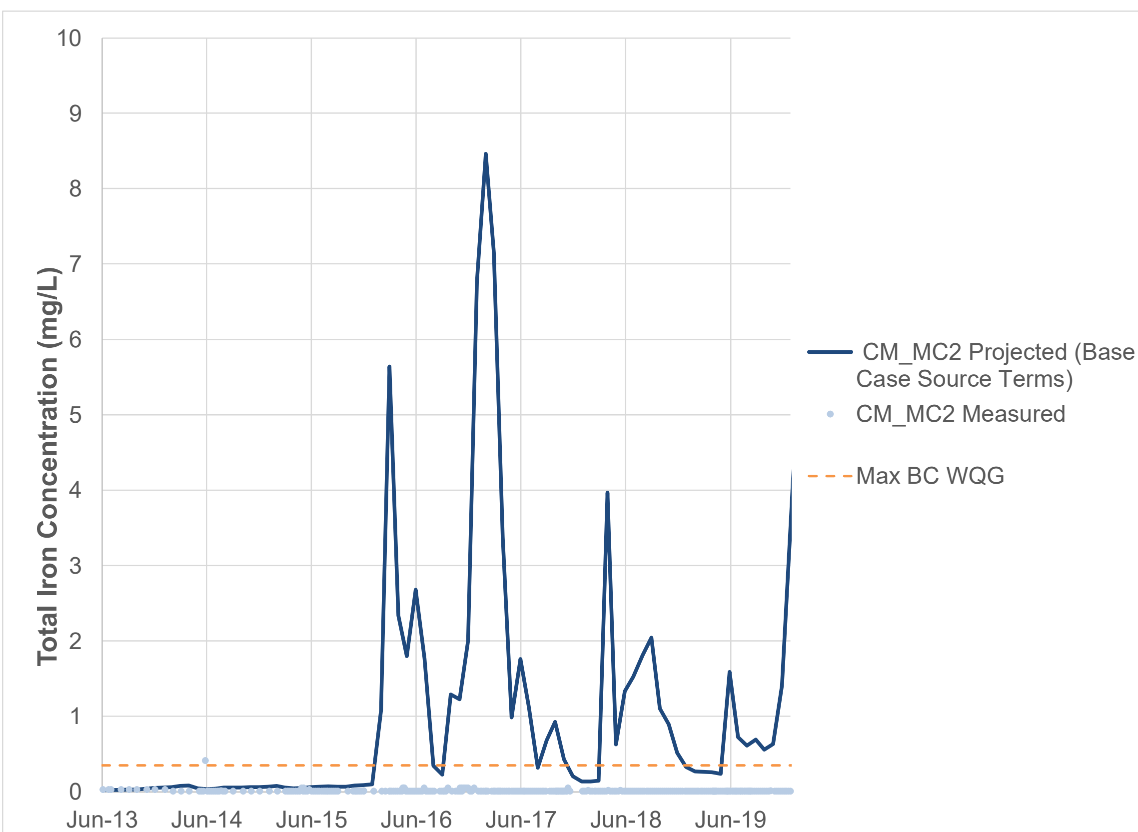

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FIGURE A45

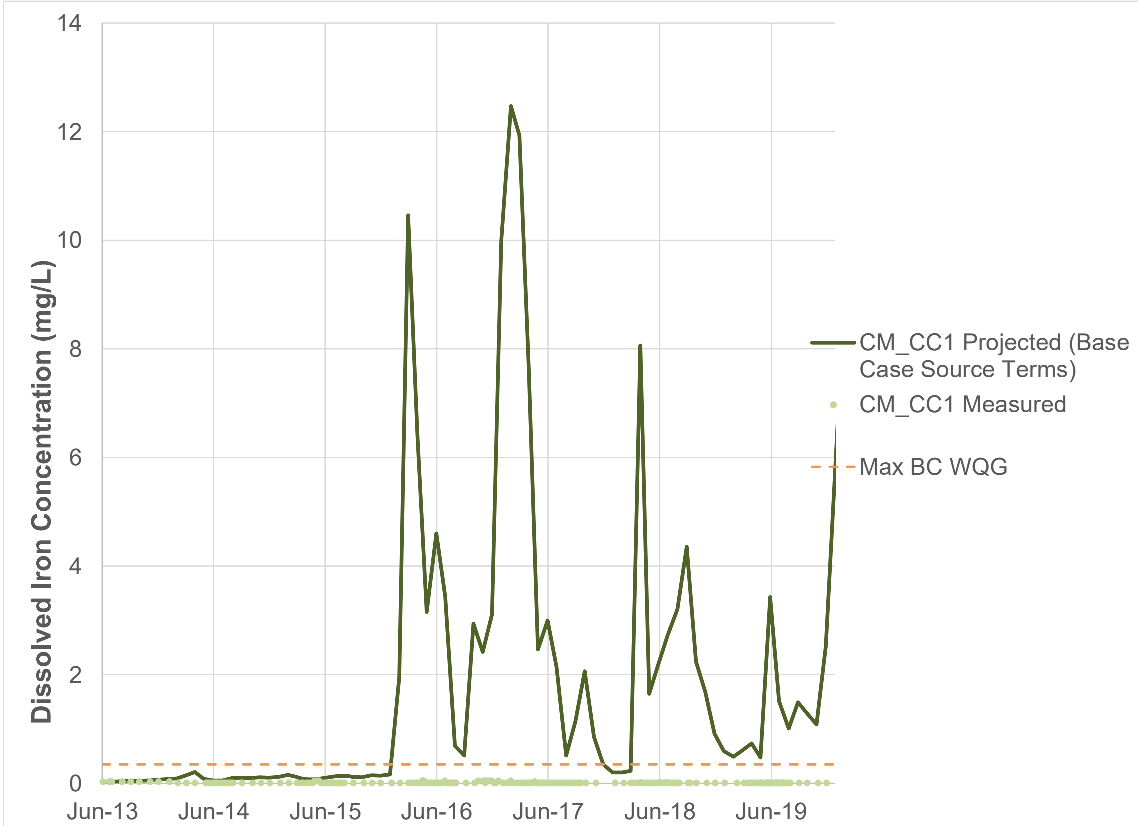

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FIGURE A46

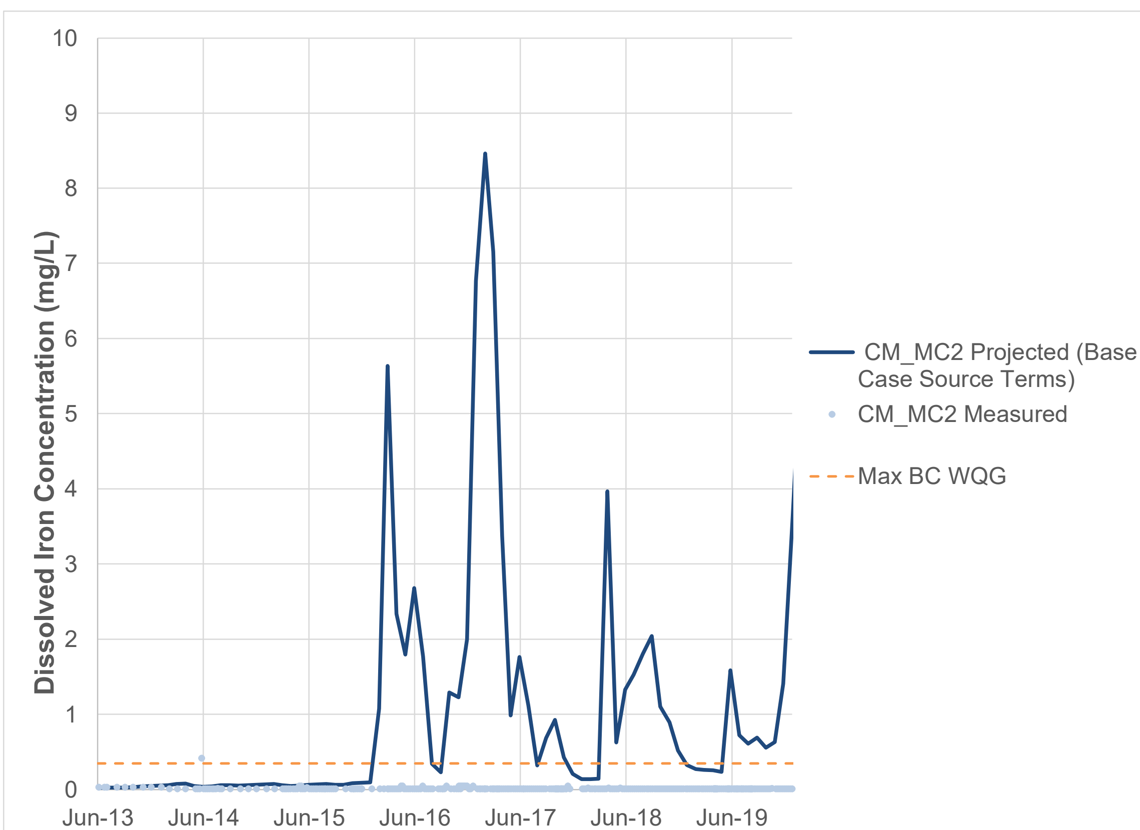

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FIGURE A47

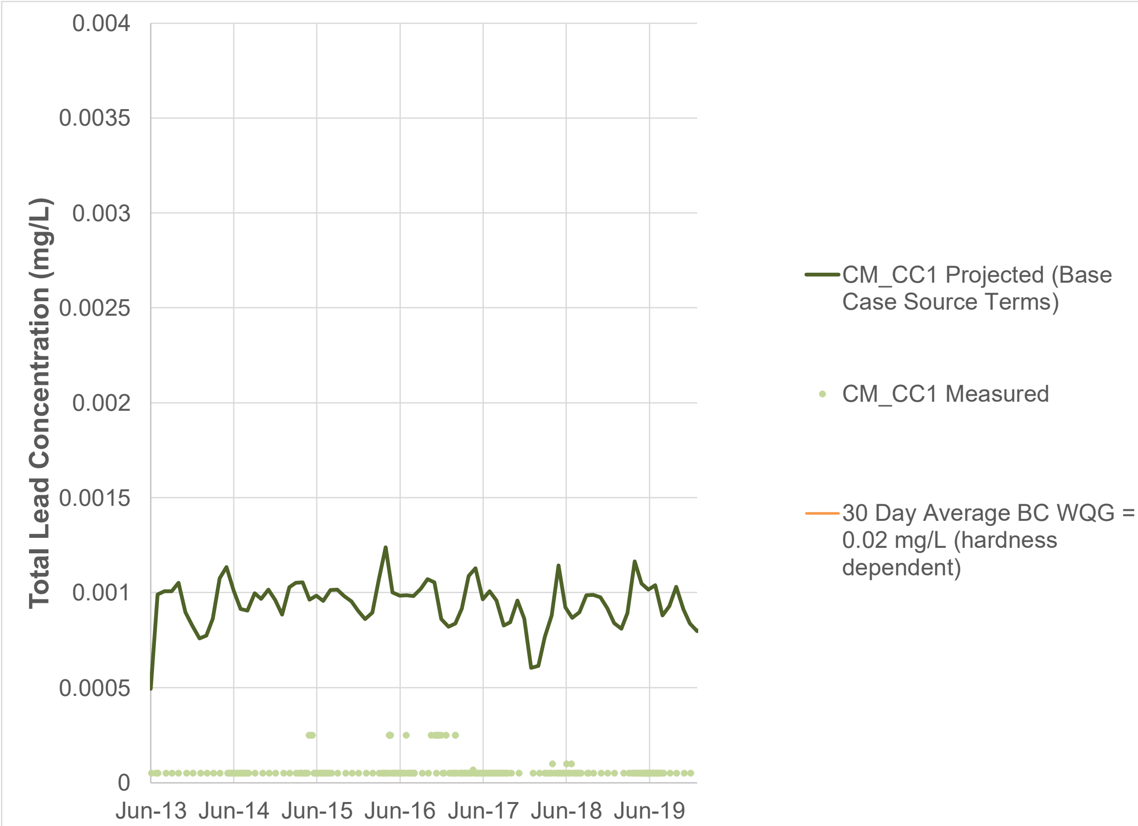

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FIGURE A48

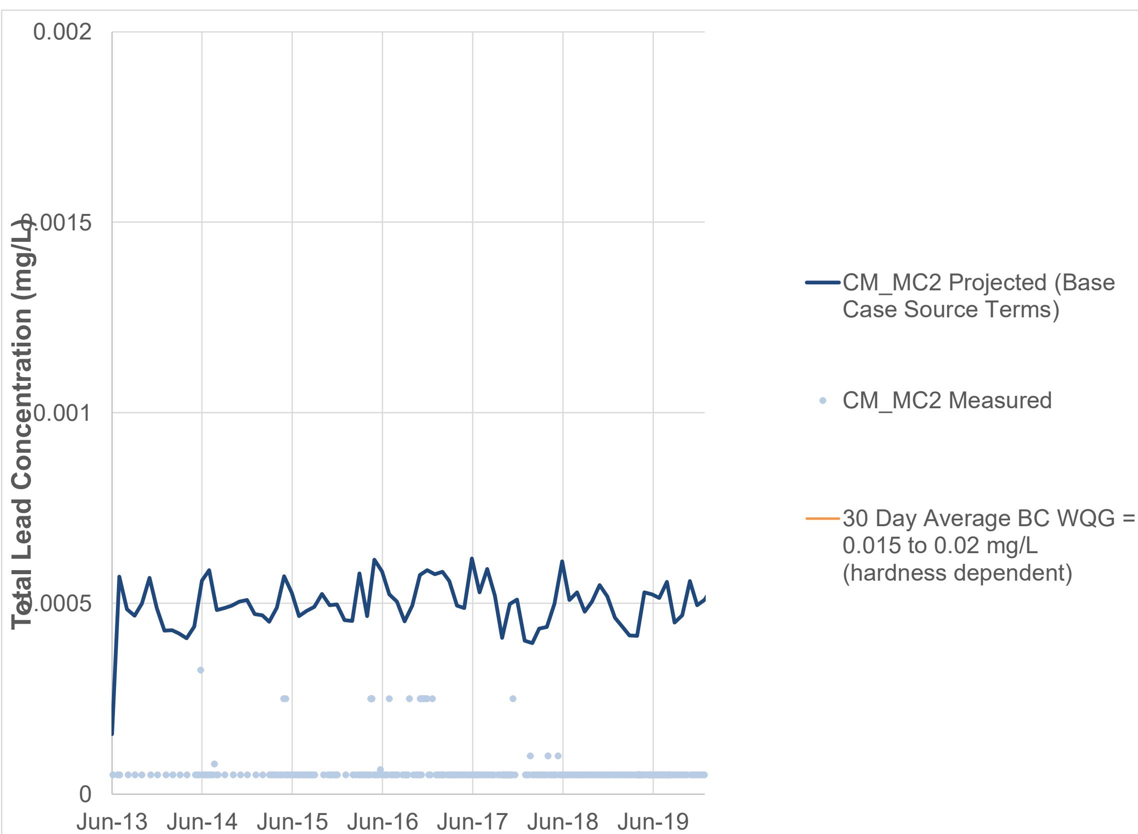

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FIGURE A49

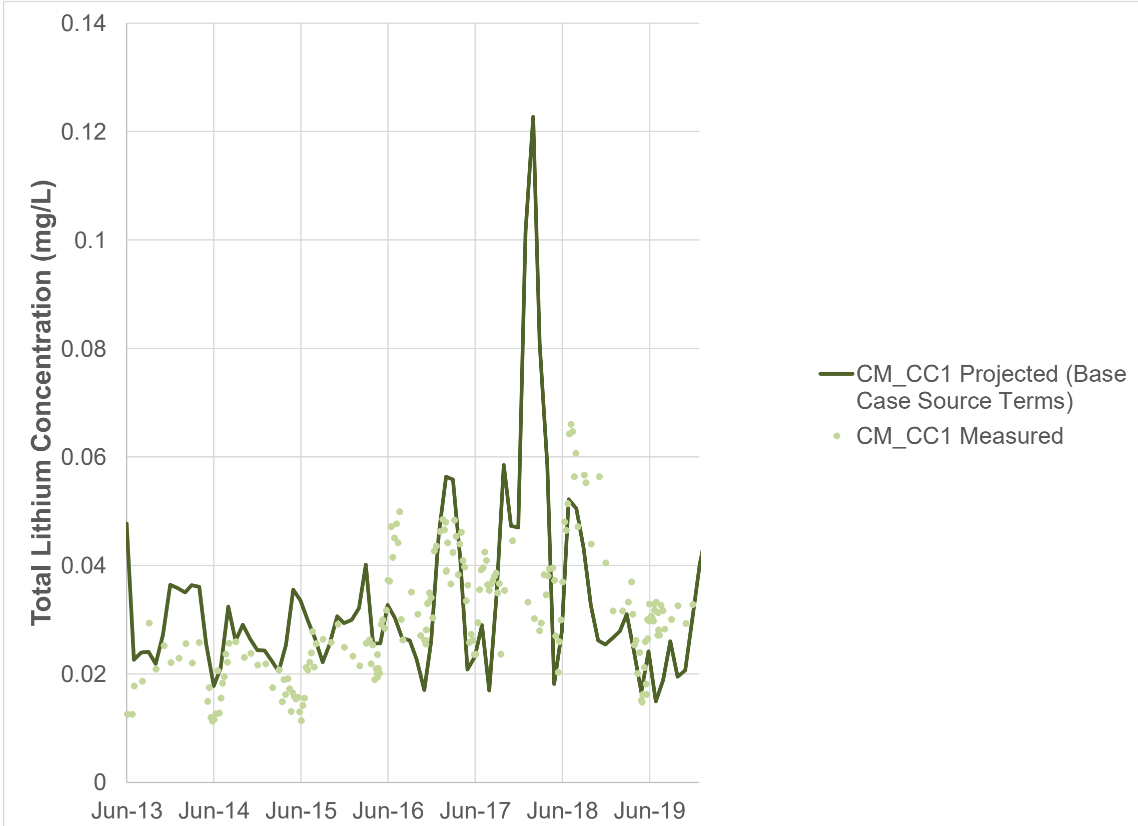

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FIGURE A50

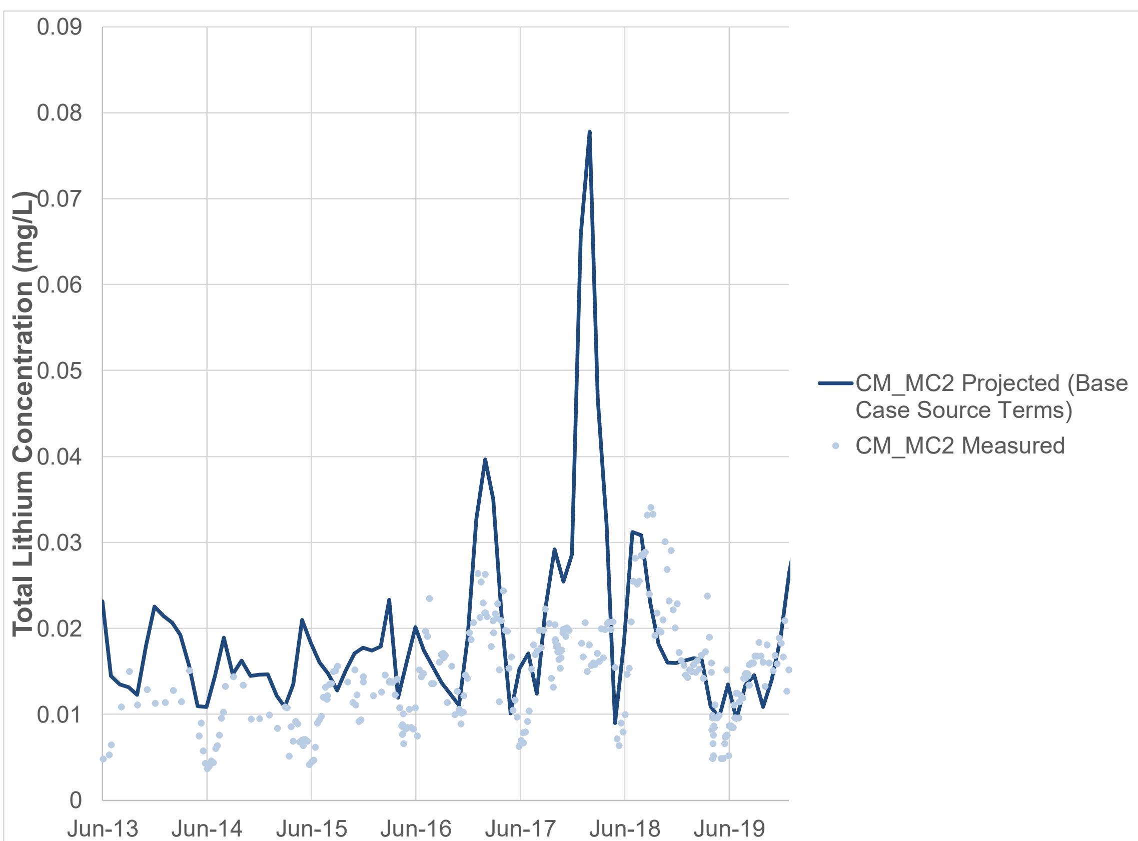

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FIGURE A51

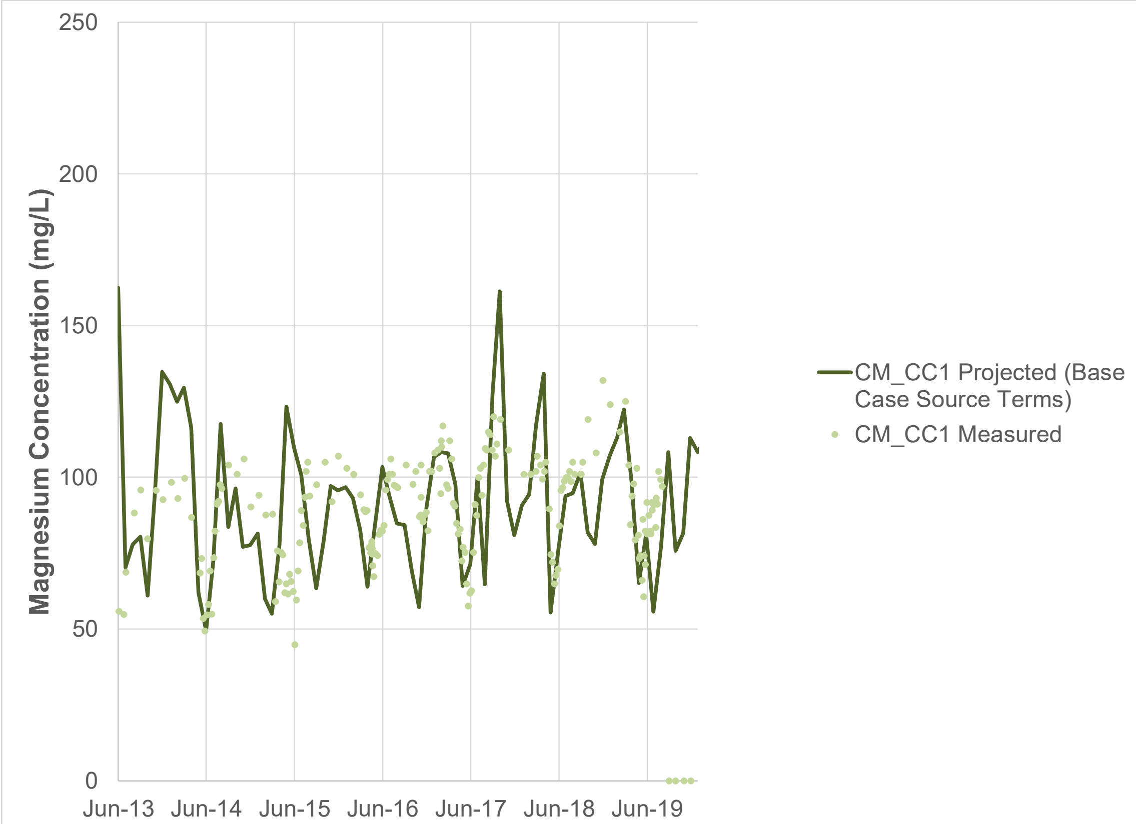

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FIGURE A52

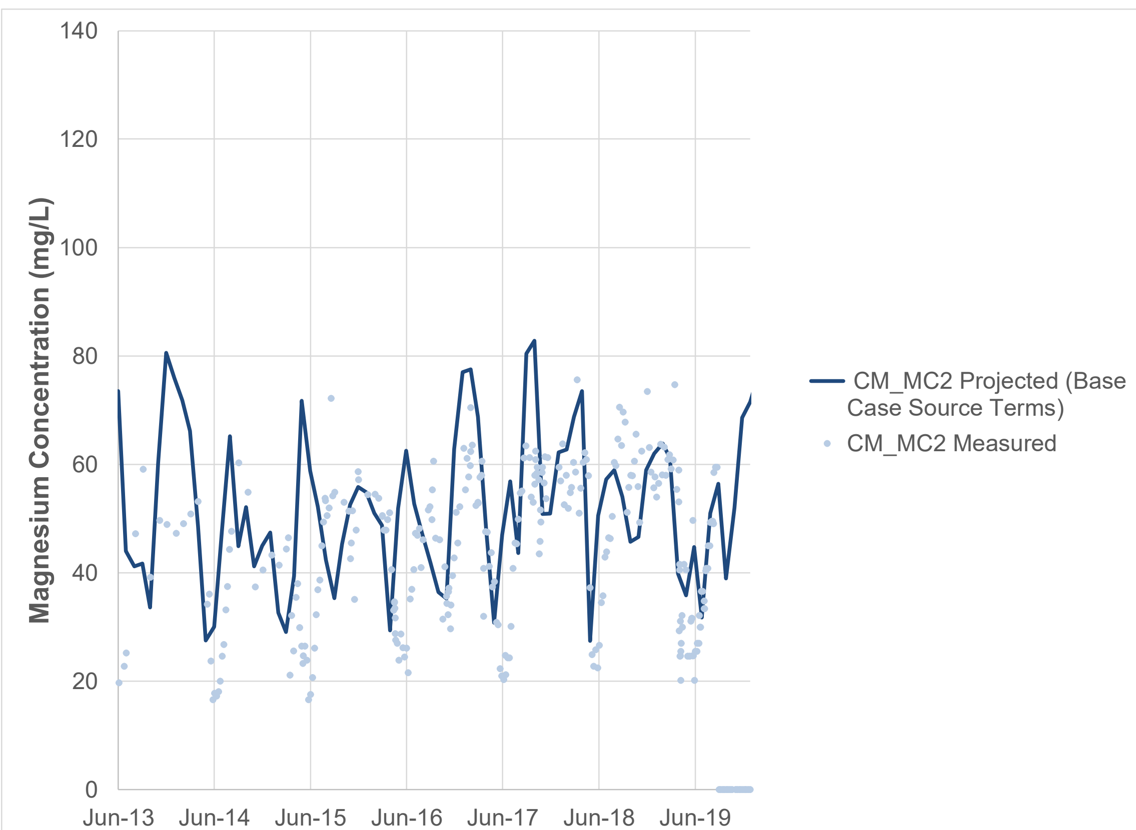

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FIGURE A53

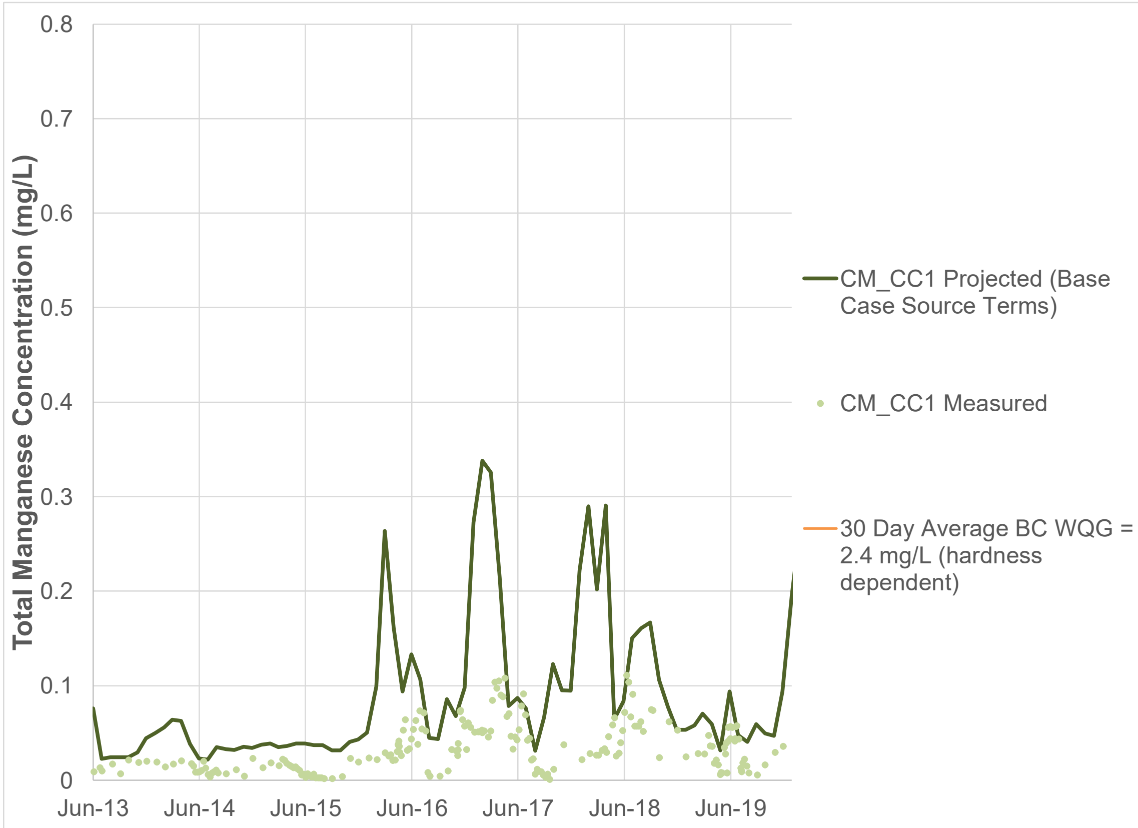

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FIGURE A54

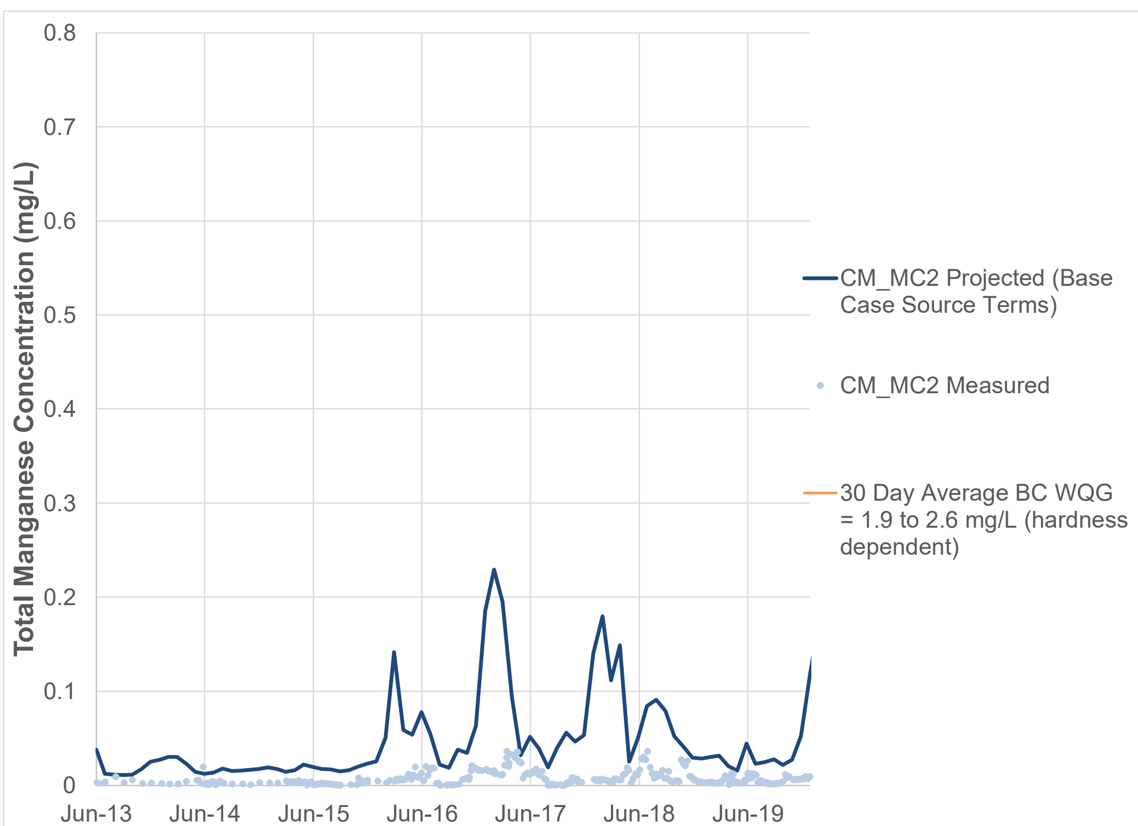

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FIGURE A55

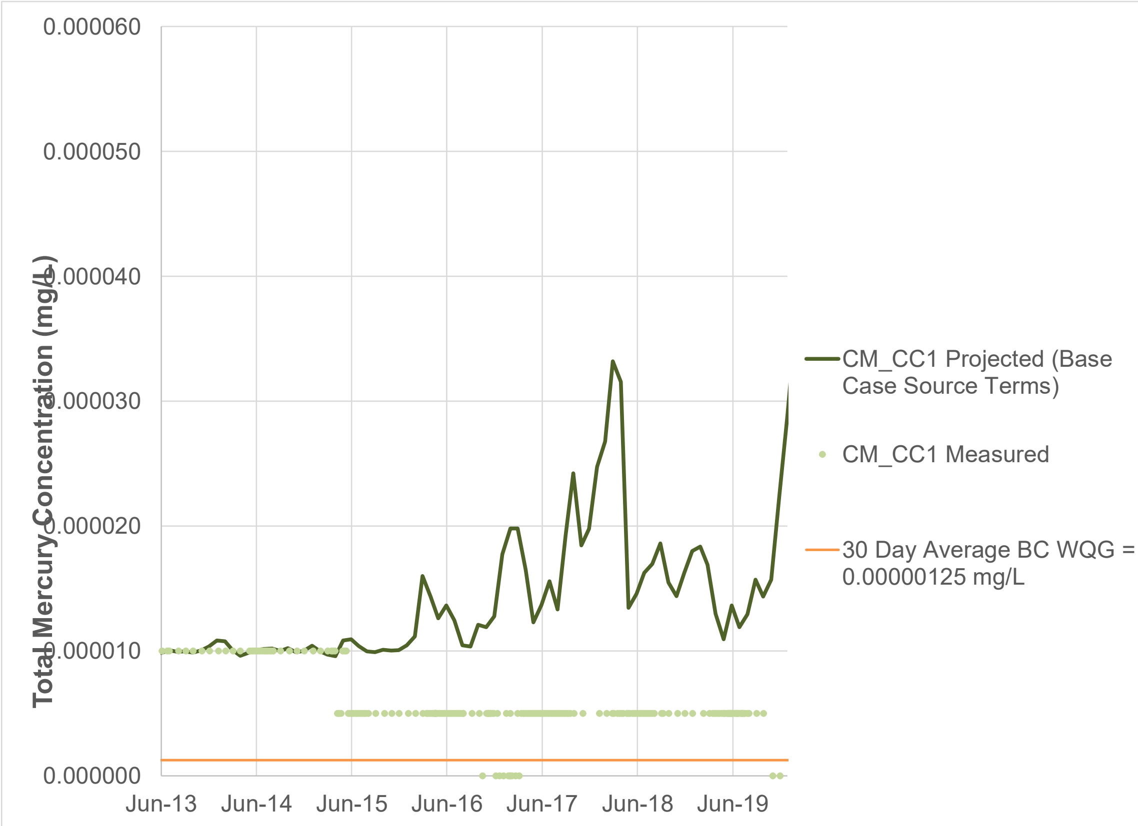

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FIGURE A56

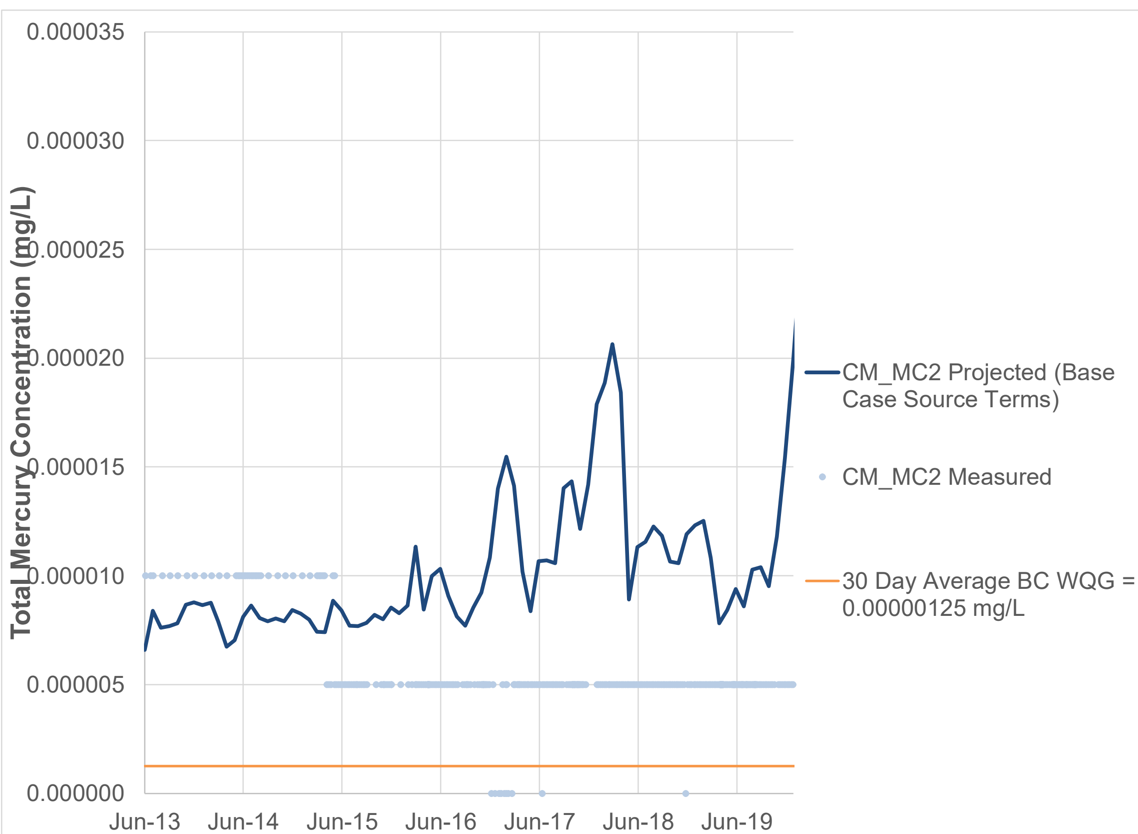

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FIGURE A57

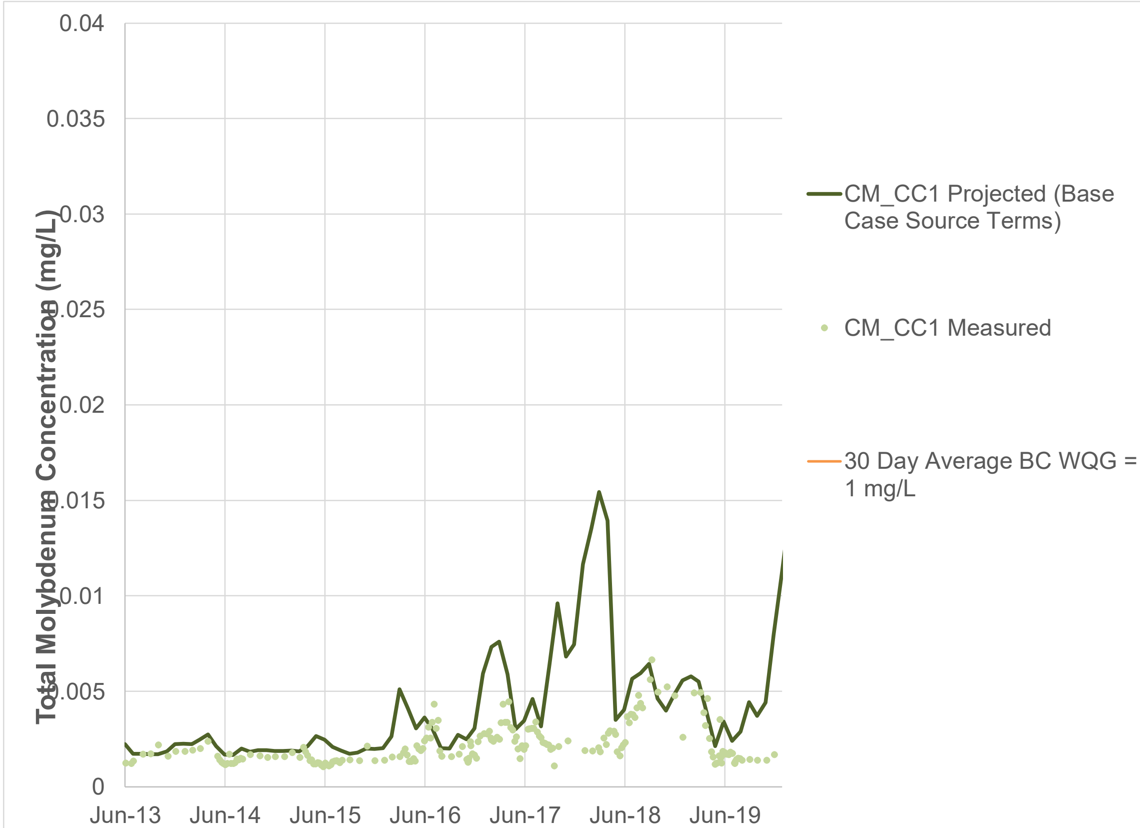

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FIGURE A58

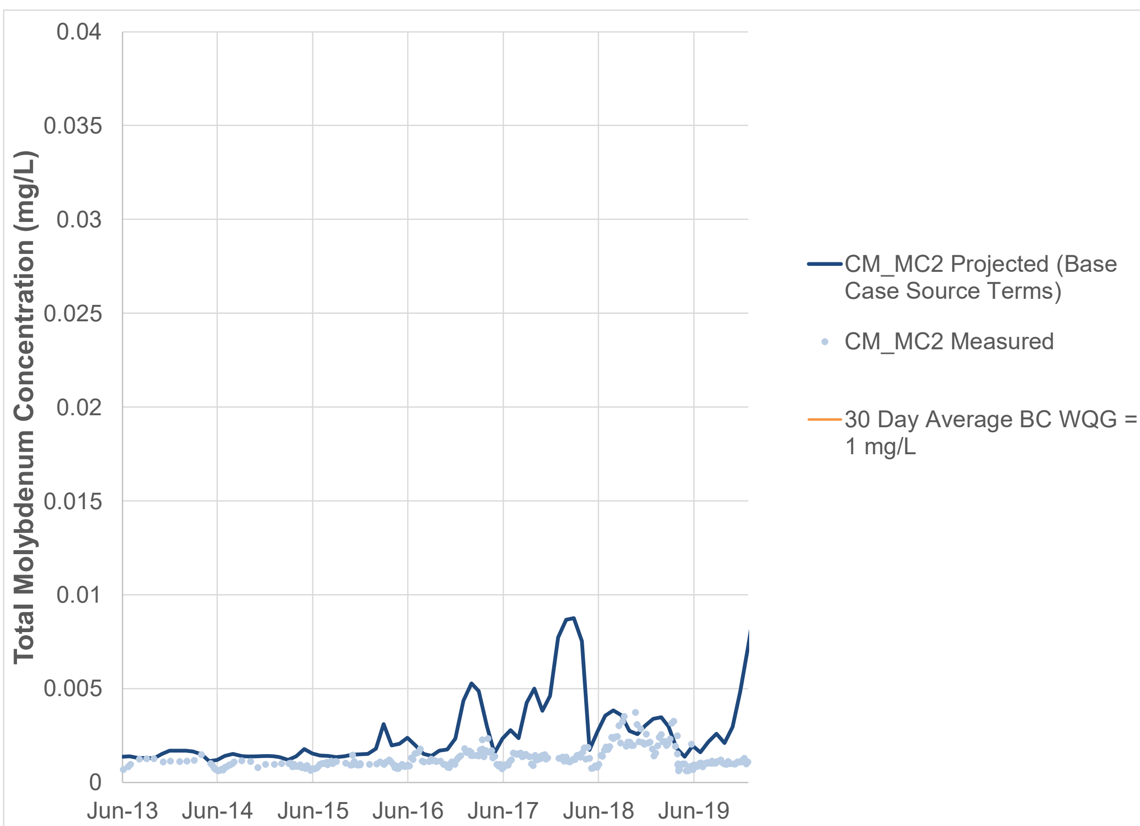

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FIGURE A59

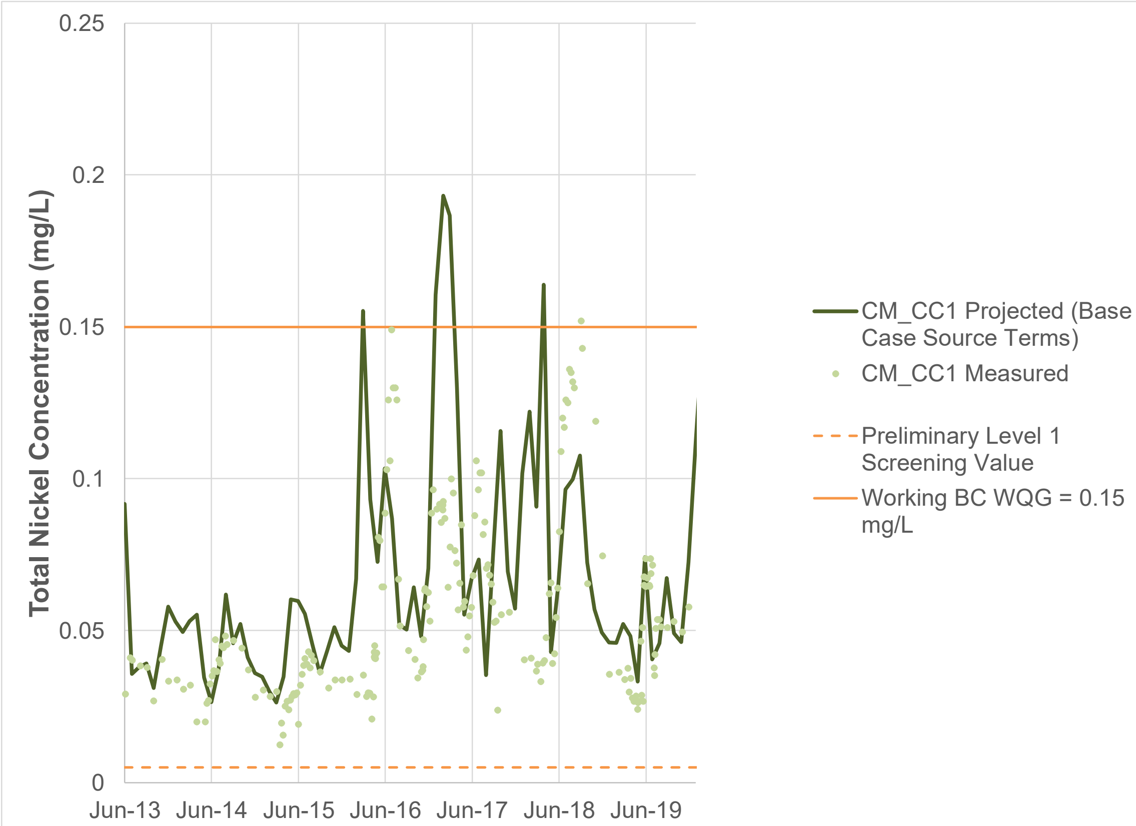

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FIGURE A60

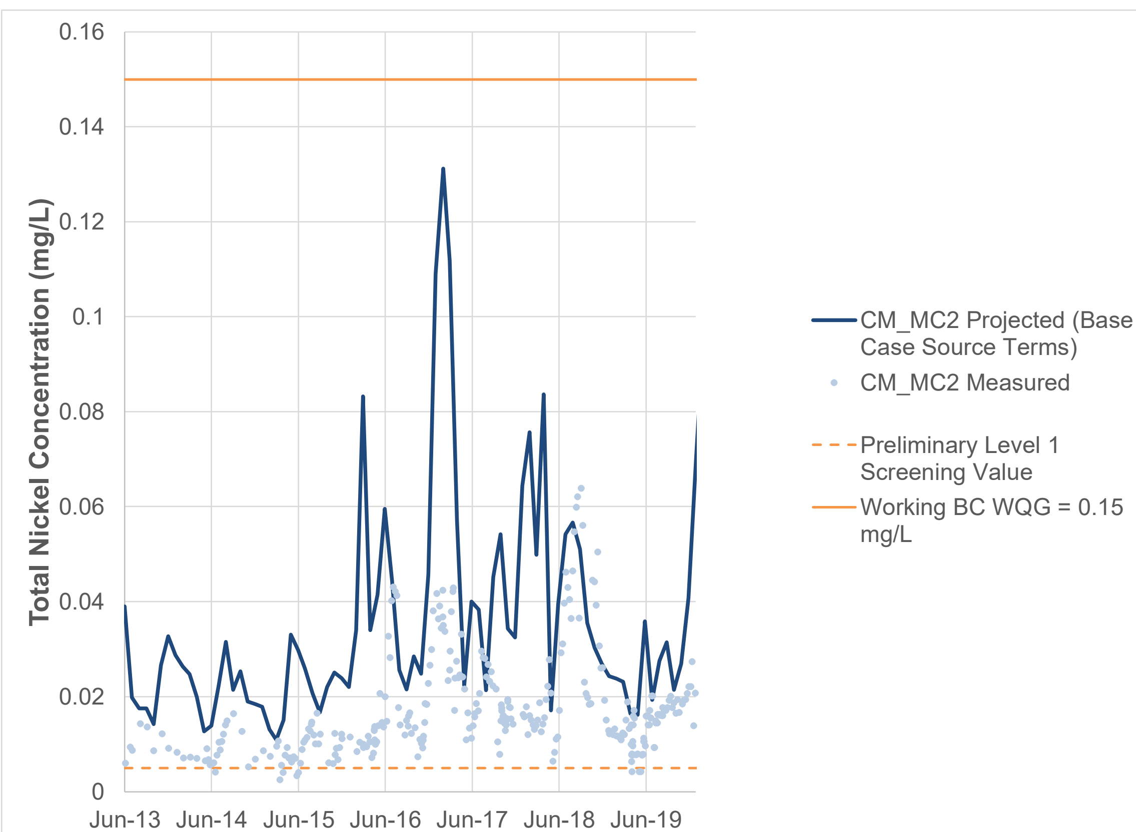

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FIGURE A61

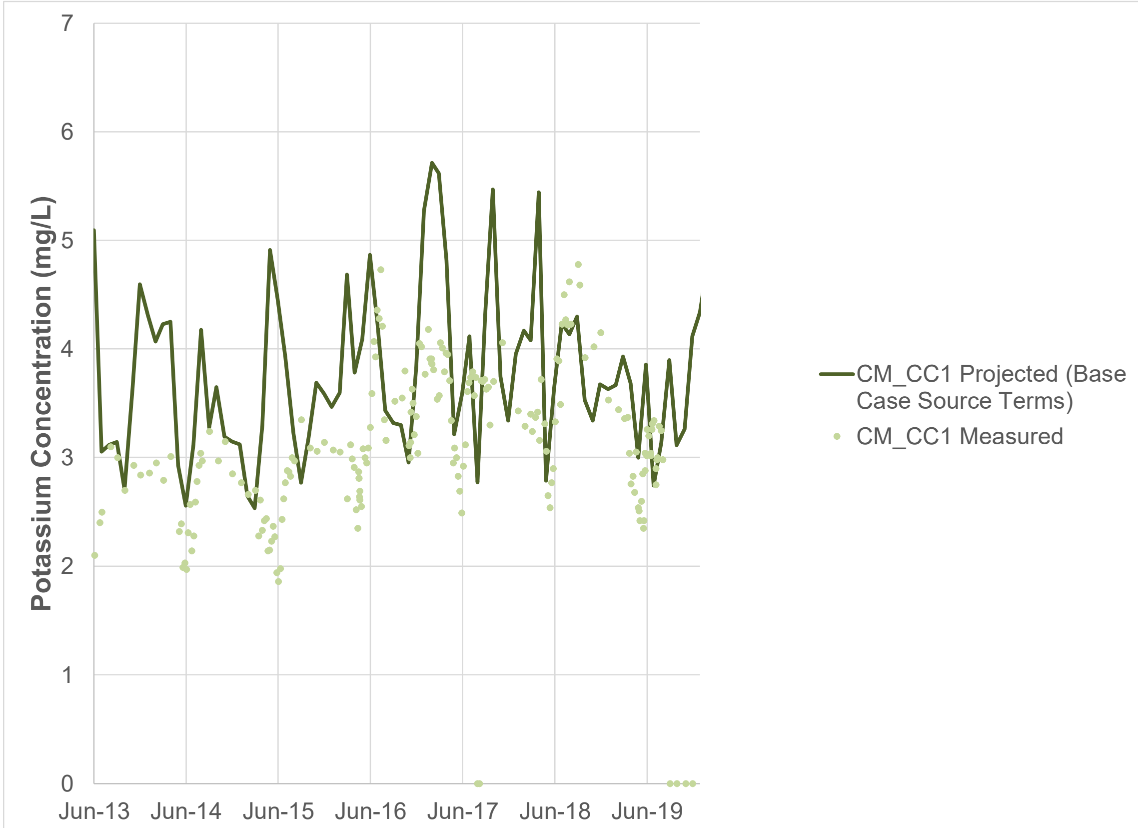

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FIGURE A62

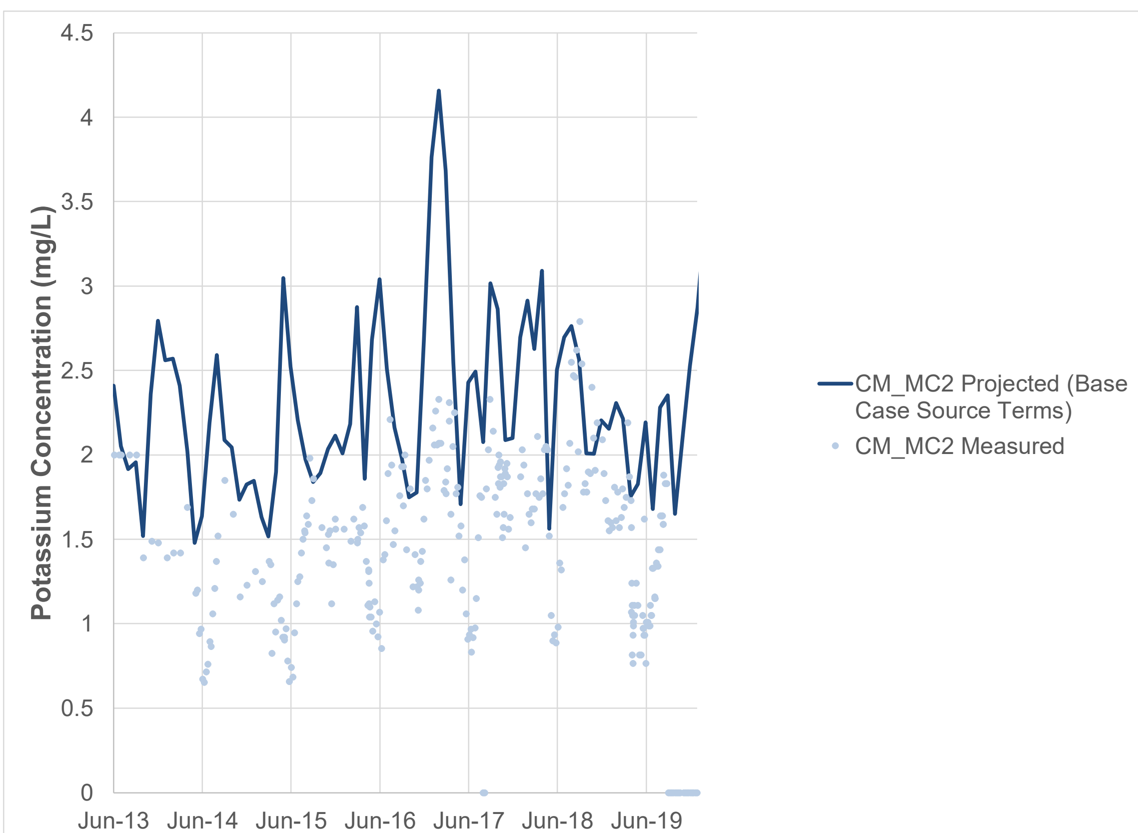

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FIGURE A63

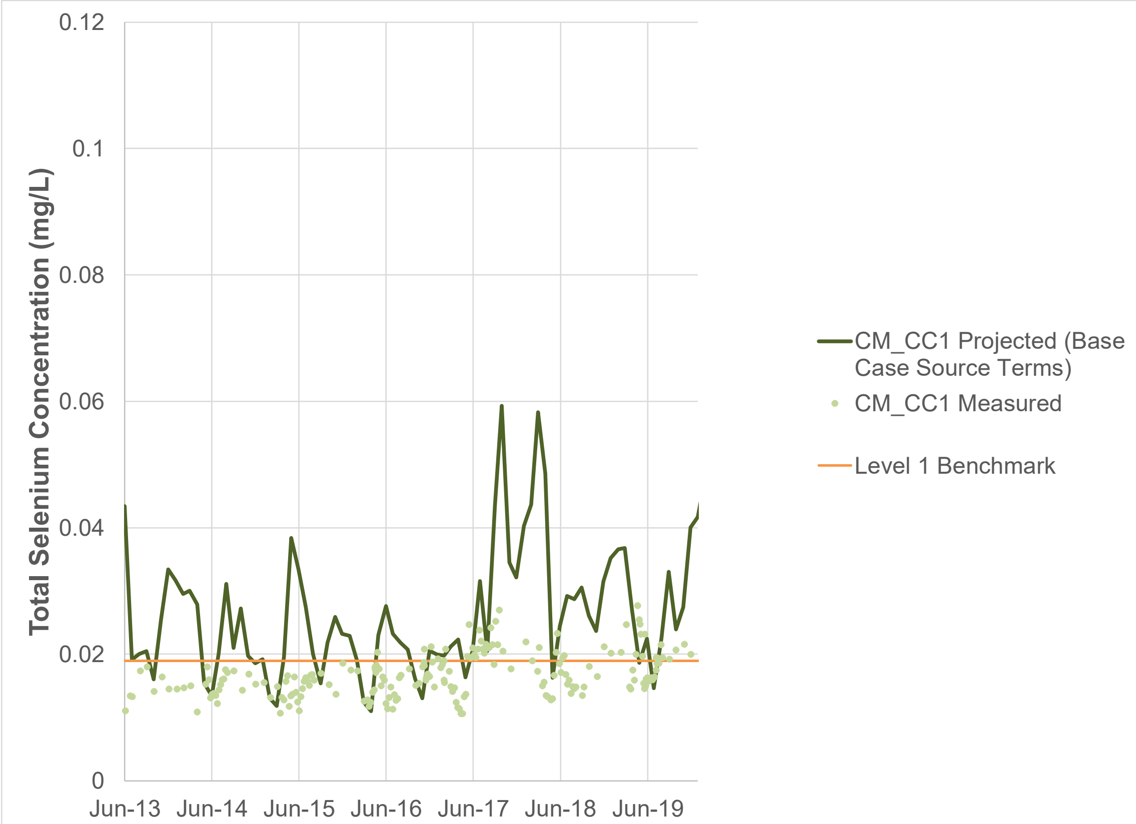

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FIGURE A64

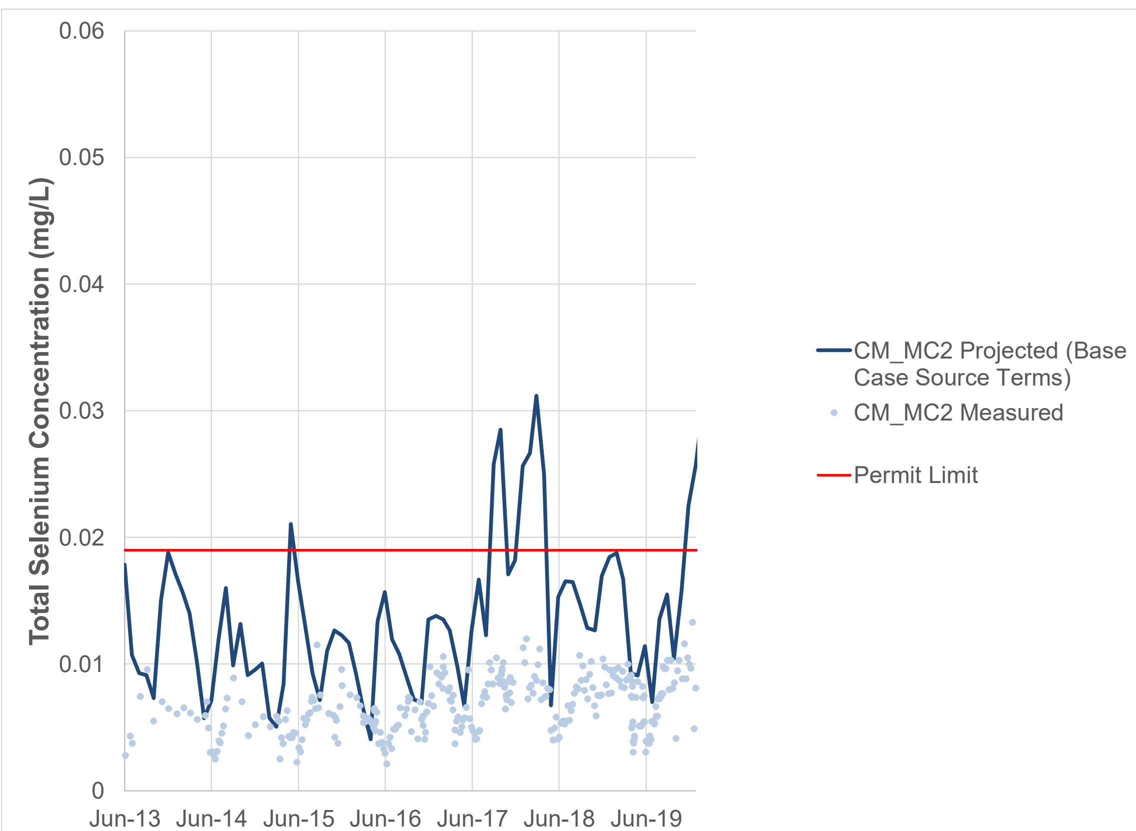

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FIGURE A65

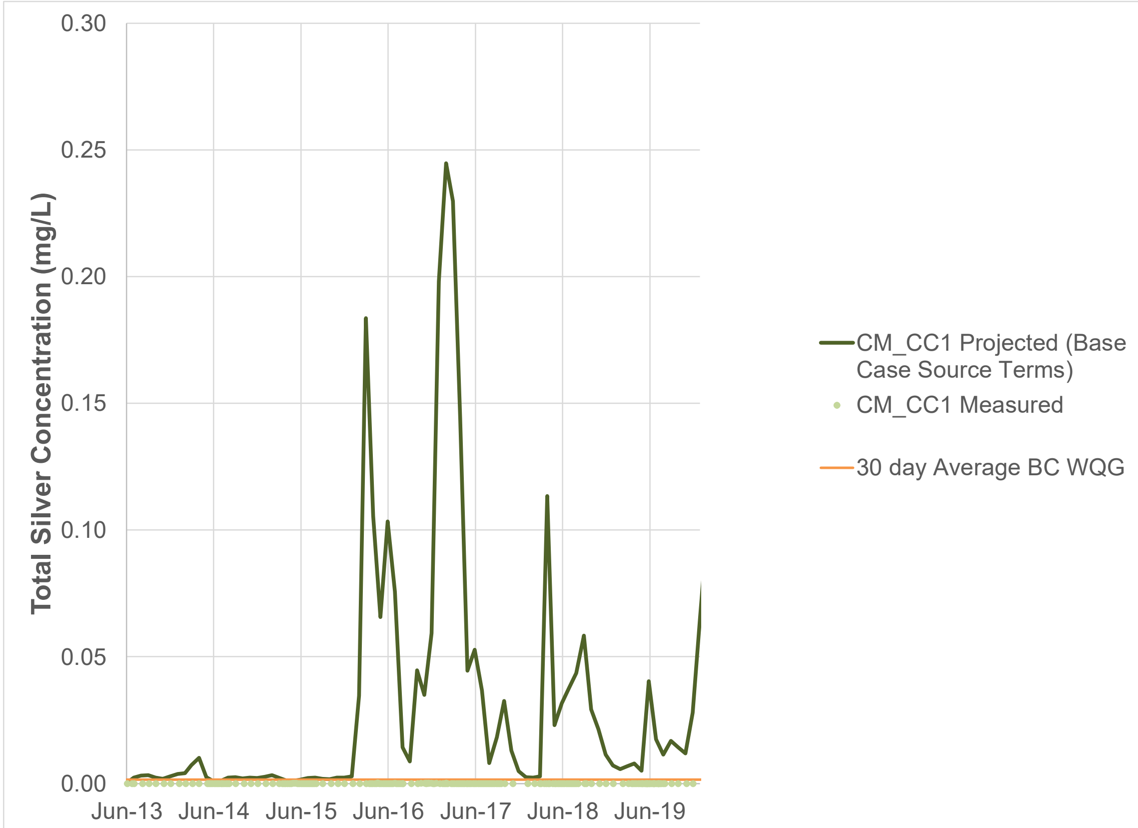

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FIGURE A66

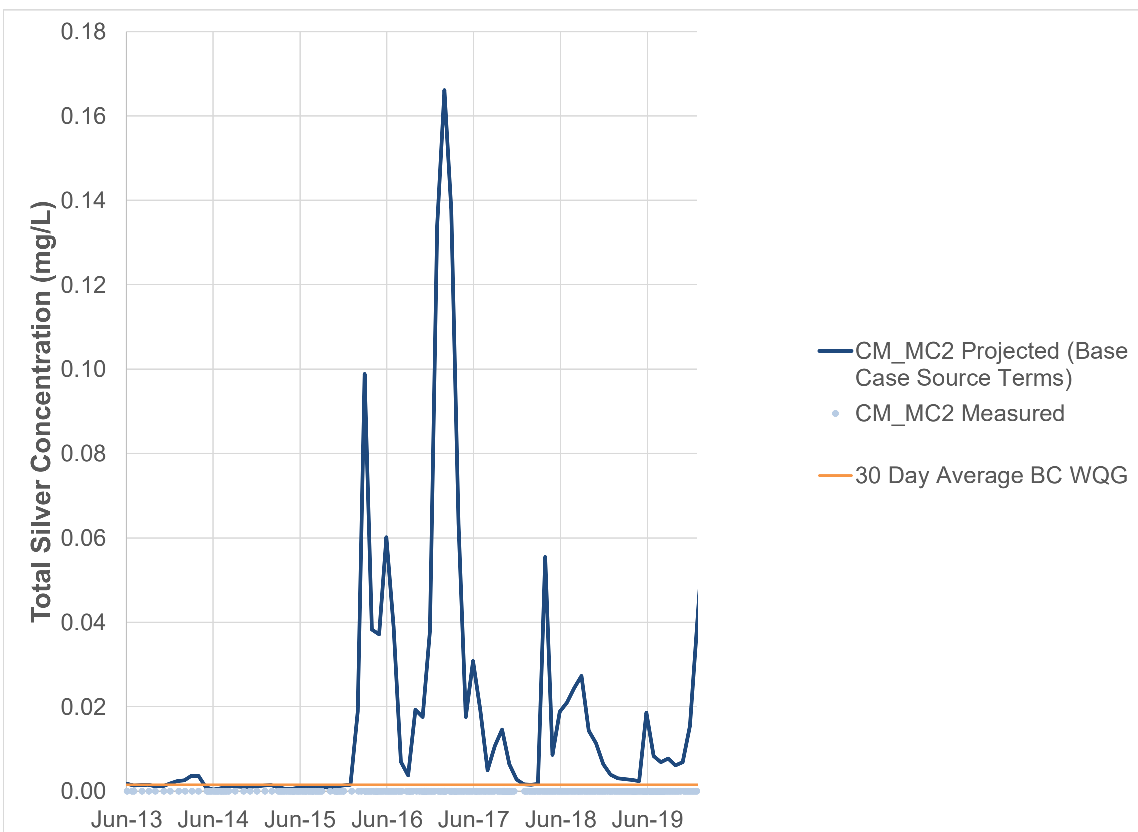

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FIGURE A67

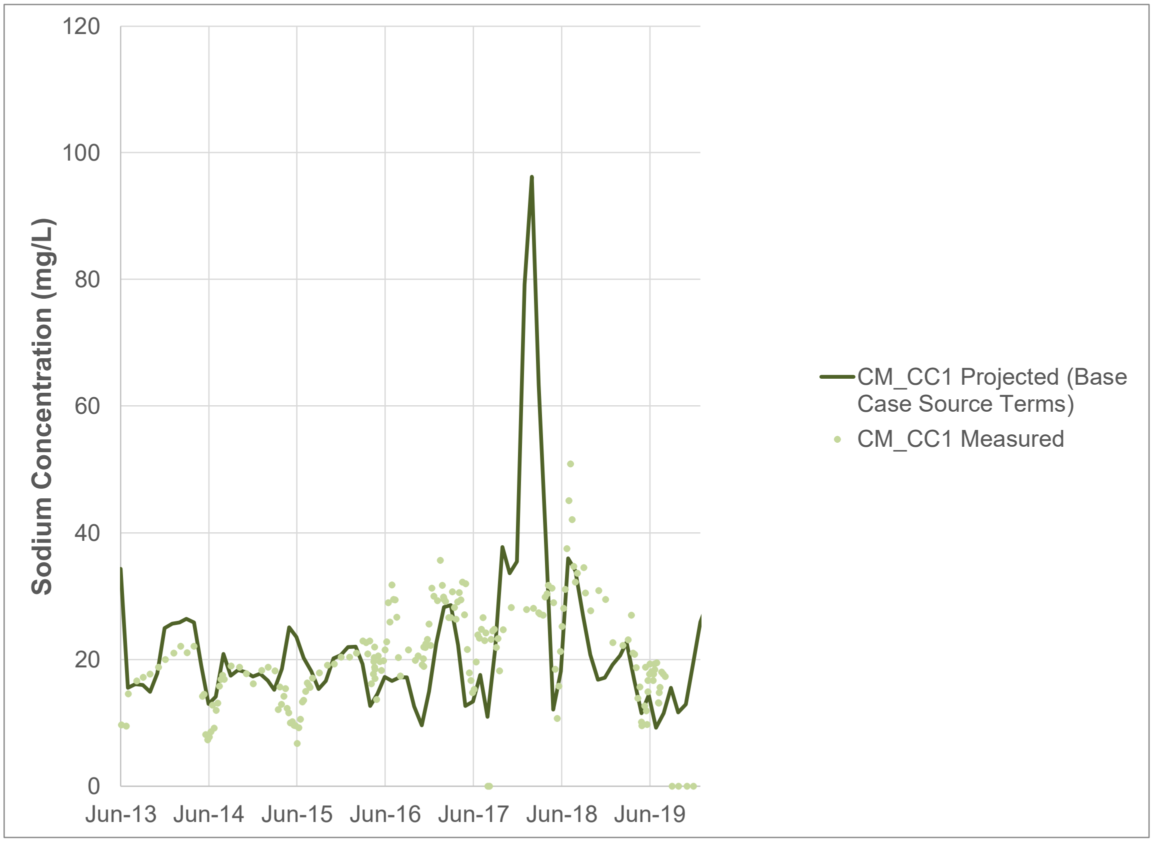

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FIGURE A68

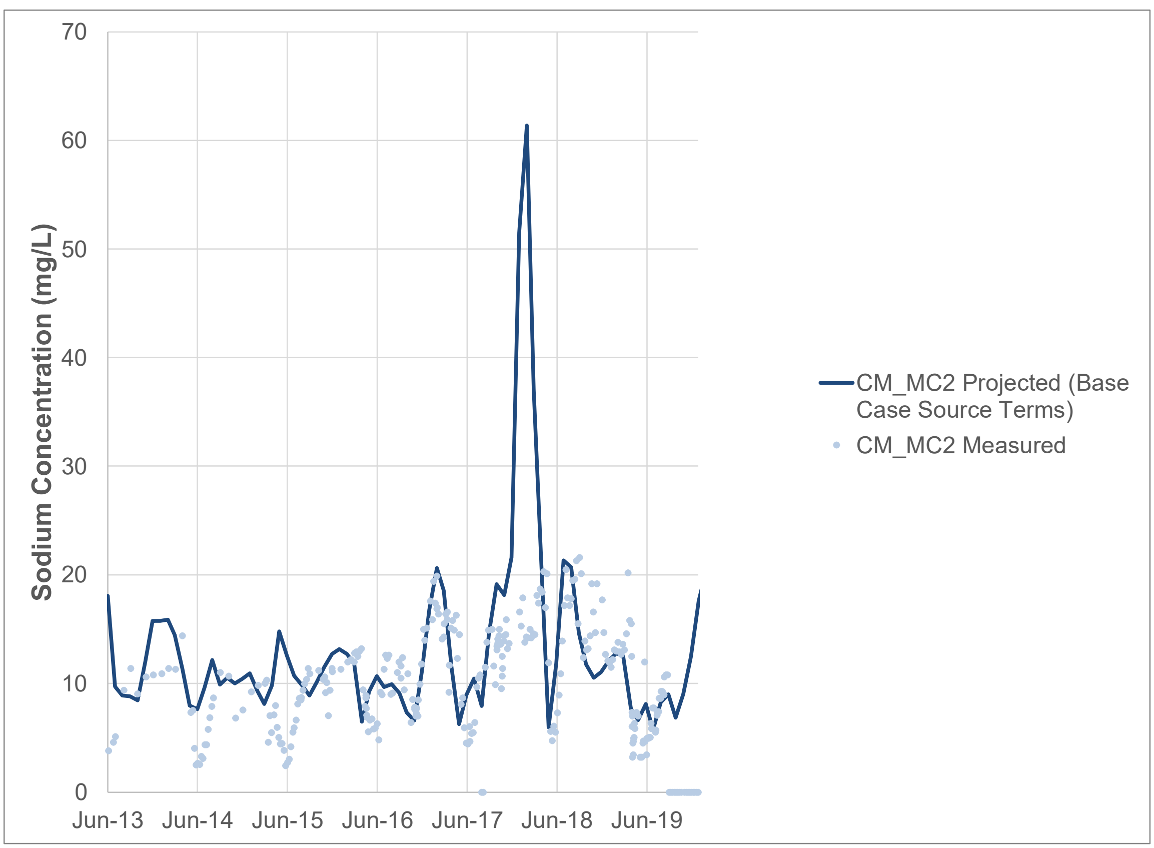

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FIGURE A69

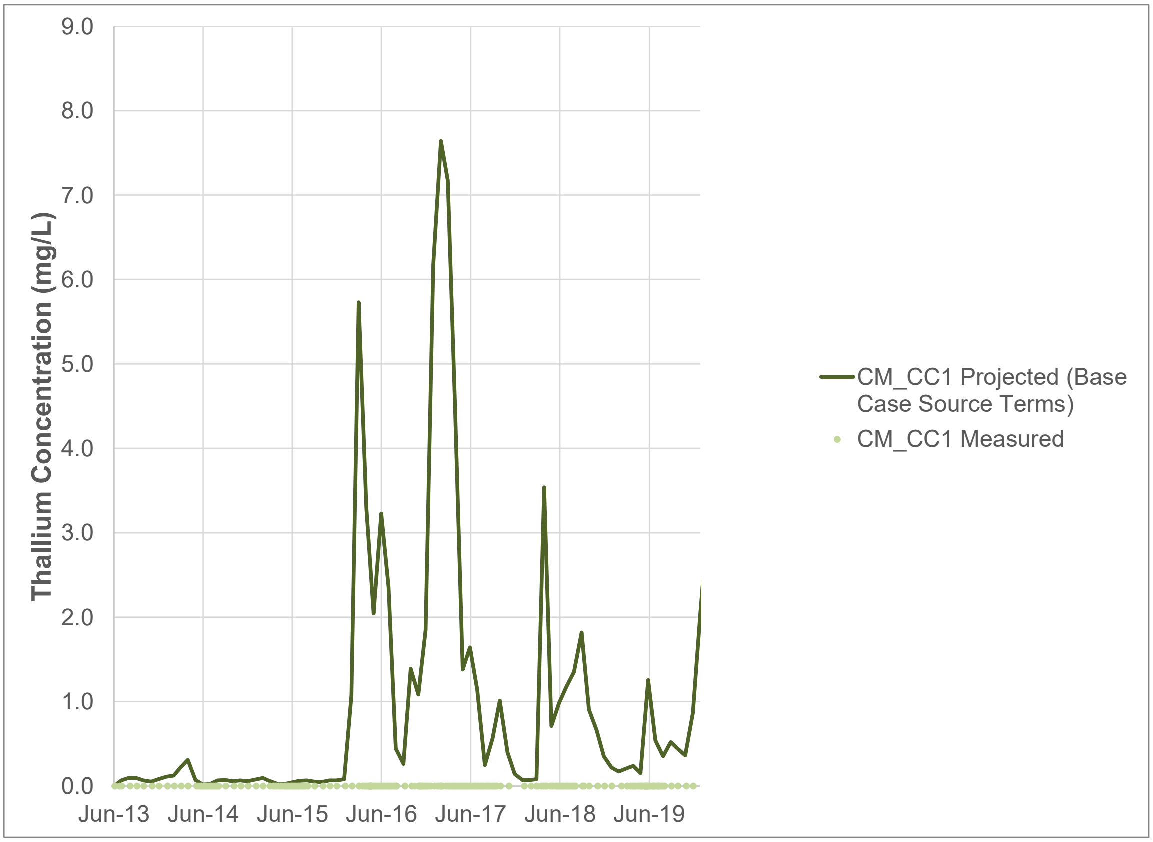

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FIGURE A70

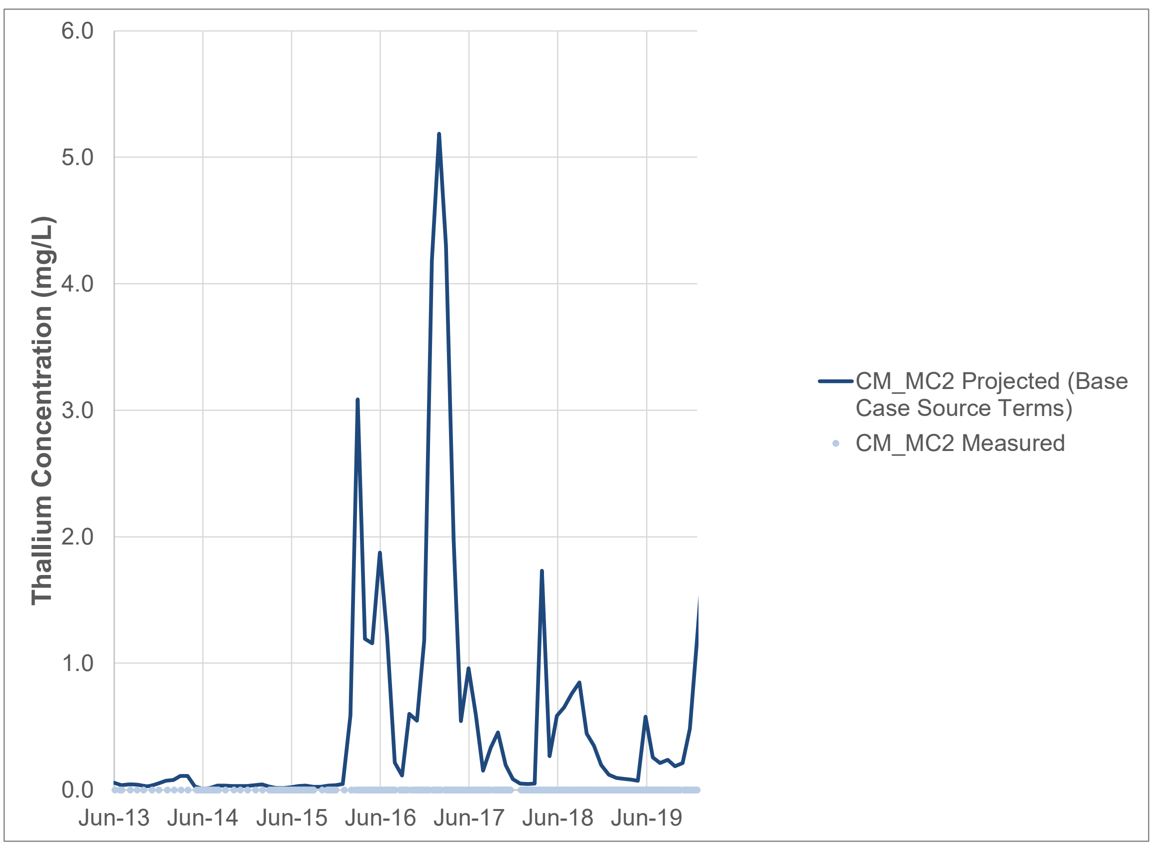

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FIGURE A71

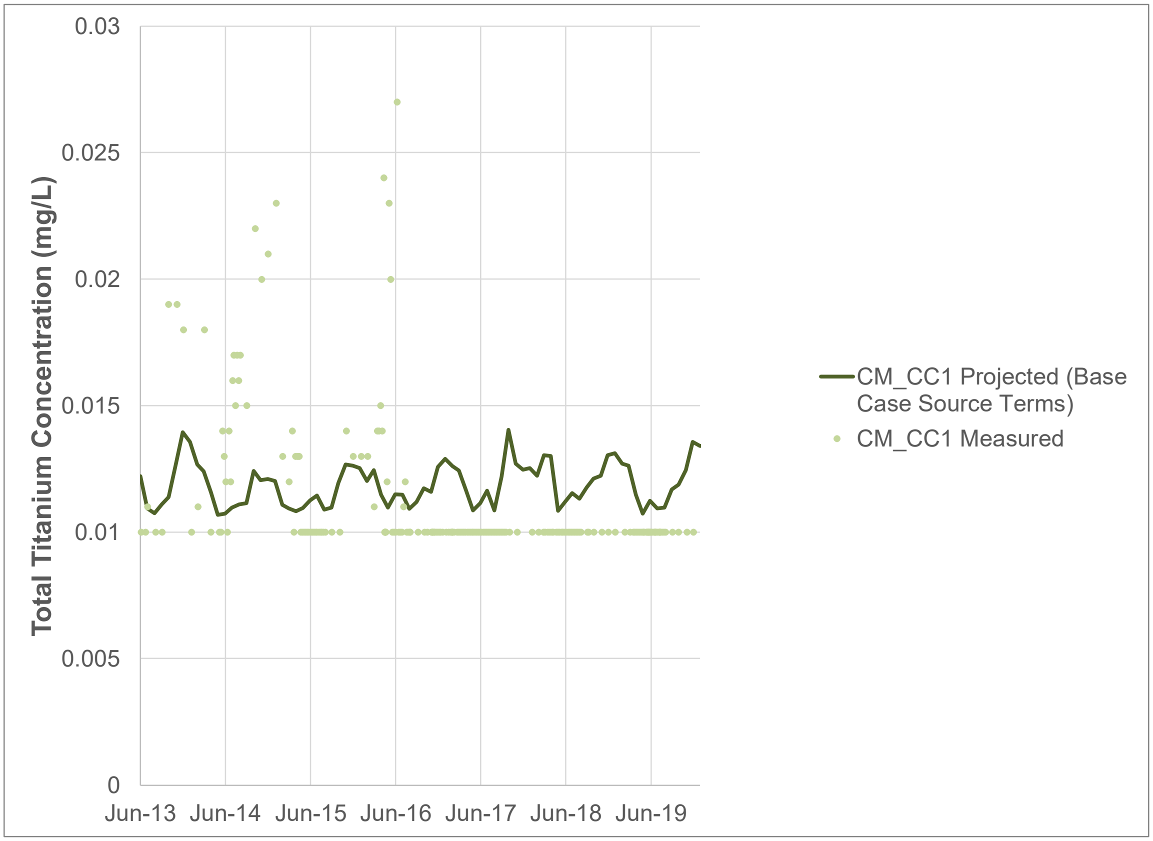

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FIGURE A72

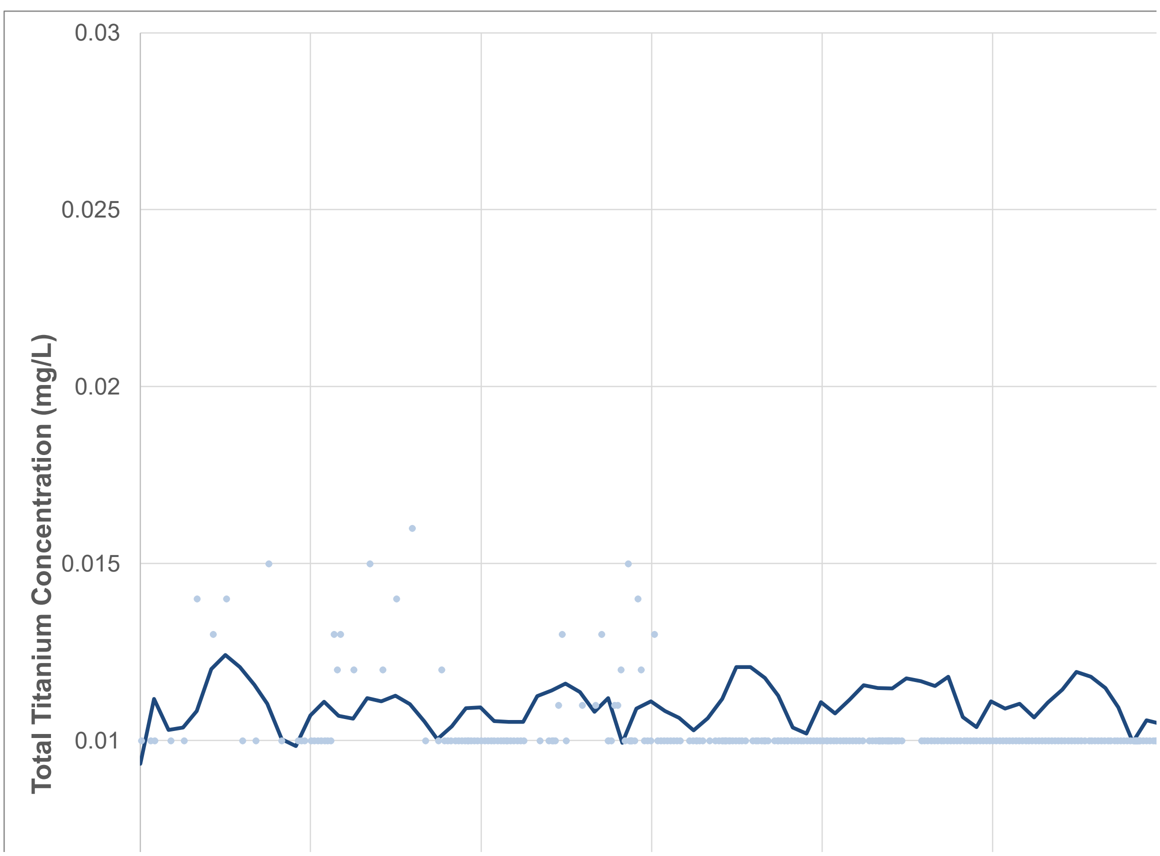

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FIGURE A73

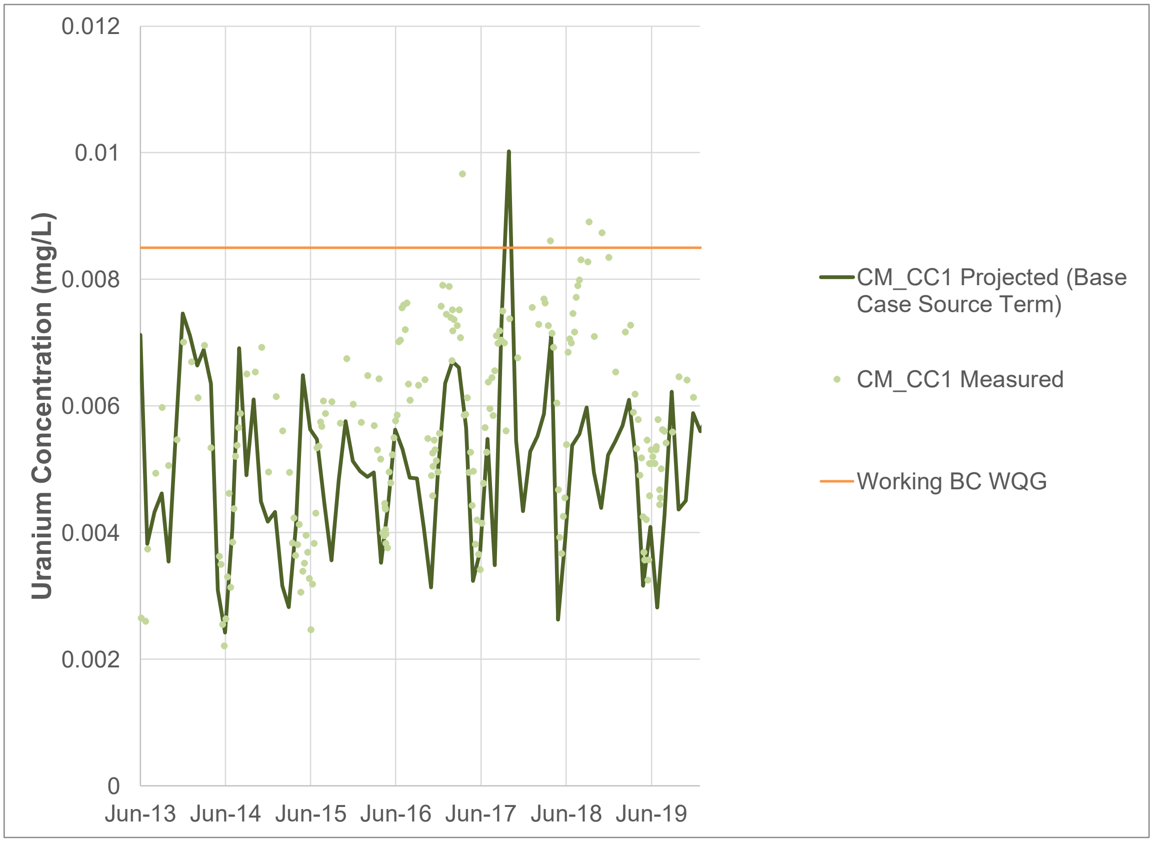

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FIGURE A74

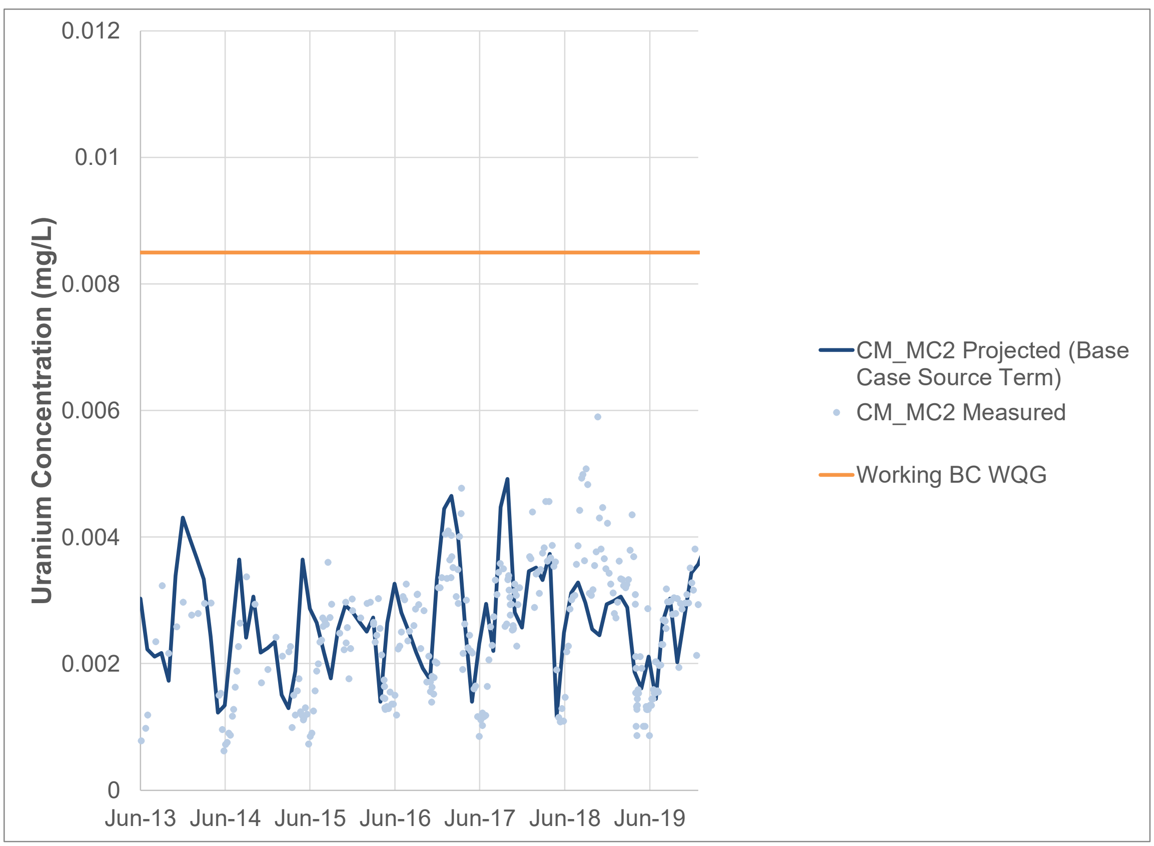

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FIGURE A75

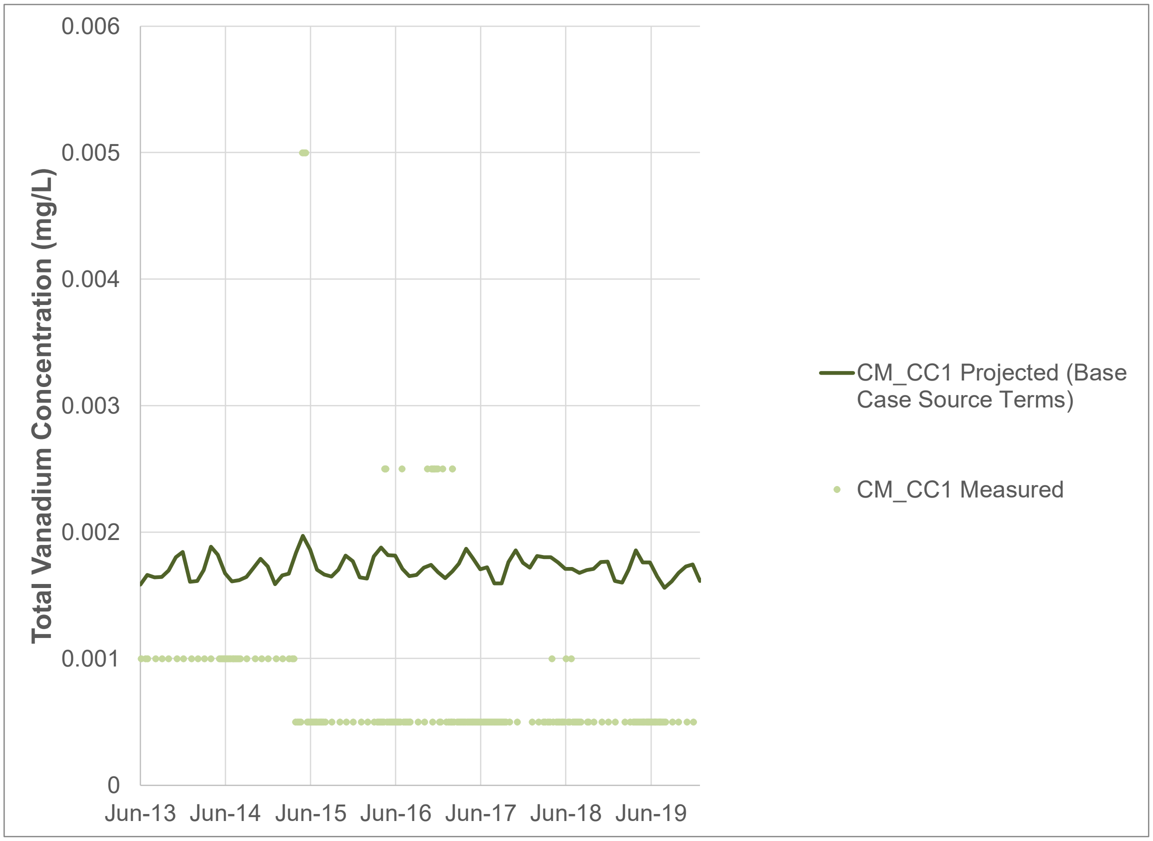

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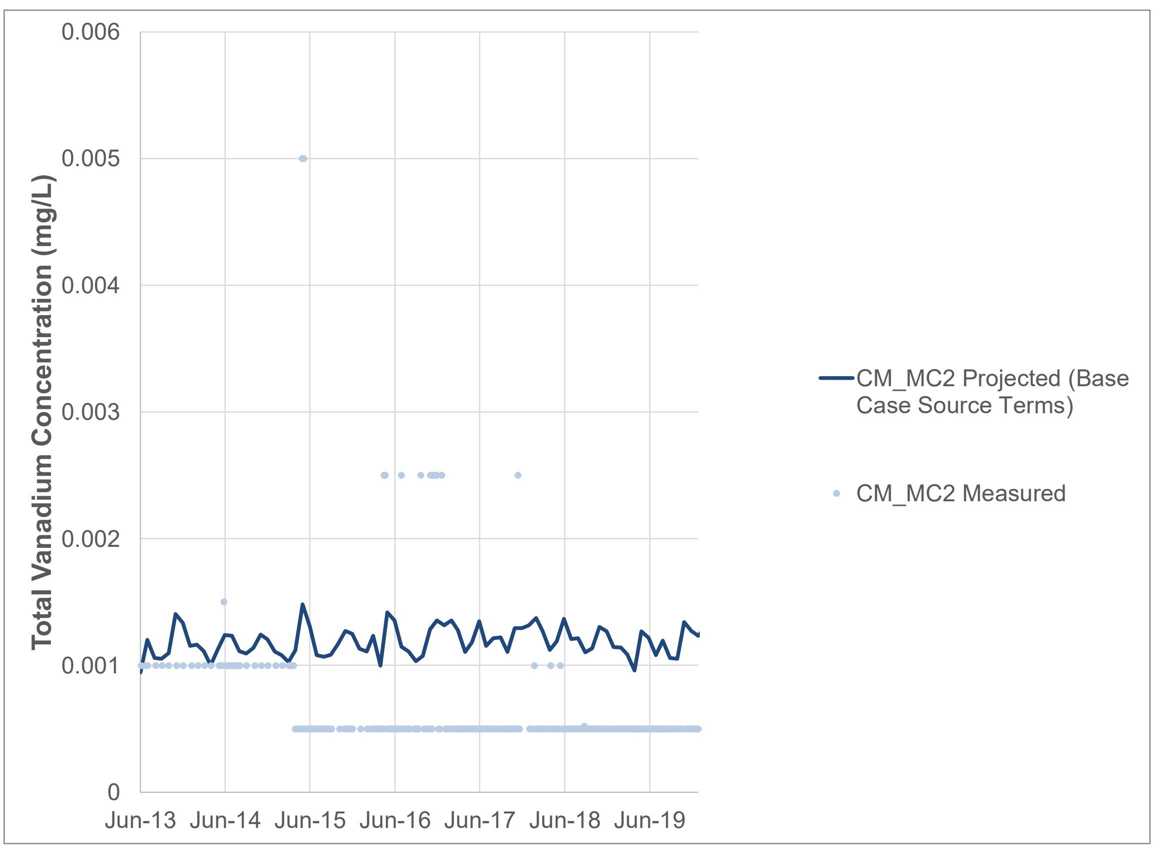
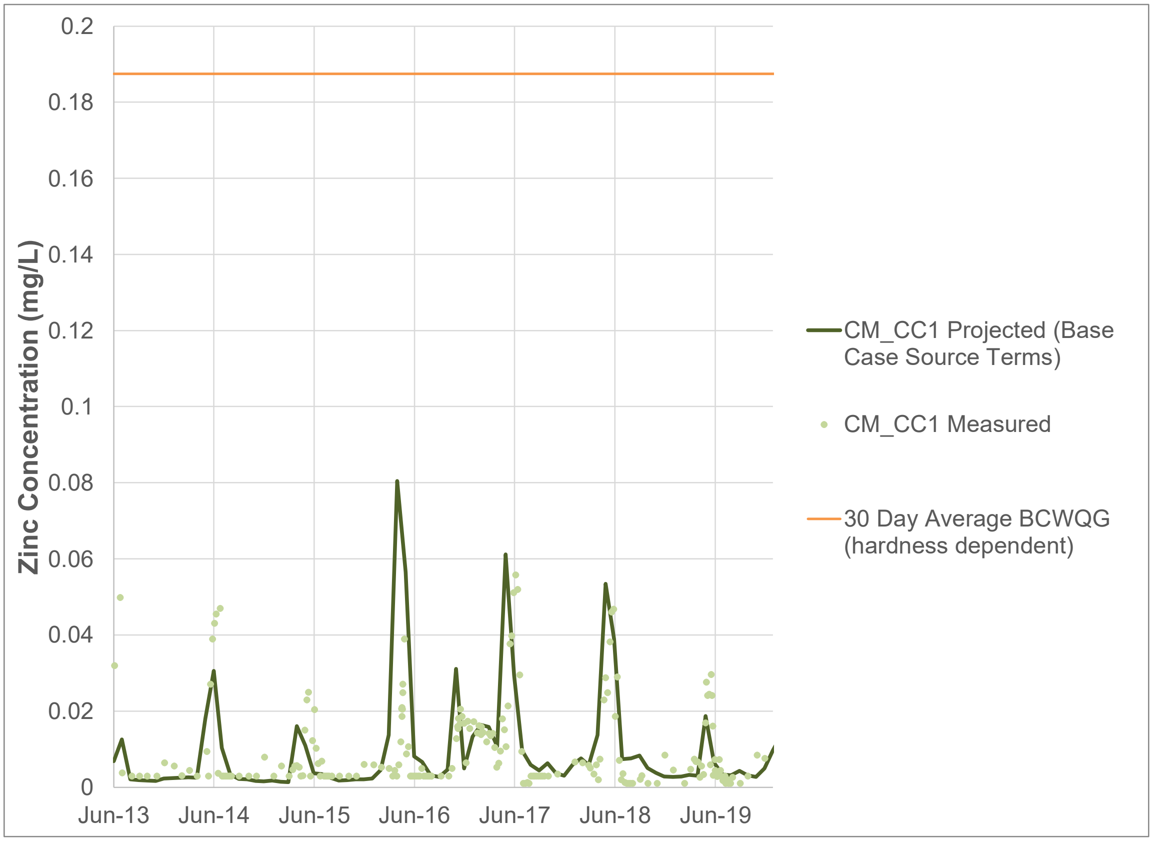
FIGURE A76



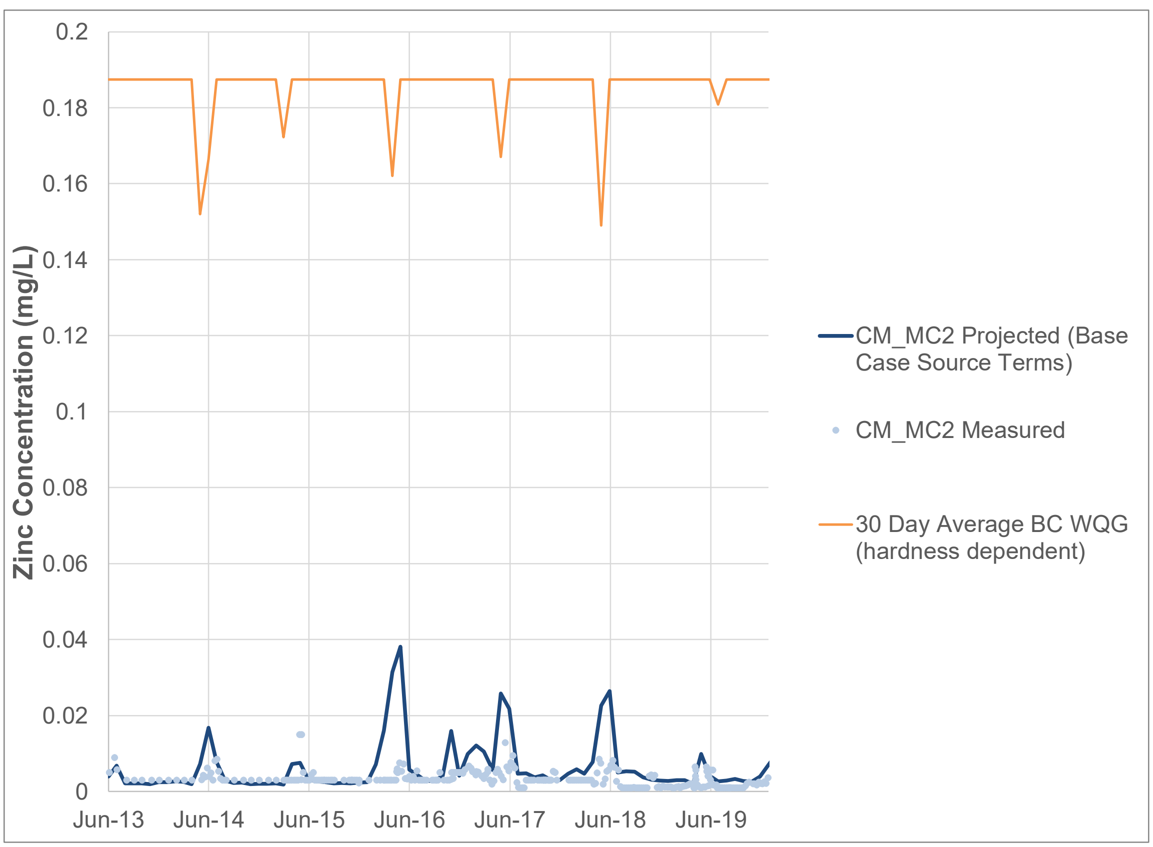
\\srk.ad\dfs\na\van\Projects\01_SITES\Coal Mountain\1CT017.260 CMO RWQM Transfer\05_Consolidate WLBM Report\Appendix C\CMO_WLBModelPlots_1CT017.260_CAJ_v2

FIGURE A77



\\srk.ad\dfs\na\van\Projects\01_SITES\Coal Mountain\1CT017.260 CMO RWQM Transfer\05_Consolidate WLBM Report\Appendix C\CMO_WLBModelPlots_1CT017.260_CAJ_v2

FIGURE A78



\\srk.ad\dfs\na\van\Projects\01_SITES\Coal Mountain\1CT017.260 CMO RWQM Transfer\05_Consolidate WLBM Report\Appendix C\CMO_WLBModelPlots_1CT017.260_CAJ_v2

Appendix B

Waste Rock Volumes, Coal Refuse Areas and Blasting Information

Table B-1: Cumulative Waste Rock Volumes by Drainage at Fording River Operations

Year		Henretta Creek (FR_HC1)	Post Ponds Rock Drain (FR_PP1)	Turnbull Bridge Spoil (TBS)	North and East Tributary Rock Drain (LM2_NET)	John Creek (LM2_JC)	Lake Pit (Lake Pit)	Tower Diversion	Tower Diversion Extension	Lake Mountain Pit (FR_LMP1)	Turnbull South Pit	Clode Creek Upper (Clode_Ck_Upper)	Clode Creek Lower (Clode_Ck_Lower)	Eagle 6 Pit to Clode
1971	1971-12-31	-	-	-	-	-	-	-	-	-	-	0	0	-
1972	1972-12-31	-	-	-	-	-	-	-	-	-	-	2	3	-
1973	1973-12-31	-	-	-	-	-	-	-	-	-	-	2	4	-
1974	1974-12-31	-	-	-	-	-	-	-	-	-	-	3	5	-
1975	1975-12-31	-	-	-	-	-	-	-	-	-	-	3	7	-
1976	1976-12-31	-	-	-	-	-	-	-	-	-	-	4	7	-
1977	1977-12-31	-	-	-	-	-	-	-	-	-	-	4	11	-
1978	1978-12-31	-	-	-	-	-	-	-	-	-	-	4	13	-
1979	1979-12-31	-	-	-	-	-	-	-	-	-	-	4	15	-
1980	1980-12-31	-	-	-	-	-	-	-	-	-	-	4	18	-
1981	1981-12-31	-	-	-	-	-	5	-	-	0	-	4	19	-
1982	1982-12-31	-	-	-	-	-	12	-	-	0	-	4	21	-
1983	1983-12-31	-	-	-	-	-	12	-	-	0	-	4	19	-
1984	1984-12-31	-	-	-	-	-	12	-	-	0	-	4	12	-
1985	1985-12-31	-	-	-	-	-	12	-	-	0	-	3	10	-
1986	1986-12-31	-	-	-	-	-	15	-	-	0	-	3	10	-
1987	1987-12-31	-	-	-	-	1	19	-	-	0	-	2	10	-
1988	1988-12-31	-	-	-	-	1	21	-	-	0	-	2	9	-
1989	1989-12-31	-	-	-	-	1	24	-	-	1	-	3	11	-
1990	1990-12-31	-	-	-	-	1	24	-	-	2	-	4	13	-
1991	1991-12-31	-	-	-	-	1	24	-	-	3	-	5	14	-
1992	1992-12-31	0	-	-	-	1	24	-	-	3	-	5	15	-
1993	1993-12-31	4	-	-	-	1	24	-	-	3	-	6	16	-
1994	1994-12-31	13	-	-	-	1	24	-	-	3	-	7	16	-
1995	1995-12-31	28	-	-	-	1	24	-	-	3	-	7	17	-
1996	1996-12-31	39	-	-	-	1	24	-	-	3	-	7	17	-
1997	1997-12-31	57	-	-	-	1	24	-	-	3	-	8	18	-
1998	1998-12-31	65	-	-	-	1	24	-	-	3	-	12	25	-
1999	1999-12-31	73	-	-	-	1	24	-	-	3	-	12	30	-
2000	2000-12-31	84	-	-	-	1	24	-	-	3	-	13	34	-
2001	2001-12-31	100	-	-	-	1	24	-	-	3	-	13	36	-
2002	2002-12-31	111	-	-	-	1	24	-	-	3	-	13	39	1
2003	2003-12-31	116	-	-	-	1	24	-	-	3	-	13	40	1
2004	2004-12-31	124	-	-	-	1	24	-	-	3	-	13	40	1
2005	2005-12-31	135	-	-	-	1	24	-	-	3	-	13	40	2
2006	2006-12-31	141	-	-	-	1	24	-	-	3	-	14	41	2
2007	2007-12-31	153	-	-	-	1	24	-	-	3	-	14	41	2
2008	2008-12-31	164	-	-	-	1	24	-	-	3	-	14	42	2
2009	2009-12-31	176	-	-	-	1	24	-	-	3	-	15	43	2
2010	2010-12-31	177	-	16	-	1	24	-	-	3	-	15	43	2
2011	2011-12-31	178	-	36	-	1	24	-	-	3	-	16	44	2
2012	2012-12-31	178	-	55	-	1	24	-	-	3	-	18	48	3
2013	2013-12-31	178	-	65	-	1	24	-	-	3	-	21	53	4
2014	2014-12-31	178	-	65	-	1	24	-	-	3	-	22	54	4
2015	2015-12-31	178	-	65	-	1	24	-	-	3	-	27	62	6
2016	2016-12-31	178	-	65	-	1	24	-	-	3	5	33	71	8
2017	2017-12-31	178	-	65	0	5	49	-	-	3	5	31	69	8
2018	2018-12-31	178	-	65	12	19	60	-	-	3	5	36	78	8
2019	2019-12-31	178	12	73	17	23	72	-	-	3	5	36	77	13
2020	2020-12-31	178	12	73	25	31	91	-	-	3	5	36	77	13
2021	2021-12-31	178	14	74	35	40	113	-	-	3	5	36	76	13
2022	2022-12-31	178	14	74	35	40	115	-	-	3	5	36	76	13
2023	2023-12-31	178	14	74	35	40	117	-	-	3	5	36	76	13
2024	2024-12-31	178	14	74	40	44	130	-	-	3	5	40	76	18
2025	2025-12-31	178	14	74	60	63	176	-	-	3	5	42	76	19
2026	2026-12-31	178	21	79	62	65	139	-	-	3	5	42	76	74
2027	2027-12-31	178	48	97	71	65	98	49	8	3	5	42	76	74
2028	2028-12-31	178	76	115	83	75	110	55	9	3	5	42	76	74
2029	2029-12-31	178	78	117	107	94	140	70	12	3	5	42	76	74
2030	2030-12-31	178	90	125	115	99	151	75	12	3	5	42	76	74
2031	2031-12-31	178	100	131	129	102	138	119	22	3	5	42	76	74
2032	2032-12-31	178	100	131	141	111	153	132	24	-	5	42	76	74
2033	2033-12-31	178	100	131	153	120	167	144	26	-	5	42	76	74
2034	2034-12-31	178	100	131	165	129	182	157	28	-	5	42	76	74
2035	2035-12-31	178	100	131	170	133	188	162	29	-	5	42	76	74
2036	2036-12-31	178	100	131	170	133	189	163	29	-	5	42	76	74
2037	2037-12-31	178	100	131	170	133	191	165	29	-	5	42	76	74
2038	2038-12-31	181	100	131	170	133	193	166	29	-	5	42	76	74
2039	2039-12-31	200	100	131	170	133	194	167	29	-	5	42	76	74
2040+	2040-12-31	212	100	131	170	133	194	167	29	-	5	42	76	74

\- = no waste rock.

Table B-1: Cumulative Waste Rock Volumes by Drainage at Fording River Operations

Year		Eagle 6 Pit to Kilmarnock	Eagle 6 West Pit	Eagle 4 Pit (Eagle_4_Pit)	Fording EC1 Eagle Ponds	Swift Pit	Swift-Bens Pit (Swift_Bens_Pit)	Fording South Tailings Pond (STP)	Wash Plant / North Loop Settling Pond (NLP)	Fording LF2 Upper (Fording_LF2_Upper)	Fording LF2 Lower (Fording_LF2_Lower)	Swift Spoil	Kilmarnock Lower	Cataract Creek	Additional GH_PC2
1971	1971-12-31	-	-	1	-	-	-	-	-	-	1	-	-	-	-
1972	1972-12-31	-	-	6	-	-	-	-	-	-	3	-	-	-	-
1973	1973-12-31	-	0	10	-	1	0	-	-	2	3	-	-	-	-
1974	1974-12-31	-	2	18	-	3	1	-	-	6	5	-	-	-	-
1975	1975-12-31	-	4	25	1	5	1	-	-	8	6	-	-	-	-
1976	1976-12-31	-	4	28	1	7	1	-	-	10	6	-	-	-	-
1977	1977-12-31	-	5	32	1	11	1	-	-	12	8	-	-	-	-
1978	1978-12-31	-	5	32	11	12	1	-	-	15	8	-	-	-	-
1979	1979-12-31	-	5	32	21	14	2	-	-	17	9	-	-	-	-
1980	1980-12-31	-	5	32	33	16	2	-	-	19	9	-	1	-	-
1981	1981-12-31	-	5	32	46	21	3	-	-	19	9	-	2	-	-
1982	1982-12-31	-	5	32	62	28	3	-	-	22	12	-	2	-	-
1983	1983-12-31	-	5	32	66	32	3	2	0	22	12	18	3	-	-
1984	1984-12-31	-	5	32	74	44	5	2	0	26	16	34	7	1	0
1985	1985-12-31	-	5	32	74	61	7	3	0	23	16	55	16	11	0
1986	1986-12-31	-	5	32	74	73	7	14	2	26	17	61	22	21	0
1987	1987-12-31	-	5	32	74	80	11	26	2	31	17	68	28	30	0
1988	1988-12-31	-	5	33	74	88	15	47	2	32	19	77	30	39	0
1989	1989-12-31	1	6	42	74	90	15	47	2	32	19	85	42	49	0
1990	1990-12-31	1	8	53	74	93	15	47	2	32	23	90	59	59	0
1991	1991-12-31	2	10	66	74	96	15	47	2	32	24	92	81	70	0
1992	1992-12-31	3	11	71	74	98	15	47	2	32	24	93	88	80	0
1993	1993-12-31	3	13	79	74	107	15	47	2	32	27	95	111	90	0
1994	1994-12-31	3	14	84	74	107	15	47	2	32	27	102	150	109	0
1995	1995-12-31	3	14	85	74	107	15	47	2	32	27	102	189	129	1
1996	1996-12-31	4	14	86	74	107	15	47	2	32	27	102	235	150	1
1997	1997-12-31	5	15	92	74	107	15	47	2	32	27	108	282	174	1
1998	1998-12-31	6	17	96	74	107	15	47	2	32	27	109	321	193	1
1999	1999-12-31	7	17	96	75	107	15	47	2	32	27	110	372	209	1
2000	2000-12-31	7	17	97	77	107	15	49	2	32	27	116	426	232	1
2001	2001-12-31	7	17	98	80	107	15	51	2	32	27	136	480	237	1
2002	2002-12-31	8	17	99	90	107	15	54	2	32	27	154	520	237	1
2003	2003-12-31	9	17	99	95	107	15	57	2	32	27	165	577	237	1
2004	2004-12-31	10	17	100	110	107	15	57	2	32	27	171	629	243	1
2005	2005-12-31	10	17	100	122	107	15	57	2	32	27	179	683	246	1
2006	2006-12-31	11	20	109	130	107	15	57	2	32	27	181	729	264	1
2007	2007-12-31	13	24	141	131	107	15	57	2	32	27	181	750	287	1
2008	2008-12-31	13	26	157	136	107	15	57	2	32	27	181	785	308	1
2009	2009-12-31	15	28	175	136	107	15	57	2	32	27	181	817	323	1
2010	2010-12-31	15	31	183	136	107	15	57	2	32	27	181	866	331	1
2011	2011-12-31	16	31	186	136	107	15	57	2	32	27	181	929	352	1
2012	2012-12-31	19	33	211	136	107	15	57	2	32	27	186	962	376	2
2013	2013-12-31	23	35	223	136	107	15	57	2	32	27	186	999	380	2
2014	2014-12-31	26	43	236	136	107	15	58	3	32	27	186	1059	382	2
2015	2015-12-31	38	49	261	136	107	15	58	3	32	27	186	1083	383	2
2016	2016-12-31	44	51	284	136	107	15	58	3	32	27	186	1107	383	2
2017	2017-12-31	63	51	302	136	107	15	58	3	36	27	191	1129	391	2
2018	2018-12-31	71	51	316	136	109	17	58	3	40	27	194	1156	391	2
2019	2019-12-31	56	52	319	136	111	17	58	3	41	28	208	1211	391	2
2020	2020-12-31	55	56	342	137	112	17	58	3	43	30	207	1231	408	2
2021	2021-12-31	56	60	363	137	113	17	58	3	44	31	204	1265	408	2
2022	2022-12-31	57	64	388	137	125	19	58	3	51	37	235	1279	410	2
2023	2023-12-31	57	71	426	137	144	19	58	3	61	45	243	1291	411	2
2024	2024-12-31	75	71	426	137	148	26	58	3	63	46	254	1314	419	2
2025	2025-12-31	80	71	426	137	151	26	58	3	64	48	254	1319	419	2
2026	2026-12-31	26	71	426	137	268	-	58	3	16	48	276	1319	461	2
2027	2027-12-31	26	71	426	137	261	-	58	3	14	48	287	1319	461	2
2028	2028-12-31	26	71	426	137	259	-	58	3	14	48	287	1319	461	2
2029	2029-12-31	26	71	426	137	264	-	58	3	14	48	287	1319	461	2
2030	2030-12-31	26	71	426	137	295	-	58	3	16	58	287	1319	461	2
2031	2031-12-31	26	71	426	137	296	-	58	3	16	58	287	1319	461	2
2032	2032-12-31	26	71	426	137	300	-	58	3	16	58	300	1319	462	2
2033	2033-12-31	26	71	426	137	300	-	58	3	16	58	314	1319	463	2
2034	2034-12-31	26	71	426	137	300	-	58	3	16	58	327	1319	464	2
2035	2035-12-31	26	71	426	137	327	-	58	3	19	60	332	1319	464	2
2036	2036-12-31	26	71	426	137	371	-	58	3	27	67	332	1319	464	2
2037	2037-12-31	26	71	426	137	407	-	58	3	38	76	333	1319	464	2
2038	2038-12-31	26	71	426	137	435	-	58	3	51	87	333	1319	464	2
2039	2039-12-31	26	71	426	137	454	-	58	3	59	93	333	1319	464	2
2040+	2040-12-31	26	71	426	137	455	-	58	3	59	94	333	1319	464	2

\- = no waste rock.

Table B-2: Cumulative Waste Rock Volumes by Drainage at Greenhills Operations (million BCM)

Year	Cougar Creek	Phase 6 Pit (GH_CSP)	West Spoil Phase 3B	Mickelson Creek (GH_MC1)	Leask Creek Upper (GH_LC1 (Upper))	Leask Creek Lower (GH_LC1 (Lower))	Phase 3 Pit (CP_P3)	Wolfram Creek North Upper (Wolfram _Ck _N_Upper)	Wolfram Creek North Lower (Wolfram_Ck_N_Lower)
1982	-	-	-	-	-	-	-	-	-
1983	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	-
1989	-	-	-	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	-
1991	-	2	-	-	-	-	1	-	-
1992	-	2	-	-	-	-	1	-	-
1993	-	4	-	-	-	-	1	-	-
1994	-	9	-	-	-	-	3	-	-
1995	-	20	-	-	-	-	8	-	-
1996	-	34	-	-	-	-	13	-	-
1997	-	42	-	-	-	-	17	-	-
1998	-	59	-	-	-	-	23	-	-
1999	-	74	-	-	-	-	29	-	-
2000	-	78	-	-	-	-	31	-	-
2001	-	81	-	-	-	-	32	-	-
2002	-	81	-	-	-	-	32	-	-
2003	-	83	-	-	-	-	33	2	-
2004	-	85	-	-	-	-	34	8	-
2005	-	88	-	-	-	-	35	10	-
2006	-	88	-	-	-	-	35	10	-
2007	-	88	-	-	-	-	35	11	-
2008	-	89	-	-	3	-	35	13	-
2009	-	95	-	-	7	-	38	16	-
2010	-	114	-	-	10	-	45	18	-
2011	-	131	-	-	12	-	52	19	-
2012	-	142	-	-	15	-	56	26	-
2013	-	146	-	-	19	-	57	36	-
2014	-	150	-	-	28	-	59	53	-
2015	-	155	0	-	36	-	61	66	-
2016	-	162	1	-	50	-	64	79	-
2017	-	170	1	-	64	-	67	92	-
2018	-	176	1	-	74	-	69	115	-
2019	-	176	5	-	82	3	69	136	3
2020	-	225	5	-	86	3	69	142	3
2021	-	277	5	-	86	3	69	142	3
2022	-	330	5	-	87	3	69	145	3
2023	-	382	5	-	87	3	69	145	3
2024	-	427	5	-	87	3	69	145	3
2025	-	443	5	-	93	3	69	155	3
2026	-	518	6	-	99	4	-	166	3
2027	2	503	6	13	99	4	-	166	3
2028	2	503	6	13	99	4	-	166	3
2029	2	503	6	13	99	4	-	166	3
2030	2	503	6	13	99	4	-	166	3
2031	2	503	6	13	99	4	-	166	3
2032	2	503	6	13	99	4	-	166	3
2033	2	503	6	13	99	4	-	166	3
2034	2	503	6	13	99	4	-	166	3
2035+	2	503	6	13	99	4	-	166	3

- = no waste rock.

Table B-2: Cumulative Waste Rock Volumes by Drainage at Greenhills Operations (million E

Year	Wolfram Creek South Upper (Wolfram_Ck_S_Upper)	Wolfram Creek South Lower (Wolfram_Ck_S_Lower)	Thompson Creek Upper (GH_TC1 (Upper))	Thompson Creek Lower (GH_TC1 (Lower))	Greenhills Creek North	Porter Creek (Porter_Ck)
1982	-	-	-	-	5.8	-
1983	-	-	-	-	13	-
1984	-	-	-	-	21	-
1985	-	-	-	-	26	-
1986	-	-	-	-	29	1
1987	-	-	-	-	31	5
1988	-	-	1	-	36	7
1989	-	-	4	-	37	9
1990	-	-	5	-	37	16
1991	-	-	5	-	39	22
1992	-	-	5	-	43	28
1993	-	-	5	-	43	33
1994	-	-	5	-	43	33
1995	-	-	5	-	46	34
1996	-	-	5	-	46	35
1997	-	-	5	-	46	36
1998	-	-	5	-	46	38
1999	-	-	5	-	46	38
2000	-	-	5	-	53	38
2001	-	-	5	-	61	39
2002	-	-	16	-	65	39
2003	2	-	24	-	72	39
2004	2	-	29	-	85	40
2005	2	-	41	-	98	41
2006	2	-	55	-	101	41
2007	3	-	63	-	105	42
2008	4	-	73	-	105	42
2009	7	-	78	-	105	42
2010	8	-	81	-	105	42
2011	9	-	82	-	105	42
2012	14	-	87	-	109	44
2013	23	-	93	-	116	44
2014	35	-	98	-	127	44
2015	46	-	104	-	130	44
2016	56	-	110	-	130	44
2017	66	-	111	-	130	44
2018	85	-	112	-	130	44
2019	89	1	112	1	130	44
2020	90	1	112	1	130	44
2021	90	1	112	1	130	44
2022	91	1	112	1	130	44
2023	91	1	112	1	130	44
2024	91	1	112	1	130	44
2025	93	1	112	1	130	44
2026	95	1	113	1	130	44
2027	95	1	113	1	130	44
2028	95	1	113	1	130	44
2029	95	1	113	1	130	44
2030	95	1	113	1	130	44
2031	95	1	113	1	130	44
2032	95	1	113	1	130	44
2033	95	1	113	1	130	44
2034	95	1	113	1	130	44
2035+	95	1	113	1	130	44

\- = no waste rock.

Table B-3: Cumulative Waste Rock Volumes by Drainage at Line Creek Operations (million BCM)

Year	Upper LCO Dry Creek	Burnt Ridge North (BRN) 1 Pit	Burnt Ridge North (BRN) 2 Pit	Mount Michael (MTM) 2 Pit	Upper Line Creek 2 (Upper_LC_2)	Horseshoe Creek 2 (HSC_2)	No Name Creek North Line Extension (NLX) Pit	No Name Creek Access Road Spoils	Mine Services Area West (MSAW) Backfilled Pit	North Line Creek (NLC)	Centre Line Creek (CLC)	West Line Creek (LC_WLC)
1981	-	-	-	-	-	-	-	-	-	-	-	2
1982	-	-	-	-	-	-	-	-	-	-	-	10
1983	-	-	-	-	-	-	-	-	-	-	-	20
1984	-	-	-	-	0	0	0	0	-	0	0	34
1985	-	-	-	-	0	0	0	0	-	0	1	47
1986	-	-	-	-	0	0	0	0	-	0	1	57
1987	-	-	-	-	0	0	0	0	-	0	1	67
1988	-	-	-	-	0	0	0	0	-	0	1	80
1989	-	-	-	-	0	1	0	1	-	1	1	88
1990	-	-	-	-	0	1	1	1	-	1	2	98
1991	-	-	-	-	1	2	1	2	-	2	3	111
1992	-	-	-	-	1	2	1	3	-	2	4	124
1993	-	-	-	-	1	3	1	3	-	3	5	138
1994	-	-	-	-	1	4	1	4	-	4	6	154
1995	-	-	-	-	1	4	2	5	-	4	7	172
1996	-	-	-	-	2	5	2	5	-	5	8	176
1997	-	-	-	-	2	5	2	6	-	6	9	180
1998	-	-	-	-	2	6	2	7	-	6	10	184
1999	-	-	-	-	2	7	3	7	-	7	11	187
2000	-	-	-	-	4	11	4	13	-	12	19	187
2001	-	-	-	-	5	16	6	18	-	17	27	187
2002	-	-	-	-	8	23	9	25	-	24	37	187
2003	-	-	-	-	9	28	11	31	-	29	45	187
2004	-	-	-	-	11	32	12	36	-	33	52	187
2005	-	-	-	-	12	37	14	41	-	38	60	187
2006	-	-	-	-	13	40	16	45	-	42	66	187
2007	-	-	-	-	15	44	17	49	-	46	72	187
2008	-	-	-	-	16	49	19	54	-	51	80	187
2009	-	-	-	-	18	53	21	59	-	55	87	187
2010	-	-	-	-	19	58	23	64	-	60	95	192
2011	-	-	-	-	20	62	24	68	-	64	101	203
2012	-	-	-	-	20	62	28	79	0	74	101	213
2013	-	-	-	-	20	62	29	83	0	99	101	214
2014	2	-	-	-	20	62	32	91	0	125	101	214
2015	3	-	-	-	20	62	34	97	0	148	101	214
2016	13	-	-	-	20	62	36	102	1	166	101	214
2017	38	-	-	-	23	62	37	105	3	170	101	214
2018	66	-	-	-	23	62	39	111	5	175	101	214
2019	74	-	-	-	23	62	47	132	5	177	101	214
2020	88	-	-	-	23	62	51	145	5	184	101	214
2021	120	-	-	-	23	62	52	149	5	193	102	214
2022	160	-	-	-	23	62	52	149	5	198	102	214
2023	188	-	-	-	24	62	52	149	20	198	102	214
2024	211	-	-	9	24	62	53	153	24	198	102	214
2025	252	-	-	9	24	62	54	154	24	198	102	214
2026	284	-	-	9	24	62	53	154	24	198	102	214
2027	306	-	-	9	24	62	57	163	24	198	102	214
2028	326	-	-	9	24	62	63	179	24	198	102	214
2029	354	-	-	9	24	62	65	185	24	198	102	214
2030	392	-	-	9	24	62	65	185	24	198	102	214
2031	436	-	-	9	24	62	65	185	24	198	102	214
2032	475	-	-	9	24	62	65	185	24	198	102	214
2033	486	6	15	9	24	62	65	185	24	198	102	214
2034	509	6	15	9	24	62	65	185	24	198	102	214
2035	528	11	15	9	24	62	65	185	24	198	102	214
2036+	529	17	15	9	24	62	65	185	24	198	102	214

- = no waste rock.

Table B-4: Cumulative Waste Rock Volumes by Drainage at Elkview Operations

Year	EVO Dry Creek	Lower Harmer Creek (LHM1)	Six Mile Creek	Balmer Creek	Cedar Pit	Breaker Lake (EVO_Breaker)	Cossarini Otto Creek	Erickson Creek Upper	Erickson Bridge (EV_ECBridge)	Erickson Creek Lower	South Pit Creek	Milligan Creek (EV_MG1)	Natal Pit 1 (Natal_Pit_1)	Natal Pit West (Natal_Pit_West)
1970	6.0	-	-	-	-	-	-	17	0.009	0.085	-	-	-	-
1971	12	-	-	-	-	-	-	35	0.018	0.17	-	-	-	-
1972	19	-	-	-	-	-	-	55	0.029	0.27	-	-	-	-
1973	27	-	-	-	-	-	-	77	0.04	0.38	-	-	-	-
1974	35	-	-	-	-	-	-	100	0.052	0.5	-	-	-	-
1975	49	-	-	-	-	-	-	124	0.065	0.62	-	-	-	-
1976	56	-	-	-	-	-	-	142	0.074	0.71	-	-	-	-
1977	62	-	-	-	-	-	-	160	0.084	0.8	-	-	-	-
1978	67	-	-	-	-	-	-	174	0.091	0.87	-	-	-	-
1979	75	-	-	-	-	-	-	194	0.1	0.97	-	-	-	-
1980	82	-	5.6	-	-	-	-	215	0.11	1.1	-	-	-	-
1981	91	-	5.6	-	-	-	-	240	0.13	1.2	-	-	-	-
1982	100	-	5.6	-	-	-	-	265	0.14	1.3	-	-	-	-
1983	104	-	5.6	-	-	-	-	278	0.15	1.4	-	-	-	-
1984	109	-	5.6	-	-	-	-	292	0.15	1.5	-	-	-	-
1985	117	-	5.6	-	-	-	-	313	0.16	1.6	-	-	-	-
1986	122	-	5.6	-	-	-	-	328	0.17	1.6	-	-	-	-
1987	129	-	5.6	-	-	-	-	349	0.18	1.7	-	-	-	-
1988	138	-	5.6	-	-	-	-	373	0.2	1.9	-	-	-	-
1989	147	-	5.6	-	-	-	-	398	0.21	2.0	-	-	-	-
1990	155	-	5.6	-	-	-	-	423	0.22	2.1	-	-	-	-
1991	166	-	5.6	-	-	-	-	452	0.24	2.3	-	-	-	-
1992	169	-	5.6	-	-	-	-	462	0.24	2.3	-	-	-	-
1993	171	-	5.6	-	0.76	0.07	-	465	0.24	2.3	-	-	1.2	1.9
1994	175	-	5.6	-	2.2	0.2	-	469	0.25	2.4	-	-	3.5	5.6
1995	179	-	5.6	-	4.1	0.38	-	476	0.26	2.4	-	-	6.5	10
1996	185	-	5.6	-	6.2	0.57	-	483	0.26	2.5	-	-	9.9	16
1997	190	-	5.6	-	8.4	0.78	-	490	0.27	2.6	-	-	13	22
1998	195	-	5.6	-	11	0.97	-	495	0.28	2.7	1.5	1.0	17	27
1999	199	-	5.6	-	12	1.1	-	499	0.29	2.7	2.5	1.8	19	31
2000	204	-	5.6	-	14	1.3	-	504	0.29	2.8	4.0	2.8	22	36
2001	211	-	5.6	-	17	1.6	-	511	0.3	2.9	6.0	4.2	27	43
2002	218	-	5.6	-	20	1.8	-	519	0.31	3.0	8.2	5.7	32	51
2003	226	-	5.6	-	23	2.2	-	527	0.33	3.1	11	7.3	37	60
2004	235	-	5.6	-	27	2.5	-	536	0.34	3.2	13	9.2	43	69
2005	245	-	5.6	-	31	2.9	-	546	0.35	3.4	16	11	49	79
2006	252	-	5.6	-	34	3.1	-	556	0.37	3.5	18	13	54	87
2007	259	-	5.6	-	37	3.4	-	566	0.38	3.6	20	14	59	95
2008	267	-	5.6	-	40	3.7	-	577	0.39	3.7	23	16	64	103
2009	276	-	5.6	-	44	4.0	-	579	0.4	3.8	23	16	70	112
2010	283	-	5.6	-	47	4.3	-	581	0.41	3.9	23	16	74	119
2011	293	-	5.6	-	51	4.7	-	586	0.43	4.1	23	16	81	130
2012	304	-	5.6	-	55	5.1	-	591	0.44	4.2	23	16	88	141
2013	306	-	5.6	-	56	5.2	-	611	0.45	4.3	24	17	100	161
2014	305	-	5.6	-	59	5.5	-	636	0.45	4.3	24	17	113	181
2015	305	-	5.6	-	69	6.4	-	667	0.45	4.3	24	17	115	185
2016	305	2.5	5.6	3.5	67	6.2	0.54	723	1.2	12	19	13	98	158
2017	305	2.5	5.6	3.5	69	6.3	0.63	763	1.2	12	19	13	104	167
2018	305	2.5	5.6	3.5	71	6.6	1.2	827	1.2	12	19	13	108	173
2019	305	2.5	5.6	3.5	87	13	1.2	870	1.2	12	19	13	101	148
2020	307	2.5	5.6	3.5	95	15	1.2	896	1.2	12	19	13	127	158
2021	319	2.5	5.6	3.5	98	16	1.2	927	1.2	12	19	13	140	165
2022	336	2.5	5.6	3.5	106	16	1.2	985	1.2	12	19	13	142	165
2023	408	2.5	5.6	3.5	107	16	1.2	1,017	1.2	12	19	13	144	165
2024	431	2.5	5.6	3.5	107	16	1.2	1,055	1.2	12	19	13	144	165
2025	460	2.5	5.6	3.5	81	18	1.2	1,086	1.2	12	19	13	144	165
2026	476	2.5	5.6	3.5	81	18	1.2	1,144	1.2	12	19	13	144	165
2027	500	2.5	5.6	3.5	81	18	1.2	1,196	1.2	12	19	13	144	165
2028	524	2.5	5.6	3.5	81	18	1.2	1,217	1.2	12	19	13	144	177
2029	548	2.5	5.6	3.5	81	18	1.2	1,217	1.2	12	19	13	144	209
2030	572	2.5	5.6	3.5	81	42	1.2	1,245	1.2	12	19	13	144	195
2031	596	2.5	5.6	3.5	81	51	1.2	1,270	1.2	12	19	13	144	198
2032	620	2.5	5.6	3.5	81	54	1.2	1,292	1.2	12	19	13	144	198
2033	644	2.5	5.6	3.5	81	68	1.2	1,312	1.2	12	19	13	144	198
2034	651	2.5	5.6	3.5	81	78	1.2	1,336	1.2	12	19	13	155	198
2035	660	2.5	5.6	3.5	81	89	1.2	1,352	1.2	12	19	13	247	198
2036	665	2.5	5.6	3.5	81	97	1.2	1,372	1.2	12	19	13	258	198
2037	665	2.5	5.6	3.5	81	102	1.2	1,385	1.2	12	19	13	270	199
2038	665	2.5	5.6	3.5	81	102	1.2	1,399	1.2	12	19	13	283	199
2039	665	2.5	5.6	3.5	81	108	1.2	1,406	1.2	12	19	13	289	199
2040	665	2.5	5.6	3.5	81	-	1.2	1,414	1.2	12	19	13	288	199
2041	665	2.5	5.6	3.5	81	-	1.2	1,415	1.2	12	19	13	304	203
2042	665	2.5	5.6	3.5	81	-	1.2	1,416	1.2	12	19	13	310	203
2043	665	2.5	5.6	3.5	81	-	1.2	1,418	1.2	12	19	13	320	201
2044	665	2.5	5.6	3.5	81	-	1.2	1,418	1.2	12	19	13	329	201
2045+	665	2.5	5.6	3.5	81	-	1.2	1,418	1.2	12	19	13	331	207

- = no waste rock.

Table B-4: **Cumulative Waste Rock Volumes by Drainage at Elkview Operations**

Year	Natal Pit 2 (Natal_Pit_2)	Gate Creek	F2 Pit (F2_Pit)	Baldy Ridge Pits	Bodie Creek	Upper Aqueduct Creek (AQ1_Upper)	Lower Aqueduct Creek	Qualtieri Creek (EV_QC1)
1970	-	-	-	-	-	-	-	-
1971	-	-	-	-	-	-	-	-
1972	-	-	-	-	-	-	-	-
1973	-	-	-	-	-	-	-	-
1974	-	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-	-
1976	-	-	-	0.46	-	-	-	-
1977	-	-	-	0.96	-	-	-	-
1978	-	-	-	1.4	-	-	-	-
1979	-	-	-	1.9	-	-	-	-
1980	-	-	-	2.5	-	-	-	-
1981	-	-	-	3.2	-	-	-	-
1982	-	-	-	3.9	-	-	-	-
1983	-	-	-	4.3	-	-	-	-
1984	-	-	-	4.7	-	-	-	-
1985	-	-	-	5.3	-	-	-	-
1986	-	-	-	5.7	-	-	-	-
1987	-	-	-	6.3	-	-	-	-
1988	-	-	-	7.0	-	-	-	-
1989	-	-	-	7.7	-	-	-	-
1990	-	-	-	8.4	-	-	-	-
1991	-	-	-	9.2	-	-	-	-
1992	-	-	-	9.5	-	-	-	-
1993	-	0.92	-	9.7	0.76	-	-	-
1994	-	2.7	-	9.9	2.2	-	-	-
1995	-	4.9	-	10	4.1	-	-	-
1996	-	7.6	-	11	6.2	-	-	-
1997	-	10	-	11	8.4	-	-	-
1998	-	13	-	12	11	-	-	-
1999	-	15	-	12	12	-	-	-
2000	-	17	-	12	14	-	-	-
2001	-	21	-	13	17	-	-	-
2002	-	24	-	13	20	-	-	-
2003	-	28	-	14	23	-	-	-
2004	-	33	-	15	27	-	-	-
2005	-	38	-	16	31	-	-	-
2006	-	38	-	16	34	-	-	-
2007	-	38	-	17	37	-	-	-
2008	-	38	-	17	40	-	-	-
2009	-	38	15	18	44	-	-	-
2010	-	38	28	19	47	-	-	-
2011	-	38	46	19	47	-	-	-
2012	-	38	65	20	47	-	0.12	-
2013	-	38	73	21	46	-	0.12	-
2014	-	38	75	17	46	-	0.12	-
2015	-	37	81	14	46	-	0.12	-
2016	-	58	84	22	70	0.37	0.12	0.3
2017	-	58	84	21	70	0.38	0.12	0.3
2018	-	62	86	19	70	0.39	0.12	1.0
2019	6.3	78	86	25	70	0.39	0.12	1.0
2020	4.4	79	86	28	70	0.39	0.12	1.0
2021	2.7	79	86	33	70	0.39	0.12	1.0
2022	2.6	79	86	48	70	0.39	0.12	1.0
2023	2.5	79	86	51	70	0.39	0.12	1.0
2024	2.1	78	86	51	70	0.39	0.12	1.0
2025	-	70	86	73	70	0.39	0.12	1.0
2026	-	69	86	72	70	0.39	0.12	1.0
2027	-	69	86	71	70	0.39	0.12	1.0
2028	-	73	86	85	70	0.39	0.12	1.0
2029	-	73	86	85	70	0.39	0.12	1.0
2030	37	73	86	59	70	0.39	0.12	1.0
2031	38	73	86	73	70	0.39	0.12	1.0
2032	38	73	86	78	70	0.39	0.12	1.0
2033	38	73	86	101	70	0.39	0.12	1.0
2034	38	73	86	117	70	0.39	0.12	1.0
2035	38	73	86	57	70	0.39	0.12	1.0
2036	38	73	86	61	70	0.39	0.12	1.0
2037	38	73	86	65	70	0.39	0.12	1.0
2038	38	73	86	66	70	0.39	0.12	1.0
2039	38	73	86	69	70	0.39	0.12	1.0
2040	38	73	86	195	70	0.39	0.12	1.0
2041	39	73	86	196	70	0.39	0.12	1.0
2042	39	73	86	209	70	0.39	0.12	1.0
2043	38	73	86	232	70	0.39	0.12	1.0
2044	38	73	86	252	70	0.39	0.12	1.0
2045+	39	73	86	256	70	0.39	0.12	1.0

- = no waste rock.