Elk Valley Water Quality Plan

Annex D.1

Water Quality Modelling Methods

Teck

ELK VALLEY WATER QUALITY PLAN

WATER QUALITY MODELLING METHODS

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Summary

A regional water quality model was constructed as a planning and assessment tool to support the development of the Elk Valley Water Quality Plan (the Plan) that was required by Ministerial Order No. M113 (the Order). The overall approach, configuration, input information and calibration of the model are described in this report.

The purpose of the model is to estimate how water quality conditions in the Designated Area (i.e., the Elk Valley) could change as a result of mining and associated management activities. At its core, the model is a water quality mass balance model that is supported by:

- a hydrology sub-model to generate surface water flows using monitored data and empirical estimates based on the application of representative hydrographs; and
- empirical geochemical source terms (also referred to as geochemical release rates) derived from water quality monitoring and flow data collected downstream of waste-rock spoils and other representative source materials.

The model was set up to simulate concentrations of constituents of interest specified in the Order: selenium, sulphate, cadmium and nitrate. It calculates concentrations at a given location by adding up all of the incoming mass of a given substance as determined by the geochemical source terms, and dividing by the total flow at the location. This approach was selected as the most appropriate method to represent the current level of understanding of geochemical processes and conditions within waste-rock spoils and other mine features at a regional scale.

The model was calibrated by simulating historical conditions, comparing the modelled output with observed monitoring data, and then adjusting its watershed-specific parameters to achieve a good fit to the observed data. Emphasis was placed on closely replicating observed patterns at the Order stations in the Fording and Elk River mainstems. After calibration, the model was able to match historical selenium and sulphate concentration trends in the Fording and Elk rivers, and in many of their tributaries. The model tends to over-predict nitrate concentrations, as well as cadmium concentrations to a greater extent, and selenium at the Mouth of the Elk River and in Lake Koocanusa. The model was not used to predict cadmium concentrations for the development of the Plan.

The model's performance is considered appropriate for development of the Plan. Water quality management measures evaluated for the Plan, including active water treatment, clean and mine-affected water handling and waste-rock covers, had their performance simulated in the model. Model bias (i.e., the over-prediction trend) and uncertainties must be considered in the selection of water quality management measures.

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ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AWTP	Active Water Treatment Plant
BC	British Columbia
BC MOE	British Columbia Ministry of Environment
BGM	Bituminous Geomembrane
CMO	Coal Mountain Operations
ANFO	Mixture of Ammonium, Nitrate, Fuel and Oil
TDS	Total Dissolved Solids
SRK	SRK Mining Consultants
EVO	Elkview Operations
EVWQP	Elk Valley Water Quality Plan
FRO	Fording River Operations
FRO N	Fording River Operations North
FRO S	Fording River Operations South
GHO	Greenhills Operations
ID	Identification
LCO	Line Creek Operations
LCO I	Line Creek Operations Phase I
LCO II	Line Creek Operations Phase II
the model	Elk Valley Water Quality Planning Model
the Plan	Elk Valley Water Quality Plan
WLC	West Line Creek

UNITS OF MEASUREMENT

%	percent
>	greater than
<	less than
+/-	positive or negative
km^2	square kilometre
m^3	cubic metre
m^2	square metre
m	metre
µg/L	micrograms per litre

ha	hectare
kg/d	kilograms per day
kg/m^3/y	kilogram per cubic metre per year
mg/m^3/y	milligram per cubic metre per year
g/m^3/y	gram per cubic metre per year
m^3/d	cubic metres per day
mg/L	milligrams per litre
kg/m^3	kilogram per cubic metre
kg	kilogram
g N/g ANFO	gram of nitrogen per gram of ammonium, nitrate, fuel and oil mixture
g N/g slurry	gram of nitrogen per gram of slurry
m^3/s	cubic metre per second
y	year
mg $CaCO_3$/L	milligram of calcium carbonate per litre
mg N/L	milligram of nitrogen per litre
mg/m^3	milligram per cubic metre

1 Introduction

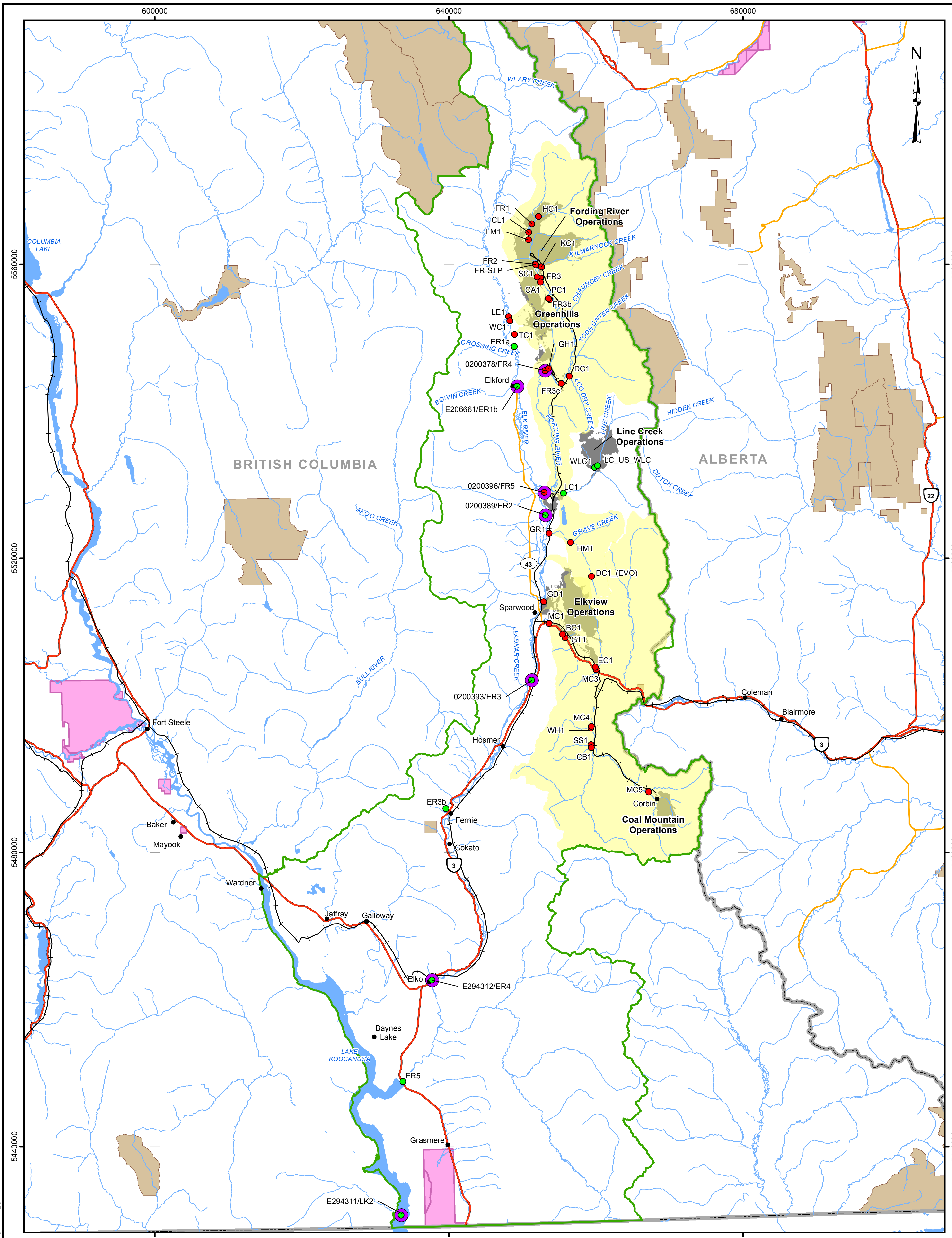
1.1 Background

Teck Coal Limited (Teck) operates five open-pit steelmaking coal mines in the Elk River watershed (also known as the Elk Valley) in southeastern British Columbia (Figure 1-1):

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

On 15 April 2013, Ministerial Order No. M113 (the Order) was issued by the BC Minister of the Environment. The Order requires Teck to develop an area-based management plan for the Elk Valley for the purpose of managing water quality concentrations of selenium, cadmium, nitrate and sulphate and the rate of calcite formation. Teck is referring to this area based management plan as the Elk Valley Water Quality Plan (the Plan). As part of the Plan, Teck must develop targets for water quality at specified locations in the Fording River, Elk River and Lake Koocanusa. The Order also requires Teck to develop a detailed implementation plan to demonstrate how water quality concentrations targets will be met at the specified locations.

To support the planning process, Teck developed the Elk Valley Water Quality Planning Model (the model). The model builds upon previous modelling tools developed to initially support the environmental assessment for the LCO Phase II project. The model was then expanded to cover Teck's other mine operations in the Elk Valley.



LEGEND

- CITY / TOWN / COMMUNITY
- FLOWS AT MODELLING NODE SIMULATED USING REPRESENTATIVE HYDROGRAPH METHOD
- MODELLING NODE
- ORDER STATION
- CANADIAN PACIFIC RAILWAY
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- WATERCOURSE
- BRITISH COLUMBIA - ALBERTA BORDER
- COAL MINING OPERATION
- DESIGNATED AREA
- FIRST NATIONS RESERVE
- PROVINCIAL PARK
- WATERBODY
- WATERSHED FLOWS SIMULATED USING REPRESENTATIVE HYDROGRAPH METHOD

15 0 15

SCALE 1:500,000 KILOMETRES

REFERENCE

Communities obtained from The Atlas of Canada, Natural Resources Canada. Roads obtained from Geobase. Parks/ protected areas, First Nations and railroad data obtained from Geogratis. Provincial boundary and hydrography data obtained from IHS Energy Inc. USA data obtained from ESRI. Projection: UTM Zone 11 Datum: NAD 83

PROJECT

TECK COAL ELK VALLEY WATER QUALITY PLAN

TITLE

DESIGNATED AREA, ORDER STATIONS AND MODELLING NODES

Teck

PROJECT No. 13-1349-0006			SCALE AS SHOWN	REV. 0
DESIGN	AC	27 Feb. 2013		
GIS	DR	27 Jun. 2014		
CHECK	JC	27 Jun. 2014		
REVIEW	AC	27 Jun. 2014		

FIGURE 1-1

I:\CLIENTS\TECK_COAL\13-1349-0006\Mapping\MXD\Hydrology\B-Hydrology-003-GIS-LocationMap.mxd

1.2 Purpose and Scope

This report describes the water quality modelling methods used in the development of the Elk Valley Water Quality Plan (the Plan). The model has been designed as a regional planning and assessment tool, which estimates concentrations of water quality constituents of interest at selected locations in the Elk Valley. It has been calibrated and refined using historical information as described in this report. It was used initially to evaluate how conditions may change now and in the future as a result of mining in the Elk Valley, and then to examine what different water management scenarios might achieve in the receiving environment.

This report outlines the water quality modelling methods used for the model, including how the model was setup and calibrated and results of the calibration. It is part of a series of technical reports that provide additional technical information on the development of the Plan, including:

- *Consolidation of Geochemical Source Term Inputs and Methods for Elk Valley Water Quality Modelling* (SRK 2014), which describes the geochemical inputs to the model
- *Site Conditions* (Teck 2014b), which describes site conditions at the Elk Valley mine operations, including historical operational data and future mine plans that were incorporated into the model
- *Hydrology* (Teck 2014c), which describes the hydrology inputs to the model
- *Water Quality Modelling for the Initial Implementation Plan* (Teck 2014d), which describes the selection of water quality management measures for the implementation plan, and the future water quality conditions predicted by the model.

An overview of the Plan is provided in the main report (Teck 2014a).

2 Model Overview and Approach

The model is a regional planning and assessment tool that has been developed based on the concepts outlined in Section 3. Its purpose is to estimate how water quality conditions in the Elk Valley could change as a result of mining and associated management activities.

At its core, the model is a water quality mass balance model that is supported by an empirical hydrology model and empirical geochemical source terms that have been derived from monitored data collected from the Elk Valley. Model outputs consist of simulated concentrations of substances including nitrate, selenium, cadmium and sulphate. The output is in the form of time series that can represent either historical or future conditions.

The model was developed using a commercially available, general-purpose simulation software platform called GoldSim (GoldSim Technology Group 2010). It was constructed using an empirical approach, which was selected as the most appropriate way of representing the current level of understanding of geochemical processes and conditions occurring within the waste-rock spoils and other mine features at a regional scale. This approach allowed for construction of a regional tool without the need for a great deal of detailed information on each watershed and the characteristics of waste-rock contained therein. Although a first-principles mechanistic model may be developed in the future, this is not required to support the development of the Plan.

Main inputs to the model include surface water flows, geochemical source terms and operational mine information (such as rate and placement of waste rock). Surface water flows were generated either using monitored data (where enough were available) or from empirical estimates, based on the application of representative hydrographs to ungauged watersheds or watersheds for which limited good-quality flow data were available. This process is discussed in more detail in Section 4.3.1.

Geochemical source terms (also referred to as release rates) were derived from observed water quality monitoring and flow data collected downstream of representative source materials, and considered in combination with known waste rock volumes and surface water flows (SRK 2014). Release rates are expressed as either a load per unit of waste-rock volume over time (e.g., $mg/m^3/year$) or, where the release is limited by solubility constraints, as a constant concentration applied to waters draining from the mine features in question. This is discussed in more detail in Section 4.3.2.

Model calibration and refinement involved simulating historical conditions and comparing outputs with observed monitoring data, and then adjusting the model as required to achieve a good fit to the observed data. This is discussed in more detail in Section 5.

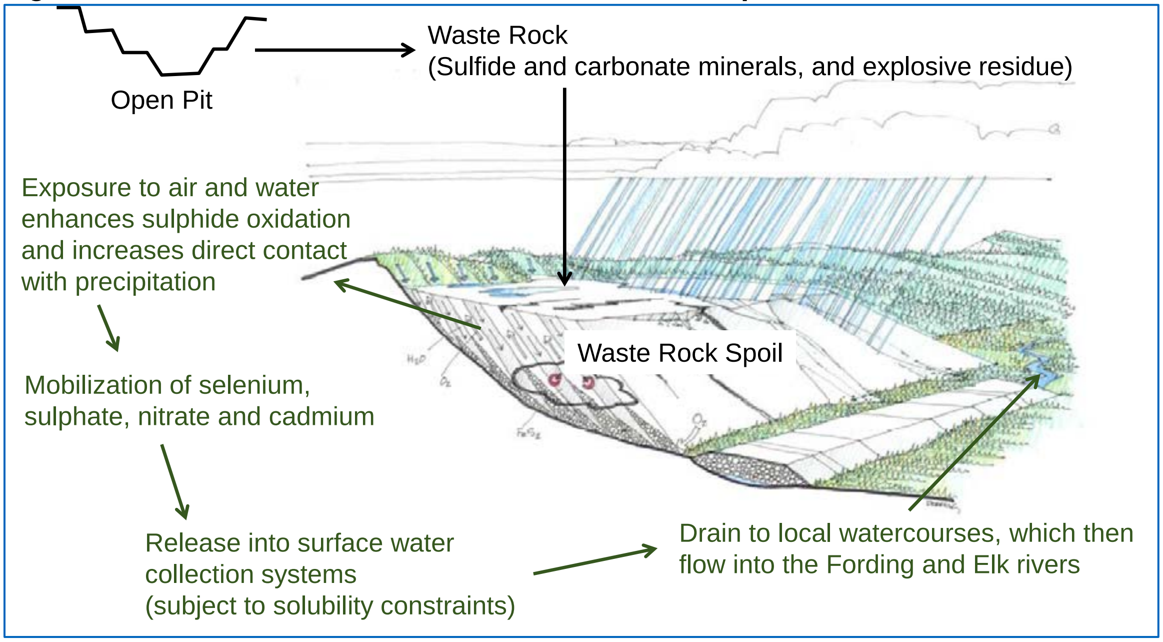
As previously noted, the model is designed to support the development of the Plan by describing how water quality conditions may change in the Elk Valley as a result of mining and associated management activities. It was not developed to predict, for example, daily concentrations of selenium, sulphate, nitrate or cadmium on an individual watershed scale. Its performance has been evaluated in terms of how well it simulates historical conditions in the Elk Valley, with a focus on the Order stations in the Fording and Elk rivers.

3 Conceptual Model

3.1 Release of Substances from Mine Operations

A conceptual model for the release of substances from mine operations is depicted in Figure 3-1 and described below.

Figure 3-1 Release of Substances from Mine Operations



Coal is present in the Elk Valley as layers or seams interlayered with sandstone, siltstone and mudstone. This rock contains sulphide and carbonate minerals that contain substances such as selenium, sulphate and cadmium. Atmospheric exposure of these minerals (primarily pyrite) through mining can enhance the release of these substances to the environment, through the processes described below:

- Accessing ore bodies requires blasting of surrounding non-ore-bearing rock. Blasting leaves nitrate-containing explosives residue on this surrounding rock and along pitwalls. Subsequent placement of the surrounding rock (commonly referred to as waste rock) in spoils facilitates the exposure and potential release of nitrate residues along with the rock's geological constituents.
- Oxidation of sulphide minerals (mainly pyrite) and other geochemical reactions are triggered when rock is exposed to the atmosphere, and to moisture along pitwalls and in waste-rock spoils. Pyrite oxidation, combined with the presence of buffers such as carbonate minerals, results in sulphate formation and the release of metallic, semi-metallic and non-metallic substances such as selenium. A detailed discussion of the geochemical process is provided in SRK 2014.
- Runoff water from rain and snowmelt mobilizes dissolved constituents of interest generated by the above-mentioned processes, at levels that depend on their solubility. Solubility is of limited importance for nitrate, but can be a limiting factor for selenium, cadmium and sulphate.

- As with waste rock, coal reject piles contain sulphide and carbonate minerals and can undergo the same oxidation processes. Since these piles comprise much smaller particles, oxygen penetration and oxidation are limited to the shallow surface layer. Nevertheless, some amount of sulphate, selenium and cadmium are also released from these piles and dissolve into runoff water.
- Runoff water generated from the above sources eventually discharges to local watercourses, which in turn drain into the Fording or Elk rivers.

As the above processes occur, the release and dissolution of the constituents of interest are assumed to continue until the source material is depleted.

3.2 Water Flow through Waste Rock

As waste-rock spoils are developed through end-dumping, segregation leads to coarser materials accumulating along the base of the spoils. These coarser materials form zones of relatively higher hydraulic conductivity, which readily transmit water through the base of the spoil. Due to the predominantly granular nature of waste rock, spoils are typically highly porous and hydraulically conductive. Consequently, little ponding, pooling or runoff is observed on their surfaces. (Atypically, ponding can be observed upstream of some spoils such as in the Kilmarnock Creek watershed at FRO.)

Following the geochemical processes described in Section 3.1, precipitation percolating through waste-rock spoils mobilizes dissolved constituents of interest including sulphate, selenium, nitrate and cadmium. The distribution of rocks within the spoils typically results in the creation of preferential flow paths, which are generally surrounded by layers of finer materials. Most of the water infiltrating the spoil uses these flow paths to reach the base of the spoil, where it mixes with the underflows. A smaller portion of runoff wets up, and is temporarily retained by the finer materials surrounding the flow paths. This water drains more slowly, reducing peaks in (or “damping”) the seasonal hydrograph.

Compared to a natural watershed, flows through waste-rock spoils are lower during the spring freshet and higher in the winter. In wetter years, more spoil material comes into contact with infiltrating water, flushing out more selenium, sulphate and other constituents of interest than in dryer years, although the amount of material released from each spoil is still subject to solubility constraints.

3.3 Water Quality Management

Water quality management can be applied at mine sites to treat or reduce the release of substances in water. As part of the development of the Plan, measures that can be implemented over the next 20 years were evaluated. In addition, research has been carried out, and will continue, on potential additional measures that may have longer-term application. Measures evaluated for the Plan included:

- active water treatment to remove dissolved substances in mine-affected water and reduce concentrations downstream of the treatment;
- diversion to divert clean (i.e., not mine-affected) surface water around waste-rock spoils and reduce the amount of mine-affected water;
- mine-affected water management to transfer water with relatively high concentrations to the water treatment plants; and
- waste-rock cover systems to reduce the infiltration of water through the waste-rock spoils.

Figure 3-2 conceptually shows an active water treatment plant with its associated clean-water diversion and mine-affected water management systems. Mine-affected water from one or more sources (e.g., waste-rock spoils) can be captured and directed as an intake to the active water treatment plant. A clean-water diversion system may be installed to capture surface water upstream and route it around the spoil, thereby reducing the volume of mine-affected water to be treated. When mine-affected water flows exceed capacity, the excess will bypass the treatment plant and discharge directly to the environment. Concentrations downstream of the treatment plant will be determined by the treated effluent volume and concentrations, relative to the volumes and concentrations of other flows.

Figure 3-2 Active Water Treatment with Clean-Water and Mine-Affected Water Management Systems

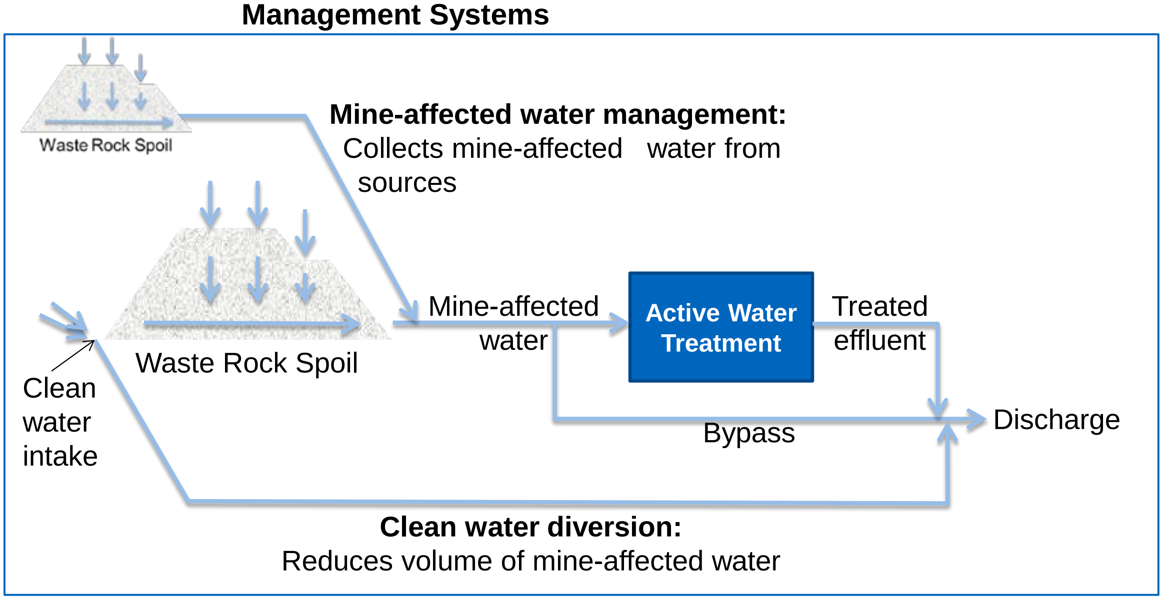
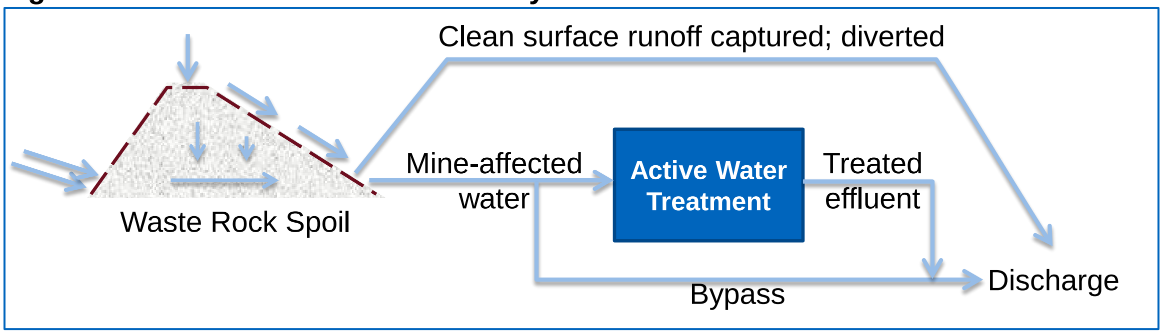


Figure 3-3 conceptually shows a cover system that could be installed during reclamation of a waste-rock spoil (when it is no longer active). A low-permeability cover layer reduces water infiltration through the spoil. More water is stored in the growth medium; this clean water is eventually lost through evapotranspiration, or released through surface runoff and interflow that can be captured and discharged. Since less water infiltrates the spoil, less material is dissolved and removed from it, reducing geochemical loading. If necessary, mine-affected water from reclaimed waste rock can be directed to active water treatment. Over the next 20 years, however, the availability of reclamation areas and the transition time to full performance may limit the suitability of cover systems.

Figure 3-3 Waste-Rock Cover System



4 Model Domain, Configuration and Inputs

This section describes the model domain (i.e., the geographical area covered by the model) and the basic configuration of the model in terms of the mass balance equation upon which it is based. It also includes an overview of the hydrologic, geochemical and operational inputs considered in the model. Model assumptions are identified where applicable, and are summarized in Section 6.1.

4.1 Model Domain

The model was configured to simulate selenium, nitrate, sulphate and cadmium concentrations at the Order stations in the Fording and Elk rivers and Lake Koocanusa. To help provide better spatial resolution of the influence of different management options, the model can also simulate conditions at additional locations (or nodes) in the Elk Valley (e.g., in the Fording River mainstem upstream of FR4 and in selected tributaries). Locations within tributaries, where flows are lower and typically more variable, do not have as much accuracy from a hydrological perspective as locations in the Fording and Elk rivers. Modelling nodes (locations) included in the domain are listed in Table 4-1.

Table 4-1 Modelling Nodes

Operation / General Location	Modelling Node ID	Node Description	Location [a]	
			Easting	Northing
Fording River Operations	HC1	Henretta Creek at the mouth	652219	5566469
	CC1	Clode Creek at the mouth	650871	5564287
	LM1	Lake Mountain Creek at the mouth	650858	5563301
	KC1	Kilmarnock Creek at the mouth	652612	5559619
	SC1	Swift Creek at the mouth	652027	5558254
	CA1	Cataract Creek at the mouth	652465	5557536
	PC1	Porter Creek at the mouth	653545	5555325
Greenhills Operations	GH1	Greenhills Creek at the mouth	653566	5545829
	LE1	Leask Creek at the mouth	648156	5552849
	WC1	Wolfram Creek at the mouth	648321	5552267
	TC1	Thompson Creek at the mouth	648938	5550421
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	660125	5532281
	WLC1	West Line Creek at the mouth	660004	5532209
	LC1	Line Creek at the mouth	655604	5528824
Elkview Operations	EC1	Erickson Creek at the mouth	659970	5504950
	GT1	Gate Creek at the mouth	655740	5509040
	BC1	Bodie Creek at the mouth	655750	5509360
	HM1	Harmer Creek at the mouth	656571	5522125
Coal Mountain Operations	MC5	Michel Creek downstream of Coal Mountain Operations	667186	5488211
	SS1	Snowslide Creek at the mouth	659348	5494653
	CB1	Carbon Creek at the mouth	659375	5494229
	WH1	Wheeler Creek at the mouth	659350	5496898
Fording River	FR1	Fording River downstream of Henretta Creek	651304	5565451
	FR2	Fording River downstream of Clode Creek	651781	5559984
Fording River	FR3	Fording River between Swift and Cataract creeks	652503	5558088
	FR3b	Fording River downstream of Porter Creek	653751	5555147
	FR4 (EMS 0200378)	**Fording River downstream of Greenhills Creek**	**653114**	**5545507**
	FR5 (EMS 0200028)	**Fording River at the mouth**	**652977**	**5528919**
Michel Creek	MC3 (EMS 0200203)	Michel Creek upstream of Elkview Operations	659950	5504890
	MC1	Michel Creek at the mouth	653590	5511060
Elk River	**ER1 (EMS E206661)**	**Elk River downstream of Greenhills Operations**	**649304**	**5543373**
	ER2 (EMS 0200389)	**Elk River downstream of Fording River**	**653250**	**5525670**
	ER3 (EMS 0200393)	**Elk River downstream of Michel Creek**	**651245**	**5503416**
	ER4 (EMS E294312)	**Elko Reservoir**	**637729**	**5492072**
	ER5	Elk River at the mouth	633583	5449048
Lake Koocanusa	**LK2 (EMS E294311)**	**Main Basin of Lake Koocanusa**	-	-

[a] NAD 83, Zone 11.

Note: Sites in bold font correspond to those listed in Ministerial Order M113.

4.2 Basic Configuration

The model is based on a simple mass balance equation, with concentrations at a given location calculated by adding up the incoming mass of a given substance and dividing by total flow. For a given location (or node) in the model, substance concentrations are predicted using the following equation:

$$c_x = \frac{\sum_{i=1}^{n} c_i q_i}{\sum_{i=1}^{n} q_i} \qquad (1)$$

where:

c_x	=	predicted concentration of substance '*x*' at a given location (mass per unit volume)
c_i	=	concentration of substance *'x'* in inflow *'i'* discharging to a given location (mass per unit volume)
q_i	=	flow rate of inflow *'i'* (volume per unit time)
n	=	number of inflows to the location in question.

Sources considered in the mass balance equation for simulations of historical conditions included waste rock, coal rejects, pitwalls and other mine-affected areas, tailings water discharges, and drainage from natural areas. Waste rock and coal rejects included the mass transported via surface flow and that travelling into the receiving environment through interflow or groundwater.

Sinks, such as mine-related active water treatment plants, were not considered when simulating historical conditions because there are no mine-related active water treatment plants in operation in the Elk Valley. They will be considered in the model when looking at future conditions.

The model excludes biological, physical and chemical decay of substances in surface water, along with adsorption, partitioning, or absorption of substances, consistent with the conceptual model. This results in conservative estimations of substance levels in the water column.

4.3 Model Input

The model uses surface flow data and geochemical source terms, combined with operational data on the placement of waste rock and other sources, to simulate effects on water quality downstream of mining operations. Its inputs are summarized below.

4.3.1 Surface Water Flow

Flows from waste rock, coal rejects, and undisturbed or non-mining affected areas were estimated using monitored data where data of sufficient quality were available, and a water balance flow model for other locations. The flow model was developed within GoldSim. The configuration and functioning of the flow model is briefly discussed below, with further details provided in Teck 2014c.

Monthly historical datasets at locations in the Elk River, the Fording River and local tributaries with mining disturbances were required to support the calibration of the model. The majority of the tributary watersheds in the Elk Valley are ungauged, or have limited monitoring data that are representative of total watershed flows. Good-quality regional flow data are available at active and discontinued Environment

Canada stations. The required flow datasets were, therefore, derived using a combination of methods, depending on location and availability and suitability of observed flow data.

Flows at locations of interest in the Elk River and the Line Creek watershed were derived from Environment Canada flow data. Transformations were applied to move the flow data from the station locations to represent flows at the node locations, as necessary.

Flows in the Fording River and Michel Creek watersheds, and in local tributaries with mining disturbance at FRO, GHO, CMO and EVO, were derived using the water balance flow model. The flow model used representative hydrographs to simulate flows from mining and natural (non-mining) areas. In this application, a representative hydrograph is a monthly time series (or annual hydrograph) of flow per unit area, derived from an analogue watershed with similar hydrological characteristics. Three analogue watersheds were defined: two for natural areas and one for mining areas.

Representative hydrographs derived from LCO Dry Creek were applied to natural areas (predominantly forested or vegetated land) draining to the Fording River, with the exceptions of Kilmarnock Creek at FRO and Line Creek at LCO, as discussed below. LCO Dry Creek is a tributary to the Fording River and its hydrograph, derived from the UBC Watershed model, is representative of the pattern of monthly flows in upper Elk Valley watersheds. Representative hydrographs derived from Hosmer Creek were applied to natural areas in the Michel Creek watershed and local tributaries at EVO. Hosmer Creek is a tributary of the Elk River between Sparwood and Fernie, and provides a better derivation of the pattern of monthly flows in these central Elk Valley watersheds than the LCO Dry Creek hydrograph.

A representative hydrograph from Cataract Creek was applied to all mining areas (i.e., those containing waste rock, coal rejects and other mine infrastructure). Cataract Creek is a small, predominantly mine-affected watershed on the western slope of the Fording River valley at FRO. Its hydrograph was selected because it had the best available observed flow data (i.e., most complete data set) for a predominantly mine-affected watershed in the Elk Valley.

Adjustments were applied to the representative hydrographs to account for broad differences between the analogue and target watersheds (e.g., change in mean annual flow with elevation and the timing of spring melt, consistent with conceptual understanding of regional flow patterns). Additional details on locations and characteristics of the analogue watersheds are reported in Teck 2014c. Flows at nodes in the Fording River and Michel Creek mainstems were derived as the sum of the incoming tributary flows.

A variety of ‘goodness-of-fit’ statistics, absolute error measures and other tools (e.g., scatterplots, flow duration curves and time series) were used to compare the simulated historical flows with observed flow data where sufficient observed data were available (e.g., Fording River at the mouth, Michel Creek below Natal, and Grave Creek at the mouth). Where limited flow data were available, goodness of fit was evaluated by visual comparisons of overall flow patterns, and seasonal timing and range of high flows. For example, at the mouth of the Fording River, simulated mean flow over the historical period (1995 to 2012) was 7% less than the observed mean flow at the Environment Canada station, and the statistics, annual hydrograph (i.e., mean monthly flows) and flow duration curves all showed good agreement.

In the Elk River, flows were derived based on monitored data. At locations for which no flow data were available, flows were transposed from the nearest upstream or downstream station as appropriate.

4.3.2 Geochemical Source Terms

Methods used to estimate releases from waste rock, pitwalls and other mine-affected areas, coal rejects, tailings water and natural areas are outlined below. These methods are consistent with the conceptual model discussed in Section 3.1.

4.3.2.1 Waste Rock

Release rates from waste rock were estimated (SRK 2014) using information collected from drainage systems associated with existing waste rock piles in the Elk Valley, and from field research plots at the LCO Phase I site. Data were compiled, reviewed, and assessed for trends including seasonal fluctuations. Conceptualization of sources and release mechanisms, combined with data interpretation, led to the division of constituents of interest into two groups according to whether release was predominantly loading-based or concentration-based. Nitrate, selenium and sulphate were characterized as mainly loading-based, as a result of their high mobility under the prevailing weathering conditions in the Elk Valley and their narrow range of release rates when normalized to waste rock volume. In contrast, leaching patterns for elements occurring as positively charged ions (including cadmium) suggested that solubility likely restricts the rate at which these substances are released from waste rock. This is consistent with the expected behaviour of these elements under pH-basic conditions. In light of these differing patterns, release rates for selenium, sulphate, nitrate and cadmium were defined using different methods as outlined below.

4.3.2.1.1 Selenium and Sulphate

Initial mass loadings of selenium and sulphate from waste rock were estimated using:

$$L = \alpha R V_R F_C \phi_1 \quad (2)$$

where:

L = mass loading for a given month (kg/d)

α = monthly loading distribution factor

R = annual release rate (kg/m^3/y)

V_R = cumulative volume of waste rock upstream of the location in question (m^3)

F_c = calibration factor

φ_1 = unit conversion factor of 0.00274 (y/d).

Annual release rates (R) and the monthly loading distribution (α) were set to the values shown in Tables 4-2 and 4-3. These were derived from monitoring as per the methods outlined in SRK 2014. Release rates for sulphate and selenium were assumed to be independent of the age of the waste rock (i.e., were held constant over time).

Waste rock volumes are summarized in the *Site Conditions* report (Teck 2014b). Calibration factors were derived by comparing simulated results to observed data. During calibration, some modifications to the monthly release distributions were completed on a watershed-specific basis to improve performance of the model (see Section 5 for details).

Table 4-2 Annual Release Rates from Waste Rock

Substance	Average Annual Release Rate	Reasonable, Worst-case Annual Release Rate	Solubility Limit
Selenium	1.6 mg/m^3/y	1.9 mg/m^3/y	1,500 µg/L
Sulphate	7.5 g/m^3/y	9.0 g/m^3/y	2,400 mg/L

Sources: Release rates and solubility limits defined by SRK 2014.

Table 4-3 Percentage of Total Annual Loading of Selenium and Sulphate by Each Month

Month	Selenium	Sulphate
January	5%	4%
February	5%	4%
March	5%	5%
April	7%	7%
May	13%	15%
June	16%	20%
July	12%	14%
August	8%	8%
September	7%	6%
October	7%	6%
November	7%	5%
December	7%	5%

Source: Monthly distribution defined by SRK 2014.

Annual selenium release rates vary with flow in the Elk Valley, as shown in Figure 4-1. As discussed in Section 3.2, more selenium, sulphate and other constituents of interest are flushed out of the waste-rock spoils in wetter years. The regression relationship is statistically the same as the equivalence line along which average normalized flow is equal to average normalized load. As such, selenium release rates in the Elk Valley were adjusted for flow using the following equation (SRK 2014):

$$R_i = R_{Ave}\left(\frac{Q_i}{Q_{Ave}}\right) \quad (3)$$

where:

R_i = release rate for year *'i'* (kg/m^3/y)

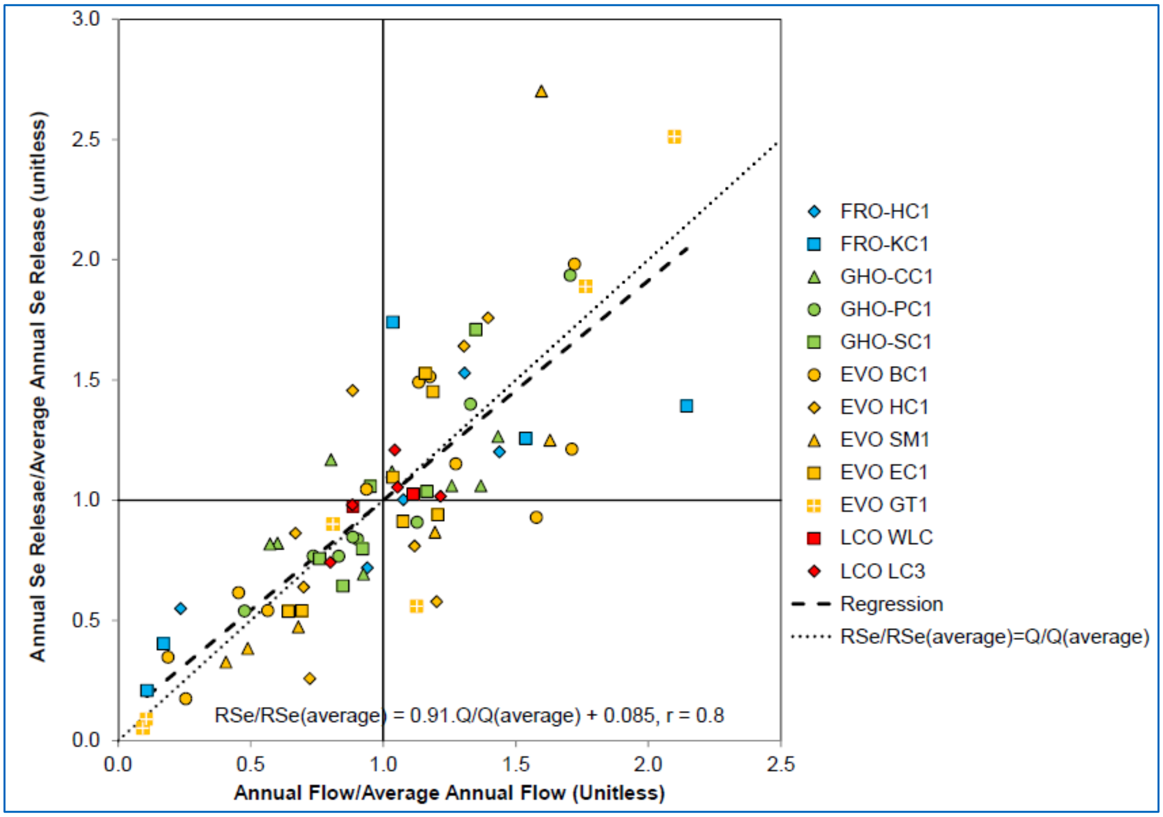
Q_i = average flow for year *'i'* (m^3/s)

Q_{Ave} = average annual flow over the period of record (m^3/s)

R_{Ave} = annual release rate (kg/m^3/y), as defined in Table 4-2.

Equation 3 was also applied to adjust sulphate release rates in the Elk Valley, based on the assumption that processes that apply to selenium should logically also apply to sulphate. This assumption is reasonable given that selenium and sulphate originate from the same bulk source material, are released through the same geochemical processes, and enter the receiving environment through the same physical mechanism (Section 3).

Figure 4-1 Selenium Release Rates from Waste Rock vs Annual Flow



Source: SRK 2014.

Once the adjusted release rate was determined and Equation 2 was solved, an initial estimate of the selenium and sulphate concentrations in water draining from the waste rock were calculated according to the following equation:

$$C = \frac{L}{Q}\varphi_2 \qquad (4)$$

where:

C = concentration in water draining from the waste rock (mg/L)

L = loading rate (kg/d)

Q = flow of water draining from the waste rock (m^3/s)

φ_2 = unit conversion factor of 0.01157 ($m^3 \cdot d \cdot mg/L/s/kg$).

Initial concentrations were compared to the geochemical solubility limit (Table 4-2), and concentrations were set equal to the solubility limit, if required, so that predicted concentrations of selenium and sulphate in waters draining from waste-rock structures did not exceed the solubility limit.

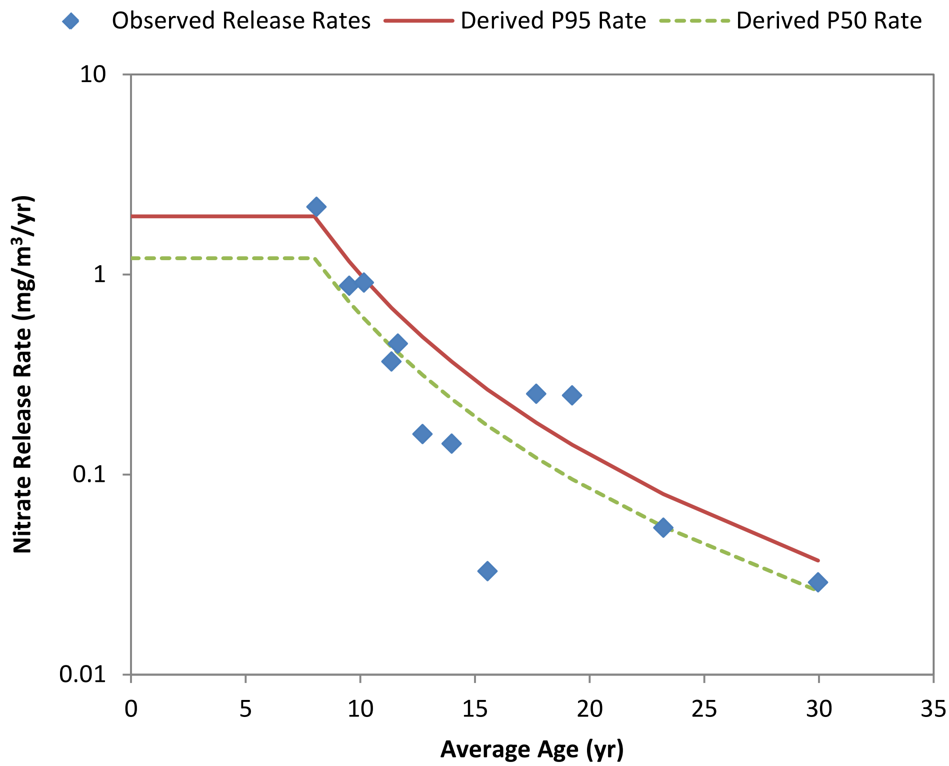
4.3.2.1.2 Nitrate

Explosives residue is the main source of nitrate released from waste rock. Varying blends of slurry (a mixture of ammonium nitrate liquids, emulsifier, water and fuel oil) and ANFO (a mixture of ammonium nitrate solids and fuel oil) have been used in the Elk Valley. Nitrate release rates from waste rock were modelled using an approach that considers the method in Ferguson and Leask 1988, and the age of the waste rock.

The Ferguson and Leask method was developed using data from coal mines in the Elk Valley. It estimates the mass of nitrate released from waste rock as a function of the ratio of slurry to ANFO used in a given year. The method assumes that all explosives residue is washed off the waste rock within one year.

Data from spoils that have been inactive for several years, such as at West Line Creek, show that nitrate is still released even when there is no active spoiling, although the rate decreases over time. This loading would not be captured by the Ferguson and Leask method. Therefore, an age-based release rate was derived from monitoring data, as described in SRK 2014, and used to estimate the nitrate release rate from inactive spoils; see Figure 4-2.

Figure 4-2 Waste-Rock Spoil Age vs Nitrate Release Rates



Source: SRK 2014.
P50 = average annual geochemical release rate; P95 = reasonable, worst-case annual geochemical release rate.

In the model, the Ferguson and Leask method is generally applied to active waste-rock spoils, whereas the age-based method is applied to spoils where there is no longer active dumping. There is an exception to this general rule: for years in which only small volumes of waste rock are deposited in a watershed with very large existing deposits, the Ferguson and Leask method can underestimate the total release rate, because it does not consider residual nitrate released from aging waste rock already in the watershed. To avoid this problem, nitrate release rates are calculated for each active spoil using both the Ferguson and Leask and age-based methods, and the higher resulting rate is carried forward.

The model also applies an adjustment to waste-rock age. This was applied because the age-based method has limitations. As shown on Figure 4-2, there are no data from waste-rock spoils less than eight years old. According to the relationship that is presented on Figure 4-2, newer spoils would produce nitrate concentrations in excess of anything previously observed in the valley. This suggests that for a young spoil, the method may produce unrealistically high nitrate loadings. Hence, waste rock with an average age less than eight years was assumed to have an age of eight years.

Incorporation of the Ferguson and Leask method and the age-based method in the model is discussed below.

Ferguson and Leask Method

To calculate nitrogen loading from waste-rock spoils using the Ferguson and Leask method, the first step was to calculate the mass of nitrogen contained in ANFO in each waste-rock spoil for any given year:

$$N_{ANFO} = V_i F_P \times f_{ANFO} \times C_{N,ANFO} \quad (5)$$

where:

N_{ANFO} = the total mass of nitrogen in ANFO used in a given year (kg)

V_i = volume of waste rock deposited in that same year (m^3)

F_P = the powder factor (the mass of explosives used per volume waste rock generated, kg/m^3)

f_{ANFO} = the fraction of the total explosives used in that year that were in the form of ANFO

$C_{N,ANFO}$ = the concentration of nitrogen in the ANFO (g N/g ANFO).

The mass of nitrogen contributed by explosives slurry at each location for any given year was then determined using the following equation (Ferguson and Leask 1988):

$$N_{Slurry} = V_i F_P \times (1 - f_{ANFO}) \times C_{N,ANFO} \quad (6)$$

where:

N_{Slurry} = the total mass of nitrogen in the explosives slurry used in a given year (kg)

$C_{N,Slurry}$ = nitrogen concentration in the explosives slurry (g N/g slurry).

Powder factors, fraction of ANFO, and nitrogen concentrations of both ANFO and the slurry used in Equations 5 and 6 are provided in Appendix A of the *Site Conditions* report (Teck 2014b).

Once N_{ANFO} and N_{Slurry} were determined, the mass of nitrate released from waste rock deposited in a given year was estimated according to the following equations (Ferguson and Leask 1988):

If % slurry is less than or equal to 1%

$$L_{NO3,A} = 0.002 N_{ANFO} \quad (7)$$

If % slurry is less than 20%

$$L_{NO3,A} = (0.001 N_{ANFO}) + (0.085 N_{Slurry)} \quad (8)$$

If % slurry is greater than or equal to 20%

$$L_{NO3,A} = (0.0094 N_{ANFO}) + (0.051 N_{Slurry}) \quad (9)$$

where:

$L_{NO3,A}$ = mass nitrate released in a given year (kg/y).

Finally, the mass of nitrate released from waste-rock spoils in a given year was converted to a monthly loading rate using the following equation:

$$L_{NO3} = \alpha L_{NO3,A} \varphi_1 \qquad (10)$$

where:

L_{NO3} = nitrate released rate for a given month (kg/d)

α = monthly loading distribution factor

φ_1 = unit conversion factor of 0.00274 (y/d).

The monthly loading distribution (α) were set to the values shown in Table 4-4. These were derived from monitoring as per the methods outlined in SRK 2014.

Table 4-4 Percentage of Total Annual Loading of Nitrate by Each Month

Month	Nitrate
January	5%
February	5%
March	6%
April	8%
May	15%
June	17%
July	11%
August	7%
September	6%
October	6%
November	6%
December	6%

Source: Monthly distribution defined by SRK 2014.

Age-Based Method

To calculate nitrogen loading from spoils using the age-based method, the nitrate release rate was estimated using the following time-dependent empirical equation:

$$R_{NO3} = 10^{(-A\log(A_{WR})+B)} \qquad (11)$$

where:

R_{NO3} = nitrate release rate (kg/m^3/y)

A_{WR} = average age of the waste rock (y).

A and B are constants that were defined based on monitored data to represent both average and reasonable, worst-case loading rates (Table 4-5).

Table 4-5 Constants Used to Calculate Nitrate Loading from Inactive Spoils

Constant	Average Value	Reasonable, Worst-case Value
A	2.9	3.0
B	2.7	3.0

Source: SRK 2014.

Nitrate loading from waste-rock spoils was then calculated using a similar method to that used for selenium and sulphate, via the following equation:

$$L_{NO3} = \alpha R_{NO3} V_R \, F_C \phi_1 \qquad (12)$$

where:

L_{NO3} = mass loading of nitrate for a given month (kg/d)

V_R = cumulative volume of waste rock located upstream of the stream location in question (m^3)

F_c = calibration factor.

Flow Relationship

The flow relationship for selenium and sulphate discussed in Section 4.3.2.1.1 (Equation 3) was applied to the nitrate release rate from spoils. The purpose of the flow relationship was to adjust the annual nitrate release rate so that more nitrate is released from waste rock in higher flow years.

4.3.2.1.3 Cadmium and Other Substances

As outlined in SRK 2014, concentrations of cadmium and other substances in waters draining from waste rock are controlled by solubility limits. Release of these substances was estimated using a constant concentration in the drainage water, calculated as follows:

$$L = C_{WR} \, Q(1/\varphi_2) \qquad (13)$$

where:

L = loading rate (kg/d)

C_{WR} = concentration in waters draining from waste rock (mg/L)

Q = flow through the waste rock (m^3/s)

φ_2 = unit conversion factor of 0.011574 (m^3·d·mg/L/s/kg).

Table 4-6 presents concentrations of cadmium and relevant substances in waters draining from waste-rock spoils.

Table 4-6 Cadmium and Other Substances in Waters Draining from Spoils

Parameter	Unit	Concentration	
		Average	Reasonable, Worst-case
Alkalinity	mg/L as $CaCO_3$	330	373
Cadmium	mg/L	0.0011[(a)]	0.0029[(a)]
Chloride	mg/L	2.1	8.6
Potassium	mg/L	2.6	6.5
Sodium	mg/L	8.4	15

[(a)] Concentrations were adjusted during model calibration, as outlined in Sections 5.2.4.3.
Source: SRK 2014.

Calcium and magnesium concentrations (mg/L) in waters draining from waste rock were calculated as follows to achieve an ion balance:

$$C_{Ca} = \left(\frac{40}{4.2}\right) \cdot \left(\frac{C_{Alkalinity}}{50} + \frac{2.C_{SO_4}}{96} + \frac{C_{NO_3}}{14} + \frac{C_{Na}}{23} - \frac{C_K}{39}\right)$$

$$C_{Mg} = 1.1 \cdot \left(\frac{24}{40}\right) \cdot C_{Ca} \qquad (14)$$

The magnesium calculation is based on a magnesium-to-calcium molar ratio of 1.1, which is the average ratio observed in waste rock drainage throughout the Elk Valley. Total dissolved solids concentrations (C_{TDS}, in mg/L) were estimated from the sum of all major ions, via:

$$C_{TDS} = C_{Ca} + C_{Mg} + C_K + C_{Na} + \left(\frac{C_{Alkalinity}}{50}\right) \cdot 61 + C_{SO_4} + C_{NO_3} + C_{Cl} \qquad (15)$$

4.3.2.2 Pitwalls and other Mine-affected Areas

The method used to calculate substance loading rates from exposed pitwalls and other mine-affected areas was the same as that outlined above for waste rock, whereby the area of exposed mine-affected area was converted to a volume of waste rock as follows:

$$V_R = A_W d \qquad (16)$$

where:

A_w = exposed area of the pitwalls and other mine-affected area (m^2)

d = an assumed reactive surface thickness (m).

The value of *d* was assumed to be 2 m, a typical overblast depth for mining (SRK 2014). All mine-affected areas that were not waste-rock spoils or coal rejects piles were included in this calculation. The size of these areas was estimated using surface topography, following the methods outlined in Teck 2014c. Once pitwall areas were converted to a volume of waste rock, release of material from the pitwalls was calculated as described above, with no changes to the monthly distribution, unit conversion or calibration factors identified in Section 3.1.1. In other words, once the pitwall areas were converted to an equivalent volume of waste rock (using Equation 16), they were considered simply as an additional waste rock volume that could be added to that contained in the waste-rock spoils within each watershed.

4.3.2.3 Coal Rejects

Weathering processes in coal rejects are similar to waste rock; however, oxygen penetration into coal rejects tends to be limited, based on gas measurements collected from the Greenhills Area A coal rejects pile (SRK 2014). As such, release rates developed for waste rock were not used for coal rejects. Instead, to obtain a conservative estimate, concentrations in waters flowing through coal rejects were estimated using maximum observed concentrations in drainage from the Greenhills Area A coal rejects pile. Loading from coal rejects was then calculated by multiplying the flow through the rejects by the observed concentration. Greenhills Area A coal rejects are considered an appropriate valley-wide analog, because their bulk mineralogy and chemical composition are comparable at all operations (SRK 2014). Estimated water quality from the coal reject piles are provided in Table 4-7.

Table 4-7 Concentrations in Waters Draining from Coal Rejects

Parameter	Units	Concentration
Alkalinity	Mg/L as $CaCO_3$	490
Cadmium	mg/L	<0.0003
Calcium	mg/L	340
Chloride	mg/L	32
Magnesium	mg/L	190
Nitrate	mg as N/L	<0.1
Potassium	mg/L	5.2
Selenium	mg/L	0.0087
Sodium	mg/L	9.8
Sulphate	mg/L	1,300

Source: SRK 2014.

4.3.2.4 Discharge from Tailings Storage

Since October 2005, EVO has been discharging tailings water from the West Fork tailings storage facility to Erickson Creek. At other operations where tailings water is generated, it has historically been stored onsite and continually recycled, with little or no active release to the environment. As a result, the West Fork tailings storage facility was the only source of tailings water included in the model.

The data available to describe tailings water quality at EVO is limited. It was assumed that tailings water chemistry is the same as that of water draining from coal rejects piles (Section 4.3.2.3). Loading from tailings water was then calculated by multiplying the tailings water flow by the estimated concentration (Table 4-7). This approach was used because mine tailings, like coal rejects, represent minor sources compared to the large volumes of waste rock generated by mine production (Section 5.3.5).

EVO discharges tailings water to Erickson Creek at rate of ~5,000 m^3/d (Gillespie 2012, personal communication). This flow was included in the model as a constant input, and is assumed to continue until active EVO operations cease in 2047.

4.3.2.5 Rehandling of Historical Waste Materials

Rehandling of historical waste materials is planned at FRO. The rehandled materials will include waste rock, hot waste rock, coal rejects and tailings. Rehandled waste rock and coal rejects will be deposited in the North (Turnbull) Spoil and rehandled waste rock, hot waste rock and tailings will be deposited in the combined Swift/Cataract watershed. The timing and volumes of the rehandled materials are summarized in Appendix A of the *Site Conditions* report (Teck 2014b).

Rehandling of historical waste materials is anticipated to result in an additional short-term release. In other words, the release of substances from the rehandled waste materials occurs only during the year following the rehandling of the material, and is in addition to the release that would occur if the materials were not rehandled.

Release rates from rehandled materials were estimated (SRK 2014) using information collected from leach tests. Substances were divided into two groups, based on whether the release would be expressed predominantly as loading-based or concentration-based. Cadmium, calcium, chloride, magnesium, nitrate, selenium, sodium and sulphate were identified as mainly loading-based, while alkalinity and potassium were identified as mainly concentration-based (i.e., solubility limits restrict the rate at which these parameters are released from rehandled materials). Methods used to estimate releases from rehandled waste materials are outlined below.

4.3.2.6 Loading-Based Parameters

Initial mass loadings of cadmium, calcium, chloride, magnesium, nitrate, selenium, sodium and sulphate from rehandled waste rock, hot waste rock, coal rejects and tailings were estimated using the following equation:

$$L_{Rh} = \alpha R_{Rh} V_R \, \phi_1 \qquad (17)$$

where:

L_{Rh} = mass loading for a given month from a given rehandled material (kg/d)

α = monthly loading distribution factor

R_{Rh} = short-term release rate from the rehandled material (kg/m^3)

V_R = volume of rehandled material deposited in the previous year upstream of the location in question (m^3)

ϕ_1 = unit conversion factor of 0.00274 (y/d).

Monthly loading distribution (α) and annual release rates (R_{Rh}) were set to the values shown in Tables 4-8 and 4-9. Annual release rates and monthly loading distributions were defined as in SRK 2014.

Loadings from the rehandled waste materials (Equation 17) were then added to the loadings from waste rock (Equation 2), and an initial estimate of the concentrations in water draining from the waste-rock spoil was calculated using Equation 3. Initial concentrations were compared to the geochemical solubility limit (Table 4-2), and loadings were reduced, if required, so that predicted concentrations in waters draining from the waste-rock spoil did not exceed the solubility limit.

4.3.2.6.1 Concentration-Based Parameters

As outlined in SRK 2014, concentrations of alkalinity and potassium in waters draining from rehandled materials are controlled by solubility limits. As a result, their release was estimated using a constant concentration in the drainage water. In watersheds containing rehandled materials, the concentration assigned to the drainage water was the maximum of the concentration assigned to the rehandled materials (Table 4-10) and waste rock (Table 4-6). Releases were calculated using Equation 13.

Table 4-8 Percentage of Annual Loading Released Each Month

Month	Selenium	Sulphate	Nitrate	Other Parameters
January	5%	4%	5%	4%
February	5%	4%	5%	4%
March	5%	5%	6%	5%
April	7%	7%	8%	7%
May	13%	15%	15%	15%
June	16%	20%	17%	20%
July	12%	14%	11%	14%
August	8%	8%	7%	8%
September	7%	6%	6%	6%
October	7%	6%	6%	6%
November	7%	5%	6%	5%
December	7%	5%	6%	5%

Source: Monthly distribution defined by SRK 2014.

Table 4-9 Annual Release Rates from Rehandled Waste Materials

Parameter	Units	Waste Rock		Hot Waste Rock		Coal Rejects		Tailings	
		P50	P95	P50	P95	P50	P95	P50	P95
Cadmium	mg/m^3	0.043	0.11	0.26	5.2	0.4	1.2	0.12	0.25
Calcium	mg/m^3	16,000	23,000	220,000	1,200,000	33,000	65,000	85,000	130,000
Chloride	mg/m^3	510	780	5,100	7,300	3,400	6,000	2,000	4,400
Magnesium	mg/m^3	6,300	8,500	100,000	400,000	11,000	26,000	34,000	83,000
Nitrate	mg/m^3	1,500	2,700	1,000	13,000	4,500	13,000	230	600
Selenium	mg/m^3	15	31	30	70	22	34	77	89
Sodium	mg/m^3	480	1,100	1,400	58,000	840	1,200	1,500	4,100
Sulphate	mg/m^3	26,000	52,000	710,000	4,400,000	56,000	96,000	180,000	510,000

Sources: Release rates defined by SRK 2014.

P50 = average, annual release rate; P95 = reasonable, worst-case annual release rate.

Table 4-10 Other Parameters in Drainage from Rehandled Waste

Parameter	Units	Waste Rock		Hot Waste Rock		Coal Rejects		Tailings	
		P50	P95	P50	P95	P50	P95	P50	P95
Alkalinity	mg $CaCO_3$/L	0.093	0.12	0.044	0.12	0.084	0.26	0.025	0.045
Potassium	mg/L	2.8	5.4	1.1	67	1.3	3.2	2.4	3.7

Sources: Concentrations defined by SRK 2014.

P50 = average, annual release rate; P95 = reasonable, worst-case annual release rate.

4.3.2.7 Natural Areas

Surface flows within a given watershed area that are not affected by coal mine development were assigned a source term concentration, derived from the geometric mean of monitored data from undisturbed watersheds in the region (with the exception of sulphate in the Elk River, as discussed below). A geometric mean was used to generate these single average values, to avoid potential biases introduced by occasional high values that may be related to spring freshets. Upstream loadings were then determined by multiplying the flow by the source term concentration.

Data from the following watersheds were used to define upstream conditions in small undisturbed tributaries and in Michel Creek and the Fording River (Table 4-11):

- Grace Creek
- Ewin Creek
- LCO Dry Creek
- the Fording River upstream of FRO
- Line Creek upstream of LCO.

Data from the Elk River upstream of all mining activity were used to define upstream conditions in the river. Data collected from the Kootenay River were used to define background conditions in all tributaries to Lake Koocanusa with the exception of the Elk River.

To improve the accuracy of the model's sulphate predictions for the Elk River, average monthly concentrations from the observed data (Table 4-12) were used to define the upstream concentration.

Table 4-11 Substances in Drainage from Undisturbed Areas

Parameter	Units	Concentration[a] in Natural Runoff Flowing into the Fording River and Michel Creek	Concentration[a] in Background Waters Flowing into the Elk River	Concentration[a] in Background Waters Flowing into Lake Koocanusa
Alkalinity	mg $CaCO_3$/L	131	135	100
Cadmium	mg/L	0.000022	0.000014	0.000037
Calcium	mg/L	55	46	35
Chloride	mg/L	0.29	2.0	5.4
Hardness	mg $CaCO_3$/L	154	160	131
Magnesium	mg/L	12	11	10
Nitrate	mg as N/L	0.039	0.043	0.12
Potassium	mg/L	0.48	0.27	0.53
Selenium	mg/L	0.0010	0.00086	0.00011
Sodium	mg/L	2.2	2.0	5.6
Sulphate	mg/L	19	-[b]	35
Total dissolved solids	mg/L	157	154	147

(a) Values presented are geometric mean concentrations.

(b) Monthly sulphate concentrations as presented in Table 4-12 were used.

Source: Teck 2013 and Environment Canada 2013.

Table 4-12 Sulphate in Drainage from Undisturbed Areas to the Elk River

Month	Units	Concentration[a]
January	mg/L	22.4
February	mg/L	22.4
March	mg/L	22.8
April	mg/L	22.9
May	mg/L	17.6
June	mg/L	11.8
July	mg/L	12.4
August	mg/L	12.9
September	mg/L	15.4
October	mg/L	13.4
November	mg/L	19.5
December	mg/L	21.2

(a) Values presented are average concentrations.

Source: Teck 2013.

4.3.3 Operational Data

Operational input data for the simulation of historical conditions consists of historical volumes of waste rock, coal rejects and tailings placed in each watershed. Other operational information of interest includes mine water management plans and topographical information that can be used to define watershed boundaries and mine pit depths. For the simulation of future conditions, operational information used is based on existing mine plans of individual mine operations.

More detailed descriptions on the operational information used in the model are provided in the *Site Conditions* report (Teck 2014b).

4.4 Additional Features

The model incorporates additional features including the effects of open pits (flooded pits and influence on local groundwater flows), as well as water quality management measures evaluated as part of the Plan.

4.4.1 Open Pits

4.4.1.1 Flooded Pits Represented as Reservoirs

The following flooded pits were included in the model as reservoirs:

- the Eagle 6 and Swift pits at FRO
- the Cougar Pit at GHO
- the Burnt Ridge North 2 Pit at LCO
- the Natal Pit at EVO
- the Wheeler and Marten pits at CMO (the Coal Mountain Phase 2 project).

Information on these pits is provided in the *Site Conditions* report (Teck 2014b). Upon completion of mining, these pits will fill with water, and many will be backfilled or partially backfilled with waste rock. Although many of these pits may act as chemical-reducing zones, this is not being evaluated as part of the Plan process. Reducing zones remain a viable option for future water management.

Concentrations of substances within these flooded pits (or reservoirs) were calculated as a mass balance of incoming flows mixing with existing pit volumes, minus outflows. Upstream loadings to each pit were calculated as outlined in Section 4.3.2. As noted above, these pits are treated as fully mixed basins and commensurately, the “reservoir” elements within GoldSim are used to track mass of substances and water volume over time. Concentrations in flooded pits were calculated as mass divided by the volume, and the mass from each reservoir was calculated as concentration in the pit multiplied by its outflow rate.

No settling, degradation or chemical reduction was assumed to occur within the flooded pits; however, as new research is completed on the potential to incorporate pits that do become flooded, this information can be incorporated.

For smaller pits and Turnbull Pit, loading from upstream waste rock and coal rejects upstream of these systems, as well as from contributing pitwalls and backfilled (i.e., in-pit) waste rock, was routed directly to the receiving environment within the model. Turnbull Pit at FRO was not modelled using a reservoir element because it will be used as a tailings storage facility.

4.4.1.2 Changes to Deep Groundwater Flows

The Turnbull and Swift pits are anticipated to be mined below the elevation of the Fording River and, as such, are anticipated to become local groundwater sinks. As outlined in Teck 2014c, groundwater inflow into Turnbull Pit is predicted to peak at ~2,000 m^3/day in 2015, and to stabilize at ~1,600 m^3/day after 2035. Groundwater flows into Swift Pit are anticipated to peak at ~7,500 m^3/day in 2041, and to reach a stable long-term rate of ~3,800 m^3/day.

Loading associated with these groundwater inflows was estimated by assuming fully advective flow (i.e., multiplying the seepage flow by the concentration in the water from which the seepage originated). The estimated loadings do not consider any attenuation or decay along the groundwater pathway.

Groundwater inflows into other mine pits were not included in the model. According to the mine plans presented in the *Site Conditions* report (Teck 2014b), these pits are not scheduled to reach depths below the elevation of the Fording or Elk rivers; thus, it is unlikely that they will act as groundwater sinks that could appreciably affect surface flows. Groundwater seepage to the receiving environment is accounted for by assuming that all substances released from waste rock and other source materials travel into the environment via surface water flows, and are captured in the historical monitoring data used in the model calibration (Teck 2013).

4.4.2 Water Quality Management Measures

The following water quality management measures were included in the model:

- active water treatment;
- clean water diversions and water management; and
- waste-rock cover systems[1] (simply referred to as covers).

By including a projected approximation of the influence of these measures, the model can be used to evaluate the resulting changes in in-stream water quality at the Order stations.

[1] Assumed to be equivalent performance to bituminous geomembrane cover system.

These measures are described in more detail in Teck 2014d.

4.4.2.1 Active Water Treatment

Active water treatment plants were incorporated into the model by reducing concentrations of one or more constituents of interest, according to the conceptual model presented in Section 3.3 (Figure 3-2). Mine-affected water is captured and directed to the active water treatment plant. When flows exceed capacity, the excess is modelled as bypassing the treatment plant.

Active water treatment is a sink that removes mass and reduces the concentrations of one or more substances. Based on the best available science, biological treatment (e.g. fluidized bed reactors) and membrane treatment (e.g., reverse osmosis) were considered as active water treatment options within the Plan Document (Teck 2014a). Ranges of concentrations of selenium, sulphate and nitrate in treated effluent are shown in Table 4-13. For biological technologies, modelled concentrations were defined based on 2011 pilot testing results and performance of representative full-scale operations; for membrane technologies, they assume that the performance of membrane treatment to Elk Valley waters would be similar to performance that is generally observed for full-scale operations across the industry.

These effluent concentrations continue to be evaluated through Teck's 2013 pilot testing program, and the data will be updated when available.

Table 4-13 Selenium, Sulphate and Nitrate in Water Treatment Effluent

Substance	Modelled Effluent Concentration ($C_{ef,k}$)	
	Membrane technologies	Biological technologies
Selenium	5 µg/L	20 µg/L for $C_{in,Se}$ ≤ 500 µg/L 5% of $C_{in,Se}$ for $C_{in,Se}$ > 500 µg/L
Sulphate	100 mg/L	no removal
Nitrate	3 mg/L as N	0.1 mg/L as N

$C_{ef,k}$ = effluent concentration for substance *'k'*; $C_{in,Se}$ = intake concentration for selenium.

Loading from the active water treatment plants to the downstream environments was calculated by multiplying the effluent concentration by the flow through the active water treatment plant:

$$L_{\mathrm{ef},k} = C_{\mathrm{ef},k} Q_{\mathrm{ef}} \Phi \quad (18)$$

where

$L_{\mathrm{ef},k}$ = loading of substance *'k'* in the treated effluent from the active water treatment plant (kg/d)

$C_{\mathrm{ef},k}$ = concentration of substance *'k'* in the treated effluent (mg/L), from Table 6-4

Q_{ef} = flow through the water treatment plant (m^3/d)

Φ = unit conversion factor of 0.001 (L/m^3·mg).

When multiple intake sources were identified for an active water treatment plant, it was modelled to draw sequentially from the source with the highest selenium concentration to the source with the lowest, until either its treatment capacity was reached or all available sources were treated. This was done to reflect the fact that elevated selenium concentrations are the most pressing water-quality issue in the Elk Valley.

If the capacity was reached before all available intake sources were treated, excess water was bypassed and modelled as being released into local watercourses.

4.4.2.2 Clean-Water Diversions

The purpose of clean-water diversions is to route non mine-affected water around a spoil prior to discharge: that is, to keep clean water clean. Areas considered for potential clean-water diversions were incorporated as separate watersheds in the hydrology model (Teck 2014c), to allow flows from these watersheds to be routed in a manner consistent with the conceptual model described in Section 3.3. A user-defined collection efficiency accounts for leakage and losses from a clean-water diversion system, as discussed in Teck 2014d.

4.4.2.3 Management of Mine-Affected Water and Treated Effluent

Management of mine-affected water involves collecting mine contact water downstream of spoils and conveying it to an active water treatment plant. After accounting for site topography and safety considerations, water is captured close to the toe of the spoil, to avoid mixing with clean water downstream. Sources for capture of mine-affected water are defined as separate watersheds in the model (Teck 2014c), to allow flows and loadings to serve as inputs to active water treatment plants. Similar to clean-water diversions, a user-defined collection efficiency accounts for leakage and losses from mine-affected water management systems, as discussed in Teck 2014d.

Treated effluent from the active water treatment plant is modelled as an input to the modelling node immediately downstream of the plant discharge location.

4.4.2.4 Waste-Rock Covers

To evaluate the effects of different spoil reclamation techniques, the model was expanded to simulate the effect of existing reclamation practices on infiltration and surface runoff rates from completed spoils, as well as the effect of a waste-rock cover.

4.4.2.4.1 Existing Reclamation Practices

Existing reclamation typically involves re-sloping of waste-rock spoils, and secondary treatments such as site preparation and/or soil placement where feasible. Revegetation is carried out according to each operations' reclamation plan. Some progressive reclamation may be completed during the active life of a spoil. Reclamation of completed spoils using existing practices can have an effect on flows in local tributaries, due to the increased evapotranspiration that occurs with revegetation.

Recent studies suggest that increased evapotranspiration in relation to current reclamation practices could reduce infiltration by 30% over a 40 year period (Integral Ecology and O'Kane 2013). However, based on the uncertainty around this value, the potential for reduced infiltration as a result of current reclamation practices was not considered in the model. The absence of existing reclamation practices in the model results in minor changes to flows for the period being considered by the Plan, given the long period over which infiltration is reduced (i.e., 40 years).

4.4.2.4.2 Bituminous Geomembrane Covers

For selected waste-rock spoils, the Plan considers reclamation using a waste-rock cover that includes a bituminous geomembrane (BGM). The BGM cover has the following effects:

Reduced percolation through the spoil: The low-permeability BGM layer serves as a barrier that reduces the infiltration of water through the spoil.

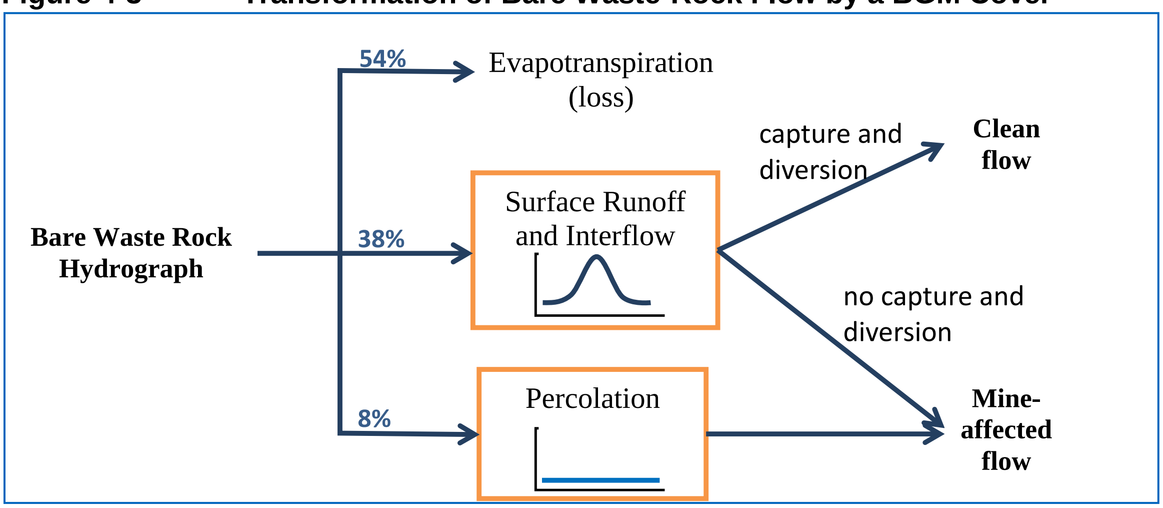
- Increased evapotranspiration and surface runoff: As infiltration is reduced, more water is stored in the growth medium and eventually lost through evapotranspiration, or released through surface runoff and interflow.

Compared to both bare waste rock and reclaimed waste rock using existing reclamation practices, the BGM cover has higher evapotranspiration and surface runoff (Integral Ecology and O'Kane 2013). With less water percolating through the spoil, the potential mass of material that can be dissolved and removed may be reduced. The model estimates selenium and sulphate concentrations in water draining from a spoil by dividing the available load by the flow of water draining from the waste rock. Initial concentrations are compared to the geochemical solubility limits, and concentrations are reduced, if required, so that this limit is not exceeded, as described in Section 4.3. The net effect can be less geochemical loading.

Estimated flow changes that result from installing BGM covers were applied to selected waste-rock areas (Teck 2014d). With BGM covers, bare waste rock hydrograph (i.e., the monthly flow from the base of the spoil before installation of any cover) is transformed into three components, as shown in Figure 4-3:

- Evapotranspiration: Water lost to the atmosphere through evapotranspiration was accounted for as a net loss of water from the model.
- Surface runoff and interflow: Clean water flow and interflow from the surface of the covered spoil was assumed to have the same monthly distribution as from bare waste rock.
- Percolation: Mine-affected flow from the base of the covered spoil was assumed to have a constant monthly rate.

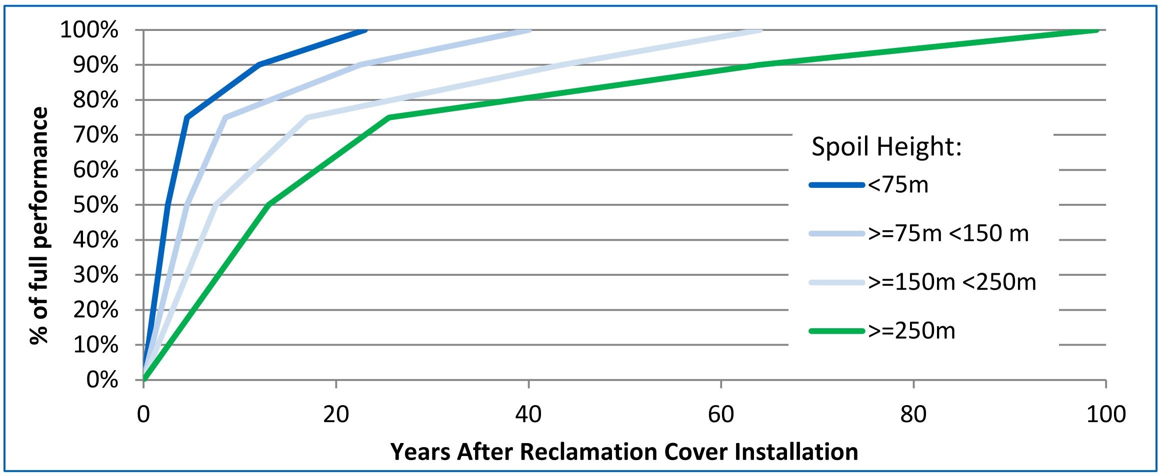
Figure 4-3 Transformation of Bare Waste-Rock Flow by a BGM Cover



Note: Percentages shown correspond to the distribution of the flow with the bituminous geomembrane cover at full performance.

A lag occurs between installation of the BGM cover and full performance, which is reached only when the spoil achieves a new equilibrium. This lag is estimated to range from 23 to 100 years, depending on the height of the spoil (Integral Ecology and O'Kane 2013), as shown in Figure 4-4. This evolution (i.e., gradual increase in effectiveness) is accounted for by applying a cover ratio ranging from zero to one. Cover ratios, shown in Table 4-14, correspond to the fraction of the bare waste-rock flow transformed to mature cover flow at full performance. Once the covered spoil is at equilibrium, the cover ratio is equal to one. At full performance, 54% of the transformed flow is lost through evapotranspiration, with 38% directed to surface runoff (and interflow) and 8% to percolation through the waste rock, as shown in Figure 4-3 (Integral Ecology and O'Kane 2013).

Figure 4-4 Performance during Evolution of a BGM Cover



Note: Performance curves are based on simulated data as outlined in O'Kane 2013.

Table 4-14 Cover Ratios during Evolution of a BGM Cover

Years After Cover Installation, based on a Spoil Height of:				Cover Ratio
<75 m	75 to <150 m	150 to <250 m	250 m	
0	0	0	0	0
2.5	4.5	7.5	13	0.54
4.5	8.5	17	25.5	0.81
12	22.5	43.5	64	0.97
23	40	64	99	1.0

Based on an examination of projected final mine topography, surface runoff and interflow component is considered as non-mine-affected and assigned background water quality, provided that it can reasonably be collected and discharged to the receiving environment without contacting waste rock or mixing with mine-affected flow.

It is assumed that the same mass of substances is present within bare and covered spoils. The smaller volume of water entering covered spoils means that concentrations may be higher and solubility limits may be reached more often, resulting in a reduction in the mass of material leaving the covered spoil.

The model does not consider other potential benefits of existing reclamation practices or BGM covers resulting from effects on the geochemical processes in the spoils.

4.4.2.4.3 Spoil Re-sloping

Some spoils in the Elk Valley develop at a natural angle of repose (approximately 37°). This angle is too steep for the purposes of supporting existing reclamation practices or the application of a BGM cover. Therefore, some spoils are re-sloped once they are no longer active to support application of a cover. Existing reclamation practices are supported by a 2H:1V (i.e., 26°) re-slope, whereas BGM covers would require a 3H:1V (i.e., 18°) re-slope.

The effect of re-sloping on watershed flows was estimated in the model as follows:

- bare waste rock flow (after re-slope) = (% increase in waste rock area) x (bare waste rock flow)
- natural flow (after re-slope) = (% decrease in natural area) x (natural flow)
- total watershed flow = bare waste rock flow + natural flow.

5 Model Calibration

5.1 Overview

Historical conditions were simulated to assess how accurately the model can replicate observed patterns in concentrations of selenium, sulphate, nitrate and cadmium in the Fording and Elk River mainstems, as well as in the mine-affected tributaries that drain into these rivers.

The model was calibrated and refined by comparing simulations of historical conditions with available data at selected locations (calibration nodes) within the Elk Valley. The model was initially calibrated to reflect conditions from 2004 to 2010 and then refined with 2011 and 2012 data. Adjustments to release rates of selenium, sulphate and nitrate were made on a watershed-by-watershed basis, to replicate observed in-stream concentration patterns.

Following the initial calibration, the model performed well in reproducing 2011 and 2012 in-stream concentrations of most constituents of interest at Order stations; however, with the initial calibration, the model did not adequately reproduce the observed 2011 and 2012 trends at some tributaries to the Fording River and Michel Creek. Additional changes were therefore made to refine the calibration for these tributaries, including:

- methodological improvements, such as refinement of the flow relationships to reflect apparent differences among predominantly natural and mine-affected watersheds (Section 4.3.2.1.1)
- refinement to the site condition information, such as incorporating changes in water management practices
- refinements to reflect apparent watershed-specific behaviours, such as adjustments in monthly loading distributions
- refinements to the watershed-specific calibration factors.

The methods for the final calibration is provided in Section 5.2.

After final calibration, the model is able to match in-stream selenium and sulphate concentration trends observed in the Fording and Elk Rivers; however, its ability to accurately simulate historical concentrations of nitrate and cadmium is not as good as for selenium and sulphate, as it tends to over predict nitrate and cadmium to a greater extent. The results of the final calibration is provided in Section 5.3.

5.2 Methods

5.2.1 Calibration Nodes

Calibration nodes were selected to correspond to locations on watercourses with monitoring records and the potential to be affected by mining operations. They include locations on the Elk and Fording River mainstems, as well as at the mouths of incoming tributaries (Tables 5-1 and 5-2 and Figures 5-1 to 5-5). A calibration node was not placed in Elko Reservoir or Lake Koocanusa, because data from these areas are limited.

Table 5-1 Elk Valley Water Quality Plan Model Calibration Nodes

Operation / General Location	Node ID	Node Description	Location[a]	
			Easting	Northing
Fording River Operations	HC1	Henretta Creek at the mouth	652219	5566469
	CC1	Clode Creek at the mouth	650871	5564287
	LM1	Lake Mountain Creek at the mouth	650858	5563301
	KC1	Kilmarnock Creek at the mouth	652612	5559619
	SC1	Swift Creek at the mouth	652027	5558254
	CA1	Cataract Creek at the mouth	652465	5557536
	PC1	Porter Creek at the mouth	653545	5555325
Greenhills Operations	GH1	Greenhills Creek at the mouth	653566	5545829
	TC1	Thompson Creek at the mouth	648938	5550421
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	660125	5532281
	WLC1	West Line Creek at the mouth	660004	5532209
	LC1	Line Creek at the mouth	655604	5528824
Elkview Operations	EC1	Erickson Creek at the mouth	659970	5504950
	GT1	Gate Creek at the mouth	655740	5509040
	BC1)	Bodie Creek at the mouth	655750	5509360
	HM1	Harmer Creek at the mouth	656571	5522125
Coal Mountain Operations	MC5	Michel Creek downstream of Coal Mountain Operations	667186	5488211
Fording River	FR1	Fording River downstream of Henretta Creek	651304	5565451
	FR2	Fording River downstream of Clode Creek	651781	5559984
	FR3	Fording River between Swift and Cataract creeks	652503	5558088
	FR3b	Fording River downstream of Porter Creek	653751	5555147
	FR4 (EMS 0200378)	**Fording River downstream of Greenhills Creek**	**653114**	**5545507**
	FR5 (EMS 0200396)	**Fording River at the mouth**	**652977**	**5528919**
Michel Creek	MC3	Michel Creek upstream of EVO	659950	5504890
	MC1	Michel Creek at the mouth	653590	5511060
Elk River	**ER1 (EMS E206661)**	**Elk River downstream of GHO**	**649304**	**5543373**
	ER2 (EMS 0200389)	**Elk River downstream of Fording River**	**653250**	**5525670**
	ER3 (EMS 0200393)	**Elk River downstream of Michel Creek**	**651245**	**5503416**
	ER5	Elk River at the mouth	633583	5449048

[a] NAD 83, Zone 11.

Note: Sites in bold font correspond to those listed in Ministerial Order No. M113.

5.2.2 Calibration Period

With the exception of nitrate, the calibration was completed with a focus on 2004 to 2012. This period was selected, because measured data were available at virtually all calibration nodes over this period (Table 5-2). For nitrate, calibration was completed with a focus on 2006 to 2012, because during this period blasting information (i.e., the powder factor and % total explosive present as ANFO) was available to support the Ferguson and Leask method.

The calibration period covers a range of wet and dry years. Table 5-3 shows the occurrence of wet and dry years at the mouth of the Fording River, and on the Elk River at Fernie, as percentiles of observed monthly or annual flow for 1995 to 2013. For illustrative purpose, a water year (April through March) was considered dry (no shading) if its flow was below the 30^{th} percentile, and wet (dark shading) if its flow was above the 70^{th} percentile. The remaining, average flows are shown in light shading. Overall for 2004 to 2012, the water years of 2004, 2009, 2010 were dry years and 2005, 2011 and 2012 were wet years. The 2012 water year was the wettest year in the period of record.

Table 5-2 Observed Data Used in the Calibration of the Model

Operation / General Location	Node ID	Node Description	Monitoring Station	Selenium		Sulphate		Nitrate		Cadmium	
				Sample Count[a]	Date Range	Sample Count[a]	Date Range	Sample Count[a]	Date Range	Sample Count[a]	Date Range
Fording River Operations	HC1	Henretta Creek at the mouth	FR_HC1	156 (-)	2004 to 2012	142 (-)	2004 to 2012	126 (-)	2006 to 2012	91 (40)	2004 to 2012
	CC1	Clode Creek at the mouth	FR_CC1	152 (-)	2004 to 2012	137 (-)	2004 to 2012	125 (-)	2006 to 2012	92 (-)	2004 to 2012
	LM1	Lake Mountain Creek at the mouth	FR_NGD1	137 (-)	2004 to 2012	124 (-)	2004 to 2012	112 (-)	2006 to 2012	82 (27)	2004 to 2012
	KC1	Kilmarnock Creek at the mouth	FR_KC1; FR_KC1A	165 (-)	2004 to 2012	152 (-)	2004 to 2012	138 (-)	2006 to 2012	105 (1)	2004 to 2012
	SC1	Swift Creek at the mouth	FR_SC1; GH_SC1; GH_SC2	146 (-)	2004 to 2012	151 (-)	2004 to 2012	122 (-)	2006 to 2012	45 (-)	2004 to 2012
	CA1	Cataract Creek at the mouth	GH_CC1; GH_CC1A	147 (-)	2004 to 2012	146 (-)	2004 to 2012	123 (-)	2006 to 2012	45 (-)	2004 to 2012
	PC1	Porter Creek at the mouth	GH_PC1; GH_PC1A	142 (1)	2004 to 2012	145 (-)	2004 to 2012	122 (-)	2006 to 2012	45 (16)	2004 to 2012
Greenhills Operations	GH1	Greenhills Creek at the mouth	GH_GH1	140 (-)	2004 to 2012	144 (1)	2004 to 2012	121 (-)	2006 to 2012	46 (9)	2004 to 2012
	TC1	Thompson Creek at the mouth	GH_TC1, GH_TC2	192 (-)	2004 to 2012	210 (-)	2004 to 2012	179 (-)	2006 to 2012	74 (28)	2004 to 2012
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	LC_LCUSWLC	110 (-)	2004 to 2012	109 (-)	2004 to 2012	103 (1)	2006 to 2012	37 (-)	2004 to 2012
	WLC1	West Line Creek at the mouth	LC_WLC	152 (-)	2004 to 2012	133 (-)	2004 to 2012	130 (-)	2006 to 2012	89 (2)	2004 to 2012
	LC1	Line Creek at the mouth	LC_LC4	160 (-)	2004 to 2012	136 (-)	2004 to 2012	130 (-)	2006 to 2012	94 (4)	2004 to 2012
Elkview Operations	EC1	Erickson Creek at the mouth	EV_EC1	141 (-)	2004 to 2012	148 (-)	2004 to 2012	111 (-)	2006 to 2012	54 (21)	2004 to 2012
	GT1	Gate Creek at the mouth	EV_GT1; EV_GT1A	87 (-)	2004 to 2012	93 (-)	2004 to 2012	64 (-)	2006 to 2012	28 (9)	2004 to 2012
	BC1	Bodie Creek at the mouth	EV_BC1; EV_BC1A	165 (-)	2004 to 2012	174 (-)	2004 to 2012	131 (-)	2006 to 2012	56 (-)	2004 to 2012
	HM1	Harmer Creek at the mouth	EV_HC1; EV_HC1A	140 (-)	2004 to 2012	140 (-)	2004 to 2012	102 (-)	2006 to 2012	57 (16)	2004 to 2012
Coal Mountain Operations	MC5	Michel Creek downstream of Coal Mountain Operations	CM_MC2	148 (-)	2004 to 2012	136 (-)	2004 to 2012	135 (-)	2006 to 2012	78 (16)	2004 to 2012
Fording River	FR1	Fording River downstream of Henretta Creek	FR_FR1	70 (-)	2004 to 2012	71 (-)	2004 to 2012	95 (-)	2006 to 2012	67 (28)	2004 to 2012
	FR2	Fording River downstream of Clode Creek	FR_FR2	95 (-)	2004 to 2012	92 (-)	2004 to 2012	125 (1)	2006 to 2012	89 (16)	2004 to 2012
	FR3	Fording River between Swift and Cataract creeks	FR_FR; GH_FR	245 (2)	2004 to 2012	233 (-)	2004 to 2012	212 (-)	2006 to 2012	105 (22)	2004 to 2012
	FR3b	Fording River downstream of Porter Creek	GH_PC2	87 (1)	2009 to 2012	15 (-)	2009 to 2012	15 (-)	2009 to 2012	13 (-)	2009 to 2012
	FR4 (EMS 0200378)	**Fording River downstream of Greenhills Creek**	**GH_FR1**	**150 (2)**	**2004 to 2012**	**134 (-)**	**2004 to 2012**	**125 (-)**	**2006 to 2012**	**48 (15)**	**2004 to 2012**
	FR5 (EMS 0200396)	**Fording River at the mouth**	**LC_LC5**	**122 (-)**	**2004 to 2012**	**126 (-)**	**2004 to 2012**	**121 (-)**	**2006 to 2012**	**58 (21)**	**2004 to 2012**
Michel Creek	MC3	Michel Creek upstream of EVO	EV_MC3	141 (1)	2004 to 2012	144 (-)	2004 to 2012	107 (2)	2006 to 2012	66 (16)	2004 to 2012
	MC1	Michel Creek at the mouth	EV_MC1	149 (-)	2004 to 2012	151 (-)	2004 to 2012	109 (-)	2006 to 2012	66 (14)	2004 to 2012
Elk River	**ER1 (EMS E206661)**	**Elk River downstream of GHO**	**GH_ER1**	**154 (5)**	**2004 to 2012**	**137 (-)**	**2004 to 2012**	**128 (11)**	**2006 to 2012**	**54 (45)**	**2004 to 2012**
	ER2 (EMS 0200389)	**Elk River downstream of Fording River**	**EV_ER4; LC_ELKDS**	**145 (-)**	**2004 to 2012**	**145 (-)**	**2004 to 2012**	**111 (-)**	**2006 to 2012**	**69 (24)**	**2004 to 2012**
	ER3 (EMS 0200393)	**Elk River downstream of Michel Creek**	**EV_ER1**	**319 (8)**	**2004 to 2012**	**268 (7)**	**2004 to 2012**	**173 (2)**	**2006 to 2012**	**234 (24)**	**2004 to 2012**
	ER5	Elk River at the mouth	BC08NK0003	166 (-)	2004 to 2012	169 (-)	2004 to 2012	127 (-)	2006 to 2012	167 (-)	2004 to 2012

[a] Sample count = total sample number (number of non-detects).

Notes: Sites in bold font correspond to those listed in Ministerial Order No. 113.

Observed data from 2004 to 2012, based on information from Teck 2013 and Environment Canada stations: BC08NK0003\BC08NK0004 and BC08NG0009 (Environment Canada 2013).

Table 5-3 Wet and Dry Water Years in the Calibration Period

Location	Flow as a Percentile of the Distribution in the Period of Record (1994 to 2013)								
	2004	2005	2006	2007	2008	2009	2010	2011	2012
Fording River at the Mouth	18%	94%	59%	41%	35%	6%	29%	71%	100%
Elk River at Fernie	33%	72%	56%	50%	39%	6%	11%	67%	100%

Notes: A water year is from April to March. For illustrative purpose, each water year is categorized as follows: no shading = "dry" (flow below the 30th percentile); light shading = "average" (flow between the 30th and 70th percentile); and dark shading = "wet" (flow above the 70th percentile).

5.2.3 Calibration Processes

One calibration process was applied to selenium, sulphate and nitrate. The objective of this process was to match seasonal and annual patterns in the observed data. Where there was scatter in the measured data compared to the modelled results, a level of conservatism was maintained in the model (i.e., on average, having the simulated concentrations exceed those measured in the field). This was done in an effort to avoid under-predicting concentrations when the model is applied to potential mitigation or management scenarios. Conservatism in model simulations will be considered when using results to make management decisions.

The second calibration process was applied to cadmium and other substances, including potential toxicity-modifying factors (i.e., hardness, alkalinity, dissolved organic carbon, TDS and individual major ions). For these parameters, historical concentrations were simulated using the average geochemical release rates described in Section 3.3. The objective of this second process was to check that simulated results generally corresponded to measured data and observed concentration ranges.

Each calibration process is discussed in more detail below.

5.2.3.1 Selenium, Sulphate and Nitrate

Calibration of selenium, sulphate and nitrate involved adjusting the geochemical release rates described in Section 3.3 for waste rock on a watershed-by-watershed basis, using a three-step process. First, the model was configured with known waste-rock volumes, pitwall areas and simulated flow data. Waste-rock volumes and pitwall areas used for model calibration are summarized in the *Site Conditions* report (Teck 2014b). Simulated flow data were generated using the EVWQP hydrology model, as discussed in the *Hydrology Report* (Teck 2014c). The release rates from waste rock in all mine areas were set to the Elk Valley average values derived by SRK 2014, and outlined in Table 4-2.

Second, the model was run, and its performance was evaluated through a visual comparison of simulated and measured data, along with examination of error and bias. This comparison involved determining if simulated results replicated the range of measured concentrations, and matched the seasonal and yearly trends in the measured data.

Error was calculated as the average absolute difference observed between individual simulated and measured data points over the entire calibration period, as per the following equation:

$$Error = \frac{\sum|C_{Mod} - C_{Obs}|}{n} \qquad (19)$$

where:

C_{Mod} = the modelled concentration

C_{Obs} = the observed concentration

n = the number of paired modelled and observed data points.

Error provides an indication of model accuracy, in terms of its ability to simulate a given concentration at a given time. Error was also expressed as a percentage, to allow comparisons between watercourses with widely differing in-stream concentrations. For example, error for Stream A may be 1 µg/L, and 10 µg/L for Stream B. This could suggest that the model is more accurate at simulating conditions in Stream A; but if average ambient concentrations in Streams A and B are 2 and 150 µg/L, respectively, then the model is actually more accurate in Stream B, because the percent error for Stream B is 7% (i.e., 10/150) rather than 50%.

Model bias was calculated as the average difference between the individual simulated and measured data points over the entire calibration period, using the following equation:

$$Bias = \frac{\sum(C_{Mod} - C_{Obs})}{n} \qquad (20)$$

Bias provides an indication of whether simulated data tend to be higher or lower than measured data. As with error, bias is also expressed as relative bias, calculated using the following equation:

$$Relative\ Bias = \frac{Bias + \overline{C_{Obs}}}{\overline{C_{Obs}}} \qquad (21)$$

As with percent error, relative bias allows comparisons to be made among watercourses with widely differing ambient concentrations.

The model was run on an internal daily time-step, to maintain model stability and to allow for accurate tracking of mass transfer into and out of a reservoir. As discussed in Section 5.2.4.3, a storage reservoir was added to the Erickson Creek watershed to improve model performance. The addition of a reservoir necessitated a smaller time-step. Although the model uses a daily time-step, it is not designed to produce daily estimates of in-stream concentrations, as outlined in the following paragraph.

Model output consisted of a concentration estimate exported in the middle of every month. This approach was chosen because input flow rates were averages that did not change over the course of a given month. Similarly, waste-rock volumes, the main driver controlling the release of selenium, nitrate and sulphate to the receiving environment, were based on annual inputs that were linearly interpolated over the calendar year. As a result, although the model was run using a daily time-step, simulated concentrations changed very little within a given month, because of the format of the inputs used to drive the model.

In contrast, monitored data were collected by grab sampling, representing an instantaneous concentration at the time of sampling. To generate calibration statistics, simulated concentrations were compared directly to available grab sampling data, as there were few periods where multiple grab samples were collected in a single month. This method assumes that the grab samples were representative of average conditions over the entire month in which they were collected. If multiple samples were collected in a given month, then they were combined and used to calculate an average value that was compared to the modelled monthly average.

The final step in the calibration process consisted of applying calibration factors to the waste-rock release rates as per Equation 2, and adjusting them in an iterative fashion to reduce error while maintaining, where possible, a slight bias towards over-predicting in-stream concentrations. The outcome was a distinct calibration factor (F_c in Equation 2) for each watershed. Processes that are not captured in the model for the historical period and would result in variations in release rates among watersheds are discussed in SRK 2014, and include:

- measurement accuracy, such as under or over estimation of spoil volumes in catchment areas
- geochemical factors, such as the presence of saturated fills, partially saturated zones in ex-pit spoils, depletion of sources of reactive minerals and depletion of explosives residues
- hydrological factors, such as the tendency of surface water flows to go to ground in some watersheds (thereby underestimating total flow at surface monitoring stations).

5.2.3.2 Cadmium and Other Substances

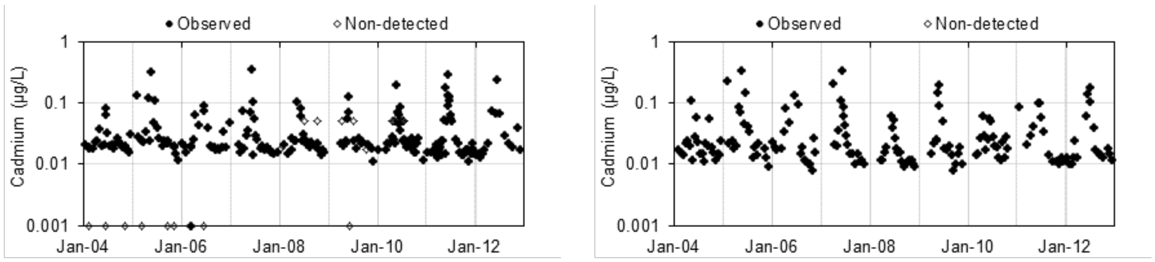
Unlike selenium, sulphate and nitrate, leaching patterns for cadmium suggest that solubility limits likely restrict the rate at which it is released from spoils. As a result, the cadmium release rate was defined as a constant concentration present in water draining from waste rock. SRK 2014 and Table 4-6 provide two values for the cadmium release rate: an average value derived from a consolidated database of water chemistry for all operations in the Elk Valley, and an upper-bound estimate on this average concentration. Model calibration proceeded using the average release rate outlined in Table 4-6. Simulated and measured data were compared visually to see if the model over- or under-predicted measured data over the calibration period. Appropriate adjustments were then made to improve the calibration.

Although some improvements could be achieved by adjusting the average release rate, the model could not reproduce observed seasonal patterns nor fully capture the observed concentration range in all seasons. In attempts to address the latter limitation, the simulation of historical conditions was repeated using the upper-bound estimate (also referred to herein as the reasonable, worst-case release rate), with adjustments made to capture the observed concentration range as required.

This approach was adopted because in the Fording River, the amount of measured data available from 2004 to 2012 are limited, and more than half of the available data are non-detectable values (Table 5-2). In addition, mining activity in the Elk Valley appears to have little effect on in-stream cadmium concentrations in the Elk River, as can be seen in Figure 5-1 by the lack of an increasing temporal trend in observed cadmium concentrations downstream of mining operations. Cadmium levels in the Elk River mainstem are more heavily influenced by background conditions. Given these facts, it was deemed ineffective to complete a more rigorous calibration to the available dataset and, consequently, calibration statistics were not calculated for cadmium.

Figure 5-1 Observed Cadmium Concentrations in Elk River, 2004-2012

Elk River downstream of Michel Creek (ER3; EMS 0200393) | Elk River at the mouth (ER5)



Calibration for hardness, alkalinity and other potential toxicity-modifying factors consisted of running the model with average release rates and visually comparing simulated and measured data. The purpose of this comparison was to evaluate if the model could replicate observed seasonal and longer-term patterns seen in the available monitoring data. Adjustments to the release rates were not instituted for these substances, nor were calibration statistics generated.

5.2.4 Watershed-specific Adjustments

Watershed-specific adjustments were made to improve selenium, sulphate and nitrate calibrations. These included adjustments in flow relationships, monthly release distributions, and other changes.

5.2.4.1 Flow Relationships

As discussed in Sections 4.3.2.1.1 and 4.3.2.1.2, a flow relationship (Equation 3) was applied to selenium, sulphate and nitrate. For each node, an analog location or hydrograph was selected to establish the flow information used in Equation 3. The average annual flow over the period of record (Q_{Ave} in Equation 3) was calculated using reference data from 1995 to 2010. The annual average flow for a given year (Q_i in Equation 3) was calculated using data from May to April at the same reference location.

The selection of the analog location or hydrograph differs from that for predominantly natural and predominantly mine-affected areas. For predominantly natural areas, one of three regional nodes was used as the analog location:

- Fording River downstream of Henretta Creek (FR1)
- Line Creek at the mouth (LC1)
- Michel Creek at the mouth (MC1).

These locations were selected as they are projected to have minimal changes over time due to mining activities. The analog location at each modelling node is presented in Table 5-4, and was selected based on proximity to the node in question.

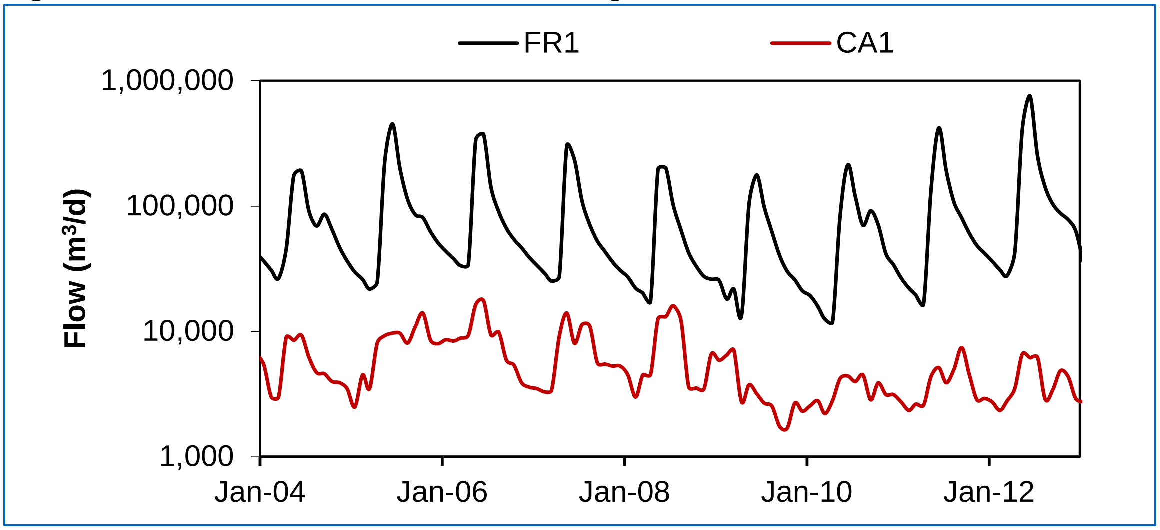
For predominantly mine-affected areas, namely Cataract, Porter and Swift creeks, flow relationships were based on the mining area representative hydrograph used to simulate flows from waste-rock spoils and other mine-affected areas (Teck 2014c), as shown in Table 5-5. These watersheds are dominated by spoils and other mine-affected areas, with little undisturbed areas remaining. As a result, flow variations at a regional node that is influenced by runoff from predominately natural areas are less relevant to these creeks in comparison to those in the mining-area hydrograph. This difference is illustrated in Figure 5-2. Flows in the Fording River downstream of Henretta Creek (FR1), which are heavily influenced by runoff from natural, non-mining areas, were higher in 2011 and 2012 (which were high flow years) than in previous years. In contrast, in Cataract Creek (CA1), a heavily mine-affected watershed, flows in 2011 and 2012 were similar to or lower than those observed in prior years.

Table 5-4 Location for Flow Relationship at Calibration Nodes

Site	Modelling Node ID	Modelling Node Description	Analog Location or Hydrograph for Flow Relationship
Fording River Operations	HC1	Henretta Creek at the mouth	FR1
	CC1	Clode Creek at the mouth	FR1
	LM1	Lake Mountain Creek at the mouth	FR1
	KC1	Kilmarnock Creek at the mouth	FR1
	SC1	Swift Creek at the mouth	mining area representative hydrograph[a]
	CA1	Cataract Creek at the mouth	mining area representative hydrograph[a]
	PC1	Porter Creek at the mouth	mining area representative hydrograph[a]
Greenhills Operations	GH1	Greenhills Creek at the mouth	FR1
	TC1	Thompson Creek at the mouth	FR1
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	LC1
	WLC1	West Line Creek at the mouth	none (no flow relationship applied)
Elkview Operations	HM1	Harmer Creek at the mouth	LC1
	EC1	Erickson Creek at the mouth	MC1
	GT1	Gate Creek at the mouth	MC1
	BC1	Bodie Creek at the mouth	MC1

[a] Based on recorded flows at Cataract Creek, see *Hydrology* report (Teck 2014c).

Figure 5-2 Simulated Flows in Fording River, 2004-2012



Note: FR1 = Fording River downstream of Henretta Creek; CA1 = Cataract Creek at the mouth.

As shown in Table 5-4, no flow relationship was applied to West Line Creek (WLC1). The flow relationship for this watershed was removed during calibration, because the simulated data were not consistent with the measured data. It is unclear what physical processes are responsible for the different behaviour of the West Line Creek watershed. This watershed is the subject of ongoing research, the results from which may help to explain the observed behaviour.

5.2.4.2 Monthly Release Distributions

As described in Section 4.3.2.1.1, average monthly release distributions for selenium, sulphate and nitrate in the Elk Valley were obtained from SRK 2014. During calibration, some watershed-specific adjustments were made to better reproduce observed seasonal patterns. These adjustments are summarized in Table 5-5, with possible physical basis and rationale for the changes.

Table 5-5 Summary of Watershed-specific Adjustments in Monthly Release Distributions to Improve Calibration

Site	Watershed	Parameters Adjusted	Description of the Adjustment	Rationale
FRO	Kilmarnock Creek	Selenium, sulphate and nitrate	Higher loadings during spring melt, with, corresponding lower loadings through the summer and fall	Adjusted pattern is consistent with the presence of a storage reservoir in the watershed. Given the consistent presence of ponded water upstream of portions of the Kilmarnock Spoil, it is likely that water is being retained within the spoil in a manner consistent with a storage reservoir.
	Swift Creek	Selenium, sulphate and nitrate	More even monthly release distribution over the year	Adjusted pattern suggests some level of detention of the drainage waters as they travel through the watershed. However, physical basis for the apparent detention is unknown.
GHO	Greenhills Creek	Selenium, sulphate and nitrate	Higher loadings in late summer, fall and winter, with corresponding lower loadings from spring to early summer	Physical processes unknown. Further study of water flow and substance transport in these watersheds could provide physical basis for the apparent behaviours.
	Cataract Creek	Sulphate	More even monthly release distribution over the year; applied to sulphate only	
LCO	West Line Creek	Selenium	More even monthly release distribution over the year; applied to selenium only	
All other tributaries of the Fording River		Sulphate	Lower loading in April, with corresponding slightly higher loadings in May and June; applied to sulphate only	

Final monthly release distributions for selenium, sulphate and nitrate are plotted in Figures 6-1 through 6-3. Discussions of watershed-specific changes to the monthly release distributions are provided below.

Kilmarnock, Swift and Greenhills Creeks

The monthly release distributions for selenium, sulphate and nitrate were modified to improve the model's ability to reproduce the seasonal patterns observed in Kilmarnock, Swift and Greenhills Creeks. Identical monthly distributions were applied to selenium, sulphate and nitrate. While selenium and sulphate are released from the waste rock through geochemical processes (i.e., pyrite oxidation) and nitrate is washed off from blasting residues, all substances are mobilized from waste rock and enter the watercourses using similar transport mechanisms. Therefore, the same watershed-specific monthly release distribution for Kilmarnock, Swift and Greenhills Creeks was applied to the three constituents.

In Kilmarnock Creek, monthly release distributions for selenium, sulphate and nitrate were modified such that greater loadings were released during spring melt, with a corresponding decrease in summer and fall. Compared to the unadjusted monthly release distributions (SRK 2014), the change results in an earlier peak in the monthly release distribution in May (Figures 5-3 through 5-5).

The shape of the updated monthly release distributions are consistent with those that would occur if a storage reservoir were present in the Kilmarnock Creek watershed. In mine-affected drainages in the Elk Valley, substance concentrations tend to be higher in fall and winter. As a result of this seasonal pattern, constituent concentrations in a storage reservoir would increase over the winter. During spring melt, flows to the storage reservoir would increase at lower concentrations. This would result in displacement of the higher-concentration water, producing higher loadings downstream in late April, May and early June. This pattern matches the updated monthly loading distribution in Kilmarnock Creek. Given the consistent presence of ponded water upstream of portions of the Kilmarnock spoil, it is likely that water is retained within the spoil in a manner consistent with a storage reservoir. As such, the adjustments to improve model performance are consistent with current understanding of physical conditions in the watershed.

In Swift Creek, monthly release distributions were modified to provide a more even distribution of the load over the course of the year, with a lower peak during the open-water period and higher loadings during fall and winter (Figures 5-3 through 5-5). The shape of the updated monthly release distributions likely reflects some level of detention and mixing of the drainage waters as they travel through the watershed, although site investigations are required to confirm this hypothesis.

In Greenhills Creek, monthly release distributions were modified to reflect lower loadings during spring freshet and higher loadings in the fall and winter, compared to the unadjusted monthly release distributions (Figures 5-3 through 5-5). At this time, it is unclear what physical processes may be responsible for this, and further study of water flow and substance transport through this watershed should be considered.

West Line Creek

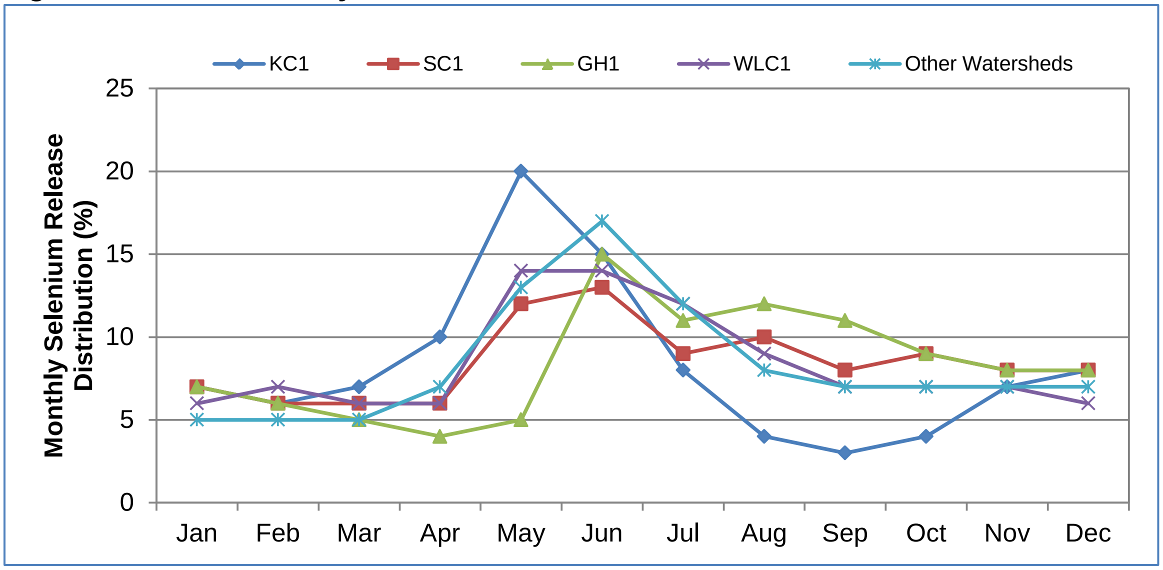
During calibration, it was noted that simulated results for selenium in West Line Creek did not produce the same seasonal pattern as the measured data. Therefore, the monthly release distribution for selenium was adjusted for West Line Creek (Figure 5-3). As with Swift Creek, the adjusted monthly distribution in the West Line Creek watershed provides a more even distribution of selenium load over the course of the year. Before the changes were implemented, simulated concentrations in April were much higher than those predicted to occur in January to March, which was not consistent with the measured data. When the changes were implemented, the simulated results for selenium better matched the measured data. It is unclear what processes are responsible for the different behaviour of the West Line Creek watershed. This is the subject of ongoing research.

Cataract Creek and other Fording River Tributaries

To improve the accuracy of simulated sulphate concentrations, watershed-specific adjustments were made to the monthly sulphate release distribution for all tributaries draining to the Fording River (Figure 5-4). Adjustments made to Kilmarnock, Swift and Greenhills Creeks are discussed above. These applied to sulphate as well as selenium and nitrate. For Cataract Creek, adjustments were applied to provide a more even monthly distribution of sulphate.

For all other tributaries of the Fording River, adjustments were made to reduce sulphate loadings in April, with a corresponding slight increase in May and June. Before these changes were implemented, simulated concentrations in April were much higher than those predicted to occur in January to March, which was not consistent with the measured data. When the changes were implemented, the simulated results better matched the measured data. It is unclear at this stage what physical processes may be responsible for this behaviour.

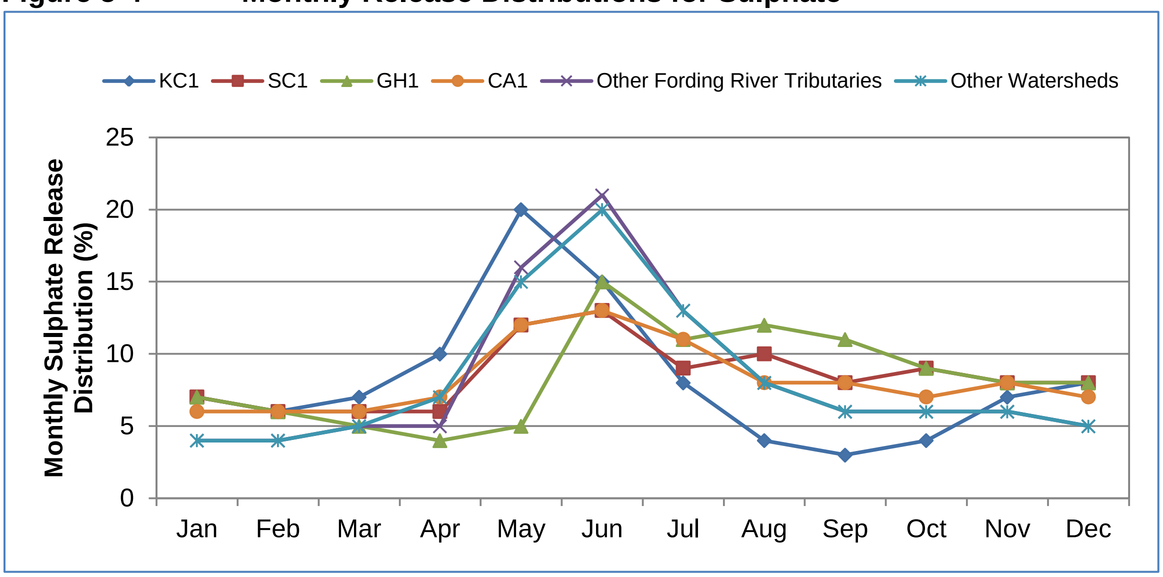
Figure 5-3 Monthly Release Distributions for Selenium



KC1 = Kilmarnock Creek; SC1 = Swift Creek; GH1 = Greenhills Creek; WLC1 = West Line Creek.

Source: SRK 2014.

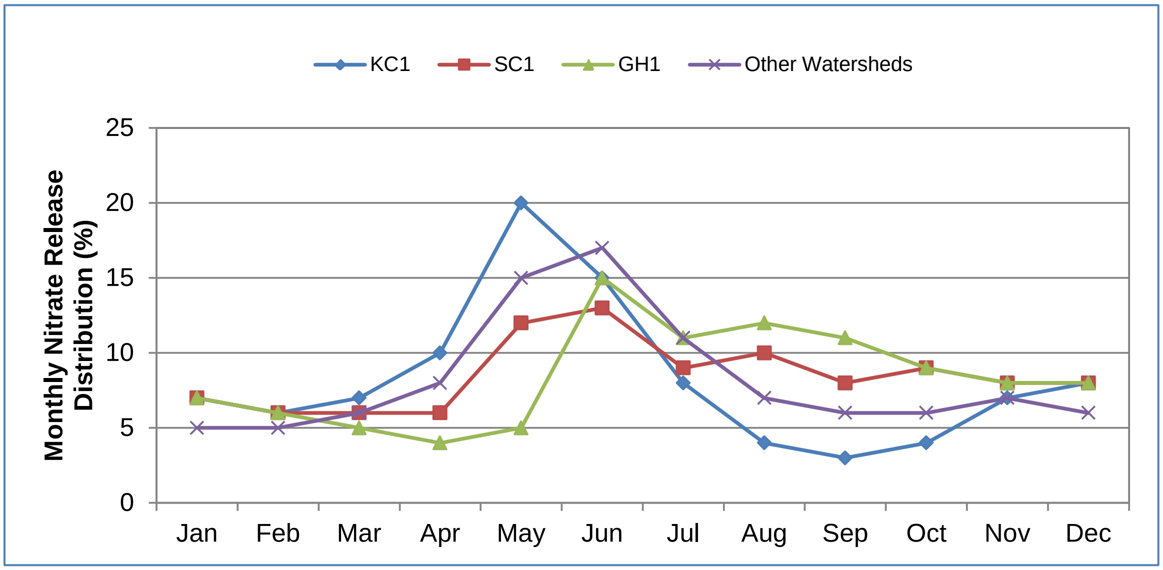
Figure 5-4 Monthly Release Distributions for Sulphate



KC1 = Kilmarnock Creek; SC1 = Swift Creek; GH1 = Greenhills Creek; WLC1 = West Line Creek; CA1 = Cataract Creek.

Source: SRK 2014.

Figure 5-5 Monthly Release Distributions for Nitrate



KC1 = Kilmarnock Creek; SC1 = Swift Creek; GH1 = Greenhills Creek.

Source: SRK 2014.

5.2.4.3 Other Watershed-specific Adjustments

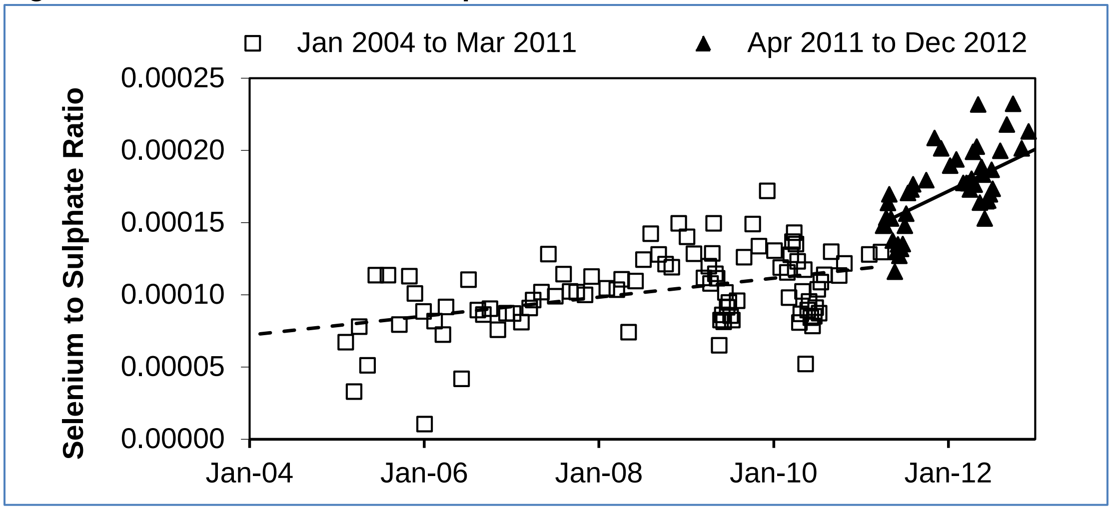
Additional watershed-specific adjustments were made during calibration to allow the model to better reproduce the observed patterns in monitoring data, as described below.

Changes in Release Rates at Henretta Creek

Before the changes, simulated selenium concentrations were less than measured data in Henretta Creek in 2011 and 2012, despite simulated concentrations matching reasonably well with measured data from 2004 to 2010 (Figure 5-7). In contrast, the model was able to reasonably replicate in-stream sulphate concentrations (Appendix A, Figure A-2). As shown in Figure 5-3, the trend in measured selenium to measured sulphate concentrations was generally flat from 2004 to 2010, but began increasing near the end of the first quarter of 2011, when the Henretta Phase II pit began to fill with water. It is unclear whether these events were related, but evident that the Henretta Creek watershed underwent some physical or geochemical process changes that resulted in more selenium than sulphate being released per unit of waste rock. To capture this change in the model, a different calibration was applied beginning in April 2011, equal to the calibration factor used for sulphate from 2004 to 2012.

As with selenium and sulphate, a different calibration factor was applied to Henretta Creek from 2011 onward, in an effort to reproduce the trend toward increased nitrate concentrations.

Figure 5-6 Selenium to Sulphate Ratio in Henretta Creek, 2004-2012



Storage Reservoir at Erickson Creek

At Erickson Creek, initial attempts to match the general trends in the measured data were unsuccessful, due to an absence of seasonality. Simulated peak concentrations were roughly an order of magnitude greater than the minima predicted concentrations, a pattern not seen in the measured data (Figure 5-7). To better approximate the observed seasonal pattern, a storage reservoir was added to the model. This mixed the seasonal inflows from Erickson Creek and dampen seasonality; the larger the storage reservoir, the less seasonal variation in results for all simulated substances.

By adding a storage reservoir with a six-month residence time, the results better approximated the narrower seasonal range in measured selenium concentrations (Figure 5-7). The use of a storage reservoir also improved sulphate calibration (Figure 5-8). The physical process that the storage reservoir likely represents is the attenuation of naturally occurring seasonal variation in the middle section of the tributary, where surface flow goes to ground, travels through the surficial gravels and re-surfaces near the mouth.

Figure 5-7 Simulated Selenium Concentrations in Erickson Creek, 2004-2012

a) Before Watershed-Specific Adjustments

b) After Watershed-Specific Adjustments

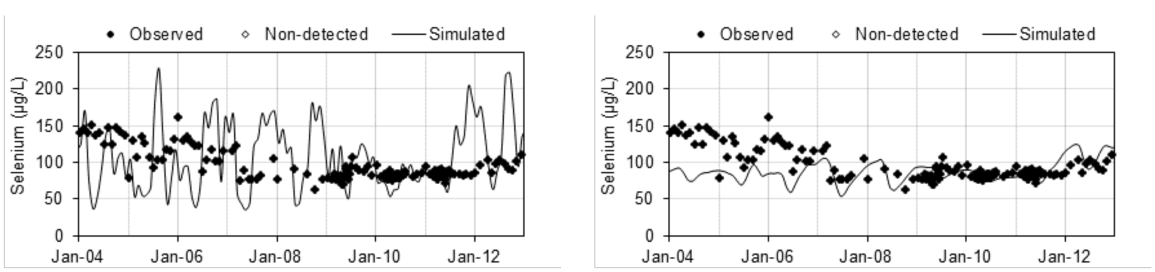
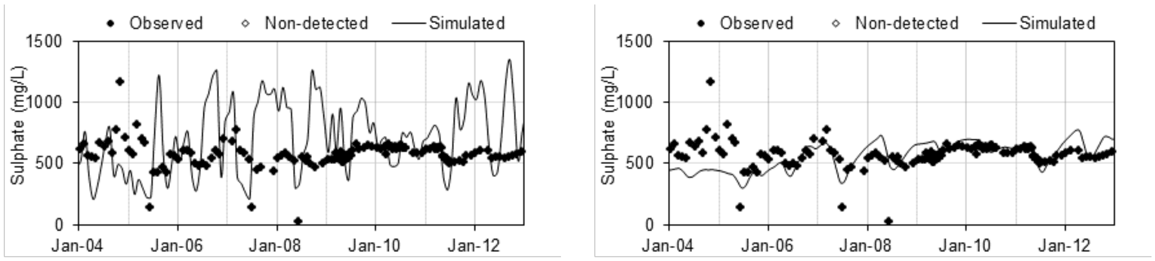


Figure 5-8 Simulated Sulphate Concentrations in Erickson Creek, 2004-2012

a) Before Watershed-Specific Adjustments b) After Watershed-Specific Adjustments



Nitrate Release at Erickson Creek

In Erickson Creek, a time-dependent empirical equation was used to calculate nitrate loading from inactive spoils throughout the entire period of record (2006-2012). The Ferguson and Leask method was not used, despite active spoiling in this watershed, because that method assumes that all explosives residue is washed off the waste rock within one year (i.e., active spoils release nitrate while non-active spoils do not). However, monitoring data indicates that wash-off from the Erickson spoil is slower than the Ferguson and Leask method would imply. The time-dependent empirical relationship provides a slower wash-off rate.

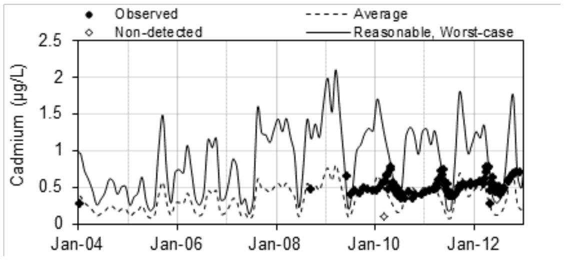
Cadmium Release Rates

In-stream cadmium concentrations using the average release rate did not match the measured data at most calibration nodes, and using the upper-bound estimate typically over-estimated the observed concentration range through most of the model domain (Figure 5-9). In an attempt to improve model performance, the average release rate was decreased from 1.1 to 0.55 µg/L, and the reasonable, worst-case rate from 2.9 to 1.5 µg/L, for all watersheds except West Line Creek. At West Line Creek, they were increased to 2.2 and 5.8 µg/L, respectively.

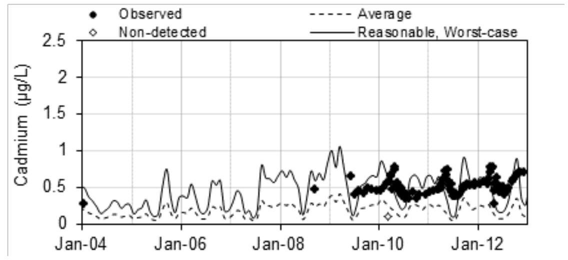
Figure 5-9 Simulated Cadmium Concentrations in the Elk Valley

Kilmarnock Creek at the Mouth (KC1)

(a) Before Adjustment of Release Rates

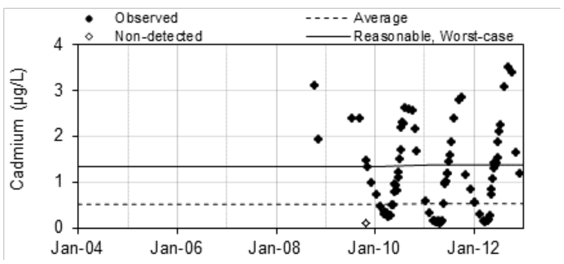


(b) After Adjustment of Release Rates

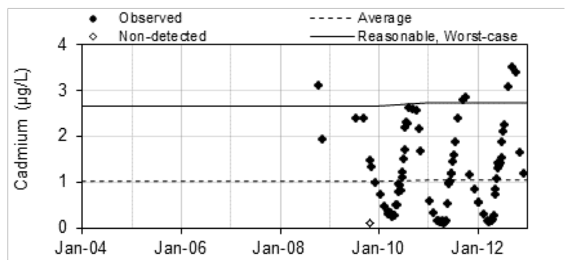


West Line Creek at the Mouth (WLC1)

(a) Before Adjustment of Release Rates



(b) After Adjustment of Release Rates



5.3 Results

This section presents results of the model calibration, including comparison between observed and simulated historical water quality conditions at the calibration nodes. Observed and simulated concentrations as well as the calibration factors and statistics for the tributaries and mainstems of the Fording and Elk rivers are presented for selenium, sulphate and nitrate. An overview of the calibration results for cadmium and other substances are also presented.

5.3.1 Selenium

5.3.1.1 In-Stream Trends in the Tributaries

Simulated results in the tributaries to the Fording and Elk rivers matched reasonably well with measured data, in terms of replicating the range of measured concentrations and matching seasonal, yearly and longer-term trends (see Figure 5-10 and additional plots included in Appendix A). In several tributaries including Greenhills and Michel Creeks, the simulated trends did not follow the observed trends as closely (Figure 5-11), possibly as a result of uncertainty in the simulated flows and/or the historical waste-rock volumes in the watersheds in question. However, these differences did not adversely affect the ability of the model to simulate measured concentrations in the Fording and Elk River mainstems (Section 5.3.1.2, Figure 5-12), which are the focus of the Plan.

Figure 5-10 Selenium Concentrations in Henretta and Line Creeks, 2004-2012

Henretta Creek at the mouth (HC1) Line Creek at the mouth (LC1)

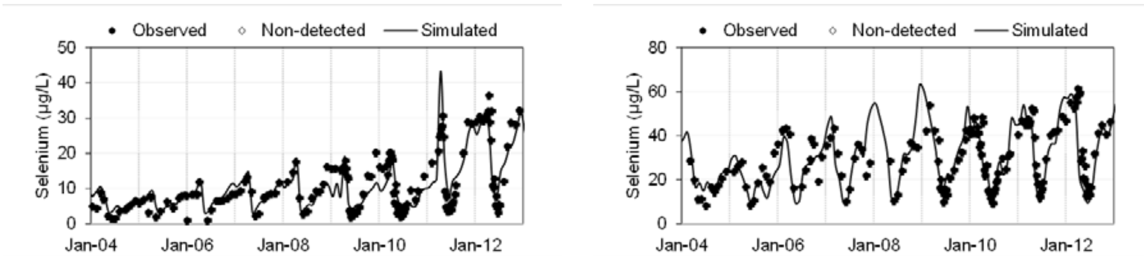
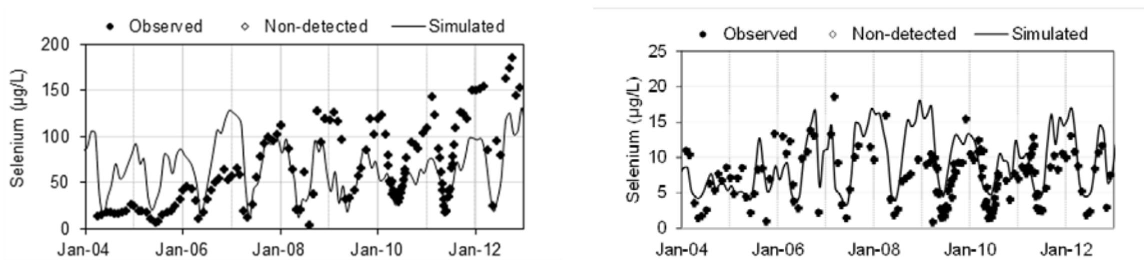


Figure 5-11 Selenium Concentrations in Greenhills and Michel Creeks, 2004-2012

Greenhills Creek at the mouth (GH1) Michel Creek at the mouth (MC1)



Selenium calibration factors applied to waste rock residing in the local tributaries are provided in Table 5-6. The bias and error statistics indicate that, while on average, simulated results reasonably matched measured concentrations (i.e., bias near 1); the errors were fairly large, ranging from 20% to 50%. The errors stem partially from the fact that the model outputs are analogous to a monthly average concentration, whereas the measured data were collected by grab sampling, which represents an instantaneous concentration at the time of collection. When multiple grab samples were collected in a single month, simulated concentrations were compared to the average grab sampling data collected for that period; however, months with multiple data points were rare.

Table 5-6 Calibration Factors for Selenium, 2004-2012

Operation / General Location	Node	Node Description	Calibration Factor
Fording River Operations	HC1	Henretta Creek at the mouth	0.50 & 1.15[(a)]
	CC1	Clode Creek at the mouth	0.82
	LM1	Lake Mountain Creek at the mouth	1.70
	KC1	Kilmarnock Creek at the mouth	0.60
	SC1	Swift Creek at the mouth	1.02
	CA1	Cataract Creek at the mouth	1.31
	PC1	Porter Creek at the mouth	0.65
Greenhills Operations	GH1	Greenhills Creek at the mouth	1.43
	LE1	Leask Creek at the mouth	0.81
	WC1	Wolfram Creek at the mouth	1.92
	TC1	Thompson Creek at the mouth	0.99
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	1.13
	WLC1	West Line Creek at the mouth	2.48
Elkview Operations	EC1	Erickson Creek at the mouth	1.90
	GT1	Gate Creek at the mouth	1.19
	BC1	Bodie Creek at the mouth	1.43
	HM1	Harmer Creek at the mouth	0.34
Coal Mountain Operations	MC5	Michel Creek downstream of CMO	0.11

(a) Two calibration factors were applied to the waste rock residing in Henretta Creek, as discussed in Section 5.2.4.3. The first factor was applied from January 2004 to March 31, 2011. The second factor was applied from April 1, 2011 onward.

Though simulated and measured data were compared and differences minimized by adjusting the geochemical release rate, time-dependent curve fitting was not completed to try to replicate measured data. The model is a planning tool, used primarily to assist with the development of a regional implementation plan. As a result, emphasis was placed on more closely replicating observed patterns in the Fording and Elk River mainstems than on matching observed patterns in individual tributaries. In addition, the model was not constructed to accurately predict daily concentrations in small watersheds, but rather to describe the general response of tributaries to mining and associated management activities. Therefore, more importance was placed on matching general trends in the tributary data than on individual data points.

As noted in Section 5.2.4.3, a storage reservoir was added to the model in Erickson Creek to better approximate the observed seasonal pattern. With the storage reservoir in place, simulated concentrations in Erickson Creek, on average, under-estimated measured concentrations with a relative bias of 0.86 and relative error of 23% (Table 5-7). This under-prediction in the simulated concentrations was primarily due to the period between 2004 and 2006, where the simulated results consistently under-predict the measured data (Figure 5-7). Measured selenium concentrations in Erickson Creek show a marked decline around 2006. This decline was not replicated by the model as cumulative waste rock volumes, and consequently selenium loading rates continue to increase. The decline in selenium may be linked to the discharge of tailings water to Erickson Creek, which began in October 2005; however, the relationship is not yet fully understood. It may reflect the submergence of some of the Erikson waste-rock spoil, and/or a consequential change in microbial conditions within the spoil, as hypothesized in AMEC 2012.

Table 5-7 Error and Bias Results for Selenium Calibration, 2004-2012

Operation	Node	Node Description	Bias [µg/L][(a)]	Relative Bias[(b)]	Error [µg/L][(c)]	Percent Error[(d)]
FRO	HC1	Henretta Creek at the mouth	0.09	1.01	2.8	26%
	CC1	Clode Creek at the mouth	5.3	1.1	20	39%
	LM1	Lake Mountain Creek at the mouth	-1.2	0.95	6.0	25%
	KC1	Kilmarnock Creek at the mouth	-5.2	0.91	29	48%
	SC1	Swift Creek at the mouth	-15	1.0	133	38%
	CA1	Cataract Creek at the mouth	33	1.1	114	31%
	PC1	Porter Creek at the mouth	9	1.1	25	37%
GHO	GH1	Greenhills Creek at the mouth	-3.1	0.95	34	50%
	TC1	Thompson Creek at the mouth	4	1.1	18	46%
LCO	LC_US_WLC	Line Creek upstream of West Line Creek	4.3	1.2	8.8	40%
	WLC1	West Line Creek at the mouth	39	1.1	94	23%
	LC1	Line Creek at the mouth	0.4	1.0	6.4	22%
EVO	EC1	Erickson Creek at the mouth	-14	0.86	23	23%
	GT1	Gate Creek at the mouth	6.17	1.1	46	41%
	BC1	Bodie Creek at the mouth	11	1.1	62	47%
	HM1	Harmer Creek at the mouth	4.6	1.2	12	47%
Fording River	FR1	Fording River downstream of Henretta Creek	0.89	1.1	2.7	31%
	FR2	Fording River downstream of Clode Creek	-0.23	0.99	4.2	20%
	FR3	Fording River between Swift and Cataract creeks	6.2	1.2	9.7	36%
	FR3b	Fording River downstream of Porter Creek	0.9	1.0	12.8	26%
	FR4 (EMS 0200378)	**Fording River downstream of Greenhills Creek**	5.6	1.2	9.1	38%
	FR5 (EMS 0200396)	**Fording River at the mouth**	4.2	1.2	7.2	32%
Michel Creek	MC5	Michel Creek downstream of Coal Mountain Operations	-0.72	0.79	1.2	34%
	MC3	Michel Creek upstream of EVO	-0.019	0.99	0.5	39%
	MC1	Michel Creek at the mouth	1.7	1.2	3.1	42%
Elk River	**ER1 (EMS E206661)**	**Elk River downstream of GHO**	0.26	1.2	0.43	38%
	ER2 (EMS 0200389)	**Elk River downstream of Fording River**	1.0	1.1	3.5	39%
	ER3 (EMS 0200393)	**Elk River downstream of Michel Creek**	1.4	1.2	2.0	31%
	ER5	Elk River at the mouth	0.92	1.2	1.12	30%

(a) The bias represents the average difference between simulated and observed concentrations. A positive bias indicates that modelled concentrations are greater, on average, than observed concentrations.

(b) A relative bias greater than one indicates that modelled concentrations are greater, on average, than observed concentrations.

(c) The error represents the average absolute difference between simulated and observed concentrations.

(d) The percent error represents the ratio of the error to the average observed concentration.

Note: Sites in bold font correspond to those listed in Ministerial Order No. M113.

As the mechanism responsible for the observed 2006 decline is not yet well-defined, it was not included in the model. Instead, effort was placed on adjusting the calibration factor so that simulated results for Erickson Creek matched the most recent measured data because, even for the period where concentrations were under-predicted in Erickson Creek, the simulated concentrations at the mouth of Michel Creek were consistently higher than the measured data (as indicated by relatively large bias and percent bias associated with this node; see Table 5-7). This pattern suggests that simulated total loadings from Erickson Creek to Michel Creek are reasonable, even if concentrations in Erickson Creek are under-predicted.

5.3.1.2 In-stream Trends in the Fording and Elk Rivers

Simulated results in the Fording and Elk Rivers matched reasonably well with the range of measured concentrations and seasonal, yearly and longer-term trends (Figure 5-12). In both the Fording River and Elk River mainstems, the model maintained a positive bias; simulated selenium concentrations in the Fording River were, on average, higher than the observed data, with relative bias ranging from 1.0 to 1.2 and error from 20% to 38%. In the Elk River, simulated selenium concentrations were, on average, higher than the observed data, with relative bias ranging from 1.1 to 1.2 and error from 30% to 39% (Section 5.3.2.1, Table 5-9).

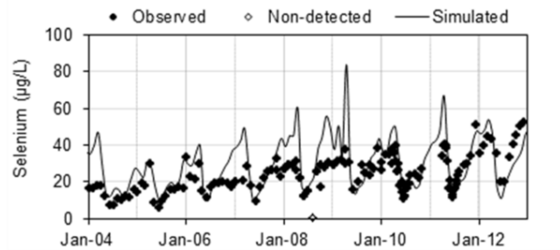
Monthly relative bias for locations in the Fording and Elk rivers are shown in Figure 5-13. Each data point on the figure represents the average relative bias, calculated using Equation 21, for the given month over the calibration period (e.g., every January from 2004 to 2012), while the bars represent the range of the monthly relative bias values for the given month. A relative bias value greater than 1 indicates that the simulated concentration is greater than the observed concentration.

As shown in Figure 5-13, over-estimation of in-stream selenium concentrations was most pronounced during winter, when water-quality mitigation measures tend to be the most effective at controlling in-stream concentrations (Teck 2014d). As a result, error and bias included in the calibrated model would not be expected to result in grossly over-designed management systems to reach a given target concentration in the Fording or Elk River mainstems. The effects of error and bias, as well as model uncertainties, must be considered in selection of the water quality management measures.

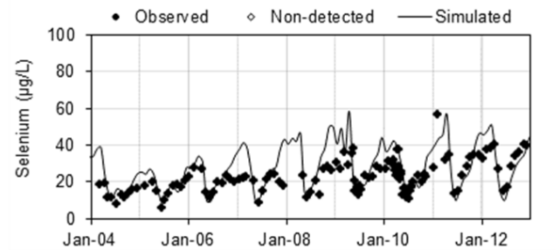
Bias correction was applied at Lake Koocanusa by correcting for the bias in the load at the mouth of Elk River (ER5), as discussed in the *Water Quality Modelling for the Initial Implementation Plan* (Teck 2014d). Bias correction at LK2 allows the model to more accurately reflect expected concentrations in the lake. Model bias is not corrected at other Order Stations.

Figure 5-12 Selenium Concentrations in the Fording and Elk Rivers, 2004-2012

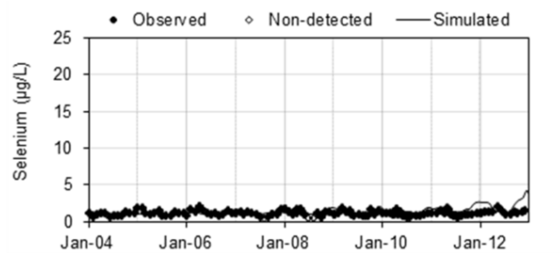
(a) Fording River downstream of Greenhills Creek (FR4; EMS 0200378)



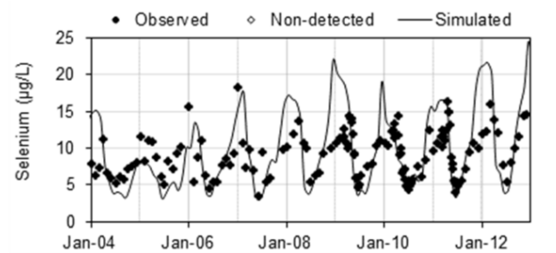
(b) Fording River at the Mouth (FR5; EMS 0200396)



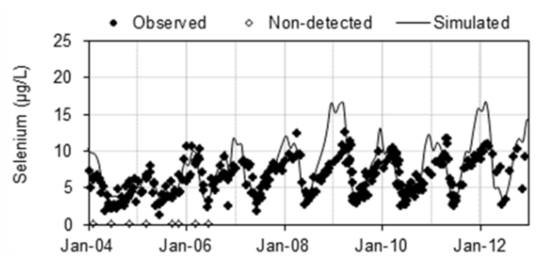
(c) Elk River downstream of Greenhills Operations (ER1; EMS E206661)



(d) Elk River downstream of Fording River (ER2; EMS 0200389)



(e) Elk River downstream of Michel Creek (ER3; EMS 0200393)



(f) Elk River at the Mouth (ER5)

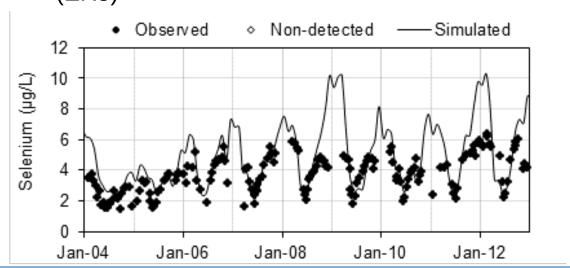
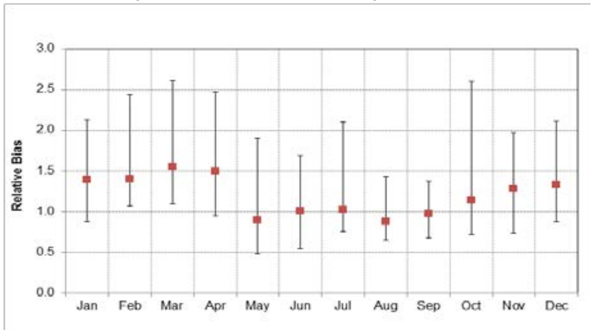
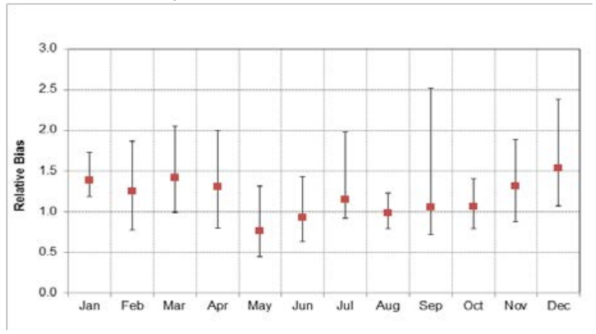


Figure 5-13 Monthly Selenium Bias in the Fording and Elk Rivers, 2004-2012

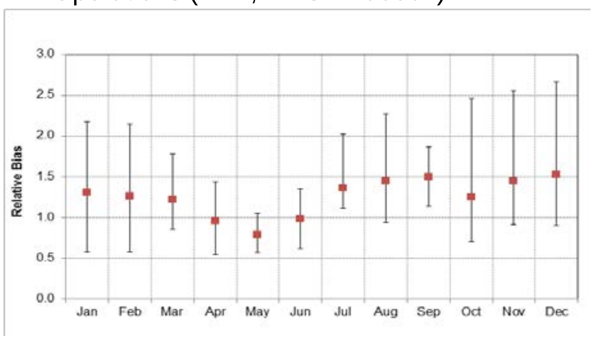
(a) Fording River downstream of Greenhills Creek (FR4; EMS 0200378)



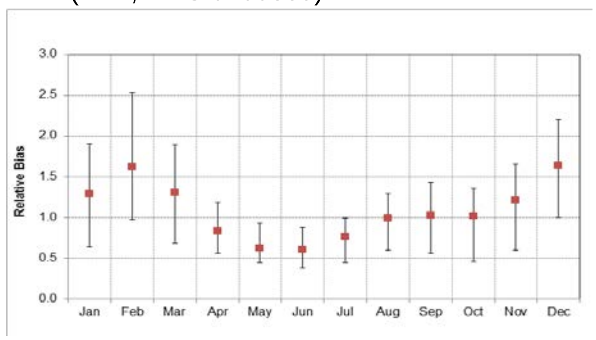
(b) Fording River at the Mouth (FR5; EMS 0200396)



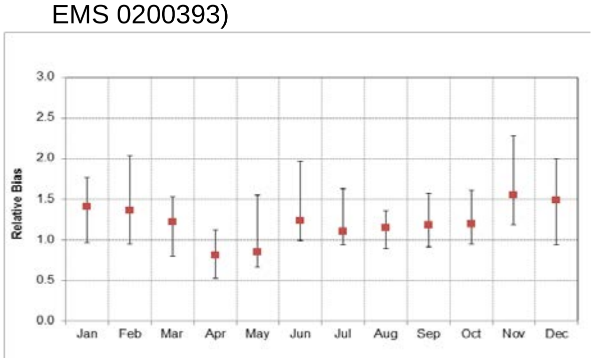
(c) Elk River downstream of Greenhills Operations (ER1; EMS E206661)



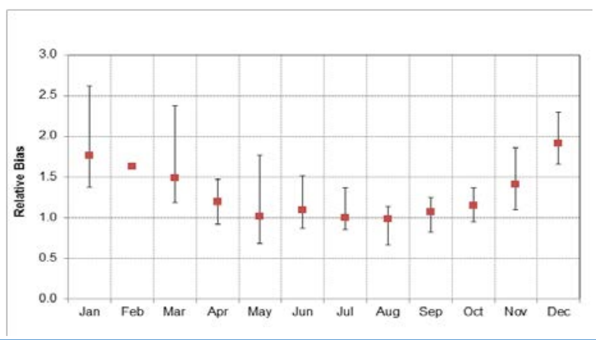
(d) Elk River downstream of Fording River (ER2; EMS 0200389)



(e) Elk River downstream of Michel Creek (ER3; EMS 0200393)



(f) Elk River at the Mouth (ER5)



5.3.2 Sulphate

5.3.2.1 In-stream Trends in the Tributaries

Simulated results in tributaries to the Fording and Elk Rivers, 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 (see Figure 5-14 and additional plots in Appendix A). In several tributaries, including in Swift and Michel Creeks, simulated trends did not follow the observed trends as closely (Figure 5-15), possibly as a result of uncertainty in the simulated flows and/or the historical waste-rock volumes in the watersheds in question. However, these differences did not detrimentally affect the ability of the model to accurately simulate measured concentrations in the Fording and Elk River mainstems, which are the focus of the Plan.

Figure 5-14 Sulphate Concentrations in Kilmarnock and Line Creeks, 2004-2012

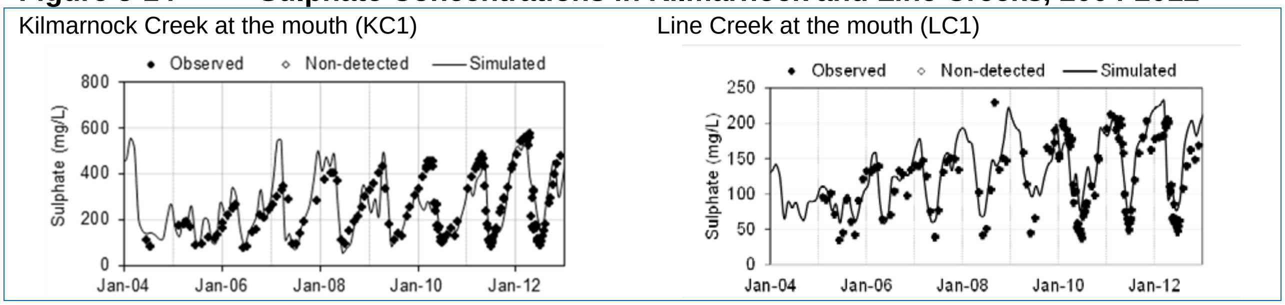
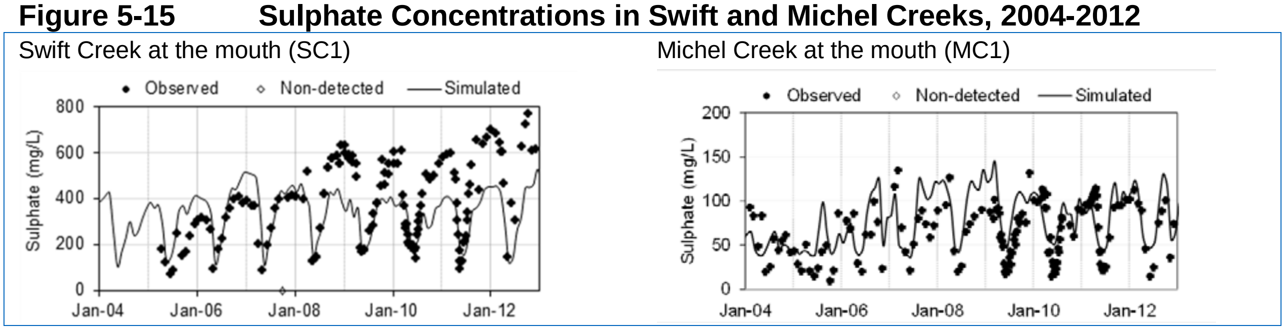


Figure 5-15 Sulphate Concentrations in Swift and Michel Creeks, 2004-2012



Sulphate calibration factors applied to the waste rock residing in the local tributaries are provided in Table 5-8. Bias and error statistics indicated that, while on average, simulated results reasonably match measured concentrations (i.e., bias near 1), the errors were fairly large, ranging from 12% to 56% (Table 4-9). As discussed in Section 5.3.1.1, the error values stem partially from the fact that the model outputs are analogous to a monthly average concentration, whereas the measured data were collected by grab sampling, which represents an instantaneous concentration at the time of collection.

Though simulated and measured data were compared and differences minimized by adjusting the geochemical release rate, time-dependent curve fitting was not completed to try to replicate measured data. As previously noted, the model is a planning and assessment tool of the Fording and Elk River mainstems, not a predictor of observed patterns in individual tributaries.

Table 5-8 Calibration Factors for Sulphate, 2004-2012

Operation / General Location	Node	Node Description	Calibration Factor
Fording River Operations	HC1	Henretta Creek at the mouth	1.15
	CC1	Clode Creek at the mouth	0.76
	LM1	Lake Mountain Creek at the mouth	1.84
	KC1	Kilmarnock Creek at the mouth	0.55
	SC1	Swift Creek at the mouth	0.63
	CA1	Cataract Creek at the mouth	0.79
	PC1	Porter Creek at the mouth	0.74
Greenhills Operations	GH1	Greenhills Creek at the mouth	0.96
	LE1	Leask Creek at the mouth	0.87
	WC1	Wolfram Creek at the mouth	4.45
	TC1	Thompson Creek at the mouth	1.47
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	2.00
	WLC1	West Line Creek at the mouth	1.02
Elkview Operations	EC1	Erickson Creek at the mouth	2.10
	GT1	Gate Creek at the mouth	1.19
	BC1	Bodie Creek at the mouth	1.17
	HM1	Harmer Creek at the mouth	0.48
Coal Mountain Operations	MC5	Michel Creek downstream of CMO	1.77

Table 5-9 Error and Bias Results for Sulphate Calibration, 2004-2012

Operation	Node	Node Description	Bias [µg/L][a]	Relative Bias[b]	Error [µg/L][c]	Percent Error[d]
Fording River Operations	HC1	Henretta Creek at the mouth	0.5	1.0	21	23%
	CC1	Clode Creek at the mouth	37	1.2	77	39%
	LM1	Lake Mountain Creek at the mouth	4.58	1.04	33	28%
	KC1	Kilmarnock Creek at the mouth	4.11	1.02	65	26%
	SC1	Swift Creek at the mouth	-13	1.0	320	31%
	CA1	Cataract Creek at the mouth	143	1.1	332	30%
	PC1	Porter Creek at the mouth	38	1.1	127	36%
Greenhills Operations	GH1	Greenhills Creek at the mouth	-49	0.87	117	30%
	TC1	Thompson Creek at the mouth	3	1.0	99	33%
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	68	1.5	79	56%
	WLC1	West Line Creek at the mouth	63	1.1	188	24%
	LC1	Line Creek at the mouth	13	1.1	29	24%
Elkview Operations	EC1	Erickson Creek at the mouth	-18	1.0	111	19%
	GT1	Gate Creek at the mouth	-25	0.96	195	34%
	BC1	Bodie Creek at the mouth	-25	0.95	220	44%
	HM1	Harmer Creek at the mouth	12.1	1.1	53	34%
Fording River	FR1	Fording River downstream of Henretta Creek	1.3	1.0	20	31%
	FR2	Fording River downstream of Clode Creek	-11	0.93	48	31%
	FR3	Fording River between Swift and Cataract creeks	16	1.1	38	24%
	FR3b	Fording River downstream of Porter Creek	-6.11	0.98	31.8	12%
	FR4 (EMS 0200378)	**Fording River downstream of Greenhills Creek**	8	1.1	29	21%
	FR5 (EMS 0200396)	**Fording River at the mouth**	12	1.1	22	18%
Michel Creek	MC5	Michel Creek downstream of Coal Mountain Operations	-30	0.84	57	30%
	MC3	Michel Creek upstream of EVO	6.3	1.2	14	45%
	MC1	Michel Creek at the mouth	12	1.2	23	35%
Elk River	**ER1 (EMS E206661)**	**Elk River downstream of GHO**	1.51	1.07	3.5	18%
	ER2 (EMS 0200389)	**Elk River downstream of Fording River**	-0.08	1.0	14	24%
	ER3 (EMS 0200393)	**Elk River downstream of Michel Creek**	-1.4	0.98	10	18%
	ER5	Elk River at the mouth	1.6	1.05	6.7	19%

(a) The bias represents the average difference between simulated and observed concentrations. A positive bias indicates that modelled concentrations are greater, on average, than observed concentrations.

(b) A relative bias greater than one indicates that modelled concentrations are greater, on average, than observed concentrations.

(c) The error represents the average absolute difference between simulated and observed concentrations.

(d) The percent error represents the ratio of the error to the average observed concentration.

Note: Sites in bold font correspond to those listed in Ministerial Order No. M113.

5.3.2.2 In-stream Trends in the Fording and Elk Rivers

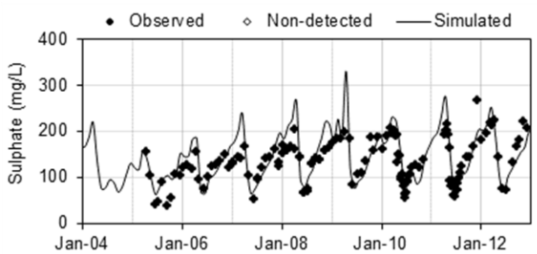
Simulated results in the Fording and Elk Rivers matched reasonably well with measured data in terms of replicating the range of measured concentrations and matching seasonal, yearly and longer-term trends (Figure 5-17).

In the Fording River, errors for sulphate ranged from 12% to 31% with a relative bias from 0.9 to 1.1 (Table 5-9). In the Elk River, errors for sulphate ranged from 18% to 24%, with relative bias from 1.0 to 1.1 (i.e., simulated sulphate values tended to be a little higher or just below the observed data).

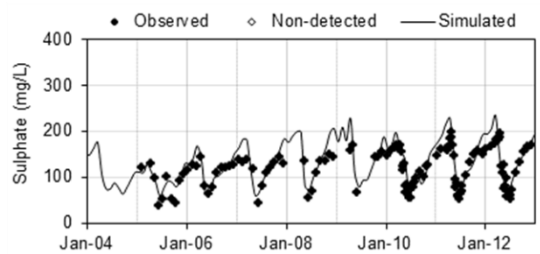
Unlike selenium, over-prediction occurs more evenly throughout the year, as shown in Figure 5-17. Each data point in Figure 5-17 represents the average relative bias, calculated using Equation 21, for the given month over the calibration period (e.g., for every January from 2004-2012), while the bars represent the range of the monthly relative bias values for the given month. The effects of error and bias, as well as model uncertainties, should be considered in selection of water quality management measures.

Figure 5-16 Sulphate Concentrations in the Fording and Elk Rivers, 2004-2012

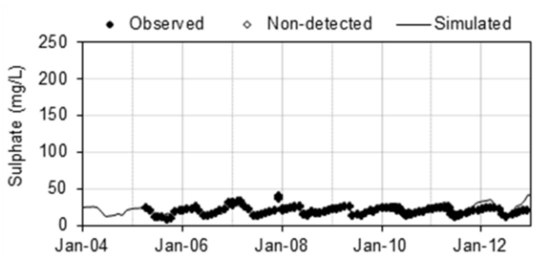
(a) Fording River downstream of Greenhills Creek (FR4; EMS 0200378)



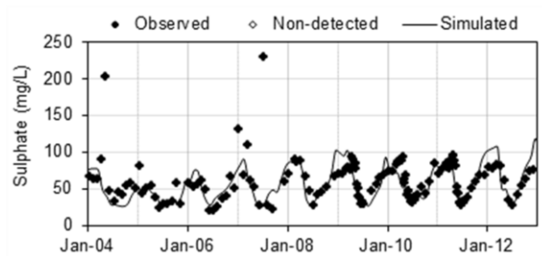
(b) Fording River at the Mouth (FR5; EMS 0200396)



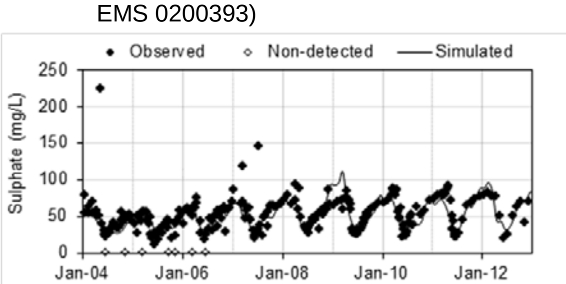
(c) Elk River downstream of Greenhills Operations (ER1; EMS E206661)



(d) Elk River downstream of Fording River (ER2; EMS 0200389)



(e) Elk River downstream of Michel Creek (ER3; EMS 0200393)



(f) Elk River at the Mouth (ER5)

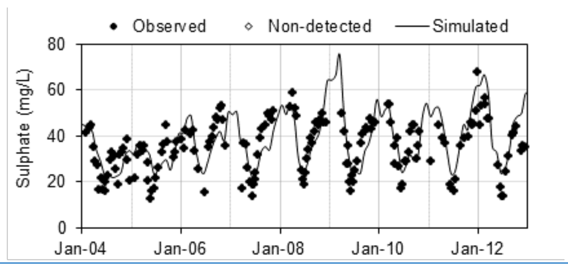
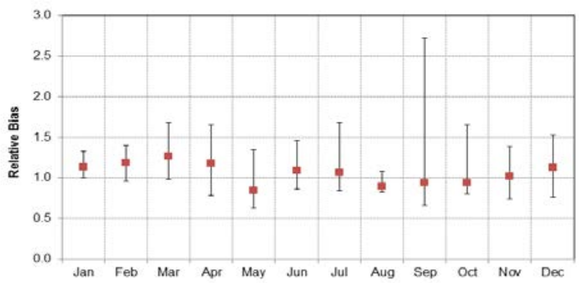
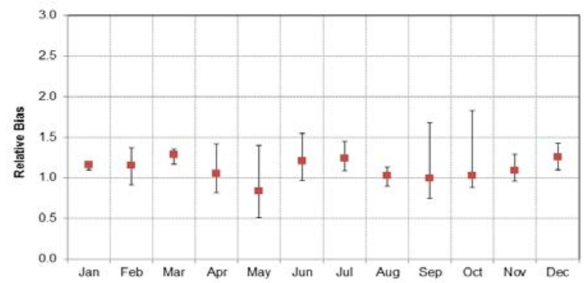


Figure 5-17 Monthly Sulphate Bias in the Fording and Elk Rivers, 2004-2012

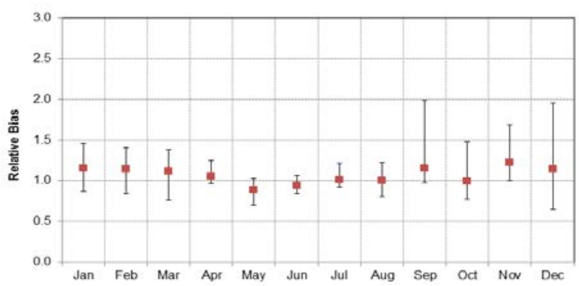
(a) Fording River downstream of Greenhills Creek (FR4; EMS 0200378)



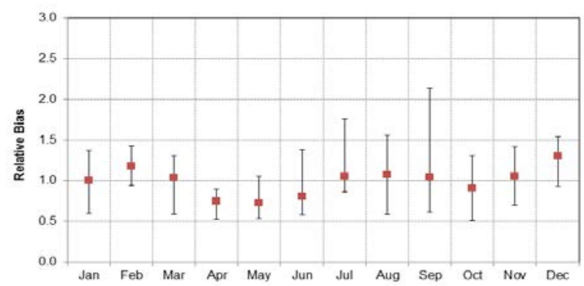
(b) Fording River at the Mouth (FR5; EMS 0200396)



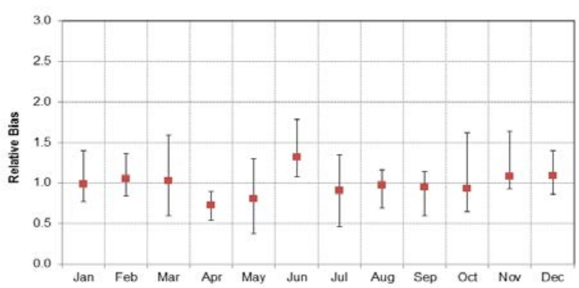
(c) Elk River downstream of Greenhills Operations (ER1; EMS E206661)



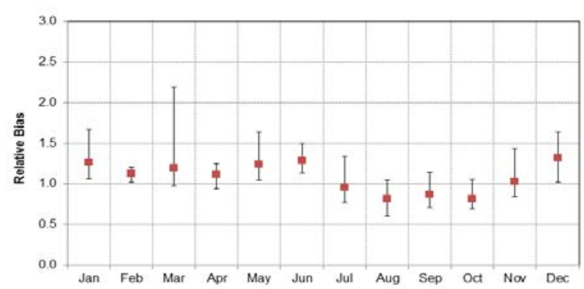
(d) Elk River downstream of Fording River (ER2; EMS 0200389)



(e) Elk River downstream of Michel Creek (ER3; EMS 0200393)



(f) Elk River at the Mouth (ER5)

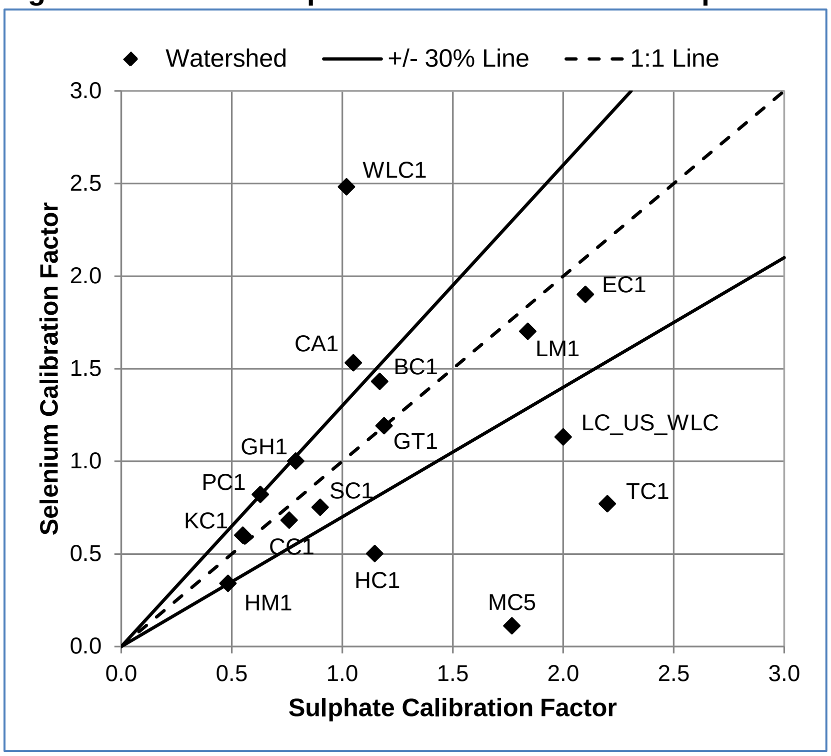


5.3.2.3 Comparison of Selenium and Sulphate Calibration Factors

Following completion of the selenium and sulphate calibrations, selenium and sulphate calibration factors assigned to each watershed in the Elk Valley were compared to determine if factors assigned to a given watershed were of a similar magnitude, and both either <1 or >1. If calibration factors in a given watershed were <1, then the selenium and sulphate release rates were less than the average Elk Valley release rates. If they were >1, then the selenium and sulphate release rates were greater than the average Elk Valley release rates listed in Table 3-2. Similarity between the selenium and sulphate calibration factors would be expected, because both are released from waste rock by pyrite oxidation.

The comparison of calibration factors was completed by plotting the selenium calibration factor against the sulphate calibration factor assigned to a given watershed, to determine how close the factors were to one another. Selenium calibration factors assigned to each watershed in the Elk Valley were typically within 30% of the corresponding sulphate calibration factors (Figure 5-18). Their proximity supports the conceptual model, suggesting that selenium and sulphate originate from the same geochemical processes.

Figure 5-18 Comparison of Selenium and Sulphate Calibration Factors



(a) Calibration factor applied to Henretta Creek from 2004 to March 2011.

(b) Calibration factor applied to Henretta Creek from April 2011 onward.

Notes: HC1(a) and HC1(b) = Henretta Creek; CC1 = Clode Creek; LM1 = Lake Mountain Creek; KC1 = Kilmarnock Creek; SC1 = Swift Creek; CA1 = Cataract Creek; PC1 = Porter Creek; GH1 = Greenhills Creek; LE1 = Leask Creek; WC1 = Wolfram Creek; TC1 = Thompson Creek; LC_US_WLC = Line Creek upstream of West Line Creek; WLC1 = West Line Creek; EC1 = Erickson Creek; GT1 = Gate Creek; BC1 = Bodie Creek; HM1 = Harmer Creek; MC5 = Michel Creek downstream of Coal Mountain Operations.

5.3.3 Nitrate

5.3.3.1.1 In-stream Trends in the Tributaries

The model was able to replicate observed seasonal patterns of in-stream nitrate concentrations in most tributaries, including Henretta and Lake Mountain Creeks (see Figure 5-19 and Appendix A). The model was also able to typically match in-stream concentrations during spring runoff events. However, the overall ability of the model to simulate historical concentrations was not as good for nitrate as it was for selenium and sulphate, and, in some tributaries (including in Greenhills and Thompson Creeks), the simulated trends did not follow the measured data as closely (Figure 5-20).

Figure 5-19 Nitrate Concentrations in Henretta and Lake Mountain Creeks, 2006-2012

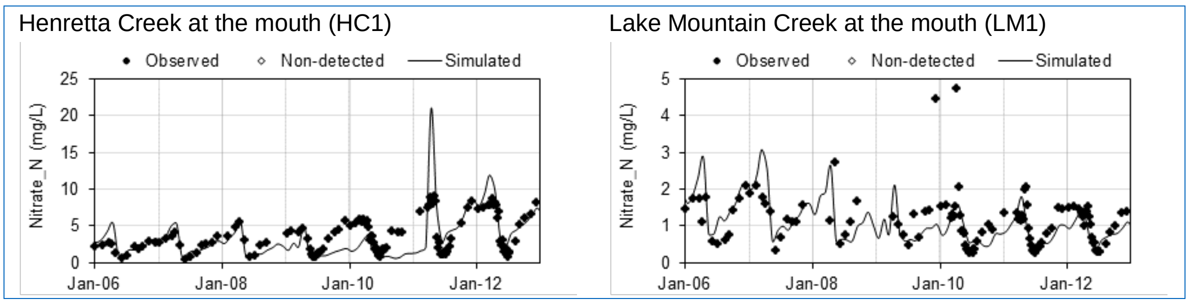
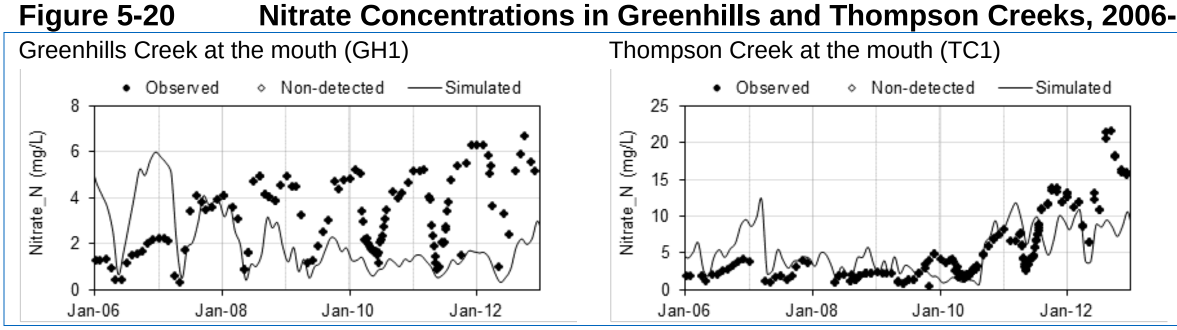


Figure 5-20 Nitrate Concentrations in Greenhills and Thompson Creeks, 2006-2012



Nitrate calibration factors applied to the waste rock in local tributaries are provided in Table 5-10. The relative bias statistics indicate that simulated concentrations were greater on average than measured concentrations. Errors were fairly large, ranging from 25% to 202% (Table 5-11). Factors likely 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.

Table 5-10 Calibration Factors for Nitrate, 2006-2012

Operation / General Location	Node	Node Description	Calibration Factor
Fording River Operations	HC1	Henretta Creek at the mouth	0.14 and 1[a]
	CC1	Clode Creek at the mouth	0.60
	LM1	Lake Mountain Creek at the mouth	3.30
	KC1	Kilmarnock Creek at the mouth	1.75
	SC1	Swift Creek at the mouth	0.43
	CA1	Cataract Creek at the mouth	0.40
	PC1	Porter Creek at the mouth	0.10
Greenhills Operations	GH1	Greenhills Creek at the mouth	0.22
	LE1	Leask Creek at the mouth	0.37
	WC1	Wolfram Creek at the mouth	1.06
	TC1	Thompson Creek at the mouth	0.13
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	0.38
	WLC1	West Line Creek at the mouth	2.90
Elkview Operations	EC1	Erickson Creek at the mouth	2.85
	GT1	Gate Creek at the mouth	0.83
	BC1	Bodie Creek at the mouth	0.46
	HM1	Harmer Creek at the mouth	0.14
Coal Mountain Operations	MC5	Michel Creek downstream of CMO	0.08

[a] Two calibration factors were applied to the waste rock residing in Henretta Creek, as discussed in Section 5.2.4.3. The first factor was applied from January 2004 to March 31, 2011. The second factor was applied from April 1, 2011 onward.

Table 5-11 Error and Bias Results for Nitrate, 2006-2012

Operation	Node	Node Description	Bias [µg/L][a]	Relative Bias[b]	Error [µg/L][c]	Percent Error[d]
Fording River Operations	HC1	Henretta Creek at the mouth	-0.17	0.95	1.5	40%
	CC1	Clode Creek at the mouth	3.7	1.3	10	69%
	LM1	Lake Mountain Creek at the mouth	-0.083	0.93	0.47	39%
	KC1	Kilmarnock Creek at the mouth	6.8	1.2	24	54%
	SC1	Swift Creek at the mouth	-4.7	0.89	21	49%
	CA1	Cataract Creek at the mouth	-1.1	0.97	14	41%
	PC1	Porter Creek at the mouth	-0.13	0.94	0.94	46%
Greenhills Operations	GH1	Greenhills Creek at the mouth	-1.2	0.62	2.3	69%
	TC1	Thompson Creek at the mouth	-0.21	0.96	2.8	51%
Line Creek Operations	LC_US_WLC	Line Creek upstream of West Line Creek	0.61	1.1	3.7	47%
	WLC1	West Line Creek at the mouth	13	1.3	24	66%
	LC1	Line Creek at the mouth	0.096	1.0	1.9	34%
Elkview Operations	EC1	Erickson Creek at the mouth	-0.28	0.97	2.2	25%
	GT1	Gate Creek at the mouth	13	1.3	34	68%
	BC1	Bodie Creek at the mouth	-7.9	0.8	17	42%
	HM1	Harmer Creek at the mouth	-0.21	0.79	0.46	46%
Fording River	FR1	Fording River downstream of Henretta Creek	0.014	1.0	0.9	42%
	FR2	Fording River downstream of Clode Creek	-0.69	0.85	1.7	35%
	FR3	Fording River between Swift and Cataract creeks	12	3.0	12	202%
	FR3b	Fording River downstream of Porter Creek	0.069	1.0	5.3	31%
	FR4 (EMS 0200378)	**Fording River downstream of Greenhills Creek**	**4.5**	**1.7**	**5.7**	**90%**
	FR5 (EMS 0200396)	**Fording River at the mouth**	**2.6**	**1.5**	**3.5**	**62%**
Michel Creek	MC5	Michel Creek downstream of Coal Mountain Operations	-0.4	0.55	0.58	64%
	MC3	Michel Creek upstream of EVO	-0.076	0.58	0.13	75%
	MC1	Michel Creek at the mouth	0.37	1.3	0.63	49%
Elk River	**ER1 (EMS E206661)**	**Elk River downstream of GHO**	**0.094**	**1.7**	**0.11**	**90%**
	ER2 (EMS 0200389)	**Elk River downstream of Fording River**	**0.95**	**1.5**	**1.4**	**68%**
	ER3 (EMS 0200393)	**Elk River downstream of Michel Creek**	**0.62**	**1.5**	**0.71**	**56%**
	ER5	Elk River at the mouth	0.33	1.5	0.43	62%

(a) The bias represents the average difference between simulated and observed concentrations. A positive bias indicates that modelled concentrations are greater, on average, than observed concentrations.

(b) A relative bias greater than one indicates that modelled concentrations are greater, on average, than observed concentrations.

(c) The error represents the average absolute difference between simulated and observed concentrations.

(d) The percent error represents the ratio of the error to the average observed concentration.

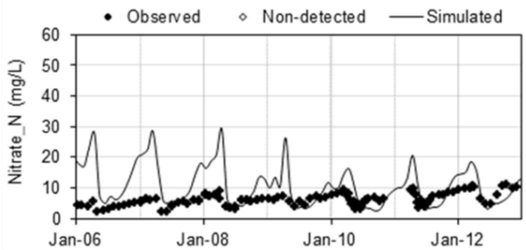
5.3.3.2 In-stream Trends in the Fording and Elk Rivers

Simulated nitrate concentrations generally matched measured data in terms of replicating seasonal trends in the Fording and Elk River mainstems (Figure 5-21). The model also replicated in-stream concentrations during spring runoff events in the Fording and Elk Rivers, and simulated results typically encompassed observed concentration ranges. However, the overall ability of the model to simulate historical concentrations was not as good for nitrate as it was for selenium and sulphate. The model had a strong tendency to over-predict nitrate concentrations in the Fording and Elk River mainstems in lower flow periods, particularly in winter when in-stream concentrations peak. Due in large part to the low-flow over-predictions, simulated concentrations in the Fording and Elk River mainstems were greater, on average, than measured data by 31% to 202% and 56% to 90%, respectively (Table 5-11). Monthly relative bias are shown in Figure 5-22, which also shows over-prediction (high relative bias values) mainly during low-flow months.

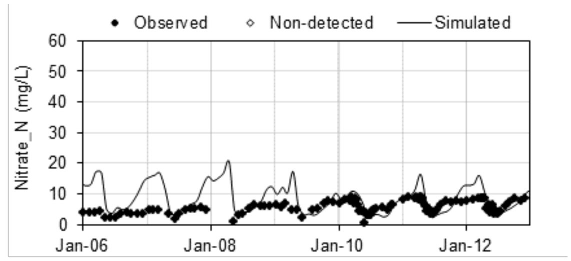
Over-prediction during lower-flow months can, at least partially, be attributed to the absence of an apparent nitrate sink along a dominantly sub-surface flow path between the monitoring locations at the mouths of Swift and Kilmarnock Creeks and the Fording River mainstem. During low-flow periods, nitrate concentrations in Kilmarnock and Swift Creeks are in the order of 80-100 and 50-70 mg-N/L, respectively. The combined flow from both tributaries is sufficient to result in an observed shift in nitrate levels in the Fording River, as predicted by the model. However, nitrate concentrations downstream of Swift and Kilmarnock Creeks are similar to those upstream. Waters from Swift and Kilmarnock Creeks enter the Fording River largely as sub-surface seepage, and the observations outlined above would suggest that nitrate loss is occurring along these flow paths. The absence of this removal mechanism from the model results in over-prediction of nitrate levels in the Fording River, which consequently affects simulated concentrations in the Elk River. The tendency of the model to over-predict nitrate levels must be considered when evaluating water management options.

Figure 5-21 Nitrate Concentrations in the Fording and Elk Rivers, 2006-2012

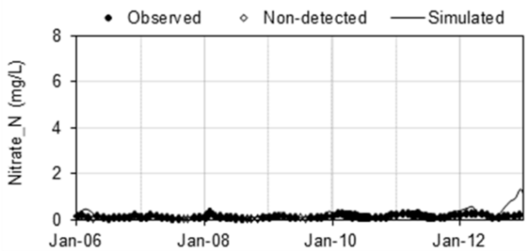
(a) Fording River downstream of Greenhills Creek (FR4; EMS 0200378)



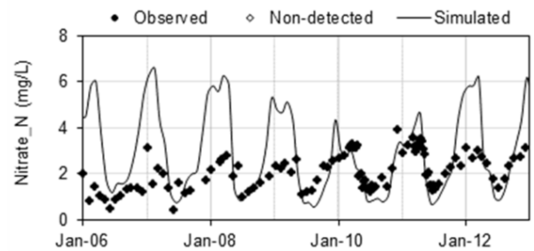
(b) Fording River at the Mouth (FR5; EMS 0200396)



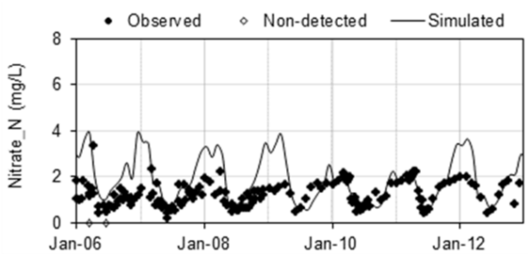
(c) Elk River downstream of Greenhills Operations (ER1; EMS E206661)



(d) Elk River downstream of Fording River (ER2; EMS 0200389)



(e) Elk River downstream of Michel Creek (ER3; EMS 0200393)



(f) Elk River at the Mouth (ER5)

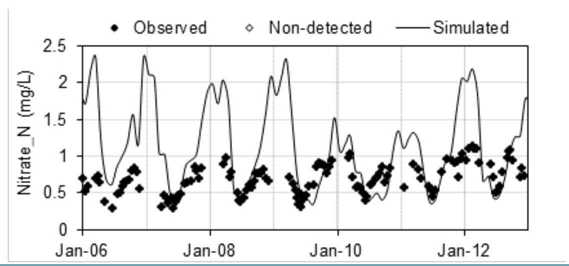
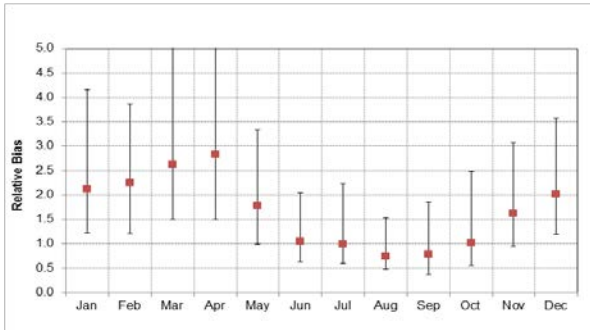
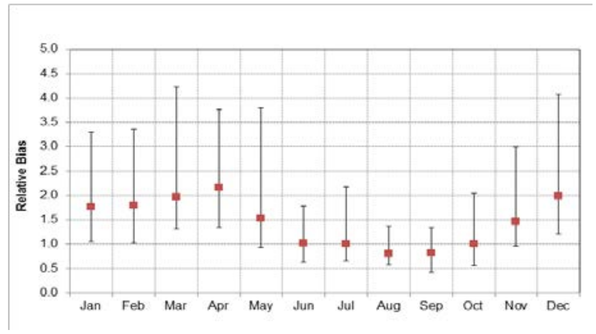


Figure 5-22 Nitrate Bias Values in the Fording and Elk Rivers, 2004-2012

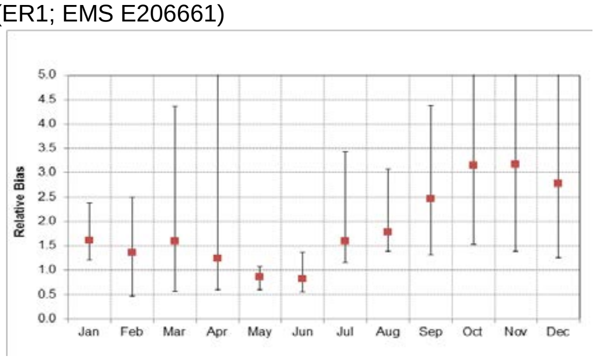
(a) Fording River downstream of Greenhills Creek (FR4; EMS 0200378)



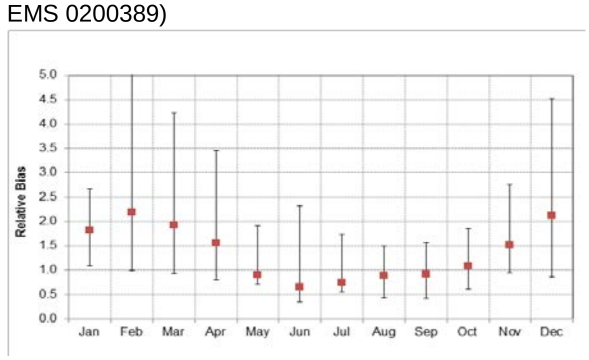
(b) Fording River at the Mouth (FR5; EMS 0200396)



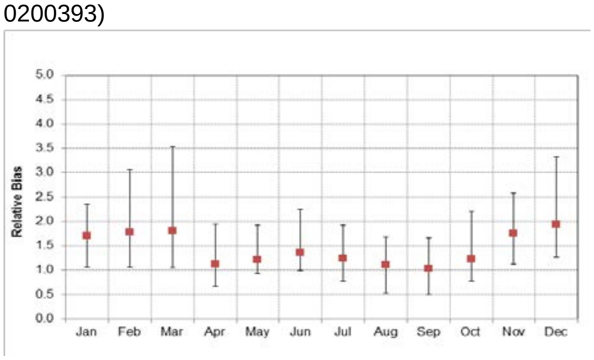
(c) Elk River downstream of Greenhills Operations (ER1; EMS E206661)



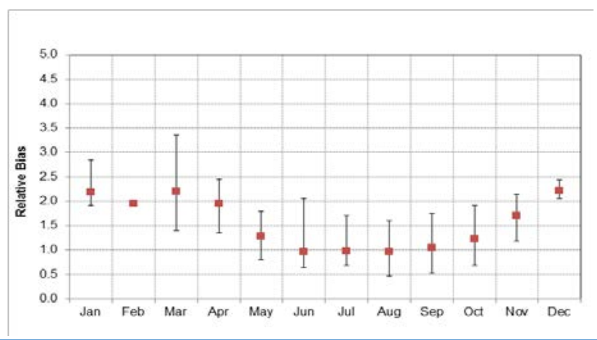
(d) Elk River downstream of Fording River (ER2; EMS 0200389)



(e) Elk River downstream of Michel Creek (ER3; EMS 0200393)



(f) Elk River at the Mouth (ER5)



5.3.4 Cadmium and Other Substances

In-stream cadmium concentrations produced using the valley-wide average release rate did not match the measured data at most nodes, and results using the upper-bound estimate typically over-estimated the observed concentration range through most of the model domain (Figure 5-23). In an attempt to improve model performance, the average release rate was decreased from 1.1 to 0.55 µg/L, and the reasonable worst-case rate from 2.9 to 1.5 µg/L, for all watersheds except West Line Creek. At West Line Creek, the average and reasonable, worst-case release rates were increased to 2.2 and 5.8 µg/L, respectively.

These changes resulted in some improvement in the model, in that the degree of over-prediction decreased. That said, predicted results continued to be greater than observed cadmium concentrations in the Fording and Elk Rivers, and in most of the modelled tributaries in the winter, fall and summer. In spring, simulated cadmium concentrations in the Fording River were generally equivalent to those observed, whereas in the Elk River they were typically lower.

In both the Fording and Elk Rivers, and in many tributaries, the model was unable to replicate observed seasonal trends. Simulated cadmium concentrations peaked in the winter and reached their minimum in the spring. The observed data indicate that cadmium concentrations typically follow the reverse pattern in the Elk Valley, with peak concentrations in the spring and annual minimums in the fall and winter. When the model was run using the valley-wide average cadmium release rate, the range of cadmium concentrations produced by the model also tended to be smaller than that observed at most nodes.

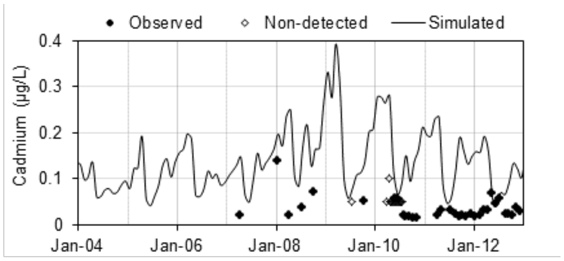
When the modified upper estimate of the valley-wide average was used, the upper end of the simulated cadmium concentration range more closely matched with that observed, although they occurred at different times of the year. In other words, annual peak concentrations produced by the model were comparable to those observed, when the model was run with an upper estimate of the cadmium release rate (as defined by SRK 2014). However, the simulated peaks occurred in winter, whereas the observed peaks occurred in spring.

These results indicate that the model, in its current form, can be used as a screening tool to evaluate potential changes to in-stream cadmium concentrations in relative terms, and can provide an estimate of potential peak concentrations. However, as currently configured and calibrated, it does not represent spatial and temporal trends associated with mine influences on cadmium concentrations well enough to make it an effective planning tool for assessing water management measures involving cadmium.

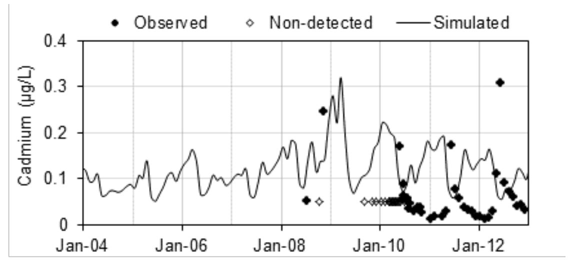
With respect to alkalinity, hardness and most major ions, simulated concentrations generally followed observed trends (see Appendix B). Simulated concentrations of chloride, potassium and dissolved organic carbon were not well-correlated to observed data, suggesting that monitoring data should be used to evaluate the concentrations of these elements, if and as appropriate, when assessing their role as potential toxicity-modifying factors.

Figure 5-23 Cadmium Concentrations in the Fording and Elk Rivers, 2004-2012

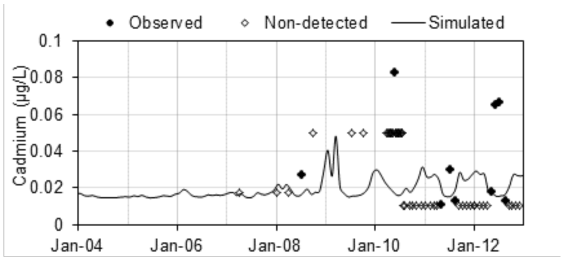
(a) Fording River downstream of Greenhills Creek (FR4; EMS 0200378)



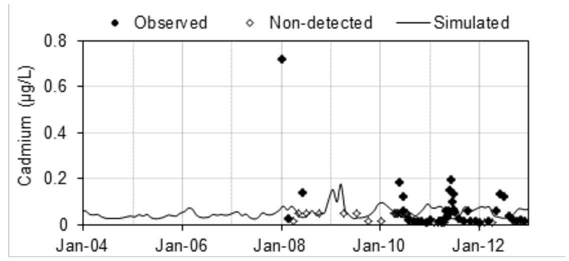
(b) Fording River at the Mouth (FR5; EMS 0200396)



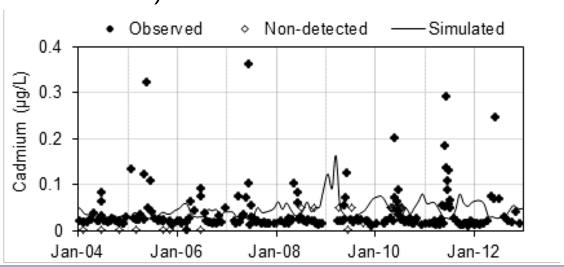
(c) Elk River downstream of Greenhills Operations (ER1; EMS E206661)



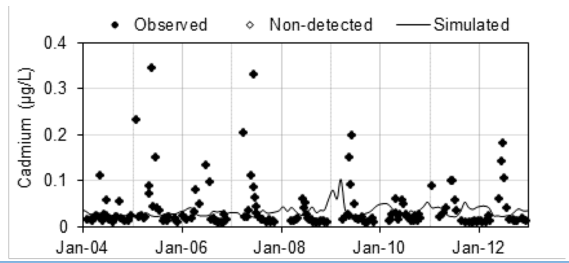
(d) Elk River downstream of Fording River (ER2; EMS 0200389)



(e) Elk River downstream of Michel Creek (ER3; EMS 0200393)



(f) Elk River at the Mouth (ER5)



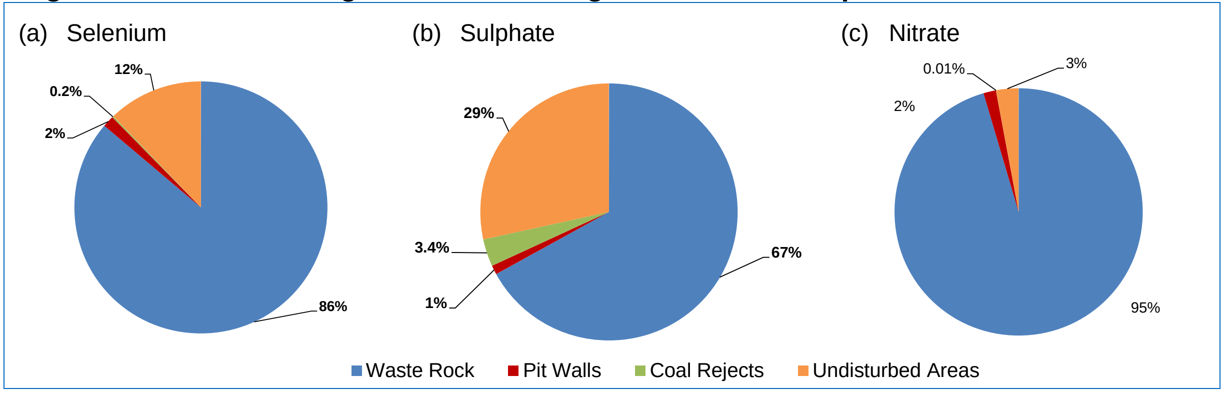
Notes: Data shown corresponds to that available when the model was calibrated.

No seasonal variation is simulated West Line Creek, because the natural and mine flows are assumed to follow the same seasonal pattern (i.e., the seasonal pattern observed at the mouth of the creek).

5.3.5 Source Distribution

The contributions of waste rock, pitwall areas, coal rejects and undisturbed areas to the average annual loading of selenium, sulphate and nitrate in the Elk Valley were calculated using the output from the calibrated model. As shown in Figure 5-24, waste rock was the main source of all three constituents and undisturbed areas the second largest source. These were followed by pitwalls and coal rejects for selenium and nitrate, and by coal rejects and pitwalls for sulphate.

Figure 5-24 Average Annual Loading of Selenium, Sulphate and Nitrate, 2010



6 Summary

6.1 Model Assumptions

The main assumptions incorporated into the setup and configuration of the model are summarized in Table 6-1. These assumptions reflect, where relevant, the conceptual model discussed in Section 3. Table 6-1 organizes the assumptions by subject, and references sections of this report where discussions on these assumptions occur.

Table 6-1 Summary of Plan Model Assumptions

Subject	Model Assumptions	Report Section
Release from waste rock	• There is no time-lag between the placement of waste rock and the release of material from the spoil. As soon as waste rock is placed in a watershed, pyrite oxidation begins and substances begin to be released. • Waste rock release rates for all substances, except nitrate, are constant and do not depend on the age of the rock, or vary with time. • Concentrations in the drainage waters are subject to solubility limits. Once the solubility limit is reached, fixed concentrations equivalent to the solubility limit are assumed to occur. The solubility limit for selenium is based on the assumption that selenate will co-precipitate with sulphate (SRK 2014).	4.3.2.1
	• The annual release of selenium from waste rock is flow dependent using the flow relationship established by SRK 2014 to account for the greater amounts of selenium released from waste rock in higher flow years. • The same flow relationship established for selenium was extended to sulphate. Modelling of historical conditions suggested greater amounts of sulphate released during high flows. Since selenium and sulphate are released from the same sources and through the same processes, the same flow relationship should apply to sulphate. • The same flow relationship established for selenium was extended to nitrate. Modelling of historical conditions suggested greater amounts of nitrate released during high flows. While nitrate is released through different processes from selenium, this behaviour likely reflects more waste rock coming into contact with infiltrating water during higher flow years.	4.3.2.1.1, 4.3.2.1.2, 5.2.4.1
	• Monthly release distributions of selenium, sulphate and nitrate were based on average monthly release distributions in the Elk Valley (SRK 2014) adjusted for apparent watershed-specific behaviours during calibration to better reproduce observed patterns.	4.3.2.1.1, 4.3.2.1.2, 5.2.4.2
Release from pitwalls	• All mine affected areas not identified as containing waste-rock spoils or coal reject piles (such as roads, buildings, parking areas and laydown areas) were assumed to be pitwalls. • Pitwall release rates for all substances, except nitrate, are constant and do not depend on the age of the rock. • Exposed pitwall area was converted to a volume of waste rock by multiplying by a reactive surface thickness. The reactive surface thickness was assumed to be 2 m, a typical overblast depth for mining (SRK 2014).	4.3.2.2
Release from coal rejects	• Release rates from coal rejects are constant for all substances and do not depend on the age of the coal rejects.	4.3.2.3
Release from tailing water	• The chemistry of tailings water was assumed to be the same as that for water draining from coal reject piles.	4.3.2.4
Release from natural areas	• With the exception of sulphate in the Elk River, all surface flows within a given watershed area not affected by coal mine development were assigned a source term concentration derived from the geometric mean of monitored data collected from undisturbed watersheds in the region. Monthly concentrations were defined for sulphate in the Elk River.	4.3.2.5
General setup	• The influence of activities related to forestry, roadways and railways on water quality are represented in the measured water quality data available to describe existing conditions in the area. As such, they are not explicitly modelled. • Historical groundwater seepages from mine sites to the receiving environment were not explicitly included in the model. However, their influence on in-stream water quality was accounted for by assuming that all substances released from waste rock and other source materials travelled into the environment via surface water flows and are captured in monitoring data. • Once released into the water column, substances remain in the water column; no degradation, precipitation or settling occurs. • Watercourses and flooded pits are completely mixed, vertically and laterally.	4.2
Effluent quality	• With biological treatment, the selenium concentration in treated effluent is 20 µg/L or 95% removal if the influent concentration is greater than 500 µg/L. The nitrate concentration in treated effluent is 0.1 mg/L and there is no removal of sulphate. • With membrane treatment, the selenium, nitrate and sulphate concentrations in treated effluent are 0.5 µg/L, 3.0 mg/L and 150 mg/L, respectively.	4.4.2.1

6.2 Model Use and Limitations

The model is a planning tool that is being used primarily to assist with the development of a regional implementation plan required by the Order. It has been constructed to describe how water quality conditions in the Elk Valley may change as a result of mining and associated management activities, at a spatial and temporal scale suitable to support the development of the Plan.

As such, emphasis was placed on more closely replicating observed patterns in the Fording and Elk River mainstems (which are the focus of the Order), rather than on matching the observed patterns in individual tributaries. In addition, the model was not constructed and does not contain the level of detail required to accurately predict daily concentrations in small watersheds. Rather, it is designed to describe the general response of individual tributaries to mining and associated management activities, based on the current understanding of the geochemical and hydrological processes that occur within waste-rock spoils and other mine features.

Model calibration was performed to maintain, where possible, a slight bias towards over-predicting in-stream concentrations. For selenium, the over-estimation of in-stream concentrations was most pronounced during the winter period, which is when water quality mitigation measures tend to be the most effective at controlling in-stream concentrations (Teck 2014d). As such, for selenium treatment, the error and bias included in the calibrated model should not to result in grossly over-estimated management systems to reach a given target concentration in the Fording or Elk River mainstems. The effects of error and bias, as well as model uncertainties, must be considered in the selection of the water quality management measures.

The model is able to match in-stream selenium and sulphate concentration trends observed in the Fording and Elk Rivers. Its ability to accurately simulate historical concentrations of nitrate and cadmium is not as good as for selenium and sulphate, as it tends to over-predict nitrate and cadmium to a greater extent. However, the model's performance is adequate for its intended purpose for the development of the Plan, as long as bias and uncertainties are considered as part of the development.

7 References

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Teck 2014b. *Elk Valley Water Quality Plan - Site Conditions*. Prepared for Teck Coal by Golder Associates Ltd, July 2014.

Teck 2014c. *Elk Valley Water Quality Plan – Hydrology*. Prepared for Teck Coal by Golder Associates Ltd, July 2014.

Teck 2014d. *Elk Valley Water Quality Plan - Water Quality Modelling for the Initial Implementation Plan*. Prepared for Teck Coal by Golder Associates Ltd, July 2014.

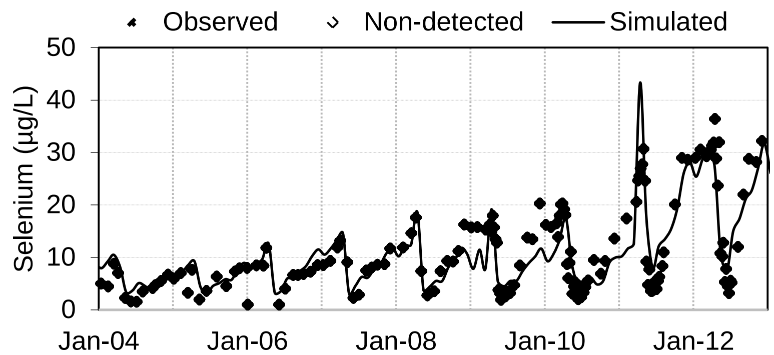
APPENDIX A

MODEL CALIBRATION RESULTS FOR SELENIUM, SULPHATE, NITRATE AND CADMIUM

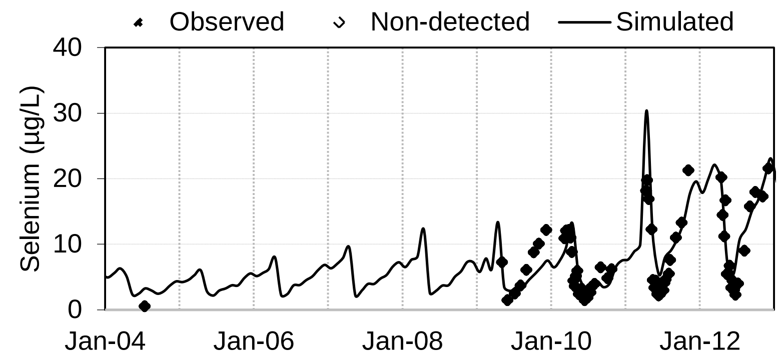
Appendix A contains four figures that illustrate how simulated concentrations produced using the re-calibrated Elk Valley Water Quality Plan water quality model compare to those measured in the Fording River and Elk River mainstems and in mine-affected tributaries to those rivers. The parameters of interest include selenium, sulphate, nitrate, and cadmium. The period of record is from January 1, 2004 to December 31, 2012.

Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012

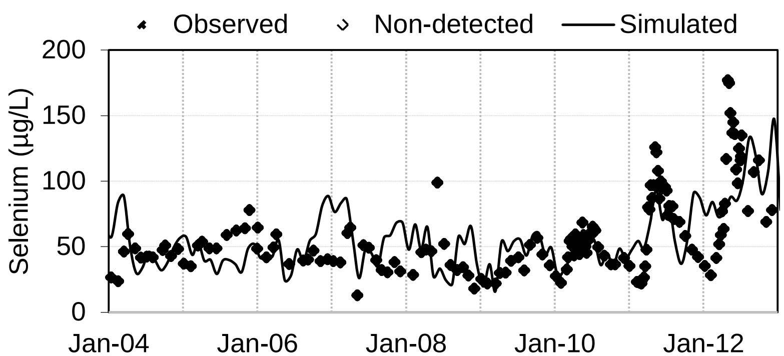
Henretta Creek at the mouth (HC1)



Fording River downstream of Henretta Creek (FR1)



Clode Creek at the mouth (CC1)



Lake Mountain Creek at the mouth (LM1)

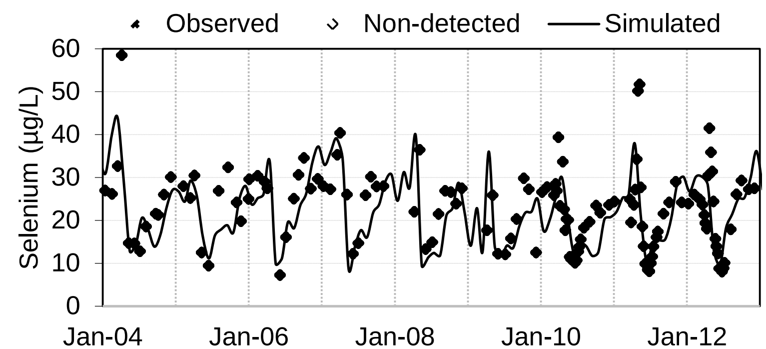


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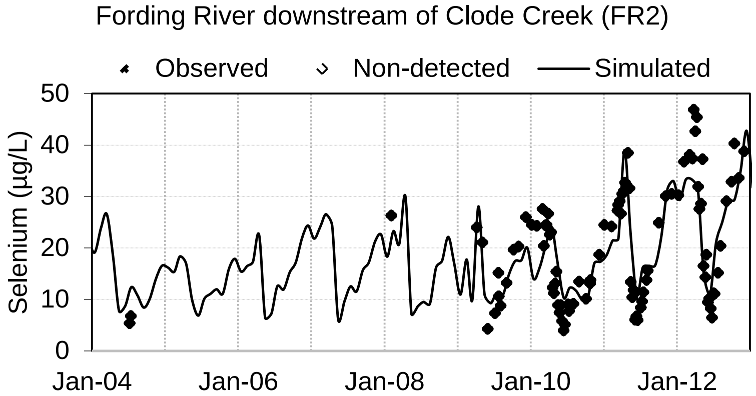
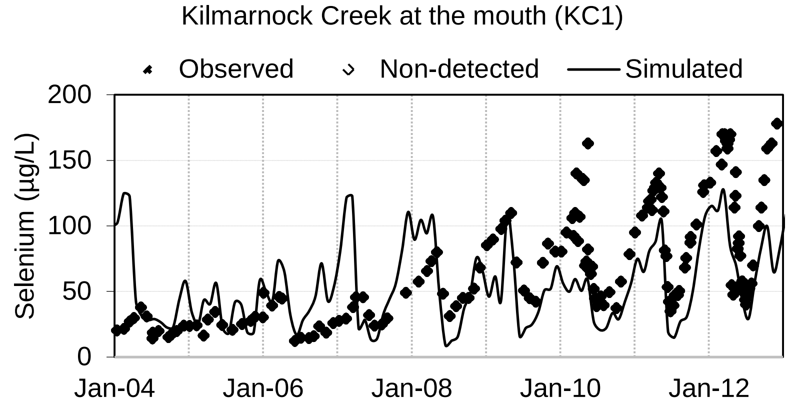
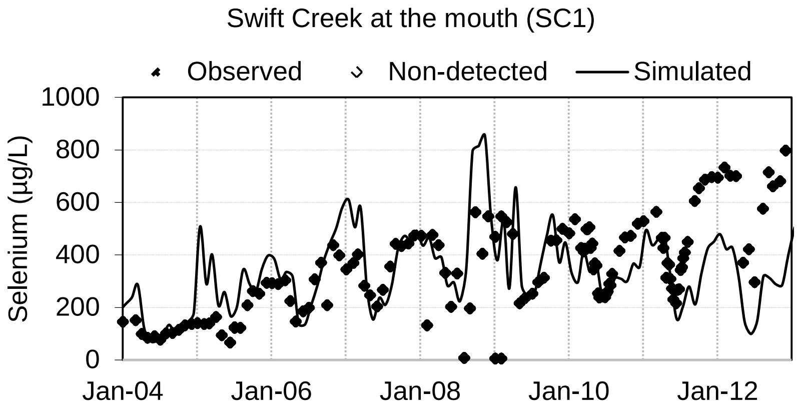
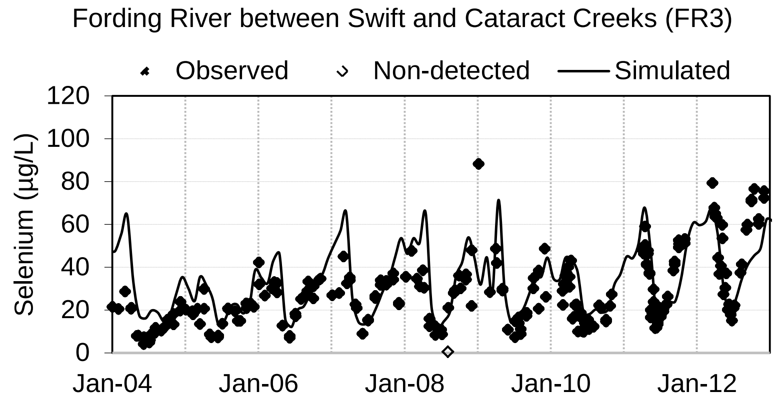
Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012 (continued)





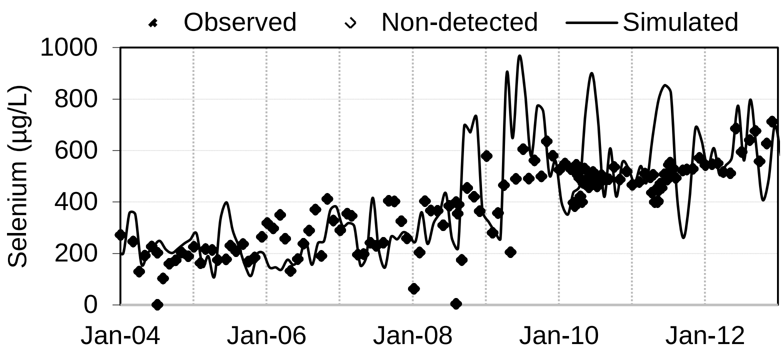




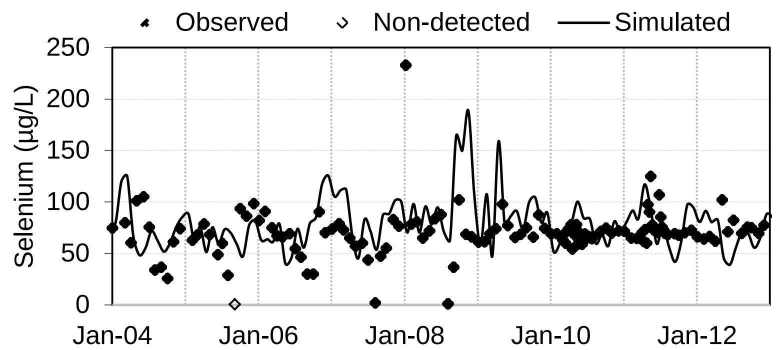
Note: One observed data point is not shown, a measurement of 152 µg/L that was recorded on December 01, 2006.

Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012 (continued)

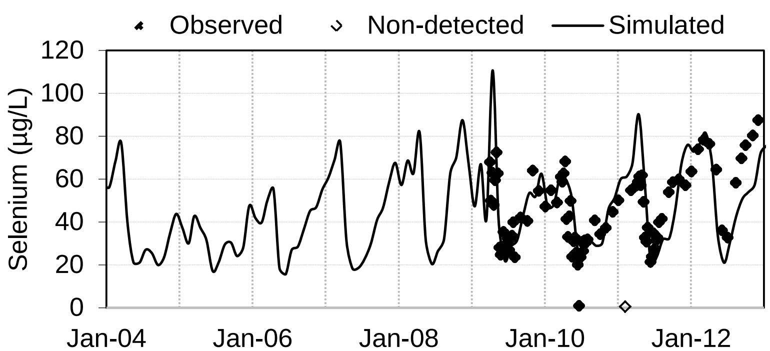
Cataract Creek at the mouth (CA1)



Porter Creek at the mouth (PC1)



Fording River downstream of Porter Creek (FR3b)



Greenhills Creek at the mouth (GH1)

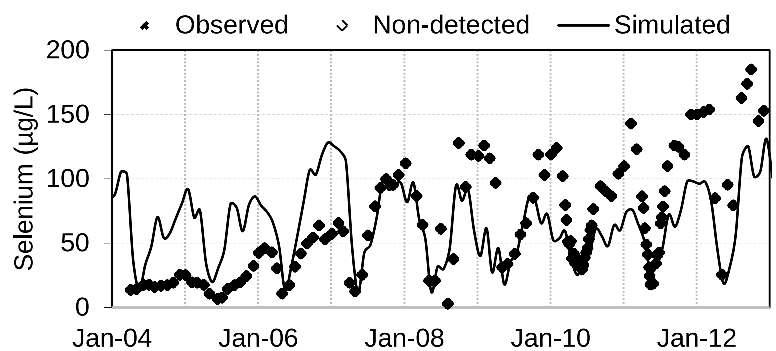
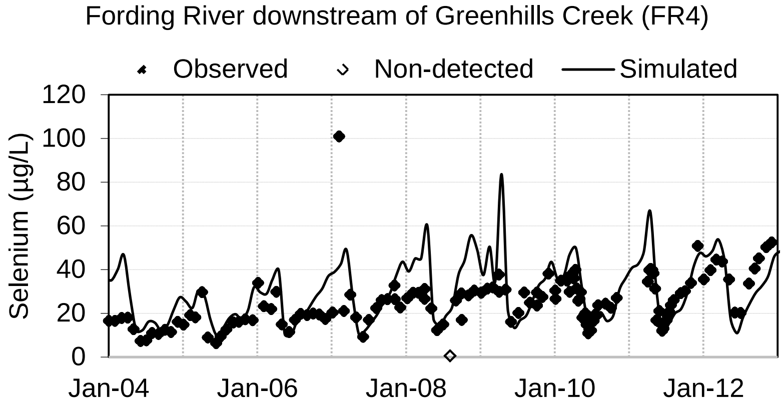
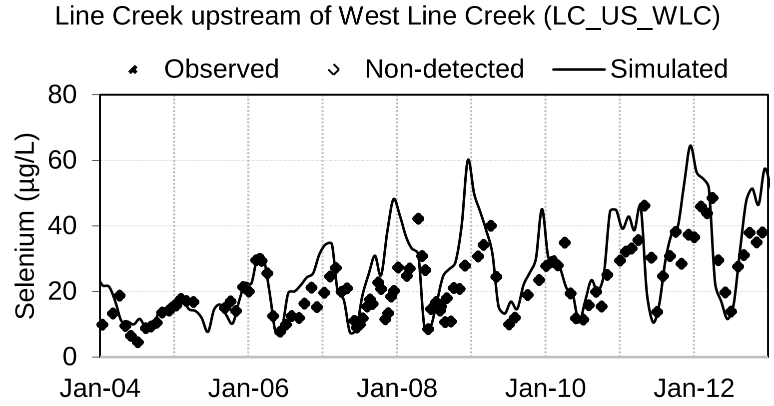
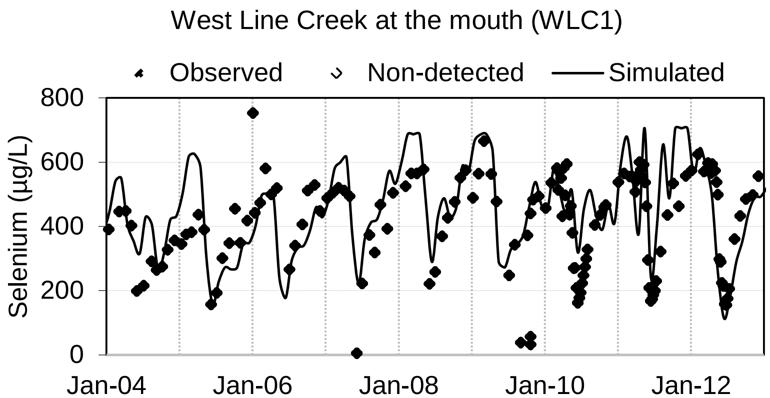


Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012 (continued)







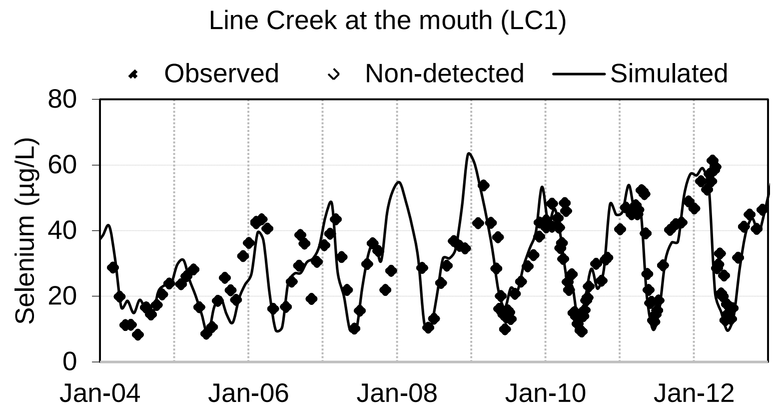
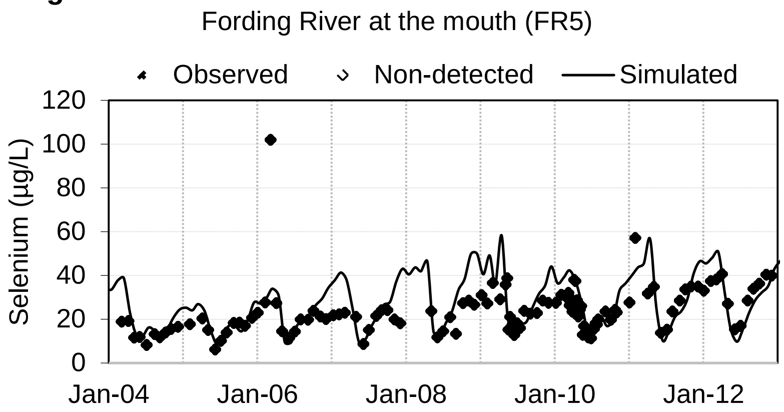
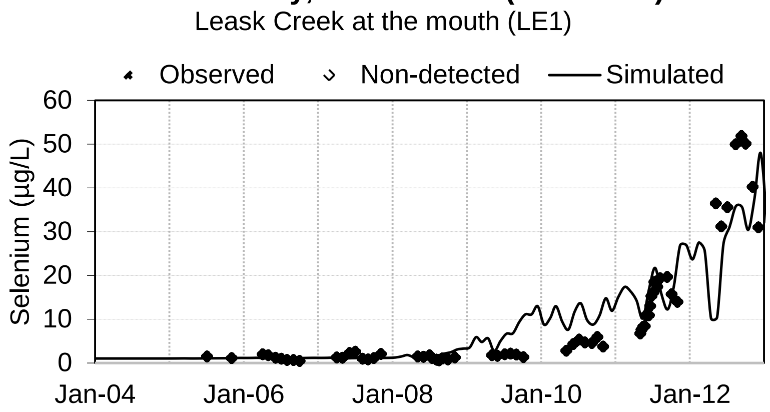
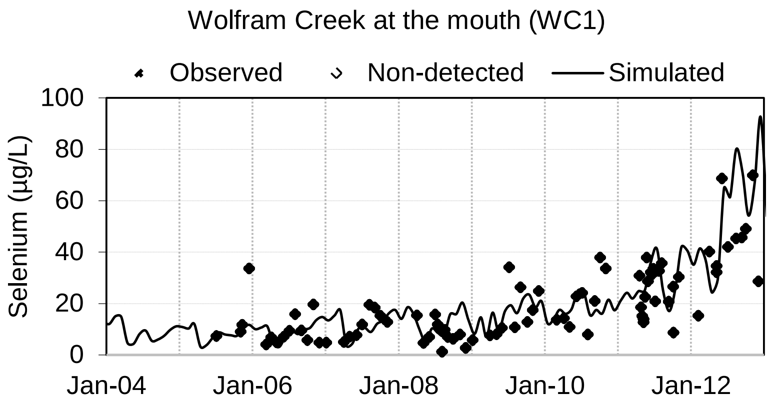


Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012 (continued)







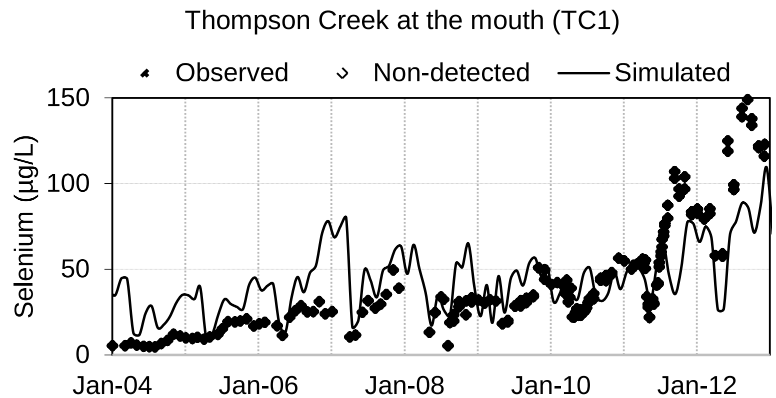
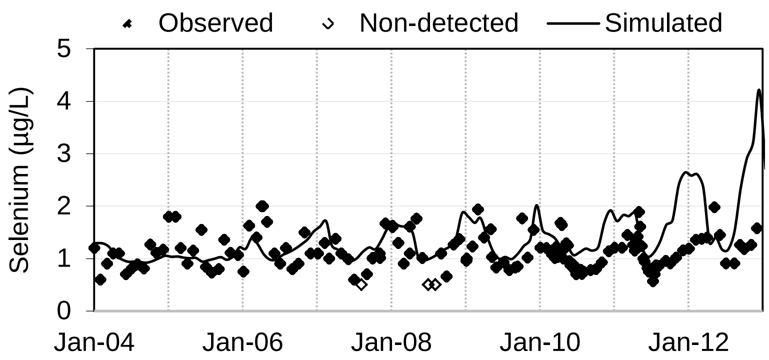
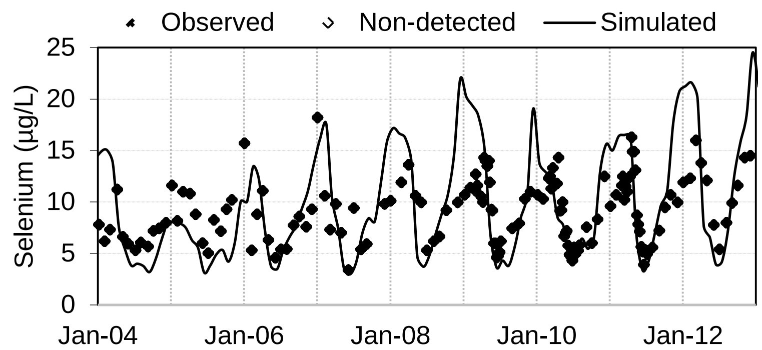


Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012 (continued)

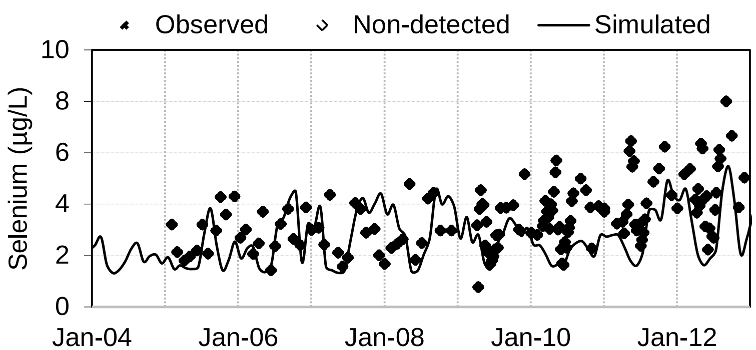
Elk River downstream of Greenhills Operations (ER1)



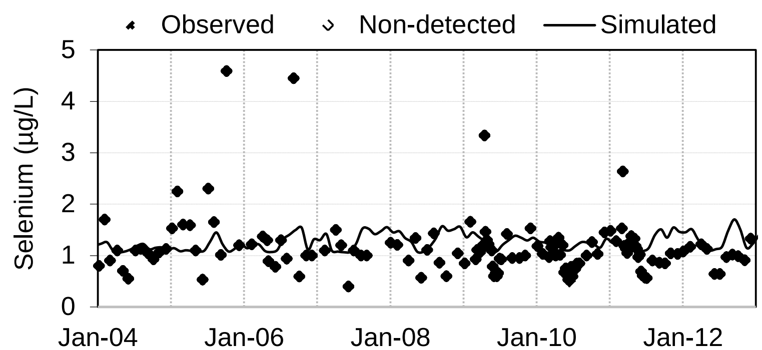
Elk River downstream of Fording River (ER2)



Michel Creek downstream of Coal Mountain Operations (MC5)

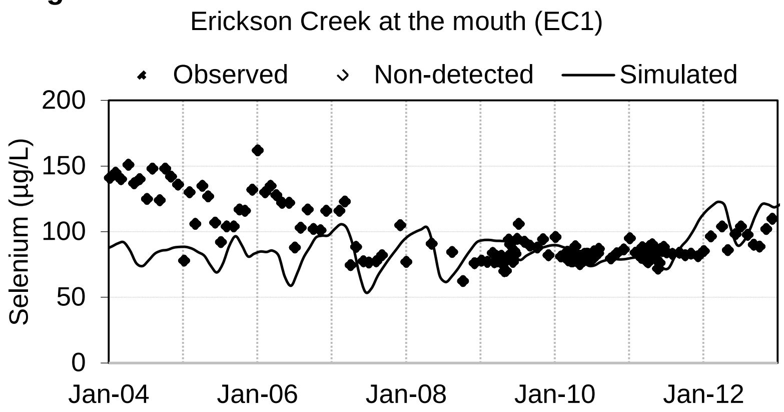


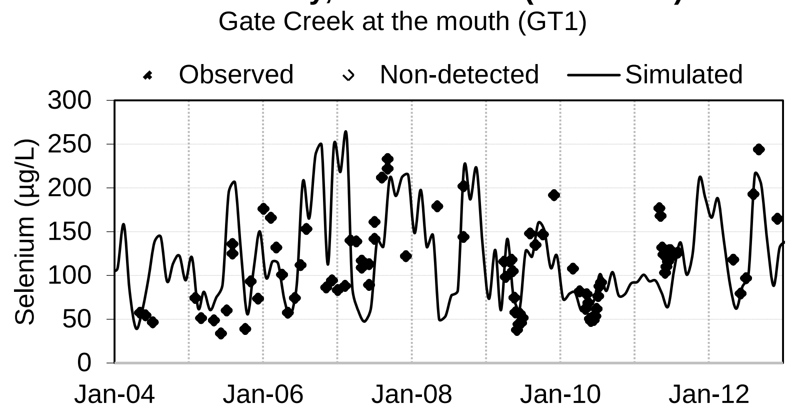
Michel Creek upstream of Elkview Operations (MC3)

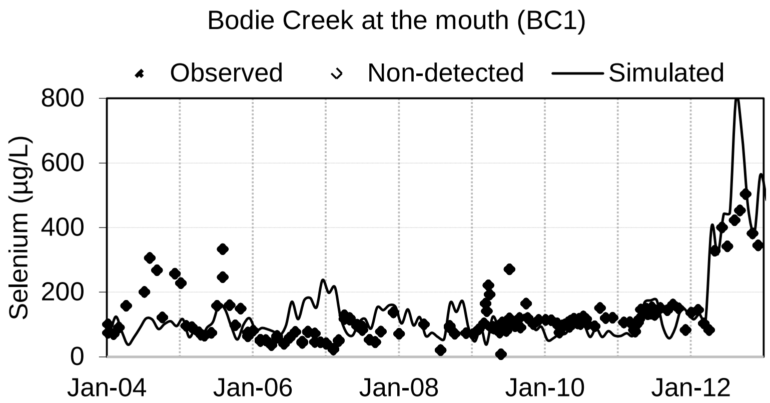


Note: One observed data point is not shown, a measurement of 12.3 µg/L that was recorded on March 06, 2007

Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012 (continued)







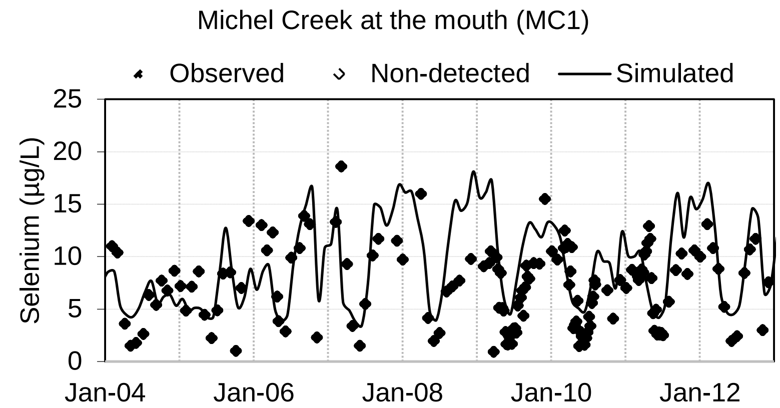
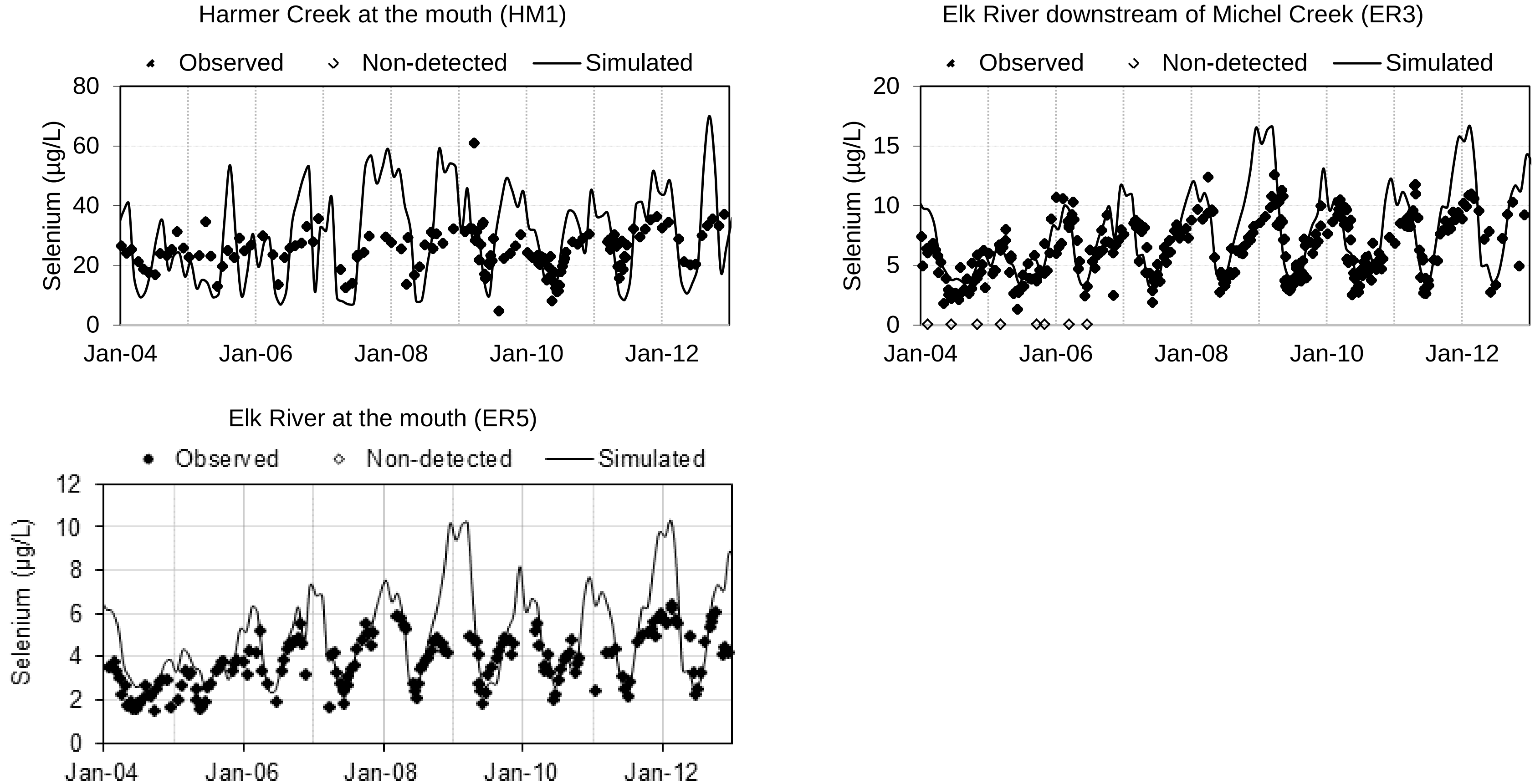


Figure A-1 Simulated and Observed Selenium Concentrations in the Elk Valley, 2004 to 2012 (continued)



Note: Data shown correspond to those available when the model was re-calibrated.

Figure A-2 **Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012**

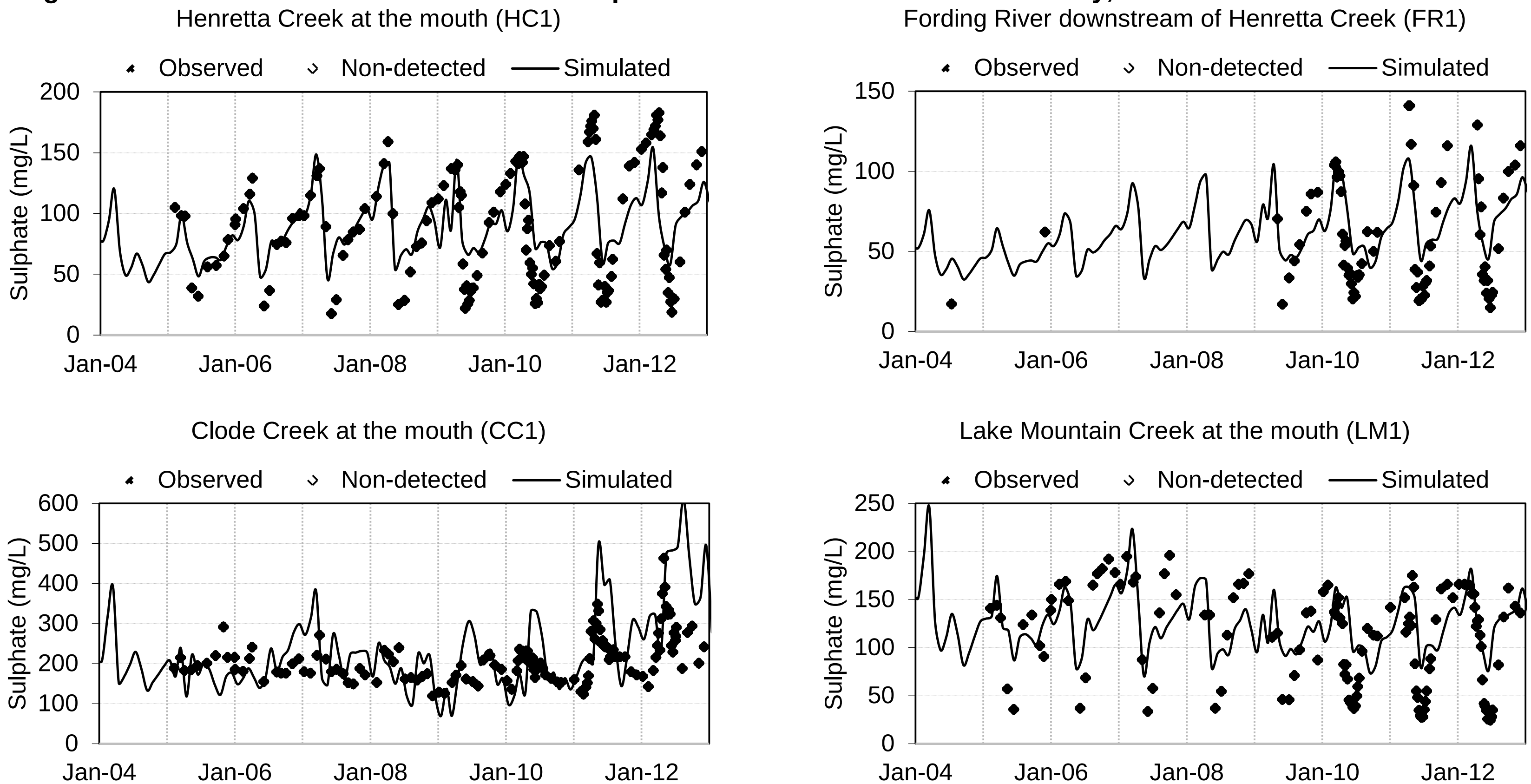


Figure A-2 Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012 (continued)

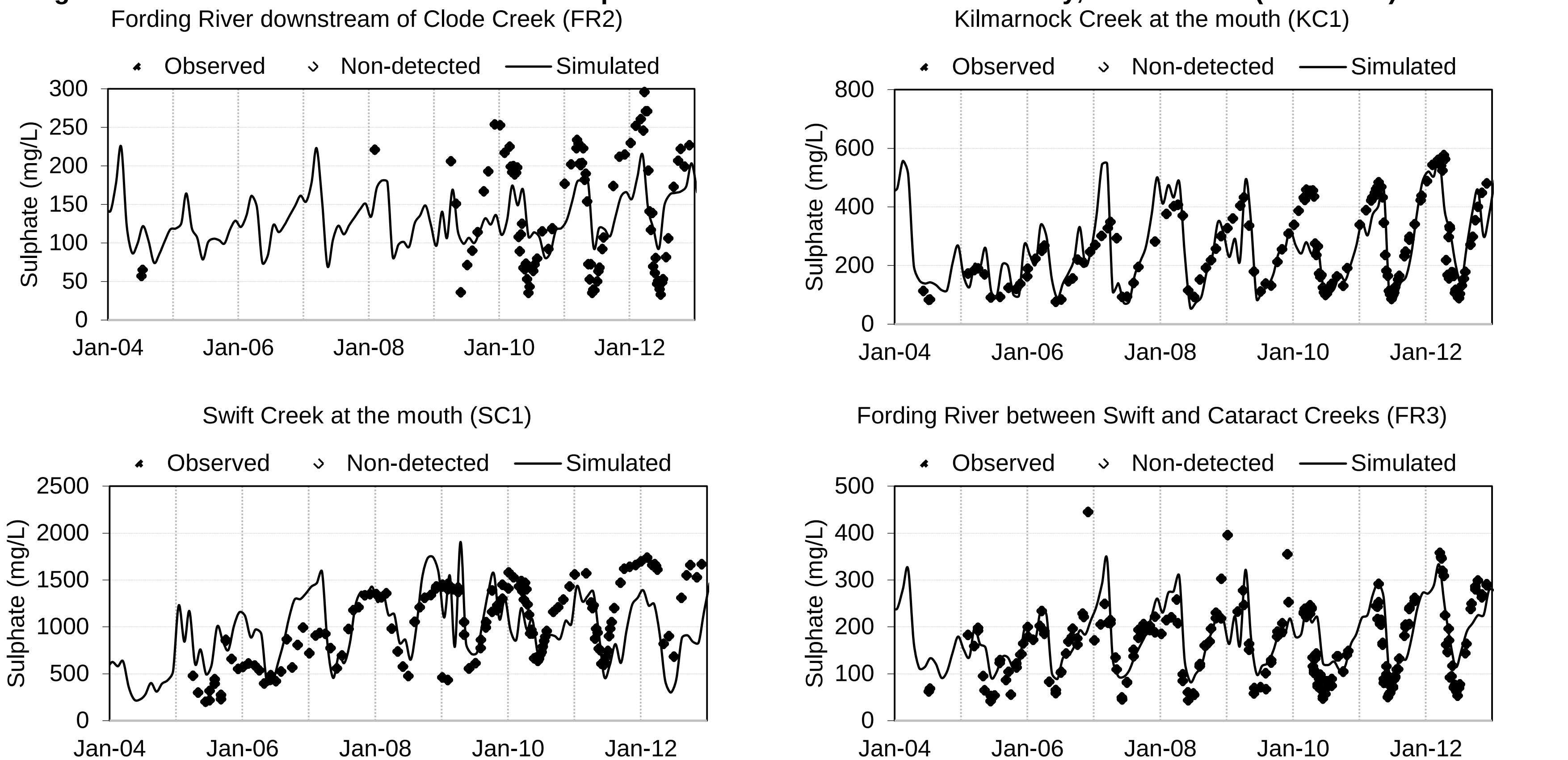


Figure A-2 Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012 (continued)

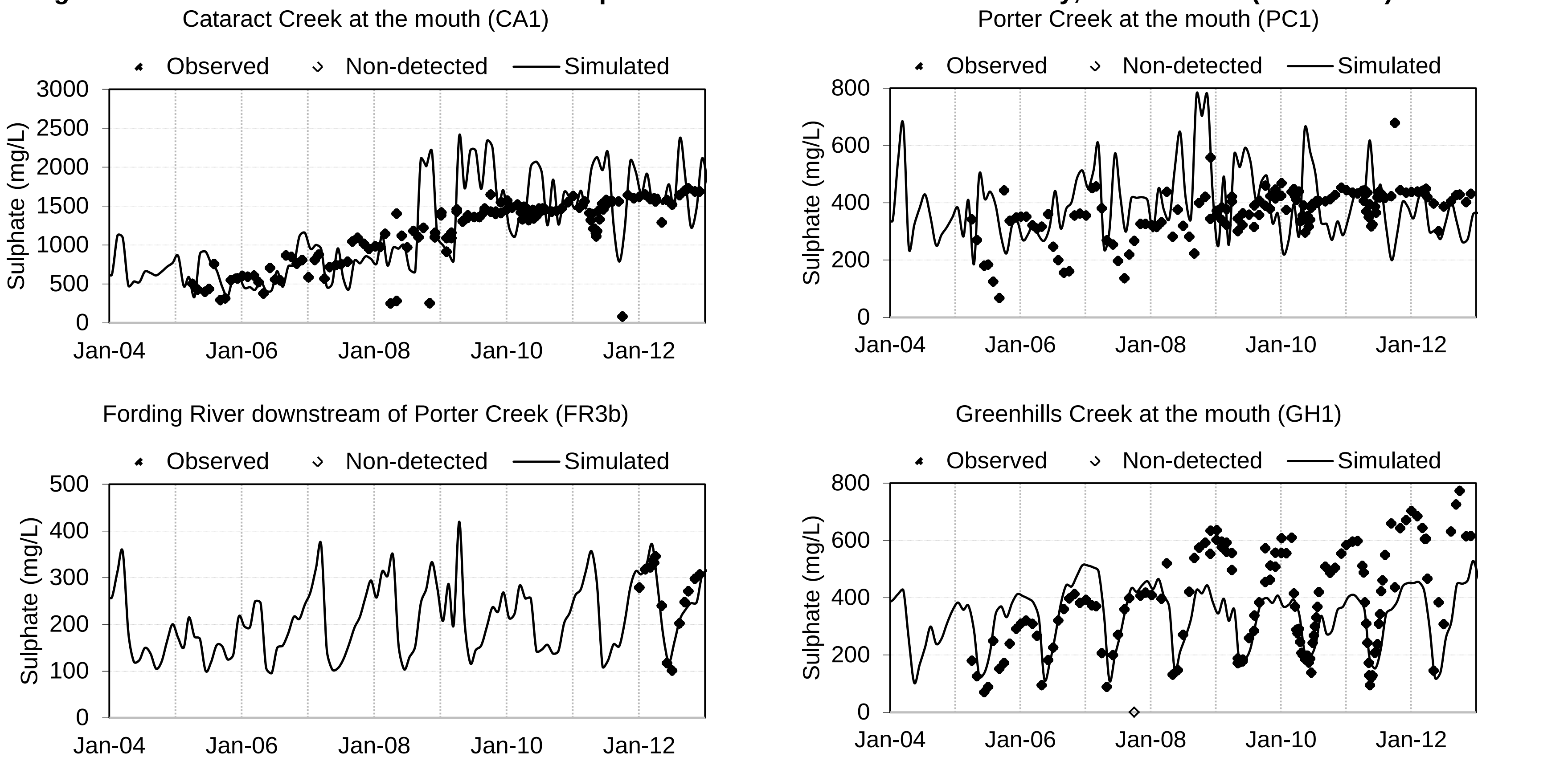
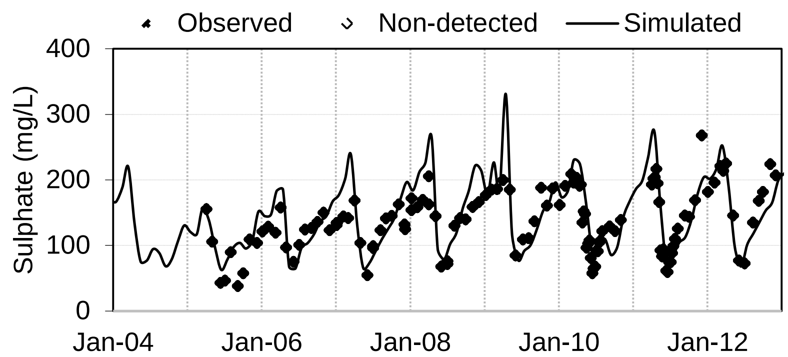
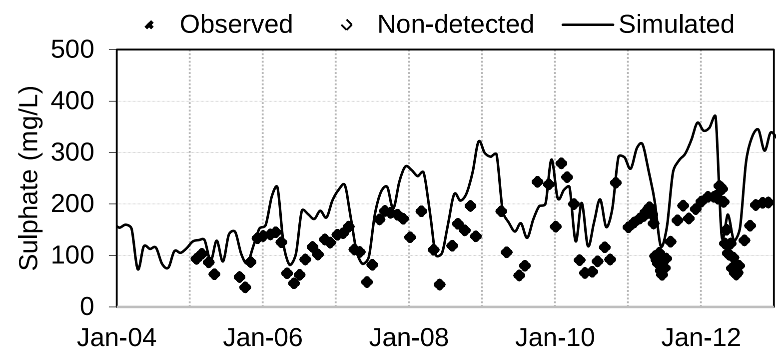


Figure A-2 Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012 (continued)

Fording River downstream of Greenhills Creek (FR4)

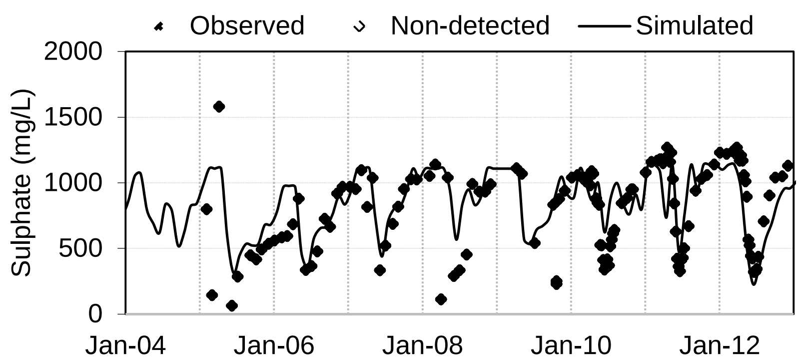


Line Creek upstream of West Line Creek (LC_US_WLC)



Note: One observed data point is not shown, a measurement of 1180 mg/L that was recorded on March 14, 2011

West Line Creek at the mouth (WLC1)



Line Creek at the mouth (LC1)

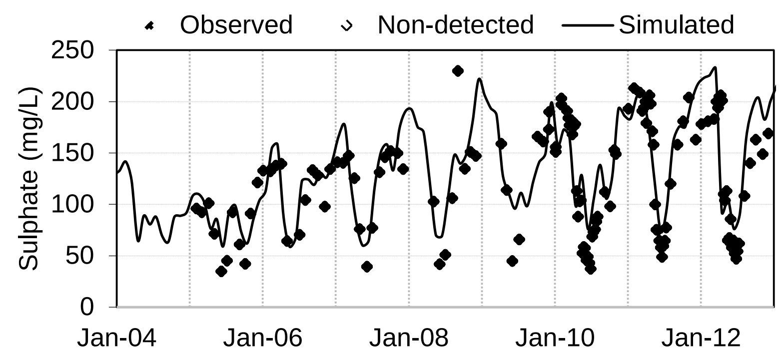
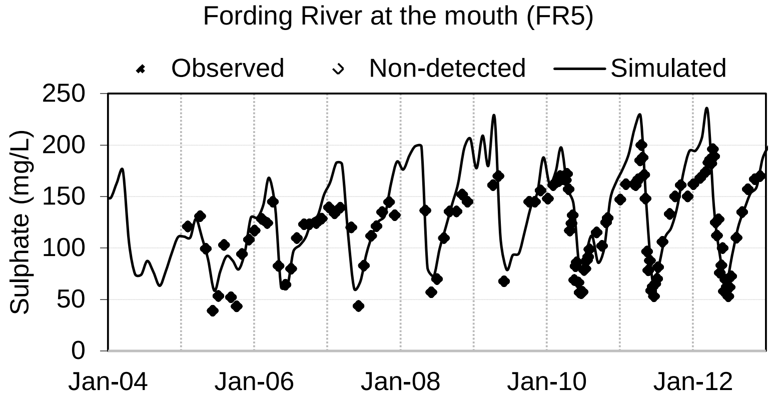
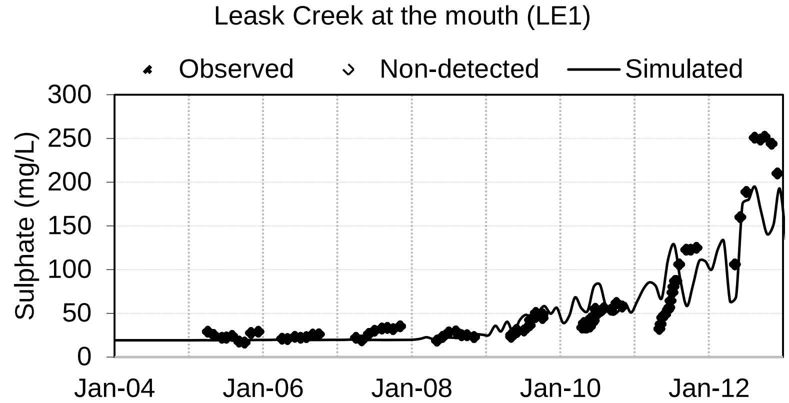
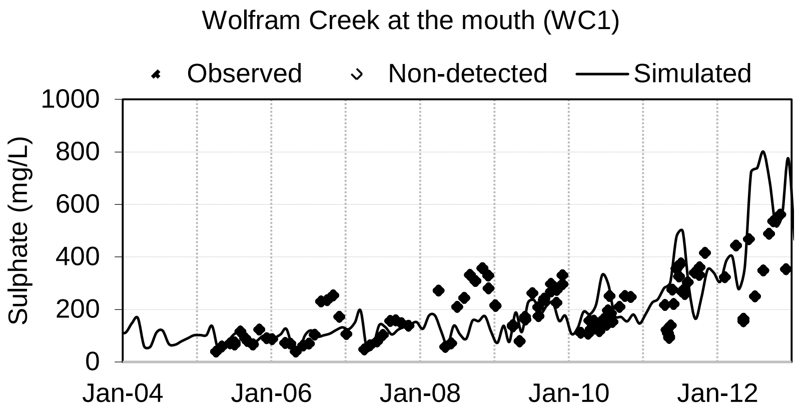


Figure A-2 Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012 (continued)







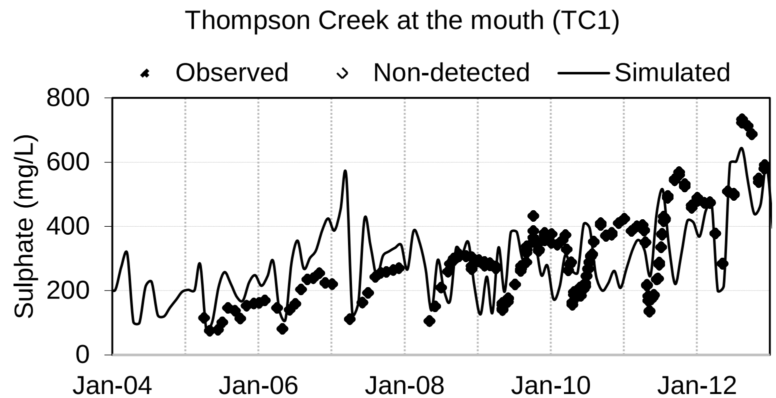
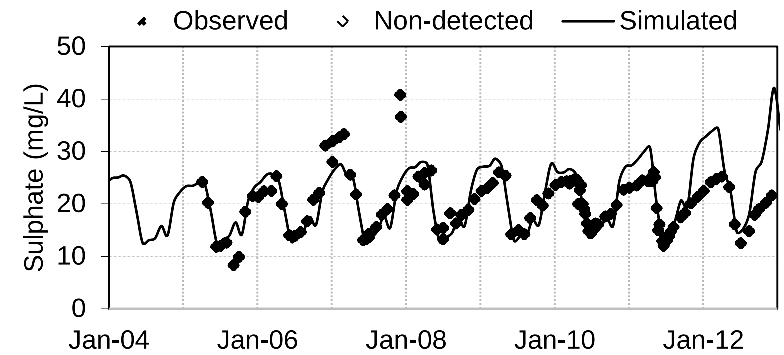
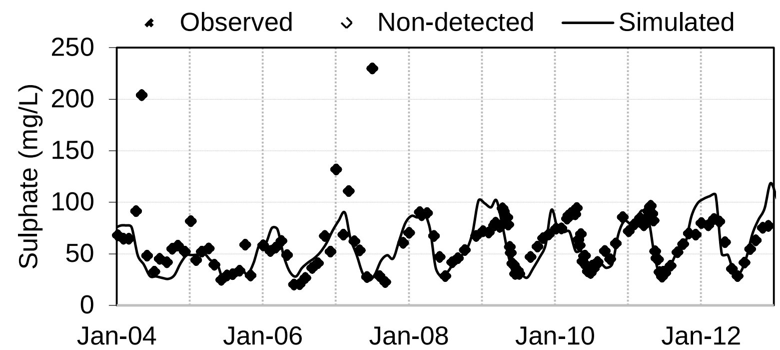


Figure A-2 Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012 (continued)

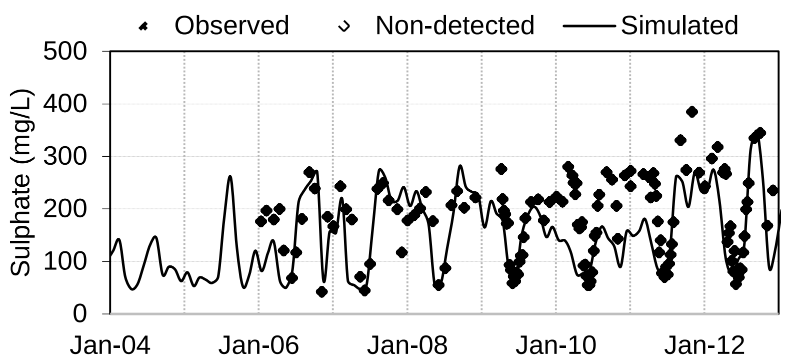
Elk River downstream of Greenhills Operations (ER1)



Elk River downstream of Fording River (ER2)



Michel Creek downstream of Coal Mountain Operations (MC5)



Michel Creek upstream of Elkview Operations (MC3)

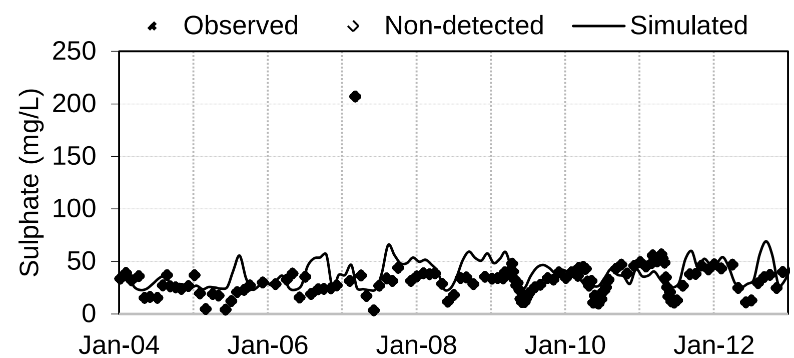
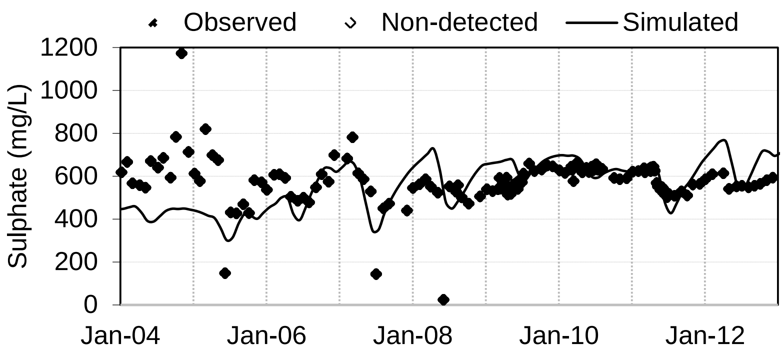
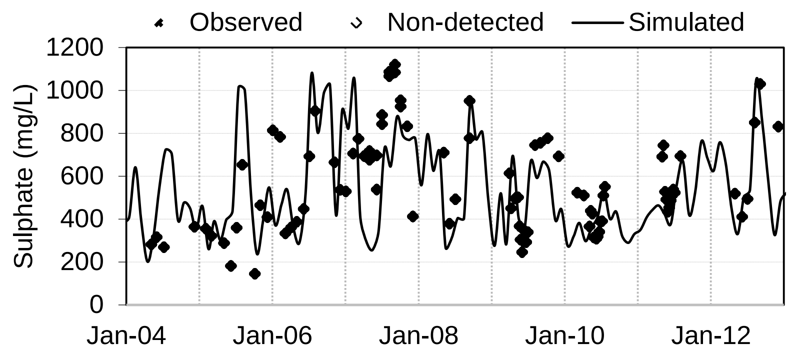


Figure A-2 Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012 (continued)

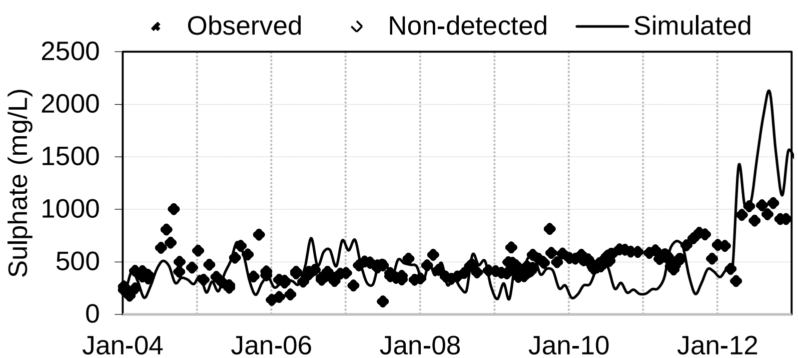
Erickson Creek at the mouth (EC1)



Gate Creek at the mouth (GT1)



Bodie Creek at the mouth (BC1)



Michel Creek at the mouth (MC1)

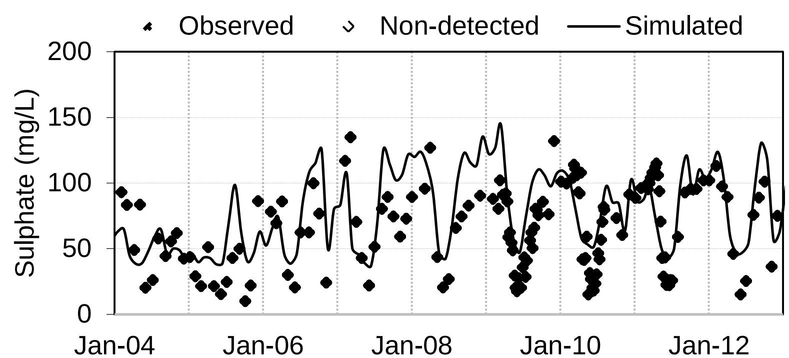
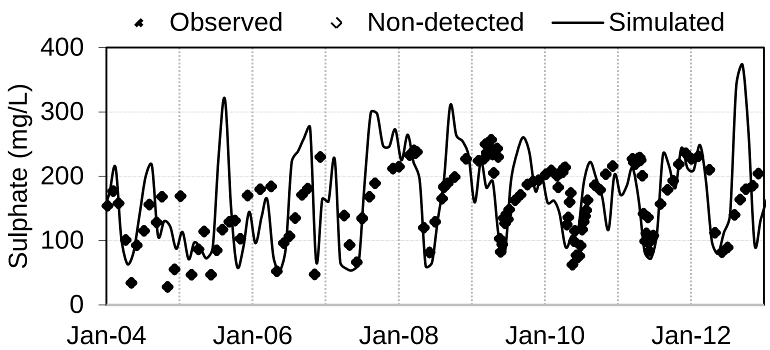
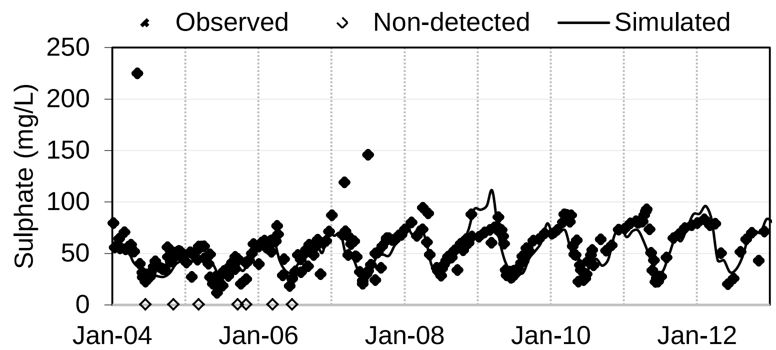
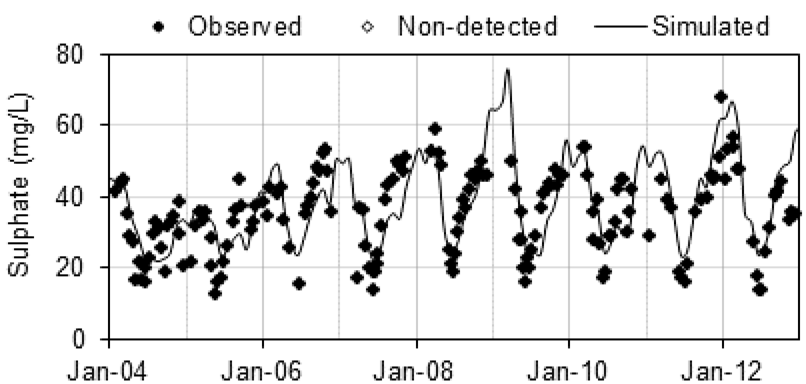


Figure A-2 Simulated and Observed Sulphate Concentrations in the Elk Valley, 2004 to 2012 (continued)





Note: One observed data point is not shown, a measurement of 537 mg/L that was recorded on June 03, 2008.



Note: Data shown correspond to those available when the model was re-calibrated.

Figure A-3 **Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012**

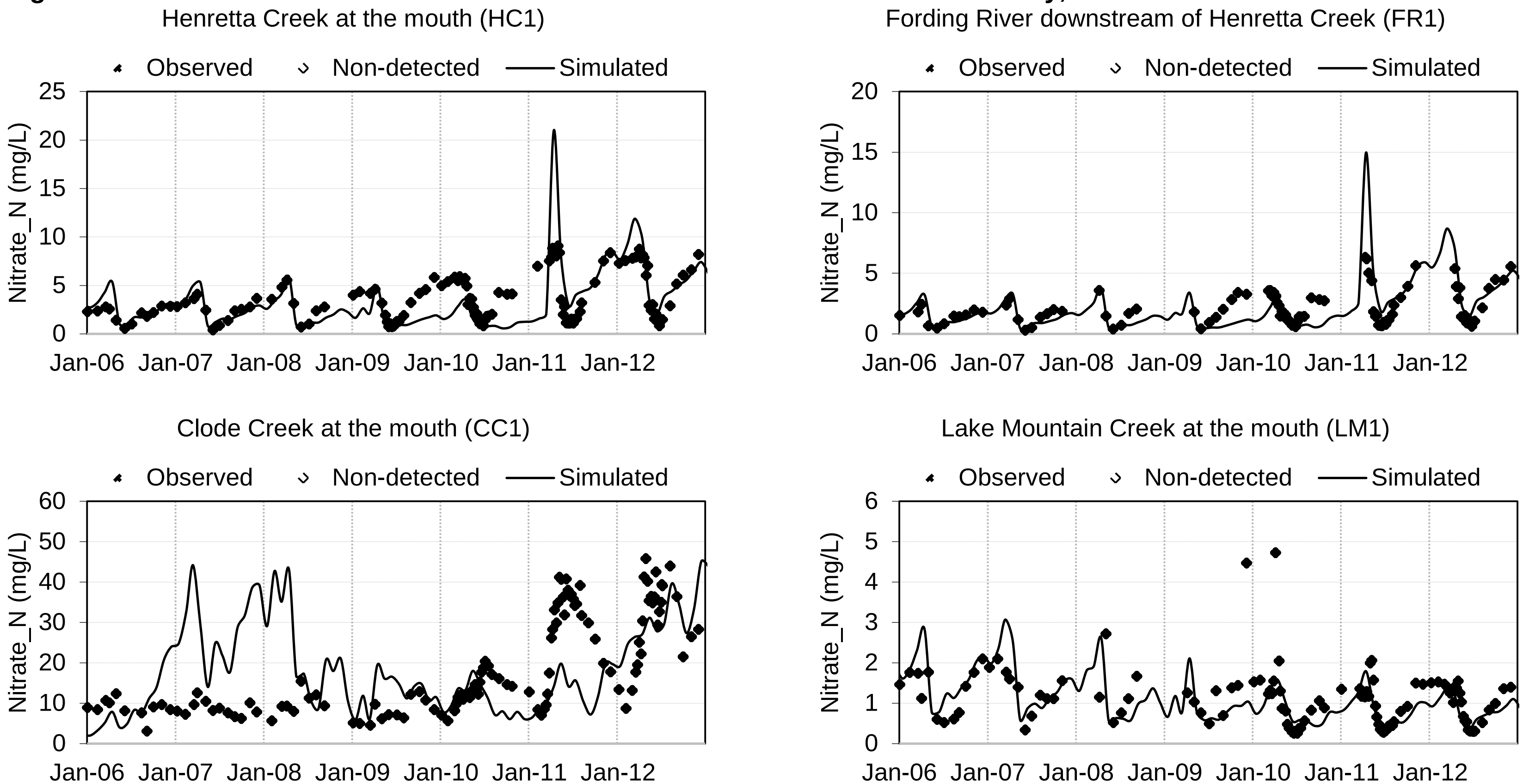


Figure A-3 Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012 (continued)

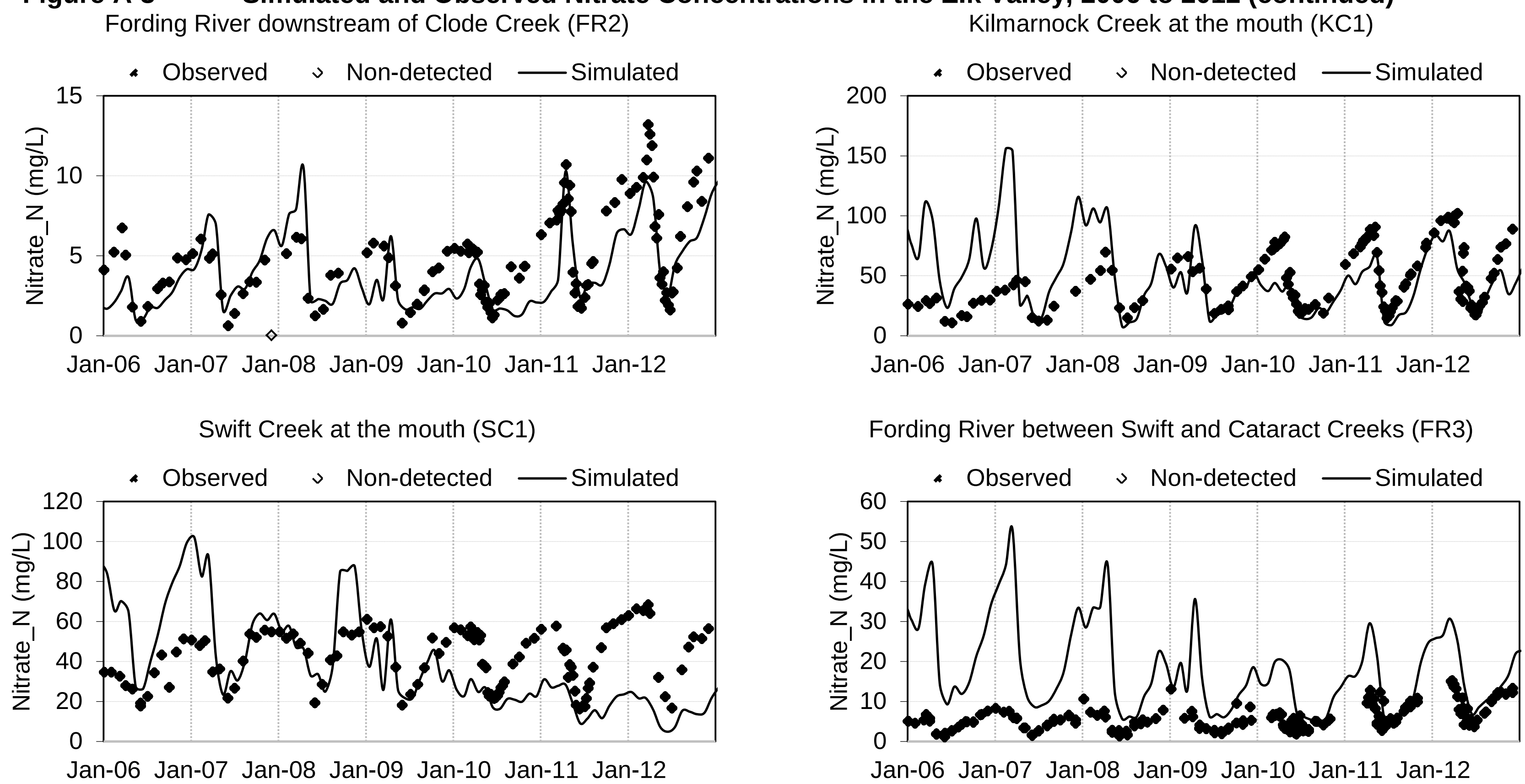


Figure A-3 Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012 (continued)

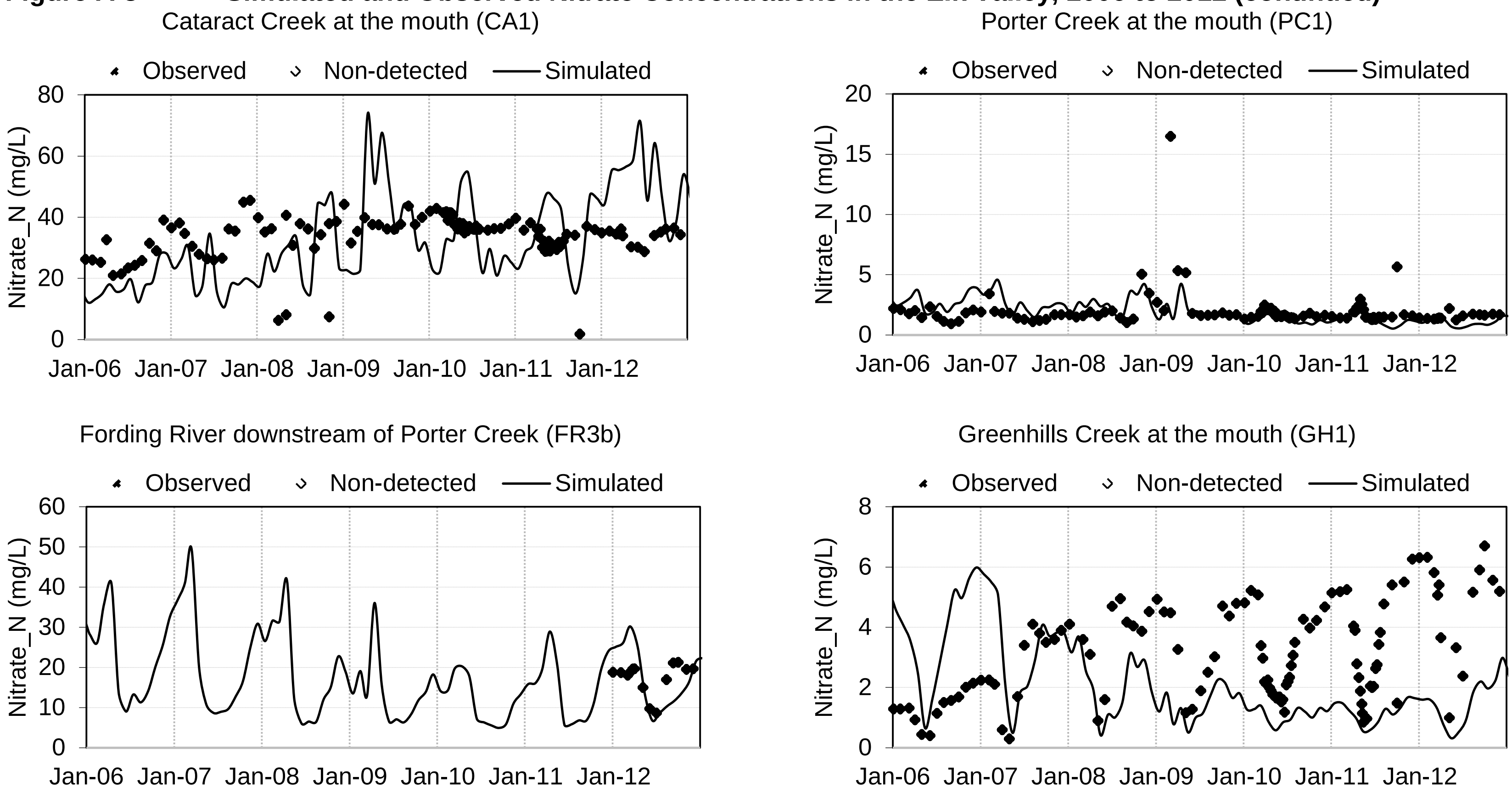


Figure A-3 Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012 (continued)

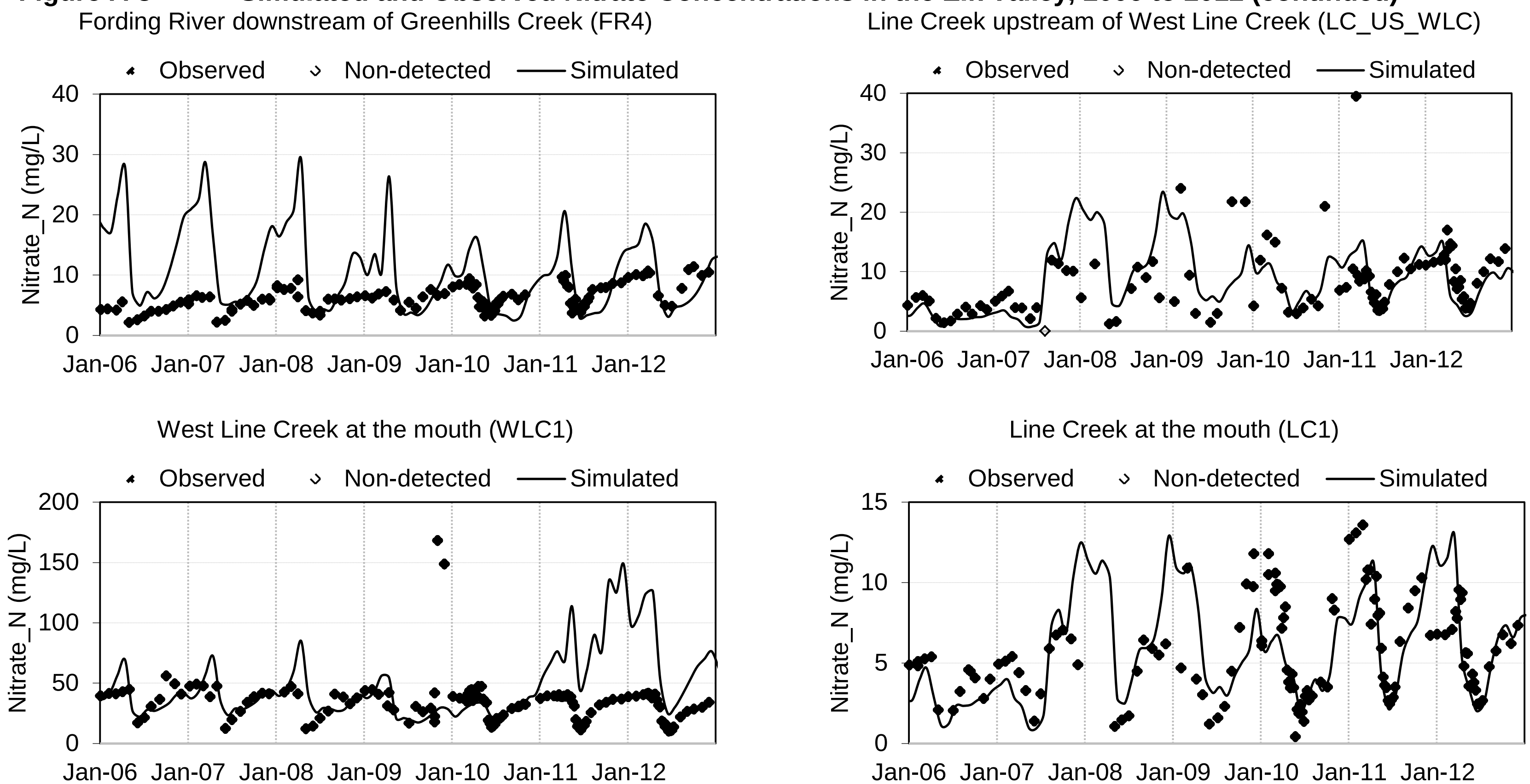
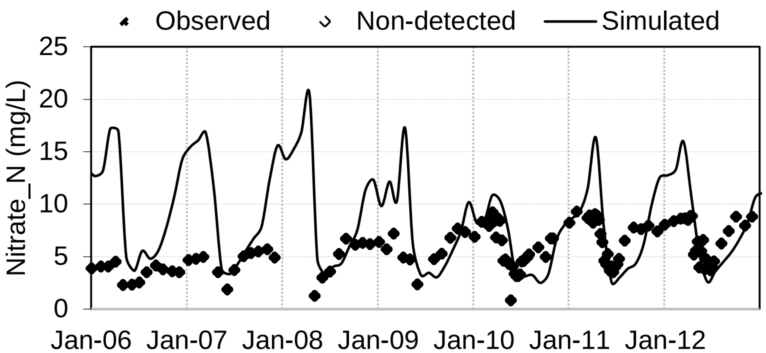
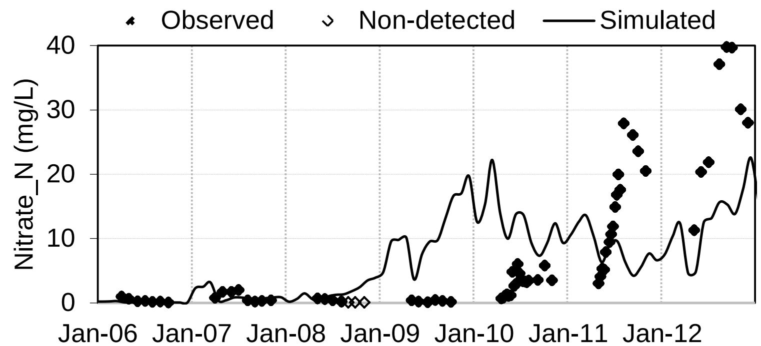


Figure A-3 Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012 (continued)

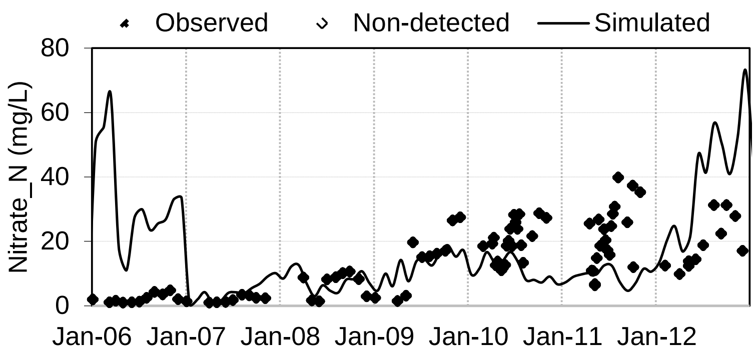
Fording River at the mouth (FR5)



Leask Creek at the mouth (LE1)



Wolfram Creek at the mouth (WC1)



Thompson Creek at the mouth (TC1)

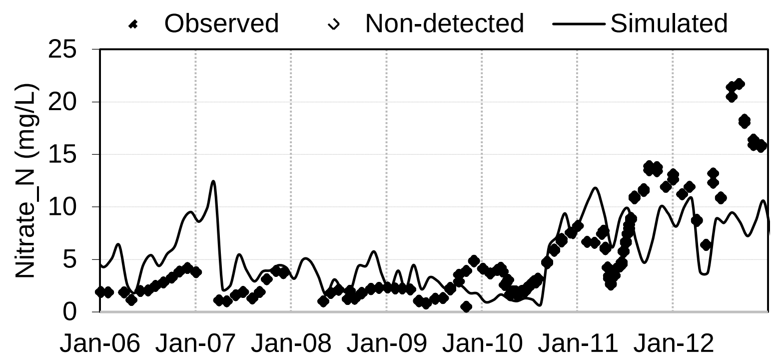


Figure A-3 Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012 (continued)

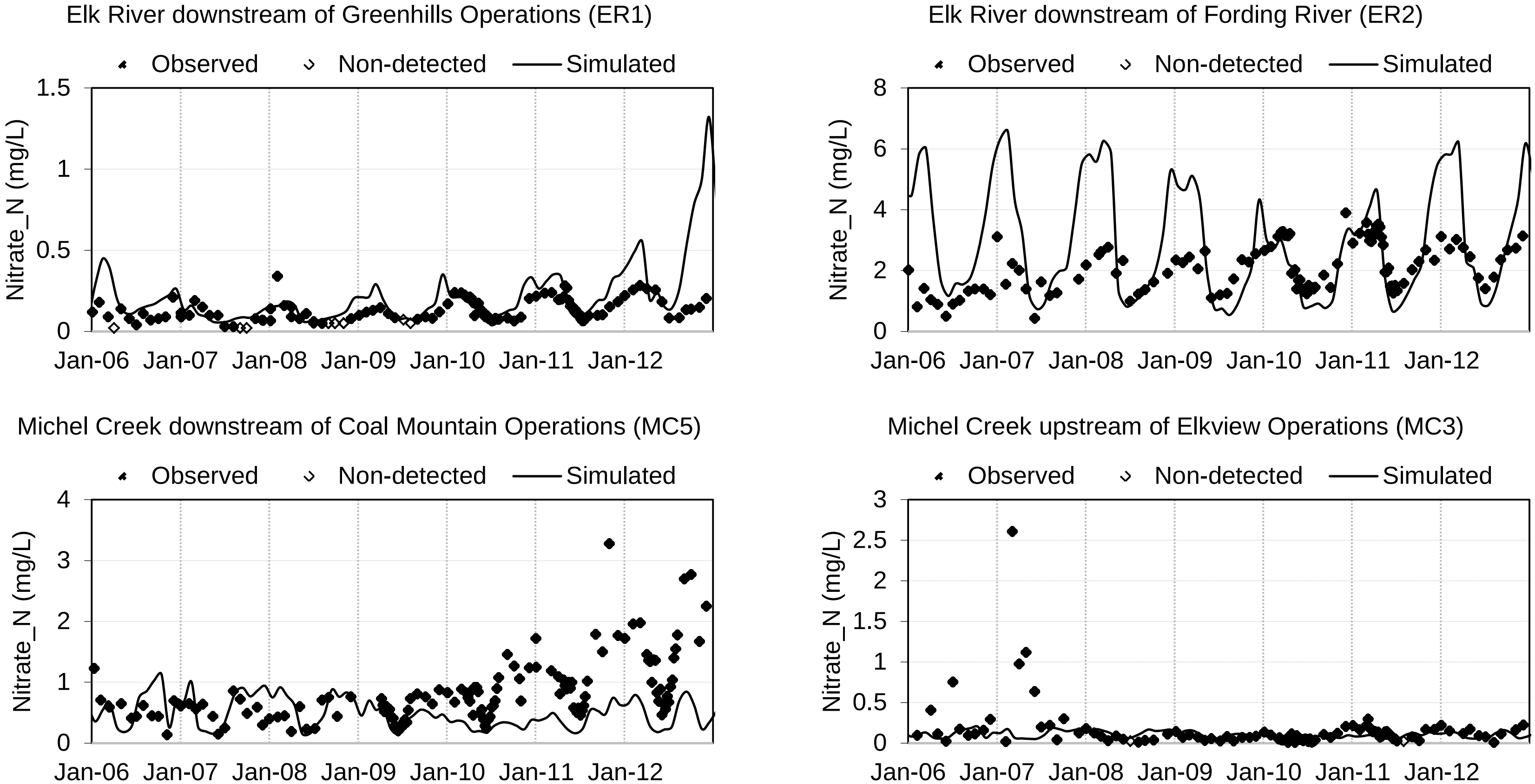
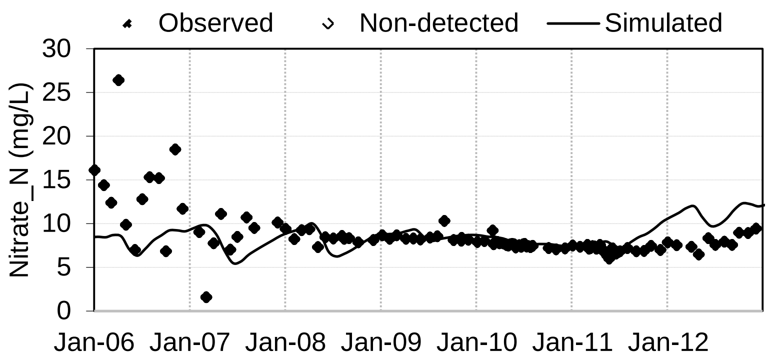
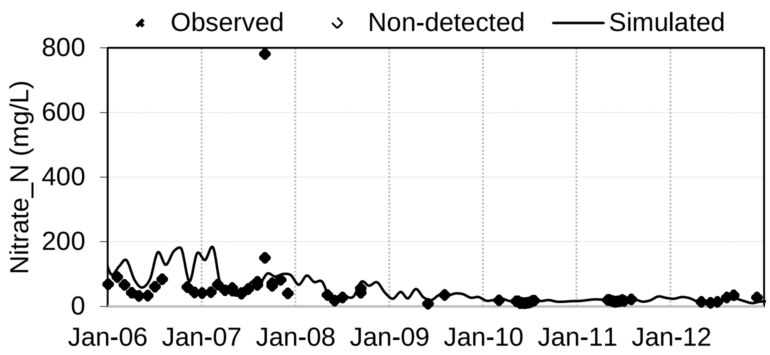


Figure A-3 Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012 (continued)

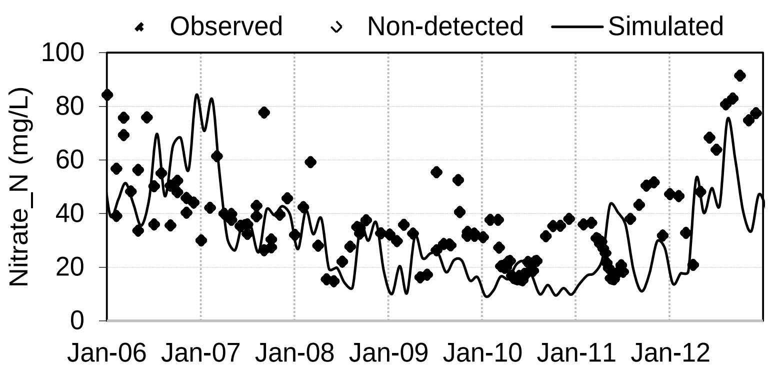
Erickson Creek at the mouth (EC1)



Gate Creek at the mouth (GT1)



Bodie Creek at the mouth (BC1)



Michel Creek at the mouth (MC1)

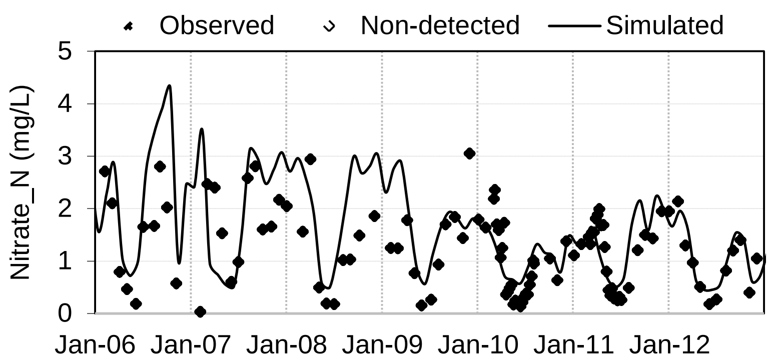
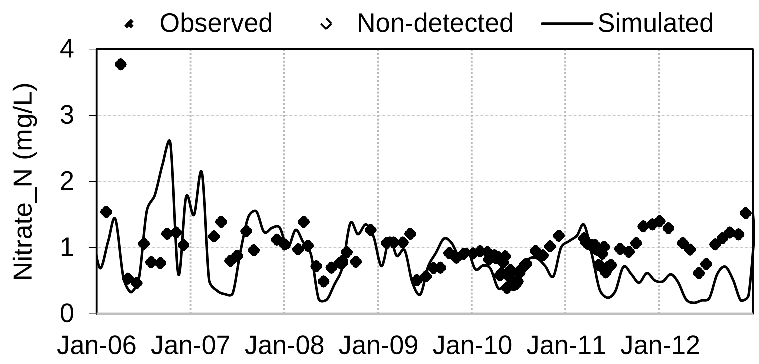
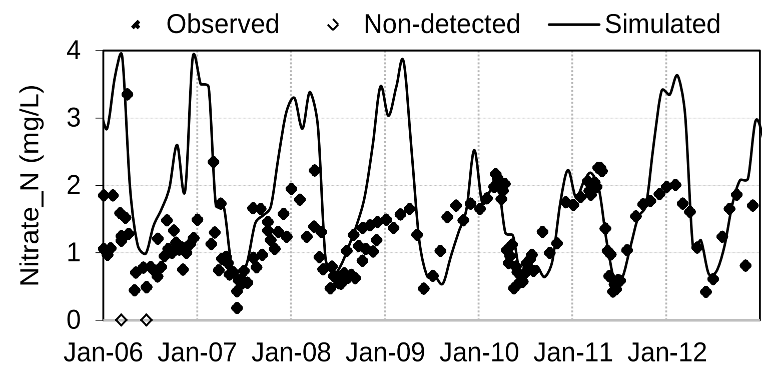


Figure A-3 Simulated and Observed Nitrate Concentrations in the Elk Valley, 2006 to 2012 (continued)

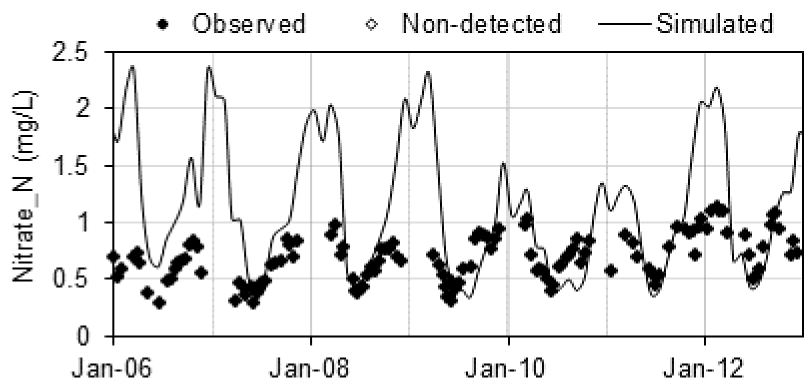
Harmer Creek at the mouth (HM1)



Elk River downstream of Michel Creek (ER3)



Elk River at the mouth (ER5)



Note: Data shown correspond to those available when the model was re-calibrated.

Figure A-4 **Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012**

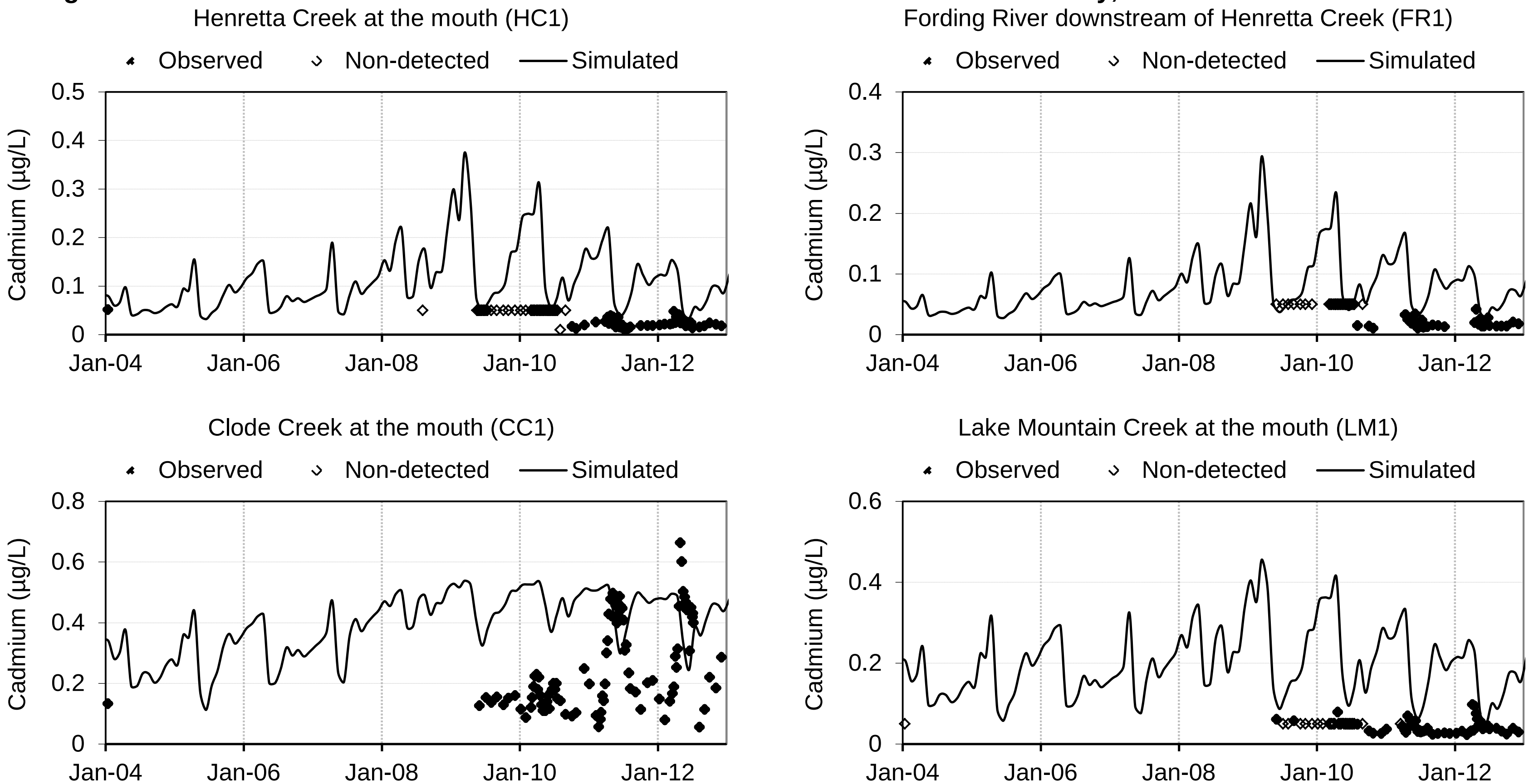


Figure A-4 Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012 (continued)

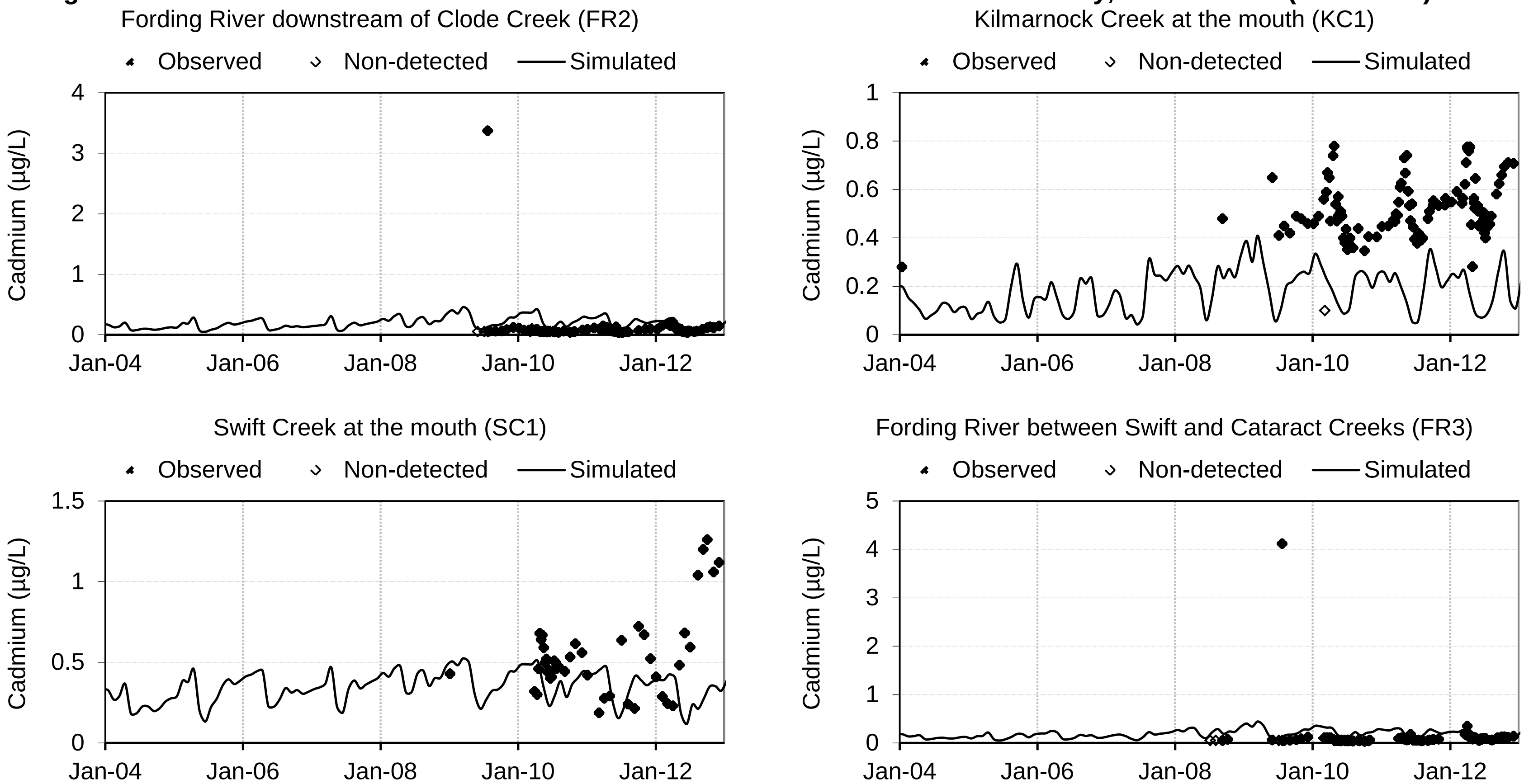


Figure A-4 Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012 (continued)

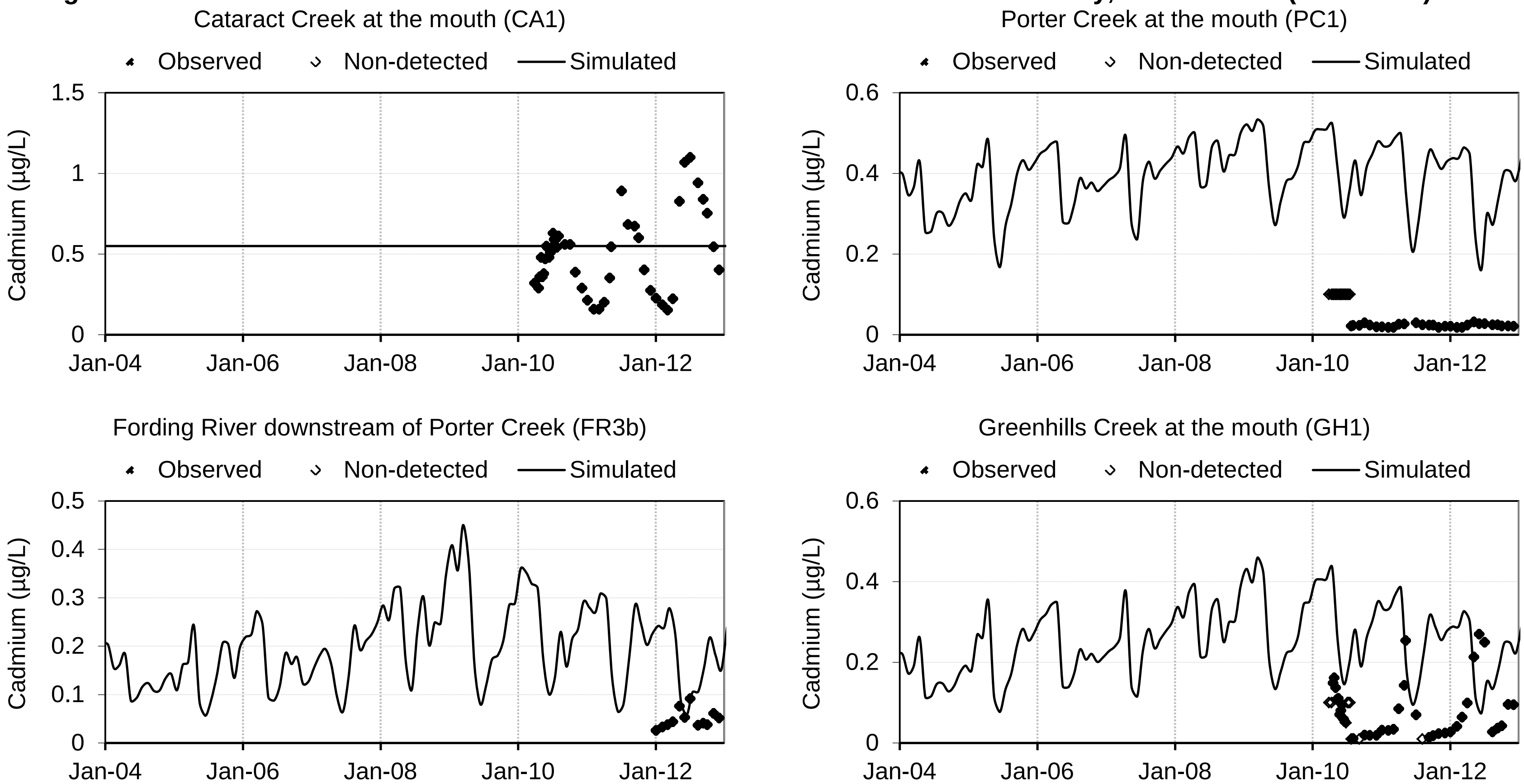


Figure A-4 Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012 (continued)

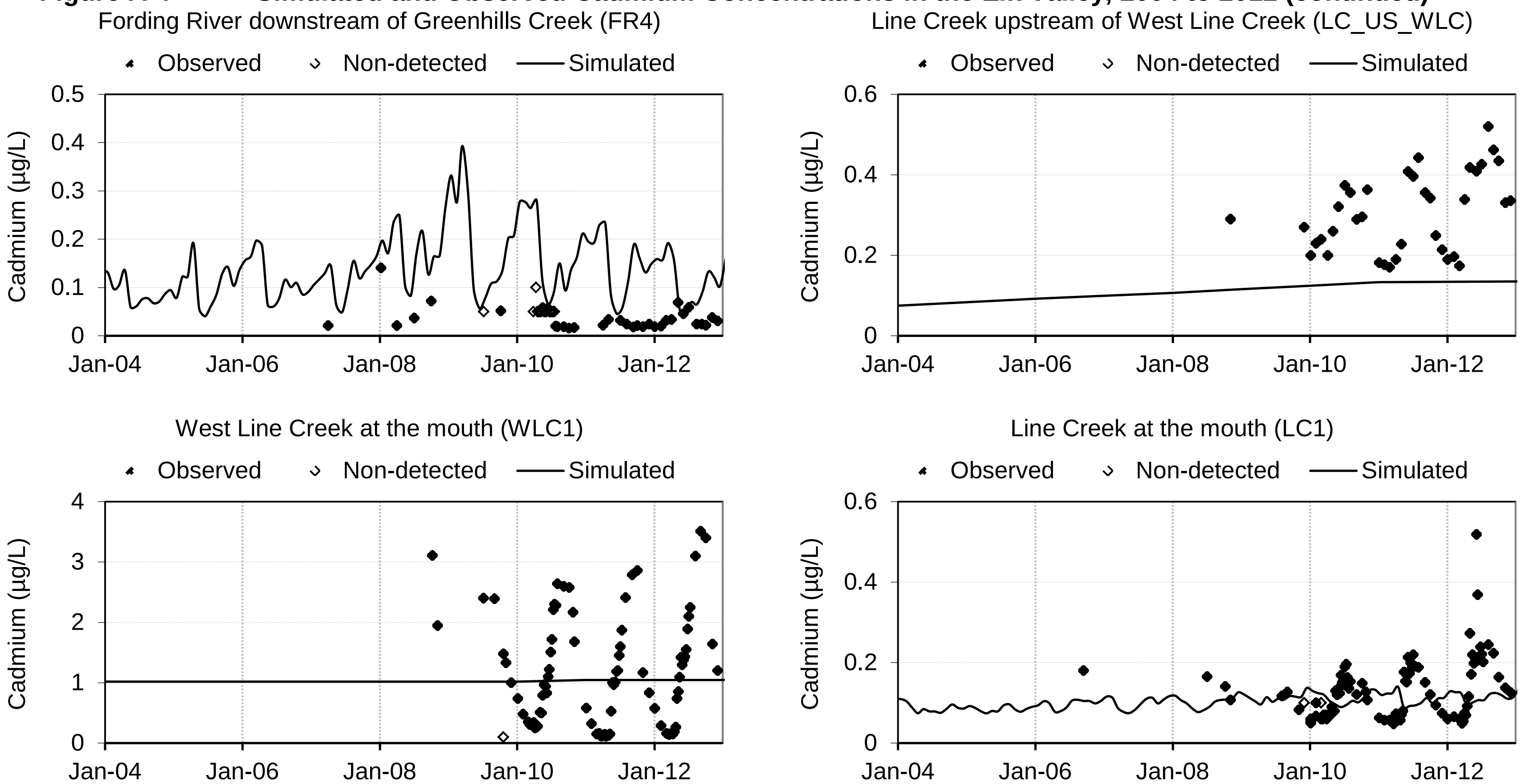


Figure A-4 Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012 (continued)

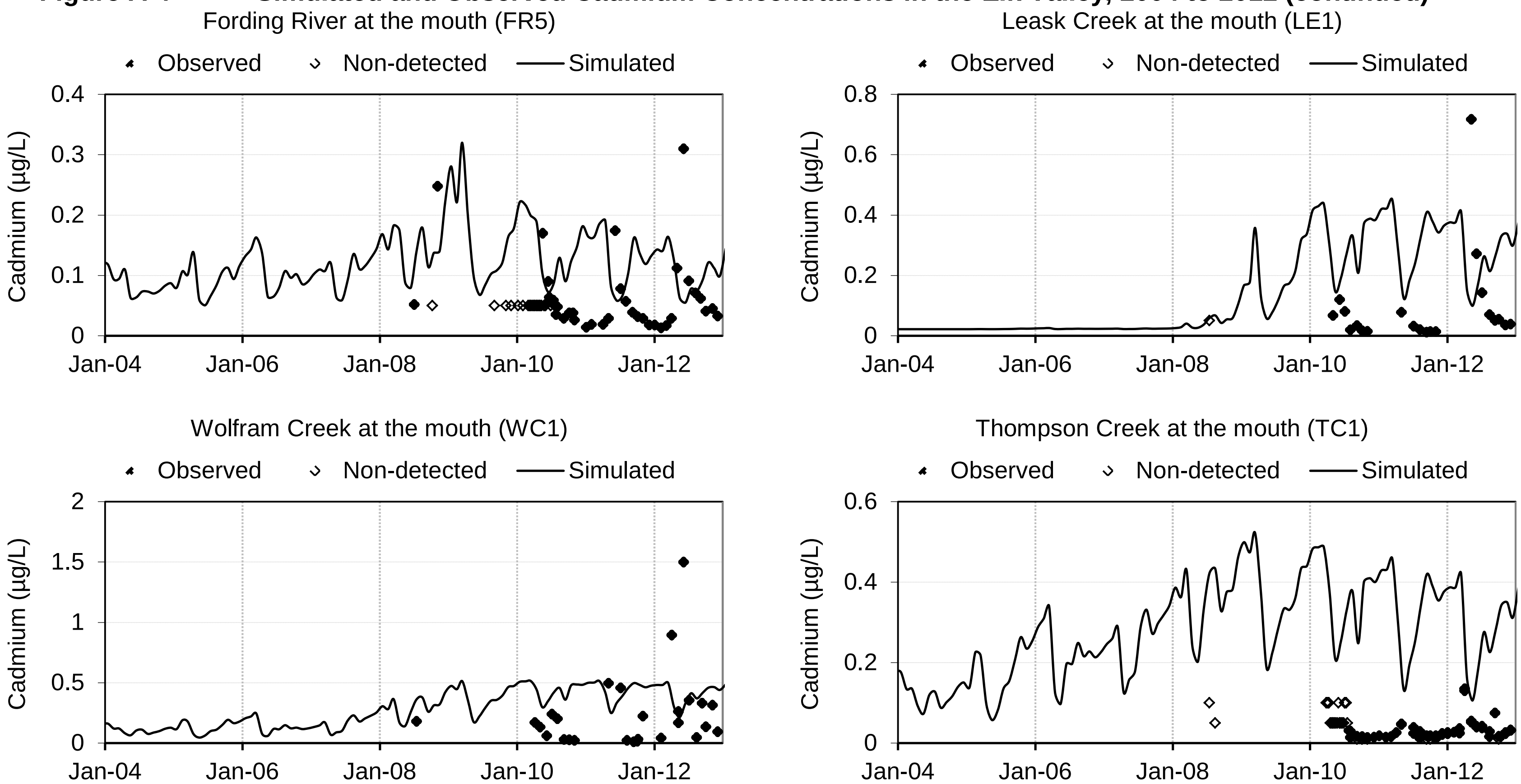


Figure A-4 Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012 (continued)

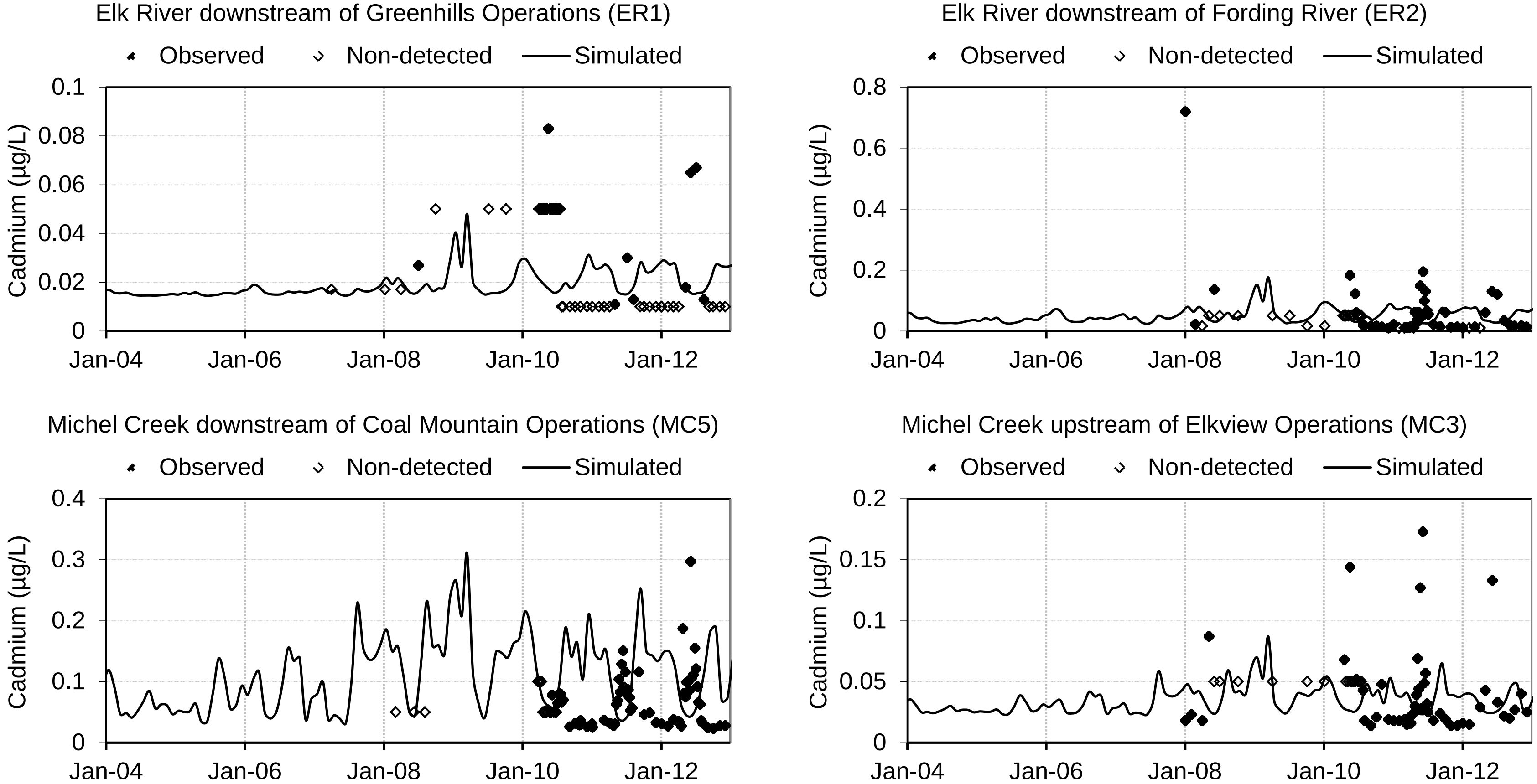


Figure A-4 Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012 (continued)

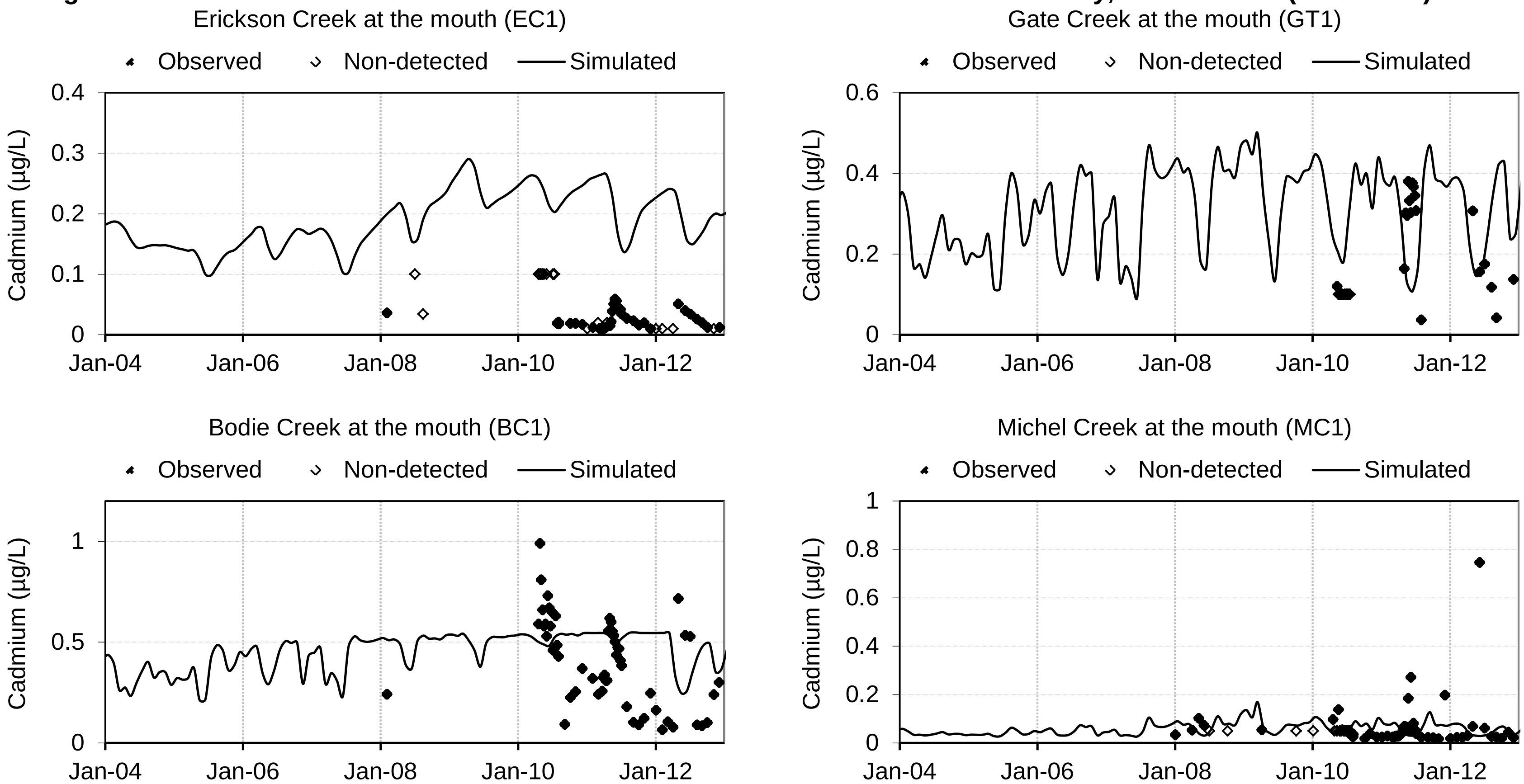
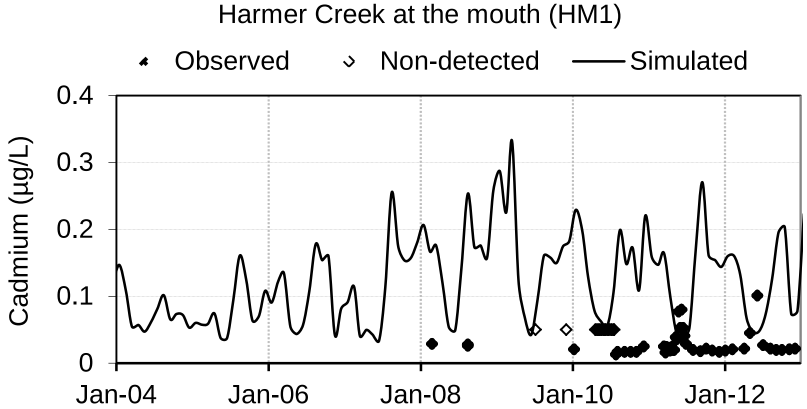
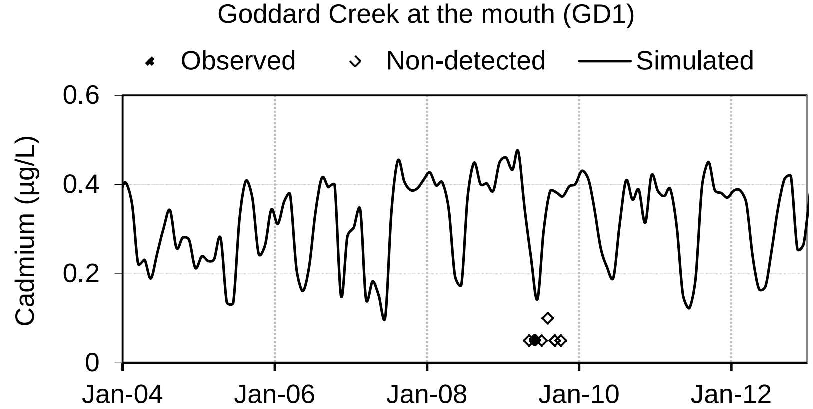
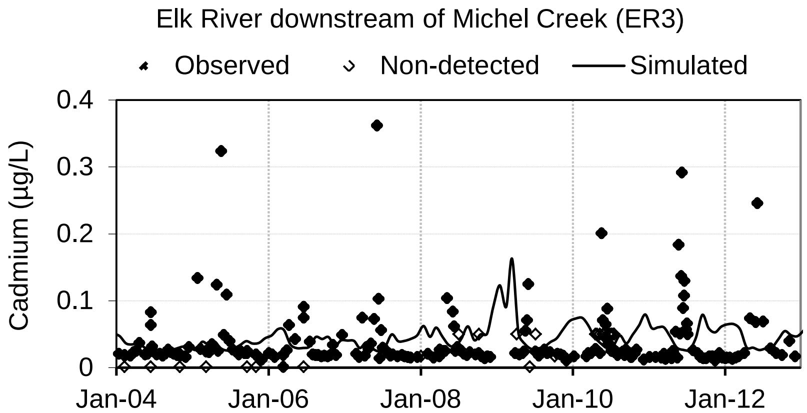
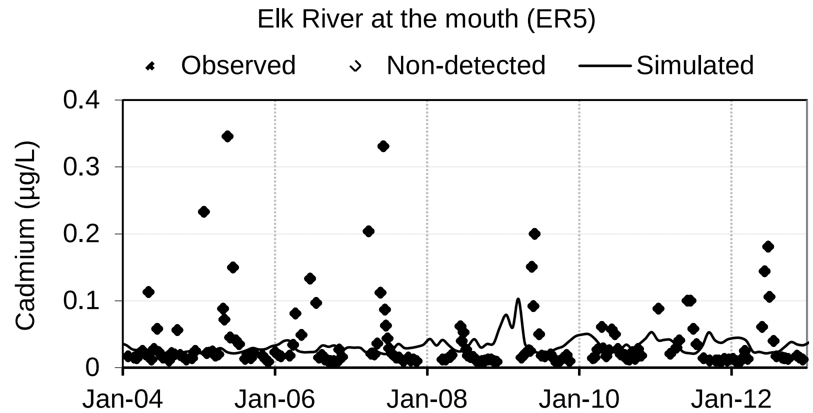


Figure A-4 Simulated and Observed Cadmium Concentrations in the Elk Valley, 2004 to 2012 (continued)









APPENDIX B

TOXICITY MODIFYING FACTORS

Appendix B contains eight figures that illustrate how simulated concentrations produced using the re-calibrated Elk Valley Water Quality Plan water quality model compared to those measured in the Fording River and Elk River mainstems and in mine-affected tributaries to those rivers. The period of record is from January 1, 2004 to December 31, 2012. The parameters of interest include:

- alkalinity
- calcium
- chloride
- hardness
- magnesium
- potassium
- sodium
- total dissolved solids (TDS).

Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012

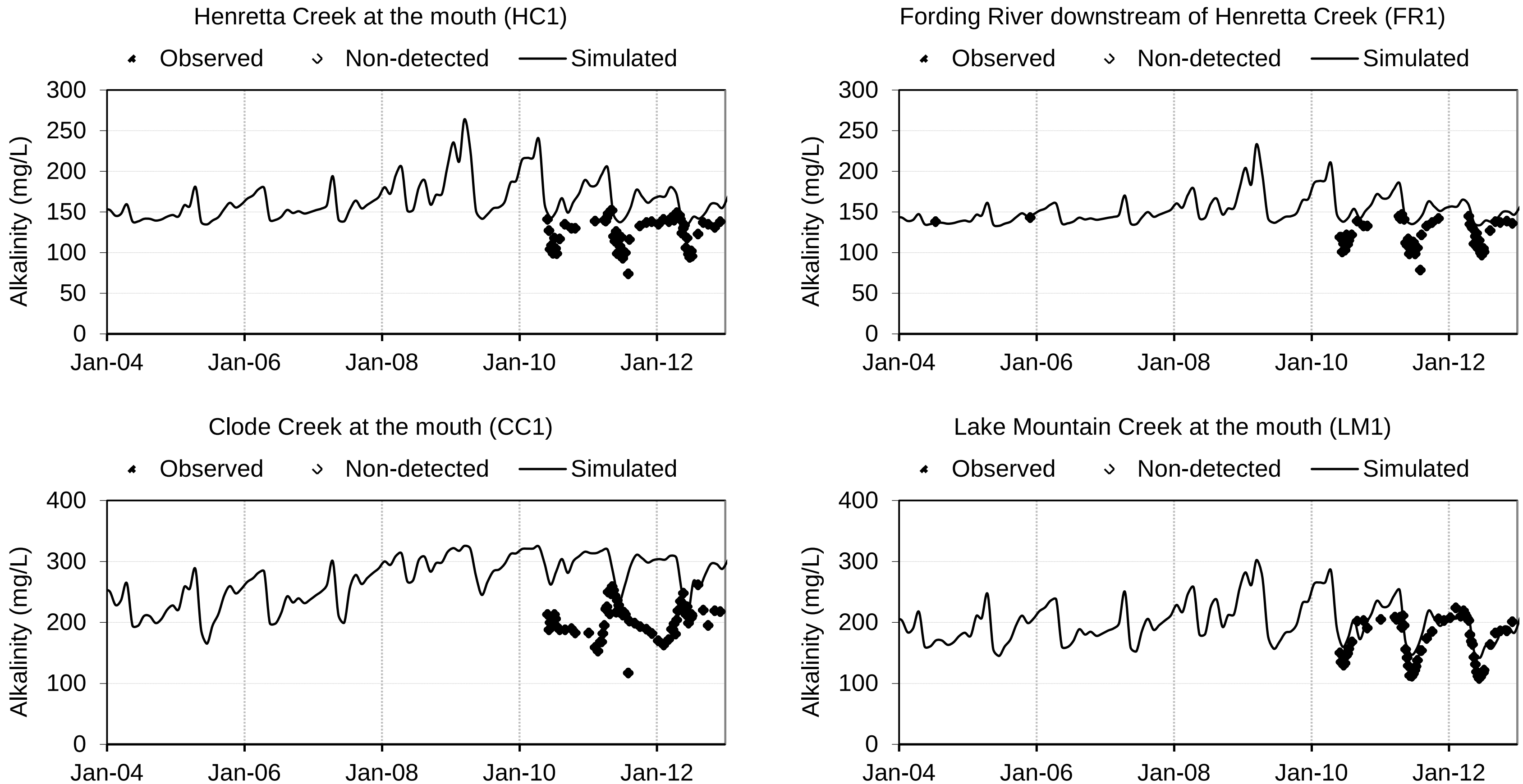


Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012

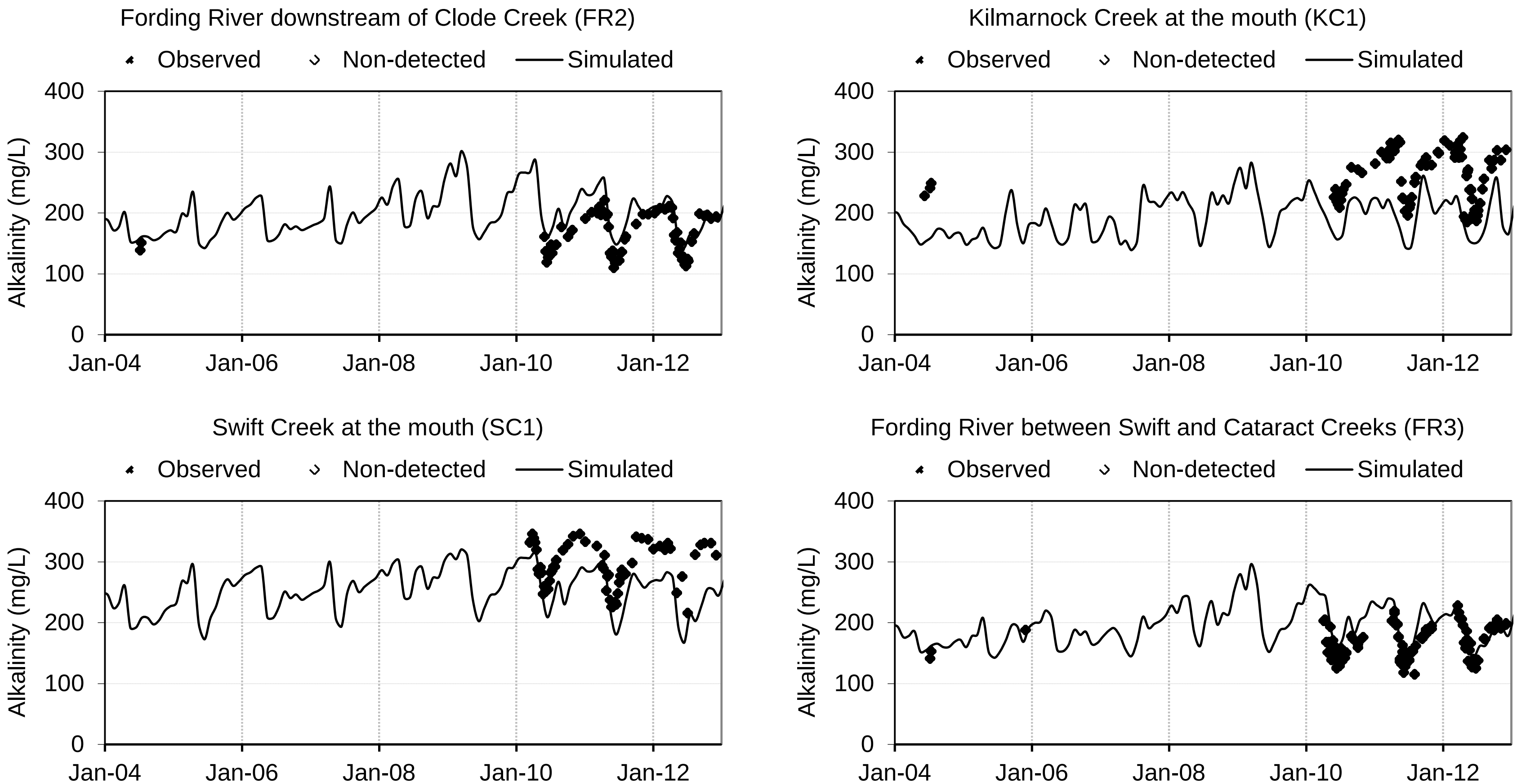
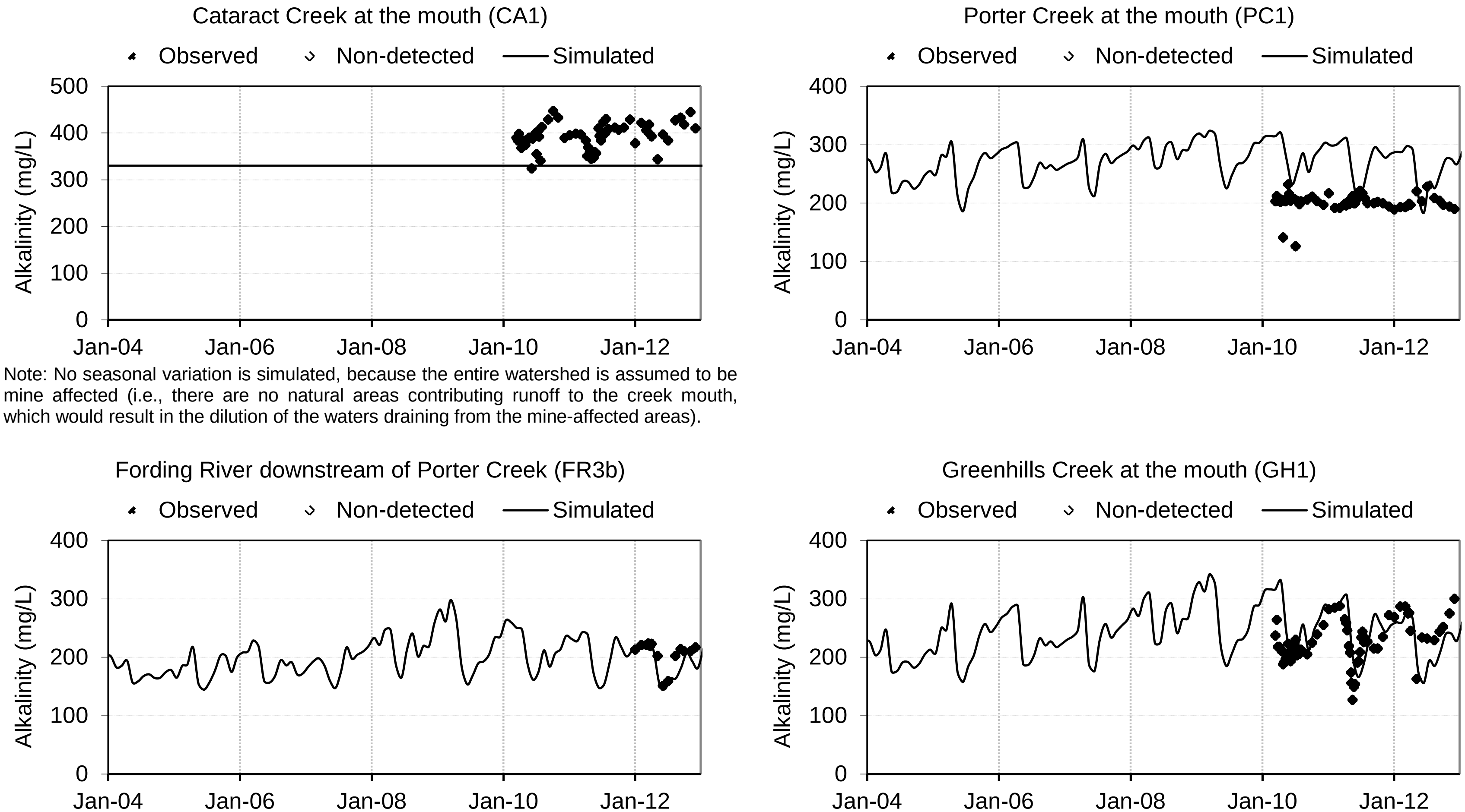
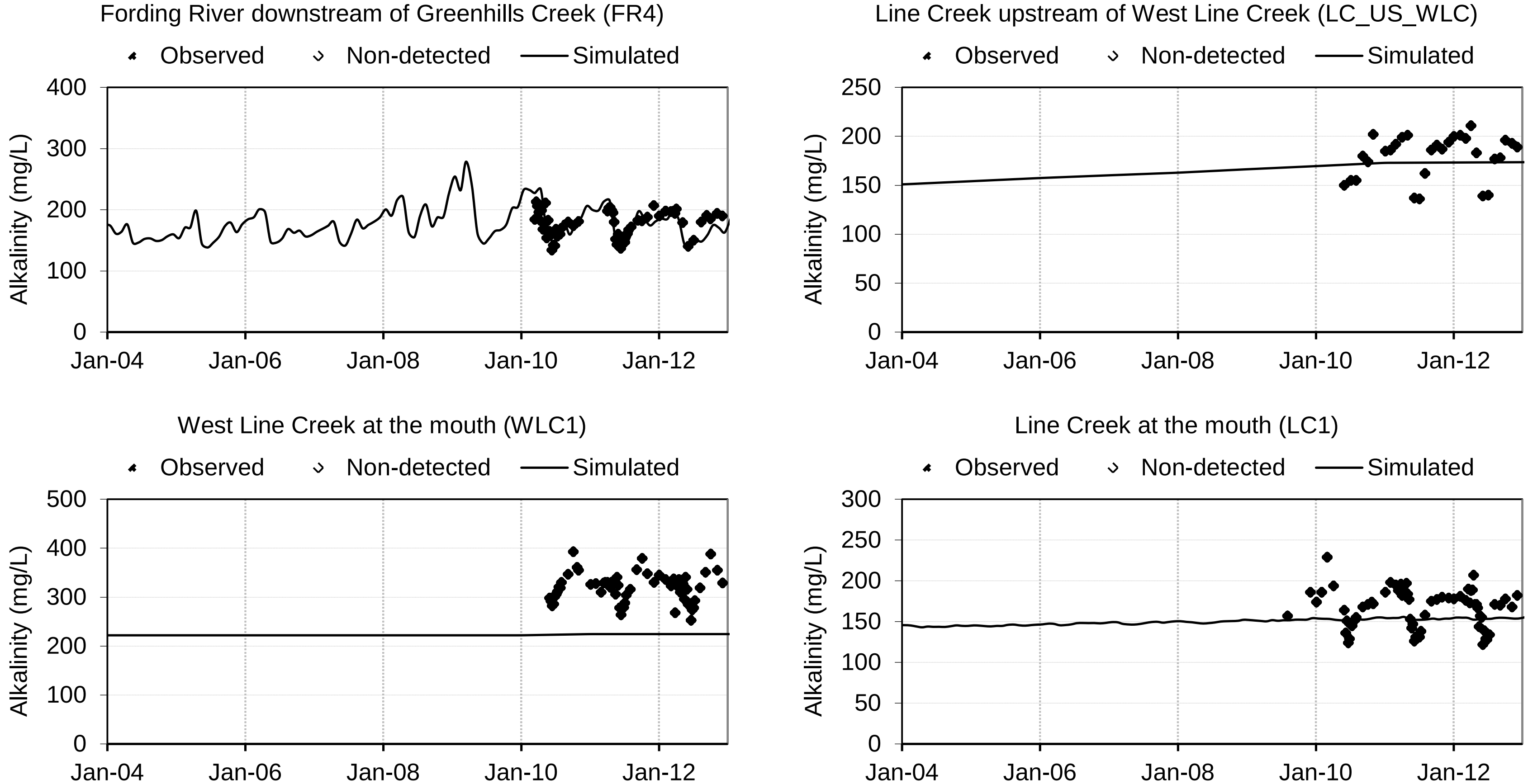


Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012



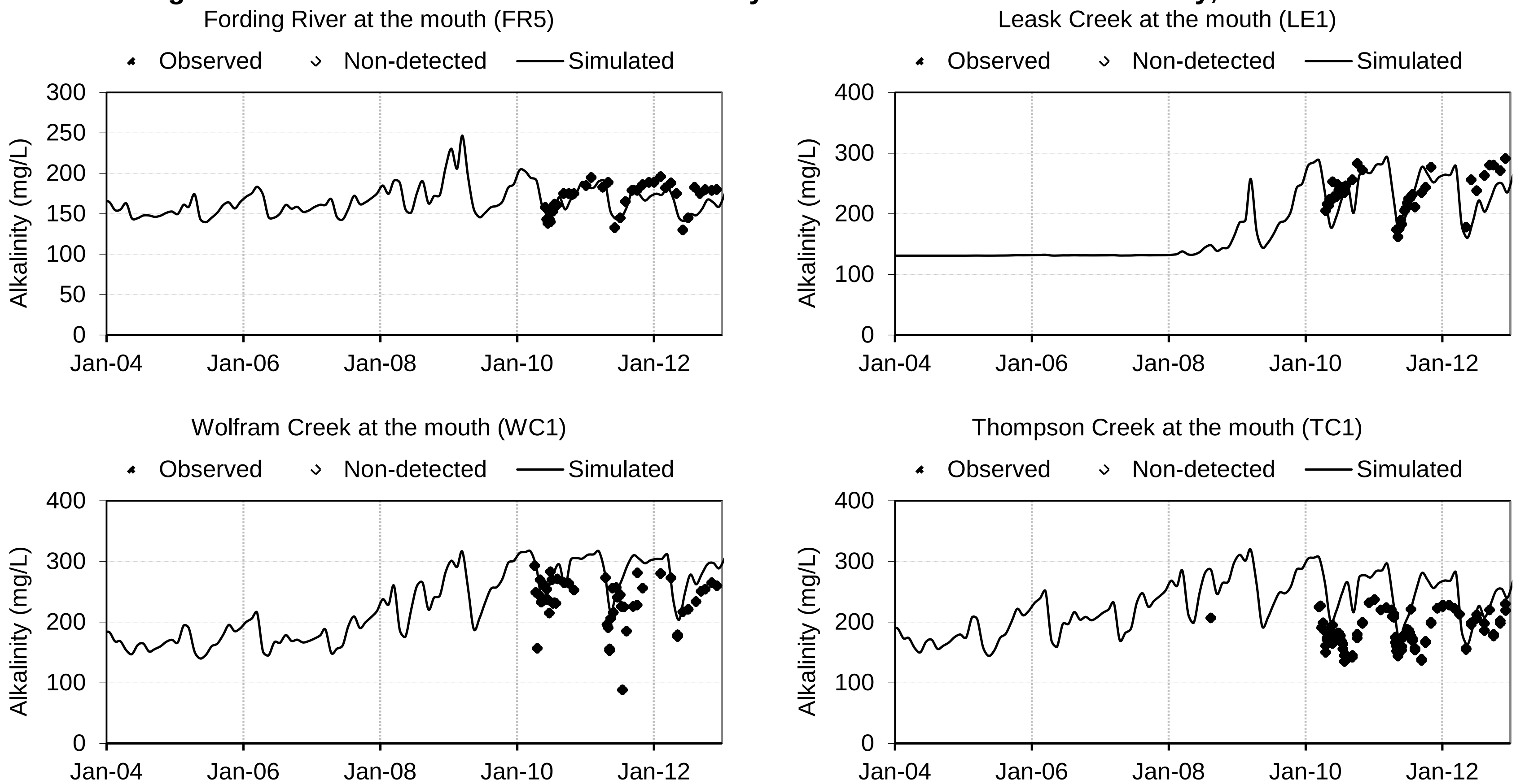
Note: No seasonal variation is simulated, because the entire watershed is assumed to be mine affected (i.e., there are no natural areas contributing runoff to the creek mouth, which would result in the dilution of the waters draining from the mine-affected areas).

Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012



No seasonal variation is simulated for Line Creek or West Line Creek, because for each of these creeks the natural and mine flows are assumed to follow the same seasonal pattern (i.e., the seasonal pattern observed at the mouth of the creek).

Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012



Teck

Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012

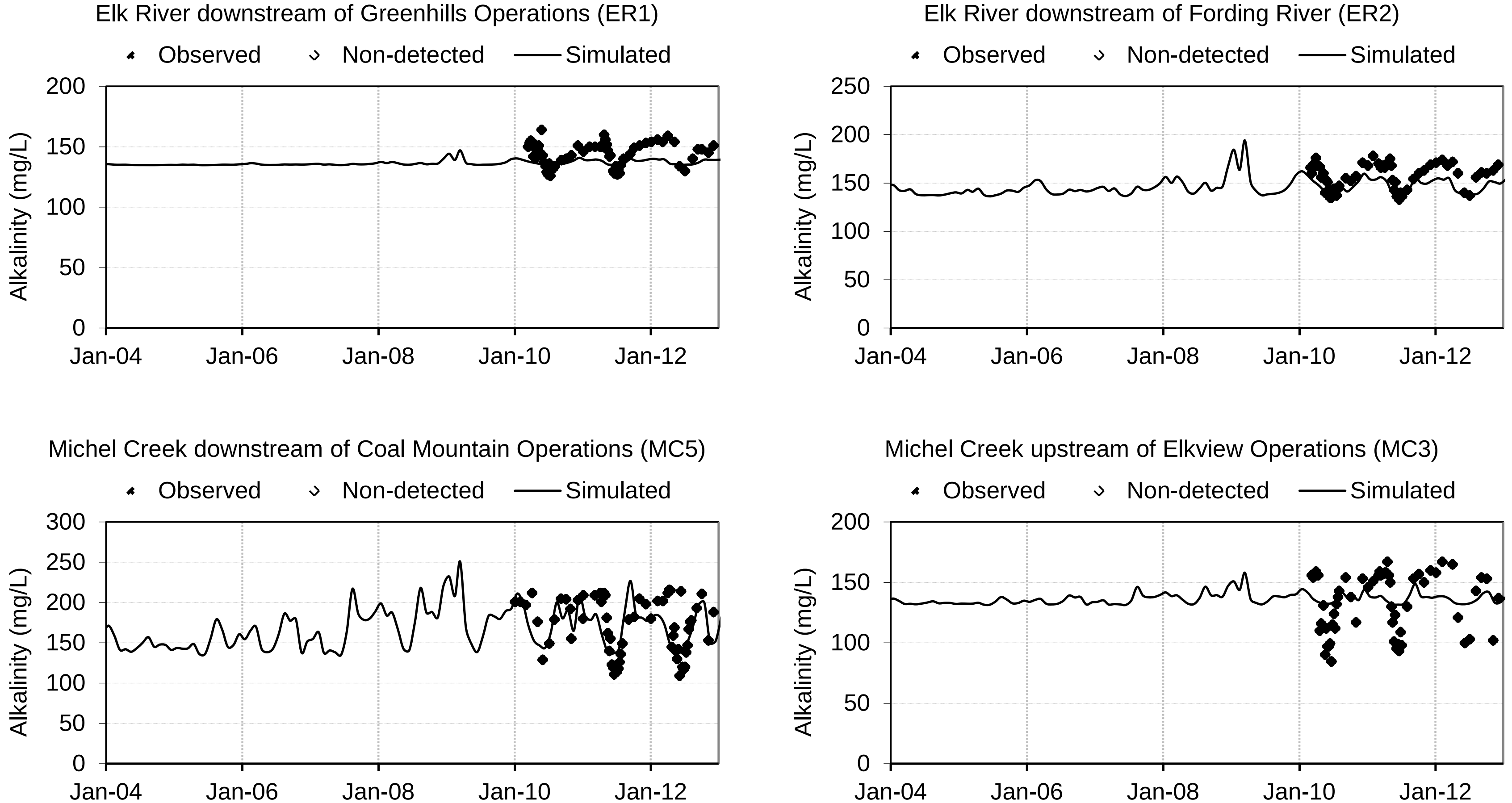


Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012

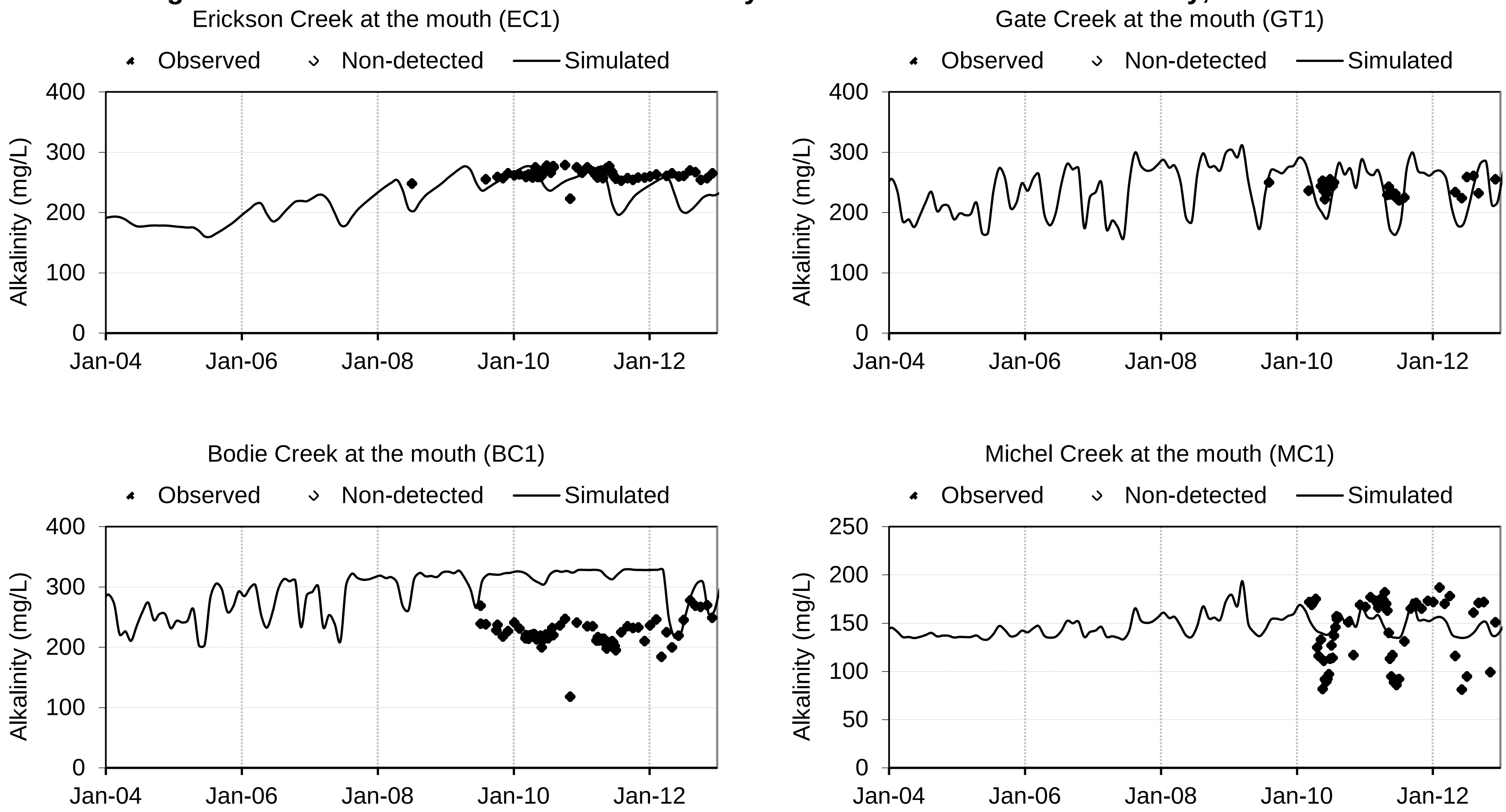
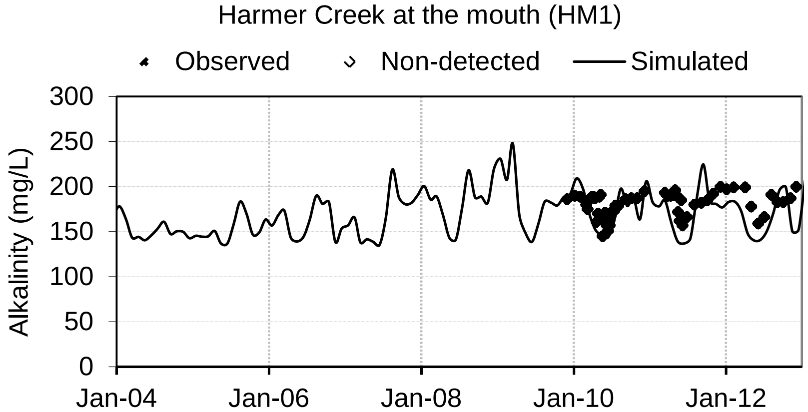
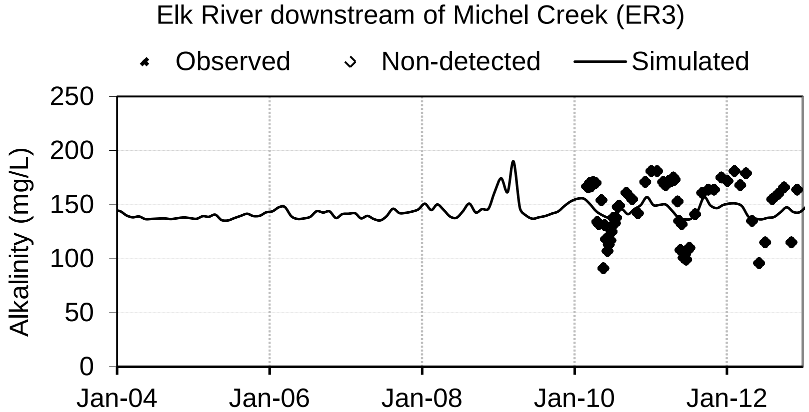


Figure B-1 Simulated and Observed Alkalinity Concentrations in the Elk Valley, 2004 to 2012





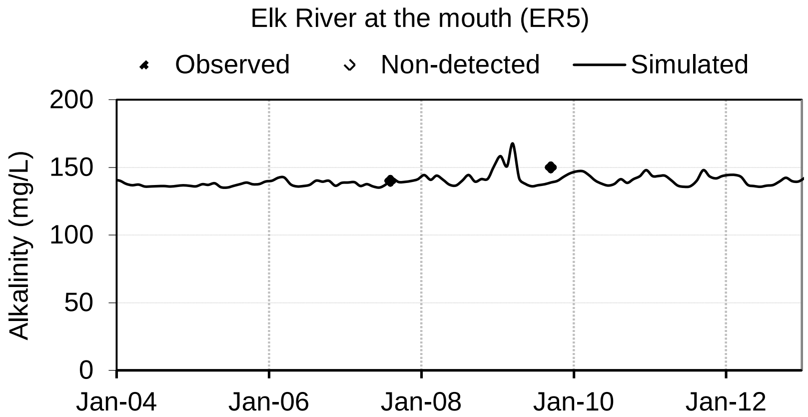


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012

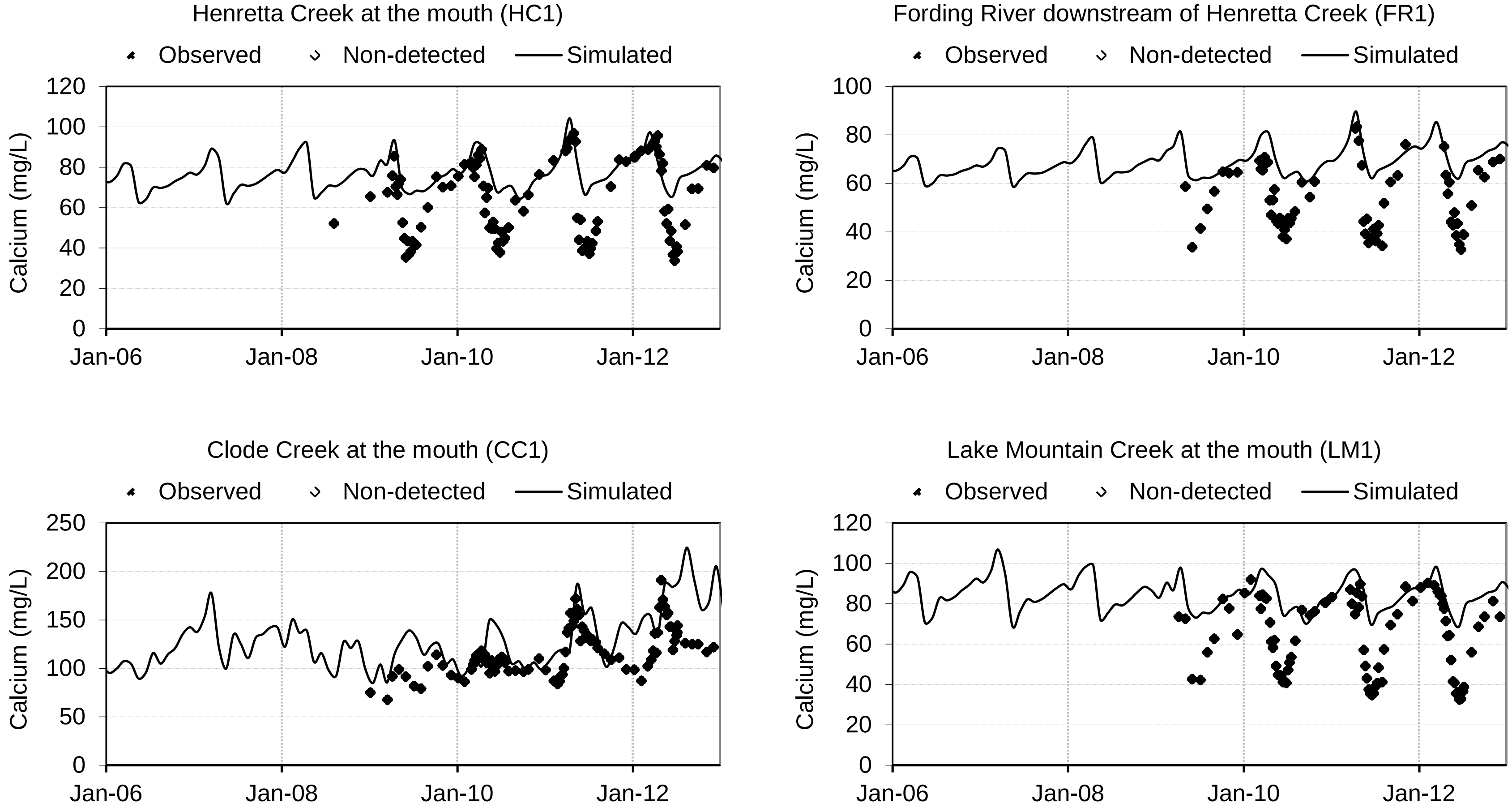


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012

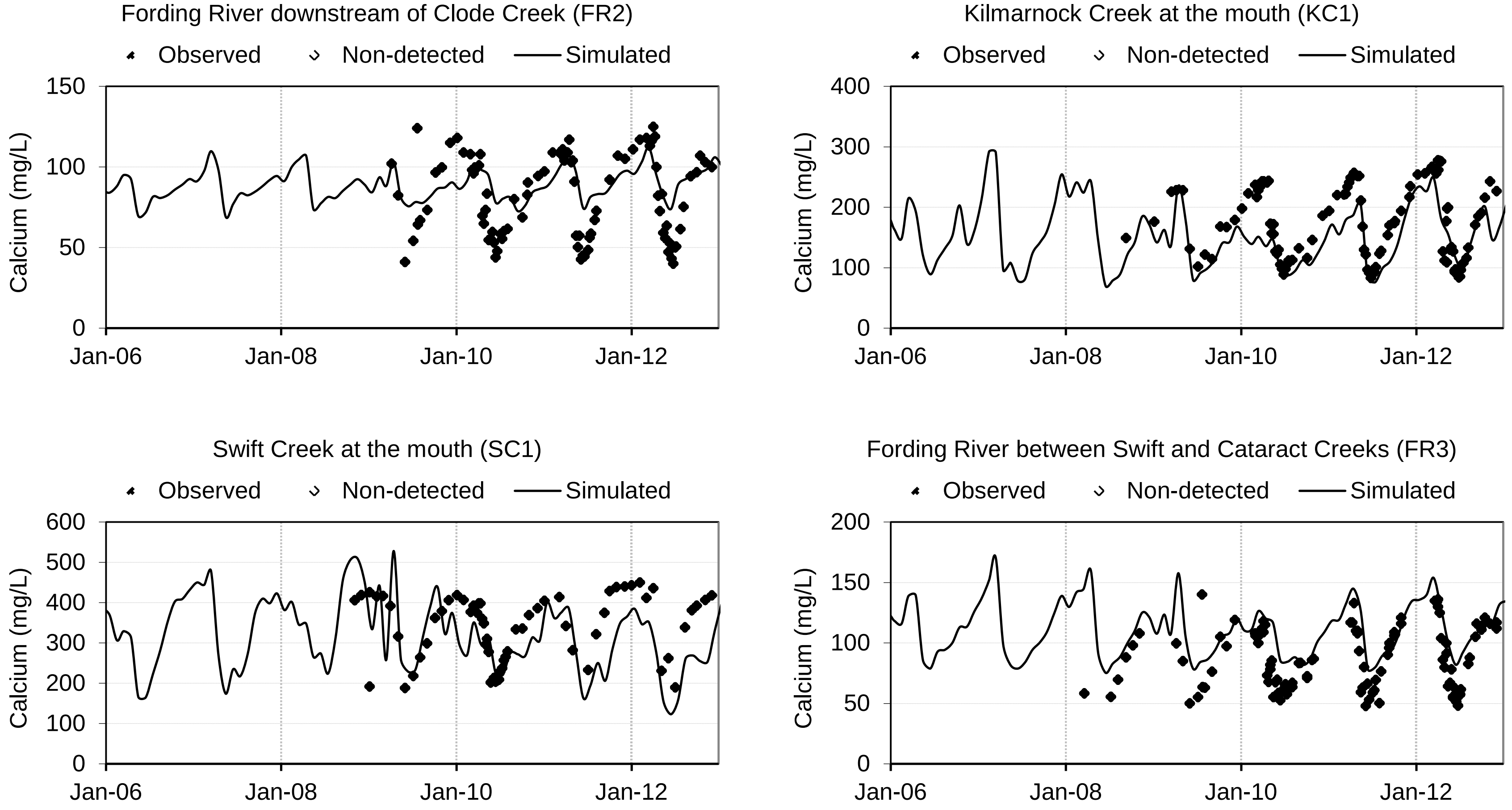


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012

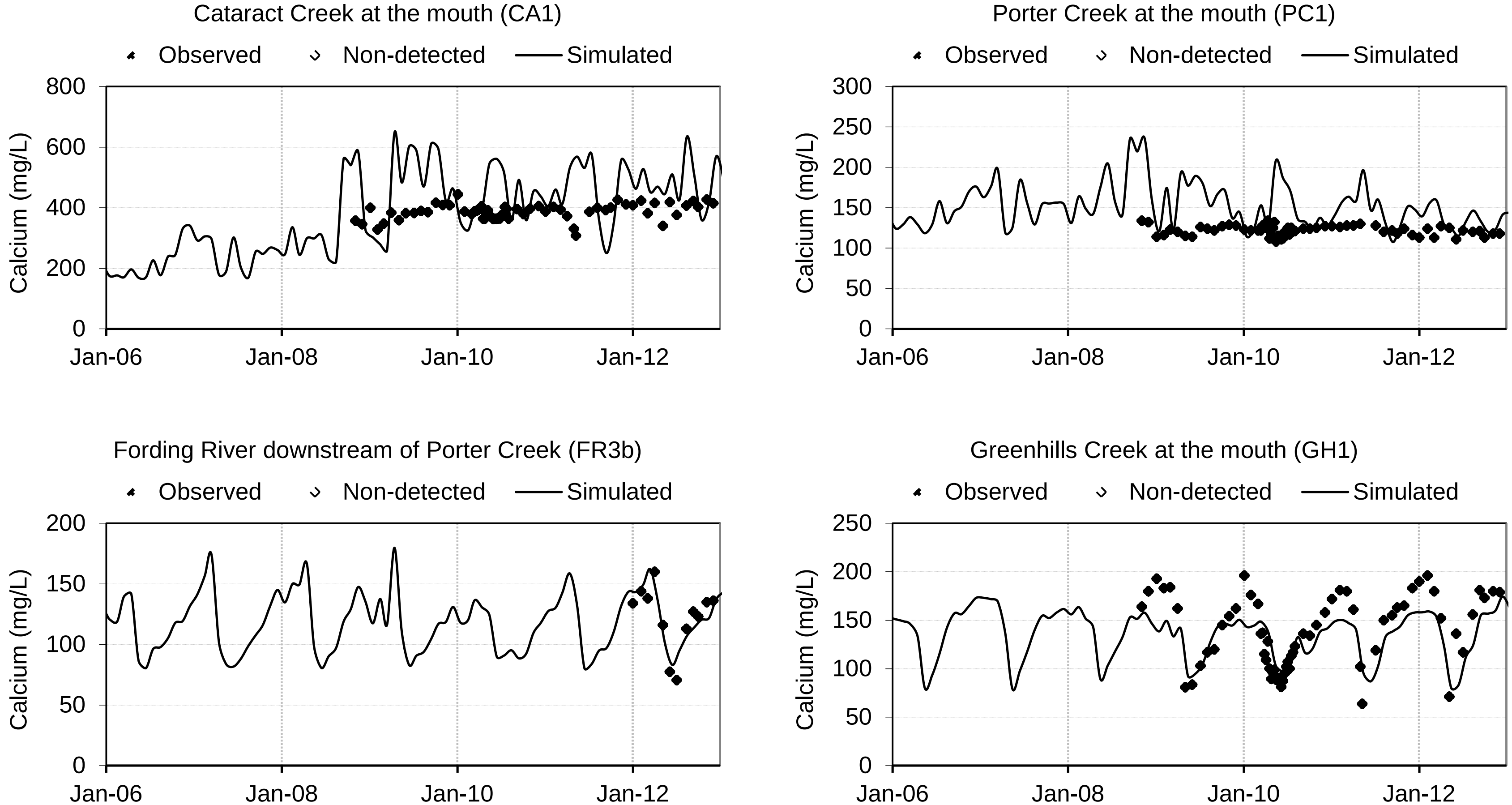


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012

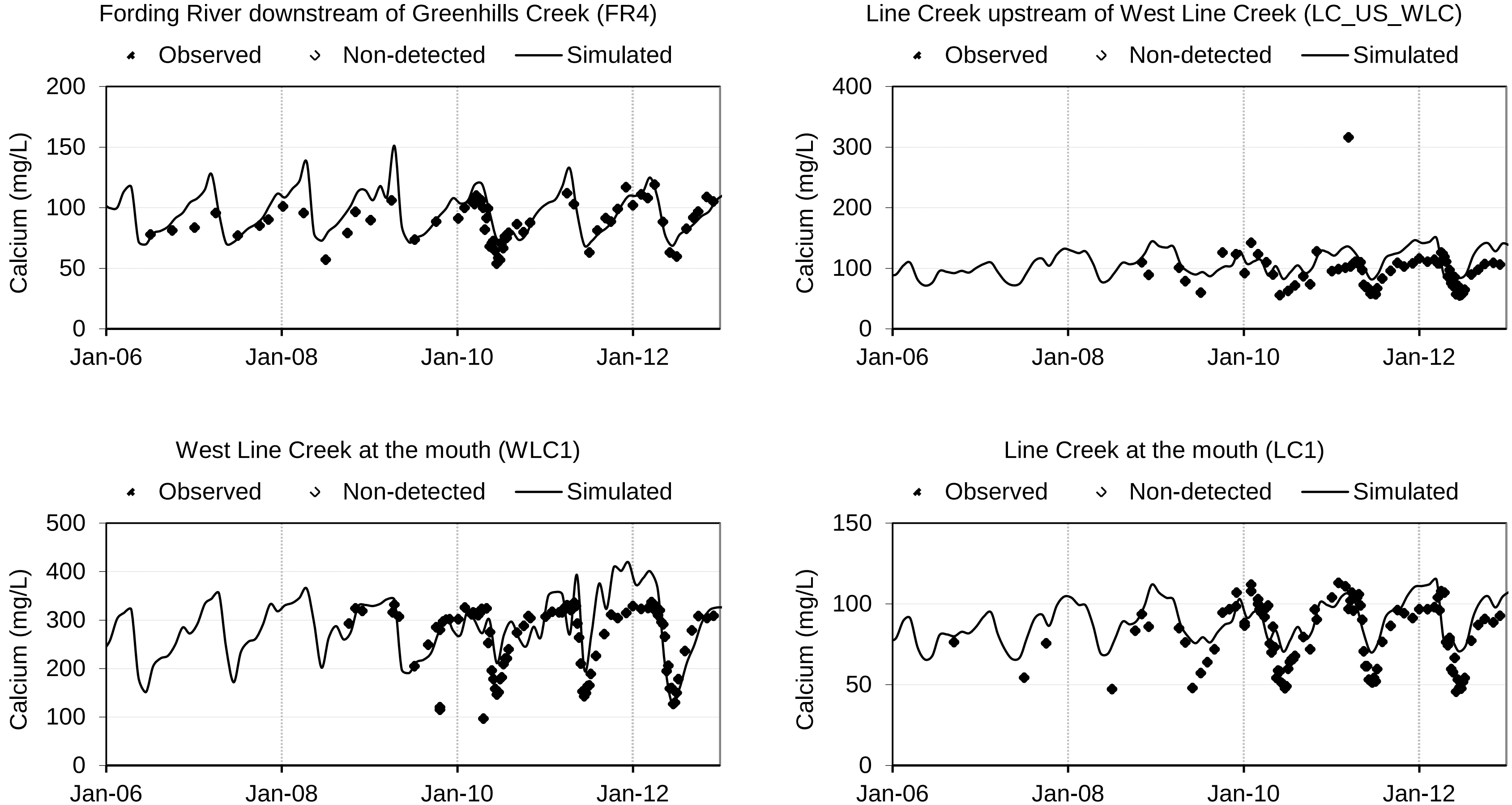


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012

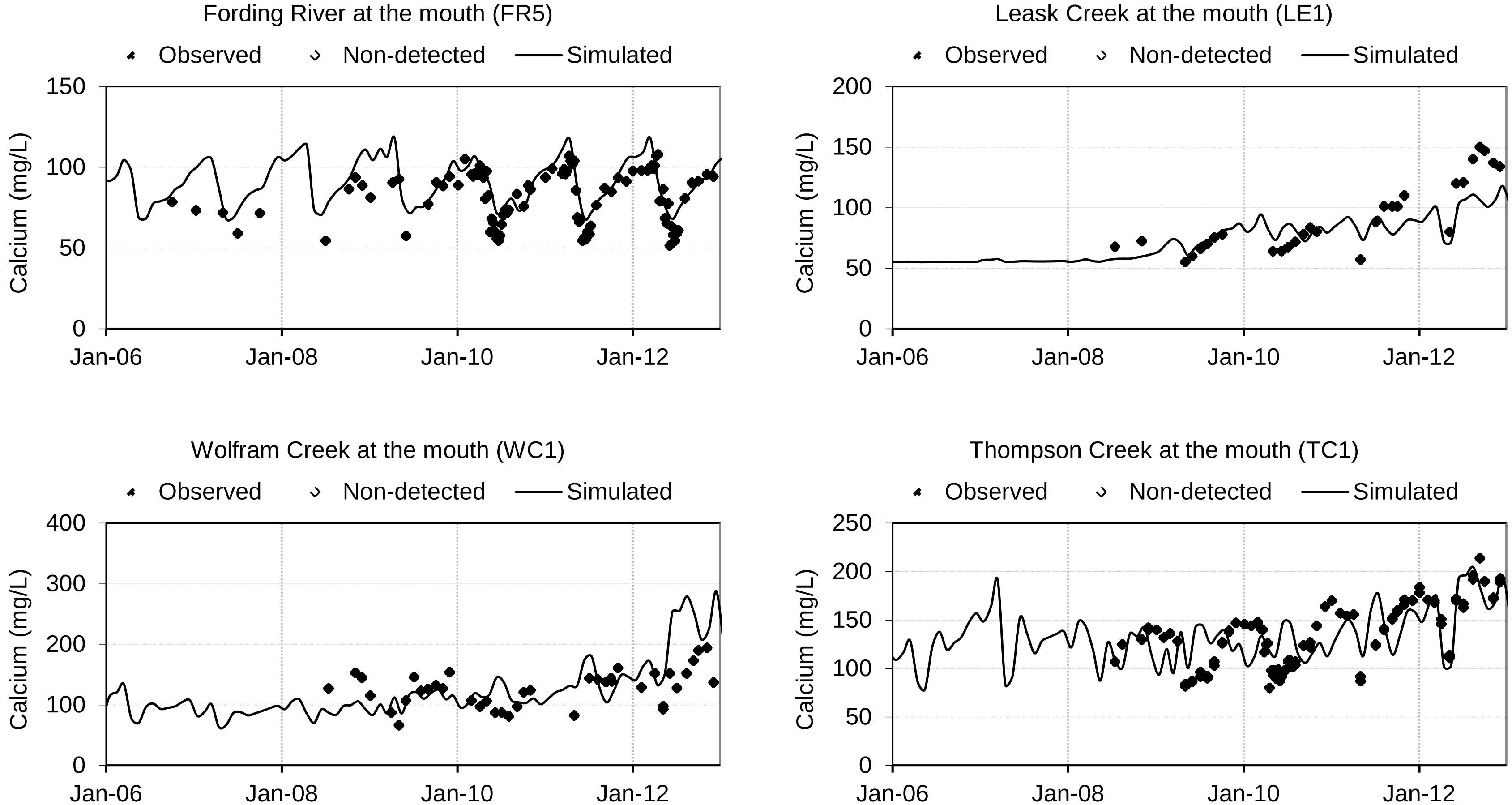


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012

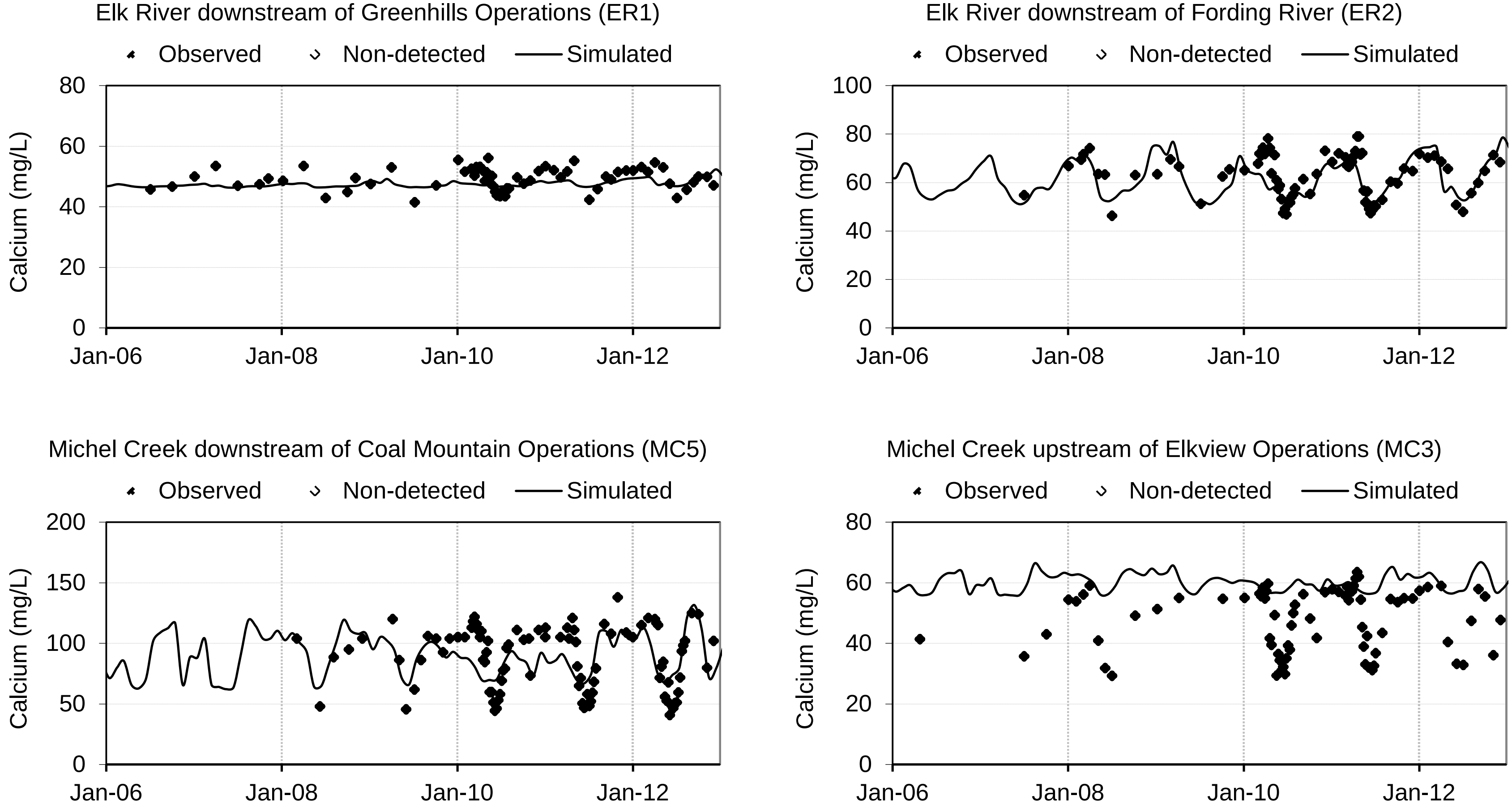


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012

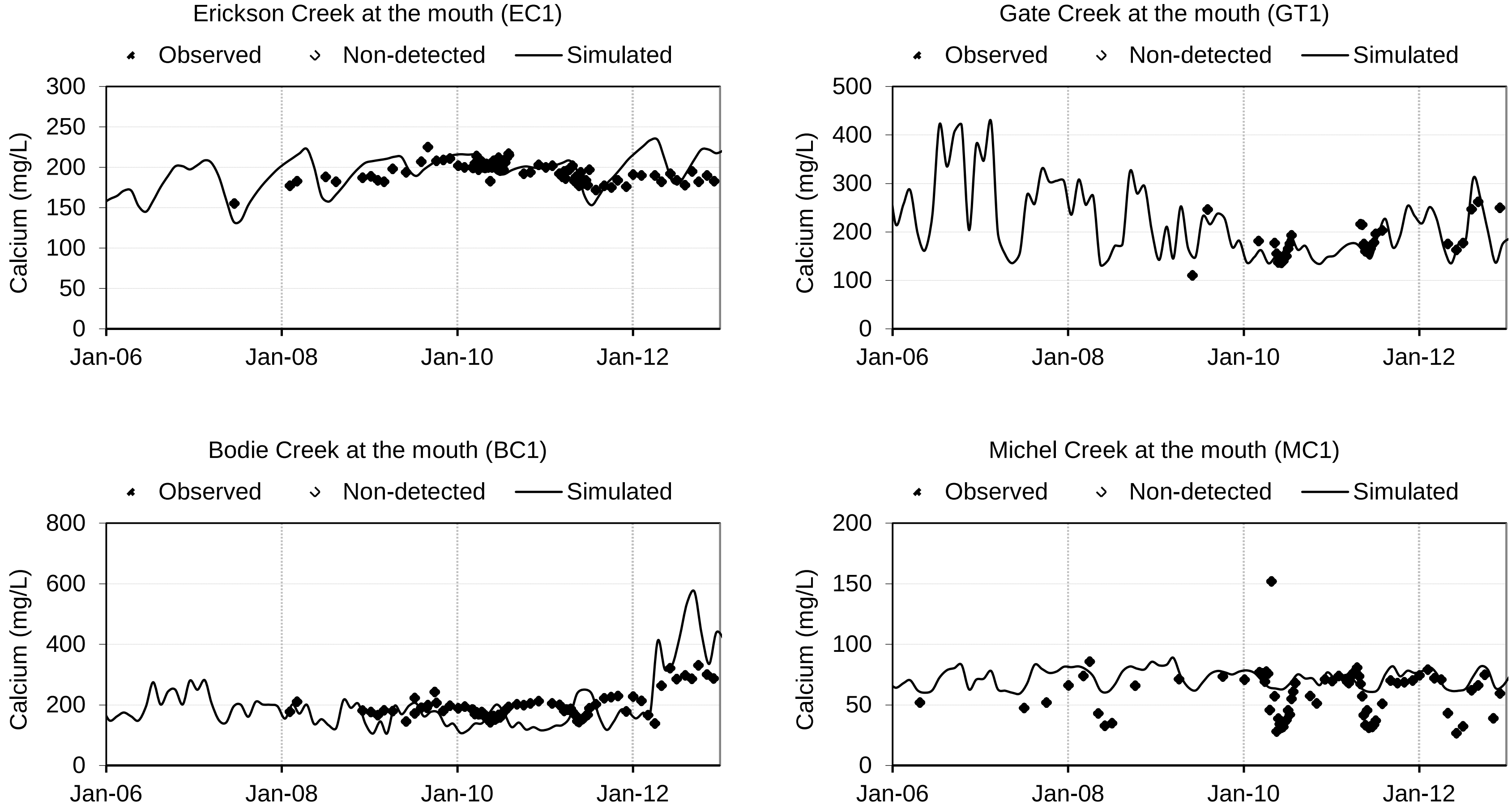
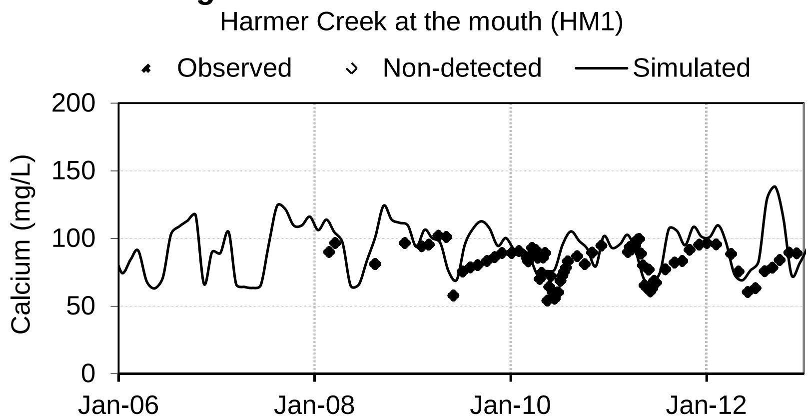
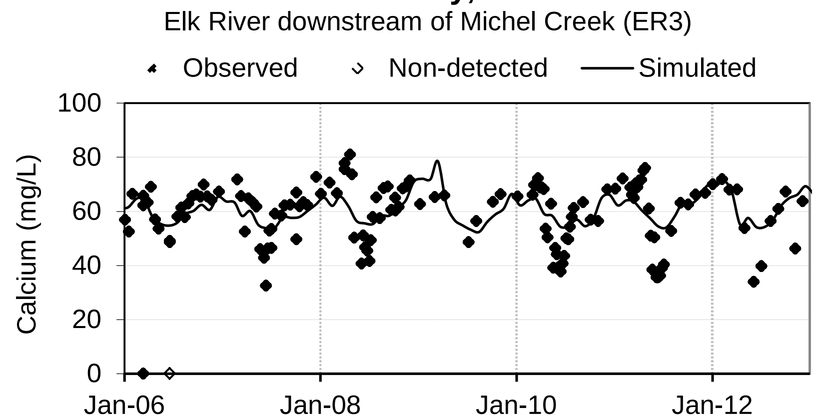


Figure B-2 Simulated and Observed Calcium Concentrations in the Elk Valley, 2006 to 2012





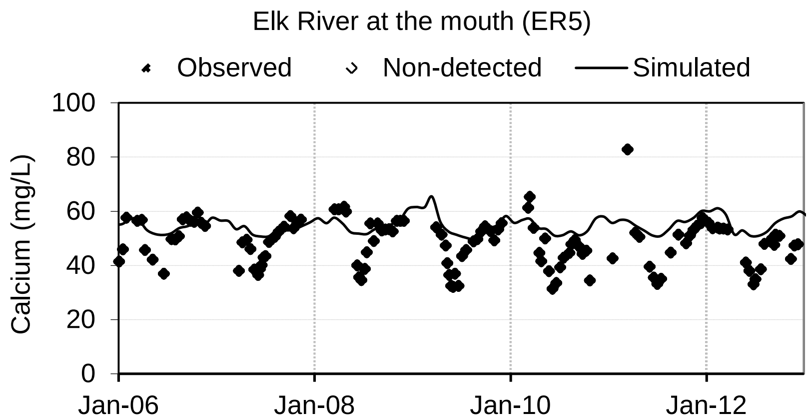
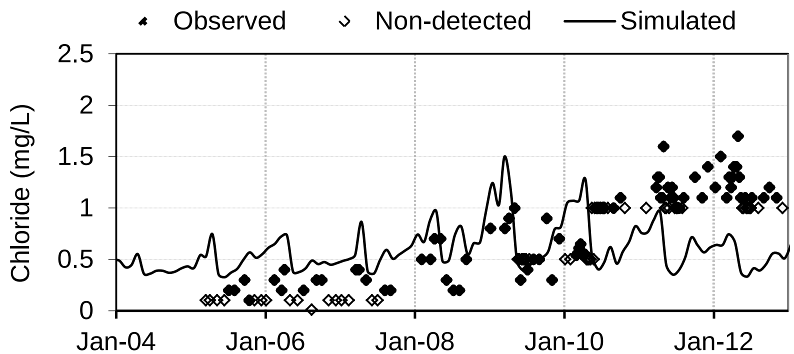


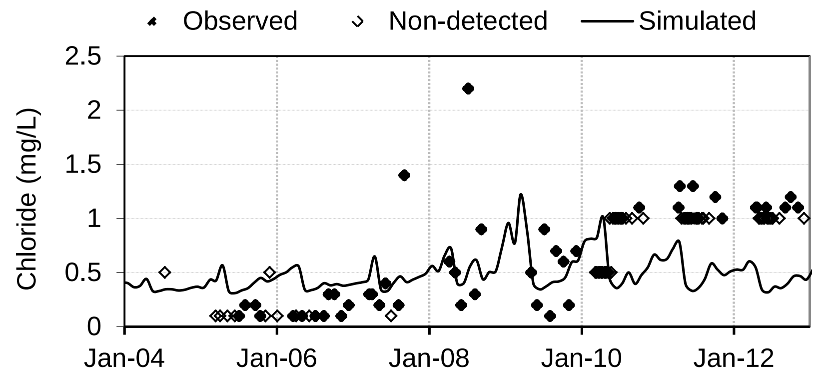
Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012

Henretta Creek at the mouth (HC1)

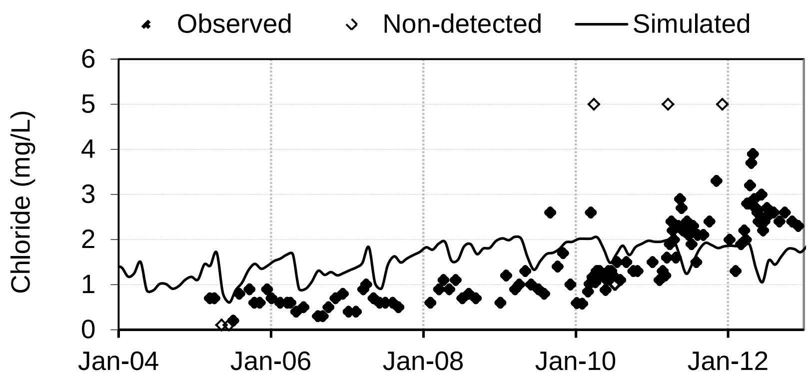


Note: One observed data point is not shown, a measurement of 6.2 mg/L that was recorded on February 02, 2009.

Fording River downstream of Henretta Creek (FR1)



Clode Creek at the mouth (CC1)



Lake Mountain Creek at the mouth (LM1)

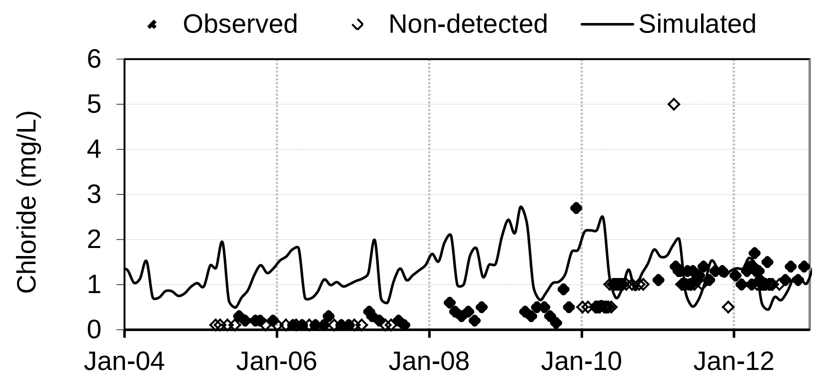


Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012

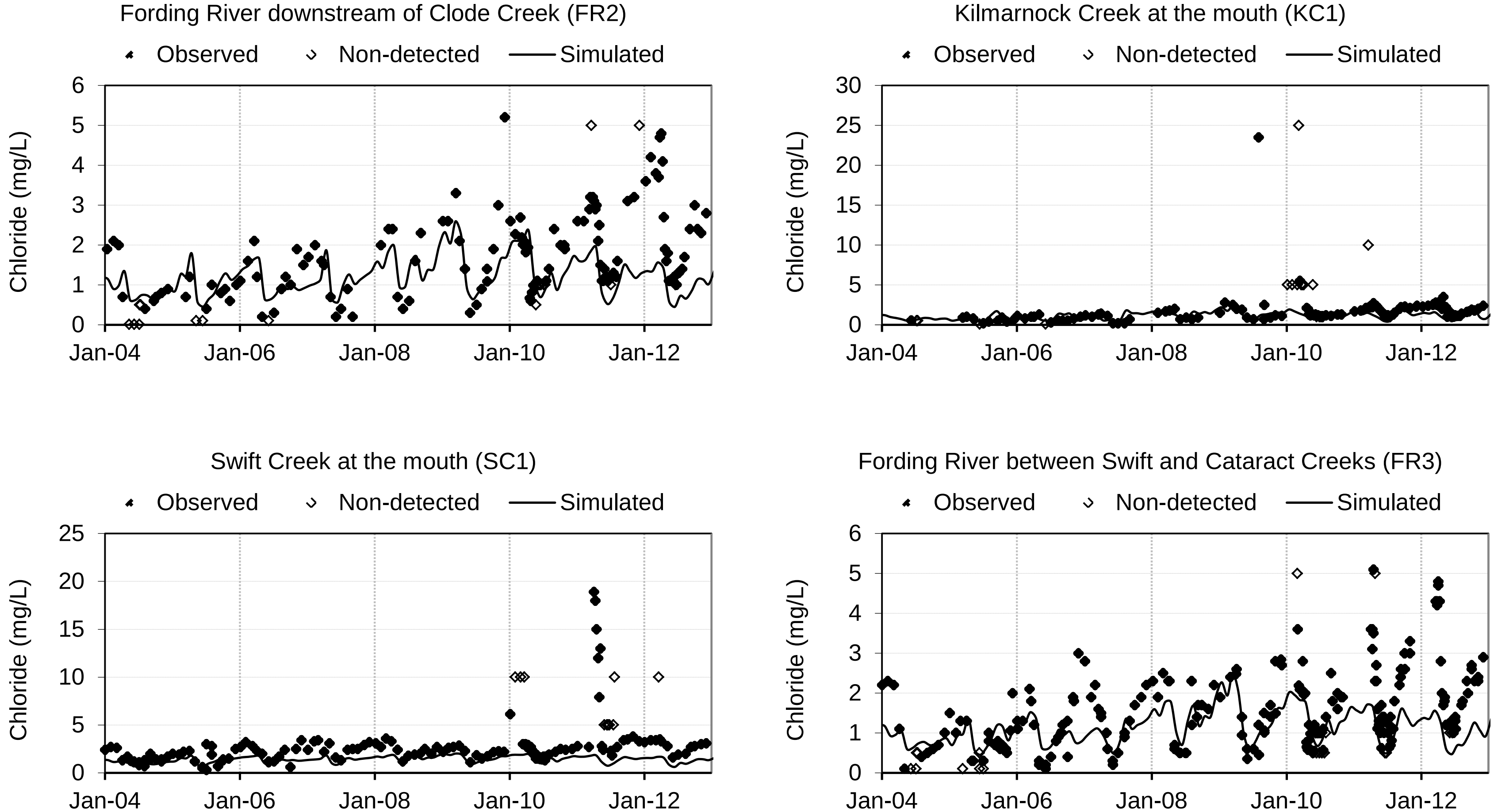
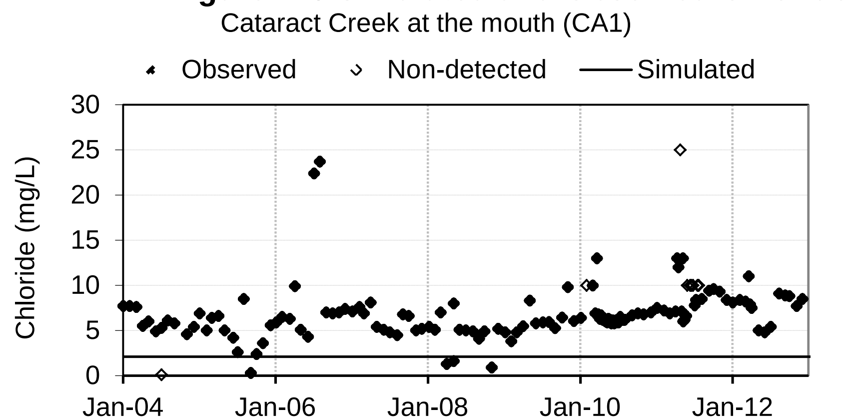
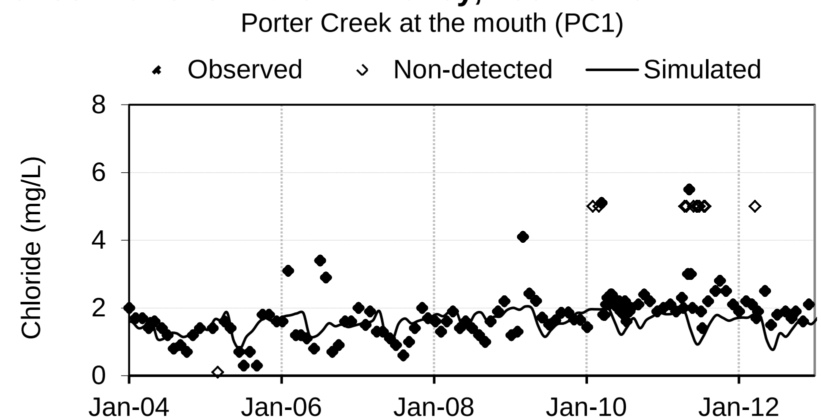
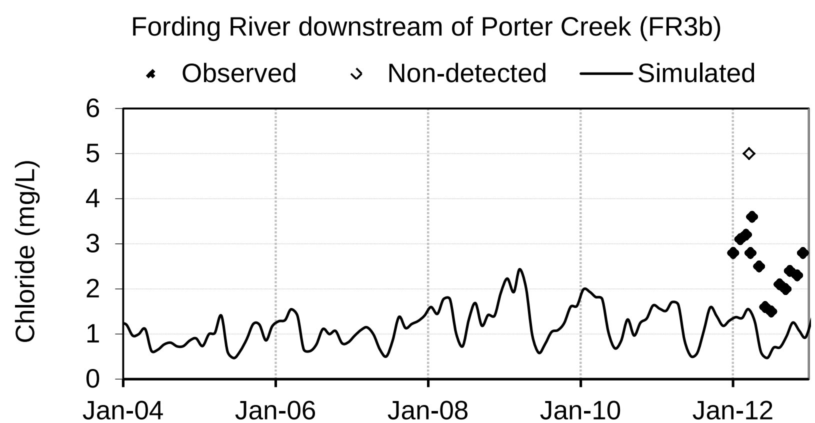


Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012





Note: No seasonal variation is simulated, because the entire watershed is assumed to be mine affected (i.e., there are no natural areas contributing runoff to the creek mouth, which would result in the dilution of the waters draining from the mine-affected areas).



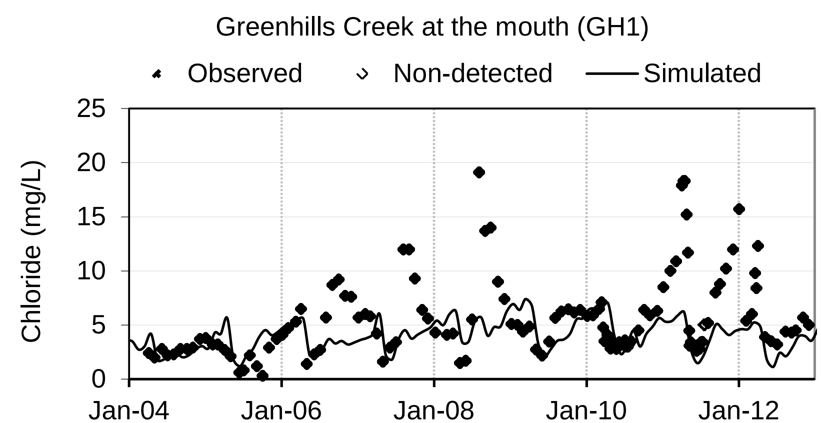
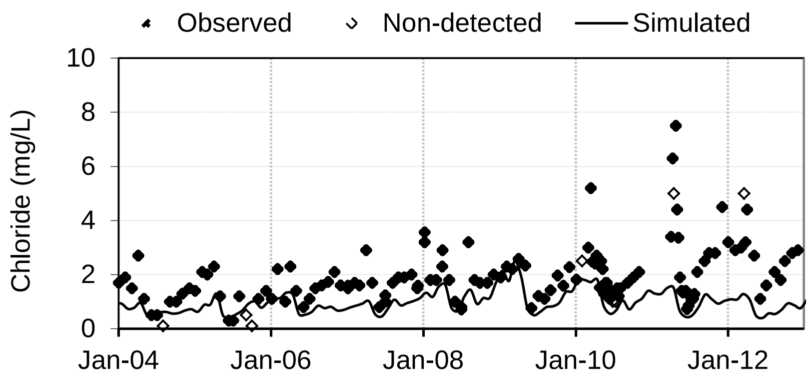
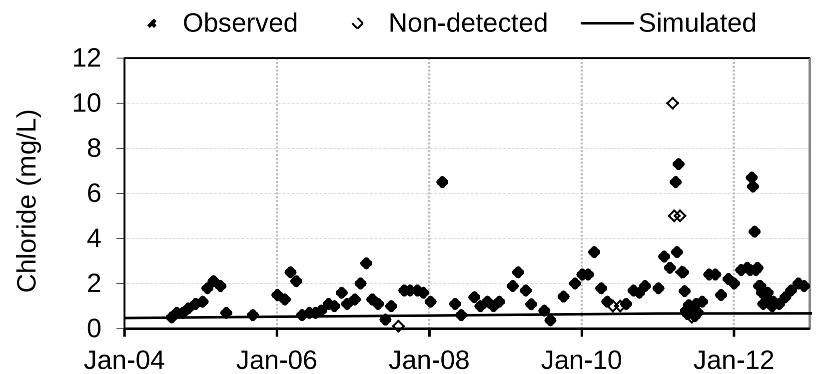


Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012

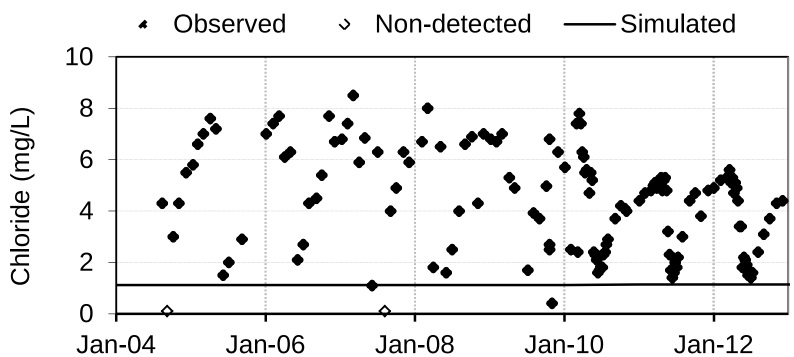
Fording River downstream of Greenhills Creek (FR4)



Line Creek upstream of West Line Creek (LC_US_WLC)

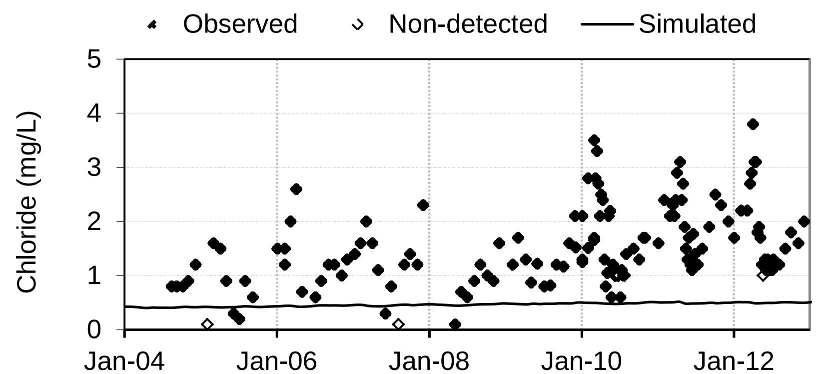


West Line Creek at the mouth (WLC1)



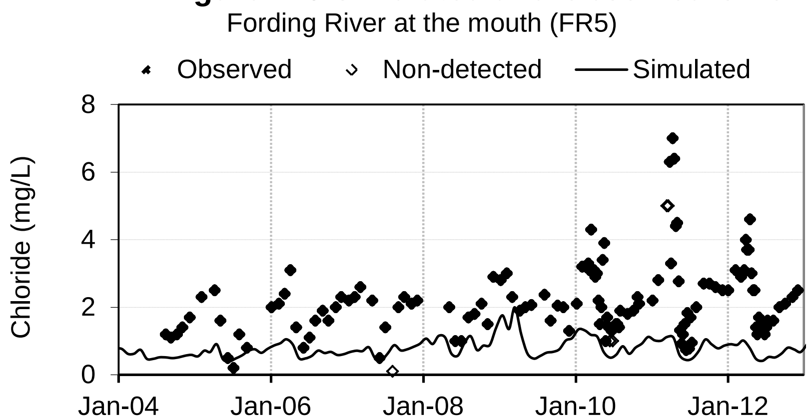
Note: One observed data point is not shown, a measurement of 25 mg/L that was recorded on April 15, 2009.

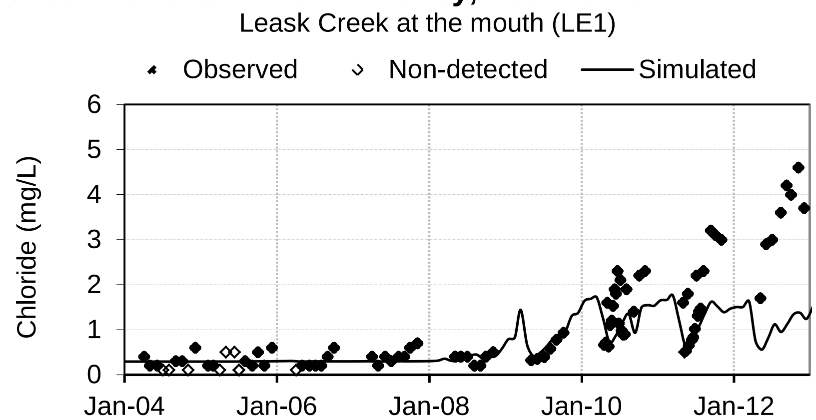
Line Creek at the mouth (LC1)

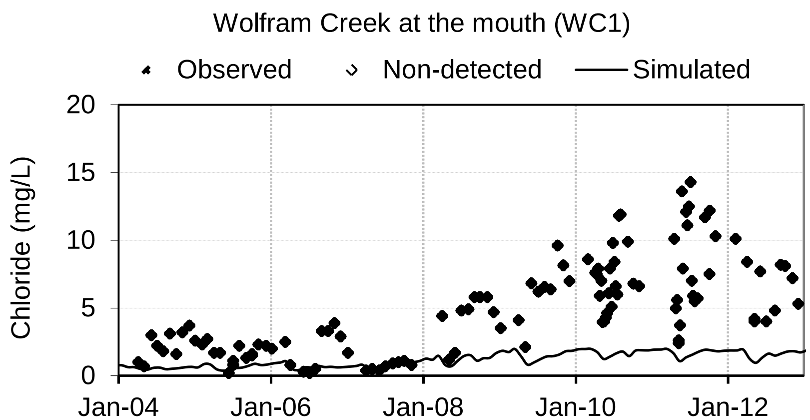


No seasonal variation is simulated for Line Creek or West Line Creek, because for each of these creeks the natural and mine flows are assumed to follow the same seasonal pattern (i.e., the seasonal pattern observed at the mouth of the creek).

Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012







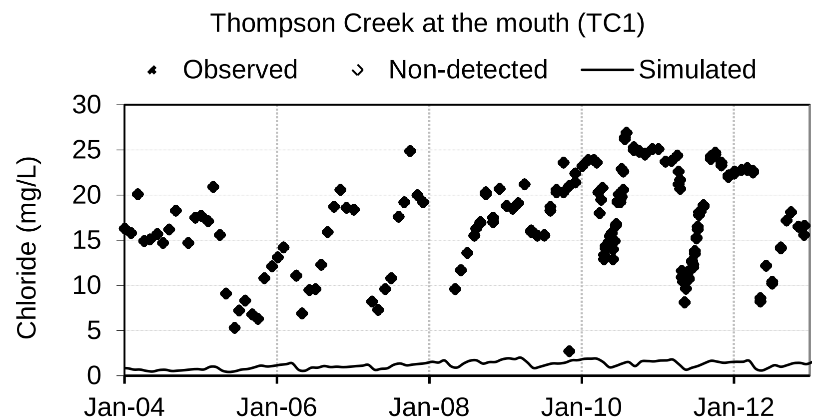
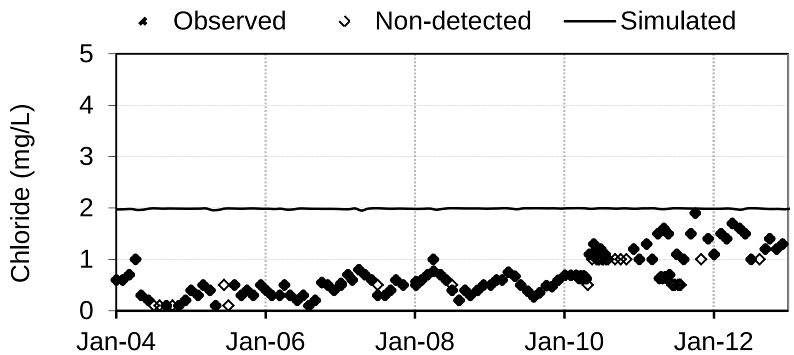


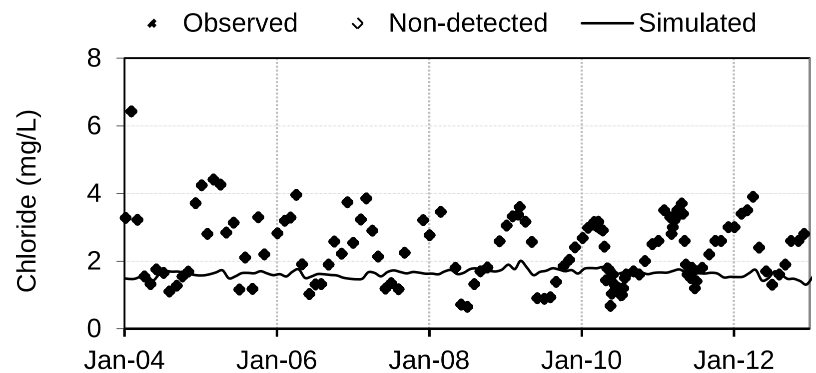
Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012

Elk River downstream of Greenhills Operations (ER1)

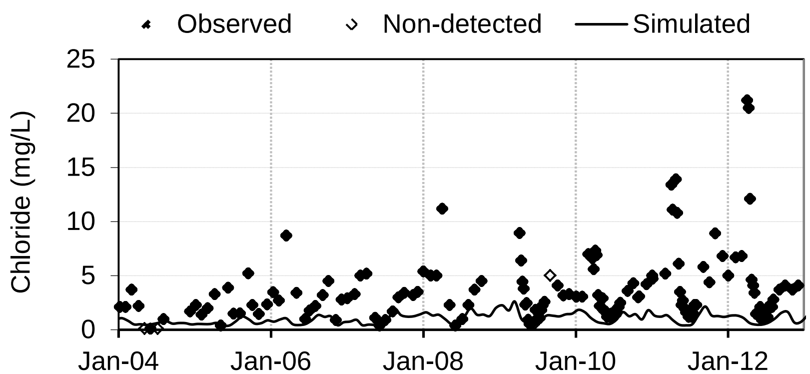


Note: Two observed data points are not shown, a measurement of 12.7 mg/L that was recorded on December 04, 2007 and 13 mg/L recorded on December 07, 2007.

Elk River downstream of Fording River (ER2)



Michel Creek downstream of Coal Mountain Operations (MC5)



Michel Creek upstream of Elkview Operations (MC3)

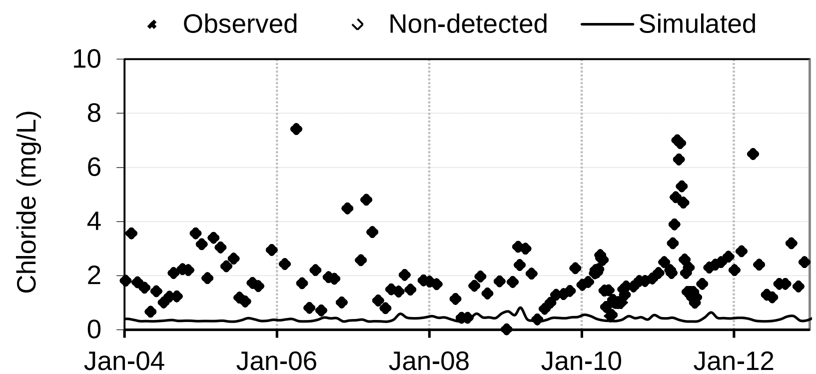
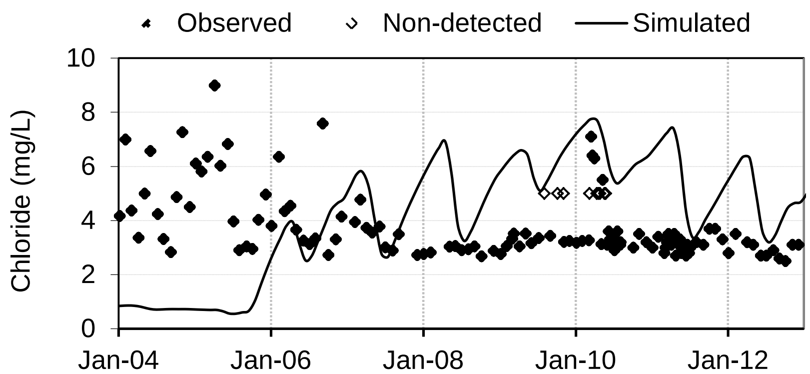
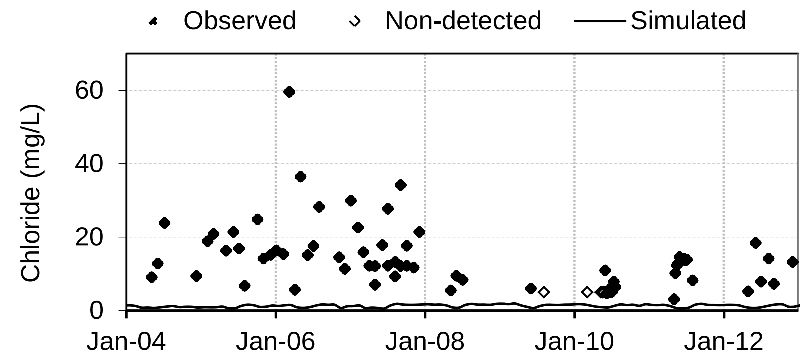


Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012

Erickson Creek at the mouth (EC1)

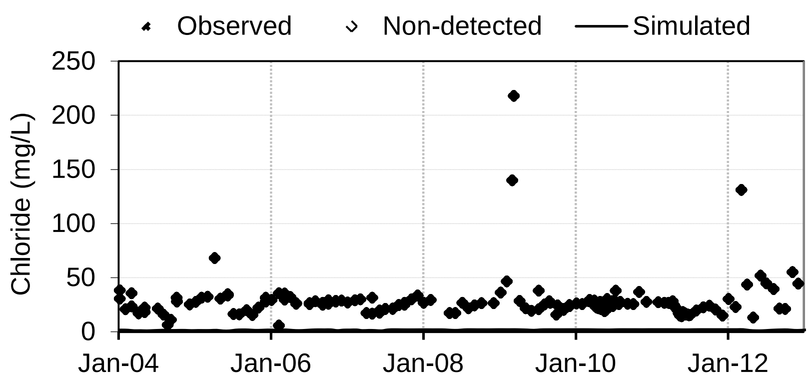


Gate Creek at the mouth (GT1)



Note: One observed data point is not shown, a measurement of 189 mg/L that was recorded on June 15, 2007.

Bodie Creek at the mouth (BC1)



Michel Creek at the mouth (MC1)

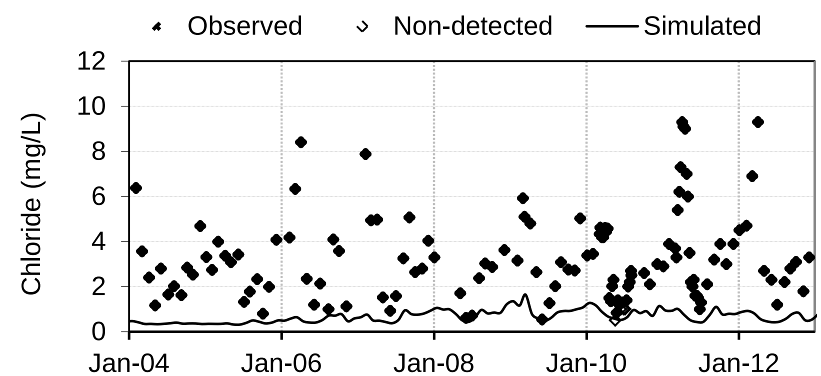
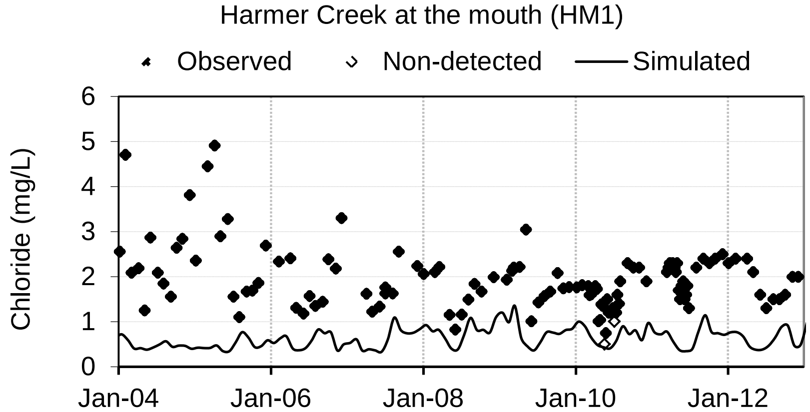
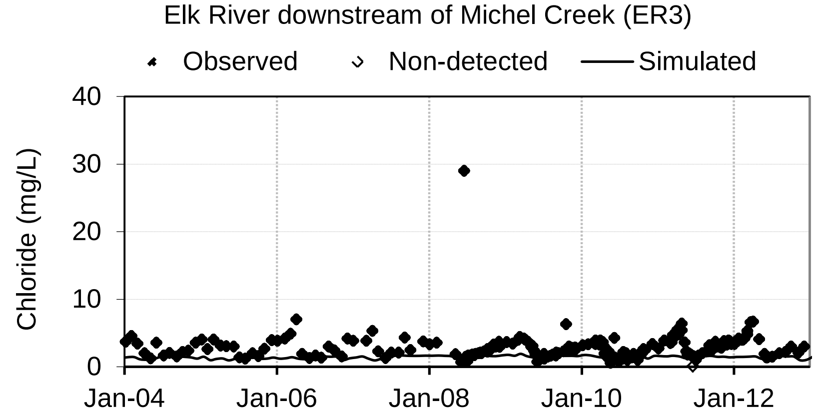


Figure B-3 Simulated and Observed Chloride Concentrations in the Elk Valley, 2004 to 2012





Note: One observed data point is not shown, a measurement of 29 mg/L that was recorded on June 16, 2008.

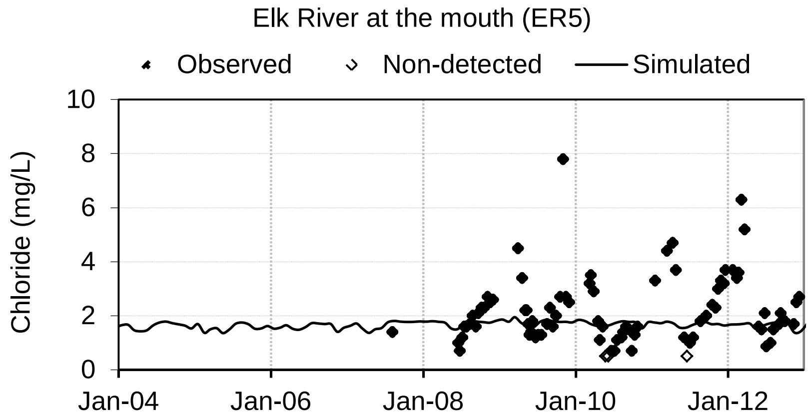


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

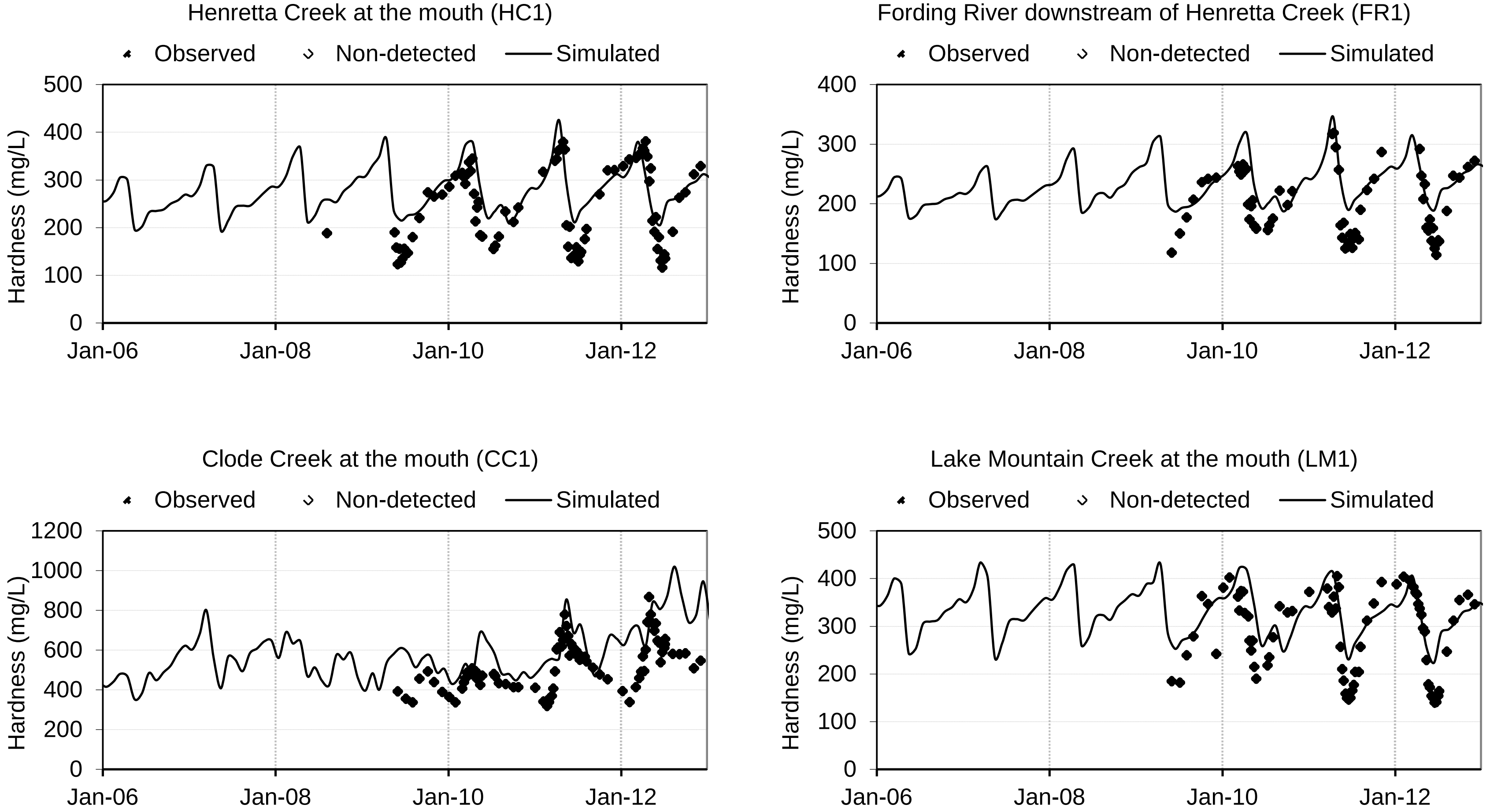


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

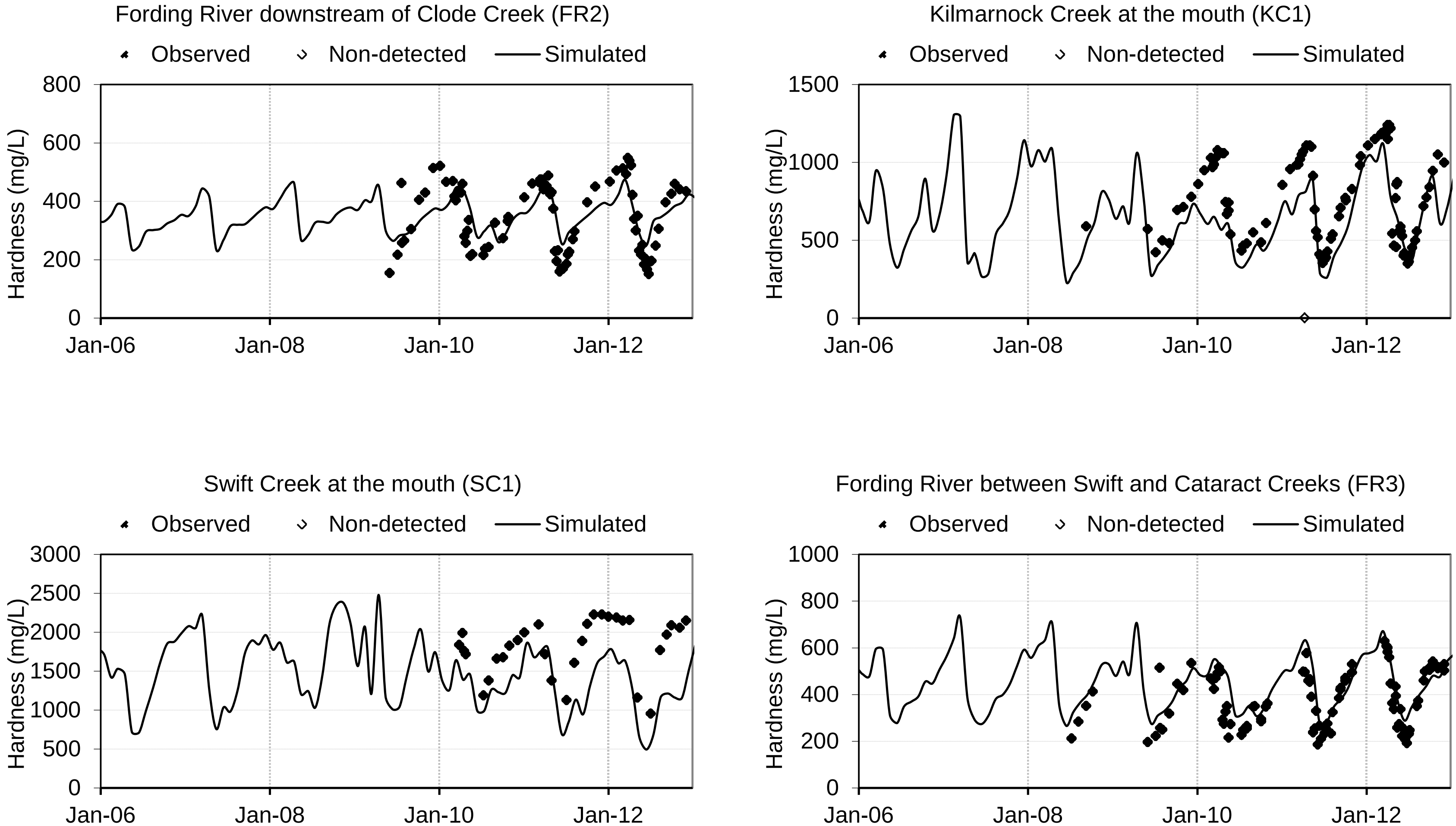


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

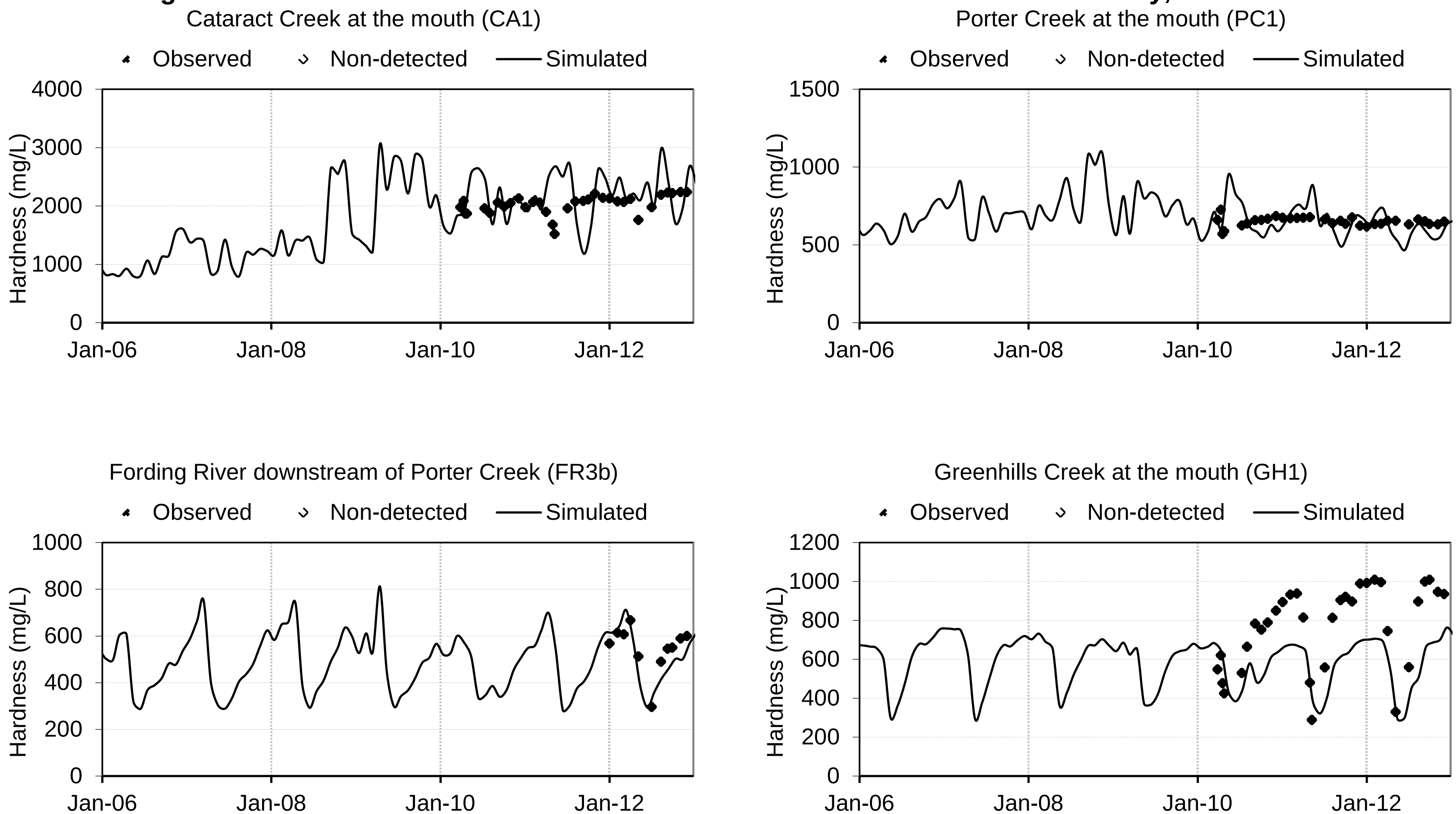


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

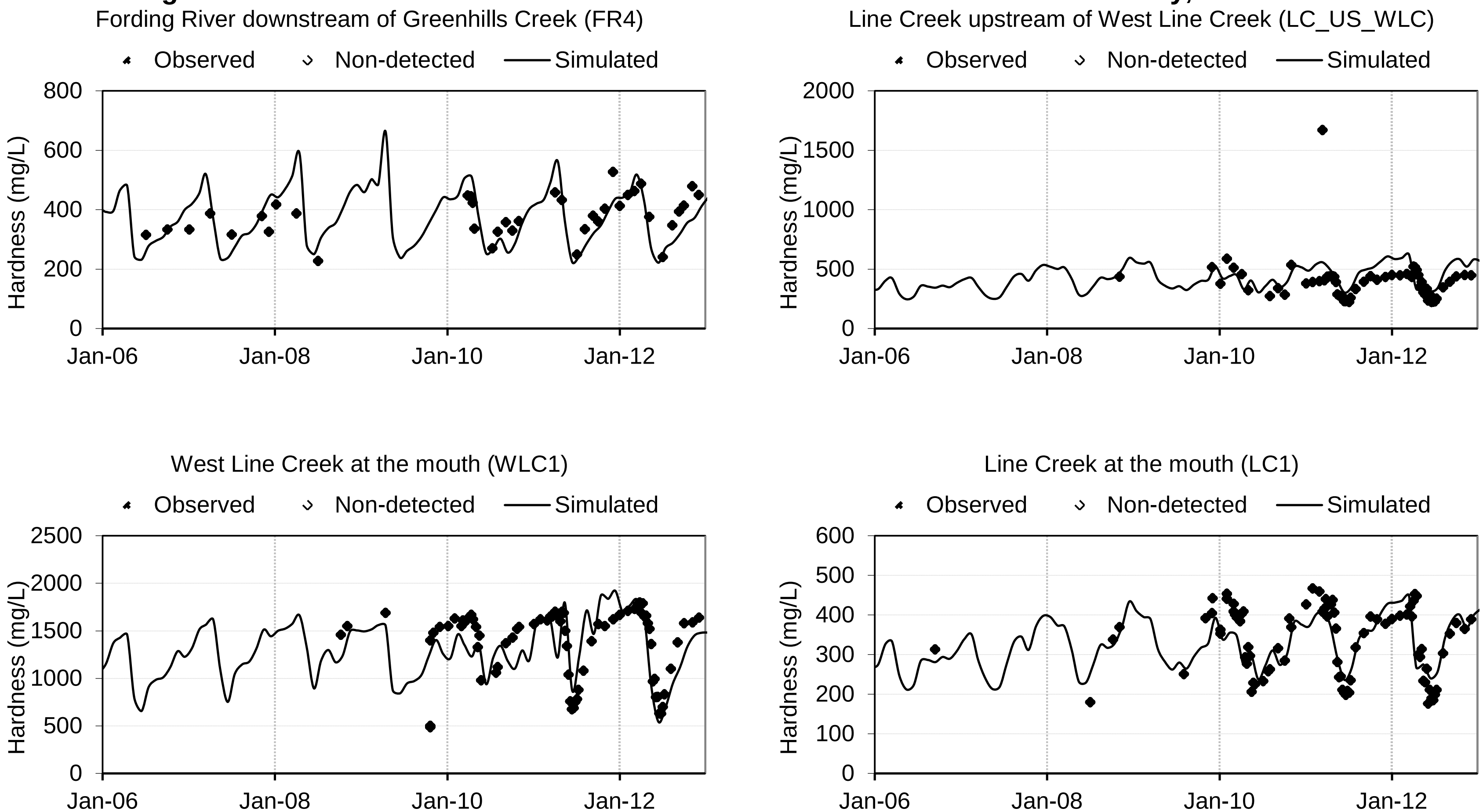


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

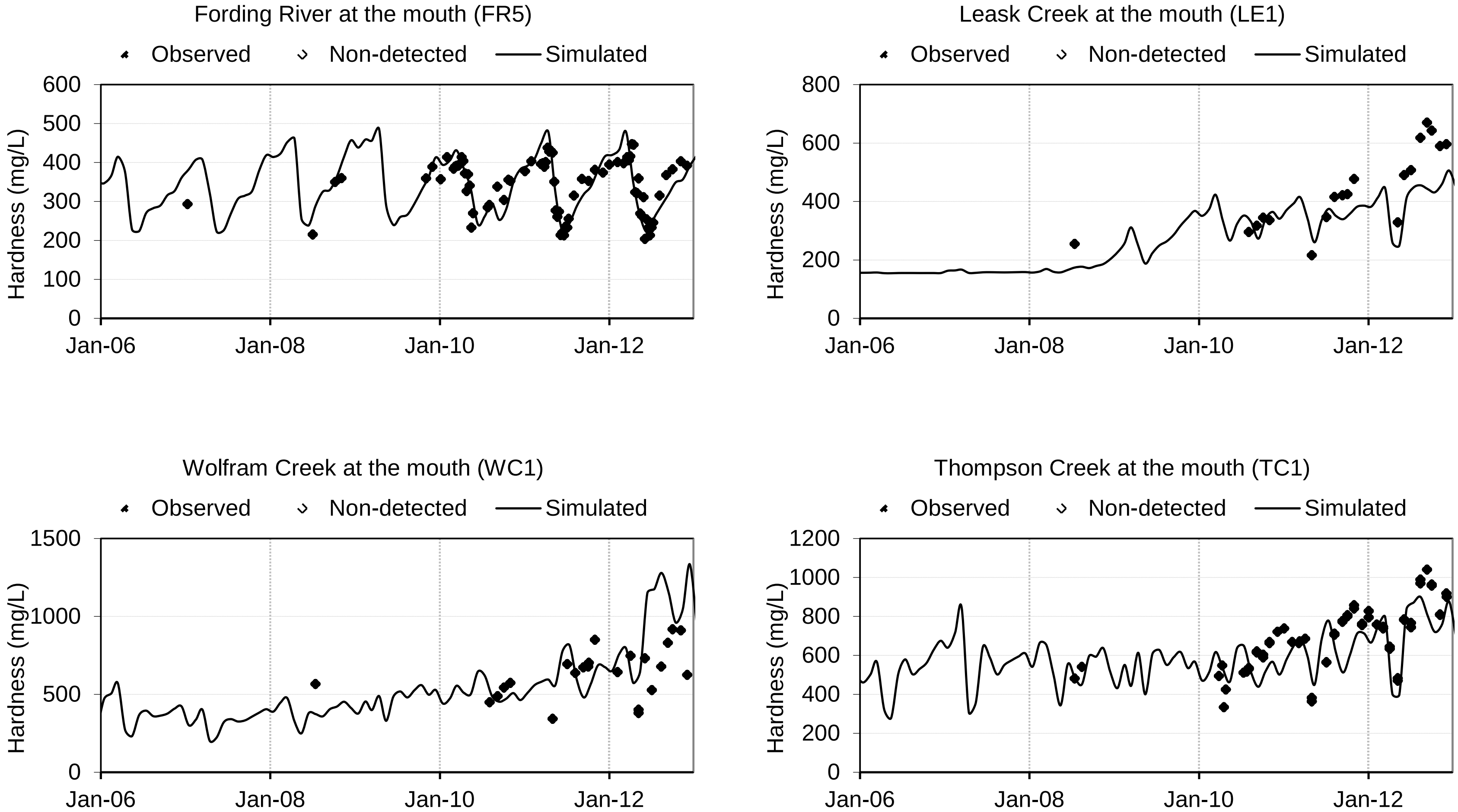


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

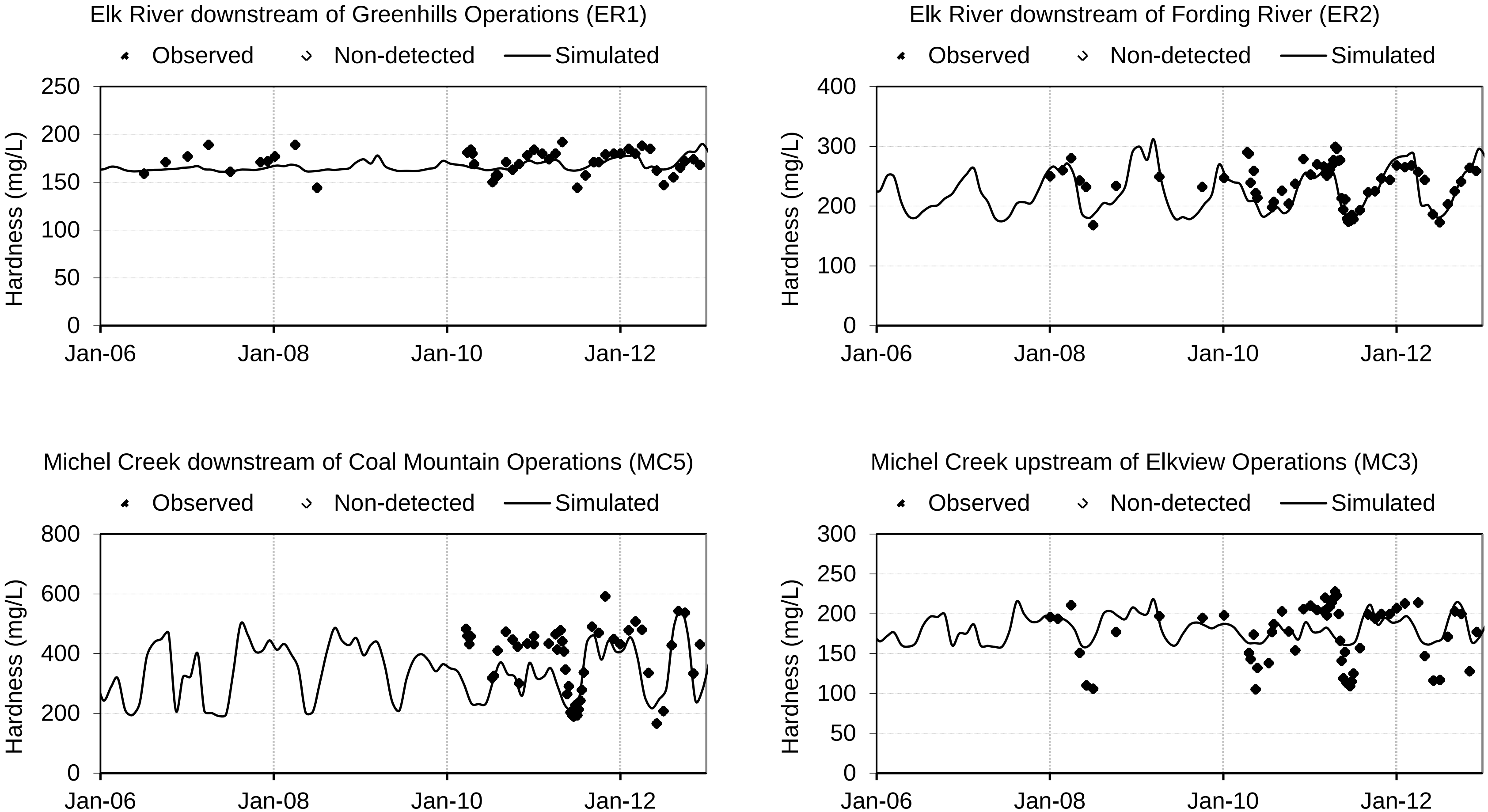


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

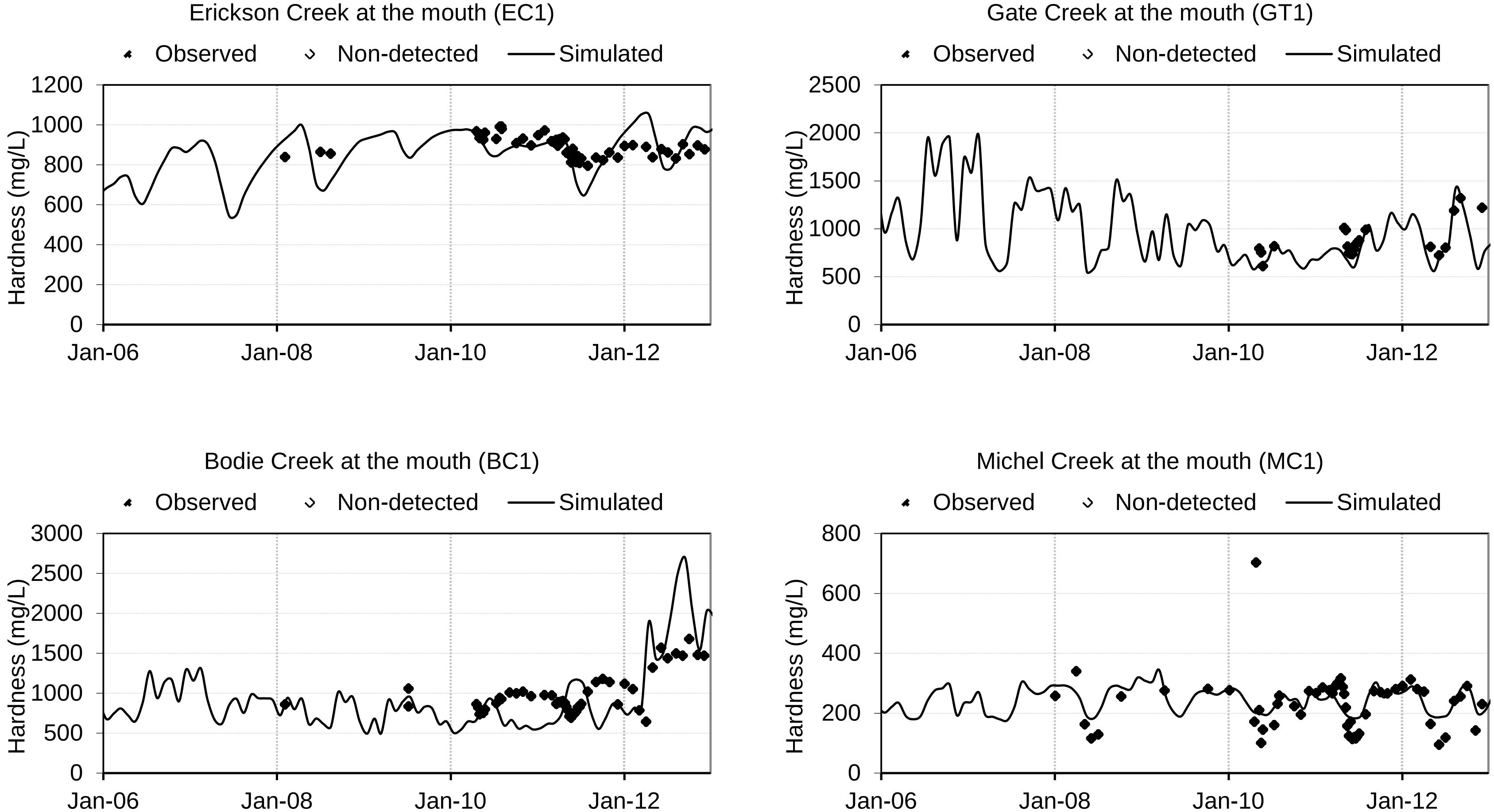


Figure B-4 Simulated and Observed Hardness Concentrations in the Elk Valley, 2006 to 2012

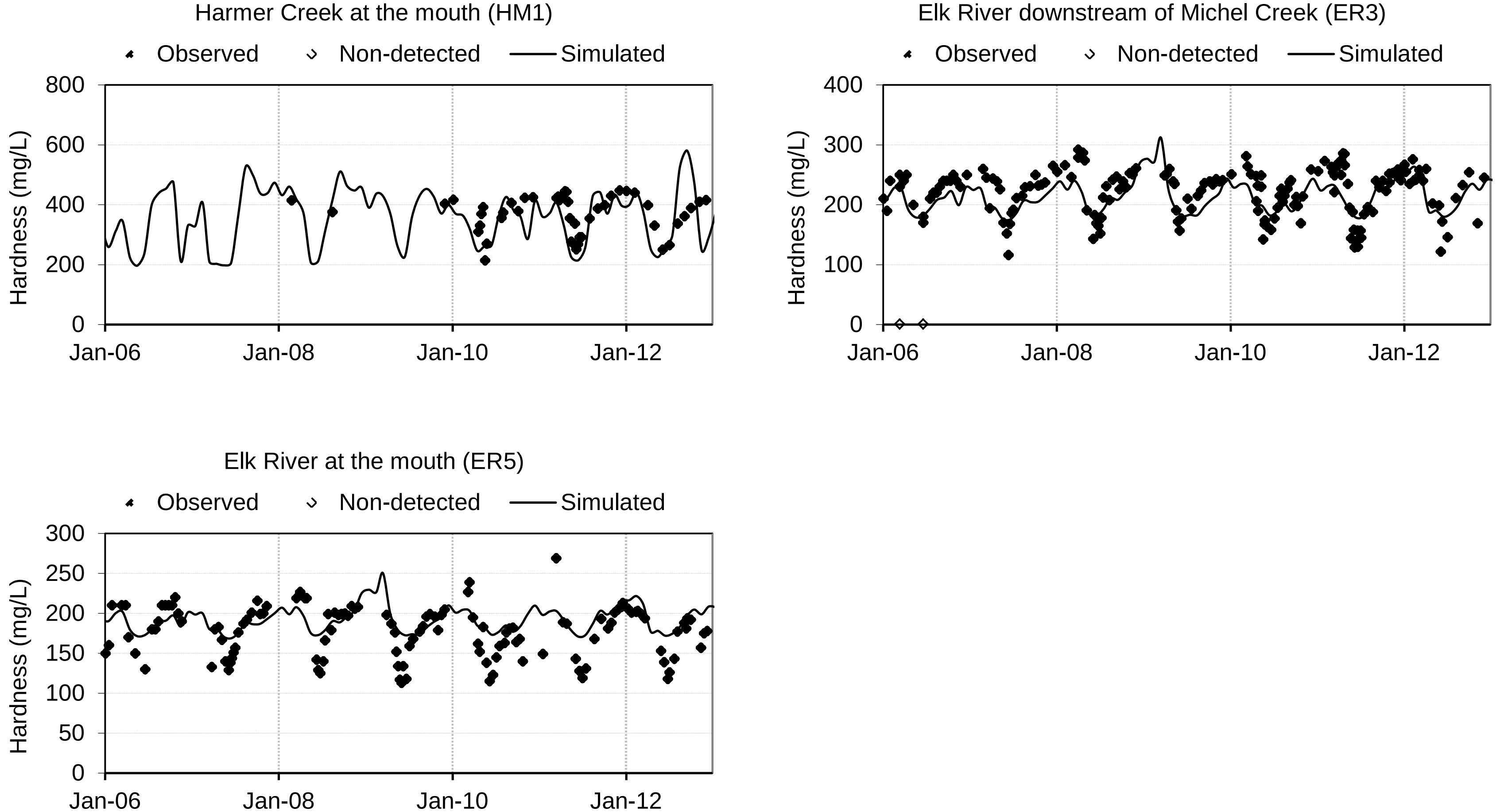


Figure B-5 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

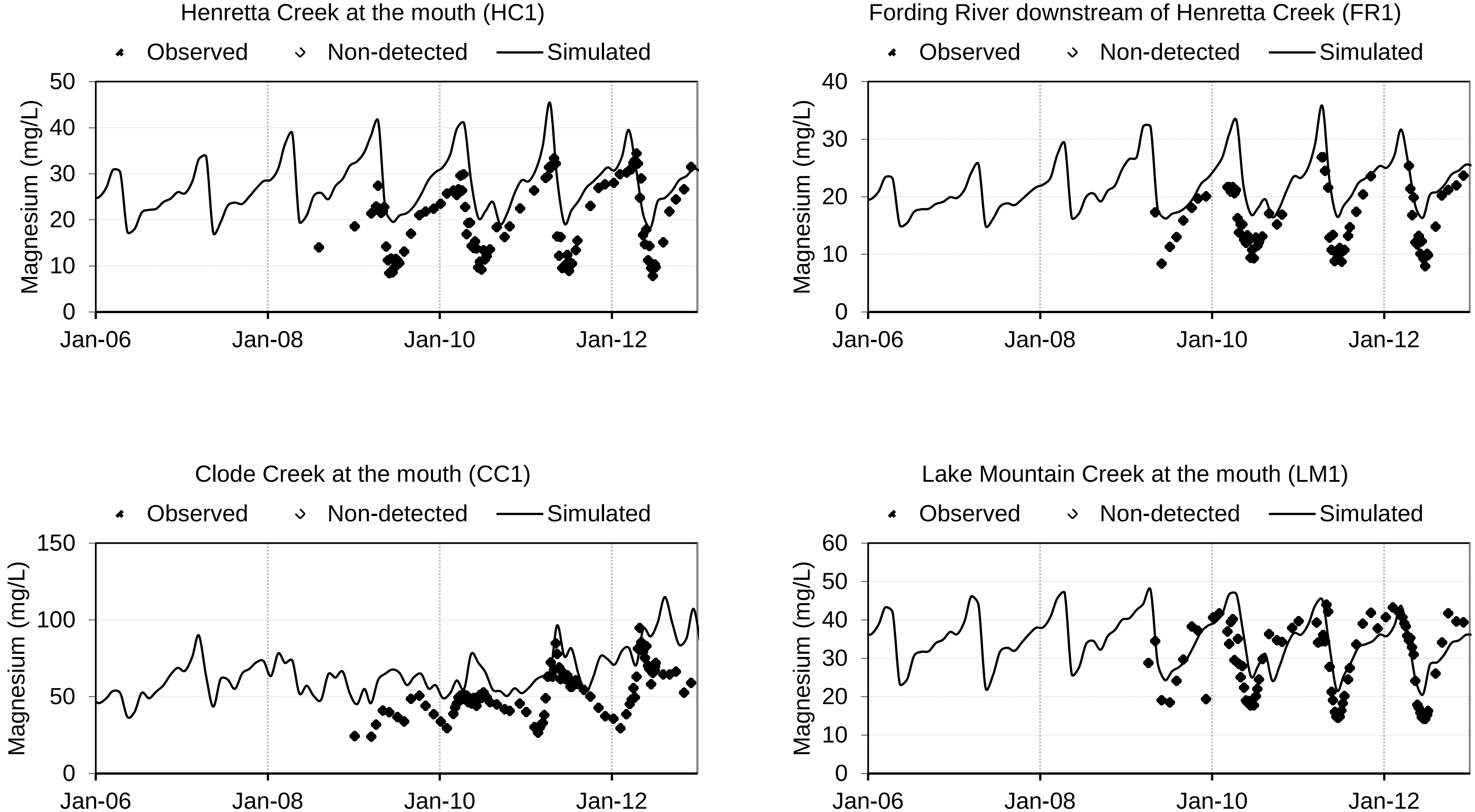


Figure B-6 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

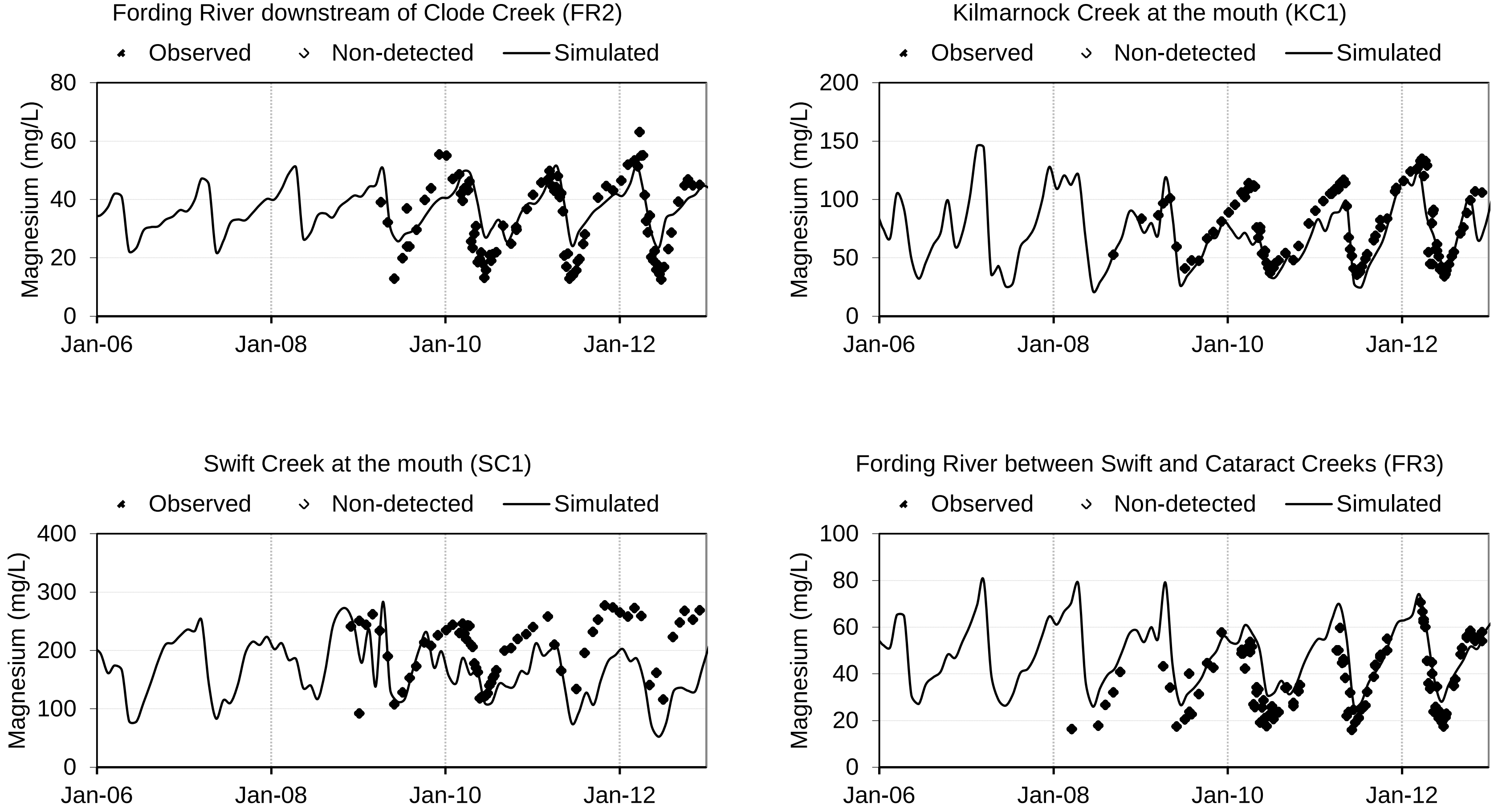


Figure B-5 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

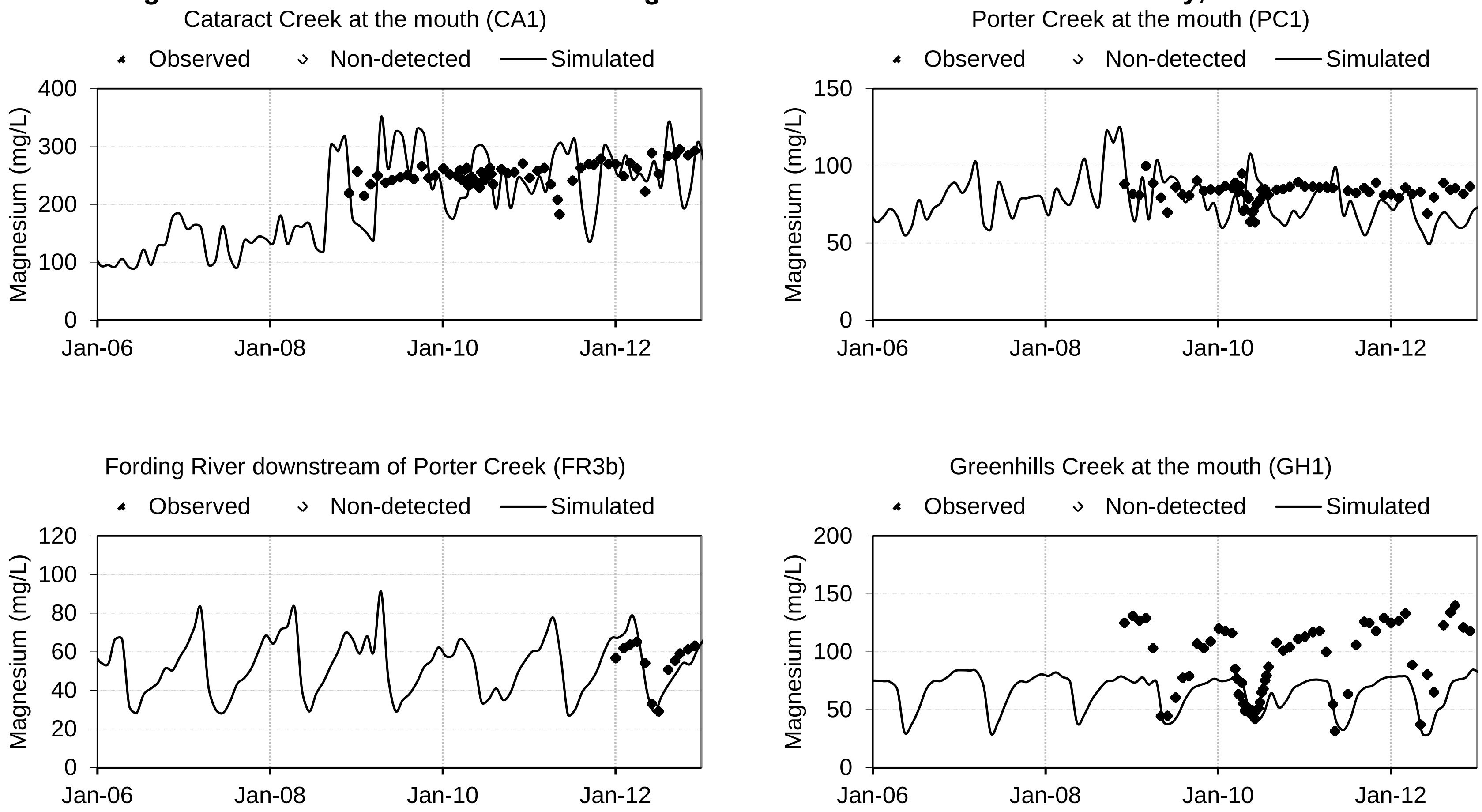


Figure B-5 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

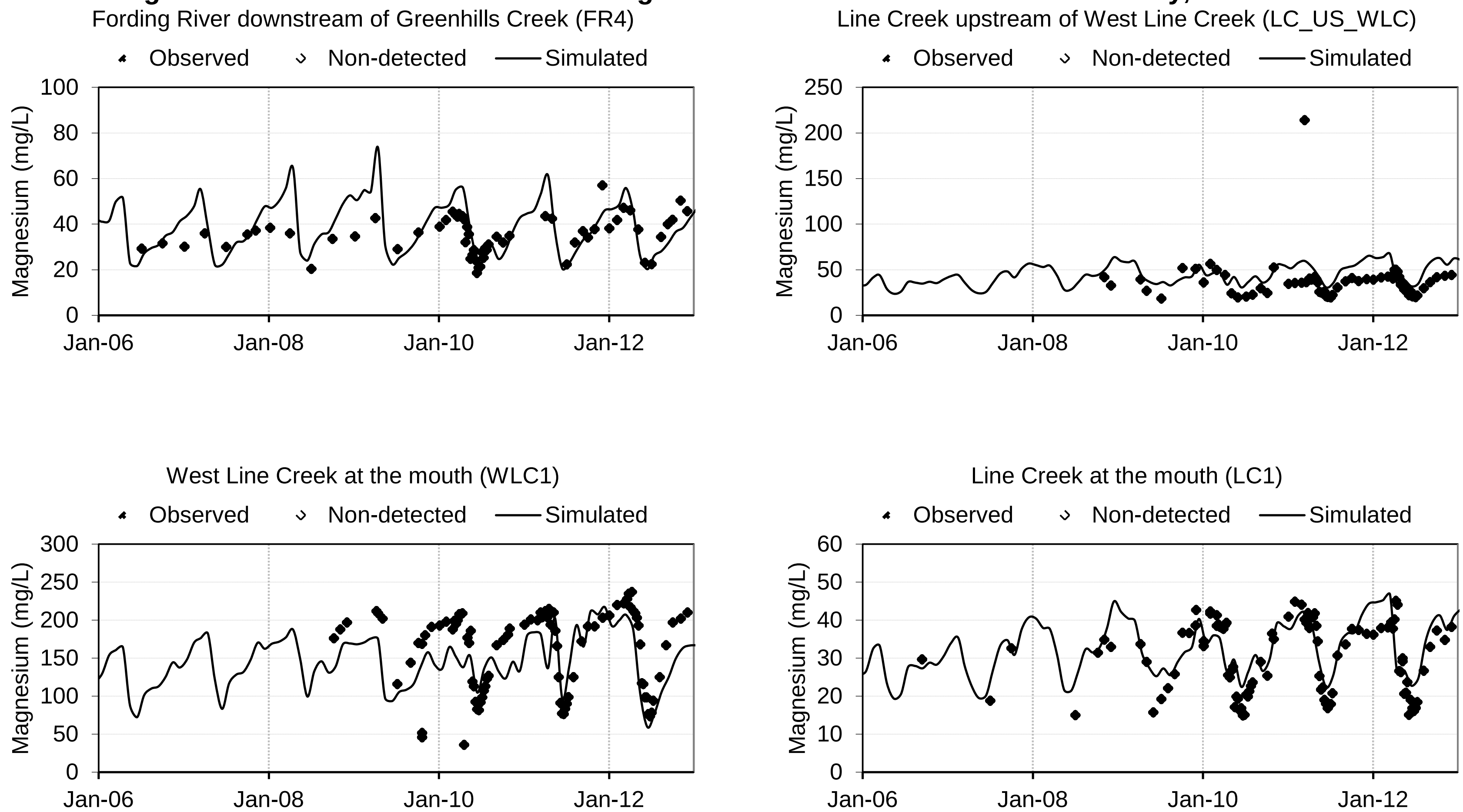


Figure B-5 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

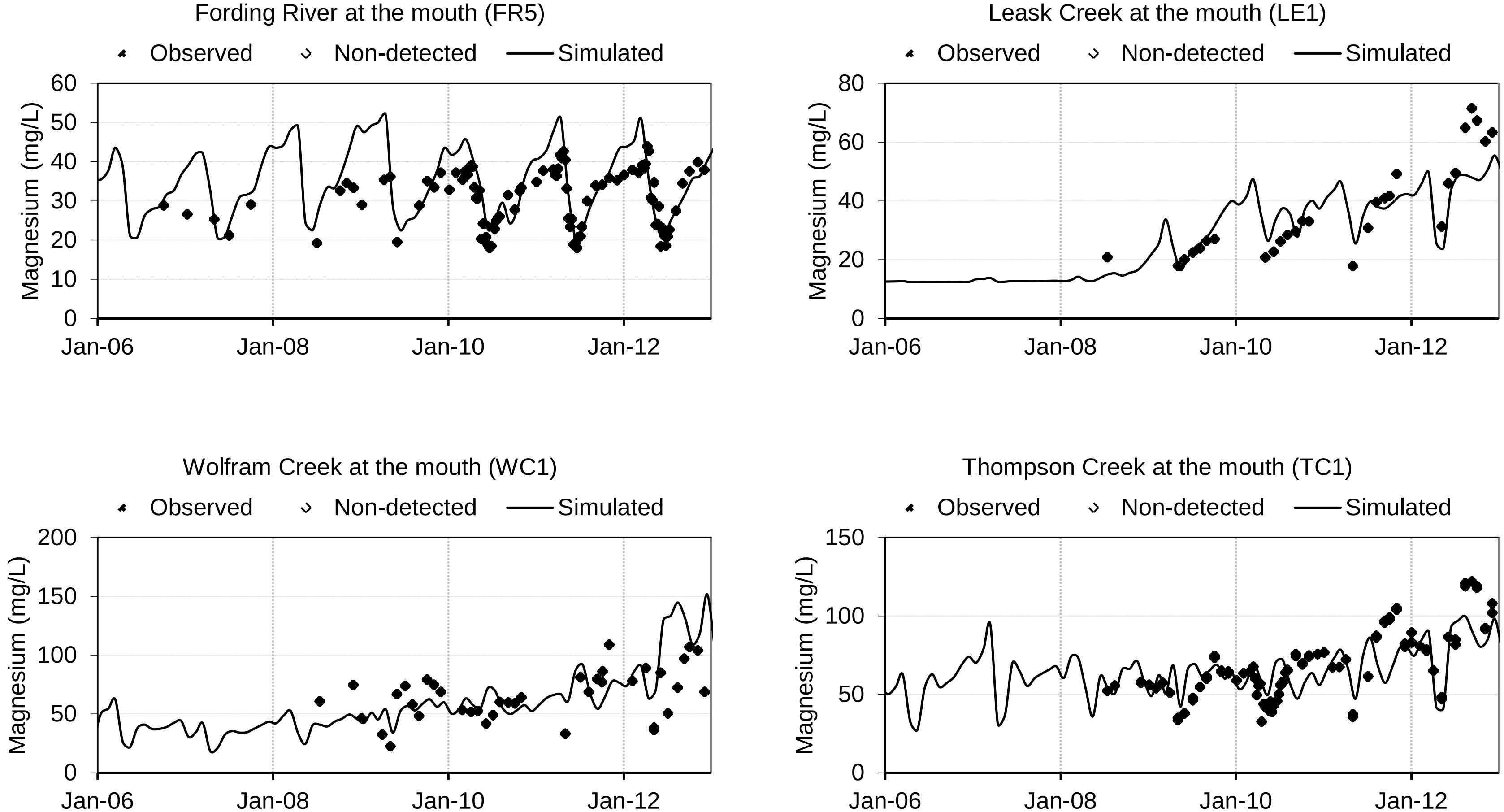


Figure B-5 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

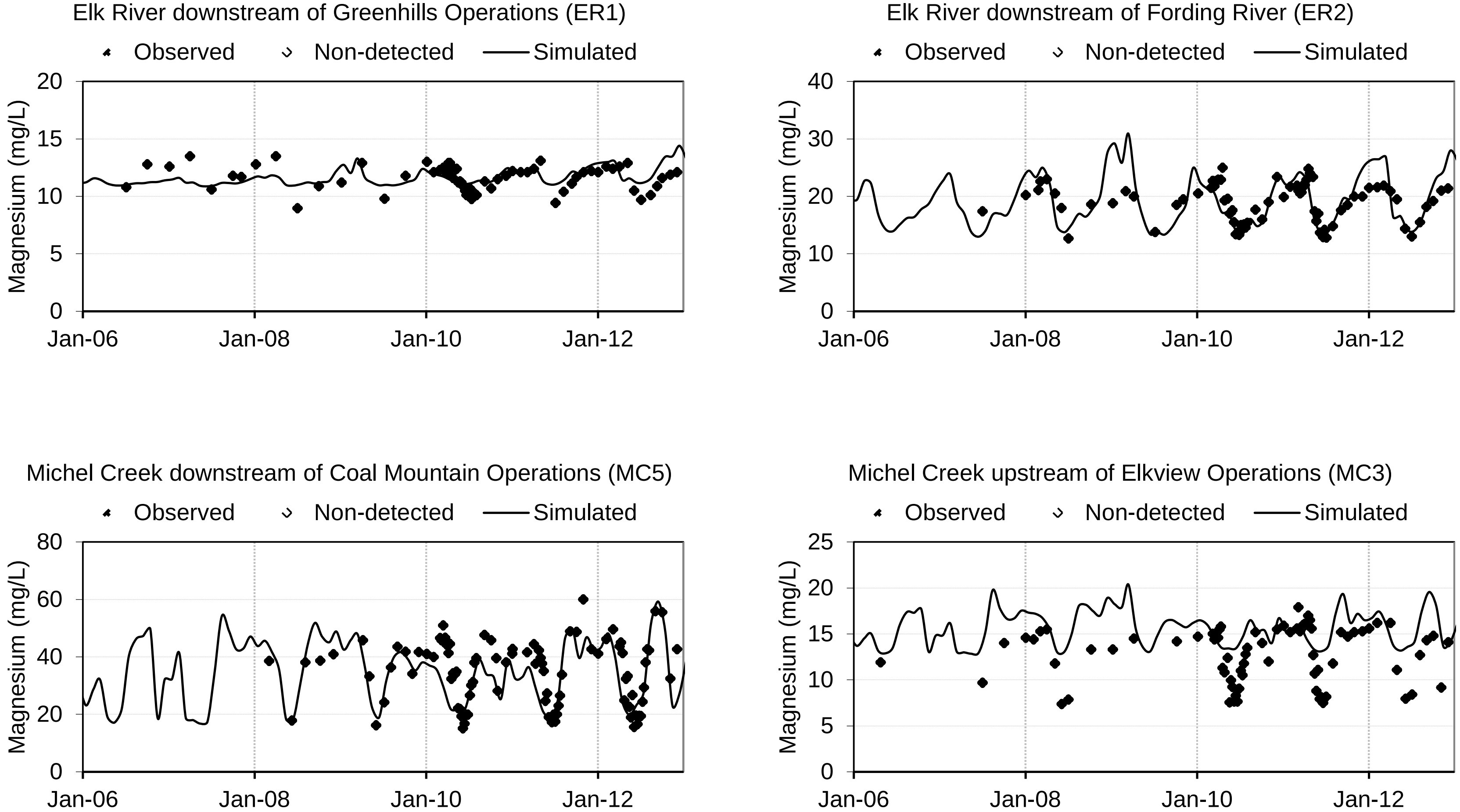


Figure B-5 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

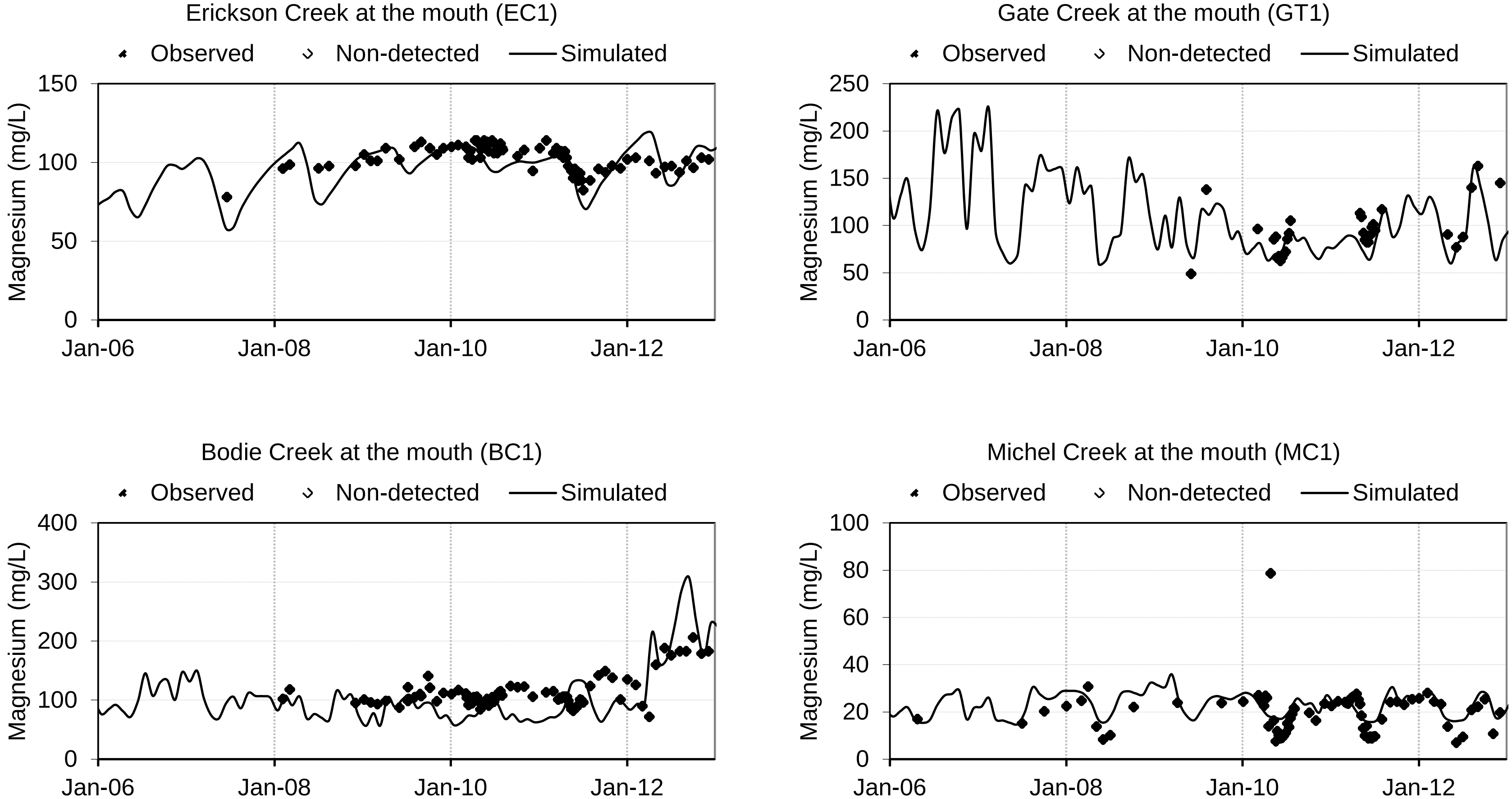


Figure B-5 Simulated and Observed Magnesium Concentrations in the Elk Valley, 2006 to 2012

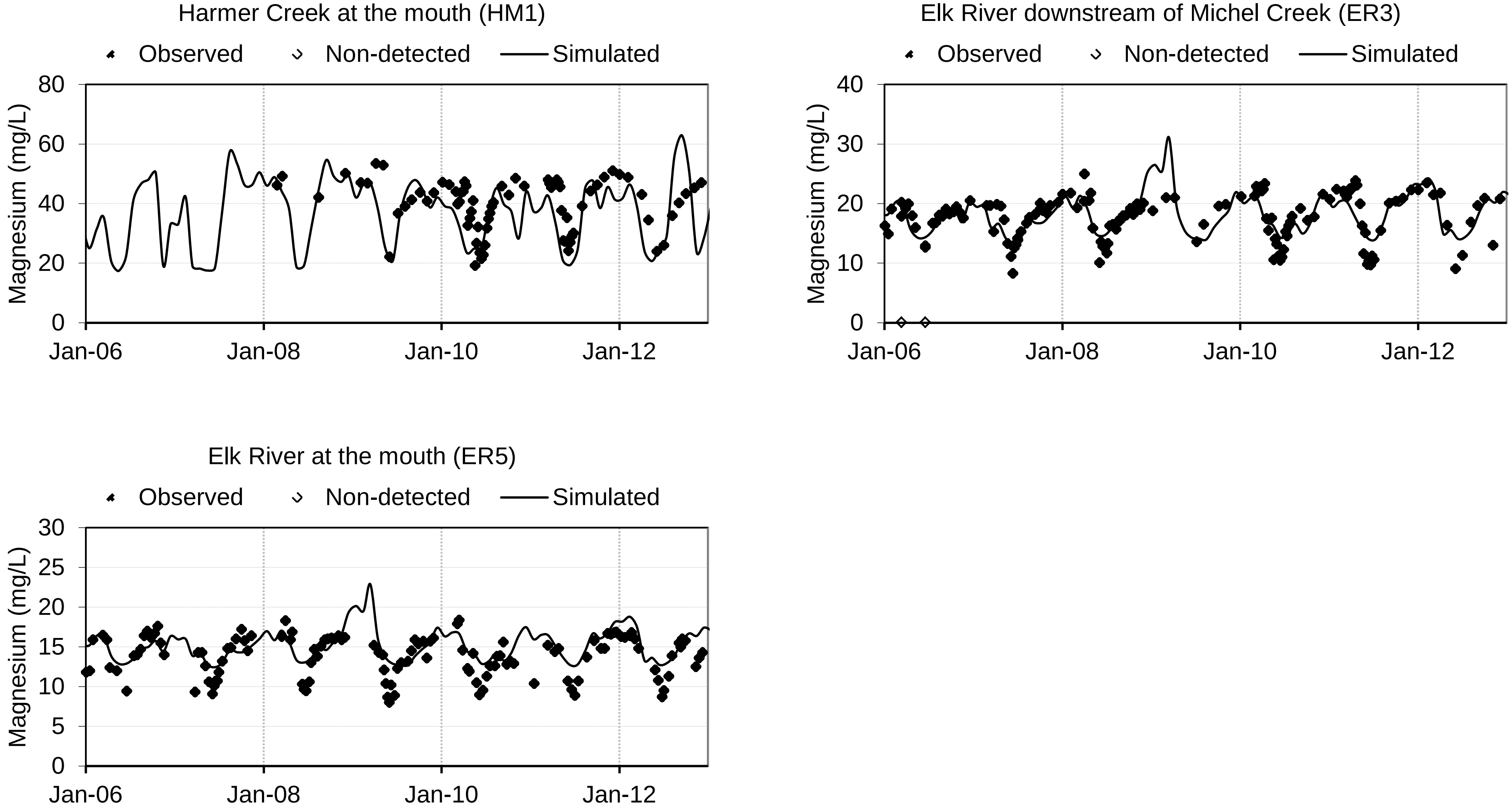


Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012

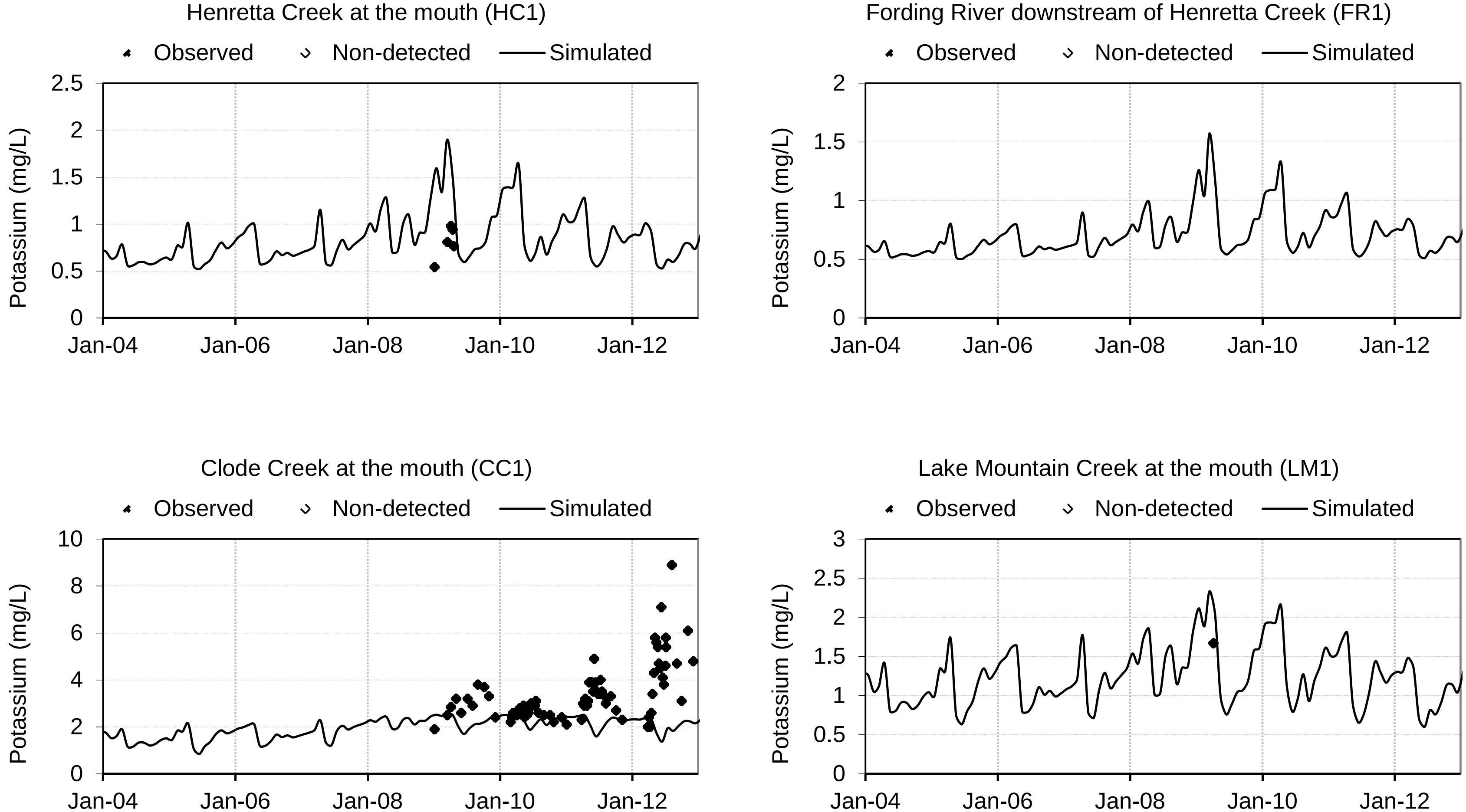


Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012

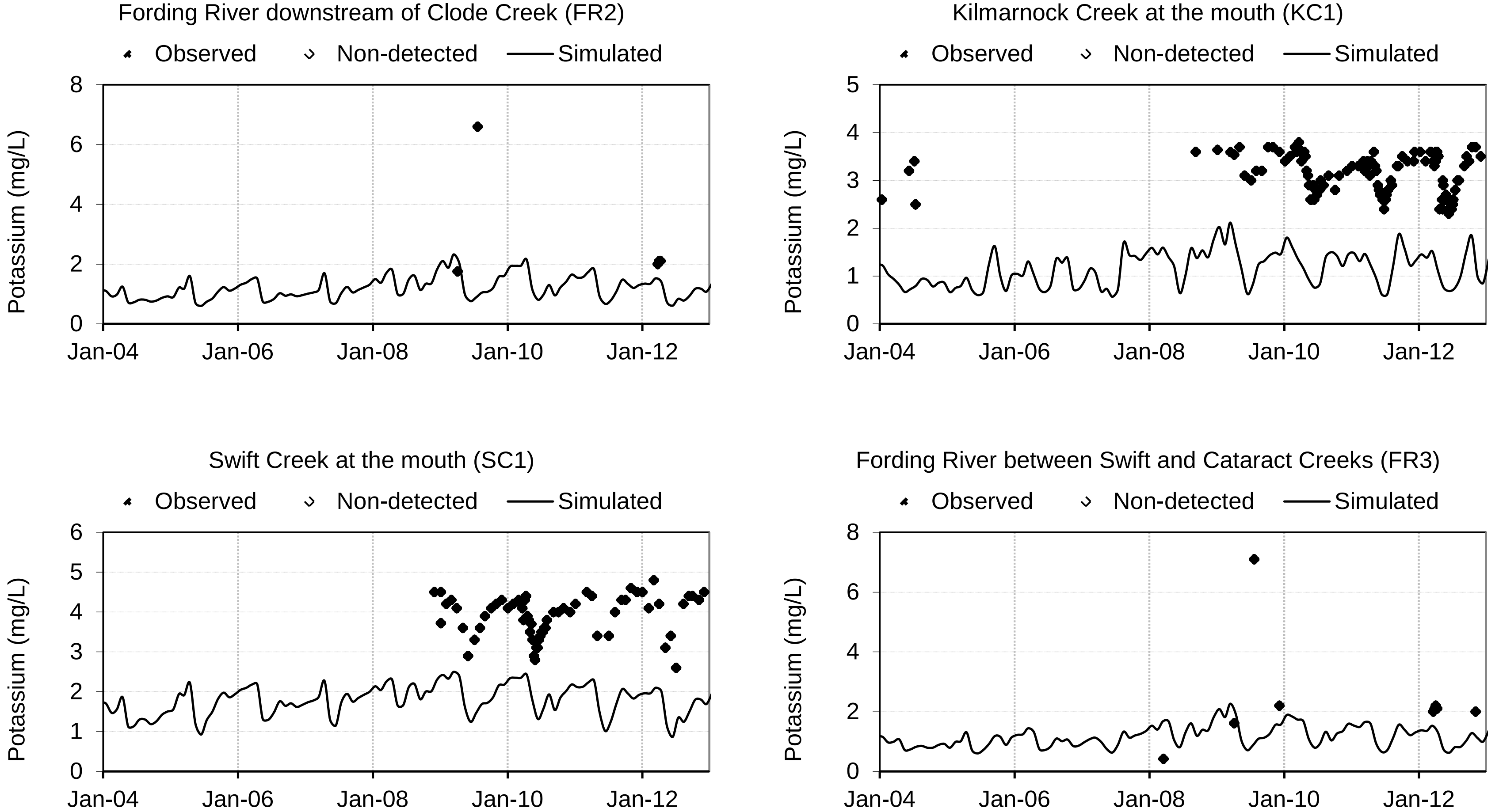


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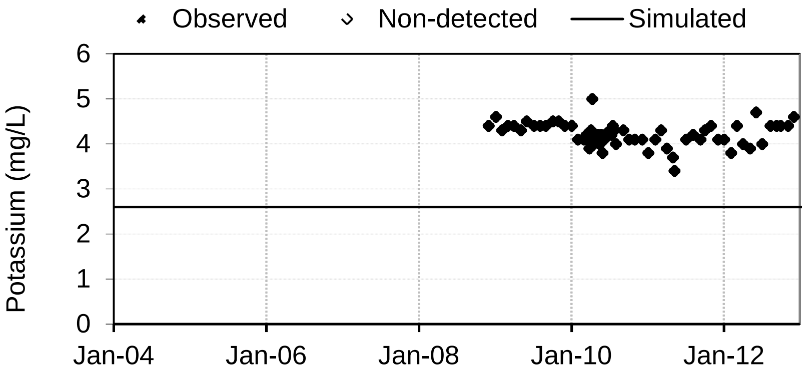
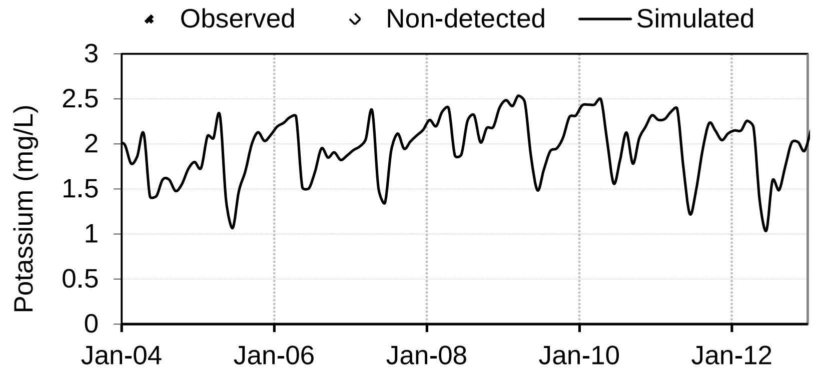
Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012

Cataract Creek at the mouth (CA1)

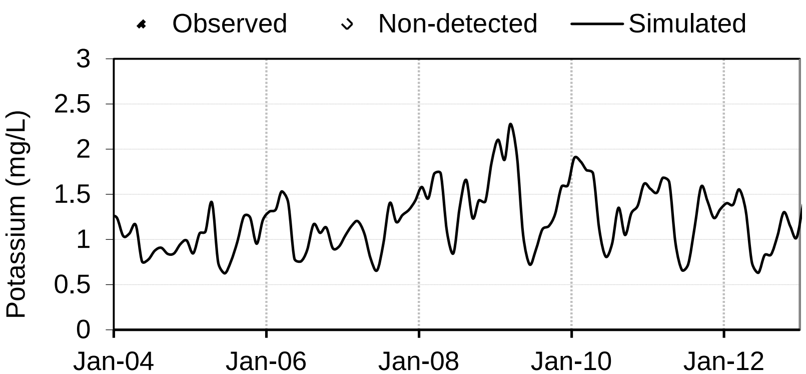


Note: No seasonal variation is simulated, because the entire watershed is assumed to be mine affected (i.e., there are no natural areas contributing runoff to the creek mouth, which would result in the dilution of the waters draining from the mine-affected areas).

Porter Creek at the mouth (PC1)



Fording River downstream of Porter Creek (FR3b)



Greenhills Creek at the mouth (GH1)

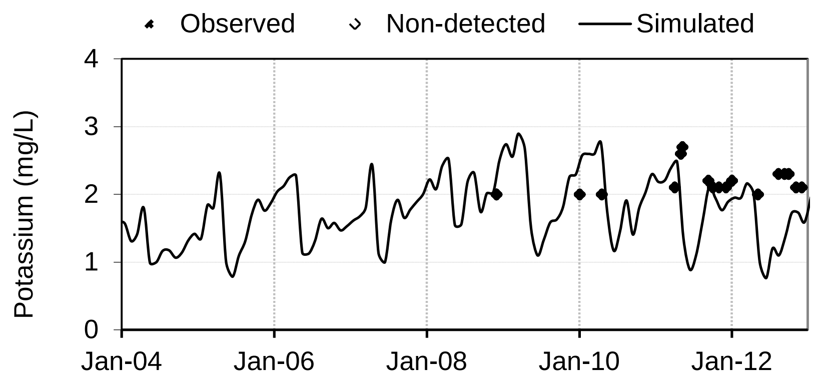
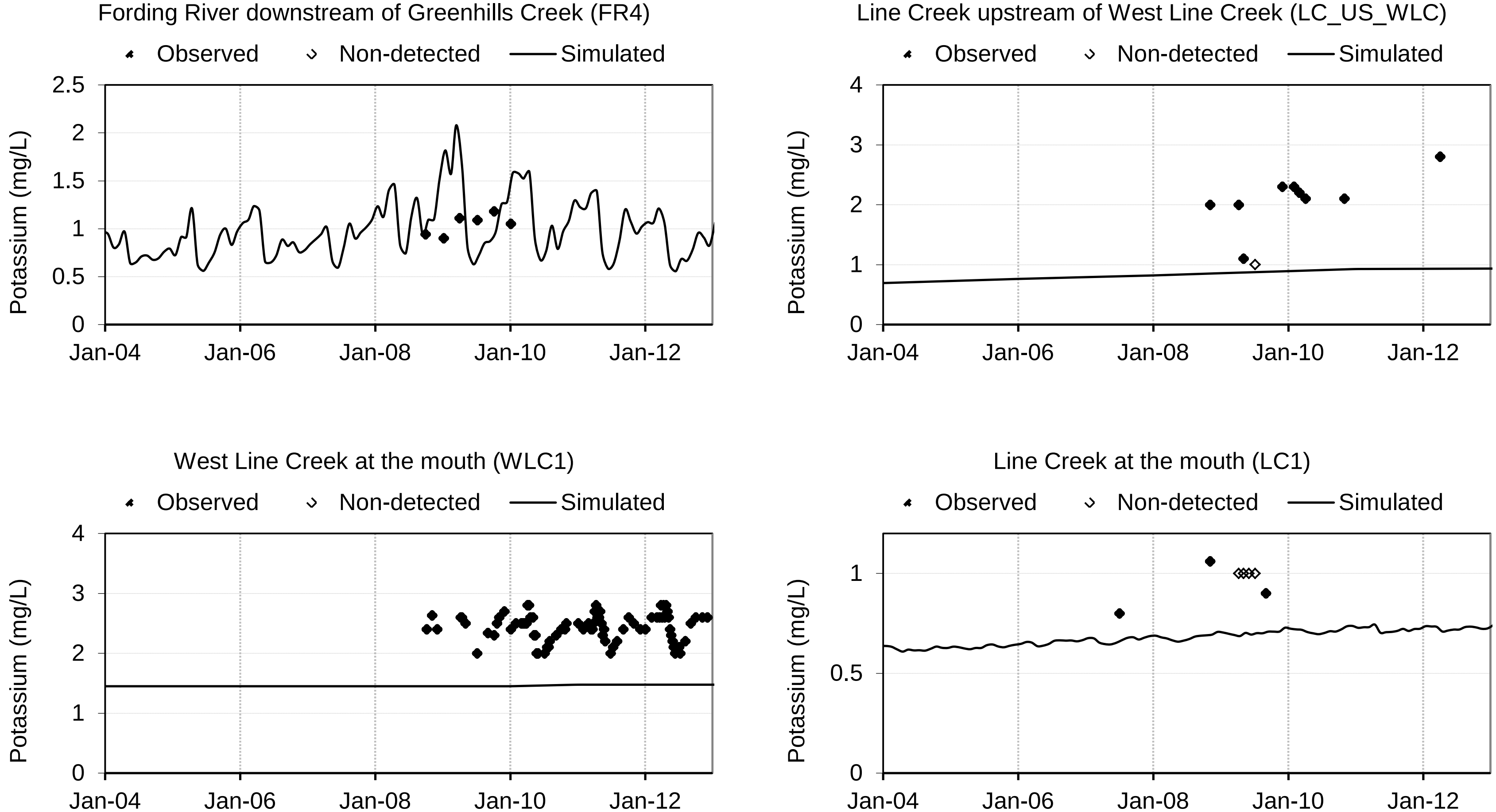


Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012



No seasonal variation is simulated for Line Creek or West Line Creek, because for each of these creeks the natural and mine flows are assumed to follow the same seasonal pattern (i.e., the seasonal pattern observed at the mouth of the creek).

Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012

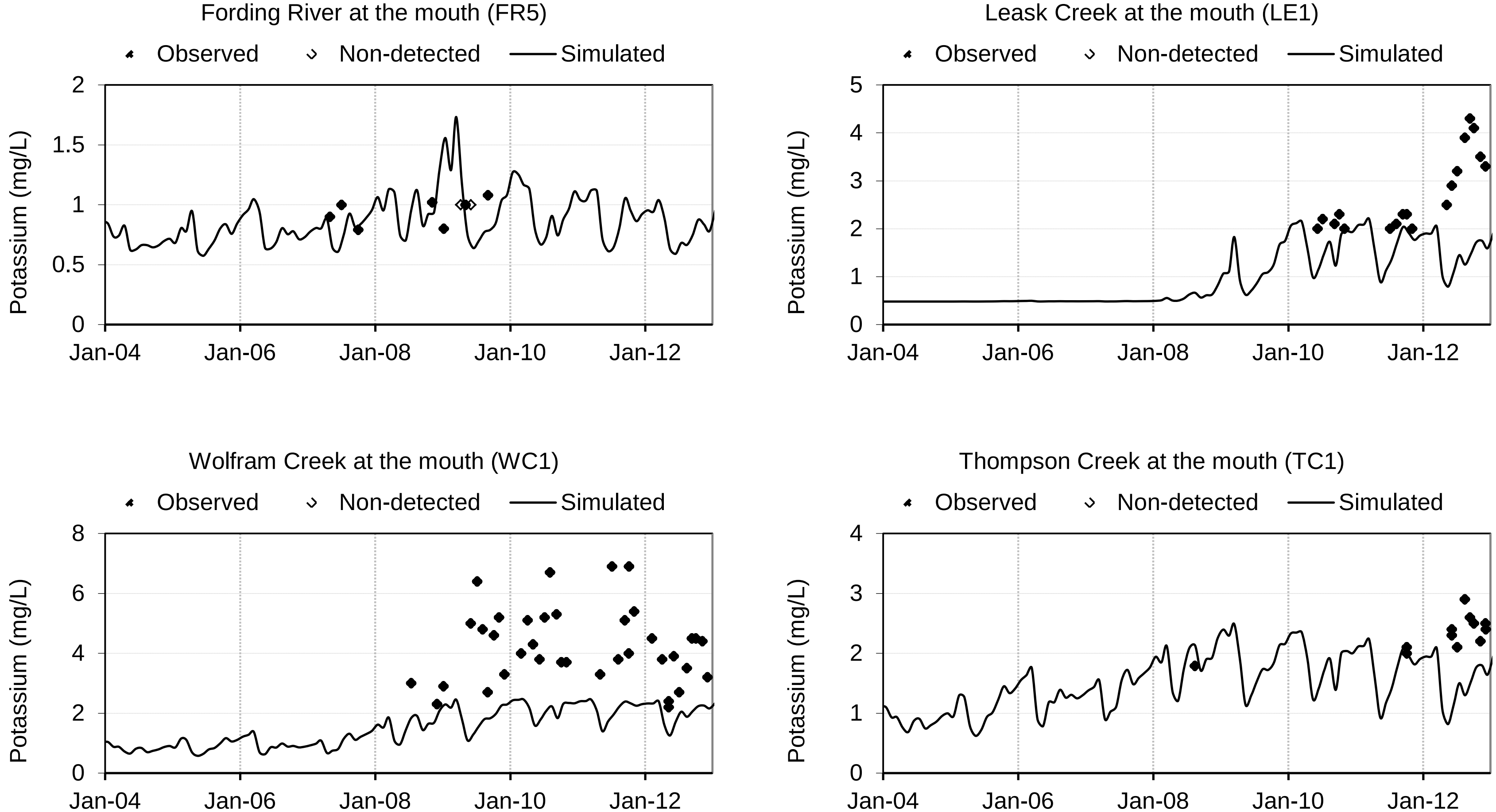


Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012

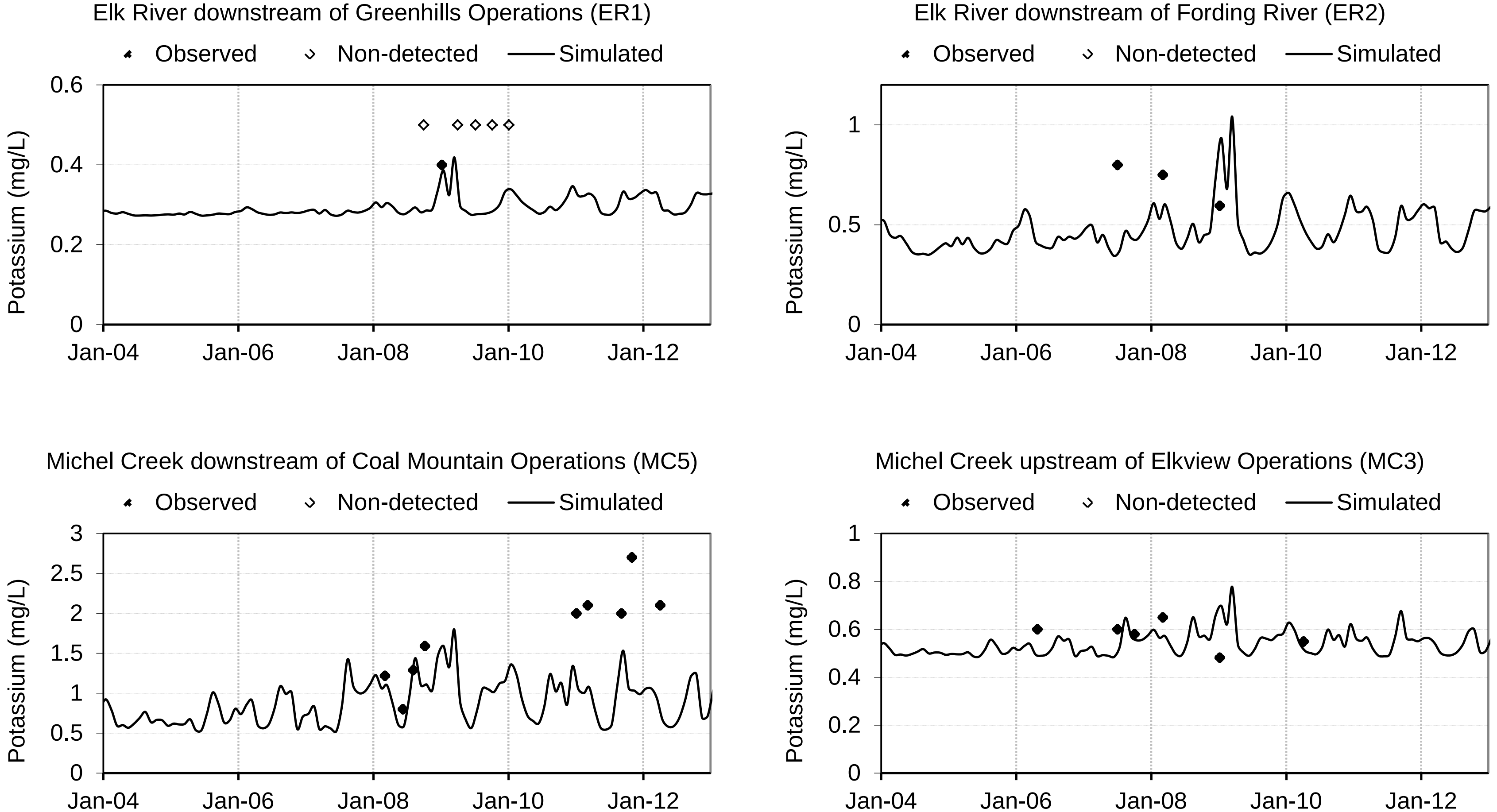


Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012

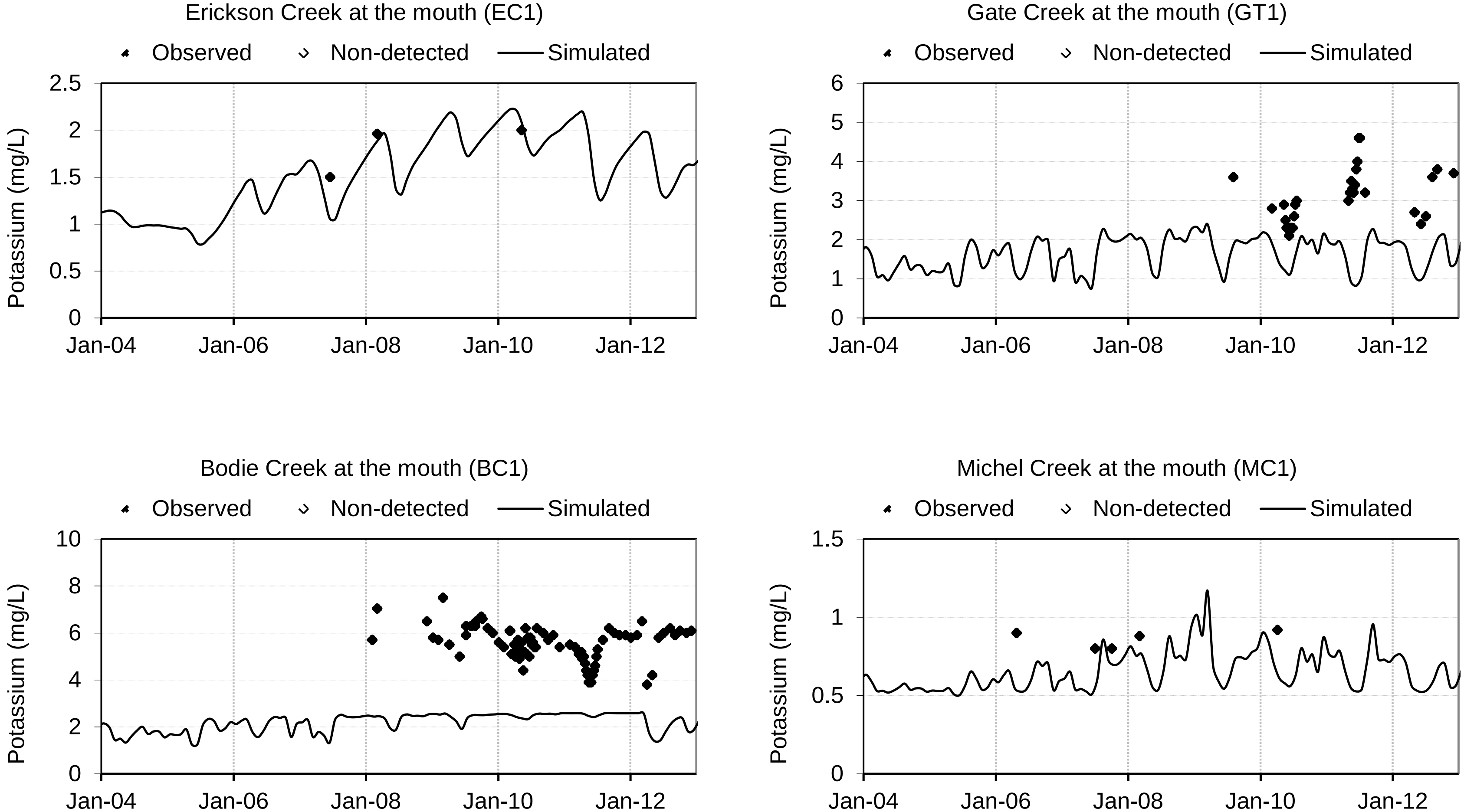


Figure B-6 Simulated and Observed Potassium Concentrations in the Elk Valley, 2004 to 2012

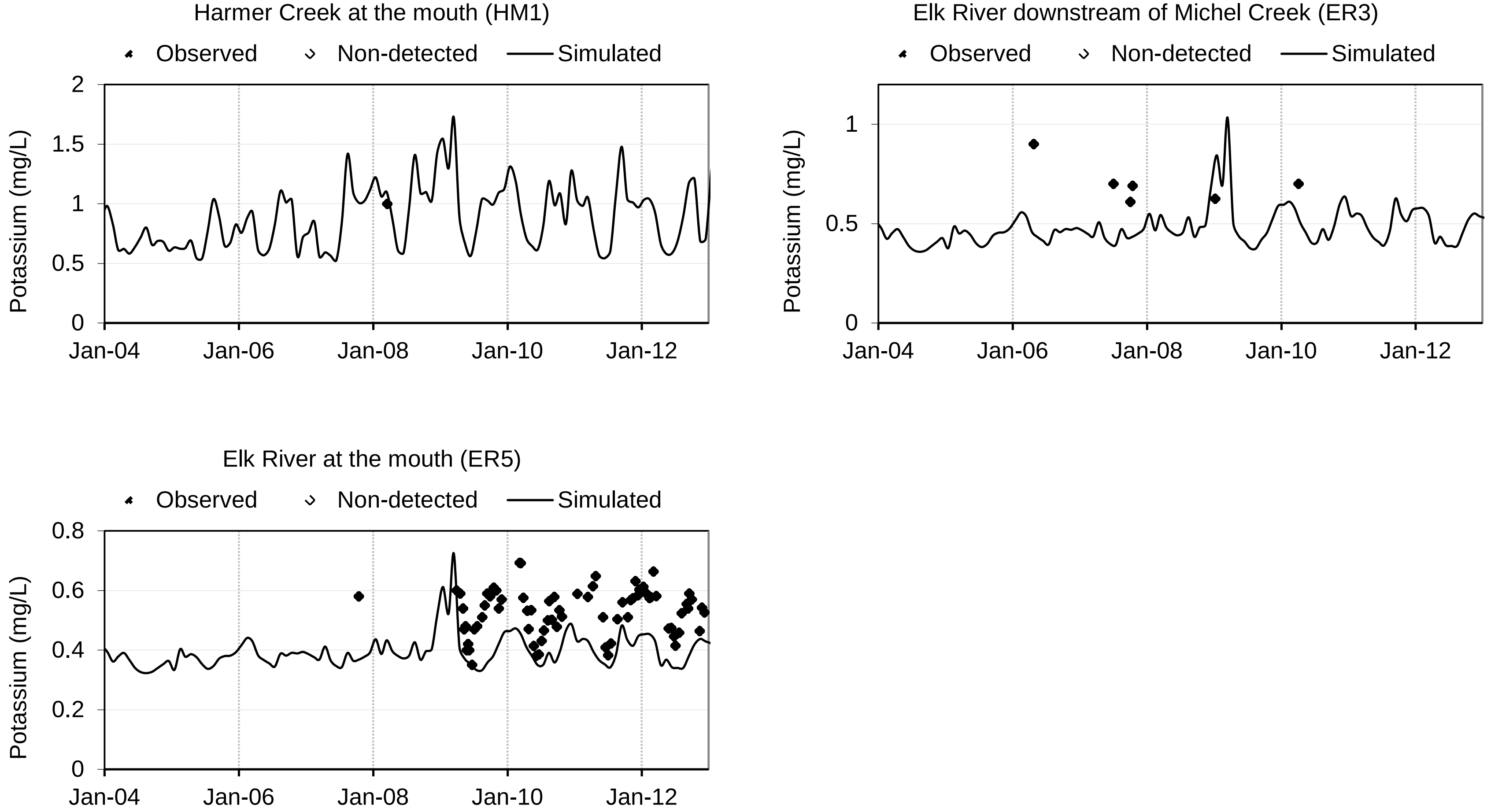


Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012

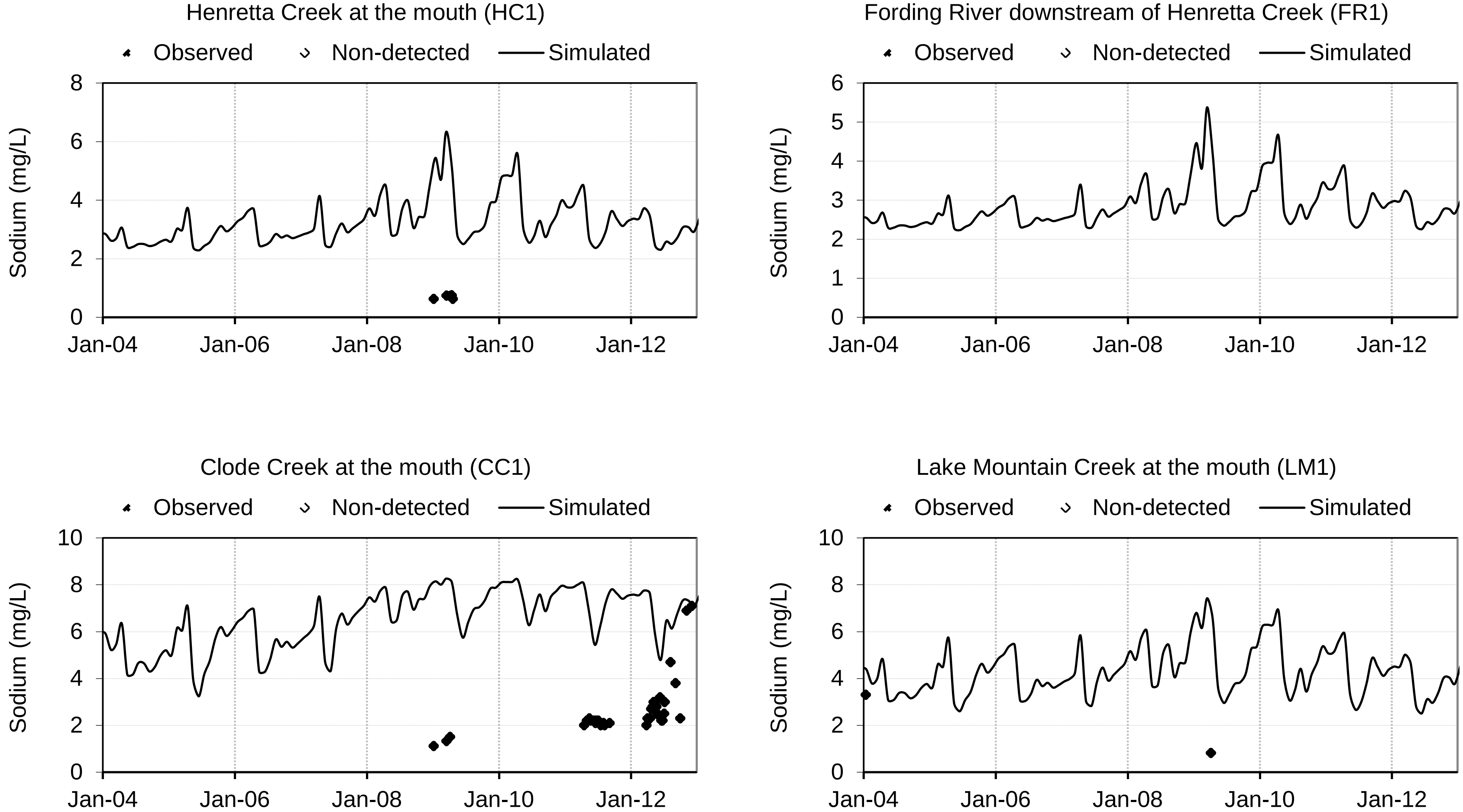


Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012

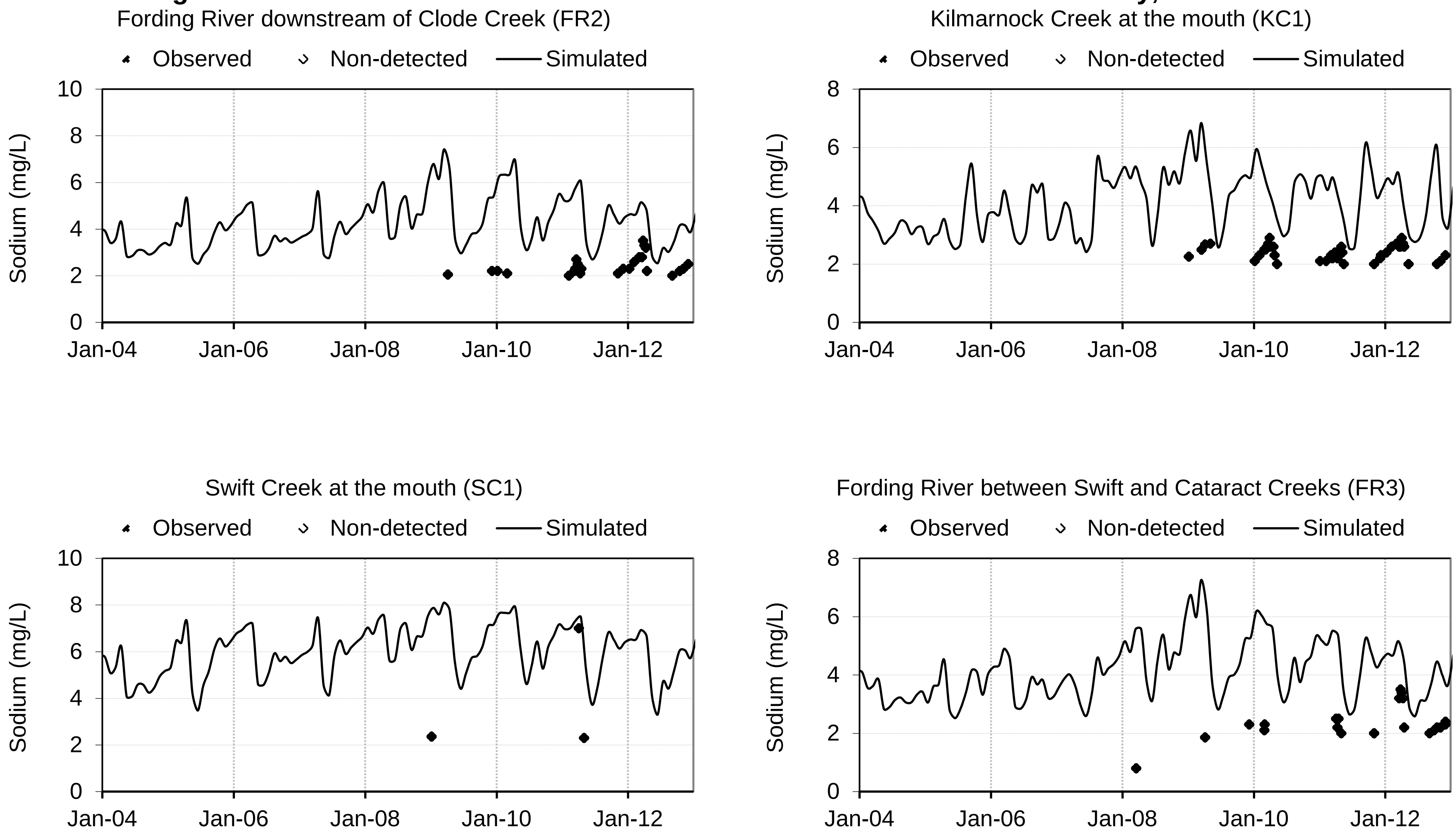
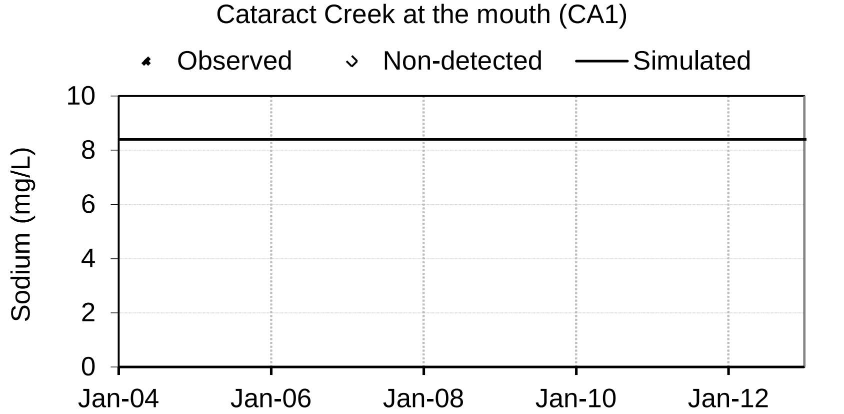
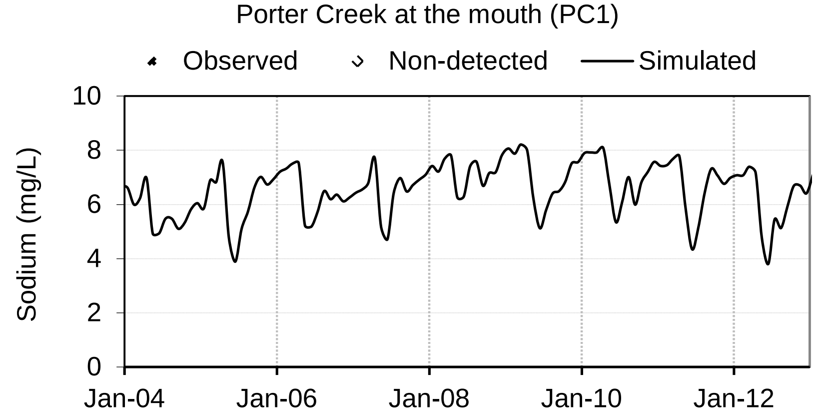
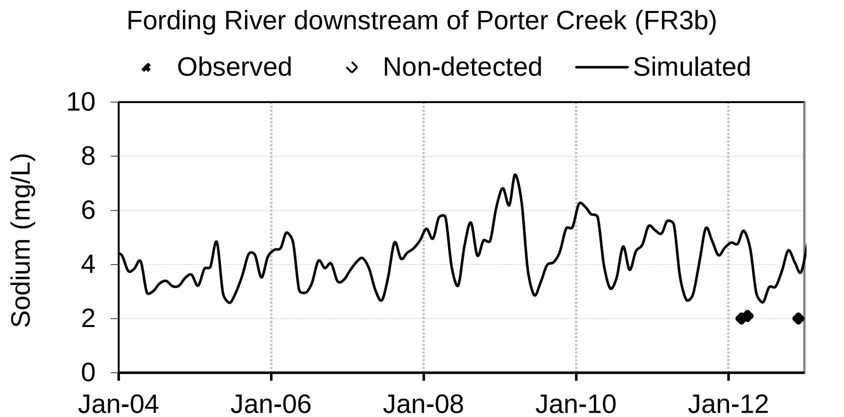


Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012



Note: No seasonal variation is simulated, because the entire watershed is assumed to be mine affected (i.e., there are no natural areas contributing runoff to the creek mouth, which would result in the dilution of the waters draining from the mine-affected areas).





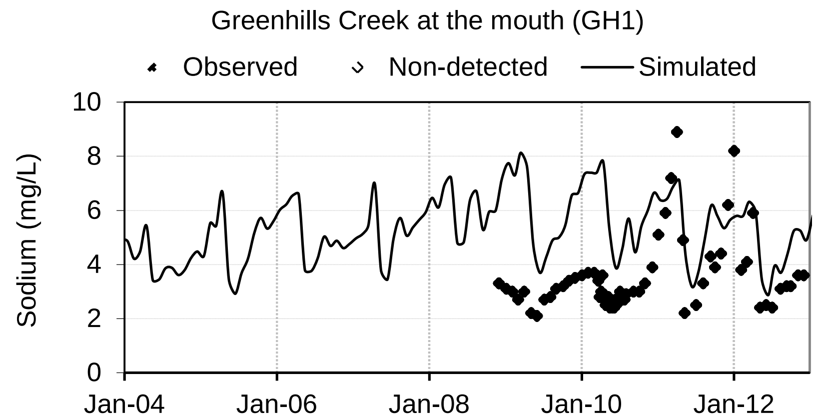
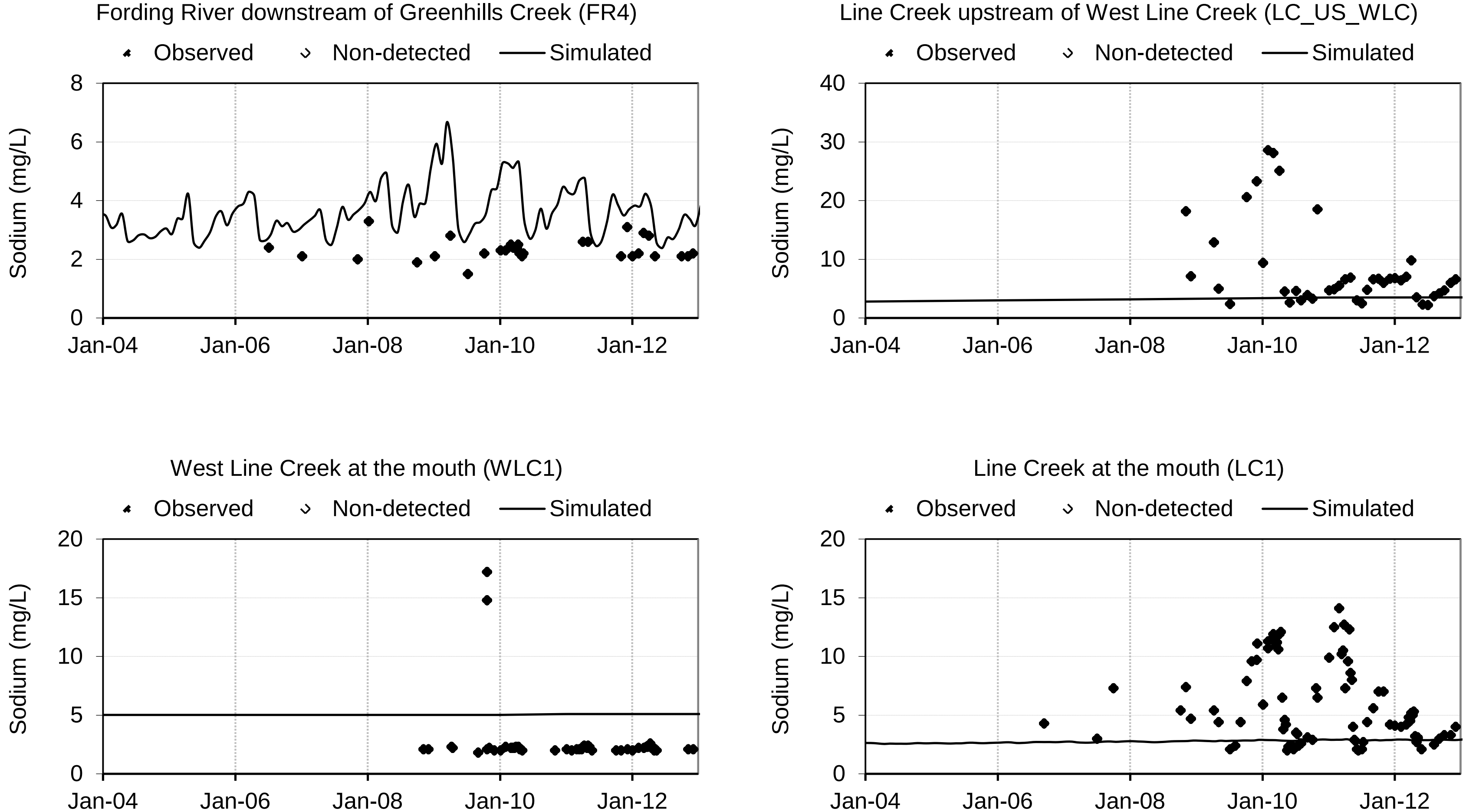


Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012



No seasonal variation is simulated for Line Creek or West Line Creek, because for each of these creeks the natural and mine flows are assumed to follow the same seasonal pattern (i.e., the seasonal pattern observed at the mouth of the creek).

Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012

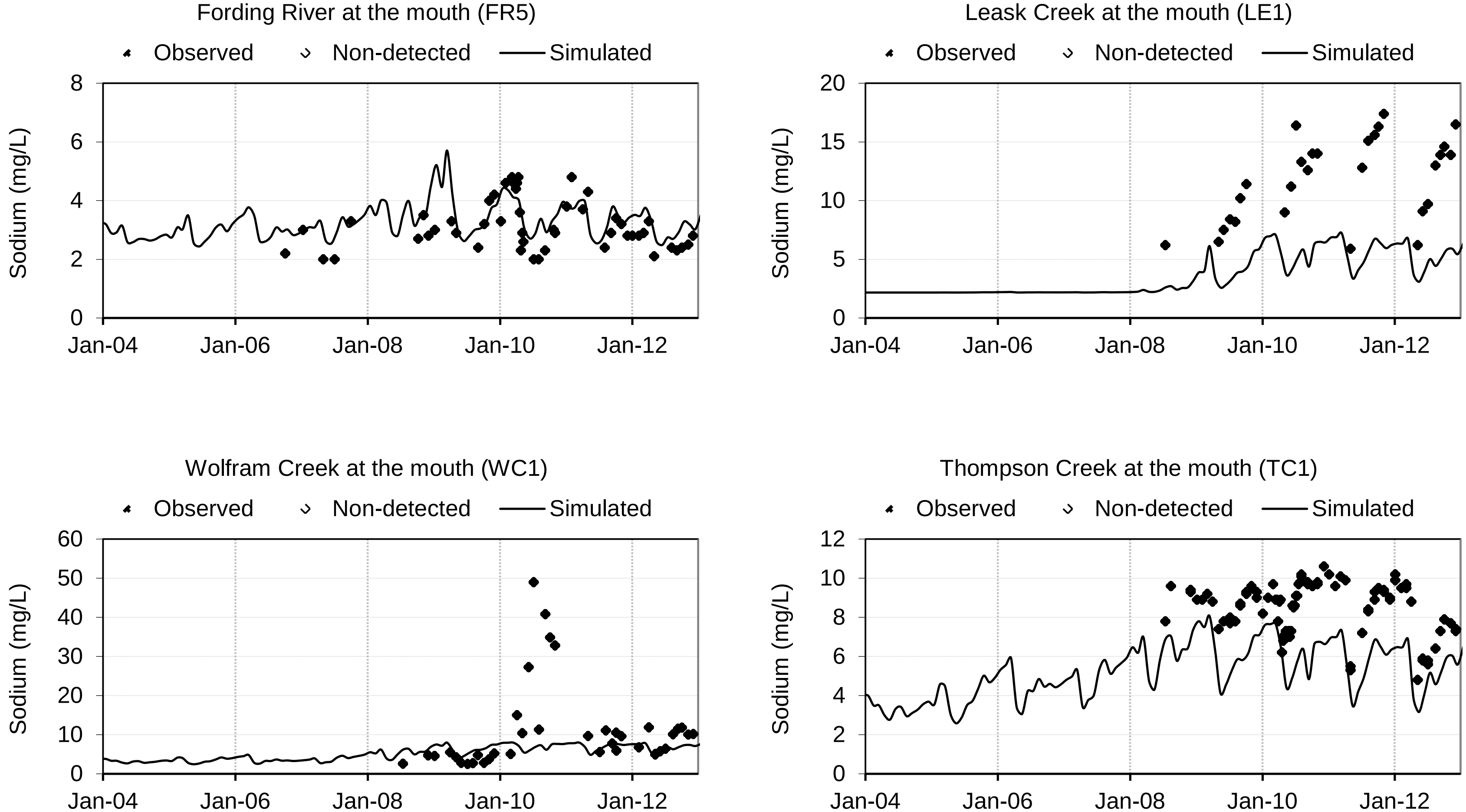
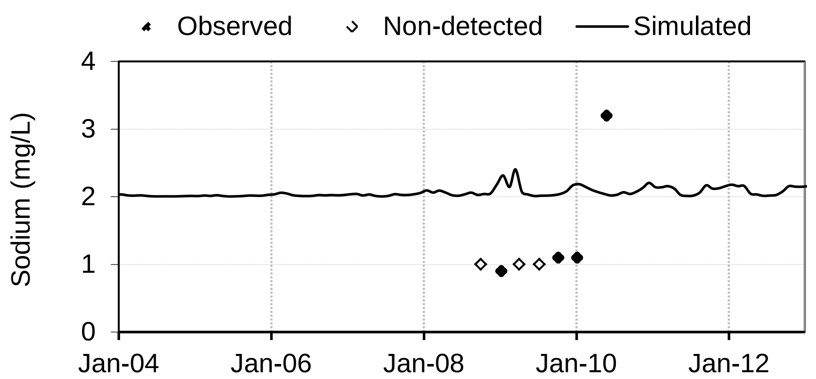
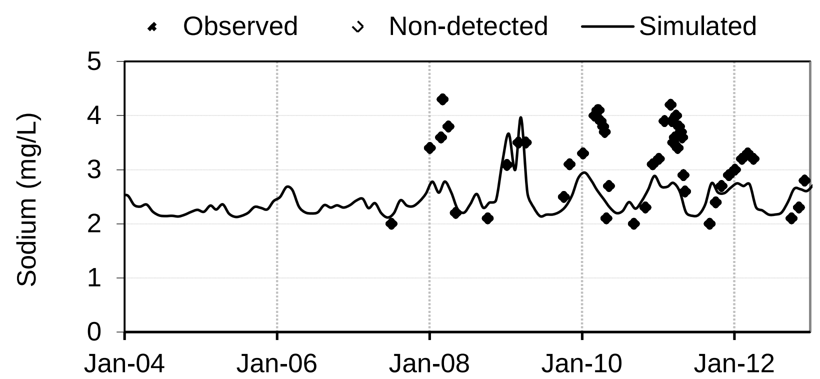


Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012

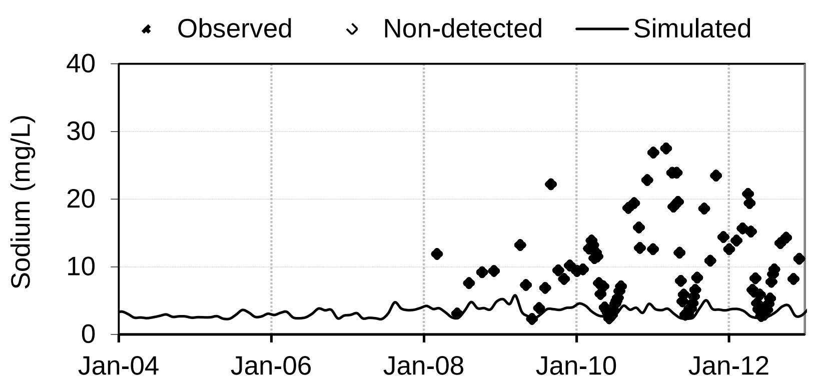
Elk River downstream of Greenhills Operations (ER1)



Elk River downstream of Fording River (ER2)



Michel Creek downstream of Coal Mountain Operations (MC5)



Michel Creek upstream of Elkview Operations (MC3)

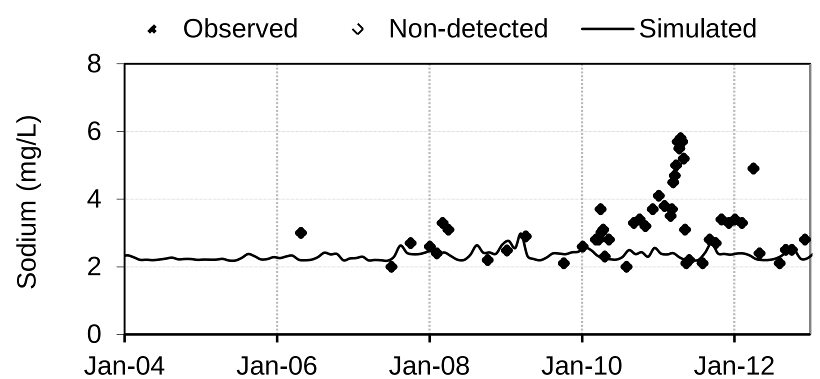


Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012

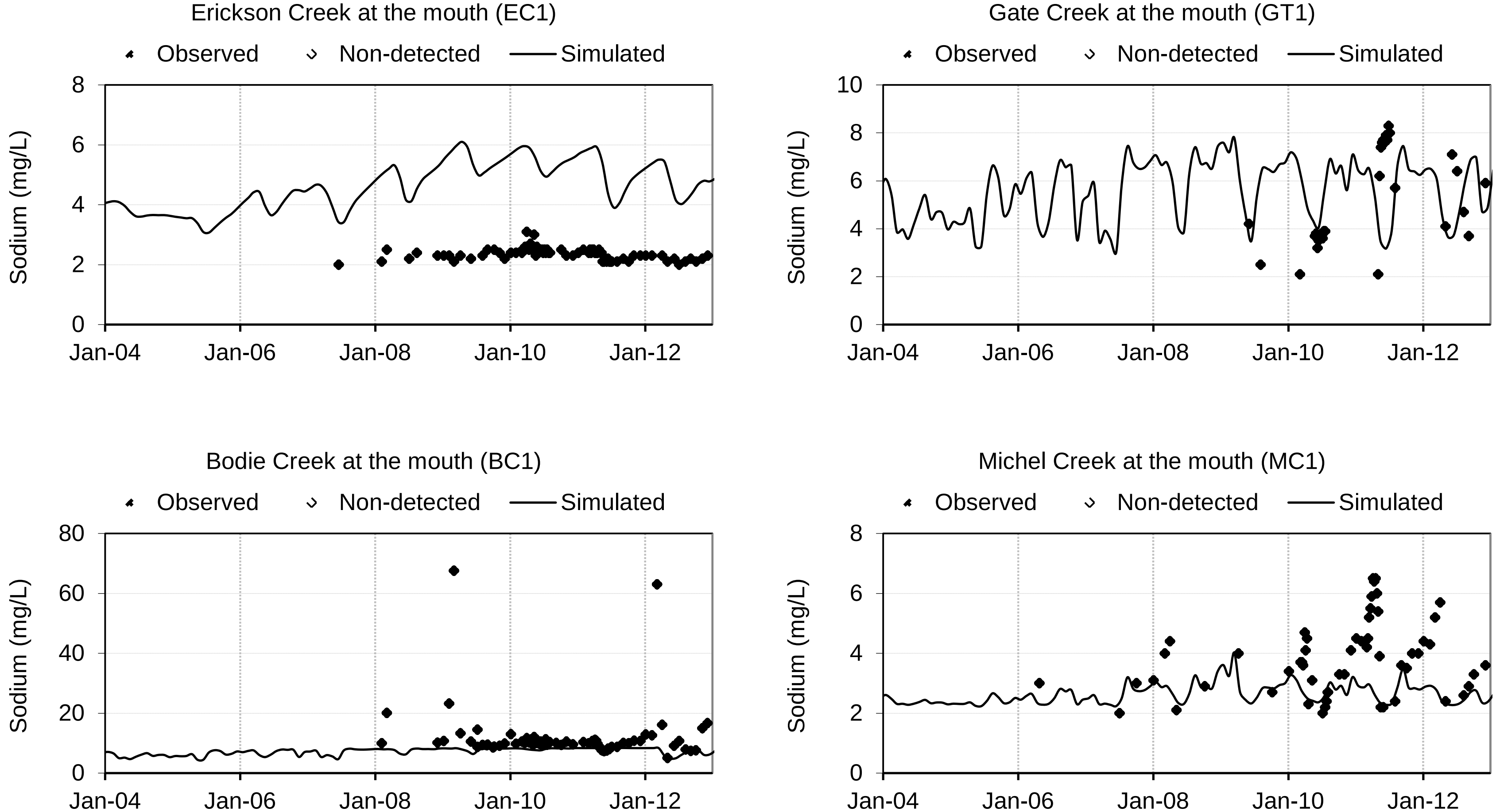
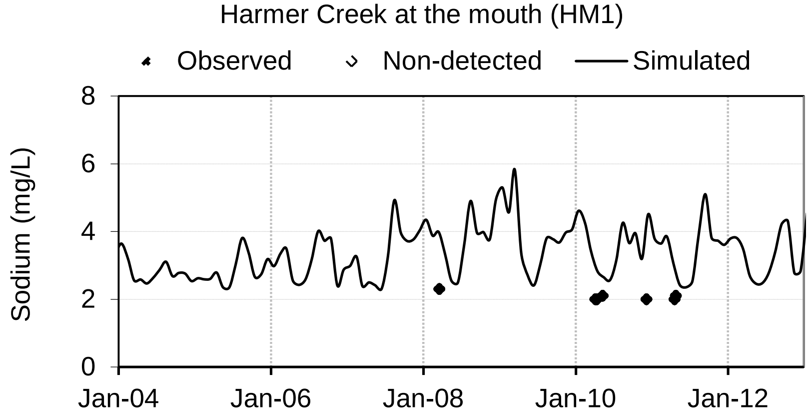
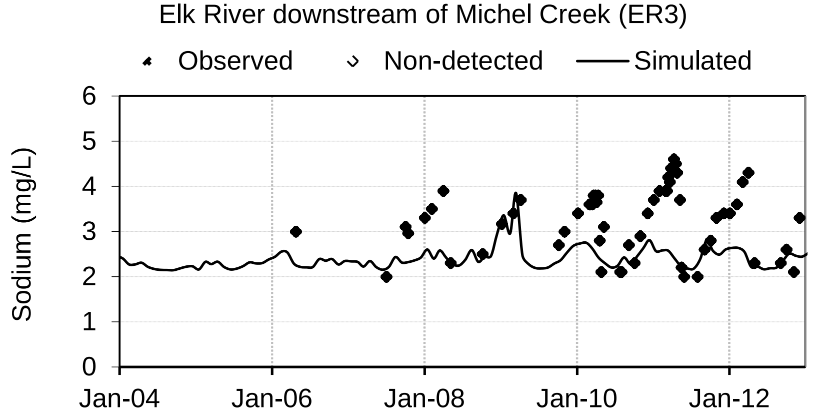


Figure B-7 Simulated and Observed Sodium Concentrations in the Elk Valley, 2004 to 2012





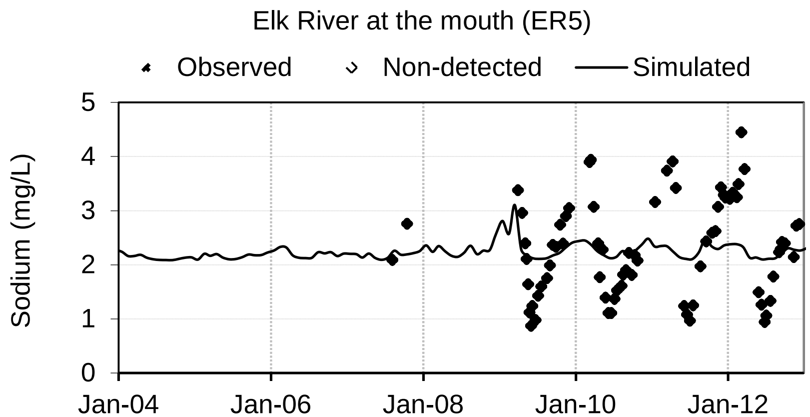


Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012

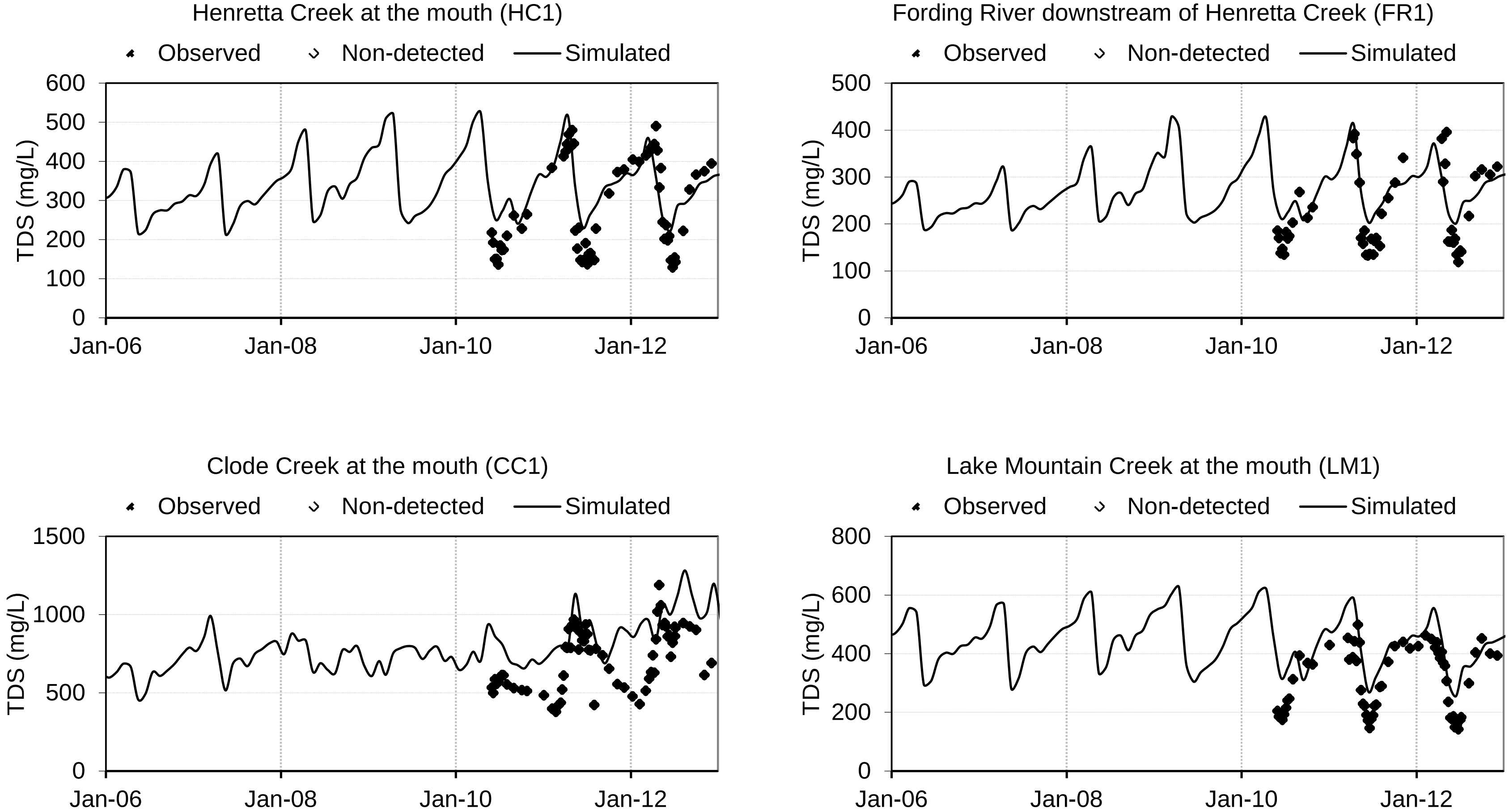
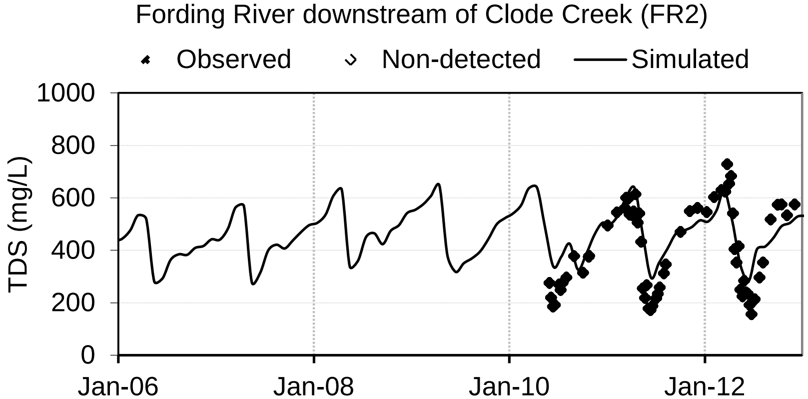
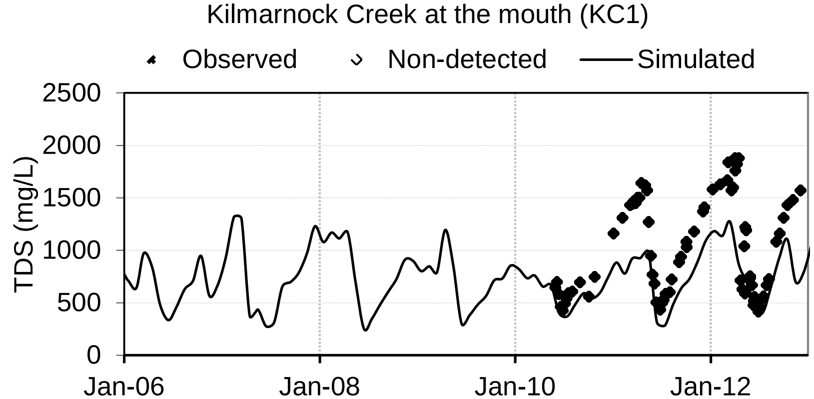
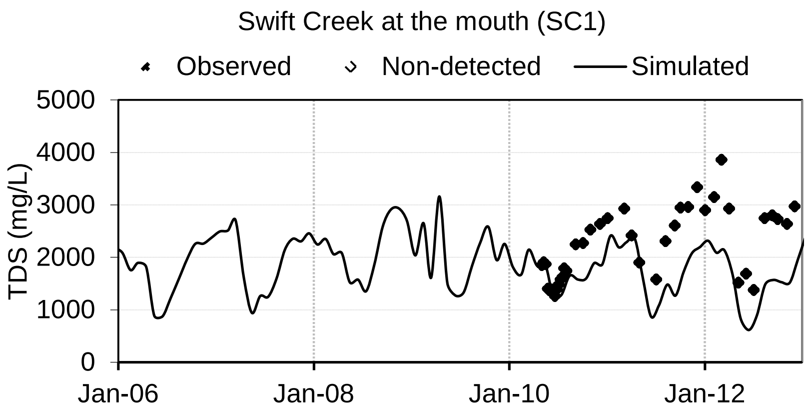


Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012







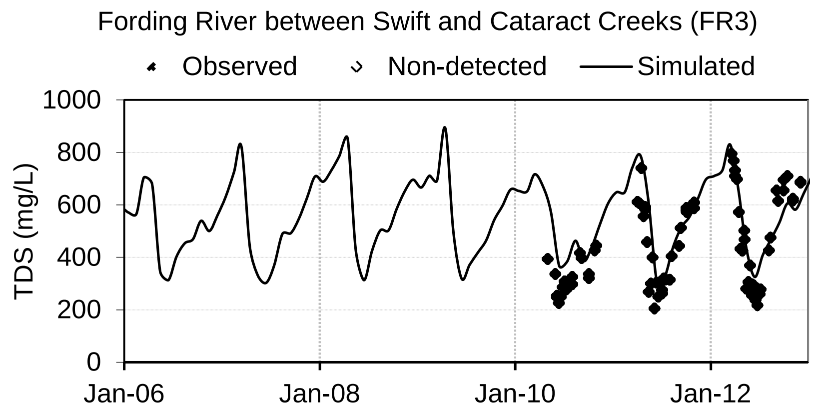


Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012

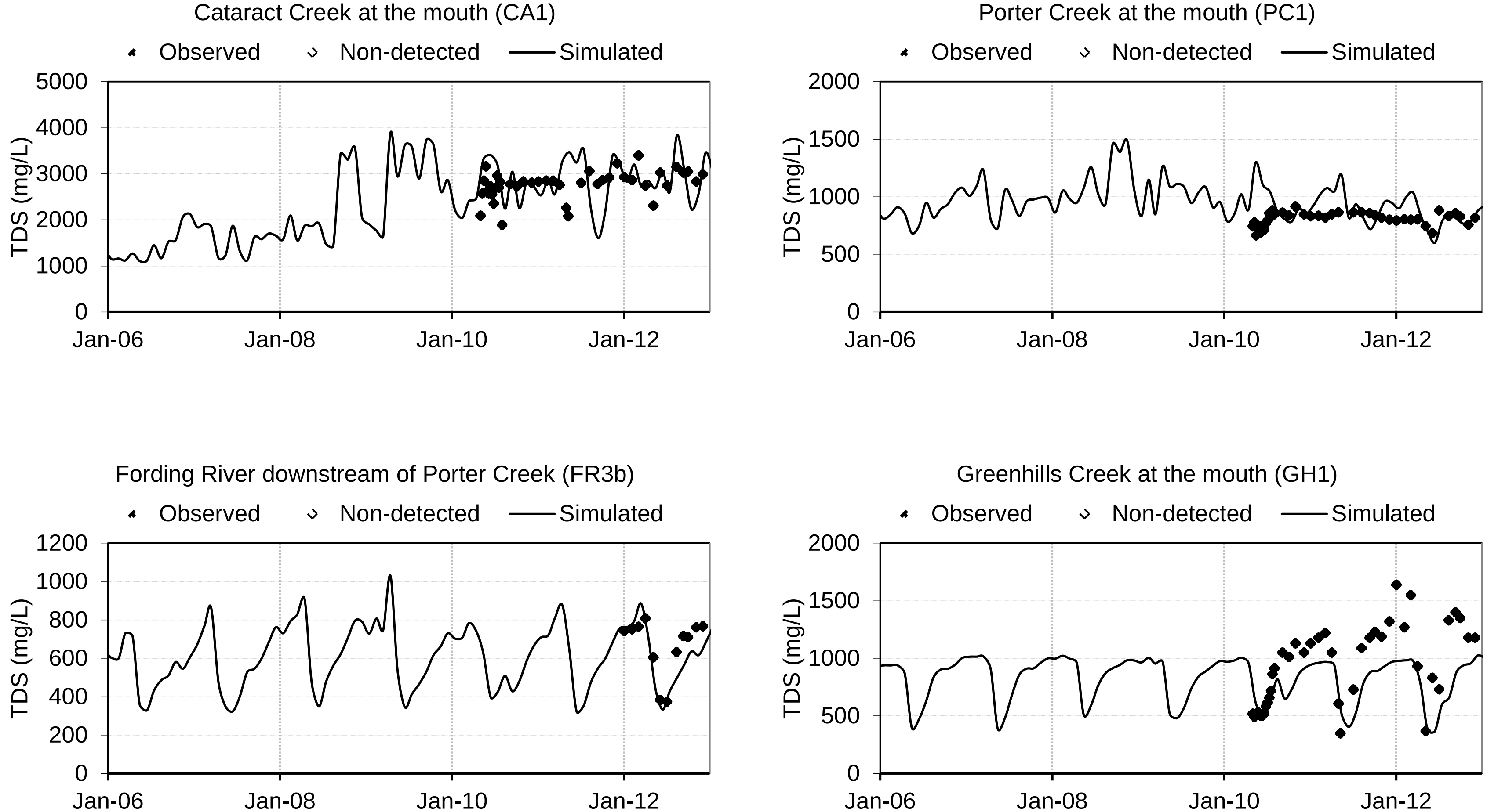


Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012

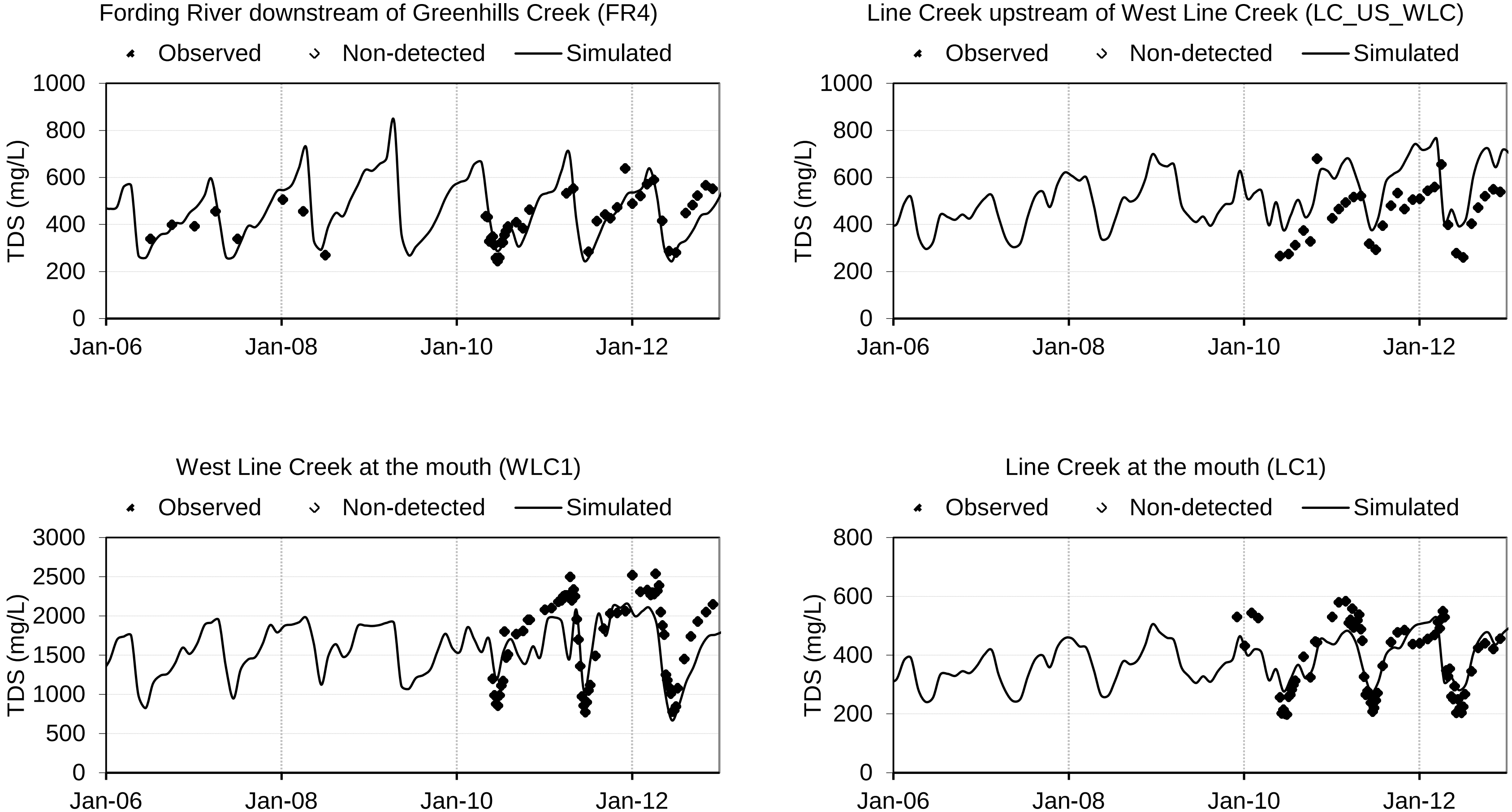


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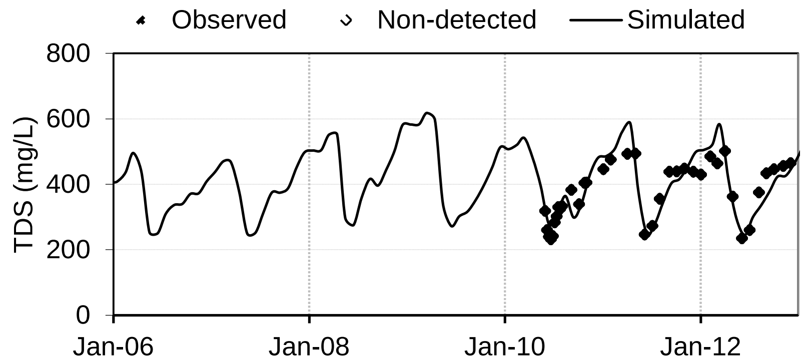
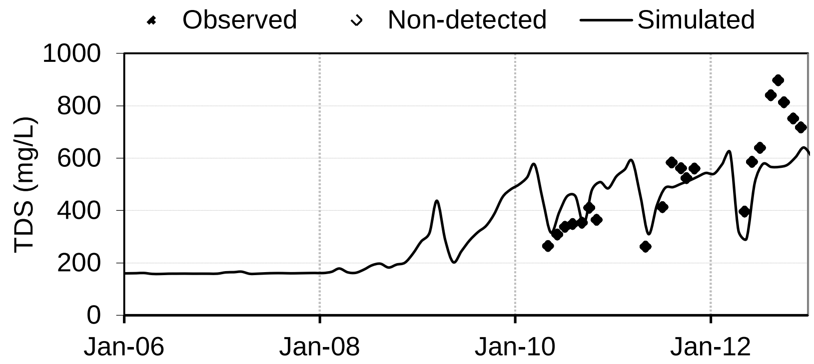
Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012

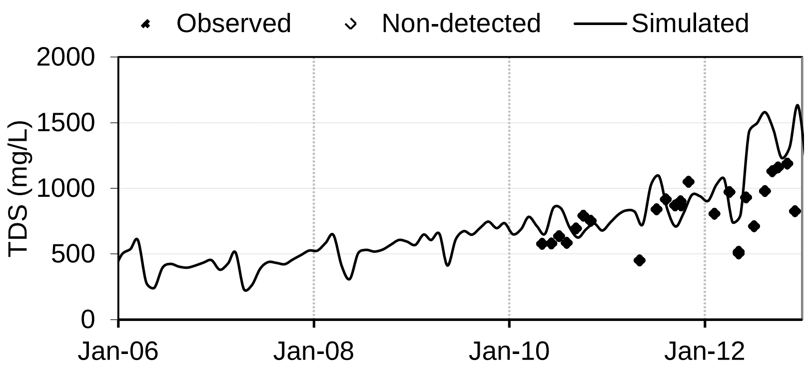
Fording River at the mouth (FR5)



Leask Creek at the mouth (LE1)



Wolfram Creek at the mouth (WC1)



Thompson Creek at the mouth (TC1)

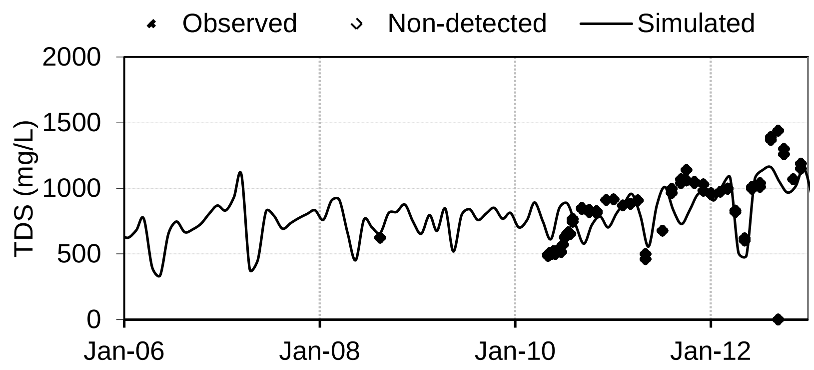


Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012

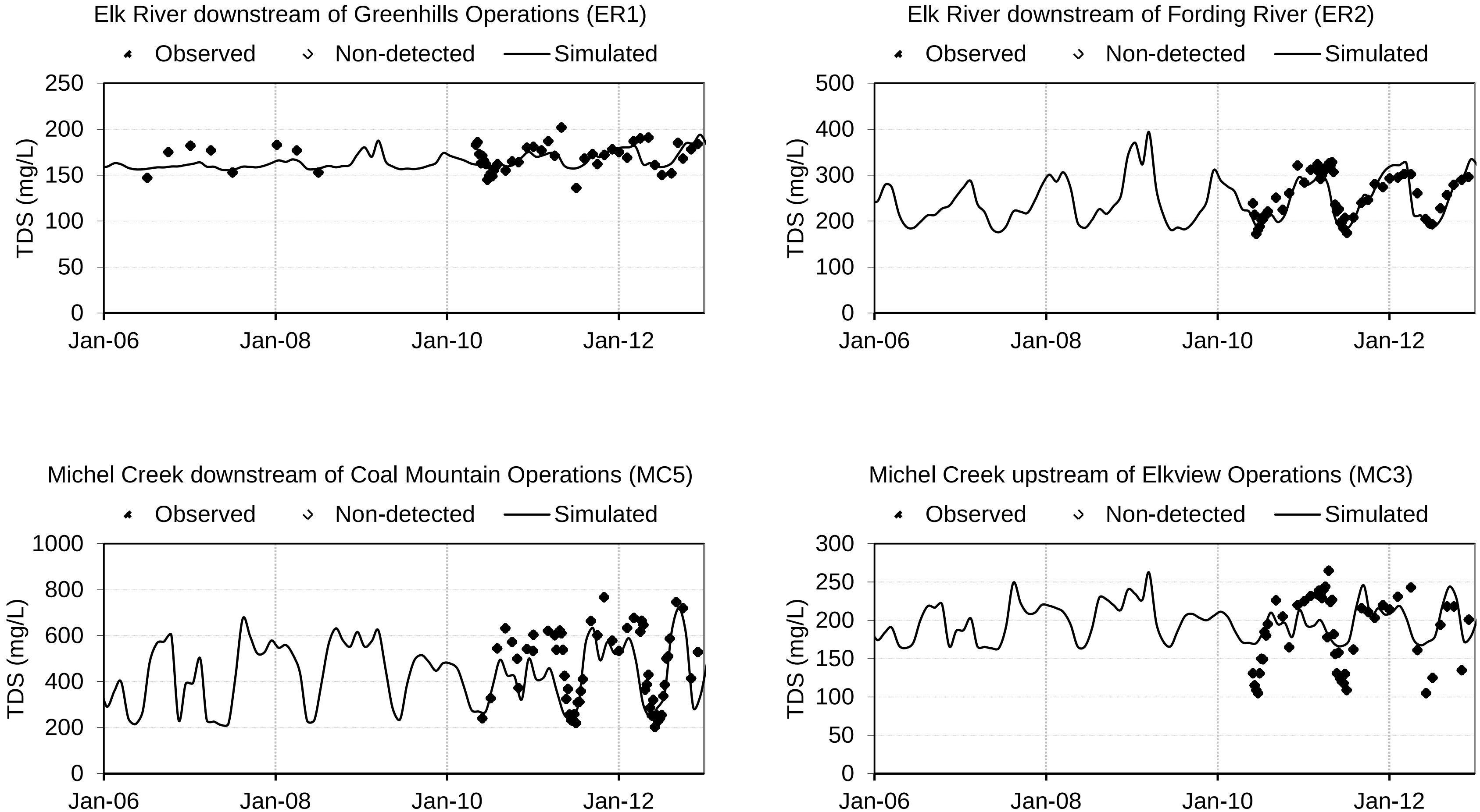


Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012

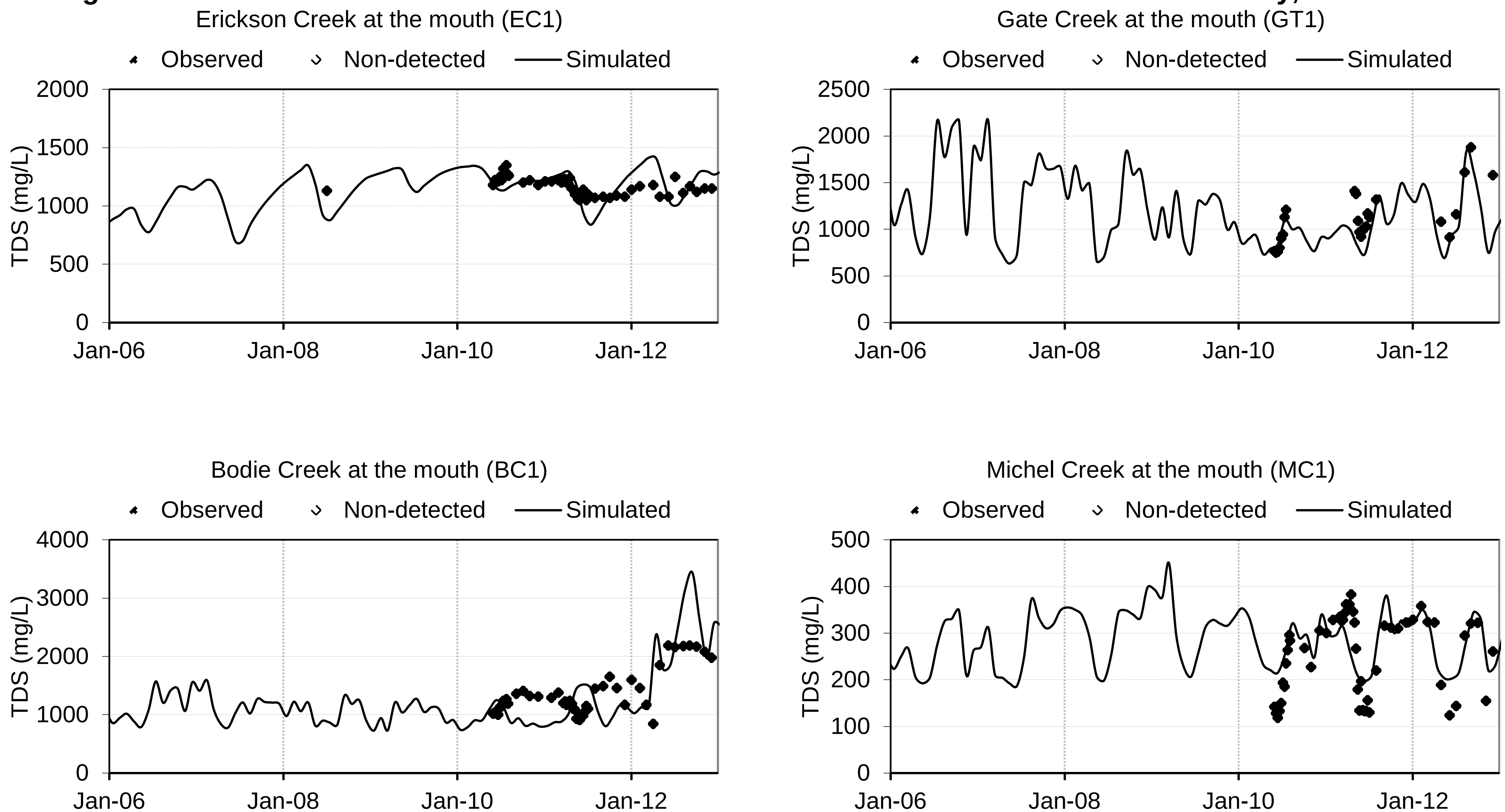
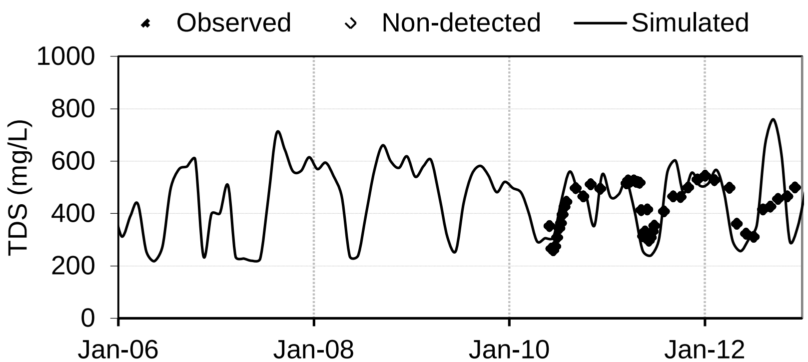
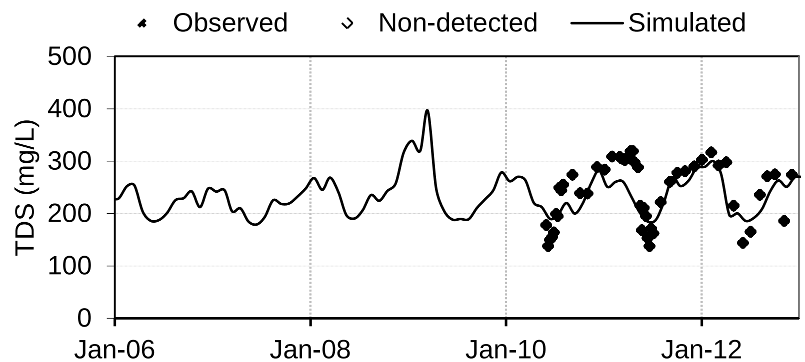


Figure B-8 Simulated and Observed Total Dissolved Solids Concentrations in the Elk Valley, 2006 to 2012

Harmer Creek at the mouth (HM1)



Elk River downstream of Michel Creek (ER3)



Elk River at the mouth (ER5)