DE BEERS CANADA INC.

SNAP LAKE MINE

SNAP LAKE HYDRODYNAMIC AND
WATER QUALITY MODEL REPORT

December 2013

EXECUTIVE SUMMARY

The three-dimensional (3-D) hydrodynamic and water quality model that was developed for Water Licence MV2011L2-0004 to predict concentrations of total dissolved solids (TDS), nutrients, major ions, metals, and metalloids in Snap Lake for the De Beers Canada Inc. (De Beers) Snap Lake Mine (Mine) was updated. Previous water quality predictions generated for Water Licence MV2011L2-0004 are no longer matching actual constituent concentrations in Snap Lake due to unanticipated increases in underground flows and in treated effluent discharges to Snap Lake. In addition, the list of parameters included in the model was updated. The present report provides details of the updated 3-D hydrodynamic and water quality model, including data inputs and model calibration, a comparison of predicted water quality to site-specific water quality objectives (SSWQOs) in Snap Lake, and a comparison of water quality predictions to Environmental Assessment Report (EAR) predictions.

The model was calibrated for the period from 2004 to 2012, and water quality predictions were generated for the following four scenarios during the operational period from 2013 to 2028:

- Upper Bound Scenario A: Minewater flows from Scenario 4 of the groundwater model and treated effluent discharge constituent concentrations from the site model based on arithmetic mean connate water TDS concentrations from the groundwater model;

- Upper Bound Scenario B: Minewater flows from Scenario 4 of the groundwater model and treated effluent discharge constituent concentrations from the site model based on geometric mean connate water TDS concentrations from the groundwater model;

- Lower Bound Scenario A: Minewater flows from Base Case of the groundwater model and treated effluent discharge constituent concentrations from the site model based on arithmetic mean connate water TDS concentrations from the groundwater model; and,

- Lower Bound Scenario B: Minewater flows from Base Case of the groundwater model and treated effluent discharge constituent concentrations from the site model based on geometric mean connate water TDS concentrations from the groundwater model.

All four scenarios used treated effluent discharge rates predicted by the site model for the applicable scenario. Model results showed the following:

- In all four scenarios, TDS concentrations are predicted to exceed the proposed SSWQO of 684 milligrams per litre (mg/L). TDS concentrations near the diffuser stations and at the outlet of Snap Lake are predicted to range from approximately 800 to 1,700 mg/L in 2028.

- Chloride concentrations are predicted to exceed the proposed SSWQO of 388 mg/L near the diffuser stations and at the outlet of Snap Lake in Upper Bound Scenarios A and B and Lower Bound Scenario A. In Upper Bound Scenarios A and B and Lower Bound Scenario A, chloride concentrations are predicted to increase to approximately 800, 500, and 600 mg/L in 2028, respectively.

- Concentrations of all nutrients, major ions, and total metals and metalloids in Snap Lake are predicted to remain below proposed SSWQOs.

- Maximum concentrations for modelled constituents in Snap Lake are predicted to exceed the maximum EAR concentrations with the exception of total copper.

De Beers Canada Inc.

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LIST OF ACRONYMS

Term	Definition
3-D	three-dimensional
ASCE	American Society of Civil Engineers
BCMOE	British Columbia Ministry of the Environment
BOD	biochemical oxygen demand
C	carbon
CaCO$_3$	calcium carbonate
CCME	Canadian Council of Ministers of the Environment
CO	Colorado
DC	District of Columbia
De Beers	De Beers Canada Inc.
DO	dissolved oxygen
EAR	Environmental Assessment Report
FL	Florida
GA	Georgia
GEMSS	Generalized Environmental Modelling System for Surfacewaters
GIS	geographical information system
Golder	Golder Associates Ltd.
LA	Louisiana
Mine	Snap Lake Mine
MS	Mississippi
MVEIRB	Mackenzie Valley Environmental Impact Review Board
MVLWB	Mackenzie Valley Land and Water Board
N	nitrogen
NJ	New Jersey
NWT	Northwest Territories
NY	New York
O$_2$	oxygen gas
P	phosphorus
SNP	Surveillance Network Program
SOD	sediment oxygen demand
SSWQO	site-specific water quality objective
TDS	total dissolved solids
USA	United States of America
USEPA	United States Environmental Protection Agency
WASP	Water Quality Analysis Simulation Program
WQG	water quality guideline

UNITS OF MEASURE

Term	Definition
%	percent
>	greater than
<	less than
-	dimensionless or no guideline available
°C	degrees Celsius
°C m^3/s	degrees Celsius cubic metre per second
/d	per day
cm	centimetre
cal/m^2/s	calories per square metre per second
d	day
g	gram
g-C/m^3	grams as carbon per cubic metre
g-N/g-C	grams as nitrogen per grams as carbon
g-N/m^2/d	grams as nitrogen per square metre per day
g-N/m^3	grams as nitrogen per cubic metre
g-O_2/m^3	grams as oxygen per cubic metre
g-P/m^3	grams as phosphorus per cubic metre
g-P/g-C	grams as phosphorus per gram of carbon
g-P/m^2/d	grams as phosphorus per square metre per day
kg	kilogram
m	metre
masl	metres above sea level
m/d	metres per day
m/s	metres per second
m^2	square metre
m^3	cubic metre
m^3/d	cubic metres per second
m^3/d	cubic metres per day
masl	metres above sea level
mg/L	milligrams per litre
mg-N/L	milligrams as nitrogen per litre
mg-P/L	milligrams as phosphorus per litre
µg/L	micrograms per litre
µS/cm	microSiemens per centimetre

1   INTRODUCTION

Initial water quality predictions were prepared and submitted as part of the Environmental Assessment Report (EAR) for the De Beers Canada Inc. (De Beers) Snap Lake Mine (Mine) to the Mackenzie Valley Environmental Impact Review Board (MVEIRB) in February 2002 (De Beers 2002). In 2011, as part of the Water Licence renewal process for Type A Water Licence MV2001L2-0002, De Beers was required to provide the Mackenzie Valley Land and Water Board (MVLWB) with updated water quality predictions for Snap Lake and the downstream receiving environment. Water quality predictions generated for the EAR and for Type A Water Licence MV2011L2-0004 (renewal of MV2001L2-0002) are no longer aligned with actual constituent concentrations in Snap Lake due to unanticipated increases in underground flows and treated effluent discharges to Snap Lake (Golder 2011a,b). Therefore, updated hydrodynamic and water quality modelling was completed to predict concentrations of total dissolved solids (TDS), nutrients, major ions, metals and metalloids in Snap Lake, given the anticipated operating conditions of the Mine.

The present report describes the hydrodynamic and water quality model developed to predict water quality in Snap Lake. The model setup, including linkages with other models, data inputs, and calibration are described in Section 2. Water quality predictions for Snap Lake are presented in Section 3 along with a comparison to proposed site-specific water quality objectives (SSWQOs) and EAR predictions. Data gaps and model uncertainty are discussed in Section 4 and model limitations are presented in Section 5.

2   METHODS

Snap Lake modelling entailed linking three models to obtain integrated water quality predictions (Section 2.1). The Snap Lake hydrodynamic and water quality model is discussed in Section 2.2. Model calibration and simulations are discussed in Sections 2.3 and 2.4, respectively.

2.1   Model Linkages

Three interlinked models were concurrently developed for the purpose of predicting water quality concentrations in Snap Lake:

- a hydrogeological model;

- a Mine site model; and,

- the Snap Lake hydrodynamic and water quality model.

The focus of the present report is the hydrodynamic and water quality model of Snap Lake. The other two models are described fully in their respective modelling documentation (Itasca 2013a; De Beers 2013a). However, a brief description of each model, and how the models are interconnected, is provided below.

The hydrogeological model considered seepage from the lake and from the surrounding formation to underground workings to derive the quality and quantity of water being pumped to the surface. This information was then incorporated into the Mine site model. The Mine site model also considered runoff from surface features of the Mine, geochemical reactions within these features, and water treatment. The Mine site model then predicted long-term treated effluent discharge quantity and quality to Snap Lake, in the form of time series, which were used as inputs to the present hydrodynamic and water quality model of Snap Lake.

The interlinked nature of the three models reflects the transport loop in which water can flow. Specifically, water can flow from the lake to the underground workings, be pumped to surface, and discharged back to the lake. Iterative simulations were run until convergence was achieved from one simulation to the next because the initialization of each model affects the long-term predictions of each subsequent model. A second iteration was generally sufficient to achieve convergence among the models.

2.2   Three-Dimensional Model Platform

The three-dimensional (3-D) hydrodynamic and water quality model that was developed for Water Licence MV2011L2-0004 to predict concentrations of TDS, nutrients, major ions, metals, and metalloids in Snap Lake was updated for this study. The model was developed in the Generalized Environmental Modelling System for Surfacewaters (GEMSS). GEMSS is an integrated system of 3-D hydrodynamic and transport modules embedded in a geographic information and environmental data system. GEMSS is in the public domain and has been used for similar studies throughout North America and worldwide. GEMSS was developed in the mid-1980s as a hydrodynamic platform for transport and fate modelling. The hydrodynamic platform ("kernel") provides 3-D flow fields from which the distribution of various

constituents can be computed. The constituent transport and fate computations are grouped into modules. The modules used for Snap Lake simulations were the hydrodynamic and transport module, the water quality module, and the user-defined constituent module.

The theoretical basis of the hydrodynamic kernel of GEMSS is the 3-D Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport model (Edinger and Buchak 1980, 1985). This computation has been peer reviewed and published (Edinger and Buchak 1995; Edinger and Kolluru 1999; Edinger et al. 1994, 1997). The "kernel" is an extension of the well-known longitudinal-vertical transport model written by Buchak and Edinger (1984) that forms the hydrodynamic and transport basis of water quality model CE-QUAL-W2 (US Army Engineer Waterways Experiment Station 1986). Improvements to the transport scheme, construction of the constituent modules, incorporation of supporting software tools, geographical information system (GIS) interoperability, visualization tools, graphical user interface, and post-processors have been developed by Kolluru et al. (1998, 1999, 2003) and Kolluru and Fichera (2003).

The "Modified WASP5" module was used for simulating water quality in Snap Lake. The Modified WASP5 module is comprised mainly of formulae from the United States Environmental Protection Agency's (USEPA) Water Quality Analysis Simulation Program (WASP) model (Ambrose et al. 1993), adapted to fit within the GEMSS framework. This module was used to simulate nutrients and oxygen-related constituents. The user defined constituent module was derived from the CE-QUAL-W2 model (Cole and Wells 2008); it was used to simulate constituents that behaved conservatively or settled in the water column.

2.2.1   Model Segmentation

The model grid was updated to achieve alignment between measured field profile depths and model grid depths, and to refine the lake volume through the calibration process. A 3-D grid (Figure 2-1) was developed that covers all of Snap Lake, with the exception of some small bays that are not anticipated to affect the overall circulation of water and constituents in the lake. The grid spacing is approximately 200 metres (m) horizontally and vertical resolution is 1 m. The grid comprises a total of 35 active layers and 2,740 active cells.

Figure 2-1   Snap Lake Model Grid in Plan View
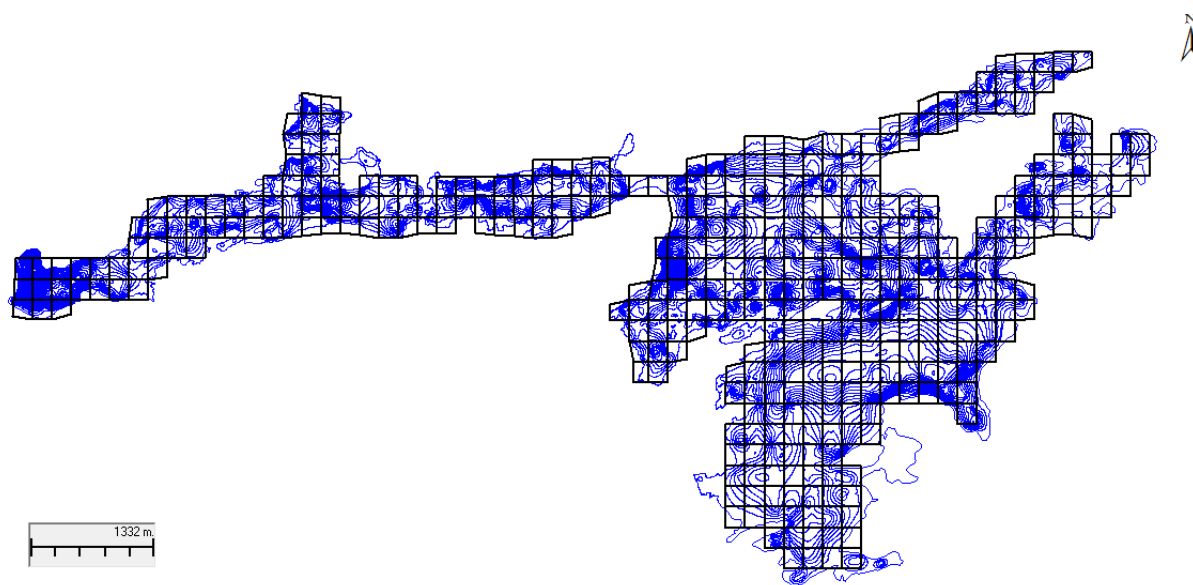
2.2.2   Inputs

All known point and non-point source inflows to the lake were included as inputs to the Snap Lake model (Figure 2-2).   Inputs to the lake are classified as meteorological, hydrologic, or chemical and are described in the following sections.

2.2.2.1   Meteorological Inputs

Meteorological inputs are drivers of lake circulation and thermal dynamics. The forcing data required for the hydrodynamic model are:
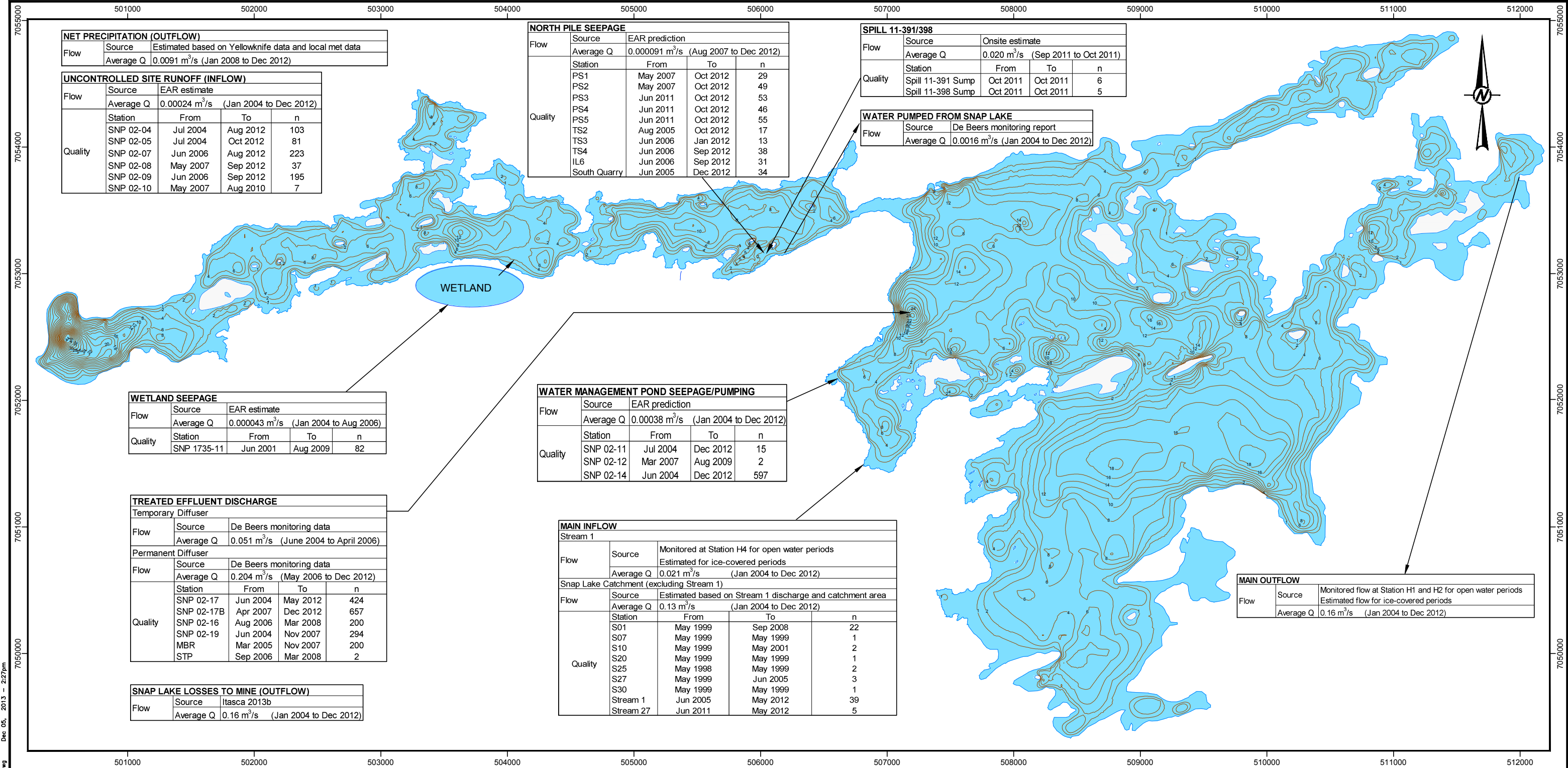
- air temperature;

- dew point temperature;

- wet bulb temperature;

- atmospheric pressure;

- wind direction;

- wind speed; and,

- solar radiation.

An hourly time series was constructed for each of these inputs during the calibration time period, 2004 to 2012, based on measured data from onsite meteorological stations at Snap Lake with the exception of the solar radiation time series. An hourly time series of modelled solar radiation data was obtained for Yellowknife, Northwest Territories (NWT) from Environment Canada's Canadian Weather Energy and Engineering Datasets (Environment Canada 2013). Where gaps existed in the site-specific data, data from the Environment Canada station at the Yellowknife Airport were used. For future simulations, the time series used to calibrate the model was repeated.

2.2.2.2   Hydrologic Inputs

The main hydrologic inputs to Snap Lake are tributary and non-point source inflows from the Snap Lake basin in addition to treated effluent. The main outflows from the lake are the outlet channel and lake-bottom seepage to the Mine. Minor inflows and outflows are direct precipitation and evaporation, non-point source seepages from the Mine site to the lake, and pumped withdrawals. These inputs are shown schematically in Figure 2-2, along with average flow rates.

The water balance used for this model was a constructed time series with temporal resolution that varied according to the availability of information for each source. Monthly information was available for most hydrologic inputs, from monthly water balance reports filed by De Beers to the MVLWB. Treated effluent discharge has been recorded daily since construction of the permanent diffuser, so this time series was used to represent treated effluent flows. Water surface elevations were used to correct inflow and outflow rates. Monthly seepage estimates from the lake to the Mine were provided by the hydrogeological model (Itasca 2013b).

NET PRECIPITATION (OUTFLOW)

Flow	Source	Estimated based on Yellowknife data and local met data		
	Average Q	0.0091 m³/s (Jan 2008 to Dec 2012)		

UNCONTROLLED SITE RUNOFF (INFLOW)

Flow	Source	EAR estimate		
	Average Q	0.00024 m³/s (Jan 2004 to Dec 2012)		
Quality	Station	From	To	n
	SNP 02-04	Jul 2004	Aug 2012	103
	SNP 02-05	Jul 2004	Oct 2012	81
	SNP 02-07	Jun 2006	Aug 2012	223
	SNP 02-08	May 2007	Sep 2012	37
	SNP 02-09	Jun 2006	Sep 2012	195
	SNP 02-10	May 2007	Aug 2010	7

NORTH PILE SEEPAGE

Flow	Source	EAR prediction	
	Average Q	0.000091 m³/s (Aug 2007 to Dec 2012)	
Quality	Station	From	To	n
	PS1	May 2007	Oct 2012	29
	PS2	May 2007	Oct 2012	49
	PS3	Jun 2011	Oct 2012	53
	PS4	Jun 2011	Oct 2012	46
	PS5	Jun 2011	Oct 2012	55
	TS2	Aug 2005	Oct 2012	17
	TS3	Jun 2006	Jan 2012	13
	TS4	Jun 2006	Sep 2012	38
	IL6	Jun 2006	Sep 2012	31
	South Quarry	Jun 2005	Dec 2012	34

SPILL 11-391/398

Flow	Source	Onsite estimate		
	Average Q	0.020 m³/s (Sep 2011 to Oct 2011)		
Quality	Station	From	To	n
	Spill 11-391 Sump	Oct 2011	Oct 2011	6
	Spill 11-398 Sump	Oct 2011	Oct 2011	5

WATER PUMPED FROM SNAP LAKE

Flow	Source	De Beers monitoring report
	Average Q	0.0016 m³/s (Jan 2004 to Dec 2012)

WETLAND

WETLAND SEEPAGE

Flow	Source	EAR estimate		
	Average Q	0.000043 m³/s (Jan 2004 to Aug 2006)		
Quality	Station	From	To	n
	SNP 1735-11	Jun 2001	Aug 2009	82

WATER MANAGEMENT POND SEEPAGE/PUMPING

Flow	Source	EAR prediction		
	Average Q	0.00038 m³/s (Jan 2004 to Dec 2012)		
Quality	Station	From	To	n
	SNP 02-11	Jul 2004	Dec 2012	15
	SNP 02-12	Mar 2007	Aug 2009	2
	SNP 02-14	Jun 2004	Dec 2012	597

TREATED EFFLUENT DISCHARGE

Temporary Diffuser

Flow	Source	De Beers monitoring data		
	Average Q	0.051 m³/s (June 2004 to April 2006)		

Permanent Diffuser

Flow	Source	De Beers monitoring data		
	Average Q	0.204 m³/s (May 2006 to Dec 2012)		
Quality	Station	From	To	n
	SNP 02-17	Jun 2004	May 2012	424
	SNP 02-17B	Apr 2007	Dec 2012	657
	SNP 02-16	Aug 2006	Mar 2008	200
	SNP 02-19	Jun 2004	Nov 2007	294
	MBR	Mar 2005	Nov 2007	200
	STP	Sep 2006	Mar 2008	2

SNAP LAKE LOSSES TO MINE (OUTFLOW)

Flow	Source	Itasca 2013b
	Average Q	0.16 m³/s (Jan 2004 to Dec 2012)

MAIN INFLOW

Stream 1

Flow	Source	Monitored at Station H4 for open water periods Estimated for ice-covered periods		
	Average Q	0.021 m³/s (Jan 2004 to Dec 2012)		

Snap Lake Catchment (excluding Stream 1)

Flow	Source	Estimated based on Stream 1 discharge and catchment area		
	Average Q	0.13 m³/s (Jan 2004 to Dec 2012)		
Quality	Station	From	To	n
	S01	May 1999	Sep 2008	22
	S07	May 1999	May 1999	1
	S10	May 1999	May 2001	2
	S20	May 1999	May 1999	1
	S25	May 1998	May 1999	2
	S27	May 1999	Jun 2005	3
	S30	May 1999	May 1999	1
	Stream 1	Jun 2005	May 2012	39
	Stream 27	Jun 2011	May 2012	5

MAIN OUTFLOW

Flow	Source	Monitored flow at Station H1 and H2 for open water periods Estimated flow for ice-covered periods
	Average Q	0.16 m³/s (Jan 2004 to Dec 2012)

REFERENCES

DIGITAL MAP FROM MACKAY LAKE, NORTHWEST TERRITORIES, PRODUCED BY DEPARTMENT OF ENERGY, MINES AND RESOURCES. MAP 75M, ORIGINAL SCALE 1:250,000, NAD 83 UTM ZONE 12.

SNAP LAKE OUTLINE AND ISLANDS WERE CORRECTED TO LANDSAT 7 SATELLITE IMAGE 45/15, DATED SEPTEMBER 2, 2000. PROVIDED BY GEOBASE.

BATHYMETRY WAS CREATED IN SURFER 8 USING SONAR DATA FROM THE 2002 NORTH LAKES PROGRAM (GOLDER) AND 2005 TRANSECT DATA FROM THE REFERENCE LAKE SEARCH PROGRAM (GOLDER).

NOTES

1. ALL DEPTH VALUES ARE SHOWN IN METRES
2. MAP MOVED TO NAD83 COORDINATE SYSTEM

Dec. 05, 2013 – 2:27pm

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For future simulations, the time series was repeated for all inputs except for:

• treated effluent discharge, which was provided by the site model (De Beers 2013b);

• lake-bottom seepage, which was provided by the hydrogeological model (Itasca 2013b);

• tributary and non-point source inflows from the Snap Lake basin, which were provided by the site model (De Beers 2013b); and,

• outflow from the outlet channel of Snap Lake, which was calculated so that the capacity of the lake remained constant.

Water volumes withdrawn for ice formation were derived from field records of ice depths recorded each winter. A water withdrawal was included for ice formation each year from October to January, and a discharge was returned back to the lake each April to June to simulate melting. Ice formation and melting volumes were derived from the annual average of maximum ice thickness measurements at Snap Lake since 2003. For future simulations, an average ice thickness of 130 centimetres (cm) was used each year. The water withdrawn and returned for ice formation had no associated constituents, meaning that salts were rejected from the ice and remained within Snap Lake.

2.2.2.3   Chemical Inputs

Water quality data for Snap Lake, tributary inflows, non-point source seepages from the Mine site, and treated effluent discharge were obtained from the Snap Lake Environmental Database. Sample date ranges and numbers for inflows and outflows are shown in Figure 2-2. Sample locations within the lake are shown in Figure 2-3.

A time series of concentrations for tributary inflows and non-point source seepages was constructed for each constituent according to the following:

• for each month, an average monthly constituent concentration was calculated from available data and assigned to the 15th of that month;

• for months when samples were not collected, the long-term average constituent concentration was used to represent inflow concentrations for that month;

• in addition to monthly average constituent concentrations, all samples collected in any given month were also used to represent inflow concentrations for that month; and,

• data were linearly interpolated to produce a daily time series for the modelled time period.

For treated effluent discharge, samples were collected approximately weekly, and a daily time series was constructed by interpolating between samples. Sample and discharge locations changed with time, as shown in the figures presented in Appendix I. During some periods, concentrations were calculated based on flow-weighted measurements, because the samples were collected upstream of the confluence of treated effluent discharges (Appendix I). To represent treated effluent discharges as accurately as possible, the time series was constructed in consultation with Mine staff familiar with the chronology of the discharges.

Figure 2-3. Water Quality Monitoring Locations Used in the Snap Lake Model

SNAP LAKE MINE

NOTES

1. ALL DEPTH VALUES ARE SHOWN IN METRES.
2. MAP MOVED TO NAD83 COORDINATE SYSTEM.

LEGEND

- WATER QUALITY MONITORING STATION: DIFFUSER
- WATER QUALITY MONITORING STATION: NEAR-FIELD
- WATER QUALITY MONITORING STATION: MID-FIELD
- WATER QUALITY MONITORING STATION: FAR-FIELD
- WATER QUALITY MONITORING STATION: NORTHWEST ARM
- WETLANDS STATION DOWNGRADIENT OF SEWAGE TREATMENT PLANT
- SNAP LAKE MINE FOOTPRINT

Water Quality Monitoring Locations Used in the Snap Lake Model

PROJECTION: UTM Zone 12

DATUM: NAD83

SCALE 1:30,000   METRES

500   0   500

FILE No: 12133700014000-02

DATE: October 11, 2013

JOB No: 12-1337-0001.4000

REVISION No: 0

OFFICE: GOLDER VICTORIA

DRAWN: JEF

CHECK: AS

Figure 2-3

De Beers
GROUP OF COMPANIES

2.2.3   Modelled Constituents

The modelled constituents were those most relevant to water quality and aquatic health in Snap Lake (Table 2-1). The calibration of each group of constituents is described in Section 2.3.

2.3   Model Calibration

The model was calibrated to measured data from 2004 to 2012.

2.3.1   Hydrodynamic Calibration

The first step in the calibration process was to achieve a water balance within the model. This was done by correcting the water balance to match measured water surface elevations. Water surface elevations were adjusted in the model by increasing or decreasing the rate of tributary inflows, since these were considered the inputs with the lowest level of certainty. Water surface elevations were available during the open-water season from 2004 to 2012.

Modelled water surface elevations matched measured water levels closely during the open-water season (Figure 2-4). The large change in water level predicted during the ice-covered season is due to abstraction of water by ice formation.

The hydrodynamic component of the model was calibrated to align measured and modelled thermal and transport behaviour in Snap Lake. Adjustment of variables is standard practice during calibration (Cole and Wells 2008), as the goal of calibration is to apply the formulae and constants that most closely approximate the behaviour of the system under study. Default model values were used for thermal variables, with the following exception:

- To improve thermal profiles during ice-covered seasons, sediment heat exchange was added to the model. Based on the calibration, the sediment temperature was set at a constant value of 4 degrees Celsius (°C), and the sediment-water heat exchange coefficient was set at 3×10^{-7} metres per second (m/s). Additionally, a negative heat load of 5°C cubic metre per second (°C m^3/s) was added to the surface of the lake to simulate an ice-water heat exchange.

Time series plots of surface water temperatures at stations near the diffuser and at the outlet of Snap Lake show that the model matched surface water temperatures reasonably well (Figure 2-5). During ice-covered and open-water seasons, the modelled thermal profiles fit the measured profiles well (see vertical profiles in Appendix II).

The transport calibration considered the horizontal distribution and vertical stratification of TDS in Snap Lake in addition to the observed temporal trend of increasing TDS. For the horizontal component of the transport calibration, the model tracked TDS concentrations reasonably well in the northwest arm, near the diffuser, in the main basin, and at the outlet of Snap Lake (Figures 2-6 and 2-7).

The cyclical annual patterns evident in time series figures presented in this report are due to salt rejection during ice formation and melting. The magnitude of these cycles varies, depending on the year and the depth of the lake at the location that the time series represents.

Table 2-1   Modelled Water Quality Constituents

Group	Constituent
Hydrodynamic	Temperature
	Total dissolved solids
Oxygen-related	Dissolved oxygen
	Biochemical oxygen demand
Nutrients	Ammonia
	Nitrate
	Ortho-phosphate
	Total phosphorus
	Phytoplankton (as chlorophyll *a*)
Ions	Calcium
	Chloride
	Fluoride
	Magnesium
	Sodium
	Sulphate
Total Metals and Metalloids	Aluminum
	Antimony
	Arsenic
	Barium
	Copper
	Lithium
	Mercury
	Strontium
	Uranium
	Zinc

Figure 2-4   Water Surface Elevation Time Series Calibration Plot
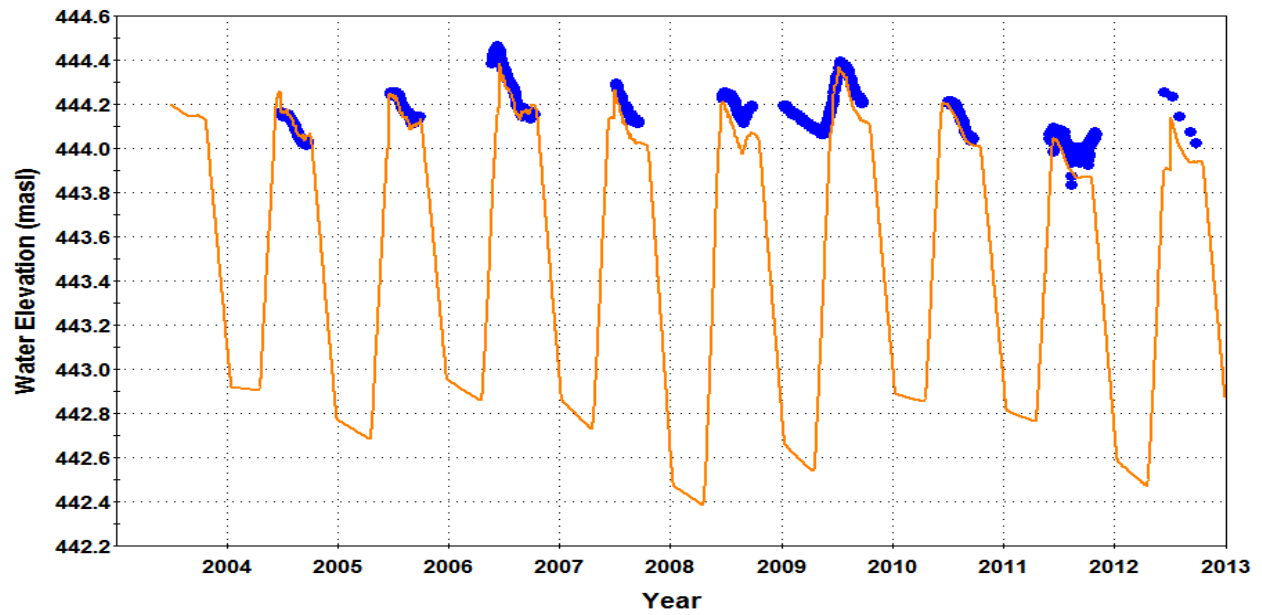
Note: Solid line represents model results; dots represent measured water elevations.

masl = metres above sea level.

Figure 2-5   Surface Water Temperature Time Series Calibration Plots
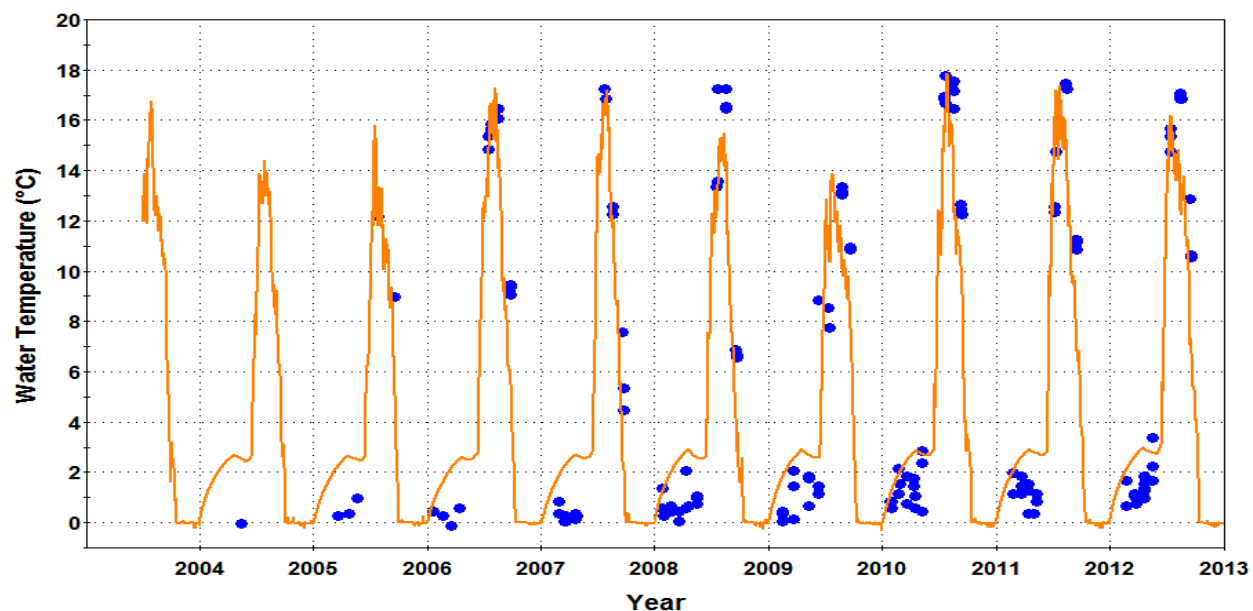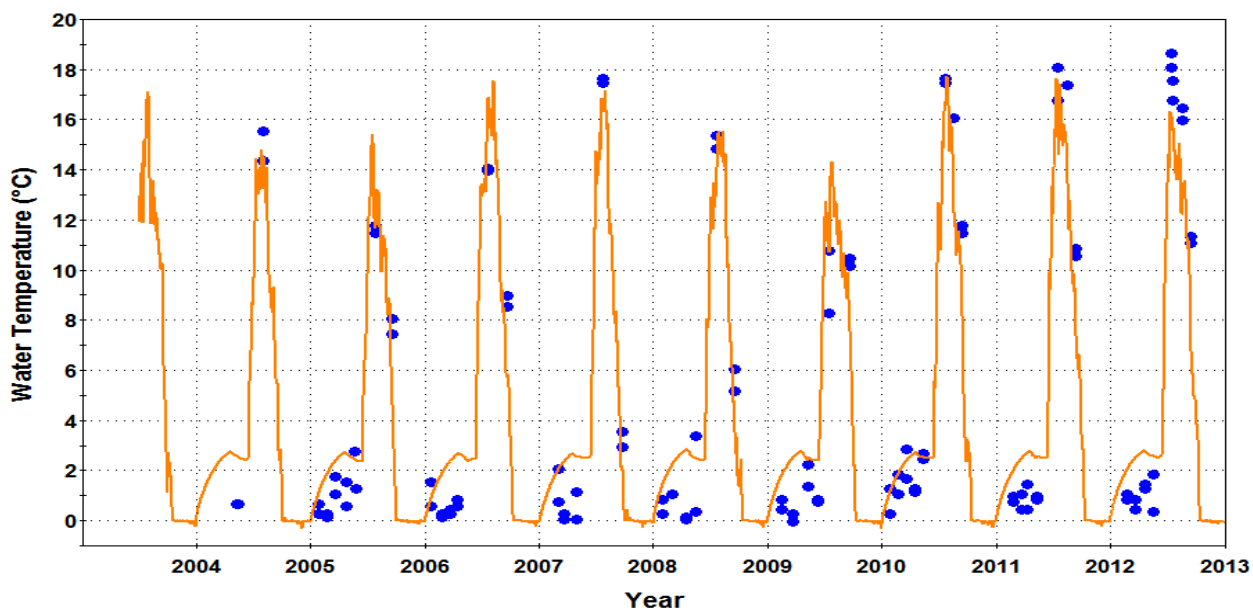
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured water temperatures.
°C = degrees Celsius; SNP = Surveillance Network Program.

Figure 2-6   **Total Dissolved Solids Time Series Calibration Plots**
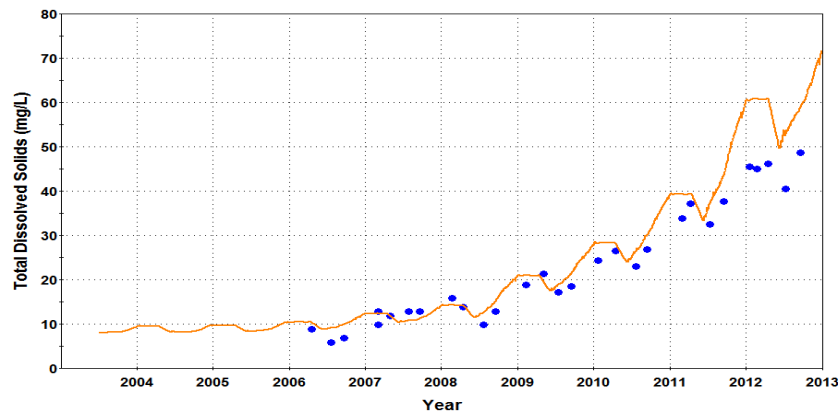
(a) Northwest arm, SNAP20 and SNAP20B
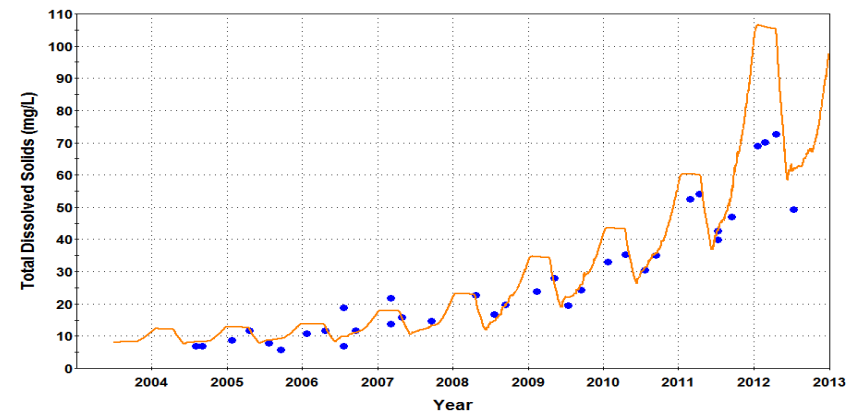
(b) Northwest arm, SNAP02 and SNAP02A
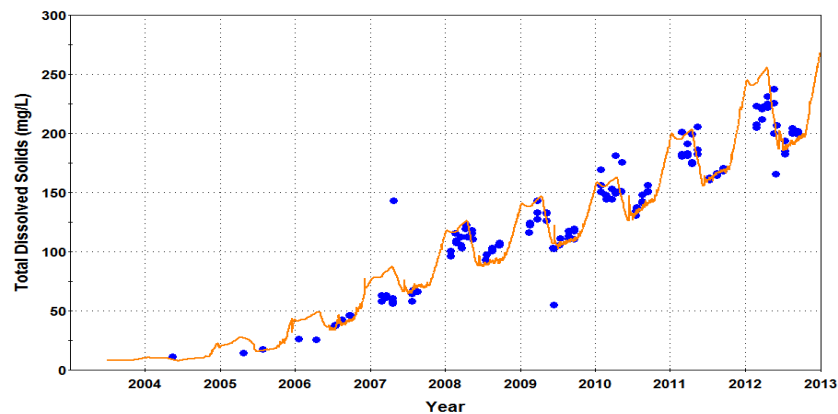
(c) Near diffuser, SNP 02-20 and SNAP13 (Surface)
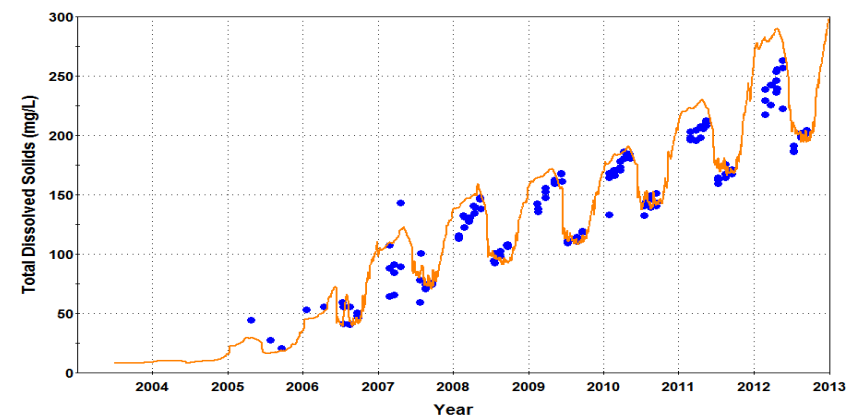
(d) Near diffuser, SNP 02-20 and SNAP13 (Mid-depth)

Note: Solid line represents model results; dots represent calculated total dissolved solids concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

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Figure 2-6   Total Dissolved Solids Time Series Calibration Plots (continued)
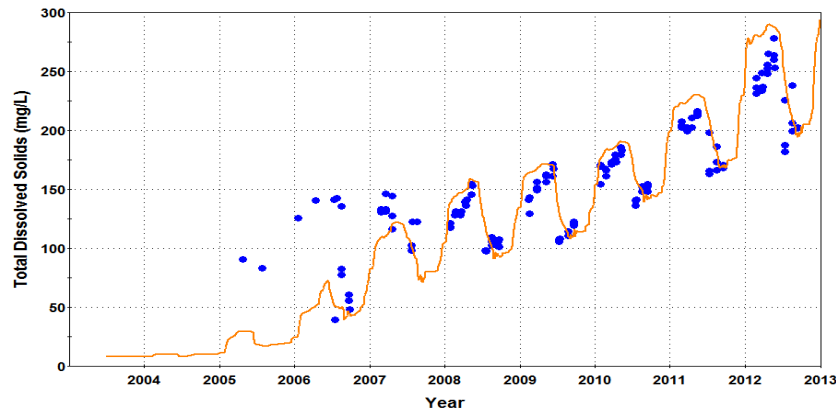
(e) Near diffuser, SNP 02-20 and SNAP13 (Bottom)
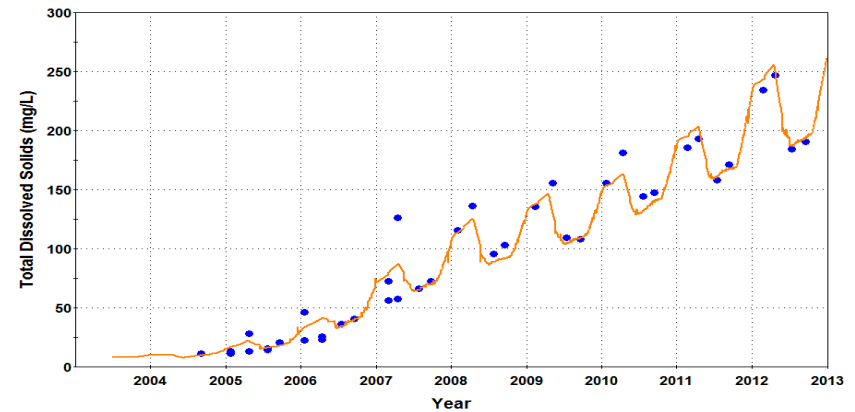
(f) Main Basin, SNAP05
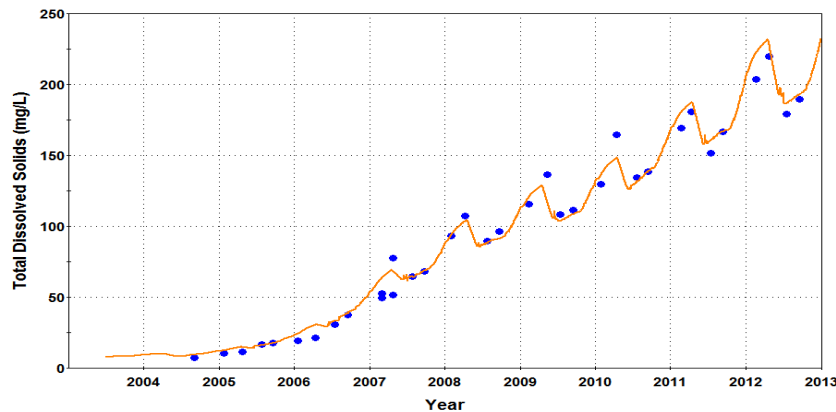
(g) Main Basin, SNAP09
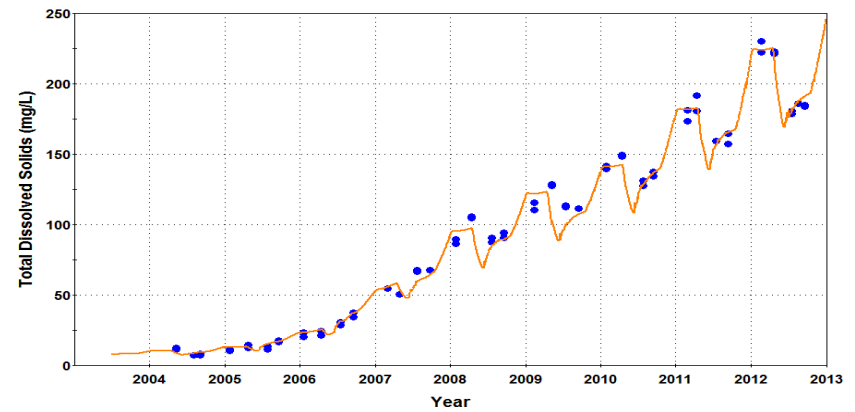
(h) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent calculated total dissolved solids concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

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Figure 2-7   Calculated (from Measured) and Modelled Total Dissolved Solids Distribution in 2012
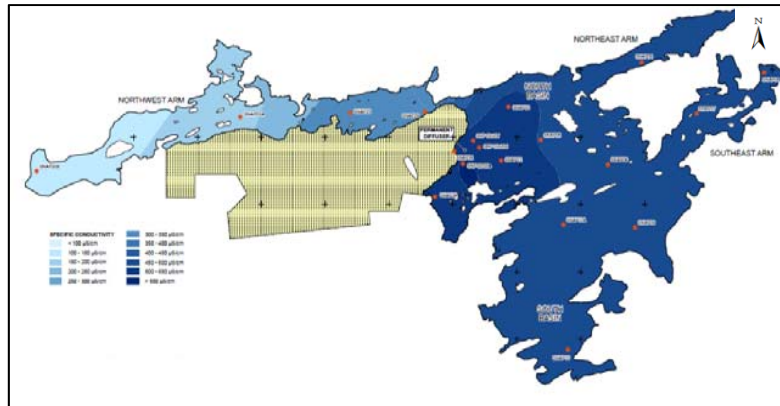
(a) Ice covered, calculated
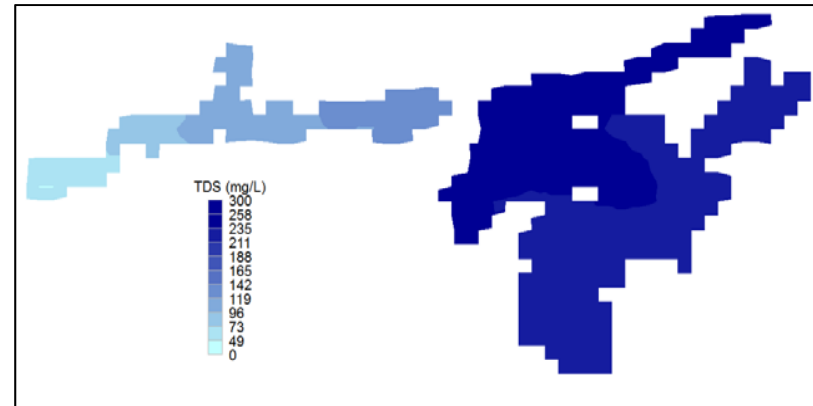
(b) Ice covered, modelled
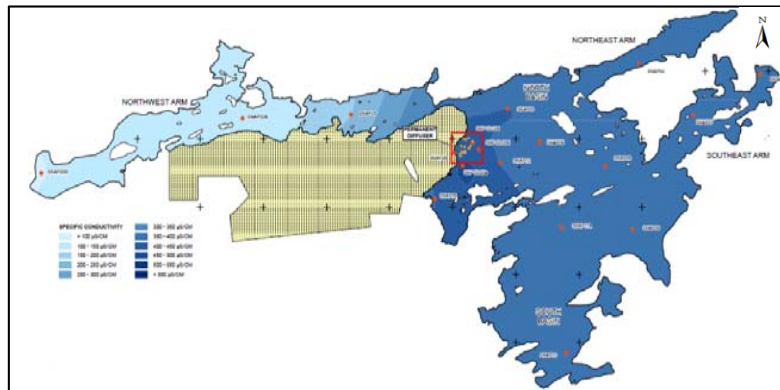
(c) Open water, calculated
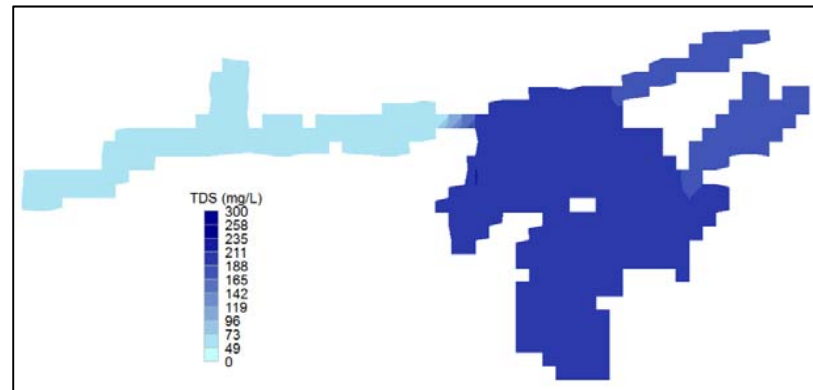
(d) Open water, modelled

mg/L = milligrams per litre; µS/cm = microSiemens per centimetre; TDS = total dissolved solids; <= less than, >= greater than.

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For the vertical component of the transport calibration, default model values were used for hydrodynamic variables, with the following exception:

- The Nikuradse mixing length was applied instead of the von Karman mixing length for the vertical momentum dispersion. This variable affects the way the model calculates circulation and turbulence patterns within Snap Lake. Applying the Nikuradse mixing length provided better calibration to monitored profile data than the von Karman mixing length.

The alignment between calculated and modelled TDS profiles in Snap Lake was generally good (Appendix II), and was adequate for predicting lake-bottom TDS. Overall, the transport calibration indicates that the model is tracking the movement of water and dissolved constituents well at all points of interest in the lake.

2.3.2   Dissolved Oxygen and Related Constituents Calibration

Dissolved oxygen (DO) was modelled, but in-lake concentrations of DO were not calibrated. Dissolved oxygen was included in the model because of its role in nutrient cycles and in phytoplankton growth and respiration. Dissolved oxygen was not the focus of the calibration because DO concentrations do not appear to have decreased as a result of treated effluent discharge (De Beers 2013c). Biochemical oxygen demand (BOD) was modelled, but in-lake concentrations of BOD were not calibrated because they are typically below detection limits. Biochemical oxygen demand was included in the model because of its role in nutrient cycles, and in phytoplankton excretion and death.

2.3.3   Nutrients and Chlorophyll *a* Calibration

The constituents included in the nutrient module were ammonia, nitrate, orthophosphate, total phosphorus, and phytoplankton. Rates and coefficients applied to the nutrient module are listed in Table 2-2. As a starting point, default model values were applied to the calibration. Model coefficients were changed from default values as follows:

- The nitrification rate was adjusted from 0.02 to 0.01 per day (/d). This rate was selected to improve the ammonia calibration.

- The denitrification rate was adjusted from 0.09 to 0.16/d. This rate was selected to improve the nitrate calibration.

- The Michaelis constant for denitrification was adjusted from 0.1 to 0.2 grams of oxygen per cubic metre (g-O_2/m^3). This constant was selected to increase the rate of denitrification at higher in-lake DO concentrations and to improve the nitrate calibration.

- The phosphorus to carbon ratio was adjusted from 0.025 to 0.015 grams of phosphorus per gram of carbon (g-P/g-C). This constant was selected to improve the orthophosphate calibration.

- The dissolved organic phosphorus mineralization rate was adjusted from 0.22 to 0.30/d. This rate was selected to improve dissolved organic phosphorus calibration, and phytoplankton growth. Dissolved organic phosphorus mineralizes to orthophosphate, which is a source of phosphorus for phytoplankton growth.

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Table 2-2   Rates and Coefficients Applied to the Nutrient Calibration

Description	Value Applied[a]	Units
Ammonia		
Nitrogen to carbon ratio	0.25	g-N/g-C
Organic nitrogen mineralization rate	0.0075	1/d
Temperature coefficient	1.08	-
Nitrification rate	**0.010**	1/d
Temperature coefficient	1.08	-
Half saturation constant for oxygen limitation of nitrification	2.0	g-O_2/m^3
Sediment release type for ammonia	0	-
Sediment flux of ammonia	0	g-N/m^2/d
Fraction of SOD (sediment oxygen demand)	0.45	-
Half saturation constant for nitrogen mineralization	1.0	g-C/m^3
Nitrate		
Denitrification rate at 20°C	**0.16**	1/d
Temperature coefficient	1.08	-
Michaelis constant for denitrification	**0.2**	g-O_2/m^3
Sediment flux of nitrate	0	g-N/m^2/d
Inorganic Phosphate		
Phosphorus to carbon ratio	**0.015**	g-P/g-C
Dissolved organic phosphorus mineralization at 20°C	**0.30**	1/d
Temperature coefficient	1.08	-
Half saturation constant for phosphorus mineralization	**1.5**	g-C/m^3
Sediment release of phosphorus	1.5	g-P/m^2/d
Phytoplankton		
Ratio of carbon to chlorophyll *a*	**20**	-
Saturating light intensity	200	cal/m^2/s
Half saturation constant for nitrogen uptake	0.001	g-N/m^3
Zooplankton grazing mode	Linear grazing	-
Grazing rate due to microzooplankton	0.0001	1/d
Grazing rate due to macrozooplankton	0.0001	1/d
Temperature coefficient	1.045	-
Death rate	**0.005**	1/d
Maximum growth rate	2.0	1/d
Temperature coefficient	1.068	-
Half saturation constant for phosphorus uptake	0.001	g-P/m^3
Fraction dissolved inorganic phosphorus	0.70	-
Endogenous respiration rate at 20°C	0.015	1/d
Temperature coefficient	1.045	-
Settling velocity	**0.02**	m/d
Excretion fraction of phytoplankton	0.1	-
Assimilation efficiency of zooplankton grazing	0.5	-
Light attenuation coefficient due to pure water	0.32	-

Table 2-2   Rates and Coefficients Applied to the Nutrient Calibration

Light attenuation coefficient due to chlorophyll *a*	0.016	-
Light attenuation coefficient due to suspended solids	0.094	-
Dissolved and Particulate Organic Nitrogen		
Organic nitrogen from dead algae	0.5	-
Organic matter settling velocity	0.08	m/d
Particulate organic nitrogen to carbon ratio	0.25	-
Dissolved and Particulate Organic Phosphorus		
Organic phosphorus from dead algae; fraction to dissolved component	0.5	-
Organic matter settling velocity	0.08	m/d
Particulate organic phosphorus to carbon ratio	0.75	-

(a) All values are default values unless shown in bold.

°C = degrees Celsius; g-N/g-C = grams as nitrogen per grams as carbon; 1/d = per day; g-O_2/m^3 = grams as oxygen per cubic metre; g-N/m^2/d = grams as nitrogen per square metre per day; g-C/m^3 = grams as carbon per cubic metre; g-P/g-C = grams as phosphorus per grams as carbon; g-P/m^2/d = grams as phosphorus per square metre per day; cal/m^2/s = calories per square metre per second; g-N/m^3 = grams as nitrogen per cubic metre; g-P/m^3 = grams as phosphorus per cubic metre; m/d = metres per day; SOD = sediment oxygen demand - = dimensionless.

- The half-saturation constant for phosphorus mineralization was adjusted from 5 to 1.5 grams of carbon per cubic metre (g-C/m^3). This constant was selected to increase the rate of particulate organic phosphorus mineralization over a wider range of in-lake phytoplankton concentrations and to improve phytoplankton growth. Particulate organic phosphorus mineralizes to orthophosphate, which is a source of phosphorus for phytoplankton growth.

- The ratio of carbon to chlorophyll *a* was adjusted from 70 to 20. This constant was selected to improve the phytoplankton calibration. A carbon to chlorophyll *a* ratio of 20 lies within the range of literature values for total phytoplankton (Bowie et al. 1985).

- The phytoplankton death rate was adjusted from 0.015 to 0.005/d. This rate was selected to improve the phytoplankton calibration.

- The phytoplankton settling velocity was adjusted from 0.05 to 0.02 metres per day (m/d). This constant was selected to improve phytoplankton calibration.

While there were large variations in measured ammonia concentrations, the calibrated model matched the general trend of measured concentrations near the diffuser stations, in the main basin, and at the outlet of Snap Lake, and reproduced peak ammonia concentrations during the ice-covered season near the diffuser stations and in the main basin (Figure 2-8). At the outlet of Snap Lake, the model generally under-predicted peak ammonia concentrations, which suggests that the nitrification rate was likely too high at the outlet. Nitrate, a by-product from an emulsion type explosive used during blasting, is recognized as a chemical signature in the treated effluent from the Mine (De Beers 2013c). Concentrations of nitrate have increased in Snap Lake since 2004. In general, the model over-predicted nitrate concentrations below 0.5 milligrams per litre (mg/L), which occurred before 2009, but matched the trend of increasing nitrate concentrations reasonably well near the diffuser stations, in the main basin, and at the outlet of Snap Lake above this value (Figure 2-9). Orthophosphate concentrations were generally at or near detection limits in Snap Lake, and in all inflows to Snap Lake, with the exception of the treated effluent discharge in the first four years of domestic waste water treatment plant operation. A

dataset with the majority of values below detection is of limited value in model calibration. The modelled orthophosphate concentrations in Snap Lake were below detection limits with the exception of peak concentrations in 2007 and 2008 (Figure 2-10). The model tracked the general range of measured phytoplankton concentrations near the diffuser stations, in the main basin, and at the outlet of Snap Lake (Figure 2-11). Overall, the nutrient and chlorophyll *a* calibration indicates that the model matches nutrient cycles and processes well at all points of interest in the lake.

Figure 2-8   Total Ammonia Time Series Calibration Plots
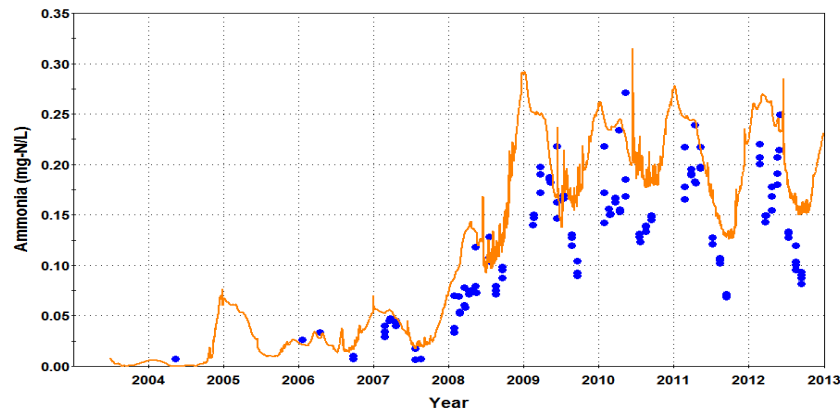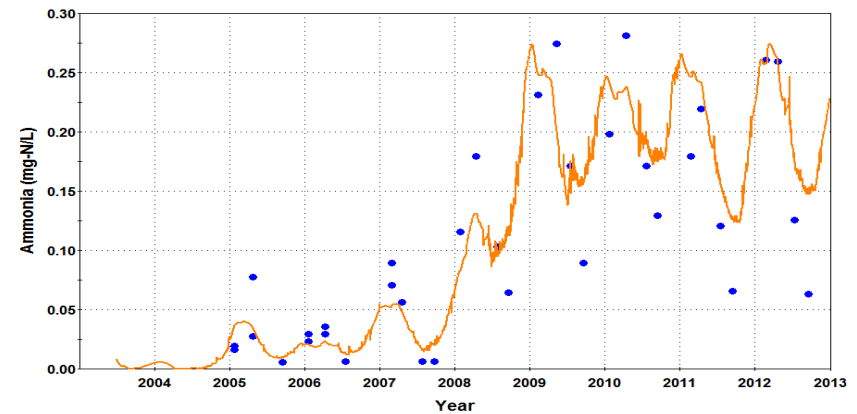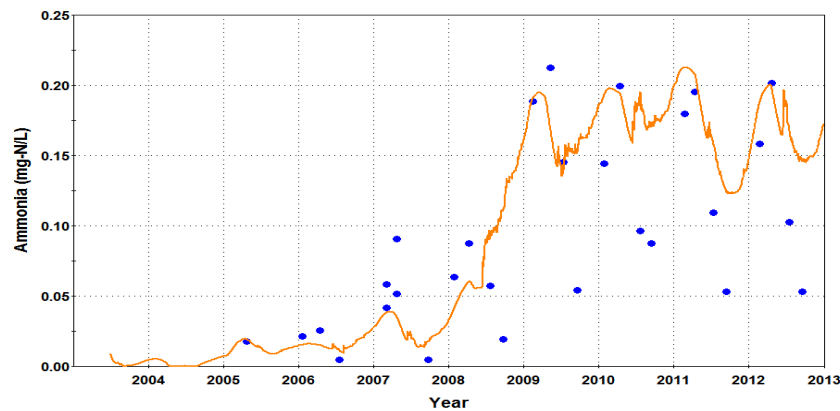
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Main Basin, SNAP05

(c) Main Basin, SNAP09
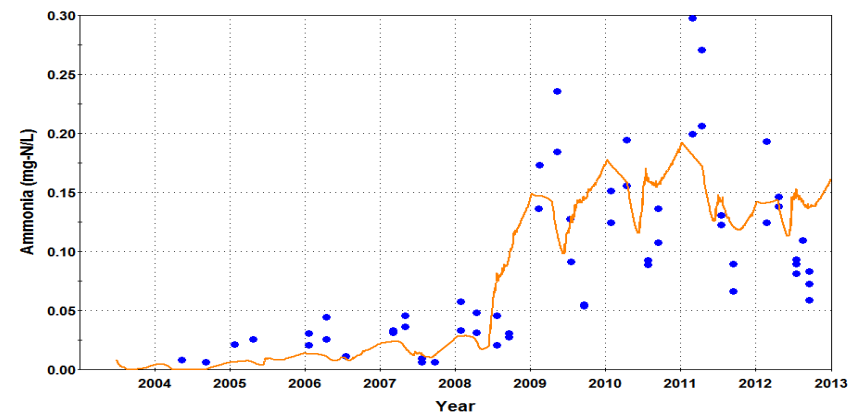
(d) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured total ammonia concentrations.

mg-N/L = milligrams as nitrogen per litre; SNP = Surveillance Network Program.

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Figure 2-9   Nitrate Time Series Calibration Plots
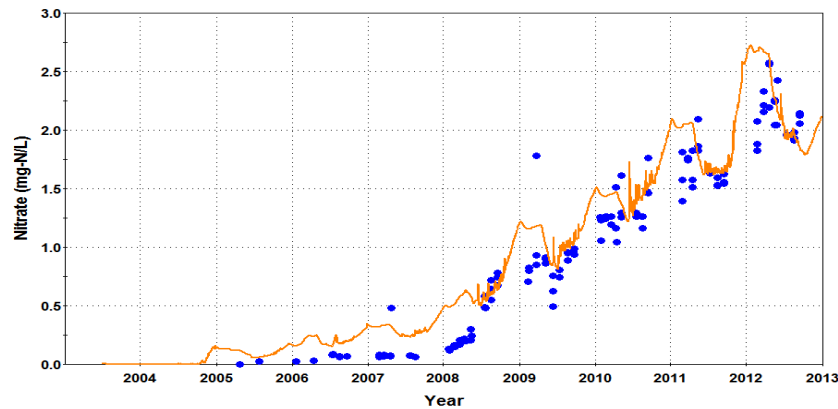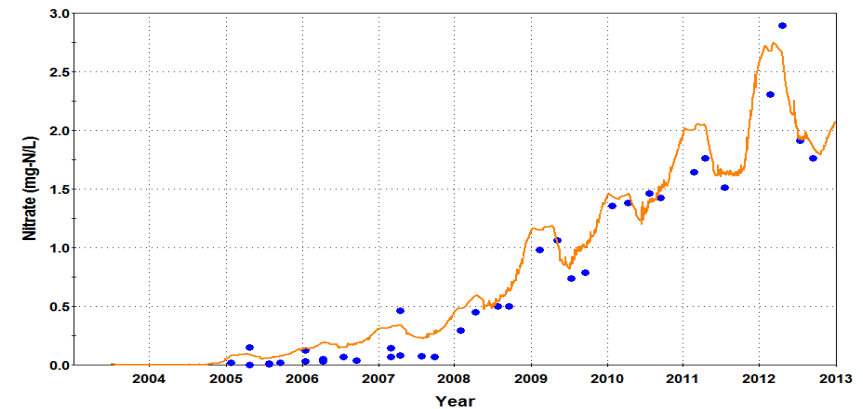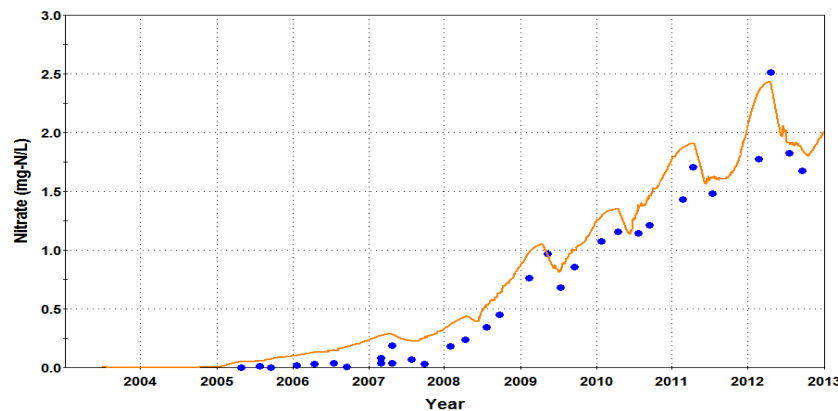
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Main Basin, SNAP05

(c) Main Basin, SNAP09
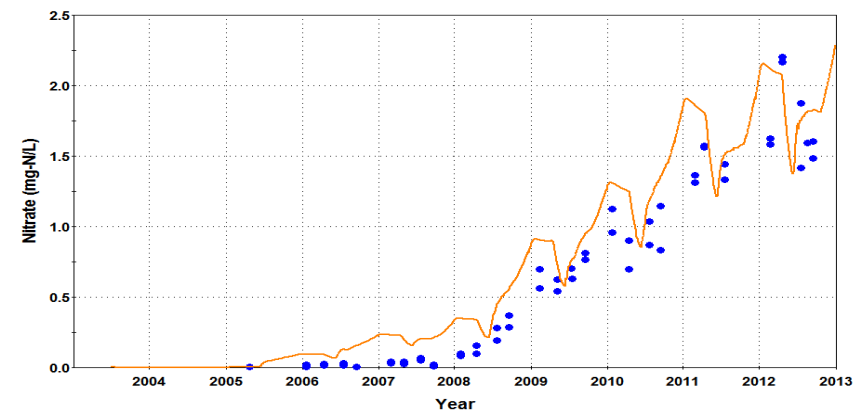
(d) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured nitrate concentrations.

mg-N/L = milligrams as nitrogen per litre; SNP = Surveillance Network Program.

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Figure 2-10   Orthophosphate Time Series Calibration Plots
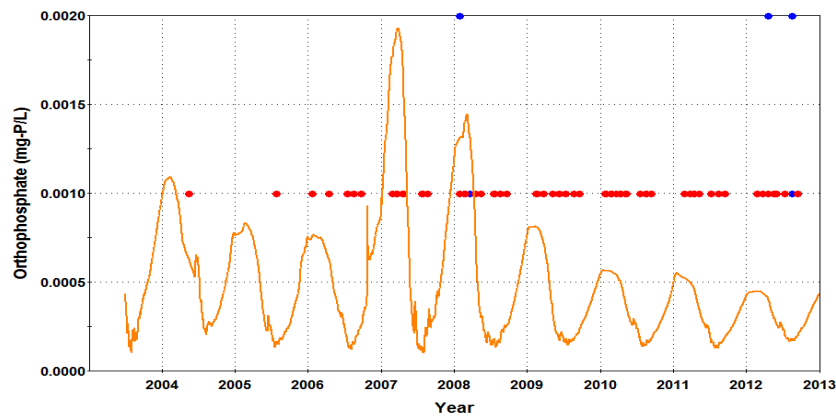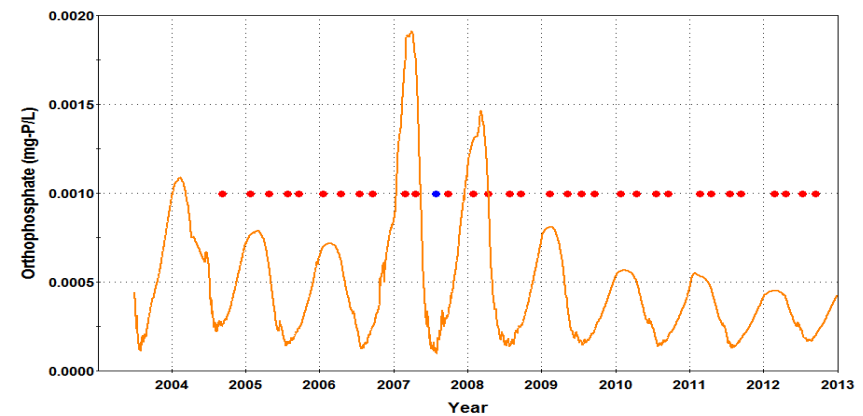
(a) Near diffuser, SNP 02-20 and SNAP13
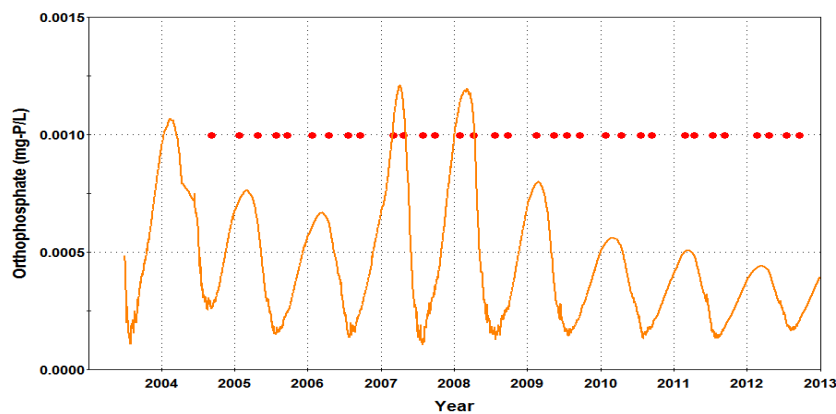
(b) Main Basin, SNAP05

(c) Main Basin, SNAP09
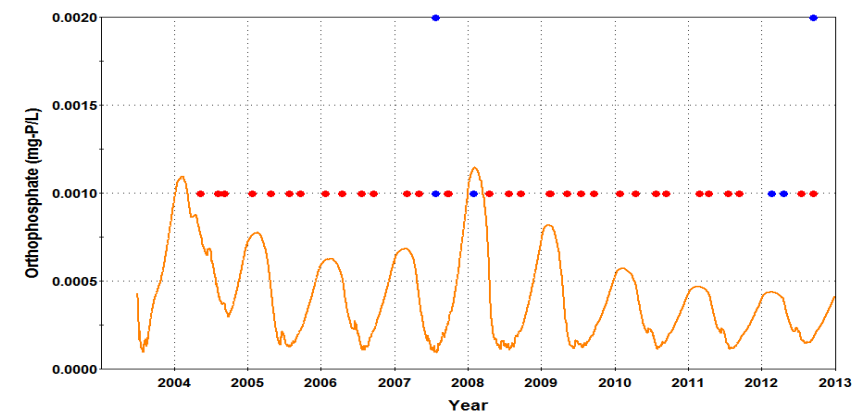
(d) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured orthophosphate concentrations reported above the detection limit; red dots represent measured orthophosphate concentrations reported below the detection limit. mg-P/L = milligrams as phosphorus per litre; SNP = Surveillance Network Program.

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Figure 2-11   Phytoplankton Time Series Calibration Plots
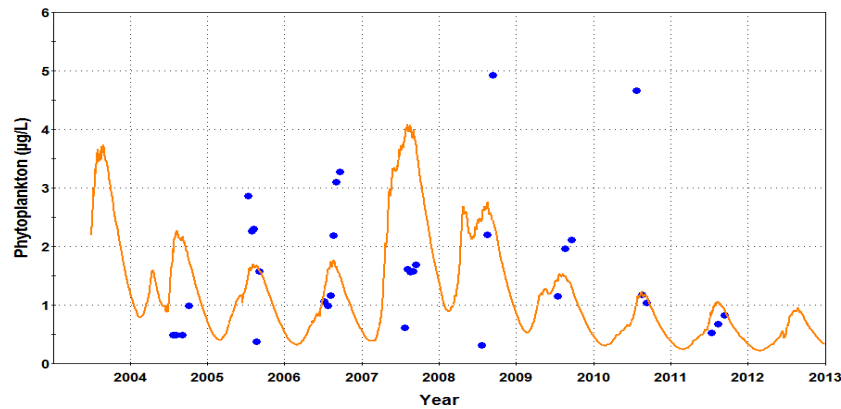
(a) Near diffuser, SNAP13
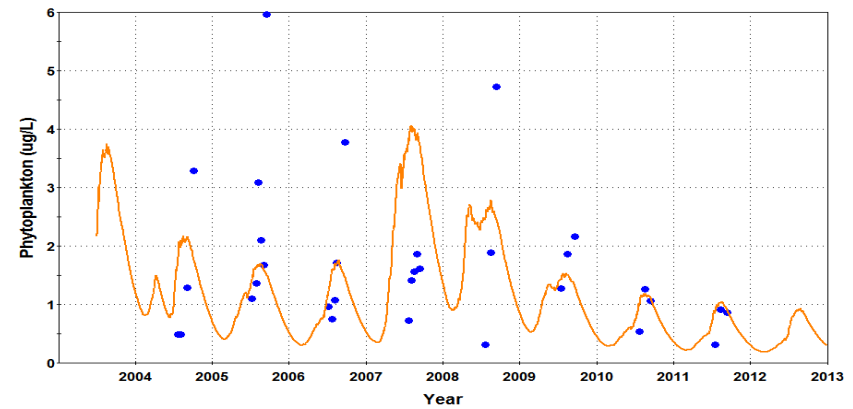
(b) Main Basin, SNAP06
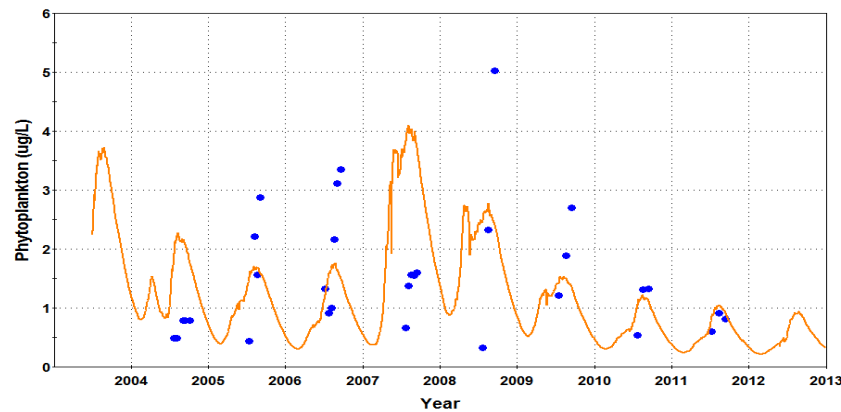
(c) Main Basin, SNAP03
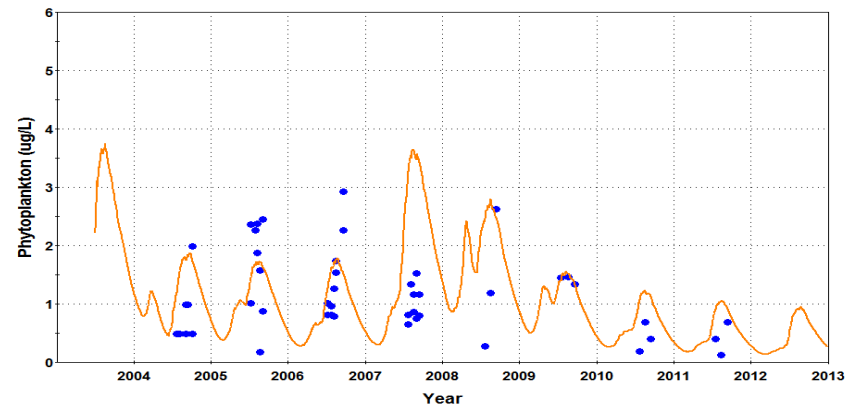
(d) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured chlorophyll *a* concentrations.

µg/L = micrograms per litre.

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2.3.4   Major Ions Calibration

Calcium, chloride, fluoride, magnesium, sodium, and sulphate were modelled as conservative constituents. Conservative constituents were assumed not to undergo chemical reactions or physical processes other than advective transport. The model matched the increasing trend in major ion concentrations well at the diffuser stations and at the outlet of Snap Lake (Appendix III) with the following two exceptions:

- the model over-predicted fluoride concentrations in 2011 and 2012 at the diffuser stations and at the outlet of Snap Lake. The over-prediction may be due to solubility controls in the lake or analytical error. Work is ongoing to understand the differences, but the present model calibration provides a conservative (i.e., worst-case) estimate; and,

- the model slightly under-predicted magnesium concentrations at the outlet of Snap Lake.

Overall, the major ions calibration indicates that the model is matching the movement of dissolved constituents well at all points of interest in the lake.

2.3.5   Metals and Metalloids Calibration

Antimony, arsenic, barium, copper, lithium, mercury, strontium, and zinc were modelled as conservative constituents. Calibration of these parameters was variable, with some modelled parameters matching measured concentrations well (i.e., lithium and strontium), some being over-predicted (i.e., zinc, copper, arsenic, and mercury), and others being under-predicted (i.e., antimony and barium) (Appendix IV).

Lithium and strontium concentrations showed increasing trends in Snap Lake, along with a low amount of scatter in the measured data. The model matched the increasing trend in lithium and strontium concentrations reasonably well near the diffuser stations and at the outlet of Snap Lake. Lithium and strontium are recognized as chemical signatures in the treated effluent from the Mine; concentrations of these parameters have increased in Snap Lake since 2004 because of increases in daily treated effluent discharge rates (De Beers 2013c).

Zinc and copper concentrations near the diffuser stations in Snap Lake showed variability during the ice-covered season. In general, the model matched the trend in zinc concentrations well near the diffuser stations with the exception of under-predicting peak zinc concentrations during the ice-covered season; the model matched peak copper concentrations near the diffuser stations reasonably well from 2006 to 2010, but over-predicted copper concentrations during the open water season. Zinc and copper concentrations at the outlet of Snap Lake were typically below detection limits and the model over-predicted these constituents at the outlet of Snap Lake. It is possible that the model over-predicted concentrations because zinc and copper are precipitating or settling in the water column. However, settling was not applied to zinc or copper because this process was not established with certainty. Therefore, model results for zinc and copper are considered to be conservatively high at the outlet of Snap Lake.

Arsenic and mercury concentrations in Snap Lake showed large variability, which may simply reflect analytical variability. In general, the model over-predicted arsenic and mercury concentrations near the diffuser stations and at the outlet of Snap Lake. It is possible that the model over-predicted mercury

concentrations in Snap Lake because the treated effluent discharge is presently not monitored for ultra-low level mercury, and mercury concentrations in the treated effluent discharge are generally below detection limits. Therefore, mercury concentrations assigned to the treated effluent discharge in the model are potentially higher than they would be if the discharge samples were analyzed using ultra-low level mercury methods. It is also possible that the model over-predicted mercury concentrations because mercury undergoes a number of transformation processes that are not accounted for in a conservative mass balance model. In any case, model results for arsenic and mercury are considered to be conservatively high at diffuser stations and at the outlet of Snap Lake.

As recommended in the 2012 Aquatic Effects Monitoring Program Annual Report (De Beers 2013c), antimony concentrations in Snap Lake were modelled. Historically, there have been large variations in measured antimony concentrations in Snap Lake, especially near the diffuser stations. The model did not match the variation in measured antimony concentrations well near the diffuser stations or at the outlet of Snap Lake, indicating that the identified inflows to Snap Lake (i.e., the treated effluent discharge, tributary and non-point source inflows from the Snap Lake basin, and non-point source seepages from the Mine site) are likely not the source of peak antimony concentrations in Snap Lake. As described in De Beers (2013c), measured antimony concentrations may have been affected by contamination or analytical interference, which would explain the large variation in antimony concentrations. There is no known physical mechanism that could cause such wide variation in water concentrations within such short time frames as indicated in Appendix IV, Figure IV-2. Thus, model results for antimony have a very high level of uncertainty.

Barium concentrations showed increasing trends in Snap Lake along with a low amount of scatter in the measured data, indicating that the increasing trend is real. The model was able to reproduce the increasing trend in barium concentrations; however, the model under-predicted the range of measured barium concentrations near the diffuser stations and at the outlet of Snap Lake (Appendix IV, Figure IV-4, panels a and c). Because barium was modelled as a conservative constituent, the model calibration indicated that there was an unidentified source of barium entering Snap Lake. To improve the barium calibration, an additional load of 733 kilograms (kg) of barium was added to Snap Lake from 2004 to 2009 (Appendix IV, Figure IV-4, panels b and d). To avoid under-predicting barium concentrations, the calibration with the additional barium load was used in future simulations.

2.3.5.1   Settleable Constituents

During the initial calibration process, modelled aluminum concentrations were much higher than measured in Snap Lake. The source of the elevated aluminum was identified as natural inflows. Based on the modelled aluminum concentrations in Snap Lake compared to the measured aluminum concentrations, it was apparent that a considerable amount of aluminum was settling, leading to lower water concentrations than would result from using a conservative mass balance. Therefore, settling was applied to aluminum, and a settling velocity of 0.02 m/d was determined to be appropriate (Appendix IV).

Similarly, modelled uranium concentrations were initially much higher than measured concentrations in Snap Lake. The source of the elevated uranium was identified as the treated effluent discharge to Snap Lake. Based on the modelled uranium concentrations in Snap Lake compared to the measured uranium concentrations, it was apparent that a considerable amount of uranium was being removed from the water column, leading to lower water concentrations than would result from using a conservative mass

balance. Therefore, in the model uranium was removed from the water column using settling, and a settling velocity of 0.0075 m/d was determined to be appropriate (Appendix IV).

2.4   Model Simulations

The following four modelling scenarios were considered for the operational period from 2013 to 2028:

- Upper Bound Scenario A: Minewater flows from Scenario 4 of the groundwater model (Itasca 2013b) and treated effluent discharge constituent concentrations from the site model based on arithmetic mean connate water TDS concentrations from the groundwater model;

- Upper Bound Scenario B: Minewater flows from Scenario 4 of the groundwater model (Itasca 2013b) and treated effluent discharge constituent concentrations from the site model based on geometric mean connate water TDS concentrations from the groundwater model;

- Lower Bound Scenario A: Minewater flows from Base Case of the groundwater model (Itasca 2013b) and treated effluent discharge constituent concentrations from the site model based on arithmetic mean connate water TDS concentrations from the groundwater model; and,

- Lower Bound Scenario B: Minewater flows from Base Case of the groundwater model (Itasca 2013b) and treated effluent discharge constituent concentrations from the site model based on geometric mean connate water TDS concentrations from the groundwater model.

All four scenarios used treated effluent discharge rates predicted by the site model (De Beers 2013b) for the applicable scenario.

3 MODEL RESULTS

Predicted constituent concentrations in Snap Lake showed the following:

- In the four scenarios, TDS concentrations are predicted to exceed the proposed SSWQO of 684 mg/L. Total dissolved solids concentrations near the diffuser stations and at the outlet of Snap Lake are predicted to range from approximately 800 to 1,700 mg/L in 2028 (Figure 3-1).

- Chloride concentrations are predicted to exceed the proposed SSWQO of 388 mg/L near the diffuser stations and at the outlet of Snap Lake in Upper Bound Scenarios A and B and Lower Bound Scenario A (Appendix V). In Upper Bound Scenarios A and B and Lower Bound Scenario A, chloride concentrations are predicted to increase to approximately 800, 500, and 600 mg/L in 2028, respectively.

- Concentrations of all nutrients, major ions, and total metals and metalloids in Snap Lake (Appendix V) are predicted to remain below proposed SSWQOs.

The values listed in Table 3-1 represent the highest concentrations that are expected to occur in Snap Lake; concentrations will decline after the treated effluent is no longer discharged to the lake.

A comparison of maximum predicted concentrations near the diffuser stations and at the outlet of Snap Lake to EAR predictions showed the following (Table 3-2):

- Maximum concentrations for modelled constituents in Snap Lake are predicted to exceed the maximum EAR concentrations with the exception of total copper (Table 3-2). When the EAR was completed, treated effluent discharge to Snap Lake was expected to peak at approximately 24,000 m^3/d. For the Upper and Lower Bound Scenarios, treated effluent discharge to Snap Lake is expected to peak at approximately 100,000 m^3/d and 60,000 m^3/d, respectively. The difference in predicted maximum concentrations is due to higher constituent loadings from the treated effluent discharge.

A comparison of depth-averaged TDS predictions near the diffuser stations, in the main basin, and at the outlet of Snap Lake against EAR predictions showed the following:

- Predicted depth-averaged TDS concentrations in Upper Bound Scenario B and Lower Bound Scenario B are similar to those in the EAR near the diffuser stations from 2004 to 2015. From 2015 to 2028, predicted TDS concentrations are greater than EAR predictions (Figure 3-2). In the main basin and at the outlet of Snap Lake, predicted TDS concentrations are greater than EAR predictions (Figure 3-2).

- Unlike EAR predictions, predicted depth-averaged total ammonia concentrations show an increasing trend at the diffuser stations, in the main basin, and at the outlet of Snap Lake; predicted total ammonia concentrations in the main basin and at the outlet are greater than EAR predictions (Figure 3-3).

- A comparison of depth-averaged nitrate predictions against EAR predictions shows that predicted nitrate concentrations are similar to EAR predictions (Figure 3-4).

Figure 3-1   Predicted Depth-Averaged Total Dissolved Solids Concentrations in Snap Lake
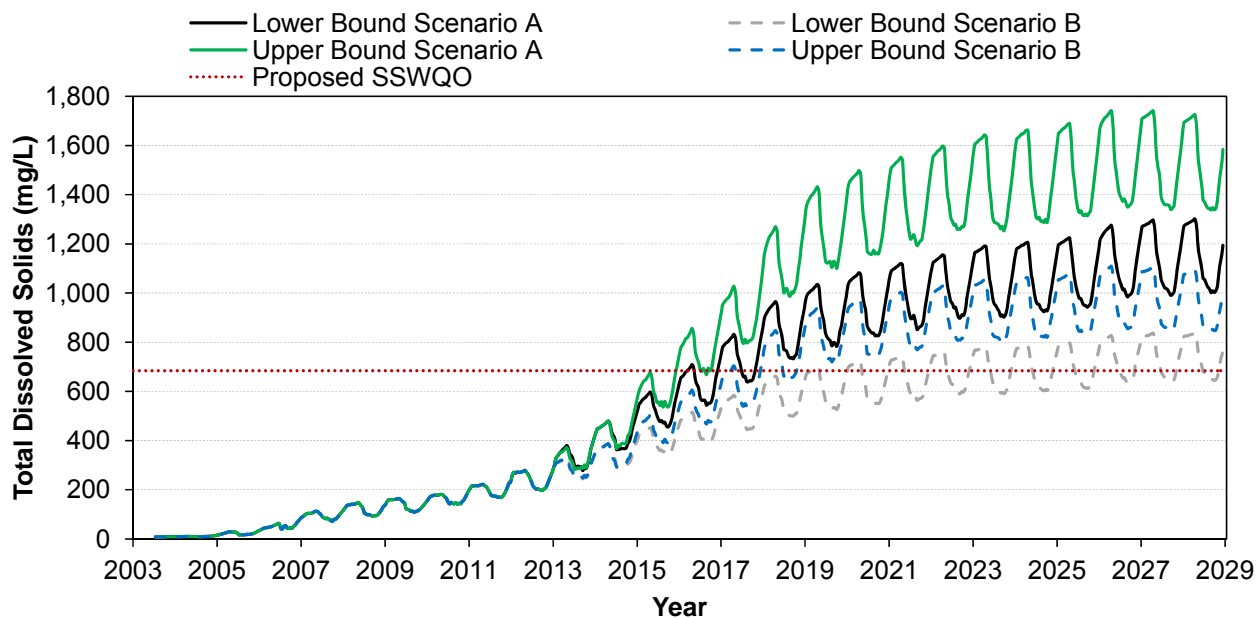
(a) Near diffuser, SNP 02-20e
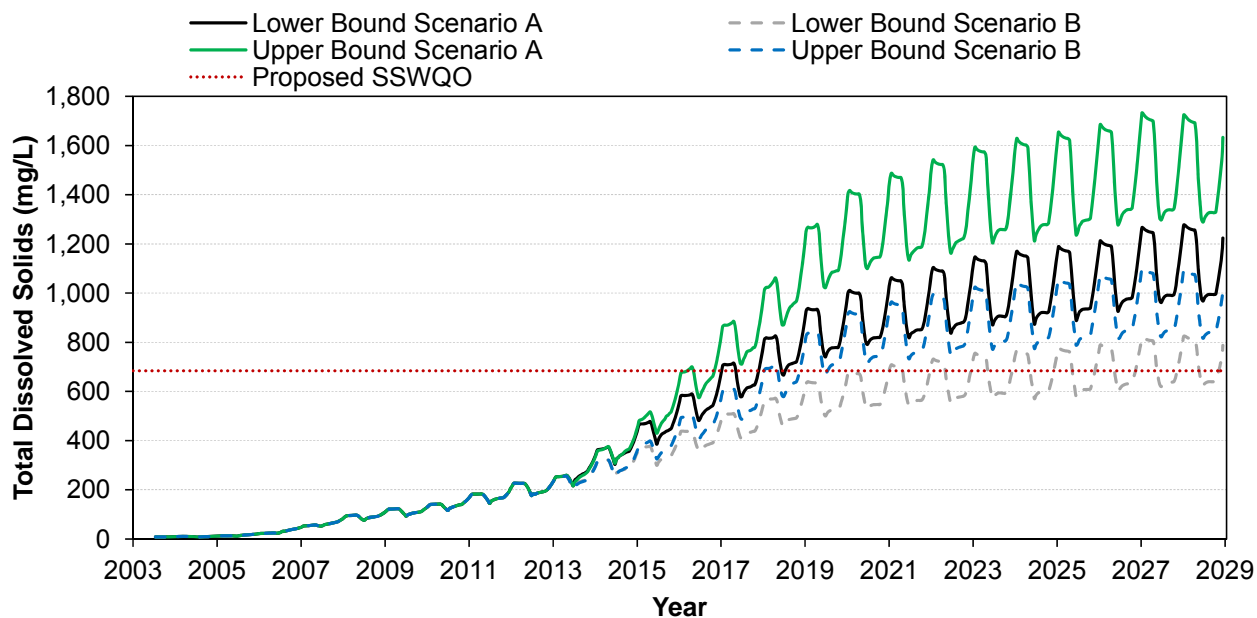
(b) Outlet, SNAP07

mg/L = milligrams per litre; SNP = Surveillance Network Program; SSWQO = proposed site-specific water quality objective.

Table 3-1   Maximum Predicted Concentrations in Snap Lake during Operations

Constituent	SSWQO[a]	Units	Maximum Concentrations at Diffuser Stations				Maximum Concentrations at Lake Outlet			
			Lower Bound Scenario A	Lower Bound Scenario B	Upper Bound Scenario A	Upper Bound Scenario B	Lower Bound Scenario A	Lower Bound Scenario B	Upper Bound Scenario A	Upper Bound Scenario B
Total dissolved solids	684[b]	mg/L	**1,311**	**845**	**1,753**	**1,117**	**1,280**	**827**	**1,735**	**1,101**
Nutrients and Chlorophyll *a*										
Total ammonia	5.21[c]	mg-N/L	2.3	2.3	2.7	2.7	0.8	0.8	1.1	1.1
Nitrate	16[d]	mg-N/L	9	9	10	10	7	7	8	8
Orthophosphate	-	mg-P/L	0.0048	0.0048	0.0048	0.0048	0.0012	0.0012	0.0012	0.0012
Phytoplankton	-	µg/L	4.1	4.1	4.1	4.1	3.8	3.8	3.8	3.8
Total phosphorus	0.011[e]	mg/L	0.0066	0.0066	0.0066	0.0066	0.0032	0.0032	0.0032	0.0032
Major Ions										
Calcium	-	mg/L	272	173	369	234	265	168	362	227
Chloride	388[f]	mg/L	**594**	375	**808**	**511**	**578**	365	**793**	**495**
Fluoride	2.46[g]	mg/L	0.47	0.47	0.48	0.48	0.45	0.45	0.47	0.47
Magnesium	-	mg/L	18	18	18	18	17	17	17	17
Sodium	-	mg/L	150	97	202	130	146	94	199	126
Sulphate	429[h]	mg/L	90	59	120	78	88	58	118	76
Metals and Metalloids										
Aluminum	100	µg/L	24	24	30	30	8	8	11	11
Antimony	6[i]	µg/L	0.54	0.54	0.58	0.58	0.54	0.54	0.58	0.58
Arsenic	5	µg/L	0.37	0.37	0.37	0.37	0.29	0.29	0.29	0.29
Barium	-	µg/L	34	34	35	35	33	33	35	35
Copper	6.4[j]	µg/L	2.1	2.1	2.1	2.1	2.15	2.15	2.2	2.2
Lithium	-	µg/L	117	73	159	100	113	70	156	97
Strontium	14,130[k]	µg/L	3,001	1,908	4,078	2,588	2,927	1,853	4,005	2,508
Uranium	15	µg/L	0.8	0.8	0.94	1.0	0.5	0.5	0.6	0.6
Zinc	30	µg/L	4.2	4.2	4.34	4.3	4.2	4.2	4.4	4.4

Note: **Bold** concentrations exceed the proposed SSWQO.

(a) SSWQOs are generic water quality guidelines (WQG) from the Canadian Council of Ministers of the Environment (CCME 1999) unless otherwise noted.

(b) Proposed SSWQO (De Beers 2013d)

(c) The total ammonia WQG is pH and temperature dependent and was calculated based on the 85th percentile value for monitored pH of 7.14 and temperature of 13.7 °C.

(d) Hardness dependent SSWQO developed for the EKATI Diamond Mine, at a hardness ≥ 160 mg/L(a) as $CaCO_3$ (Rescan 2012; De Beers 2013e).

(e) Mesotrophic status defined by phosphorus levels of 10.9 to 95.6 µg/L (Wetzel 2001).   The proposed SSWQO refers to the low end of this range.

(f) Hardness dependent SSWQO developed for the EKATI Diamond Mine, at a hardness of 160 mg/L(a) as $CaCO_3$ (Elphick et al. 2011; De Beers 2013d).

(g) SSWQO calculated from chronic toxicity data (De Beers 2013f).

(h) Hardness dependent WQG calculated at a hardness of 250 mg/L as $CaCO_3$ (BCMOE 2013).

(i) Canadian drinking water guideline from Health Canada (2012). The guideline concentration is the Maximum Acceptable Concentration.

(j) Hardness dependent SSWQO derived as part of the Snap Lake EAR and calculated at a hardness of 140 mg/L as $CaCO_3$ (De Beers 2002).

(k) Proposed SSWQO (Golder 2013).

mg/L = milligrams per litre; mg-N/L = milligrams as nitrogen per litre; mg-P/L = milligrams as phosphorus per litre; µg/L = micrograms per litre; $CaCO_3$ = calcium carbonate; SSWQO = site-specific water quality objective; "-" = no guideline available.

Table 3-2   Comparison of Maximum Predicted Concentrations in Snap Lake during Operations to Environmental Assessment Report Predictions

Constituent	Units	Maximum EAR Predictions[a]		Maximum 2013 Predictions			
				Concentrations at Diffuser Stations		Concentrations at Lake Outlet	
		1% of Lake	After Initial Mixing	Upper Bound Scenario A	Lower Bound Scenario B	Upper Bound Scenario A	Lower Bound Scenario B
Total dissolved solids	mg/L	444	350	1,753	845	1,735	827
Nutrients and Chlorophyll *a*							
Total ammonia	mg-N/L	2.1	1.1	2.7	2.3	1.1	0.8
Nitrate	mg-N/L	6.3	6.0	10	9	8	7.1
Orthophosphate	mg-P/L	0.0056	-	0.0048	0.0048	0.0012	0.0012
Phytoplankton	µg/L	2.7	-	4.1	4.1	3.8	3.8
Total phosphorus	mg/L	0.0096	-	0.0066	0.0066	0.0032	0.0032
Major Ions							
Calcium	mg/L	113	88	369	173	362	168
Chloride	mg/L	177	137	808	375	793	365
Fluoride	mg/L	-	-	0.48	0.47	0.47	0.45
Magnesium	mg/L	12	9	18	18	17	17
Sodium	mg/L	-	-	202	97	199	94
Sulphate	mg/L	-	-	120	59	118	58
Total Metals and Metalloids							
Aluminum	µg/L	-	-	30	24	11	8
Antimony	µg/L	-	-	0.58	0.54	0.58	0.54
Arsenic	µg/L	-	-	0.37	0.37	0.29	0.29
Barium	µg/L	-	-	35	34	35	33
Copper	µg/L	2.57	2.2	2.1	2.1	2.2	2.1
Lithium	µg/L	-	-	159	73	156	70
Strontium	µg/L	-	-	4,078	1,908	4,005	1,853
Uranium	µg/L	-	-	0.94	0.8	0.6	0.5
Zinc	µg/L	-	-	4.34	4.2	4.4	4.2

Note: [a] De Beers (2002).

%= percent; mg/L = milligrams per litre; mg-N/L = milligrams as nitrogen per litre; mg-P/L = milligrams as phosphorus per litre; µg/L = micrograms per litre; "-" = no data available; EAR = Environmental Assessment Report.

Figure 3-2   Comparison of Depth-Averaged Total Dissolved Solids Predictions Against Environmental Assessment Report Predictions
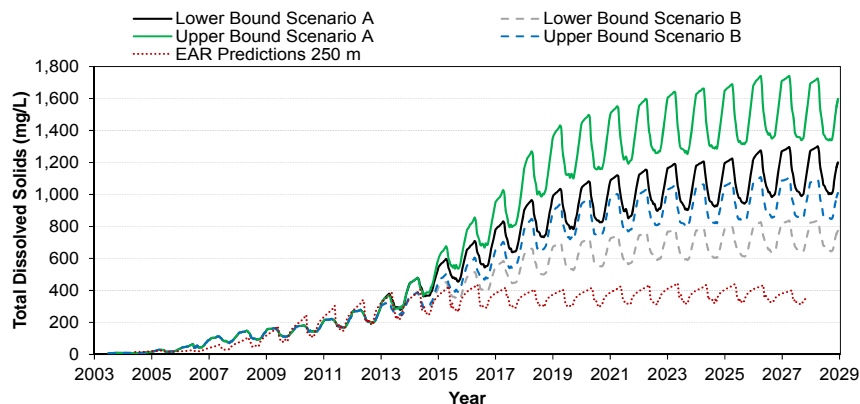
(a) Near diffuser, SNP 02-20e
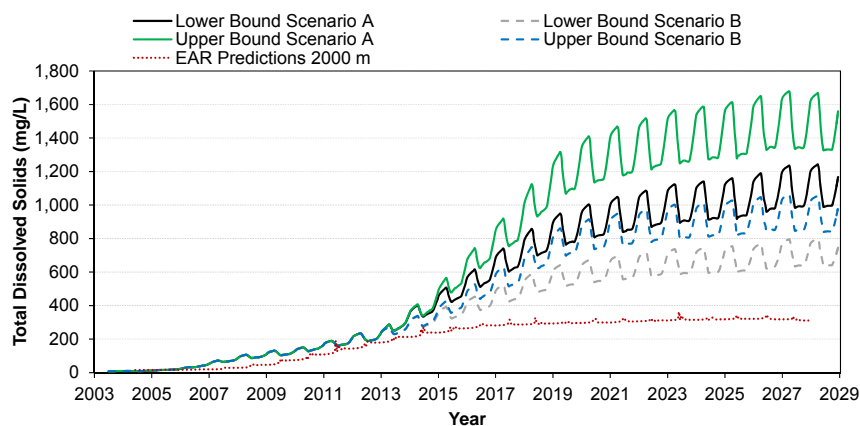
(b) Main Basin, SNAP09
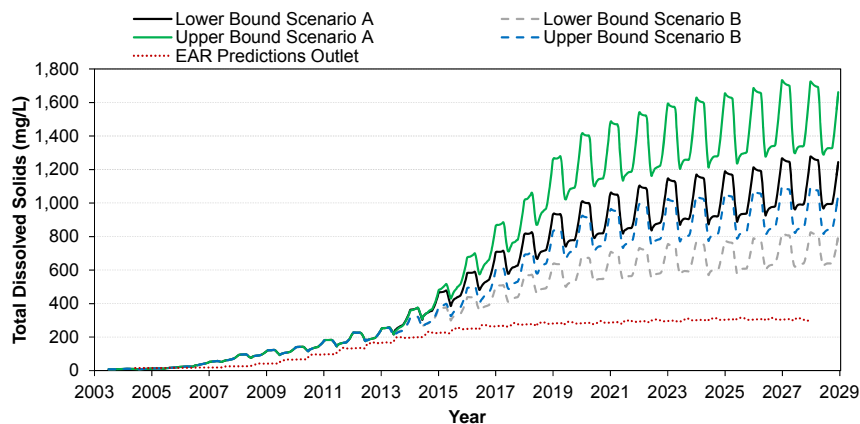
(c) Outlet, SNAP07

mg/L = milligrams per litre; EAR = Environmental Assessment Report; SNP = Surveillance Network Program.

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Figure 3-3   Comparison of Depth-Averaged Total Ammonia Predictions Against Environmental Assessment Report Predictions
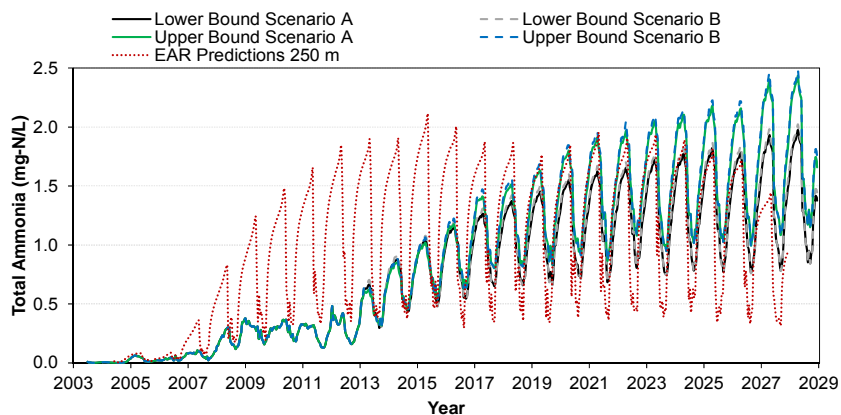
(a)   Near diffuser, SNP 02-20e

(b) Main Basin, SNAP09

(c) Outlet, SNAP07

mg-N/L = milligrams as nitrogen per litre; EAR = Environmental Assessment Report; SNP = Surveillance Network Program.

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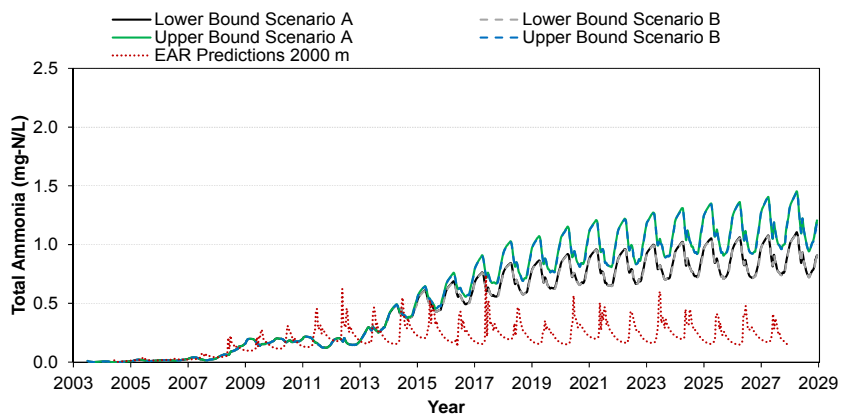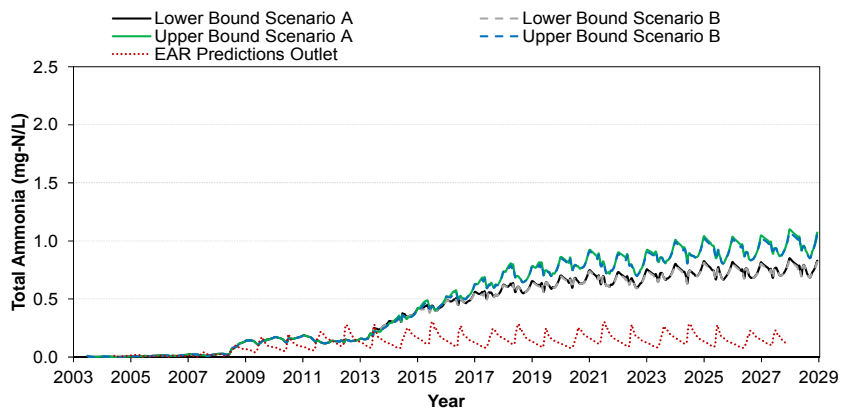
Figure 3-4   Comparison of Depth-Averaged Nitrate Predictions Against Environmental Assessment Report Predictions
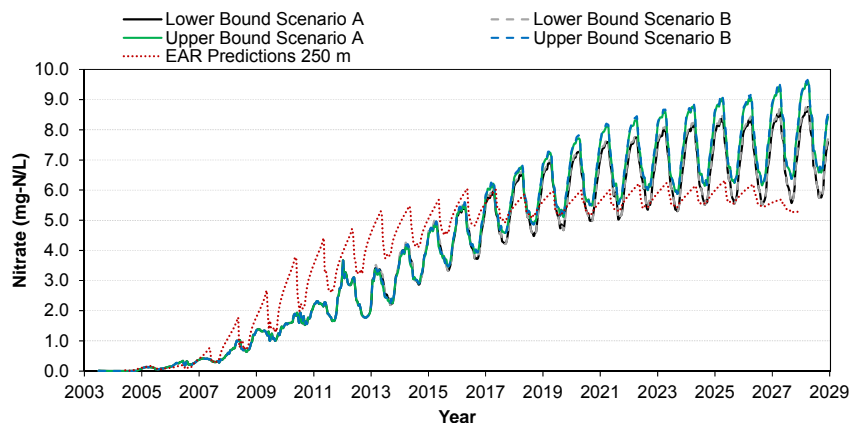
(a) Near diffuser, SNP 02-20e
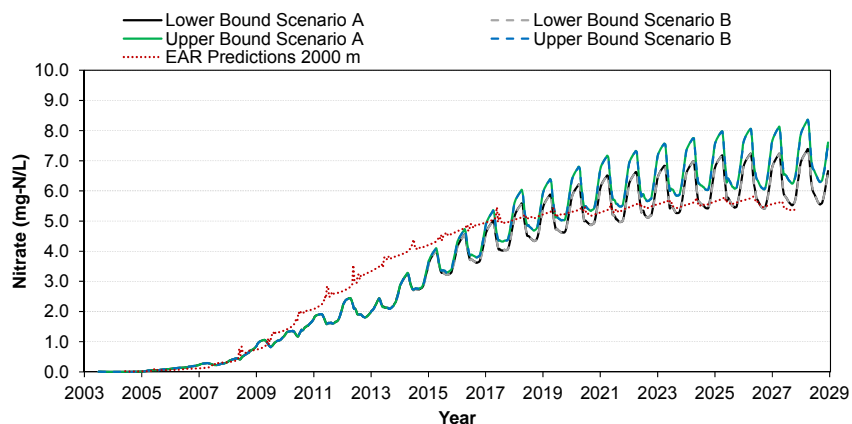
(b) Main Basin, SNAP09
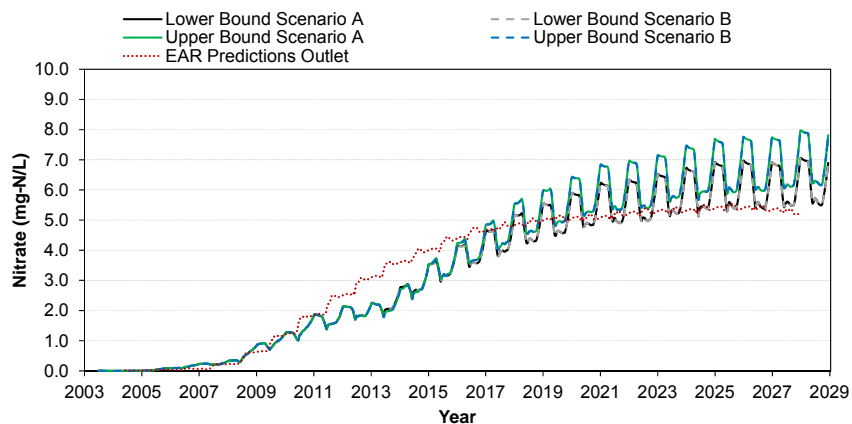
(c) Outlet, SNAP07

mg-N/L = milligrams as nitrogen per litre; EAR = Environmental Assessment Report; SNP = Surveillance Network Program.

4 DATA GAPS AND MODEL UNCERTAINTY

4.1 Data-related Uncertainty

4.1.1 Total Dissolved Solids and Major Ions

Data-related uncertainty in TDS and major ions concentrations during the calibration time period was low. As discussed in Sections 2.3.1 and 2.3.4, TDS and major ions concentrations showed an increasing trend in Snap Lake along with a low amount of scatter in the data with the exception of fluoride. The model matched the increasing trend in dissolved constituents well in Snap Lake. As discussed in Section 2.3.4, the model over-predicted fluoride concentrations in 2011 and 2012, and work is ongoing to understand the difference between measured and modelled concentrations.

Data-related uncertainty in long-term predictions of TDS and major ions concentrations was high. Uncertainty in predicted concentrations is carried forward from assumptions used in the site model and the hydrogeological model. The three models are sensitive to the assumptions used for deep groundwater (connate water) inflows, because these inflows will have very high TDS, chloride, and calcium concentrations. However, it is expected that the four simulations will bracket the long-term concentrations of TDS and major ions under reasonably foreseeable conditions.

4.1.2 Total Metals and Metalloids

Data-related uncertainty in zinc, copper, arsenic, mercury, and antimony concentrations during the calibration time period was high. As discussed in Section 2.3.5, the concentrations of these metals and metalloids showed high variability and were near or below detection limits, which posed challenges for the calibration. However, while there is uncertainty associated with the concentrations of these metals and metalloids, there is a high degree of confidence that predicted concentrations will remain well below applicable water quality guidelines (WQGs) in Snap Lake throughout the operational period of the Mine.

Data-related uncertainty in lithium and strontium concentrations during the calibration time period was low. As discussed in Section 2.3.5, lithium and strontium showed an increasing trend in Snap Lake along with a low amount of scatter in the data. The model matched the increasing trend in lithium and strontium concentrations well in Snap Lake. Data-related uncertainty in predicted lithium and strontium concentrations was high. Lithium and strontium concentrations are correlated to TDS concentrations. Uncertainty in predicted TDS concentrations by the hydrogeological model is carried forward in the site model and the present model. However, it is expected that the four simulations will bracket the long-term concentrations of lithium and strontium under reasonably foreseeable conditions.

4.1.3 Nutrients and Chlorophyll *a*

Data-related uncertainty in nitrate concentrations was low during the calibration time period. As discussed in Section 2.3.3, nitrate concentrations showed an increasing trend in Snap Lake along with a low amount of scatter in the data. The model matched the increasing trend in nitrate concentrations well in Snap Lake. Data-related uncertainty in ammonia and chlorophyll *a* concentrations during the calibration time

period was moderate because of high variability in measured ammonia and chlorophyll *a* concentrations. Despite the uncertainty, the model matched the trend in measured ammonia and chlorophyll *a* concentrations reasonably well in Snap Lake.

Data-related uncertainty in predicted ammonia and nitrate concentrations was moderate. Nitrate and ammonia are present in Snap Lake primarily as a result of the use of an emulsion type explosive as a blasting agent; the treated effluent discharge is the primary source of ammonia and nitrate concentrations in the lake. Uncertainty in explosive use rates and in mass loading rates for ammonia and nitrate were carried forward from the site model to the present model.

Data-related uncertainty in orthophosphate concentrations during the calibration time period was high. As discussed in Section 2.3.3, orthophosphate concentrations were generally at or near the detection limit in all inflows to Snap Lake, with the exception of the treated effluent in the first four years of domestic waste water treatment plant operation. A dataset with the majority of values below detection limits is of limited value in model calibration. However, even when accounting for the high uncertainty, the results indicate that orthophosphate concentrations will remain low in Snap Lake.

5   MODEL LIMITATIONS

The key limitation of the modelling approach is:

- Changes to treated effluent discharge quantity and quality – The Snap Lake hydrodynamic and water quality model was capable of reproducing constituent concentrations in Snap Lake reasonably well during the calibration time period from 2004 to 2012, when monitored treated effluent discharge data were available. Predicted constituent concentrations in Snap Lake only apply to the four modelled scenarios presented in this report. Changes to treated effluent discharge quantity and quality outside of the range predicted in the four modelled scenarios will result in possible changes to constituent concentrations in Snap Lake beyond the range of concentrations predicted in this report.

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APPENDIX I

MINE-RELATED INPUTS TO SNAP LAKE

December 2013

Figure I-1   Mine-Related Inflows to Snap Lake before June 2004
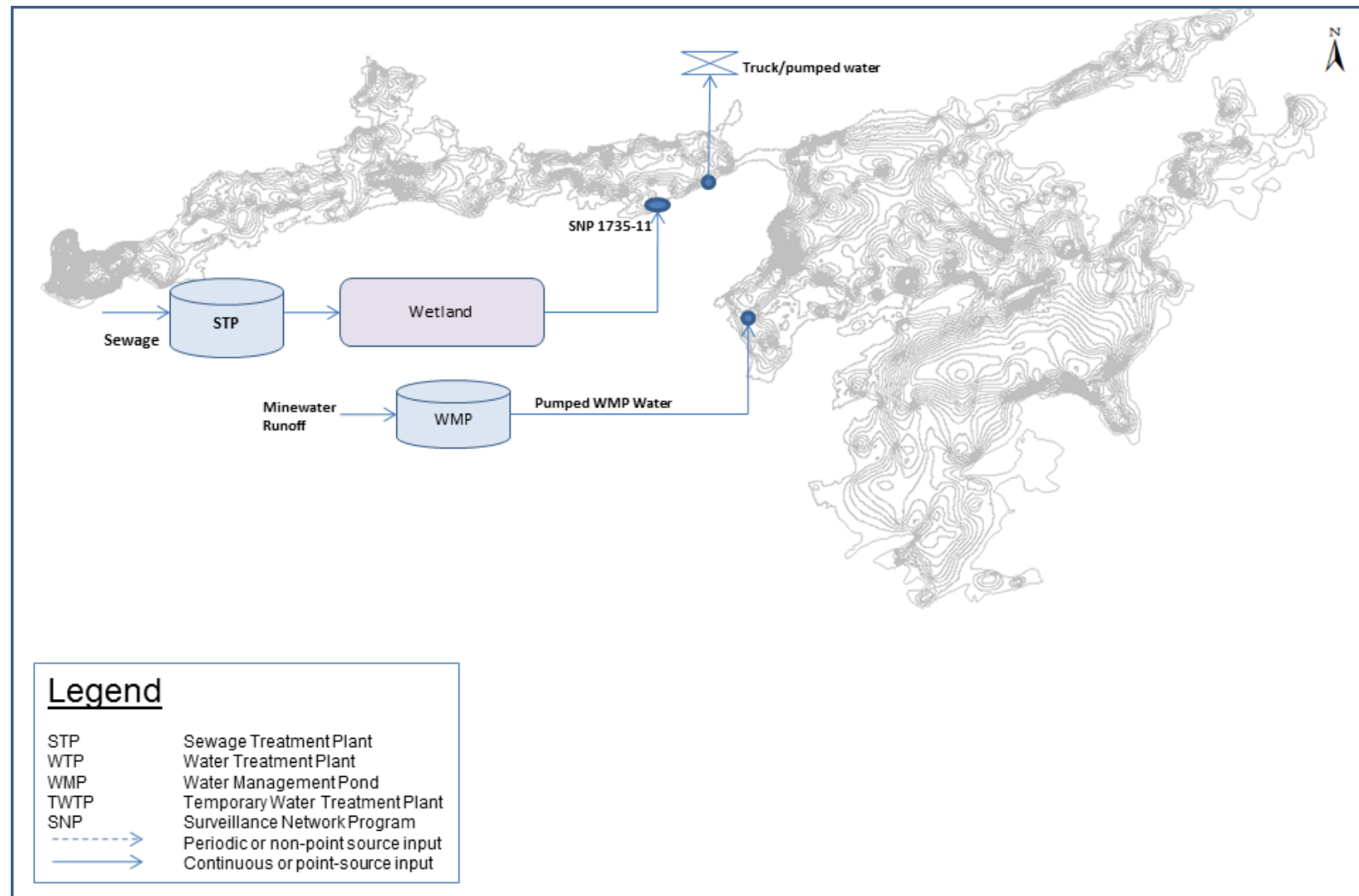
Figure I-2   Mine-Related Inflows to Snap Lake, June 2004 to April 2006
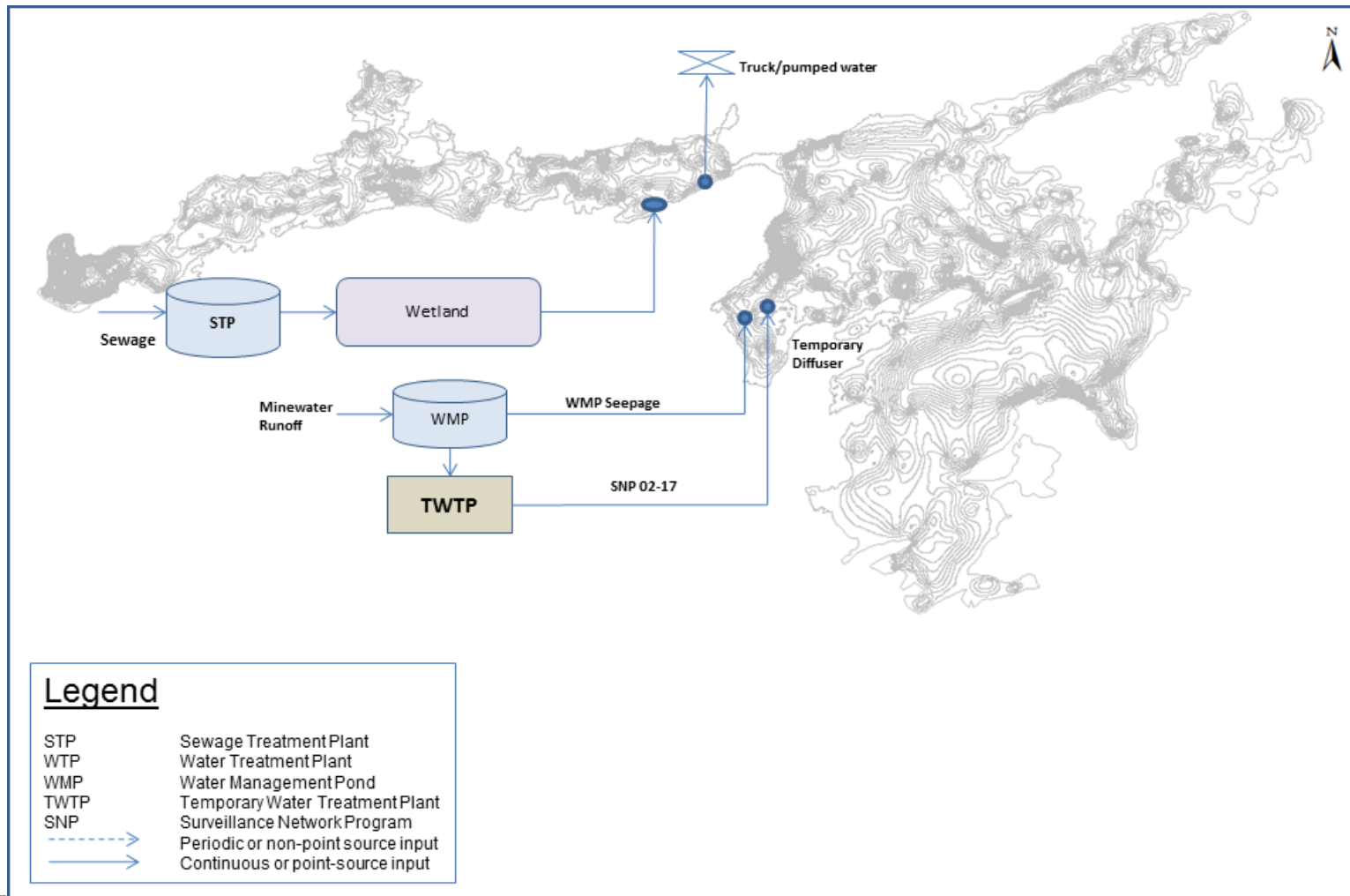
Figure I-3   Mine-Related Inflows to Snap Lake, May 2006 to July 2006
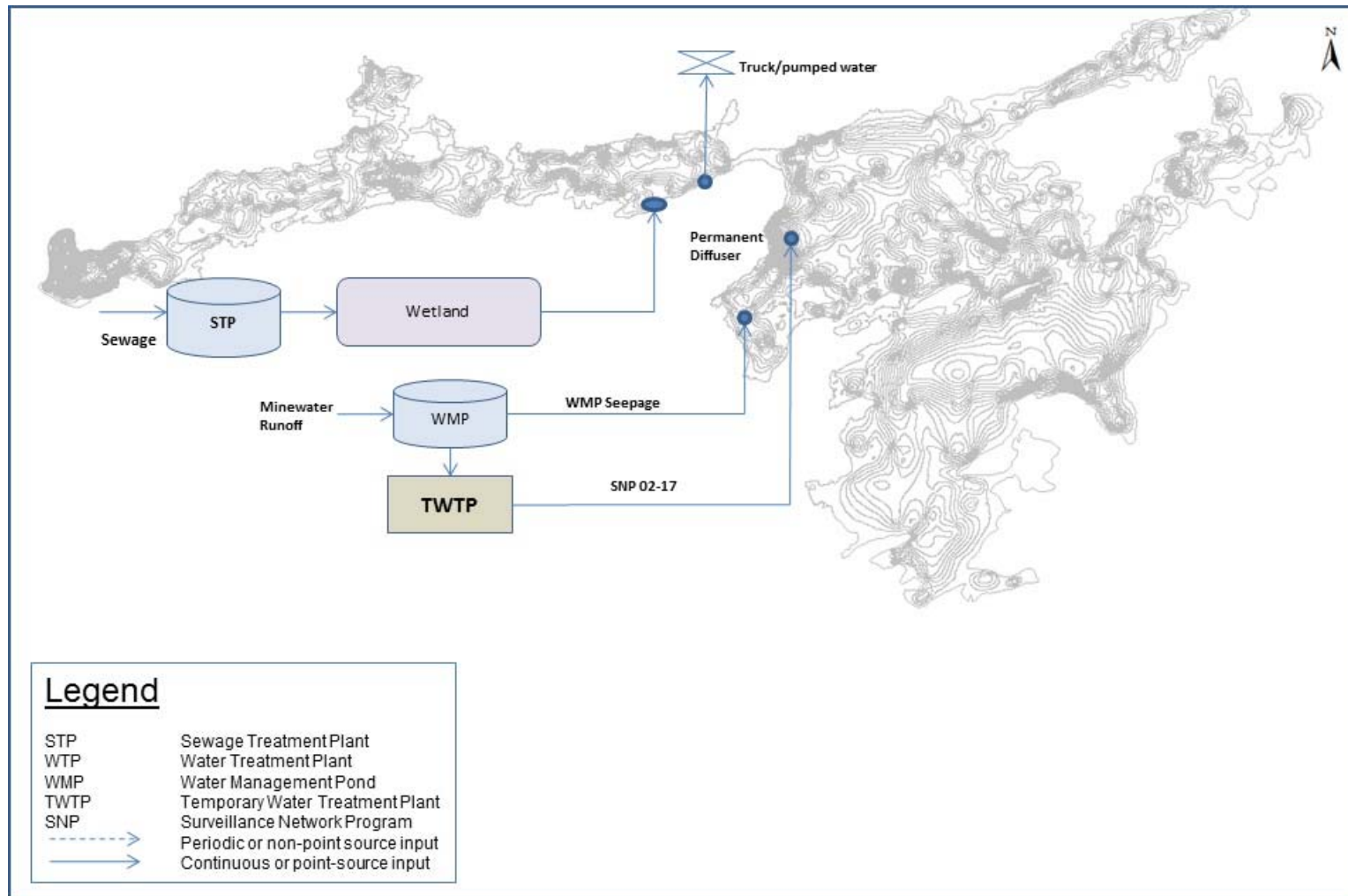
Figure I-4   Mine-Related Inflows to Snap Lake, August 2006 to March 2007
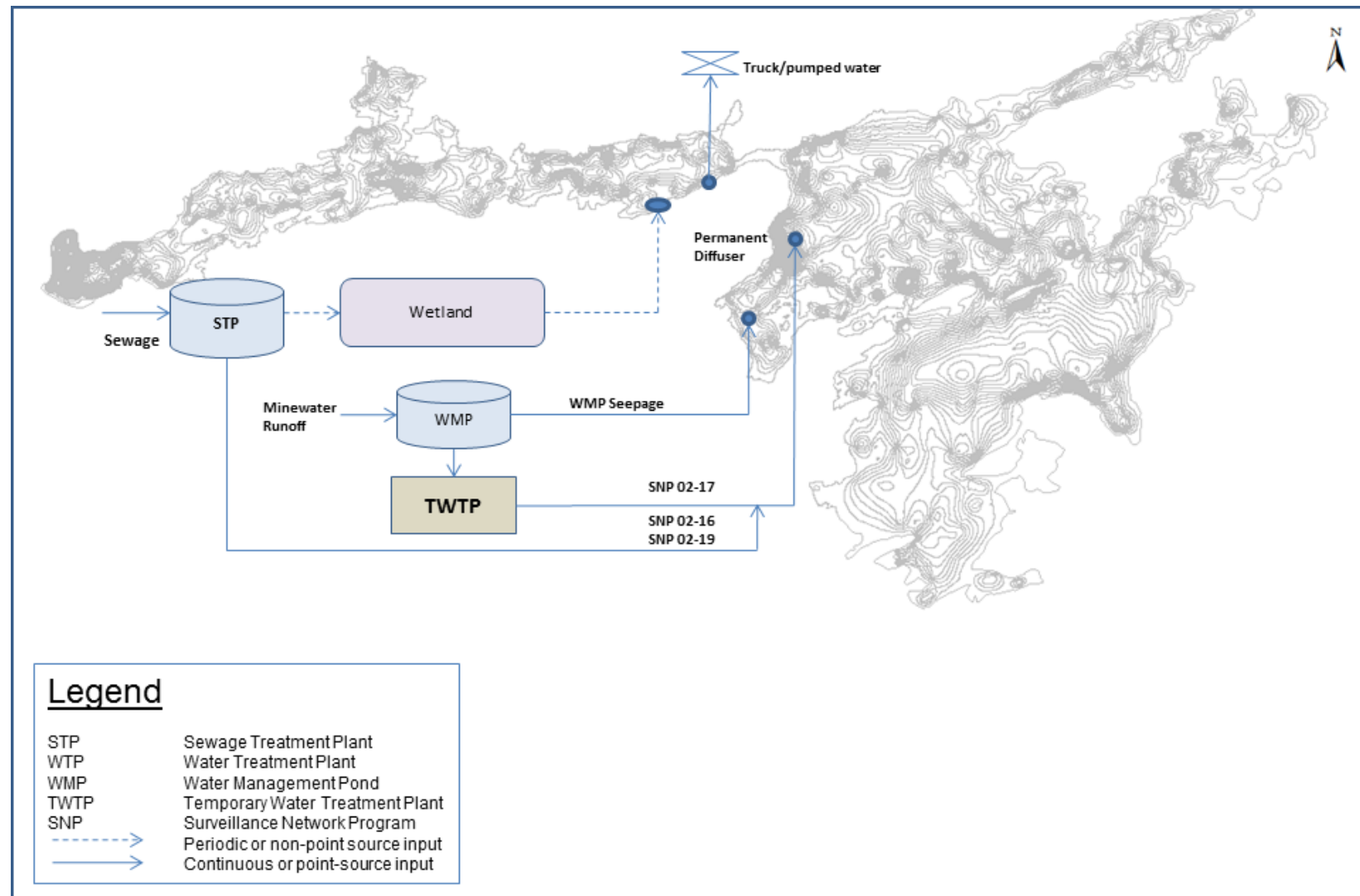
Figure I-5   Mine-Related Inflows to Snap Lake, August 2007 to March 2008
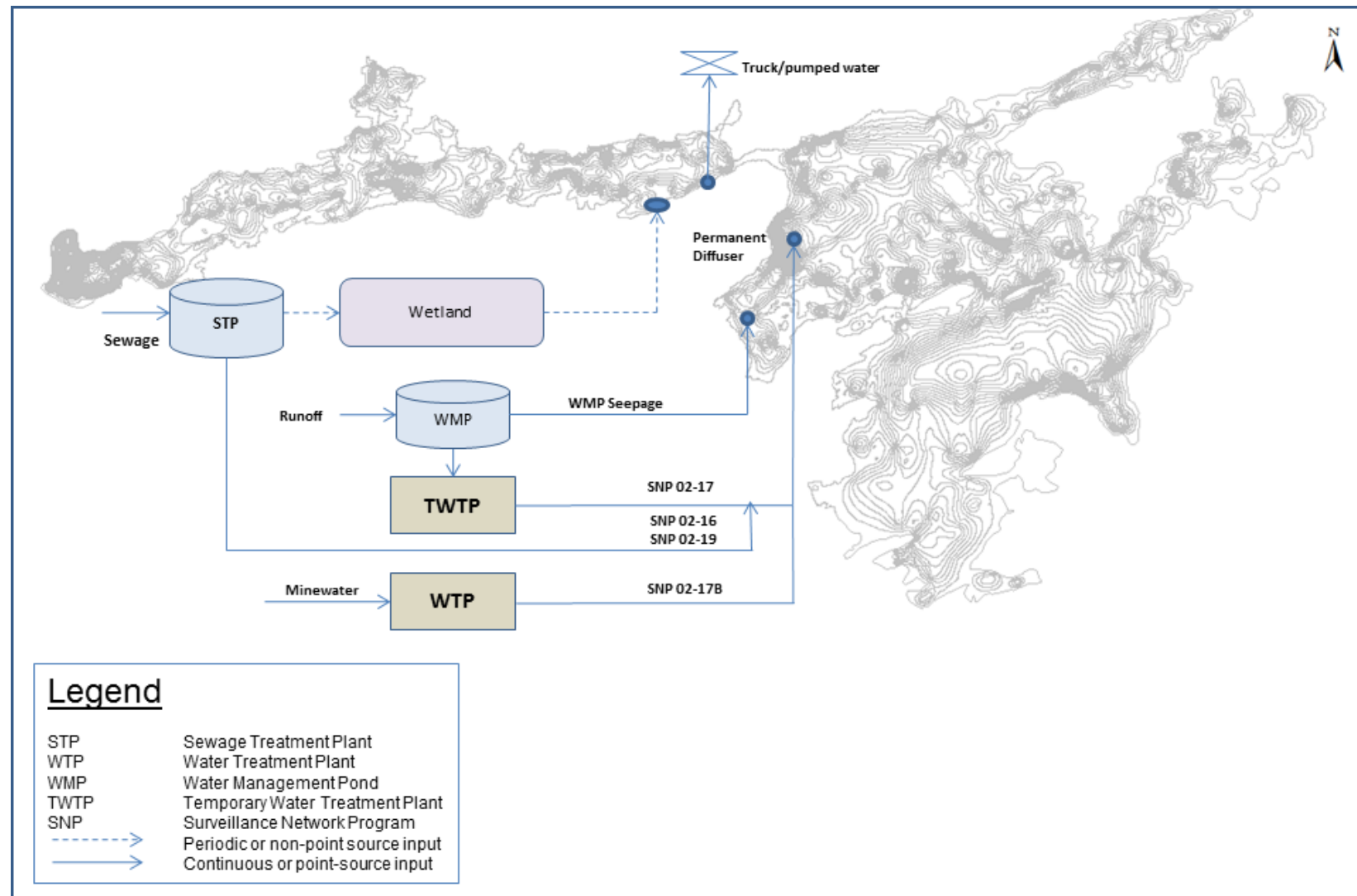
Figure I-6   Mine-Related Inflows to Snap Lake, April 2008 to September 2008

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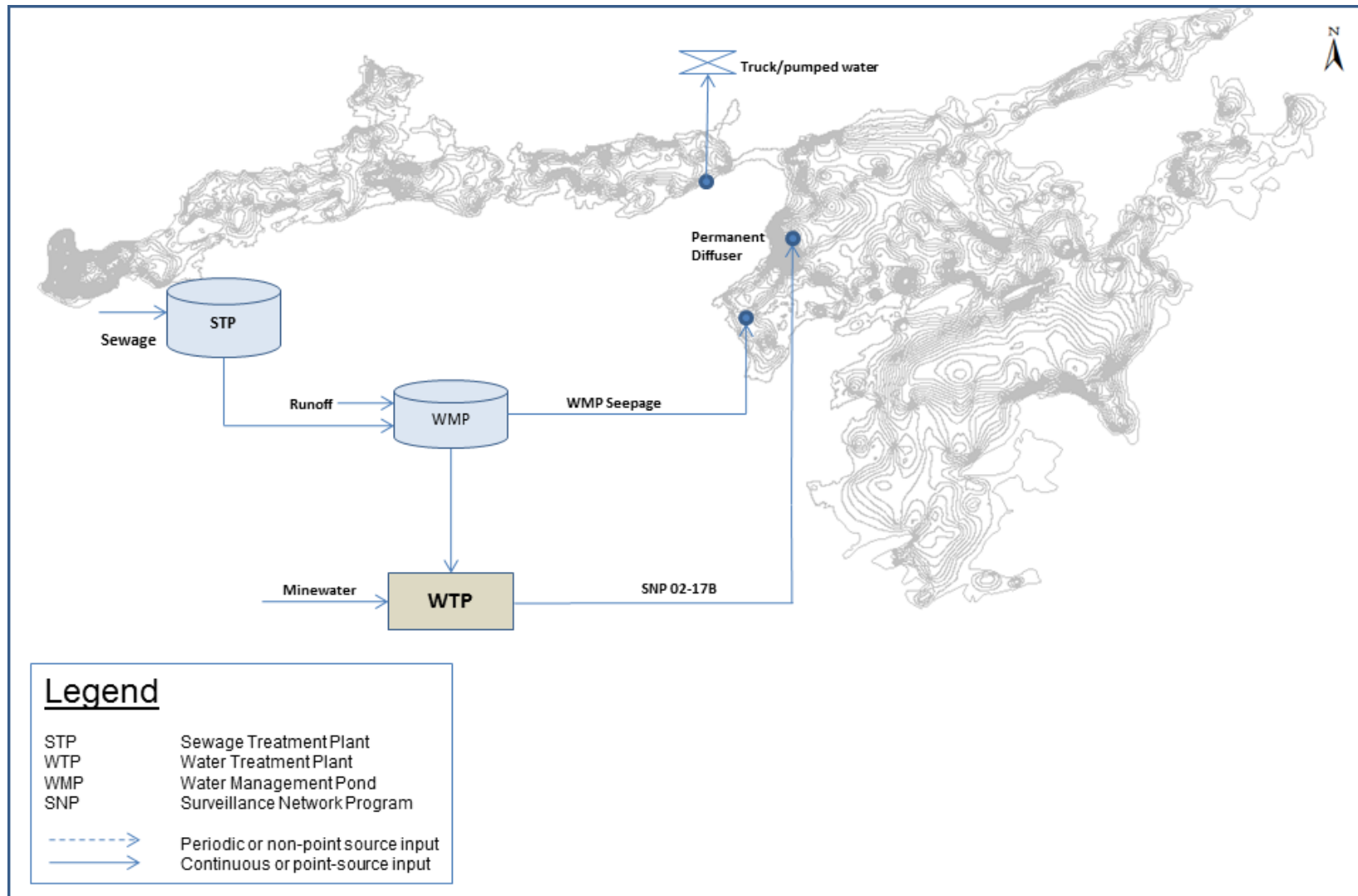
Figure I-7   Mine-Related Inflows to Snap Lake, October 2008 to June 2011
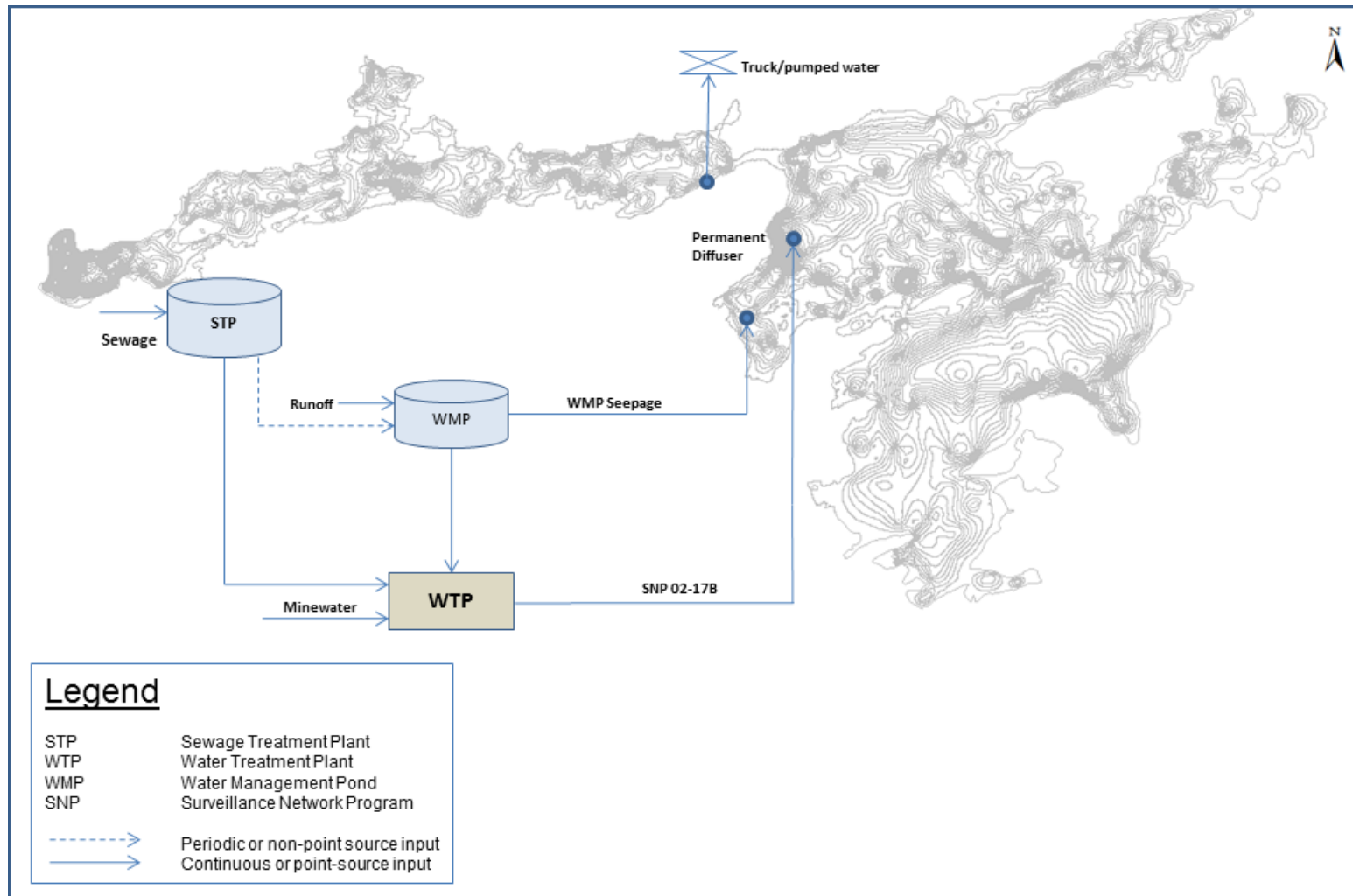
Note: A volume of 1,549 m³ of STP effluent was discharged to the wetlands in February 2009 (De Beers 2010).

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Figure I-8   Mine-Related Inflows to Snap Lake, July 2011 to March 2012
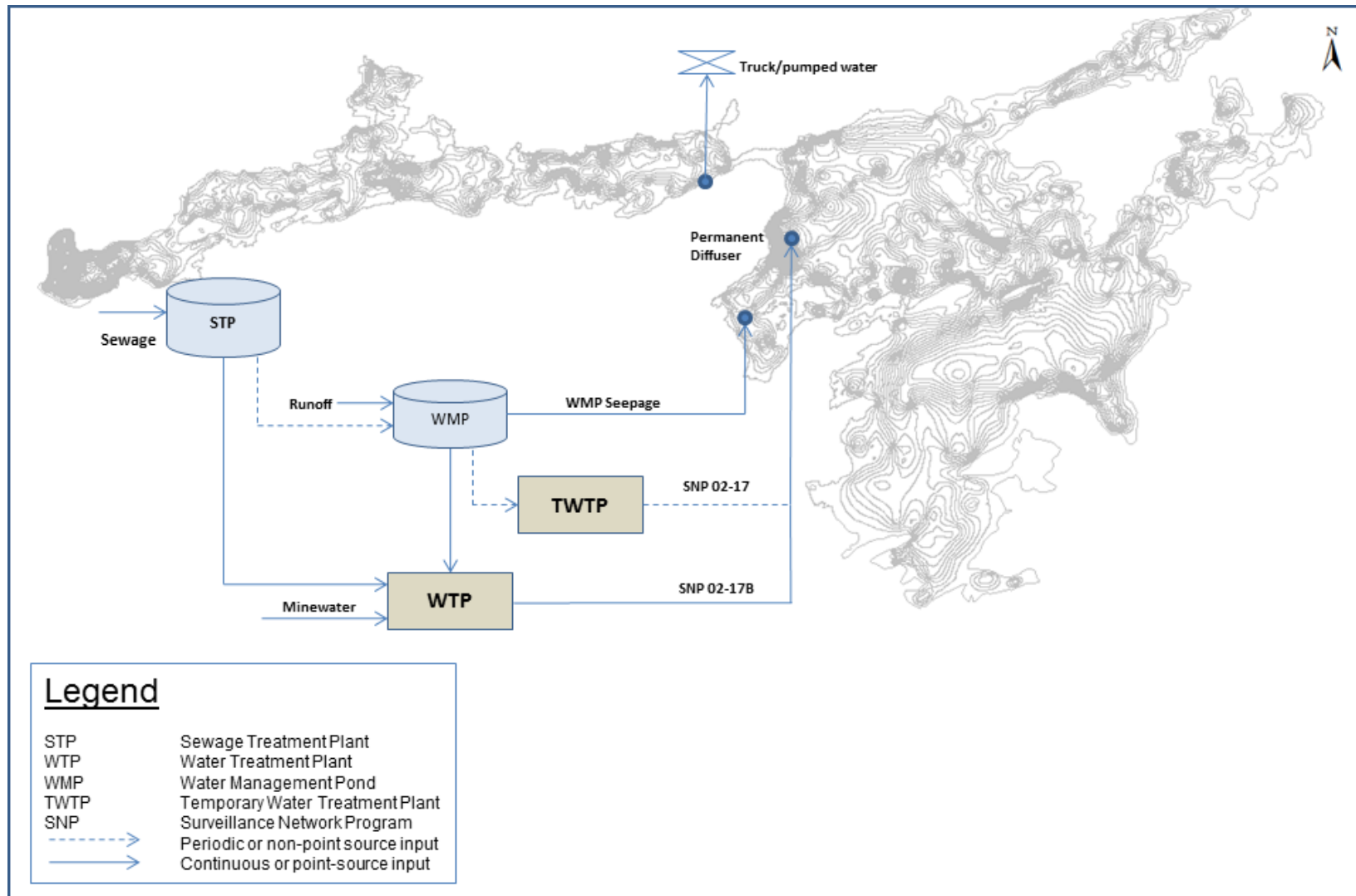
Figure I-9   Mine-Related Inflows to Snap Lake, April 2012 to September 2013
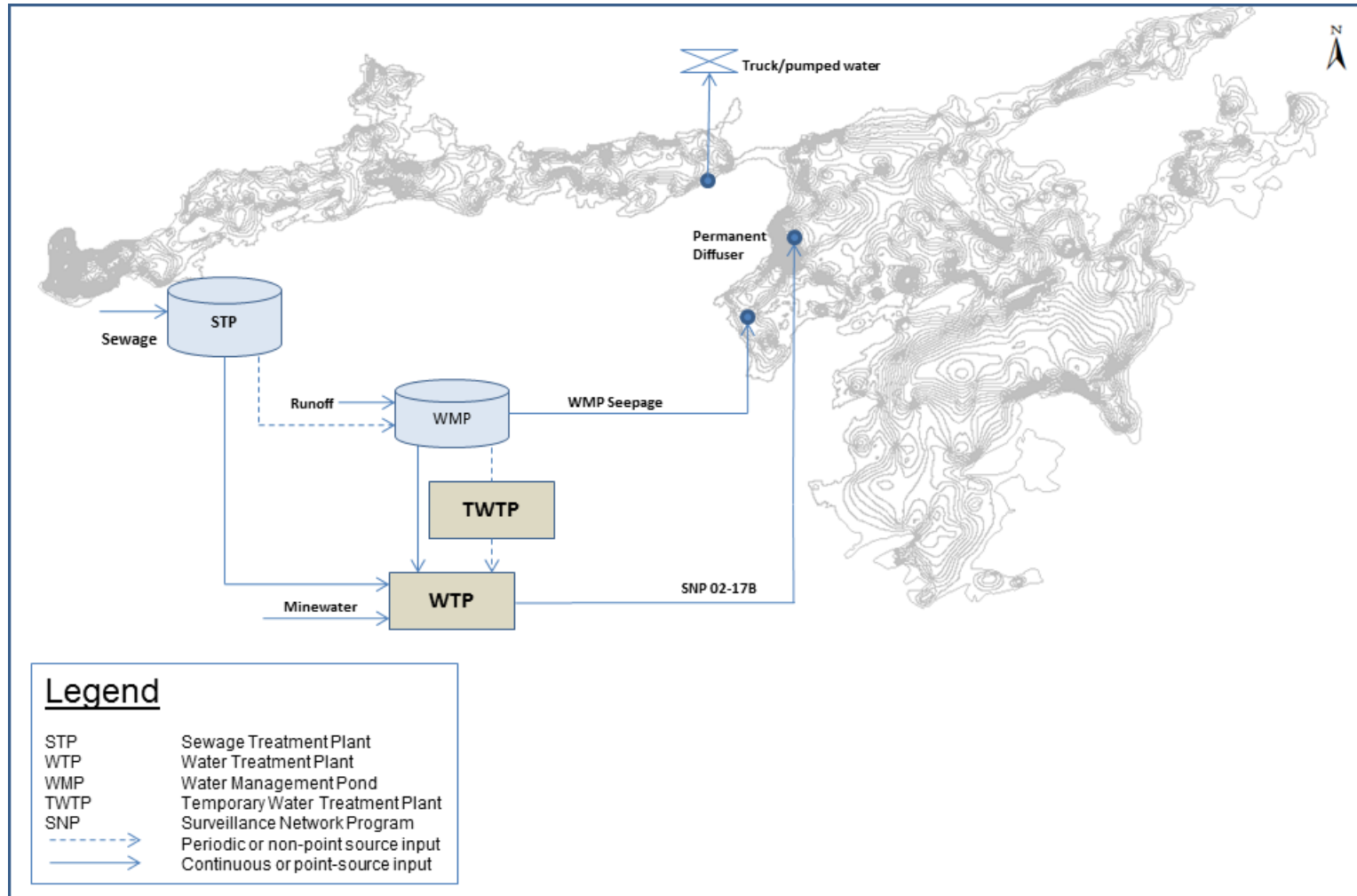
Note: In addition to the permanent diffuser, a floating diffuser was used in May 2012 and during the open-water season in 2013 to discharge treated effluent to Snap Lake. The floating diffuser has now been replaced by a second permanent diffuser.

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APPENDIX II

WATER TEMPERATURE, TOTAL DISSOLVED SOLIDS, AND DISSOLVED OXYGEN PROFILE CALIBRATION RESULTS

December 2013

Figure II-1   Water Temperature (°C) Profile Calibration Plots at SNP 02-20
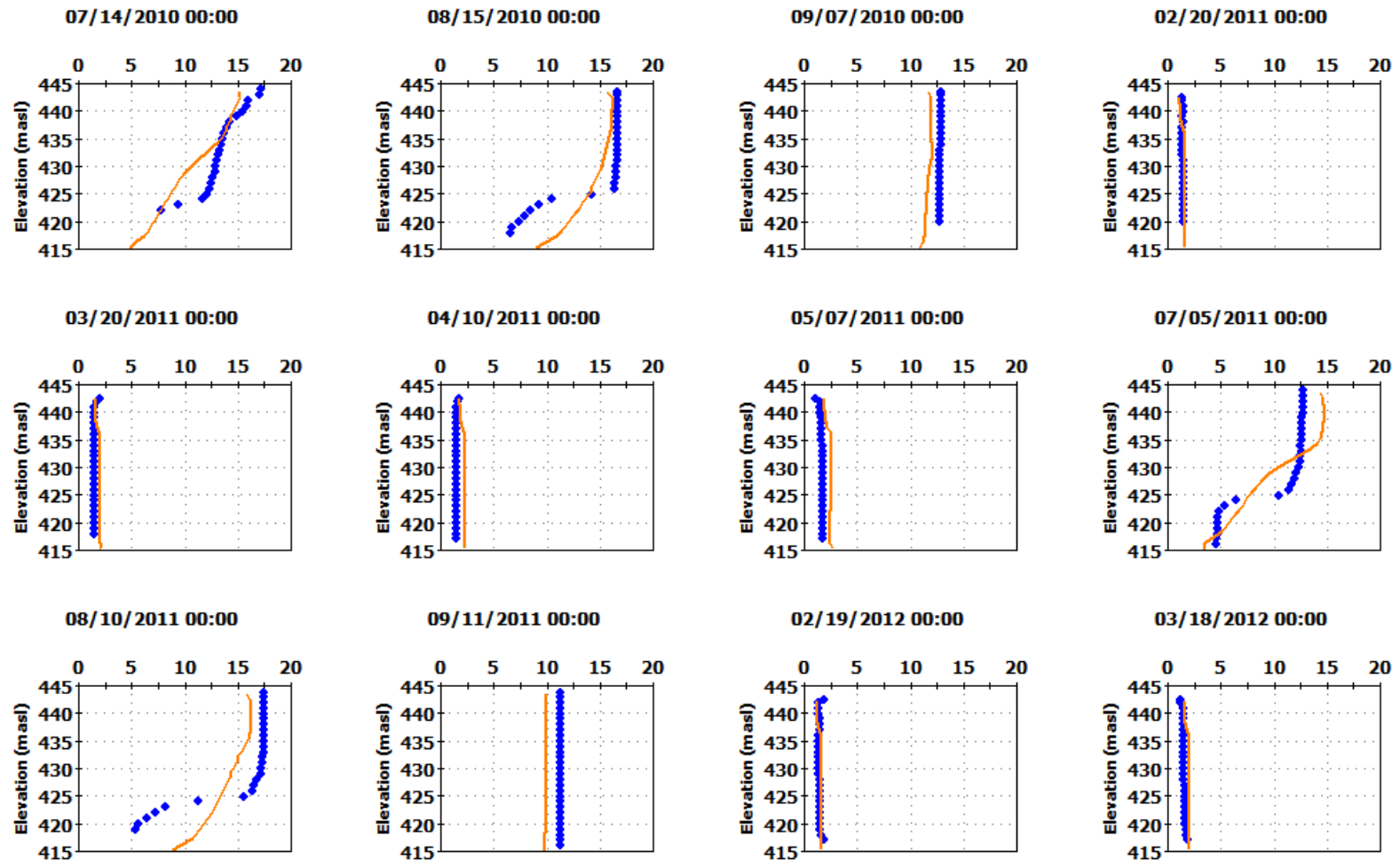
Note: Solid line represents model results; dots represent measured water temperatures. Water temperature is measured as °C.

°C = degrees Celsius; masl = metres above sea level; SNP = Surveillance Network Program.

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Figure II-2   Water Temperature (°C) Profile Calibration Plots at SNAP05
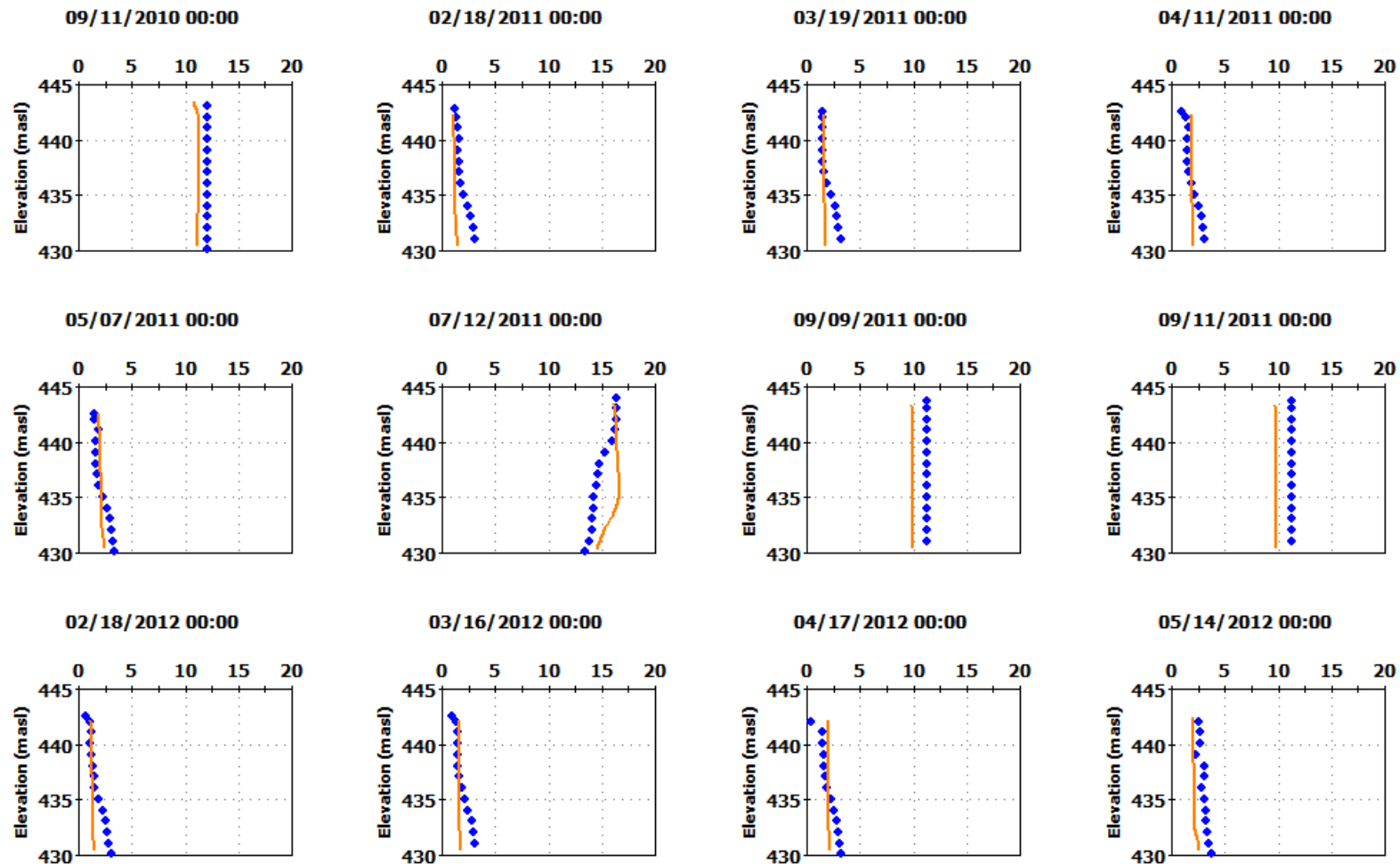
Note: Solid line represents model results; dots represent measured water temperatures. Water temperature is measured as °C.

°C = degrees Celsius; masl = metres above sea level.

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Figure II-3   Water Temperature (°C) Profile Calibration Plots at SNAP09
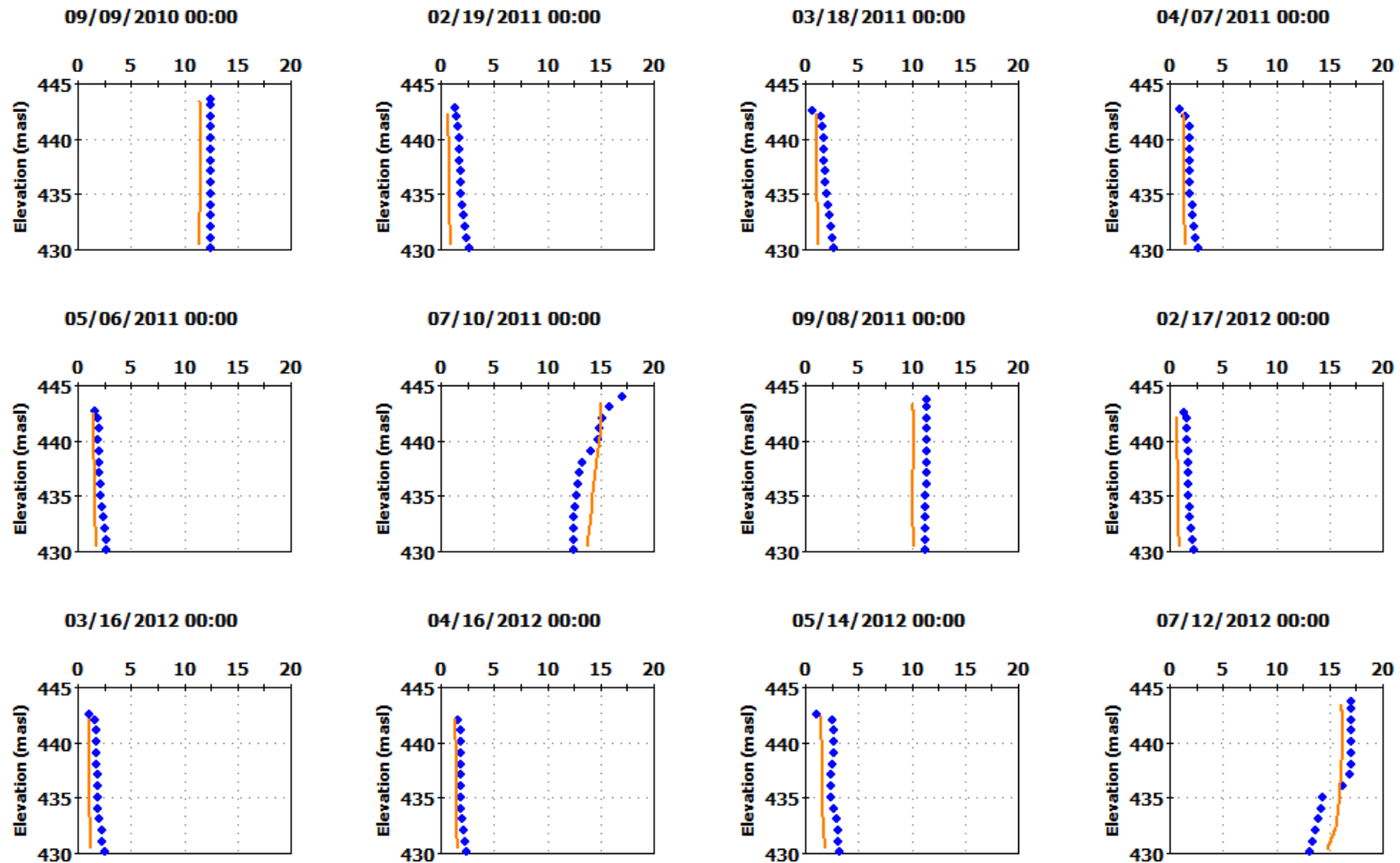
Note: Solid line represents model results; dots represent measured water temperatures. Water temperature is measured as °C.

°C = degrees Celsius; masl = metres above sea level.

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Figure II-4   Water Temperature (°C) Profile Calibration Plots at SNAP07
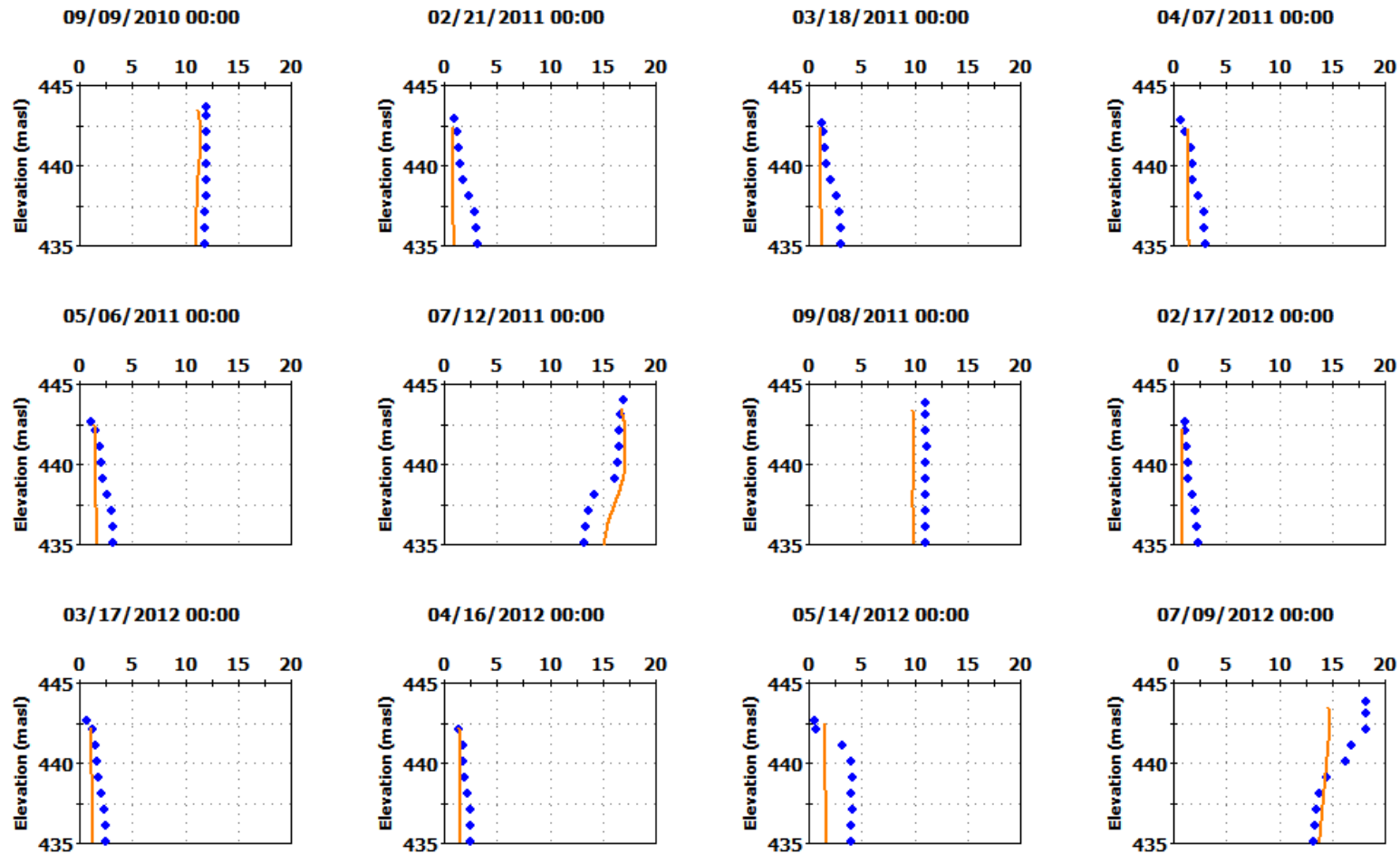
Note: Solid line represents model results; dots represent measured water temperatures. Water temperature is measured as °C.

°C = degrees Celsius; masl = metres above sea level.

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Figure II-5   Total Dissolved Solids (mg/L) Profile Calibration Plots at SNP 02-20
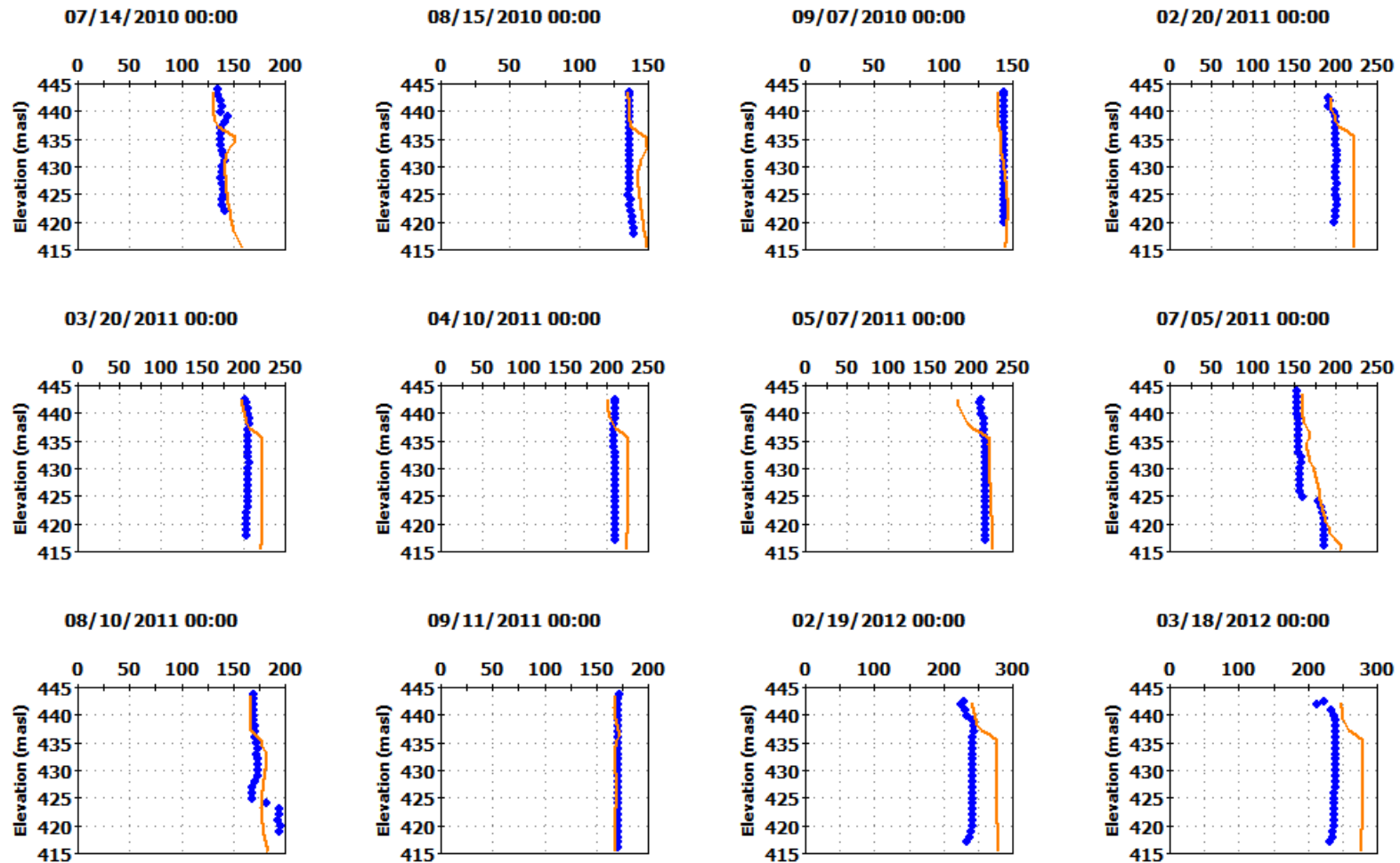
Note: Solid line represents model results; dots represent calculated total dissolved solids concentrations. Total dissolved solids measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level; SNP = Surveillance Network Program.

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Figure II-6   Total Dissolved Solids (mg/L) Profile Calibration Plots at SNAP05
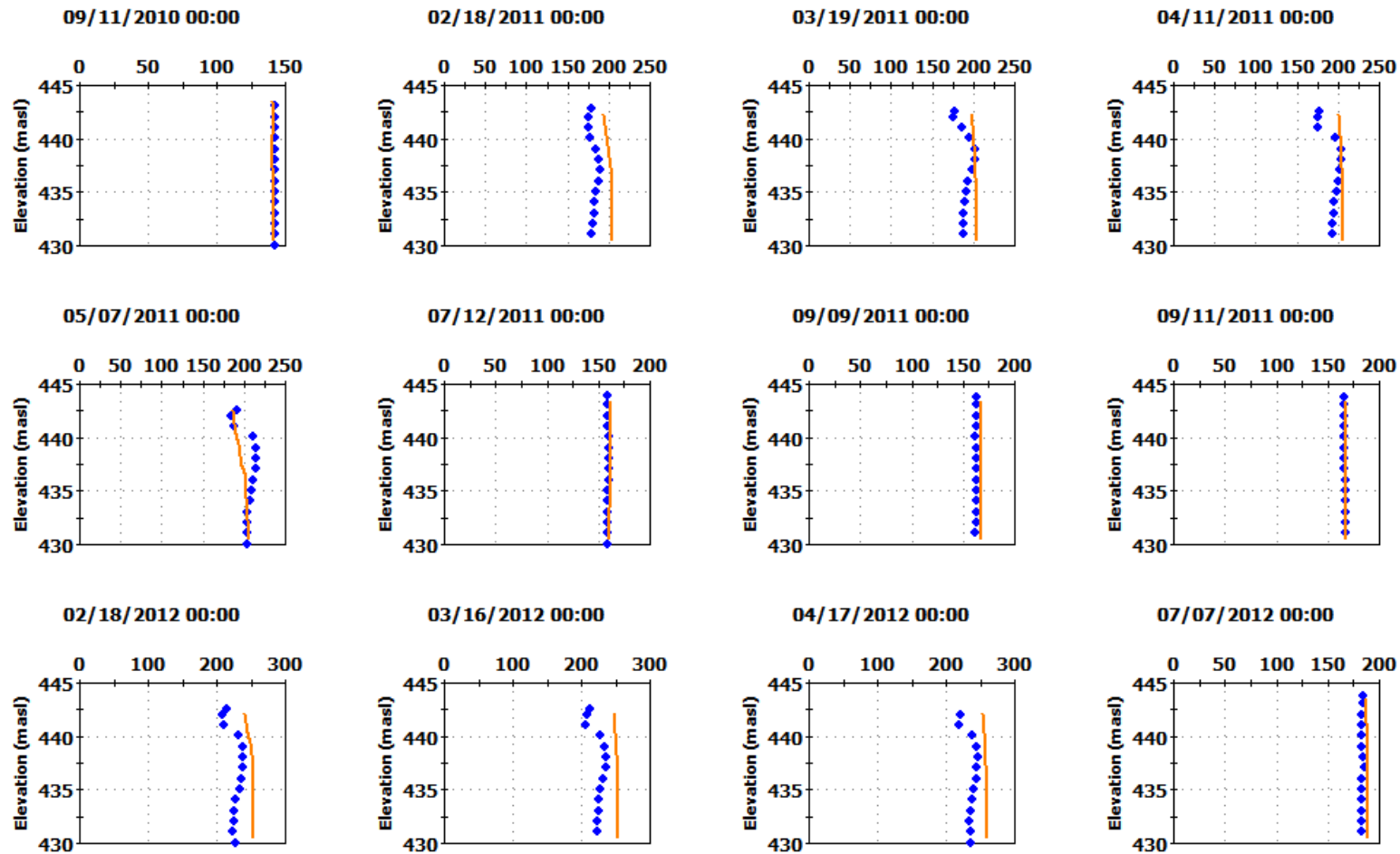
Note: Solid line represents model results; dots represent calculated total dissolved solids concentrations. Total dissolved solids measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level.

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Figure II-7   Total Dissolved Solids (mg/L) Profile Calibration Plots at SNAP09
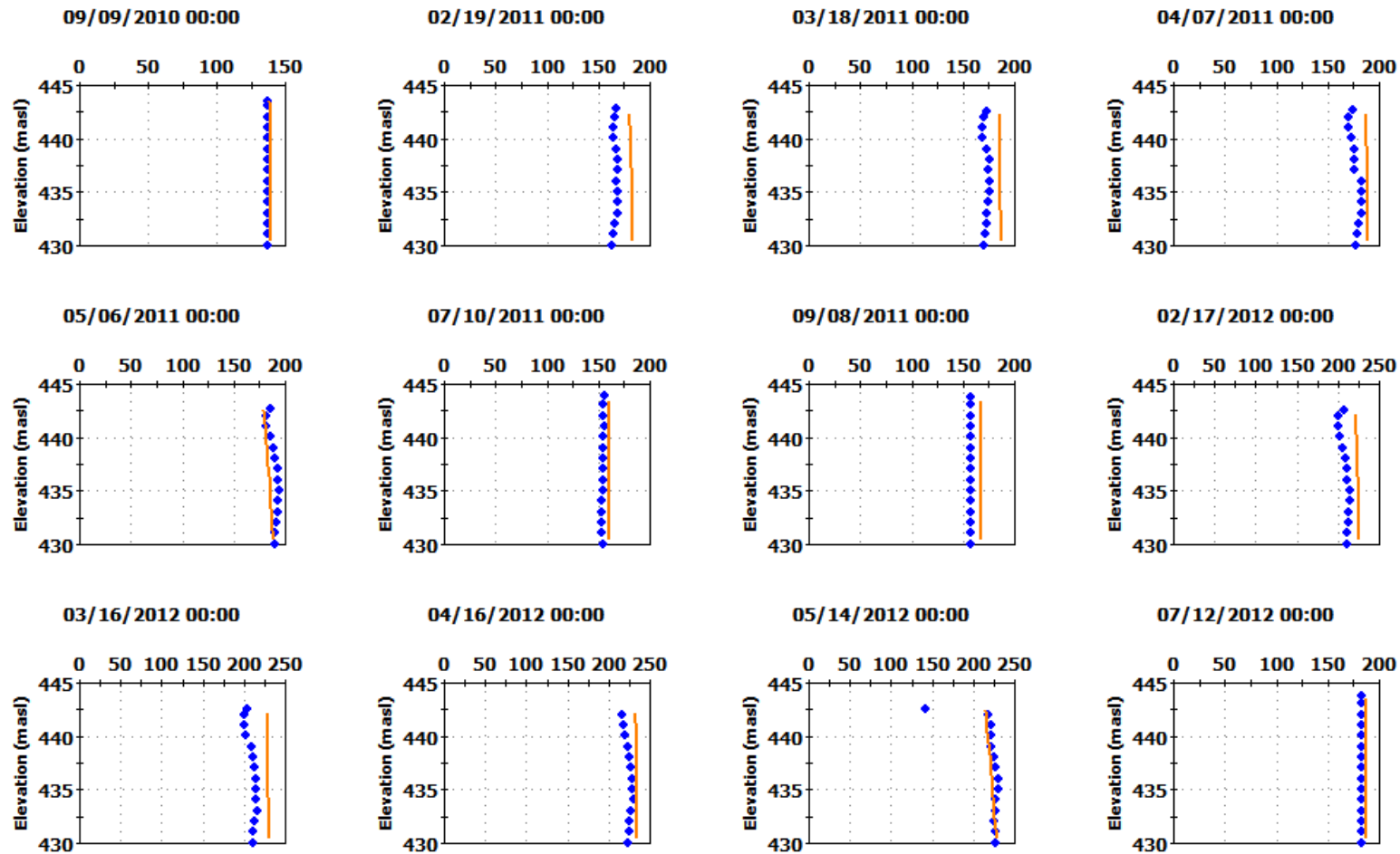
Note: Solid line represents model results; dots represent calculated total dissolved solids concentrations. Total dissolved solids measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level.

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Figure II-8   Total Dissolved Solids (mg/L) Profile Calibration Plots at SNAP07
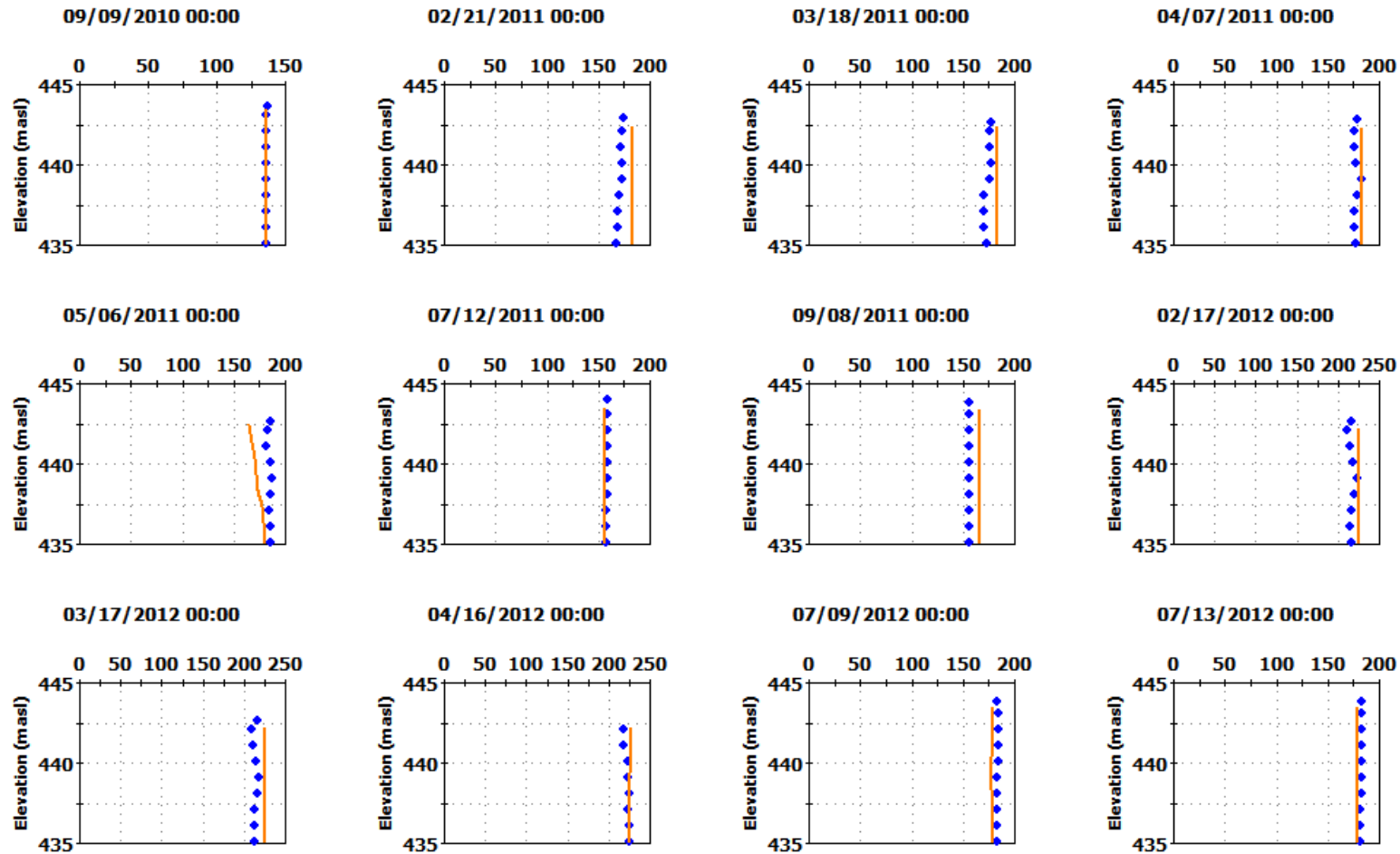
Note: Solid line represents model results; dots represent calculated total dissolved solids concentrations. Total dissolved solids measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level.

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Figure II-9   Dissolved Oxygen (mg/L) Profile Calibration Plots at SNP 02-20
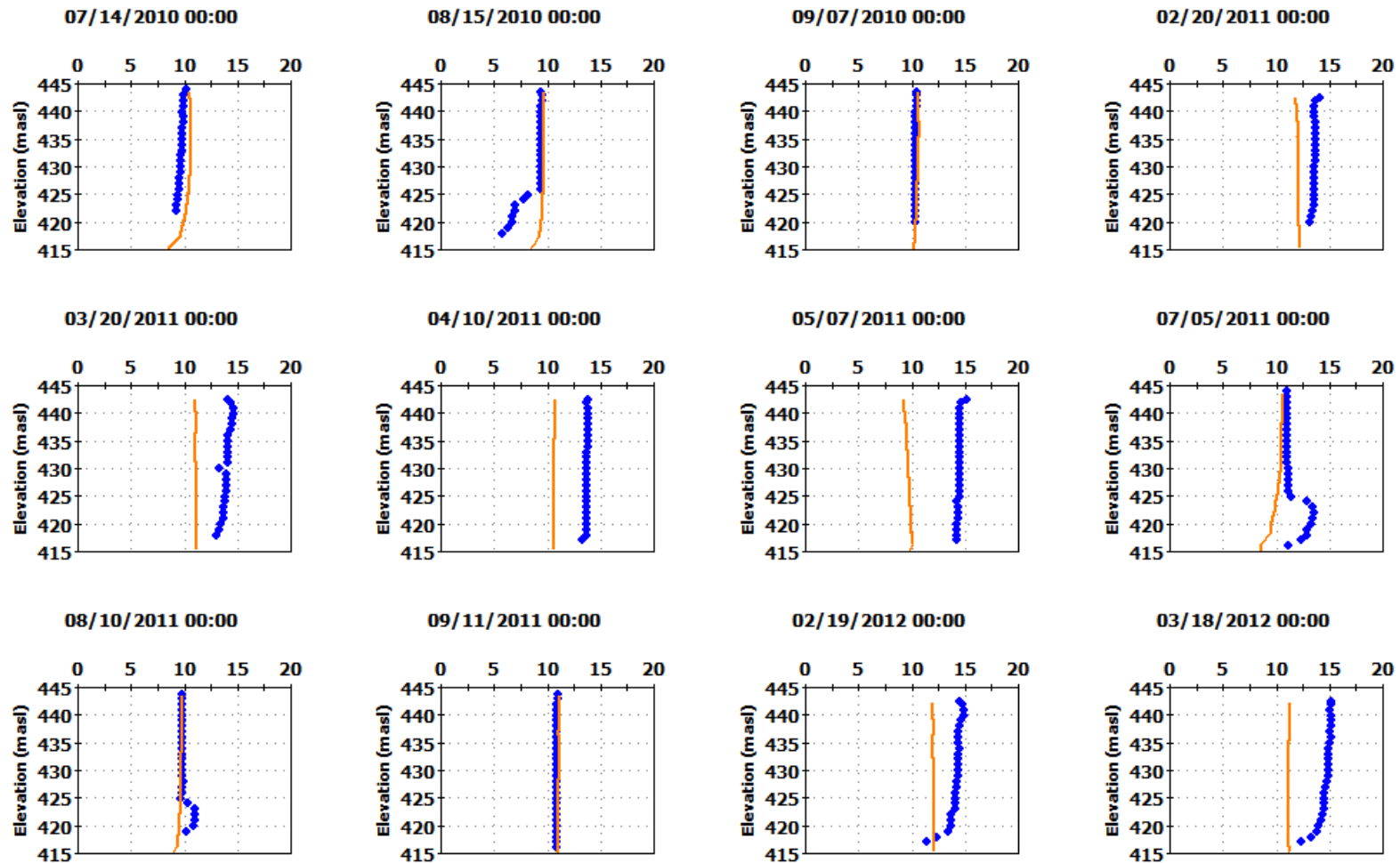
Note: Solid line represents model results; dots represent measured dissolved oxygen concentrations. Dissolved oxygen is measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level; SNP = Surveillance Network Program.

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Figure II-10   Dissolved Oxygen (mg/L) Profile Calibration Plots at SNAP05
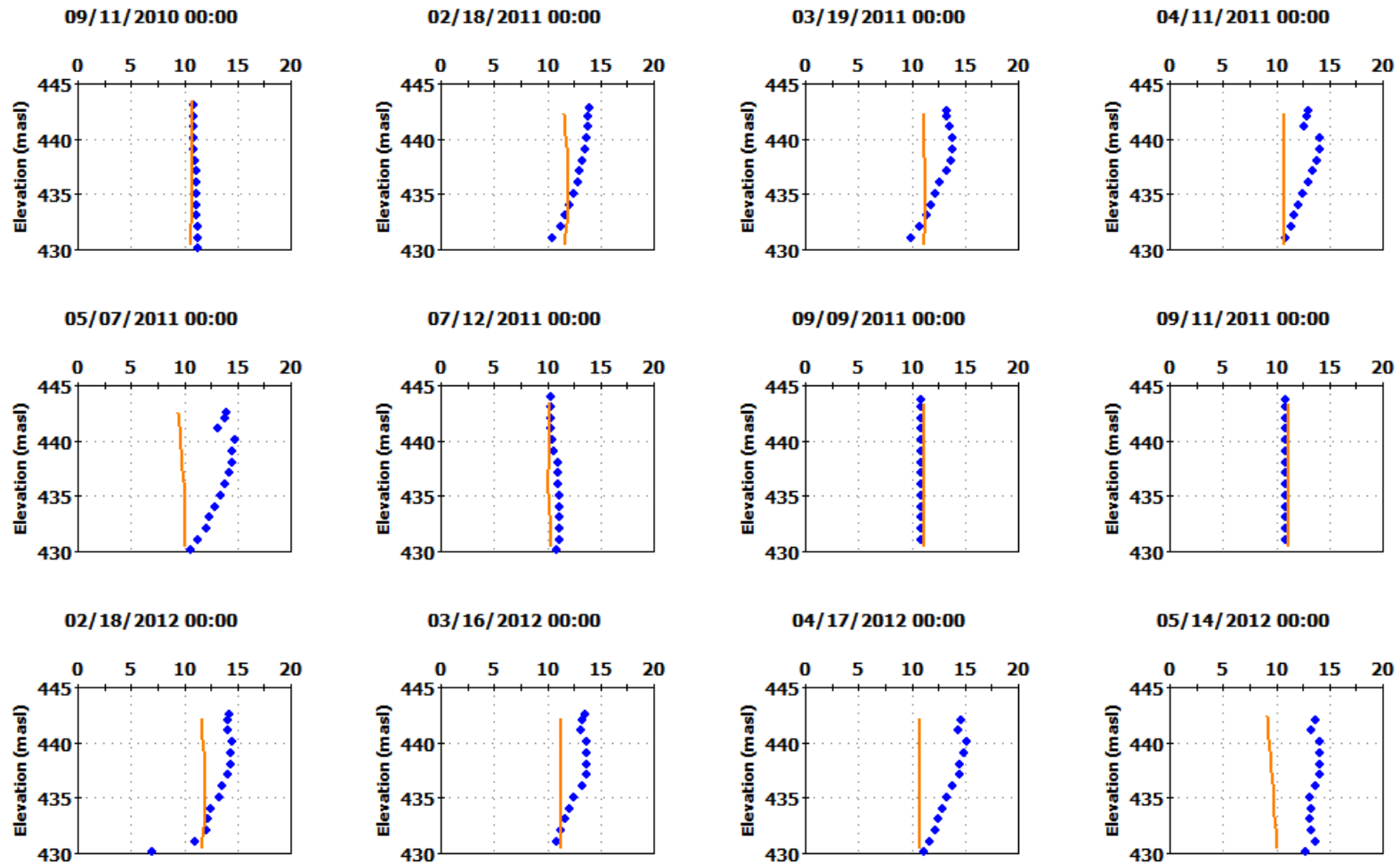
Note: Solid line represents model results; dots represent measured dissolved oxygen concentrations. Dissolved oxygen is measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level.

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Figure II-11   Dissolved Oxygen (mg/L) Profile Calibration Plots at SNAP09
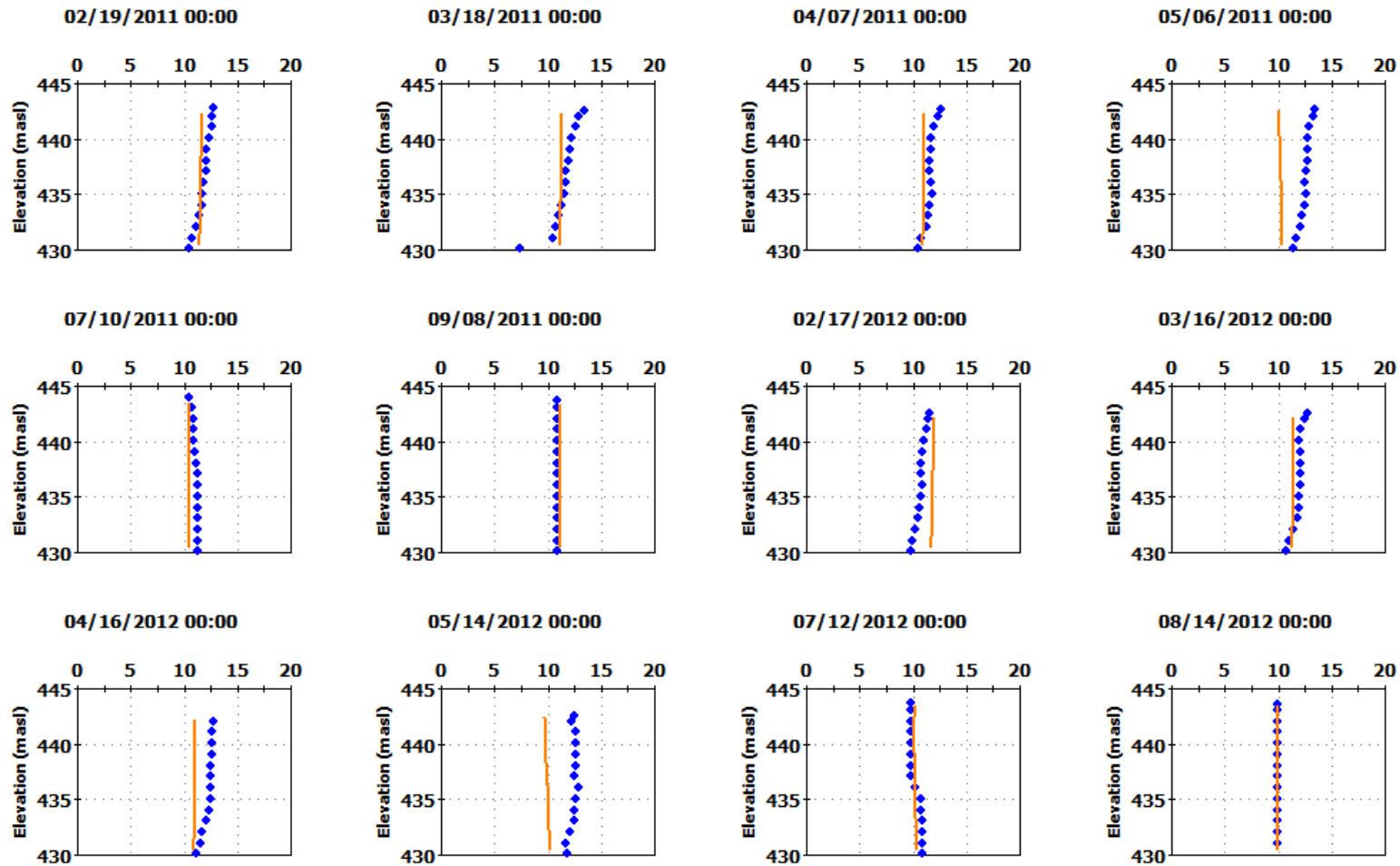
Note: Solid line represents model results; dots represent measured dissolved oxygen concentrations. Dissolved oxygen is measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level.

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Figure II-12   Dissolved Oxygen (mg/L) Profile Calibration Plots at SNAP07
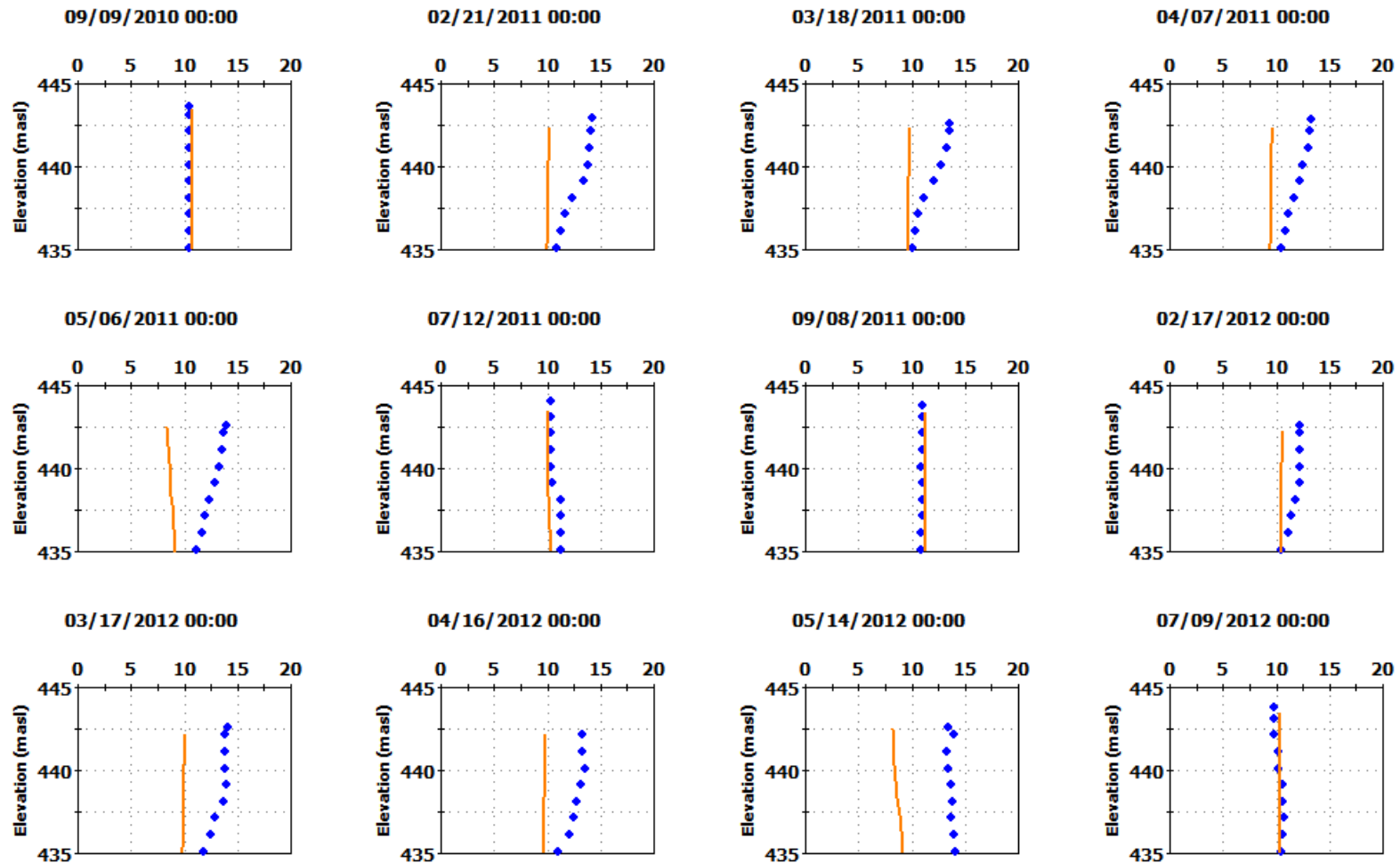
Note: Solid line represents model results; dots represent measured dissolved oxygen concentrations. Dissolved oxygen is measured as mg/L.

mg/L = milligrams per litre; masl = metres above sea level.

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APPENDIX III

MAJOR IONS TIME SERIES CALIBRATION RESULTS

December 2013

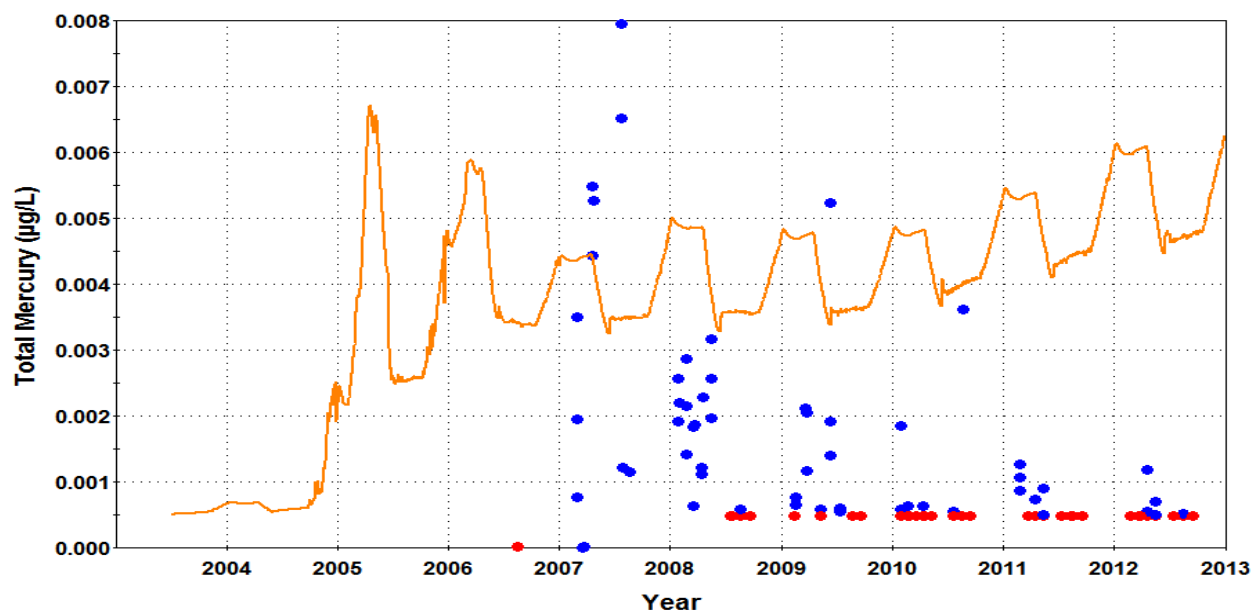**Figure III-1   Calcium Time Series Calibration Plots**
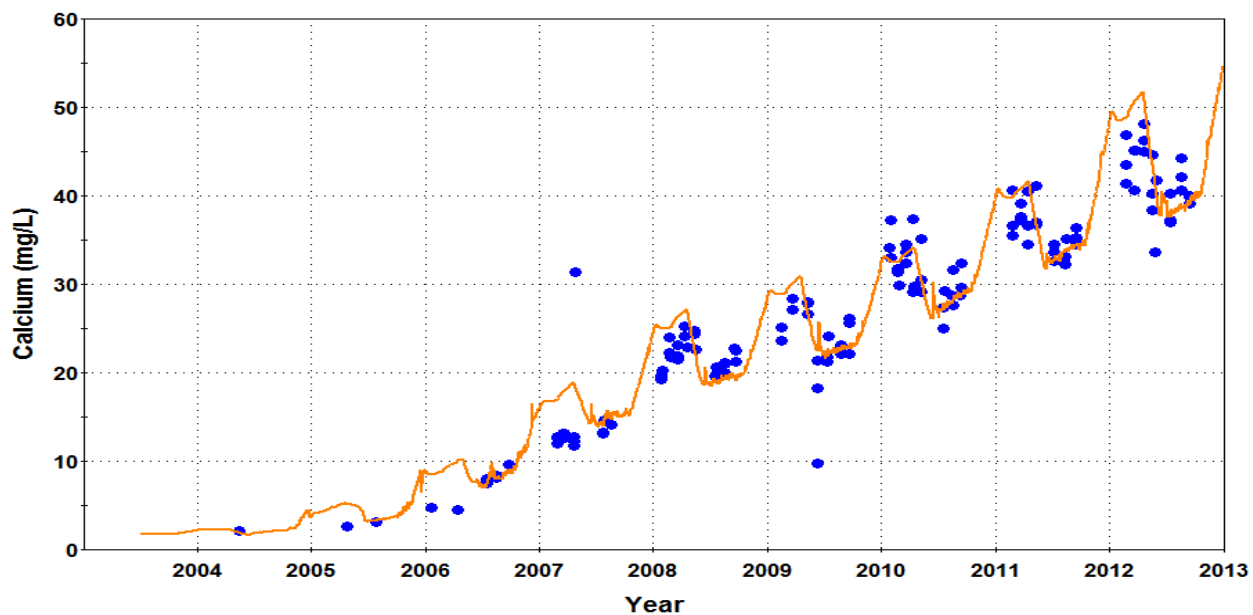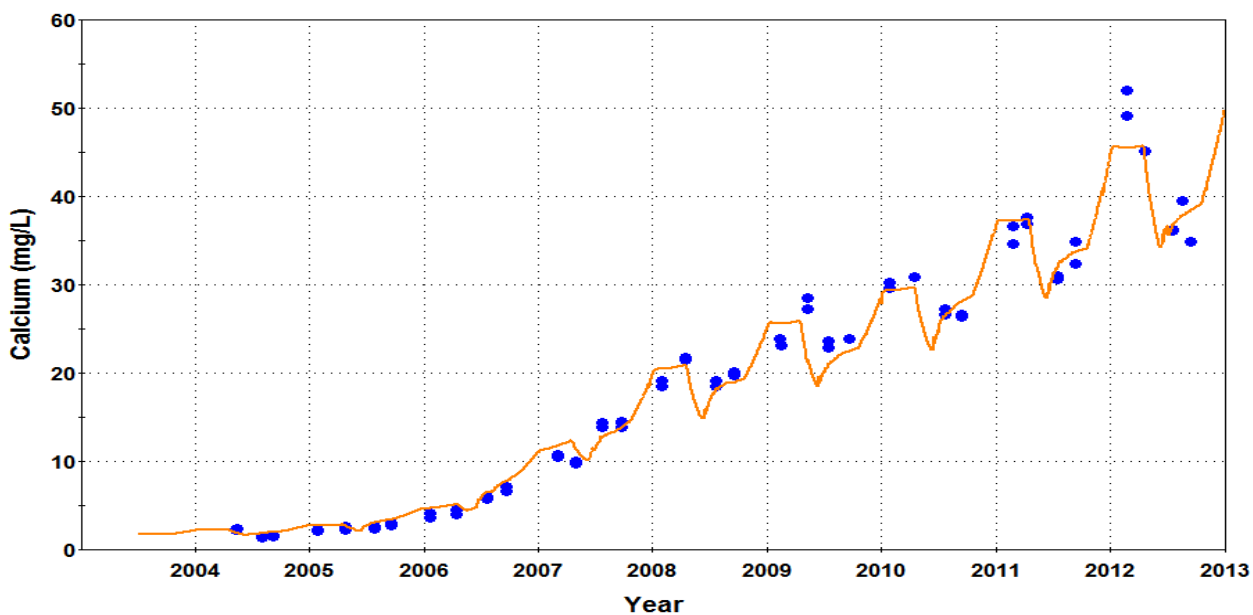
(a) Near diffuser, SNP 02-20 and SNAP13

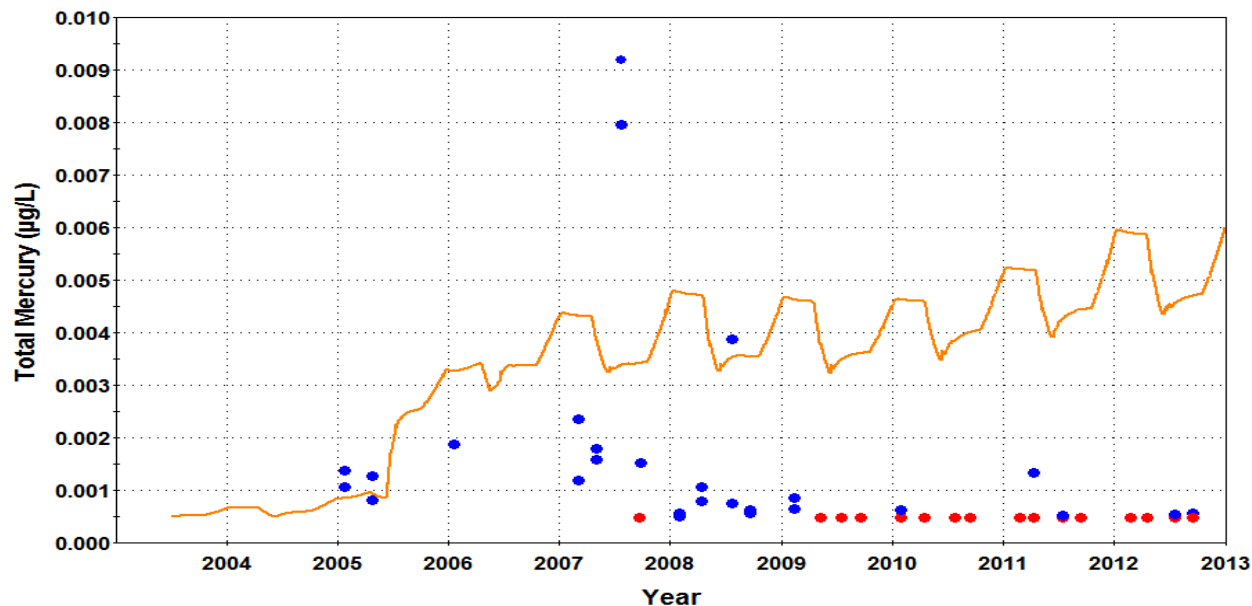

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured calcium concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

Figure III-2   Chloride Time Series Calibration Plots
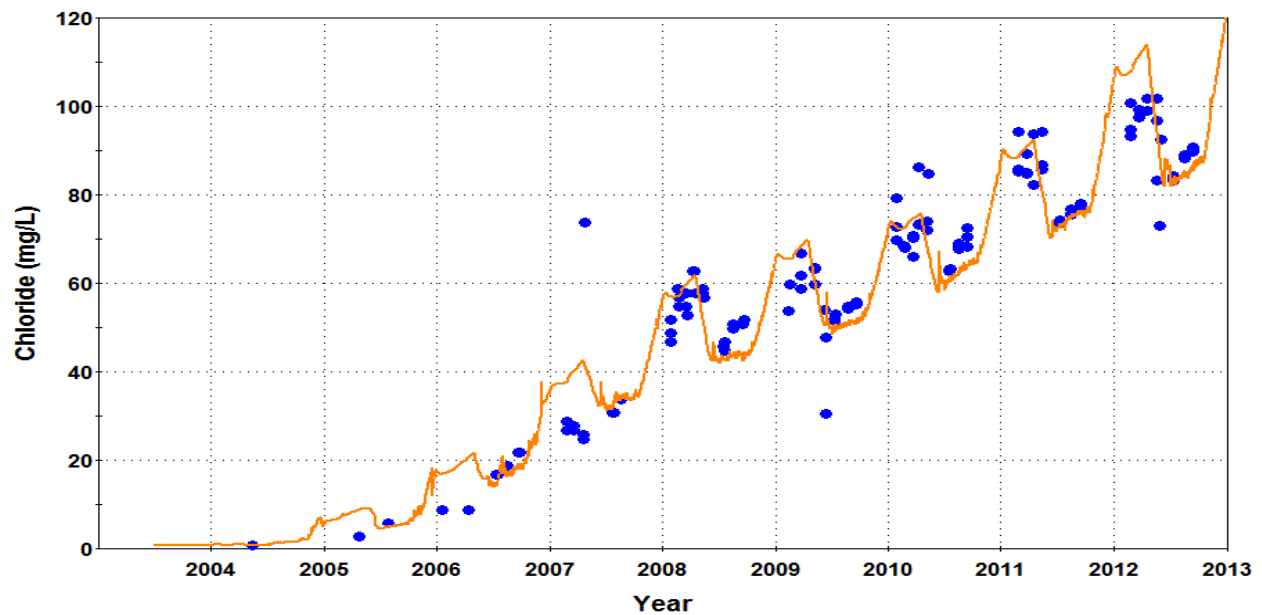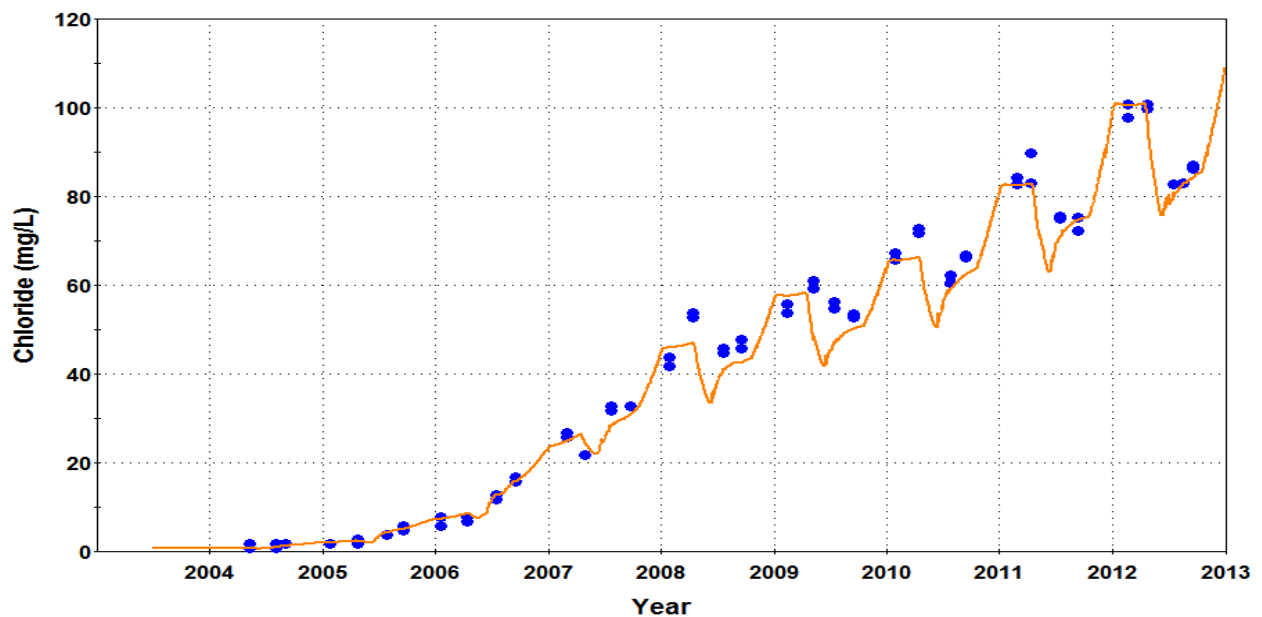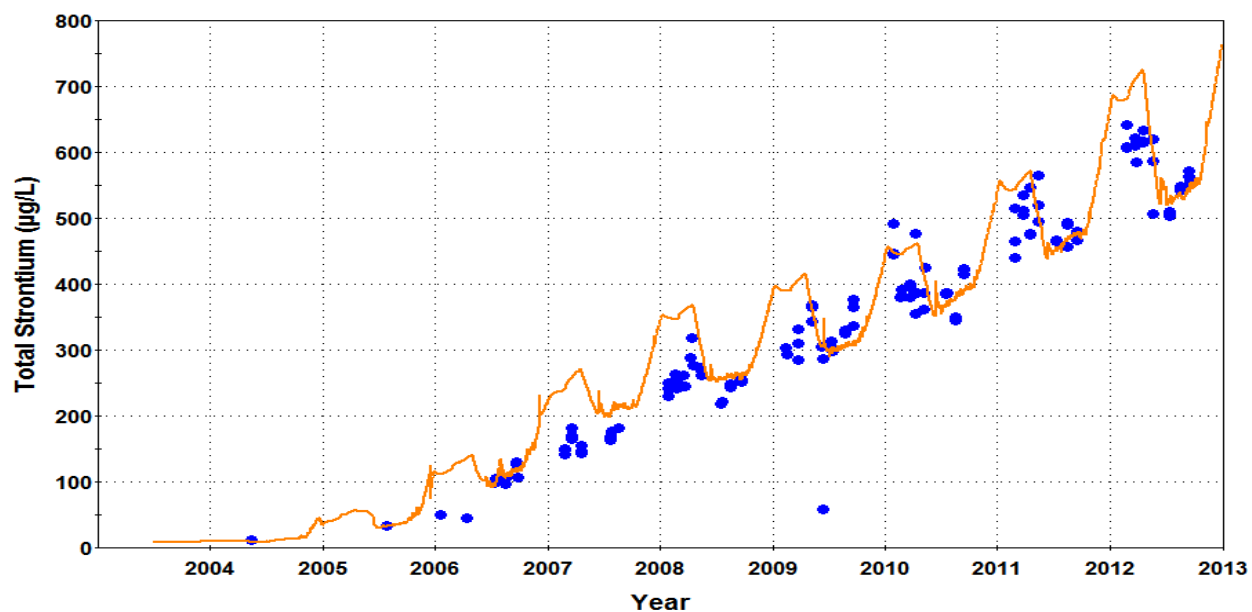

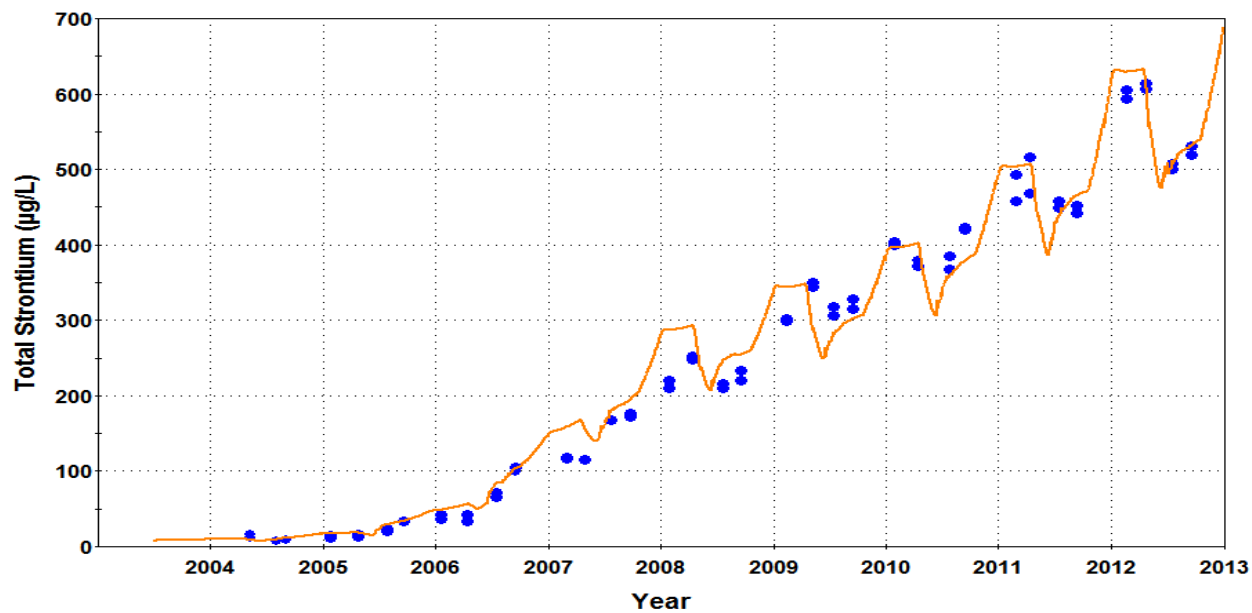(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured chloride concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

Figure III-3   Fluoride Time Series Calibration Plots
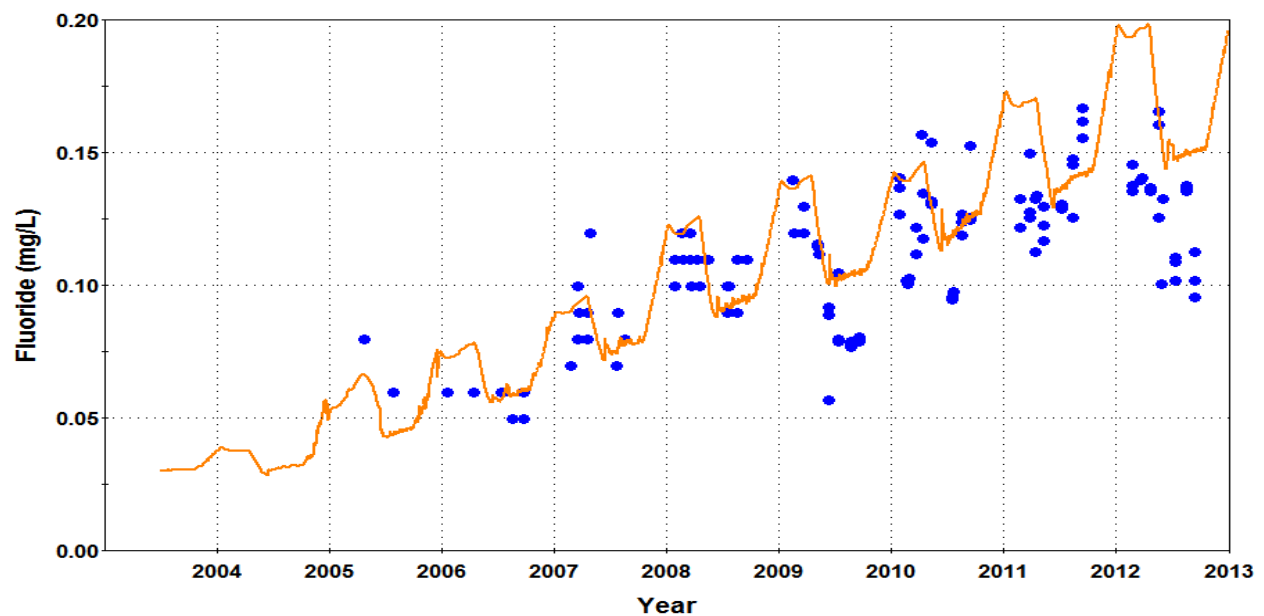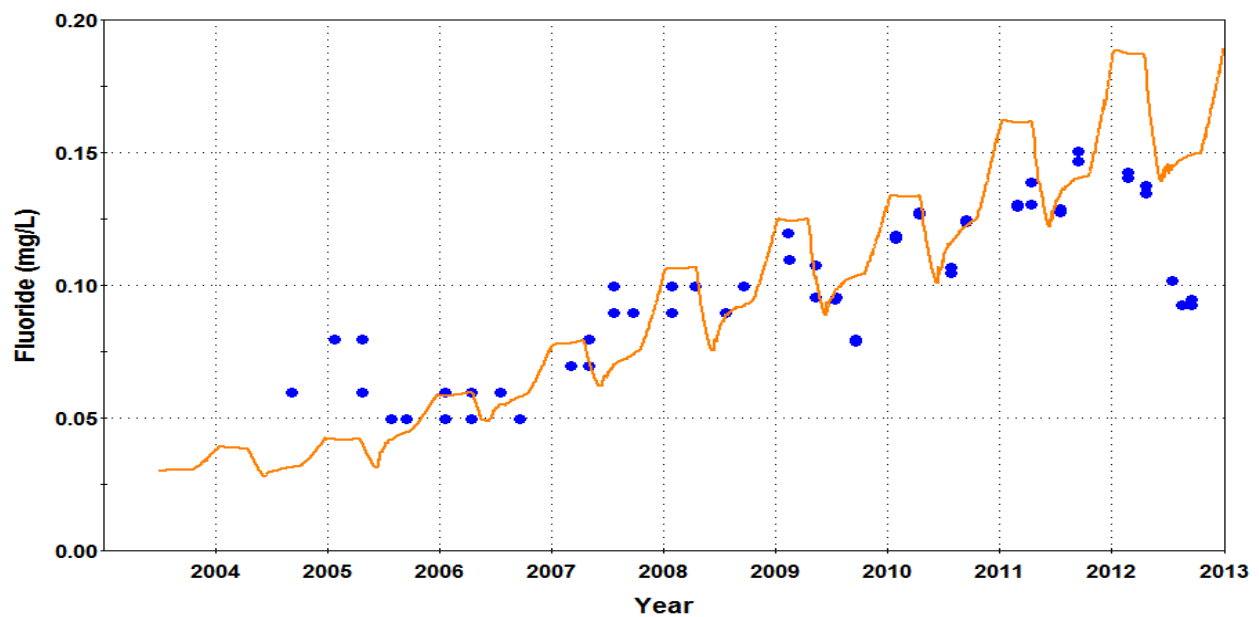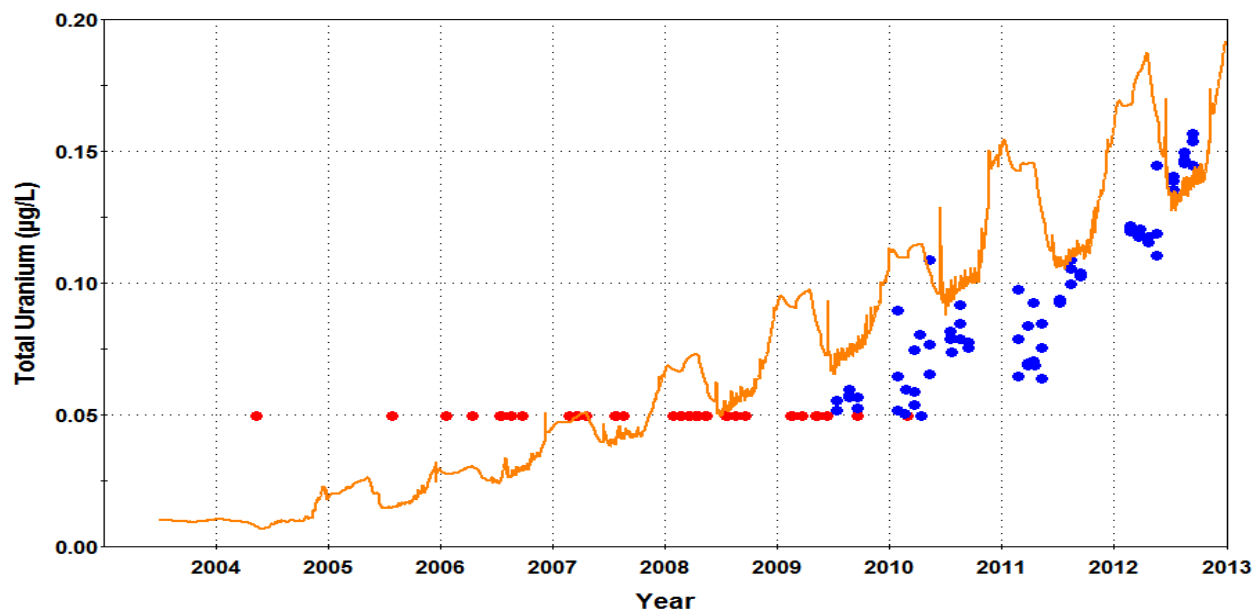

(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured fluoride concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

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Figure III-4   Magnesium Time Series Calibration Plots
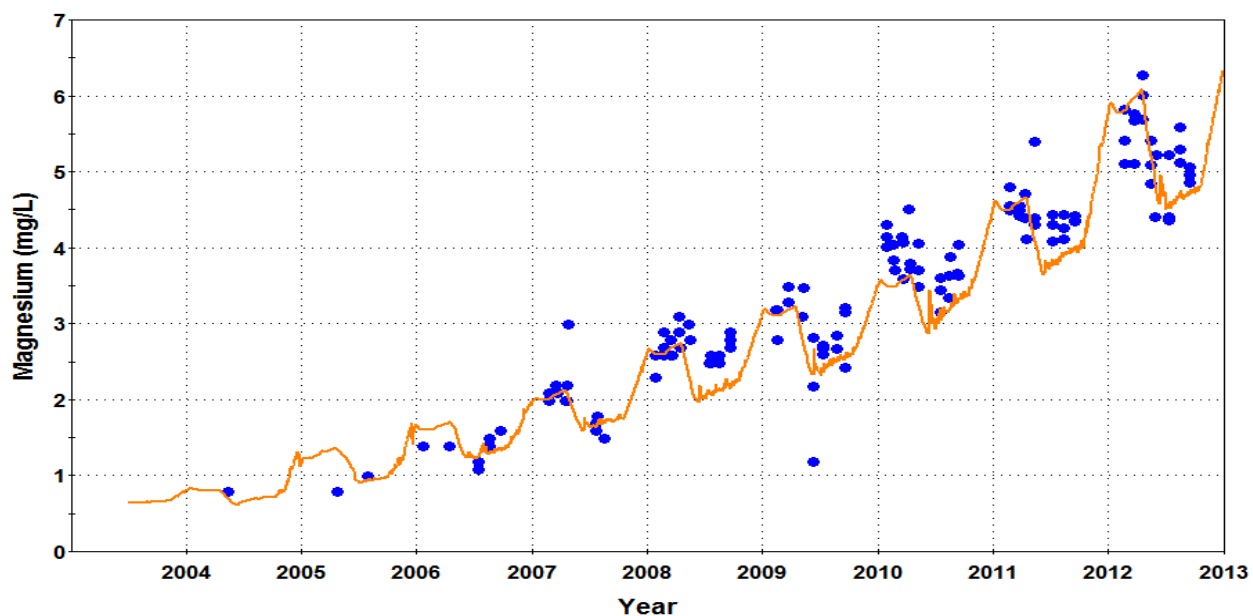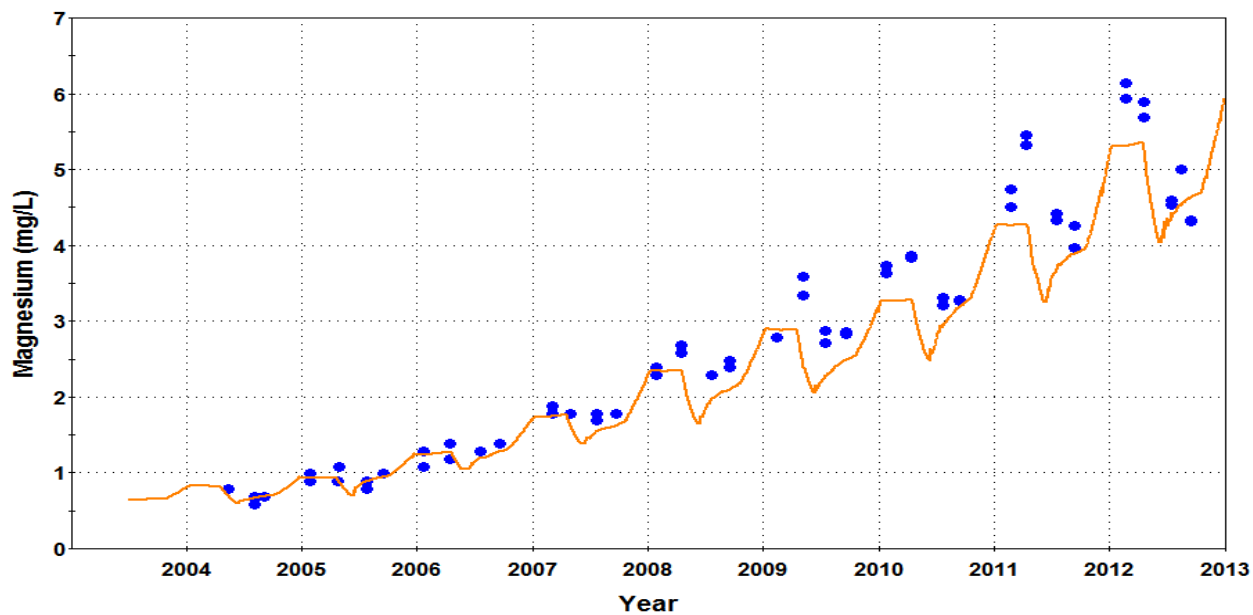
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

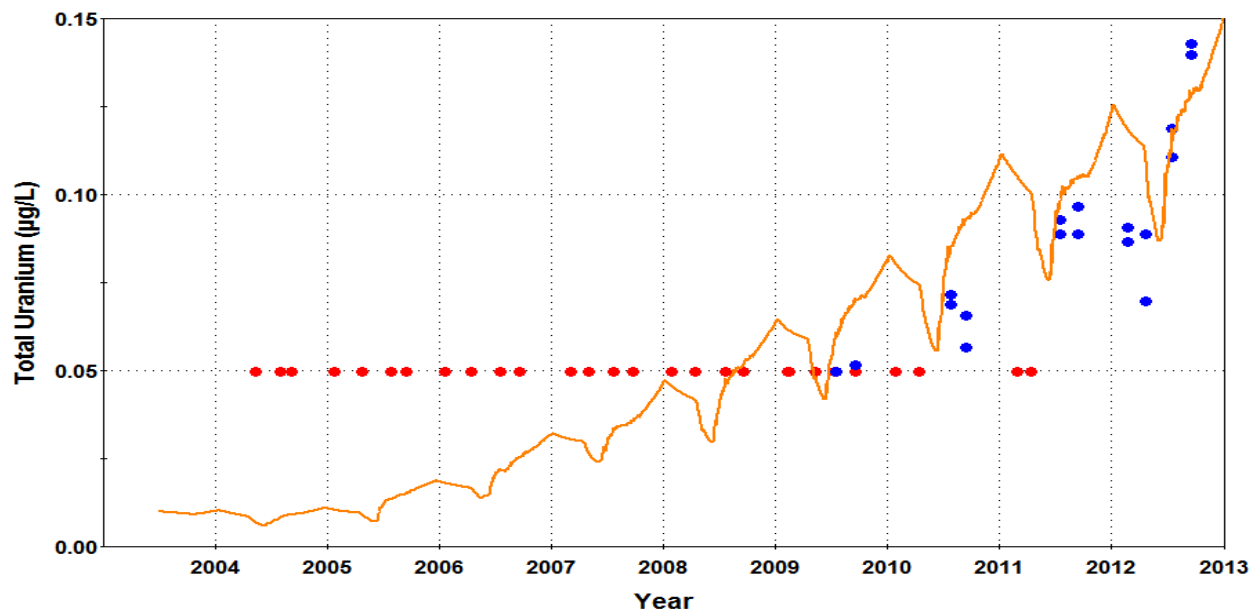Note: Solid line represents model results; dots represent measured magnesium concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

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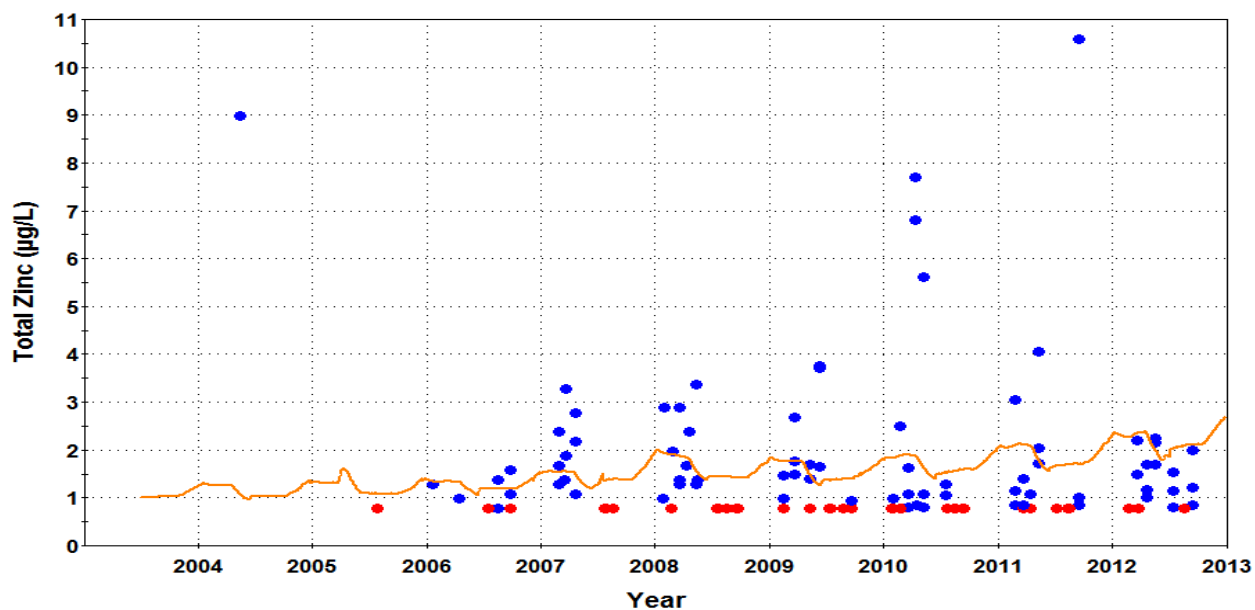**Figure III-5   Sodium Time Series Calibration Plots**
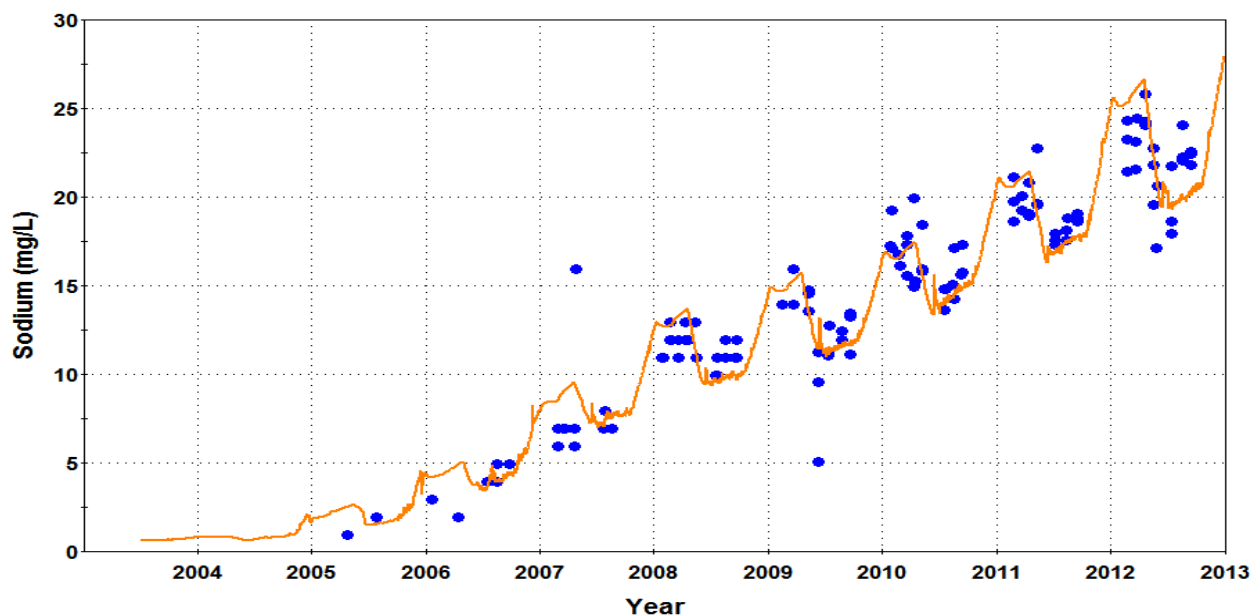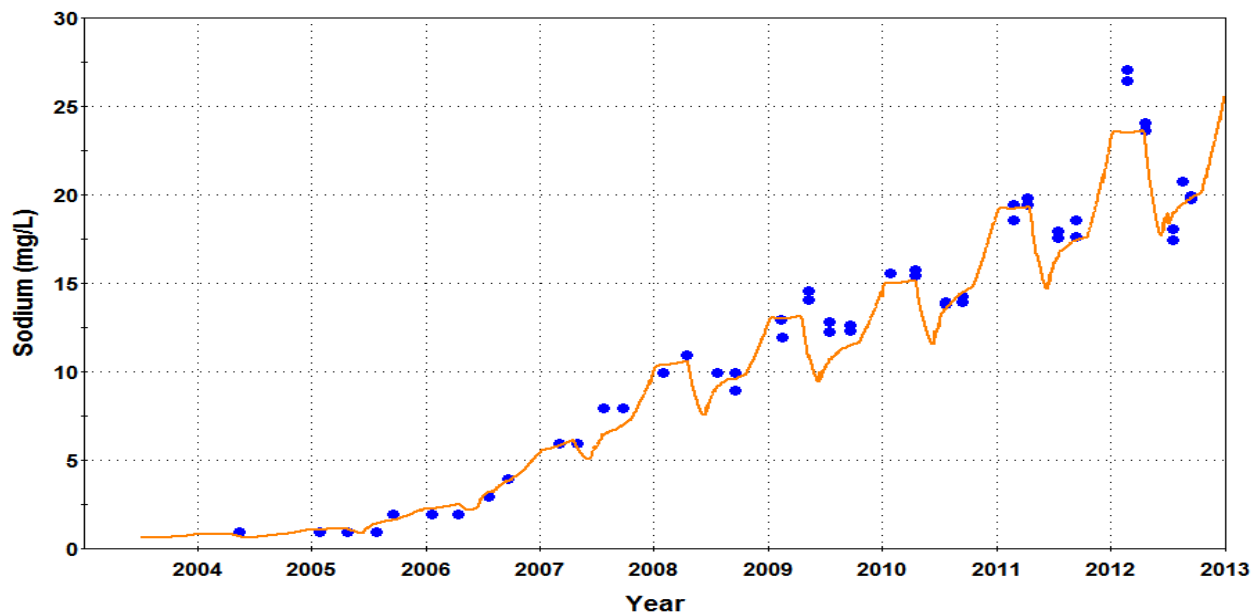
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured sodium concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

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Figure III-6   Sulphate Time Series Calibration Plots
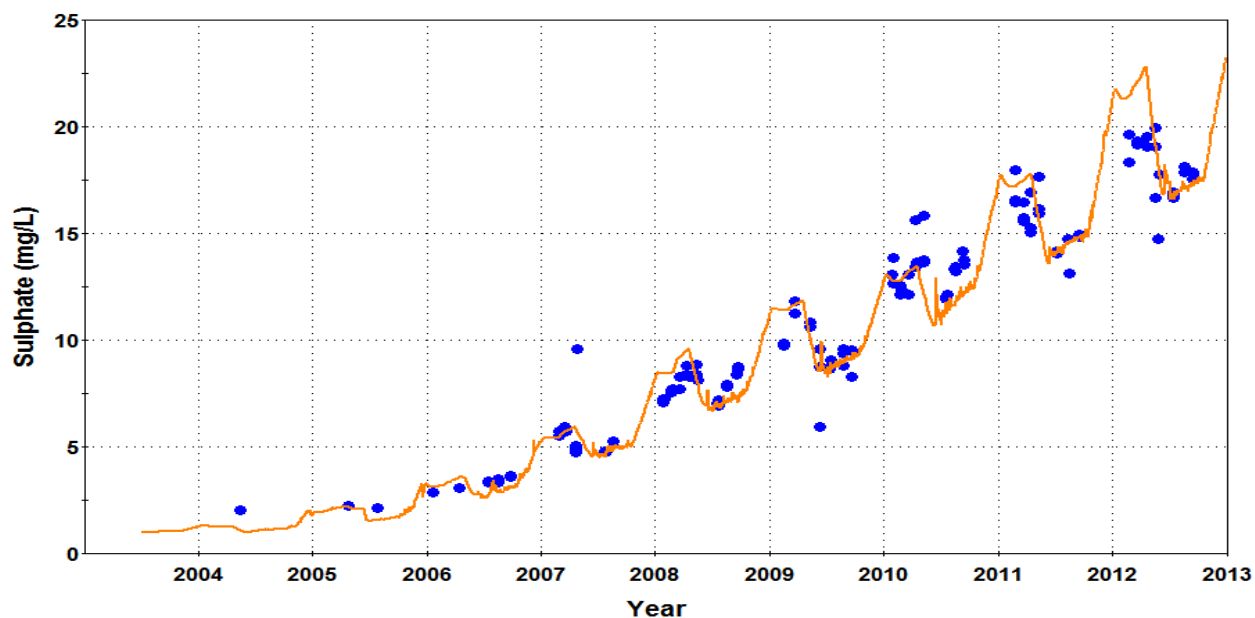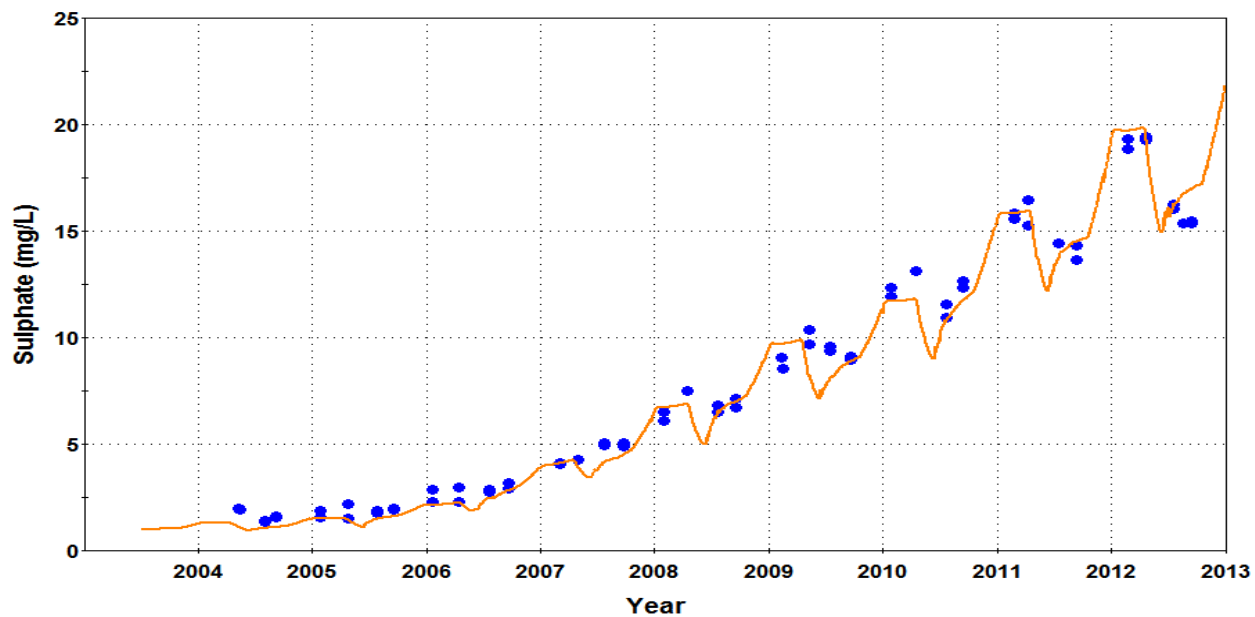
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

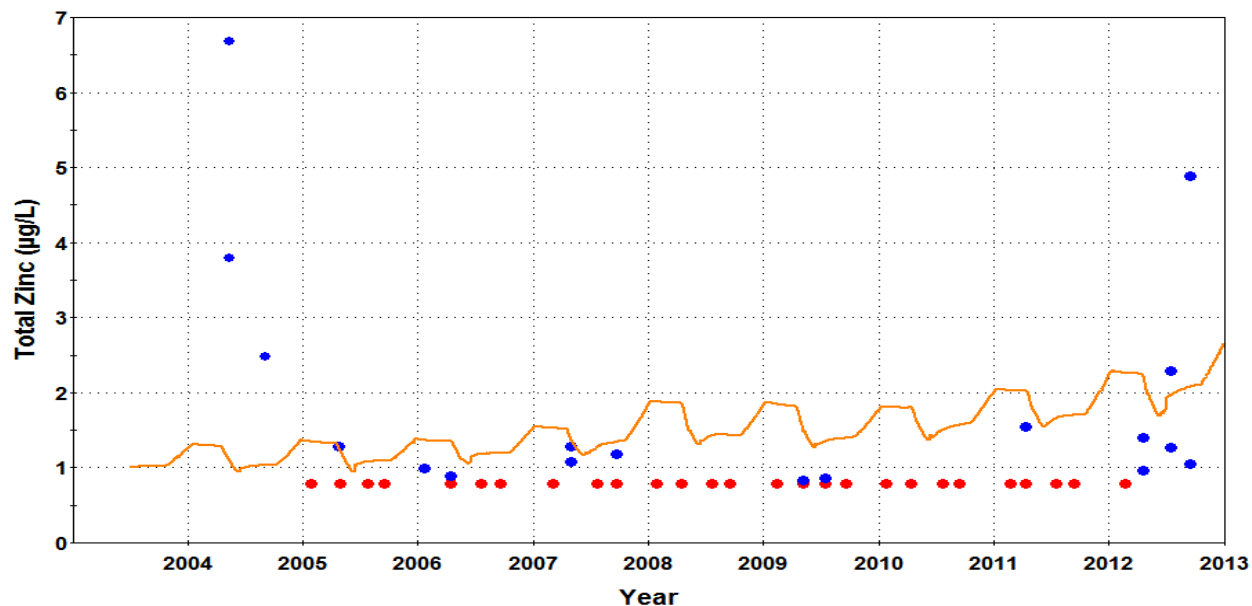Note: Solid line represents model results; dots represent measured sulphate concentrations.

mg/L = milligrams per litre; SNP = Surveillance Network Program.

APPENDIX IV

TOTAL METALS AND METALLOIDS
TIME SERIES CALIBRATION RESULTS

December 2013

Figure IV-1   Total Aluminum Time Series Calibration Plots
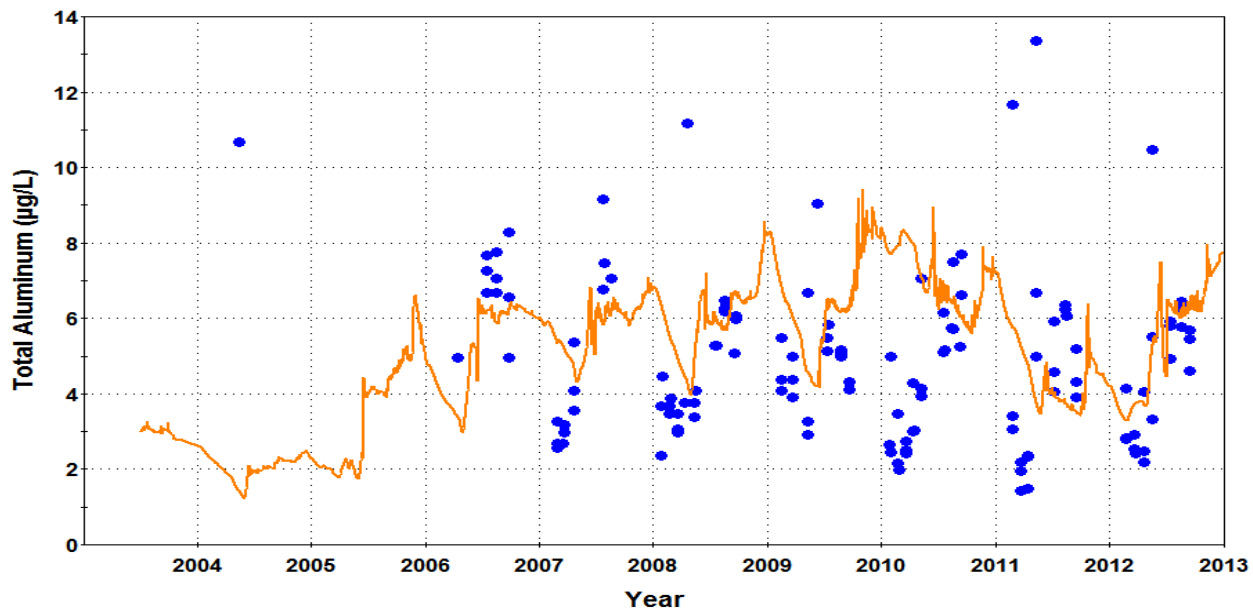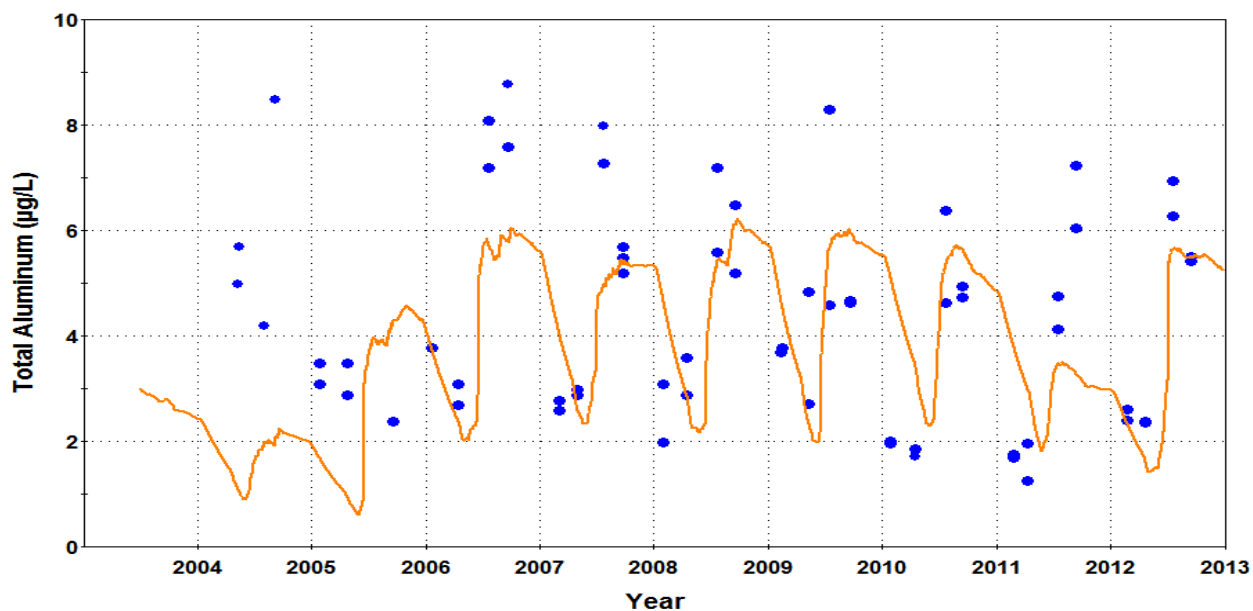
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured total aluminum concentrations.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

De Beers Canada Inc.

Figure IV-2   Total Antimony Time Series Calibration Plots
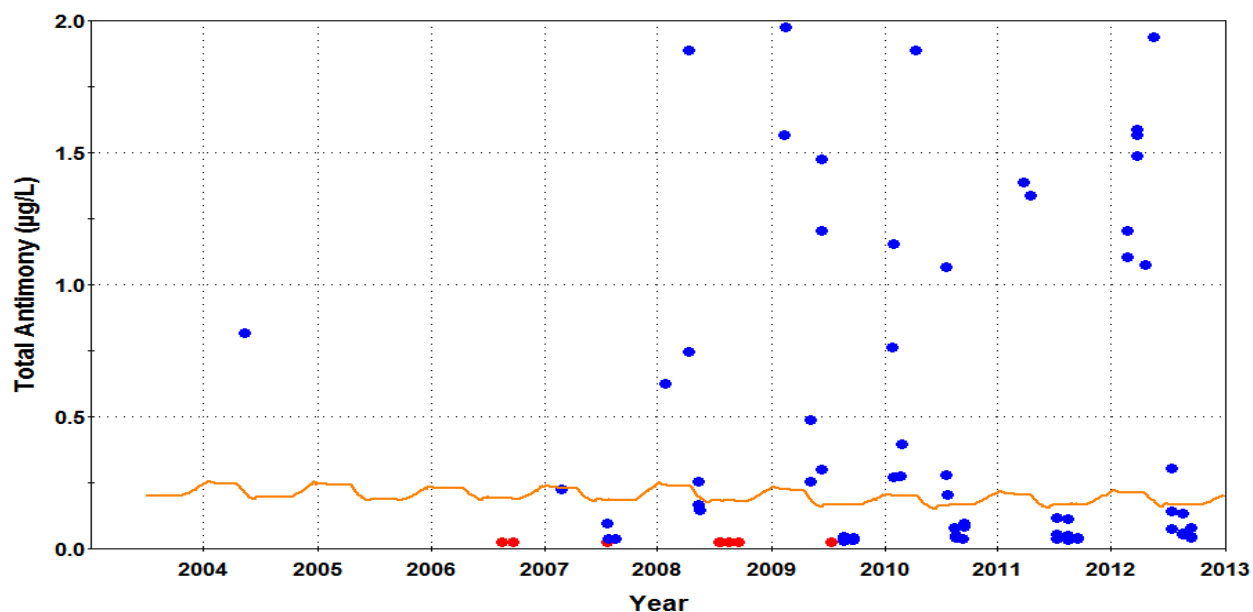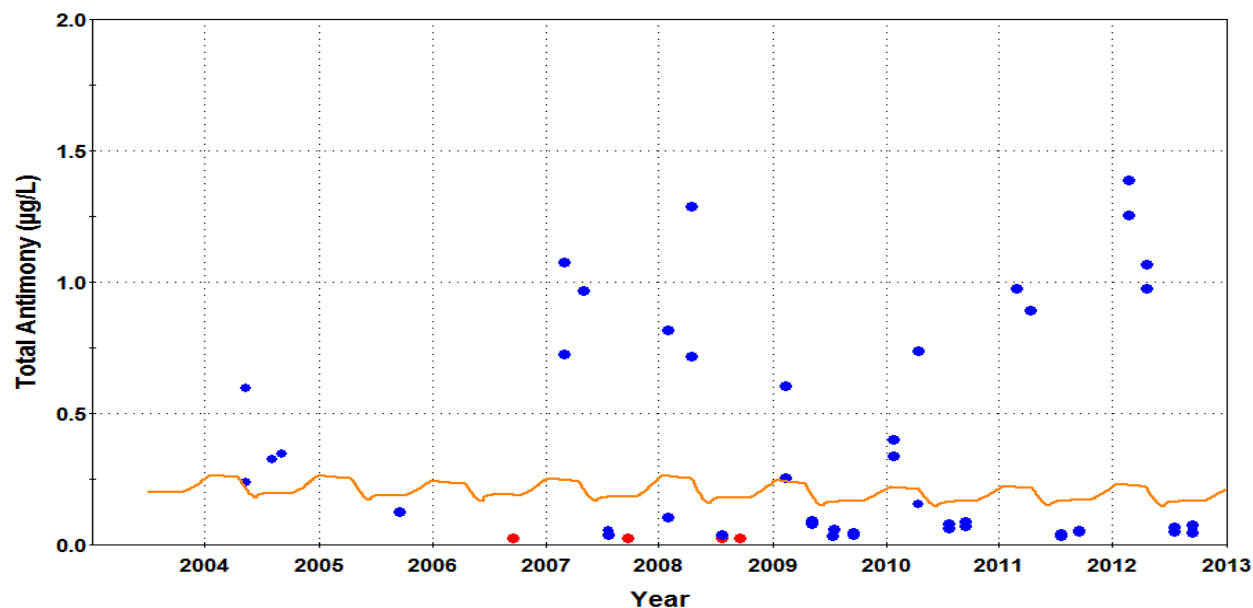
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured total antimony concentrations reported above the detection limit; red dots represent measured total antimony concentrations reported below the detection limit.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

De Beers Canada Inc.

Figure IV-3   Total Arsenic Time Series Calibration Plots
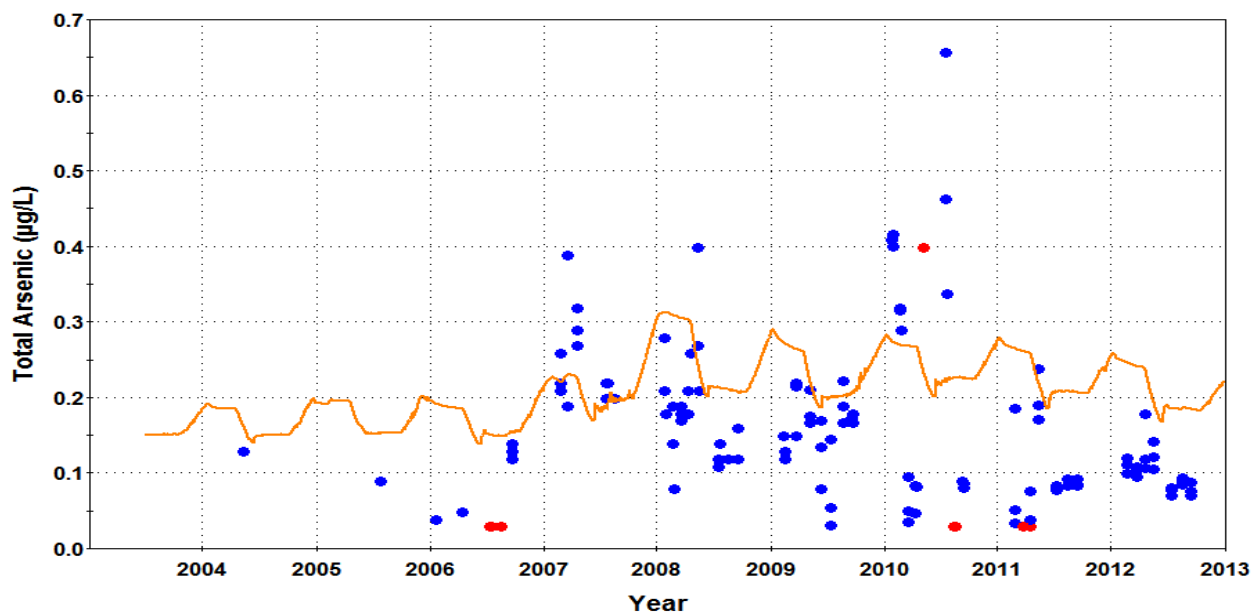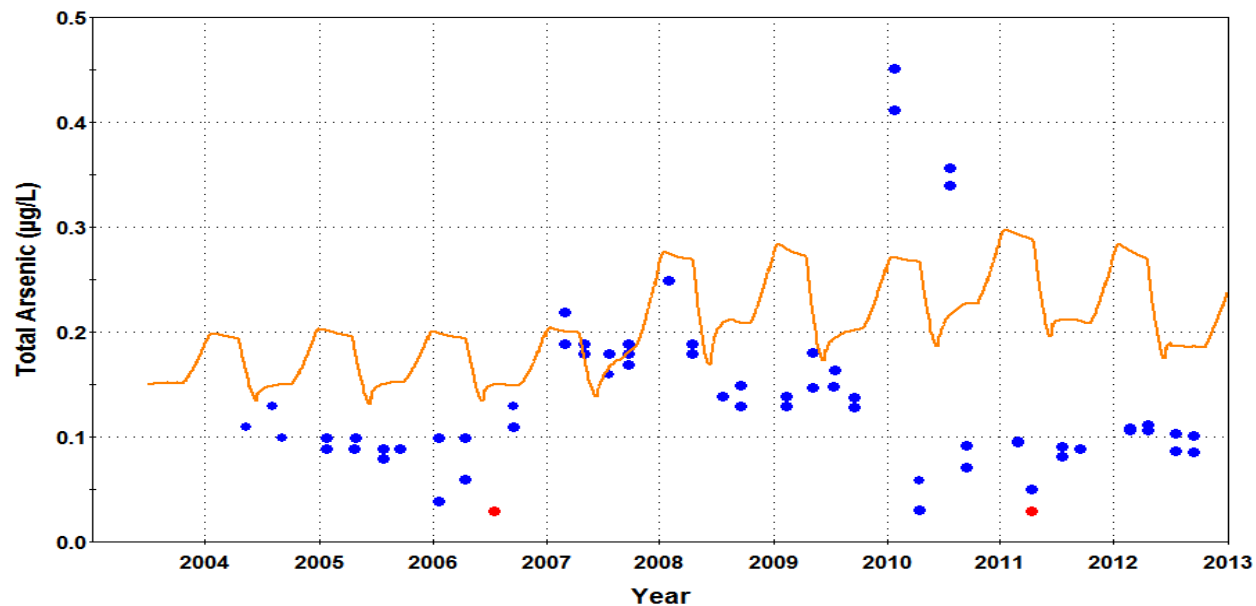
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured total arsenic concentrations reported above the detection limit; red dots represent measured total arsenic concentrations reported below the detection limit.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

Figure IV-4   Total Barium Time Series Calibration Plots
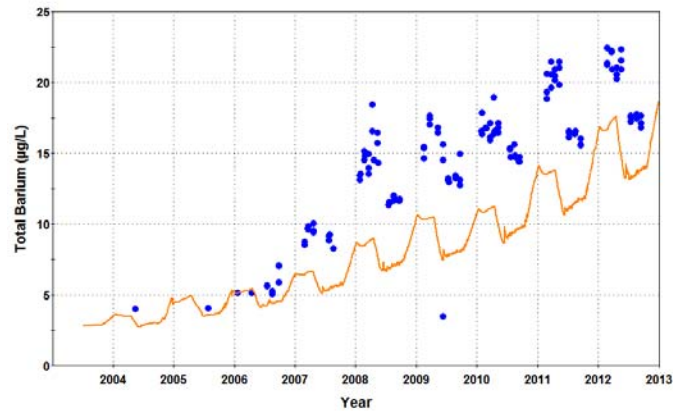
(a) Near diffuser, SNP 02-20 and SNAP13
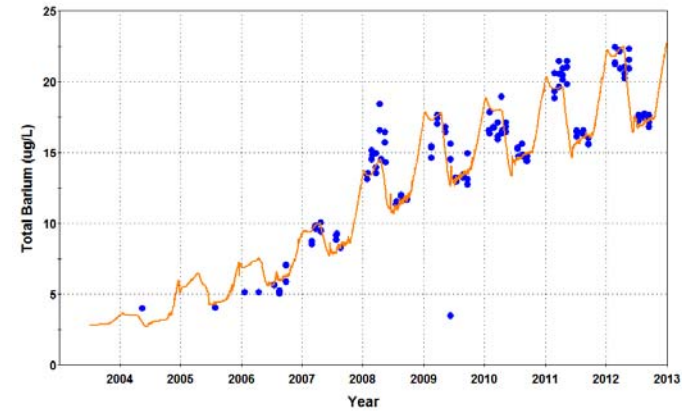
(b) Near diffuser, SNP 02-20 and SNAP13[a]
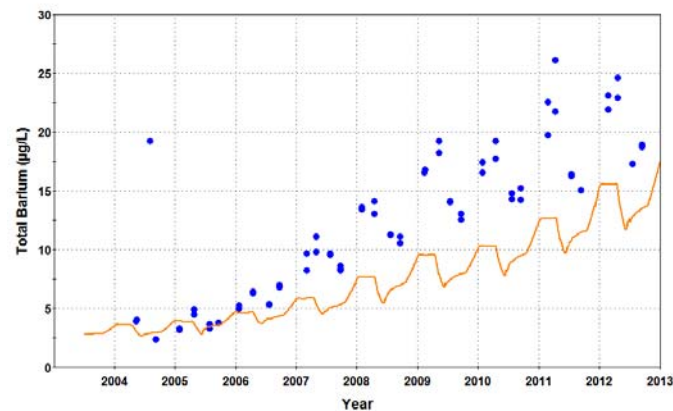
(c) Outlet, SNAP07 and SNAP08
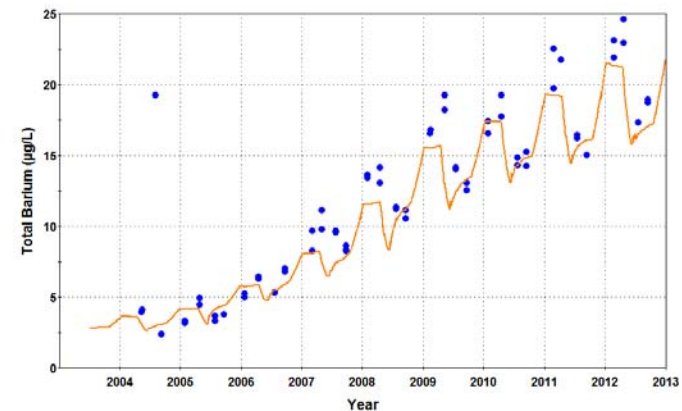
(d) Outlet, SNAP07 and SNAP08[a]

Note: Solid line represents model results; dots represent measured total arsenic concentrations.

(a)   A total Barium load of 733 kg was added to Snap Lake from 2004 to 2009 to improve the calibration.

µg/L = micrograms per litre; kg = kilograms; SNP = Surveillance Network Program.

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Figure IV-5   Total Copper Time Series Calibration Plots
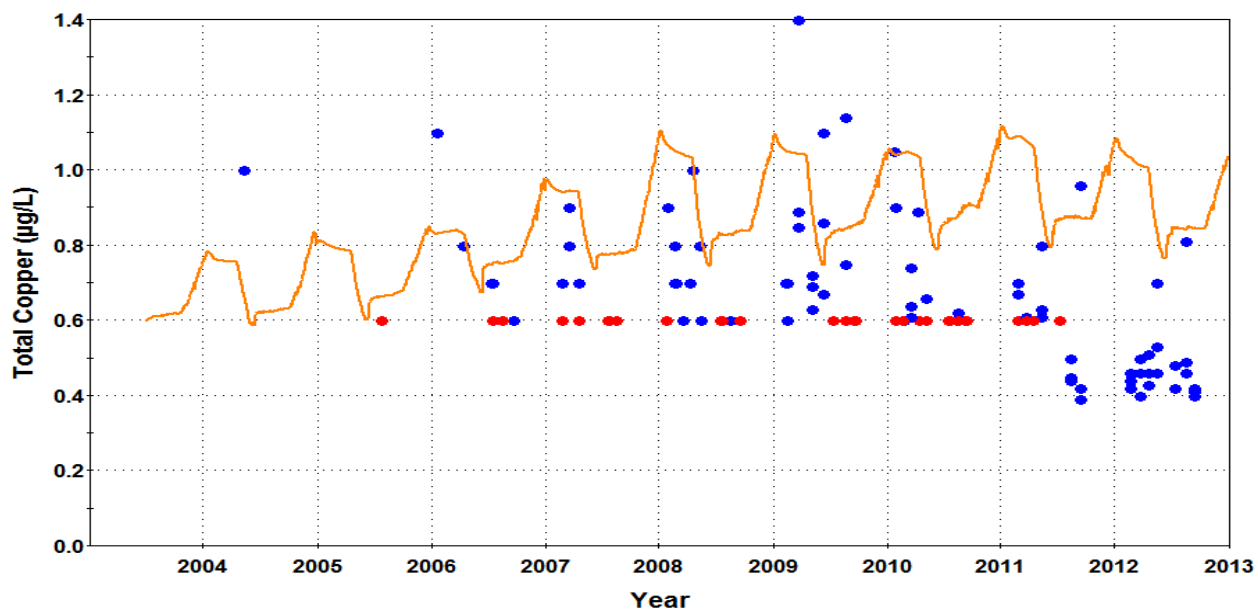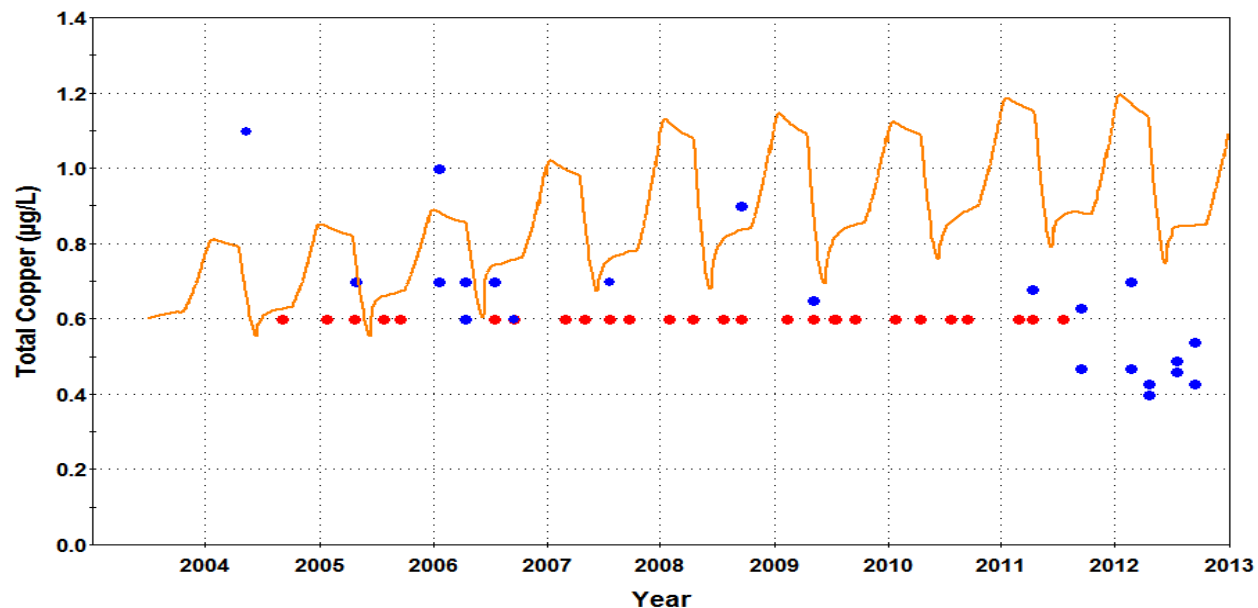
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured total copper concentrations reported above the detection limit; red dots represent measured total copper concentrations reported below the detection limit.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

Figure IV-6   Total Lithium Time Series Calibration Plots
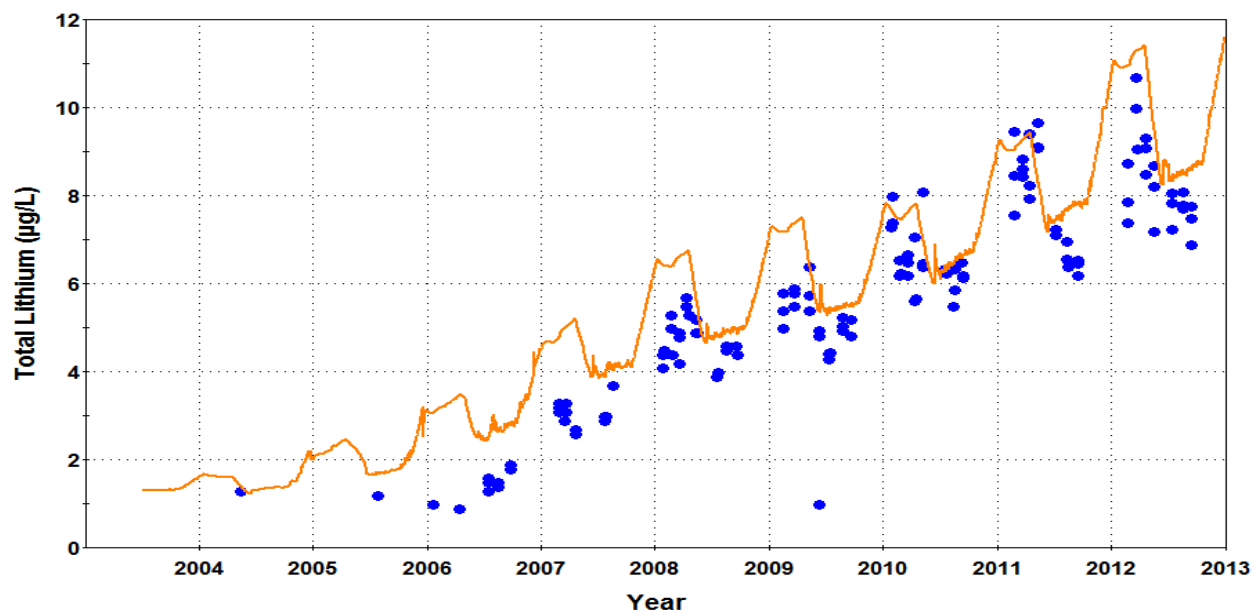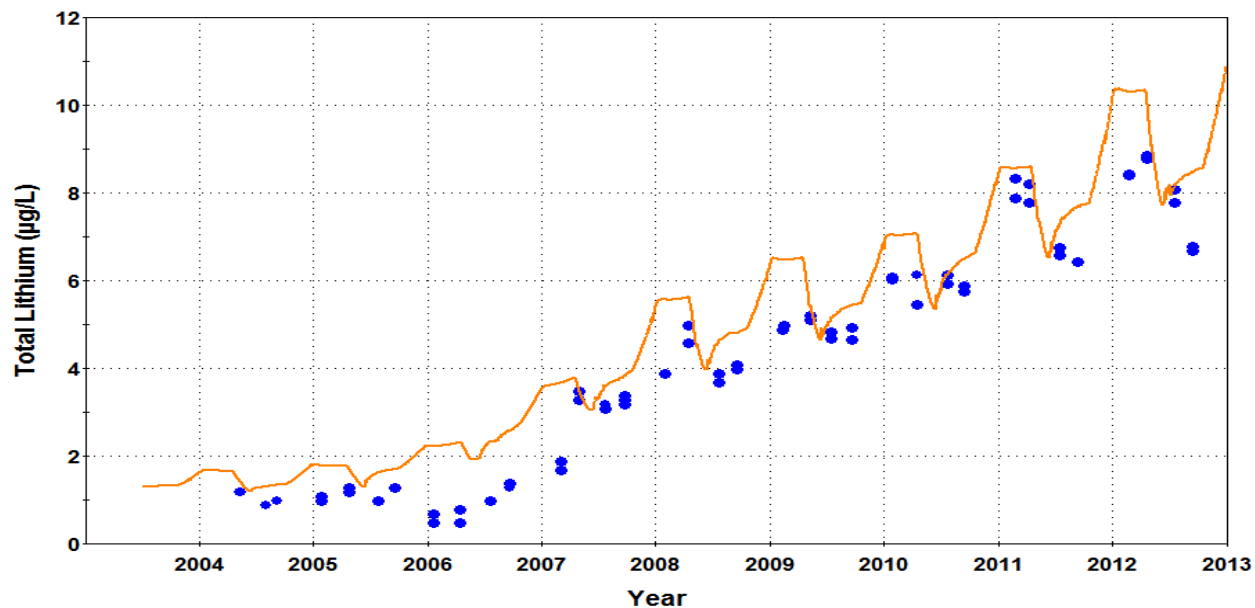
(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured total lithium concentrations.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

De Beers Canada Inc.

Figure IV-7   Total Mercury Time Series Calibration Plots

(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured total mercury concentrations reported above the detection limit; red dots represent measured total mercury concentrations reported below the detection limit.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

Snap Lake Mine   IV-8   December 2013
Total Metals and Total Metalloids
Time Series Calibration Results   Appendix IV

Figure IV-8   Total Strontium Time Series Calibration Plots

(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; dots represent measured total strontium concentrations.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

De Beers Canada Inc.

Snap Lake Mine
Total Metals and Total Metalloids
Time Series Calibration Results

IV-9

December 2013

Appendix IV

Figure IV-9   Total Uranium Time Series Calibration Plots

(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured total uranium concentrations reported above the detection limit; red dots represent measured total uranium concentrations reported below the detection limit.

μg/L = micrograms per litre; SNP = Surveillance Network Program.

De Beers Canada Inc.

Figure IV-10   Total Zinc Time Series Calibration Plots

(a) Near diffuser, SNP 02-20 and SNAP13

(b) Outlet, SNAP07 and SNAP08

Note: Solid line represents model results; blue dots represent measured total zinc concentrations reported above the detection limit; red dots represent measured total zinc concentrations reported below the detection limit.

µg/L = micrograms per litre; SNP = Surveillance Network Program.

APPENDIX V

MODEL PREDICTIONS

December 2013

Figure V-1   Predicted Depth-Averaged Ammonia Concentrations in Snap Lake
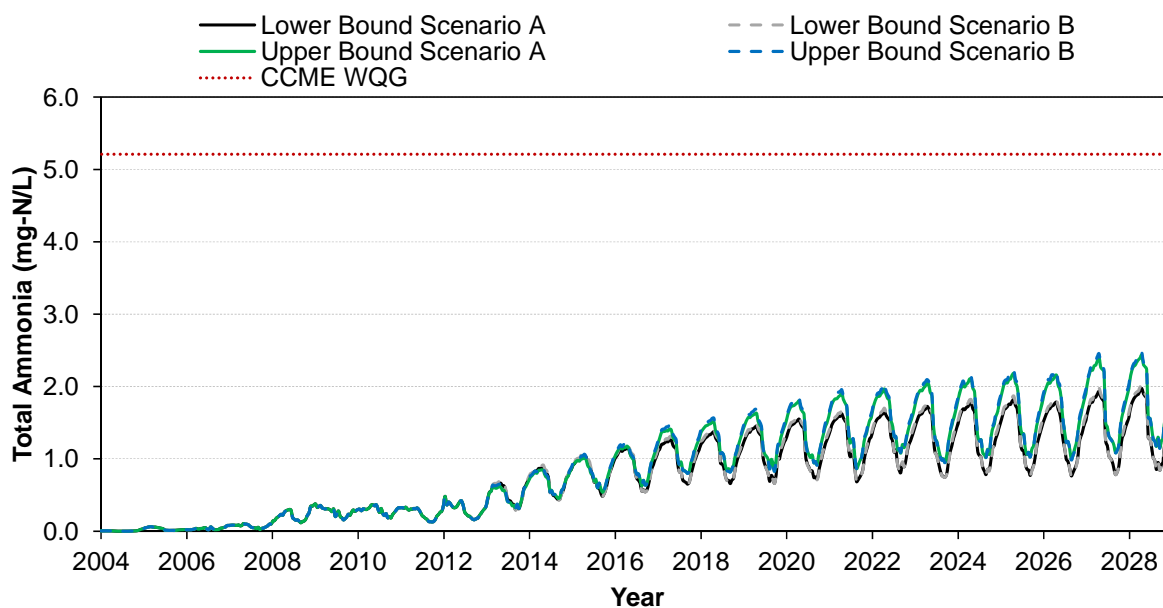
(a) Near diffuser, SNP 02-20e
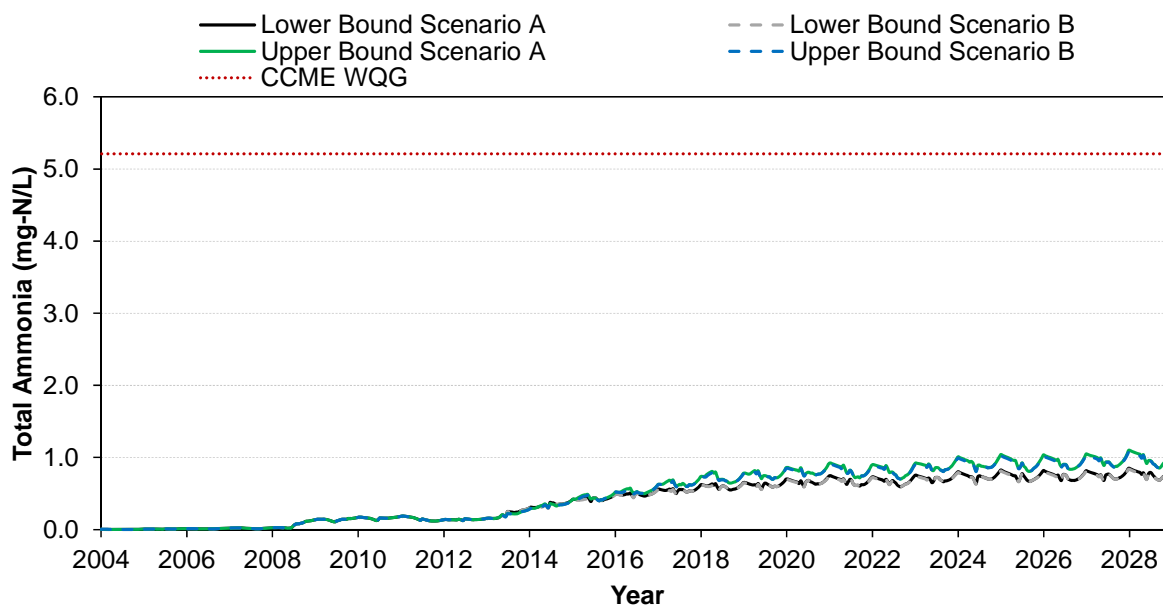
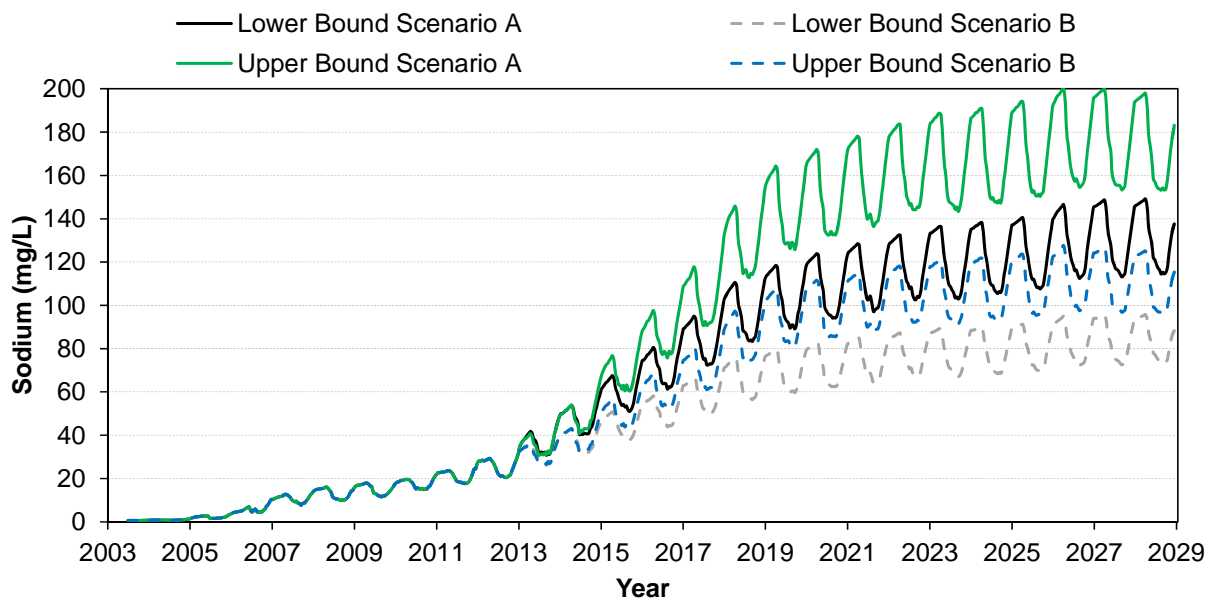(b) Outlet, SNAP07

Note: The CCME ammonia WQG is pH and temperature dependent and was calculated based on the 85th percentile value for monitored pH of 7.14 and temperature of 13.7 °C.

mg-N/L = milligrams as nitrogen per litre; CCME = Canadian Council of Ministers of the Environment; SNP = Surveillance Network Program.
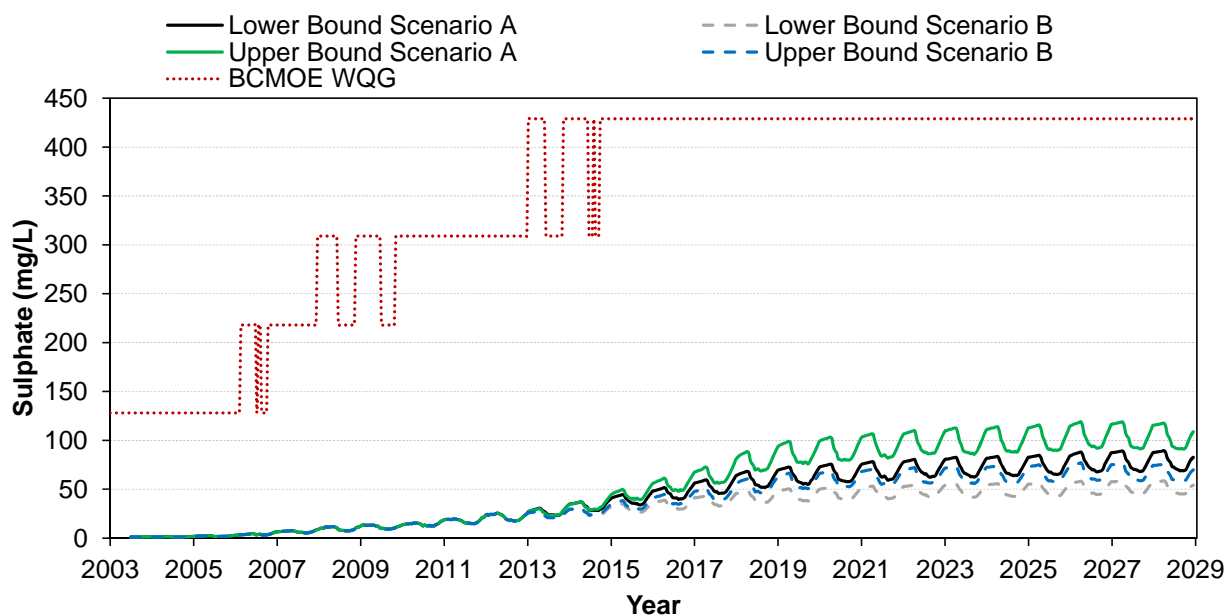
Figure V-2   Predicted Depth-Averaged Nitrate Concentrations in Snap Lake
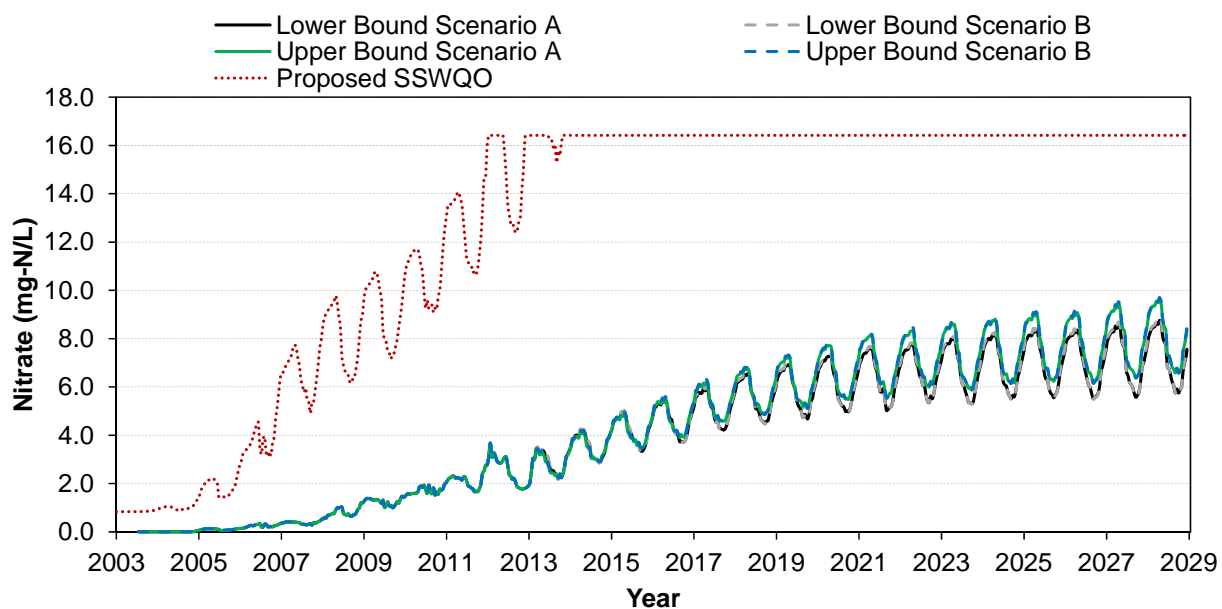
(a) Near diffuser, SNP 02-20e
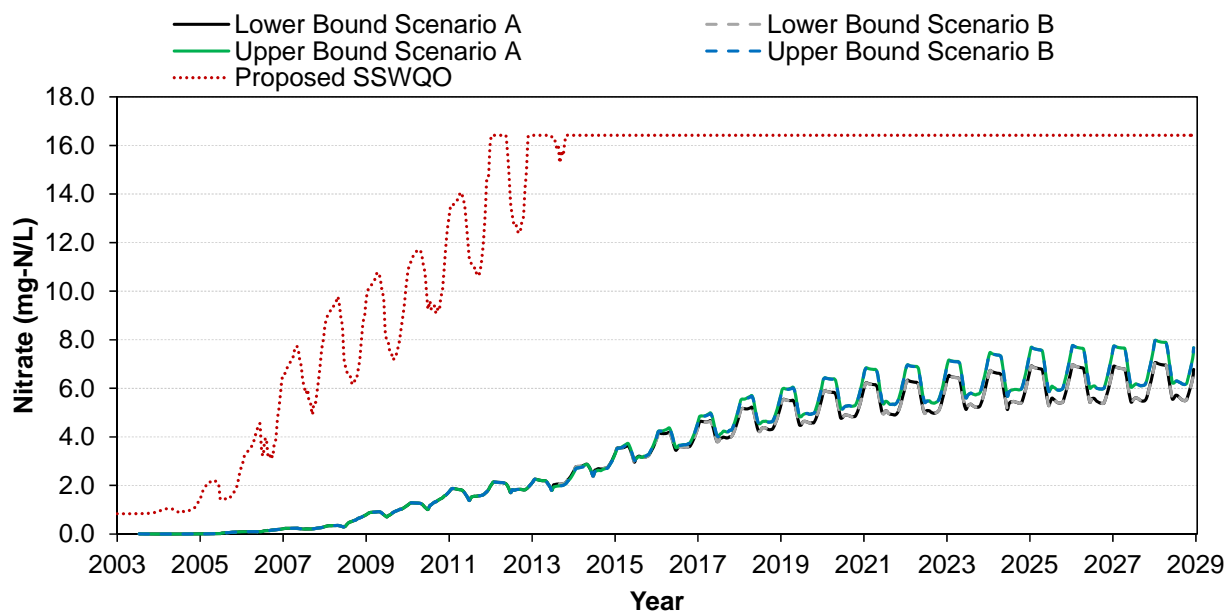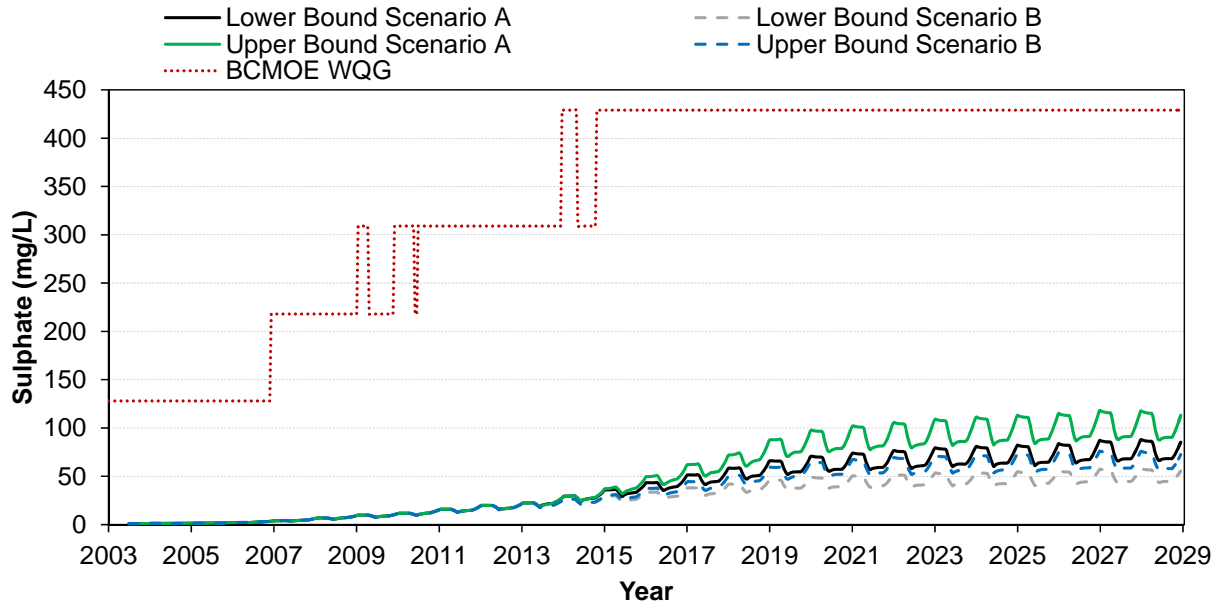

(b) Outlet, SNAP07

Note: The proposed nitrate SSWQO is hardness dependent.
mg-N/L = milligrams as nitrogen per litre; SSWQO = site-specific water quality objective; SNP = Surveillance Network Program.

Figure V-3   **Predicted Depth-Averaged Orthophosphate Concentrations in Snap Lake**
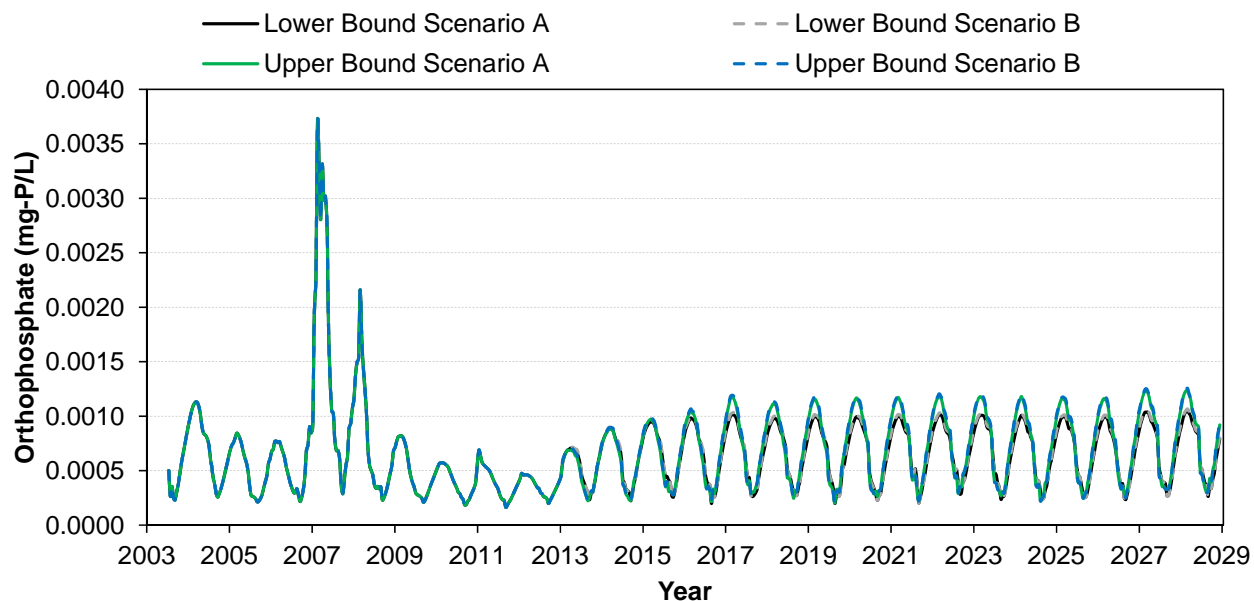
(a) Near diffuser, SNP 02-20e
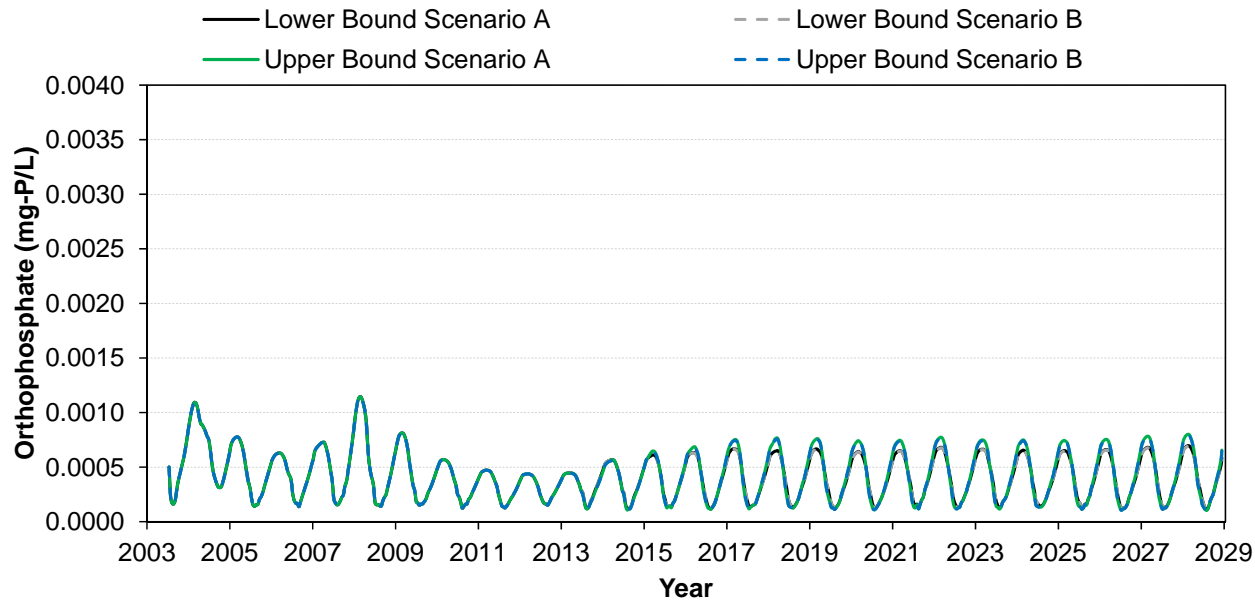
(b) Outlet, SNAP07

mg-P/L = milligrams as phosphorus per litre; SNP = Surveillance Network Program.

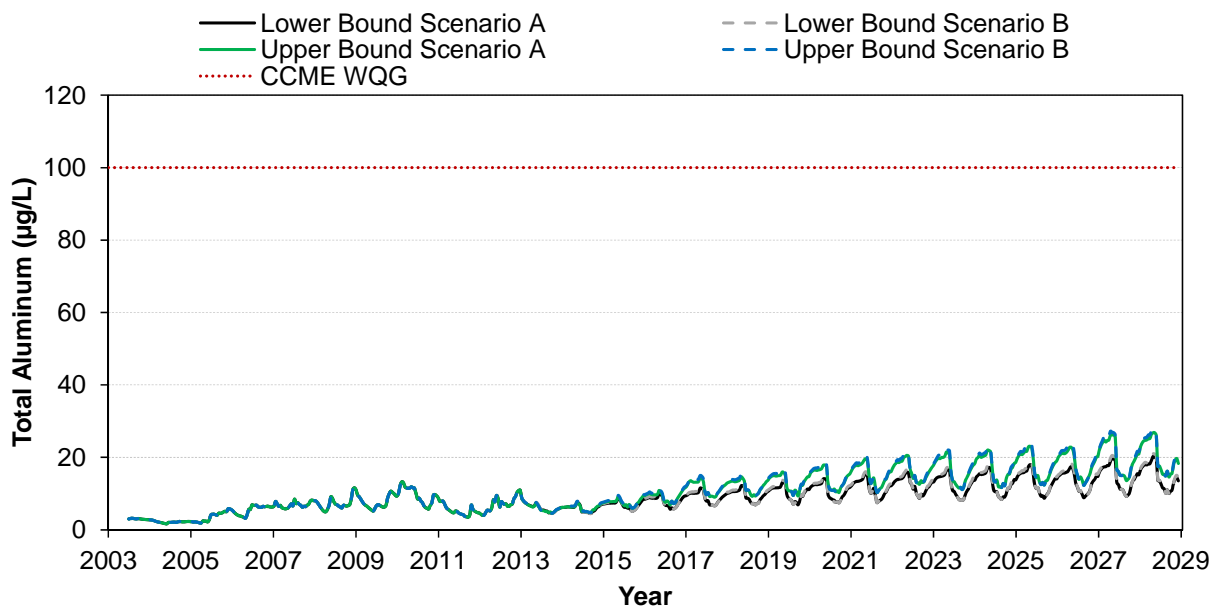**Figure V-4**   **Predicted Depth-Averaged Phytoplankton Concentrations in Snap Lake**
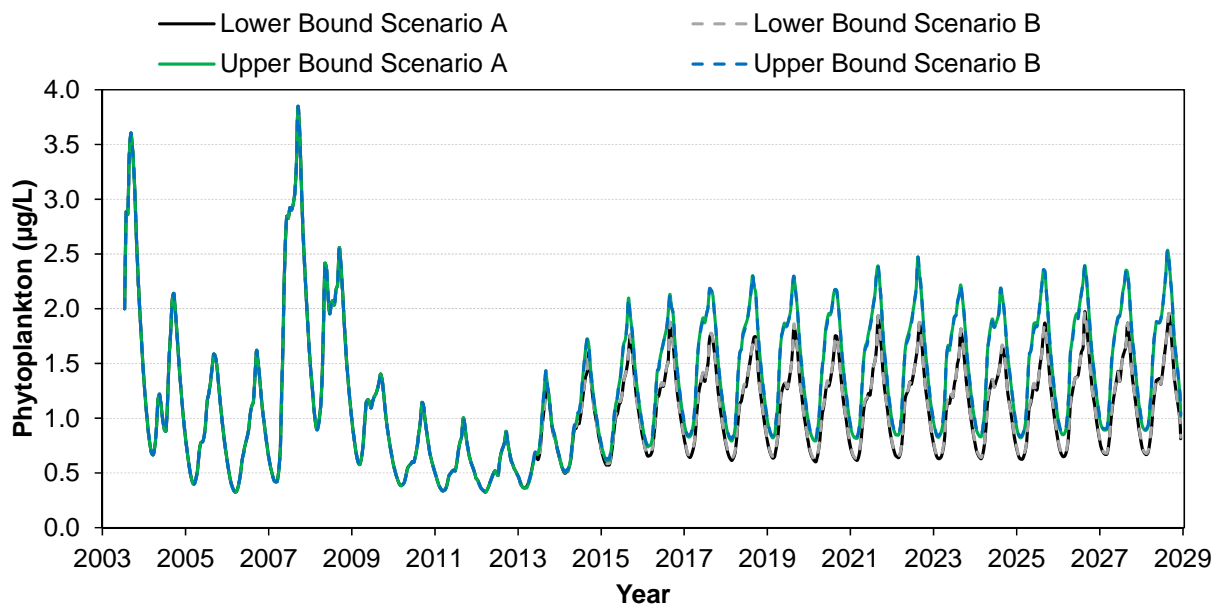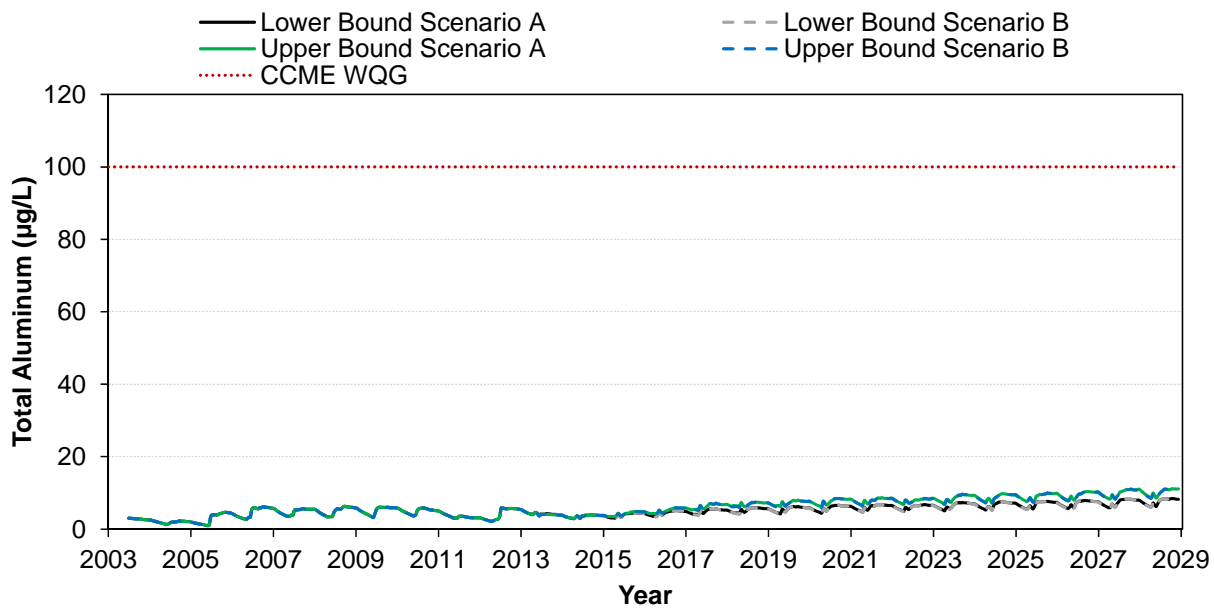

(a) Near diffuser, SNP 02-20e
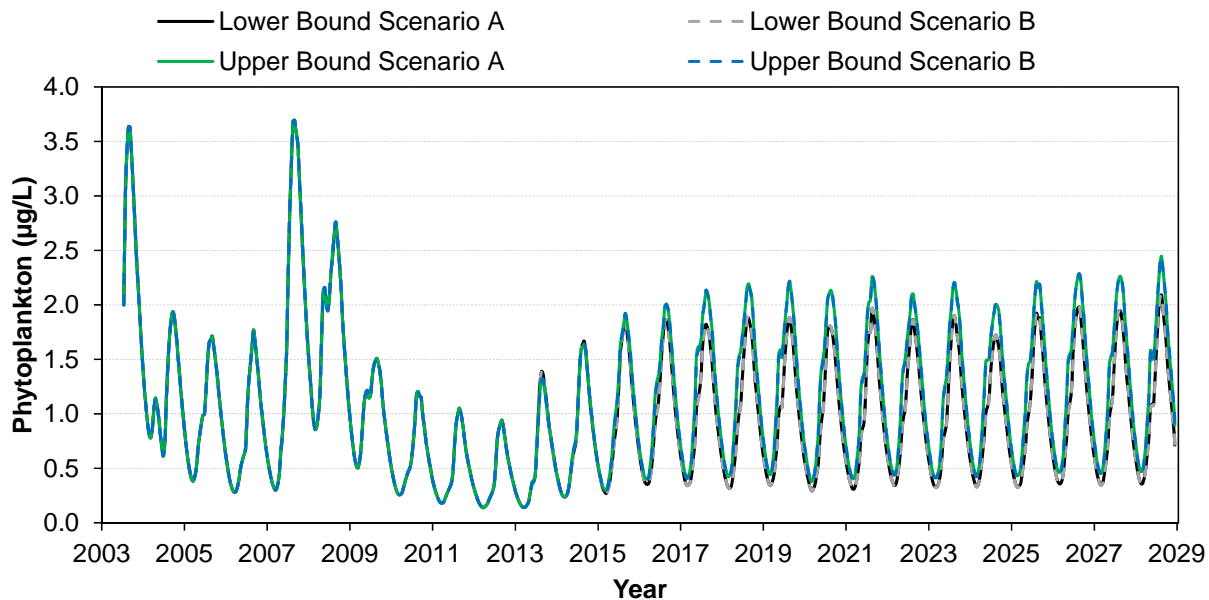
(b) Outlet, SNAP07

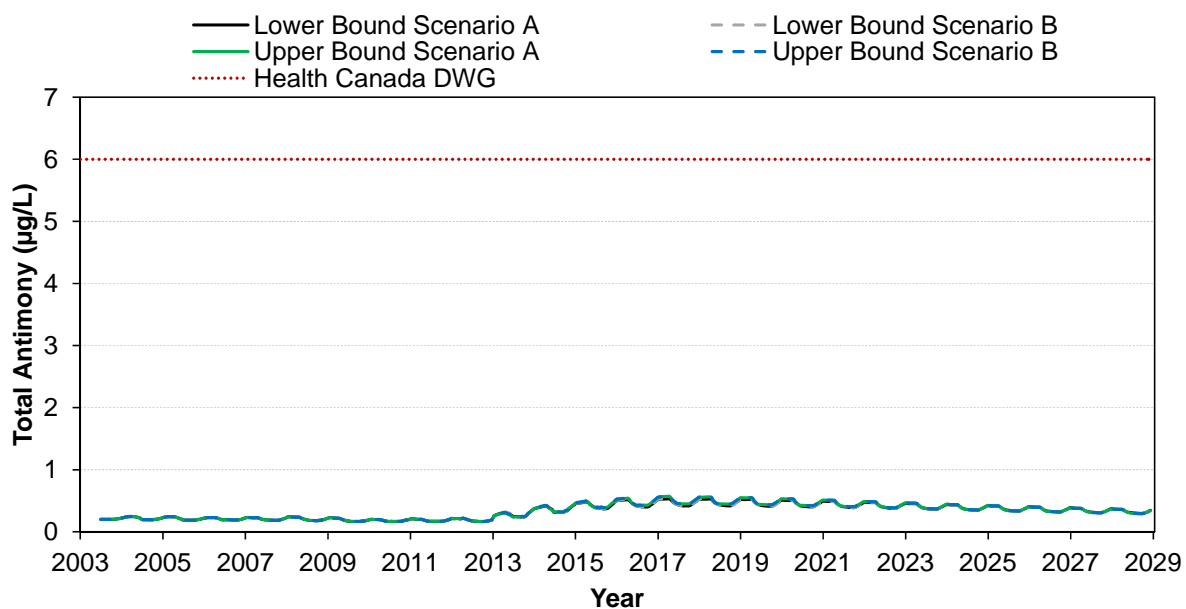µg/L = micrograms per litre; SNP = Surveillance Network Program.

Figure V-5   **Predicted Depth-Averaged Total Phosphorus Concentrations in Snap Lake**
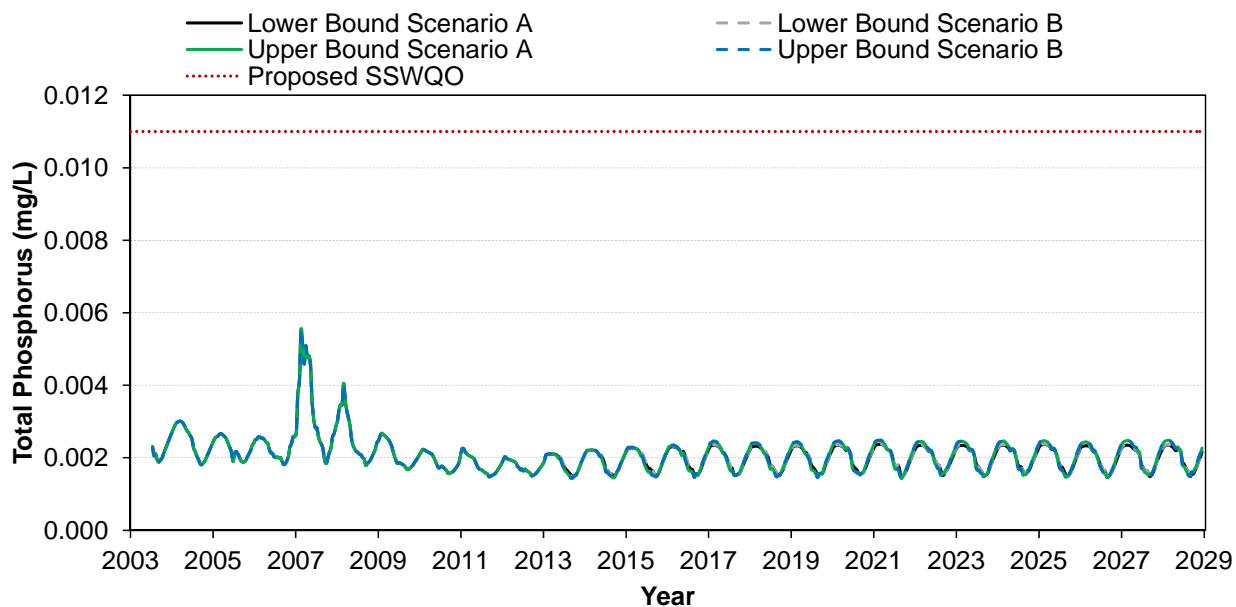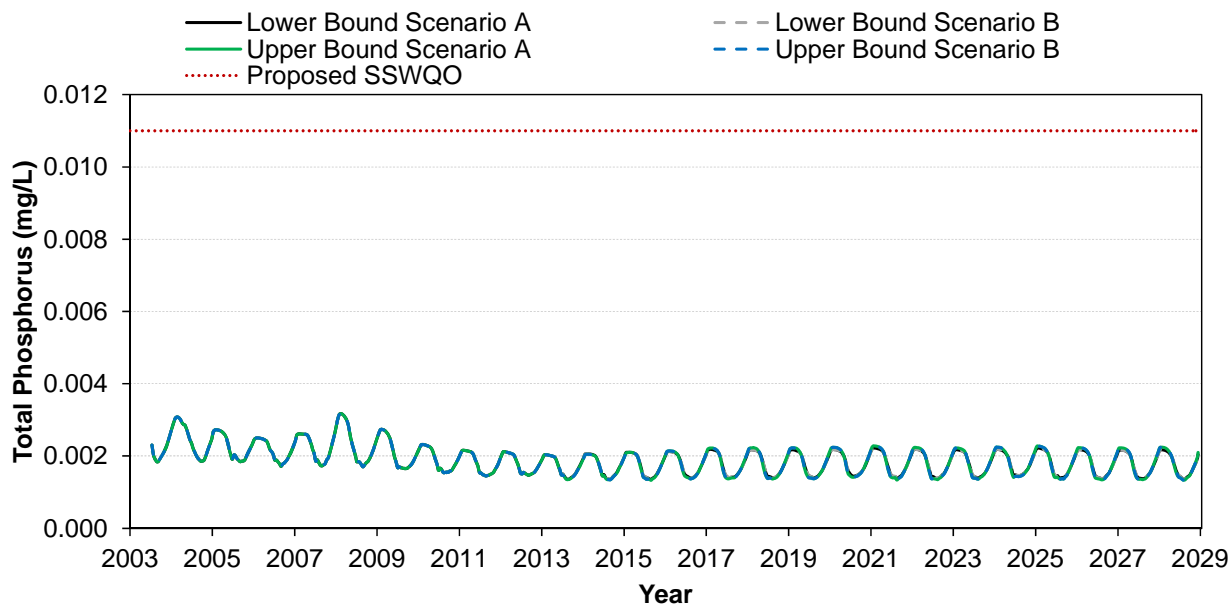
(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

mg/L = milligrams per litre; SNP = Surveillance Network Program; SSWQO = site-specific water quality objective.

Figure V-6   Predicted Depth-Averaged Calcium Concentrations in Snap Lake
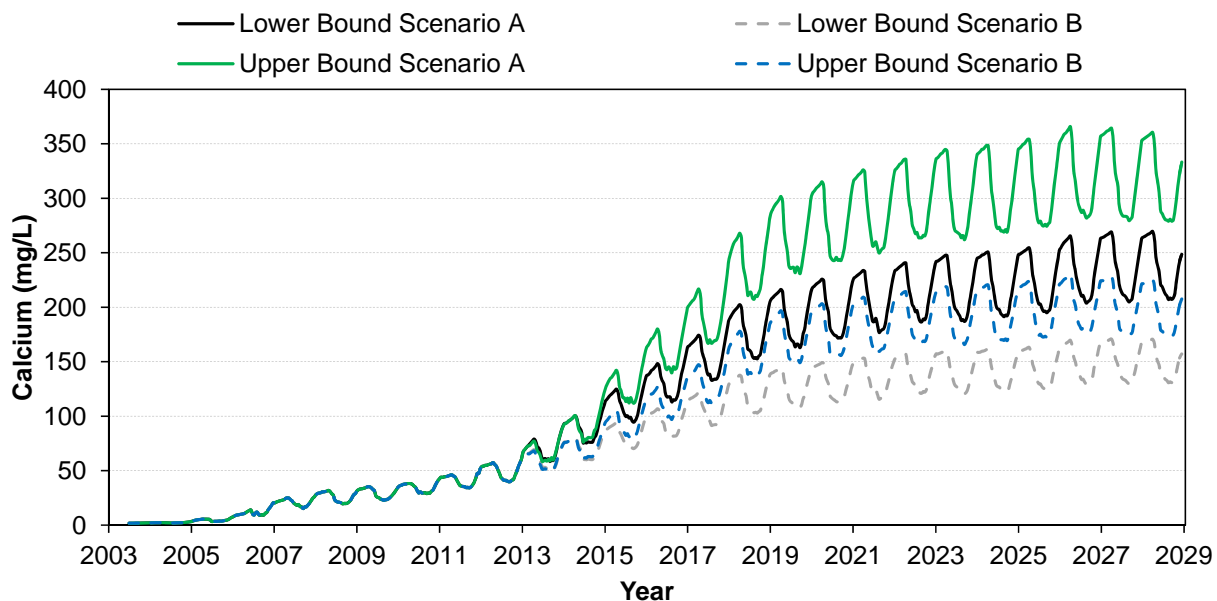
(a) Near diffuser, SNP 02-20e
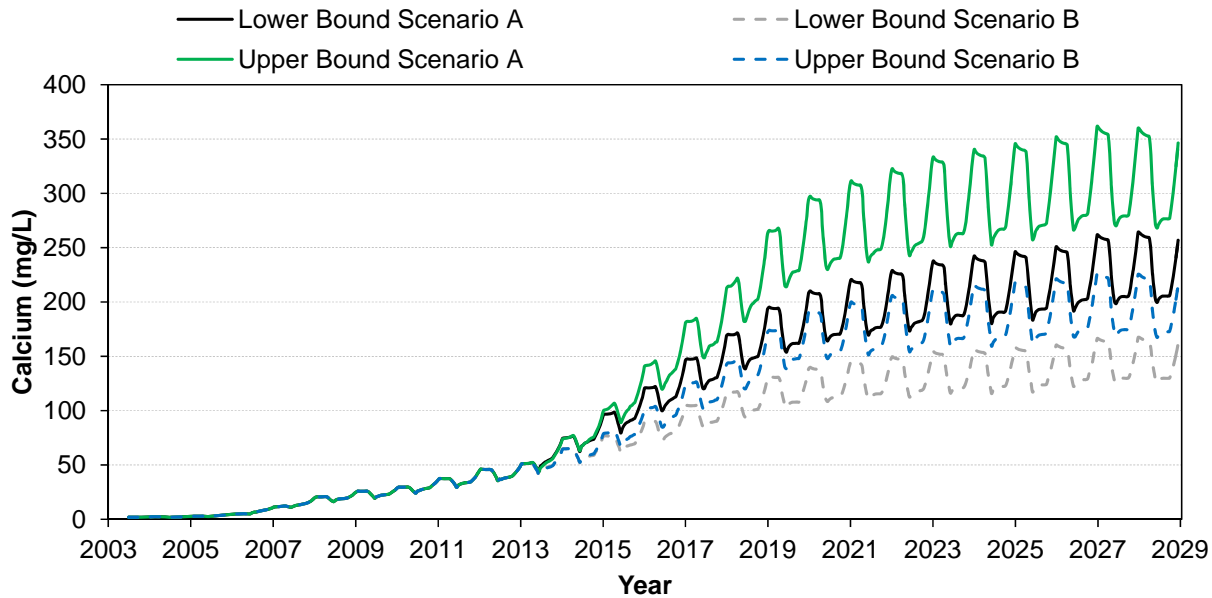
(b) Outlet, SNAP07

mg/L = milligrams per litre; SNP = Surveillance Network Program.

Figure V-7   Predicted Depth-Averaged Chloride Concentrations in Snap Lake
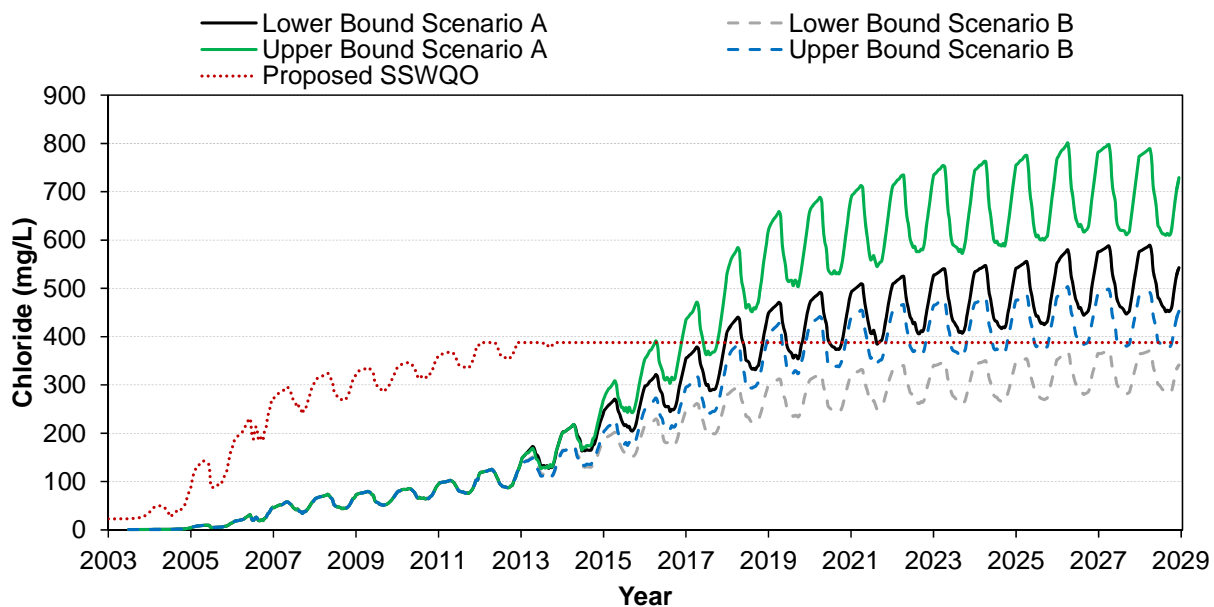

(a) Near diffuser, SNP 02-20e
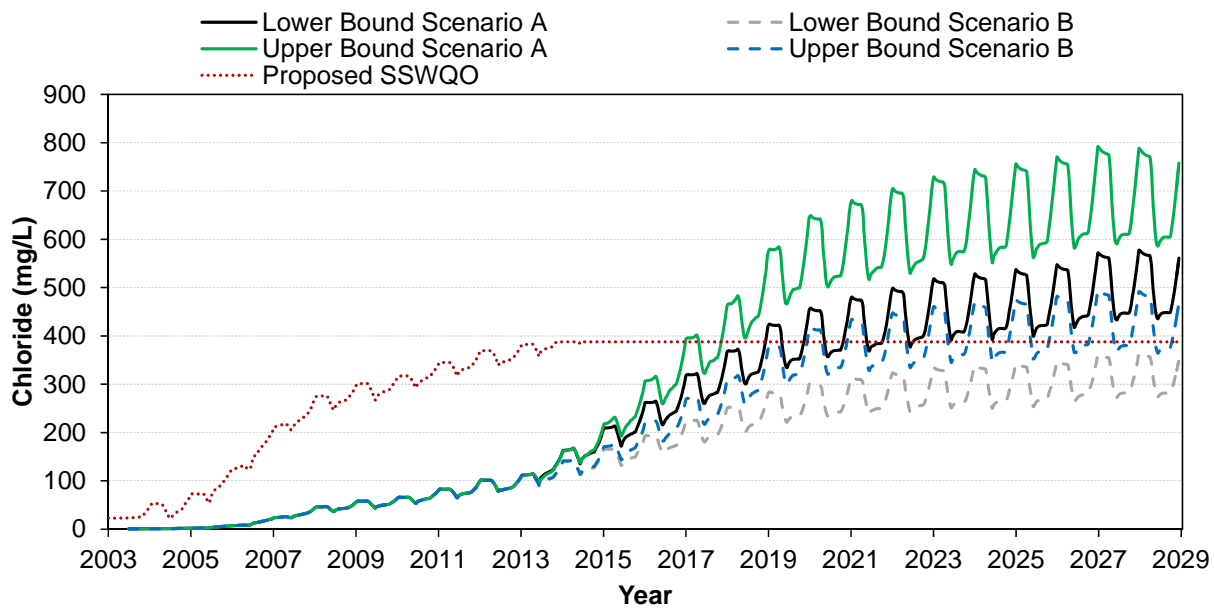
(b) Outlet, SNAP07

Note: The proposed chloride SSWQO is hardness dependent.

mg/L = milligrams per litre; SSWQO = site-specific water quality objective; SNP = Surveillance Network Program.

Figure V-8   Predicted Depth-Averaged Fluoride Concentrations in Snap Lake
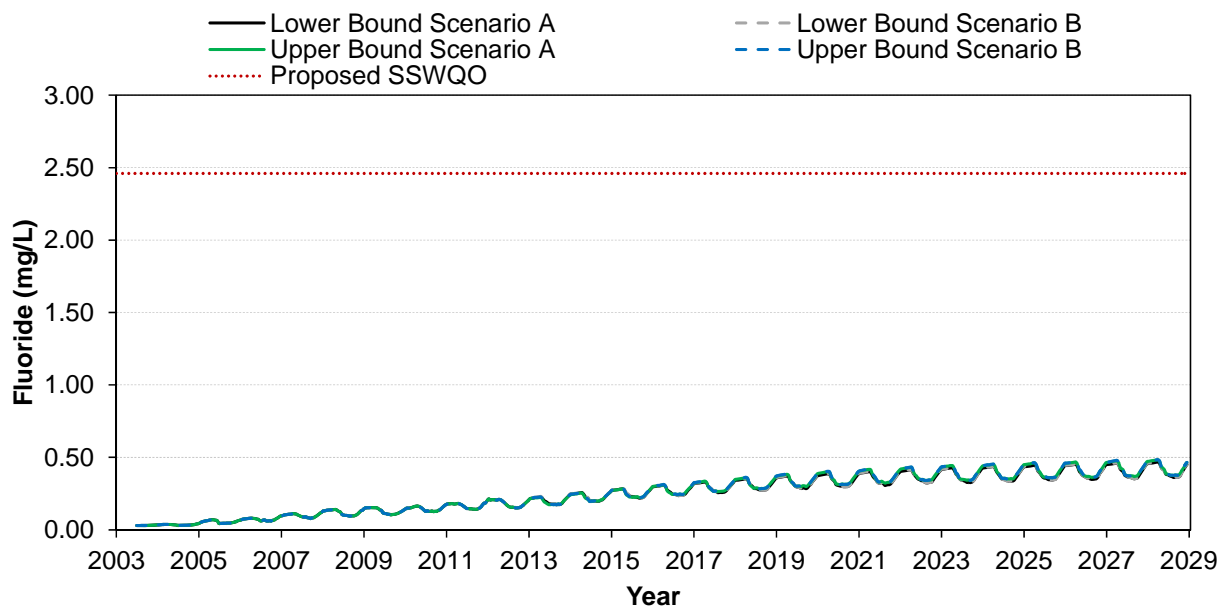
(a) Near diffuser, SNP 02-20e
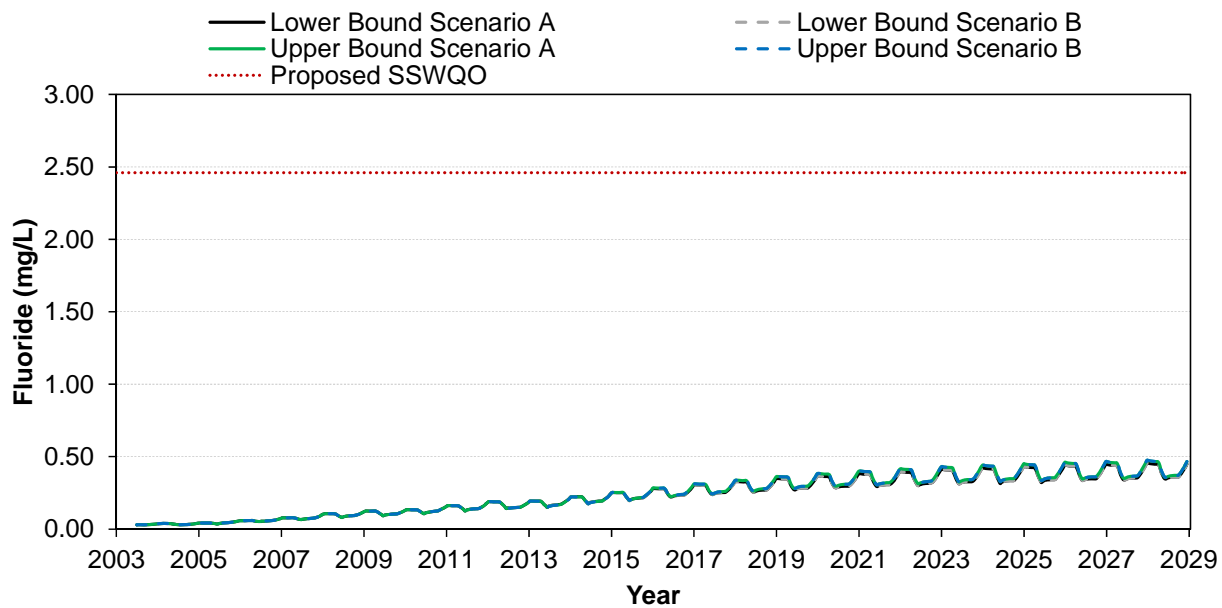
(b) Outlet, SNAP07

mg/L = milligrams per litre; BCMOE = British Columbia Ministry of Environment; SNP = Surveillance Network Program; SSWQO = site-specific water quality objective.

Figure V-9   Predicted Depth-Averaged Magnesium Concentrations in Snap Lake
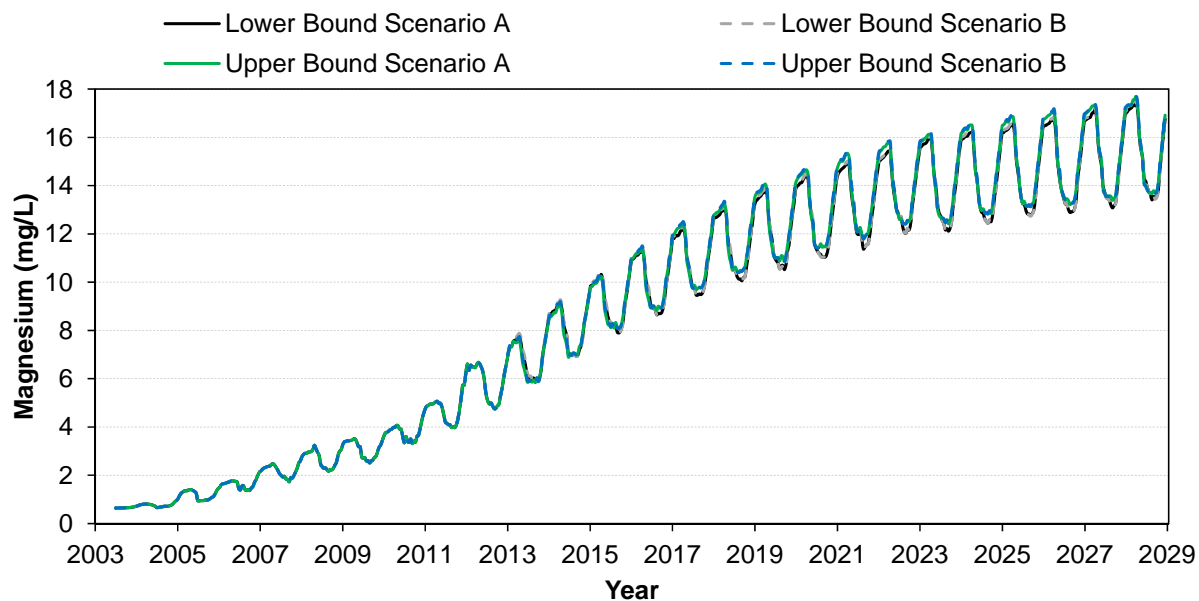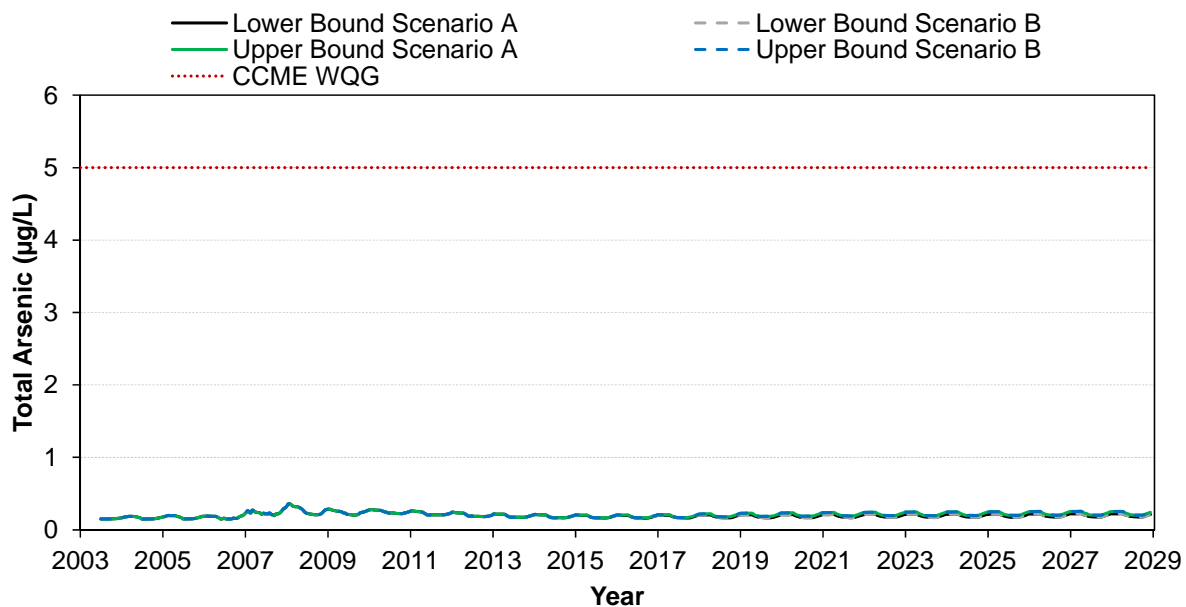

(a) Near diffuser, SNP 02-20e
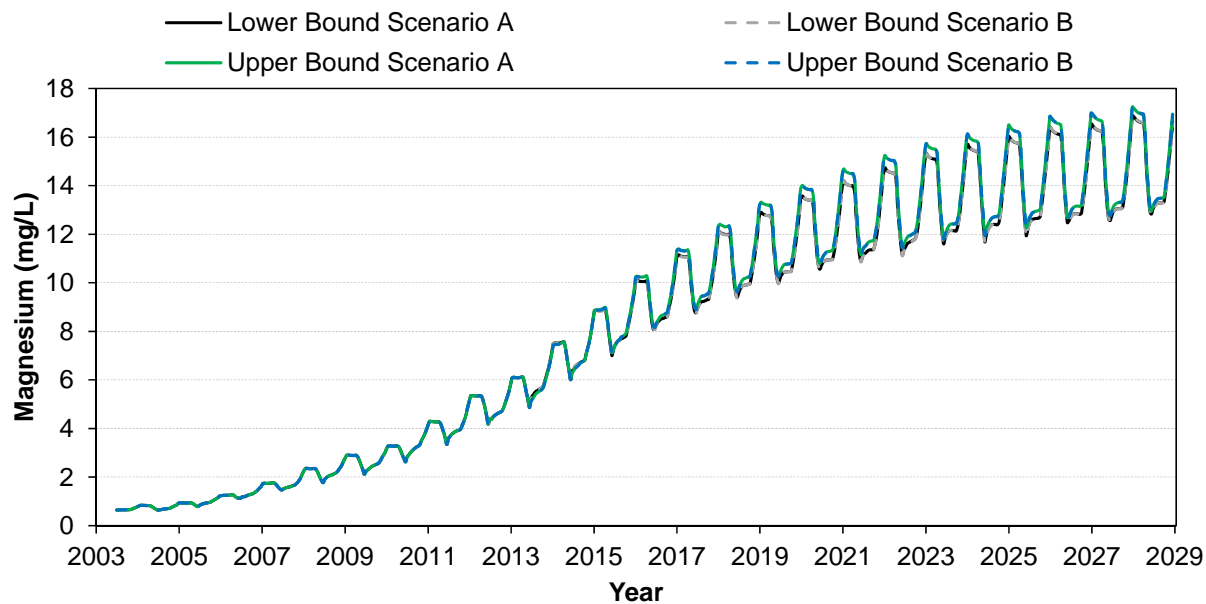
(b) Outlet, SNAP07

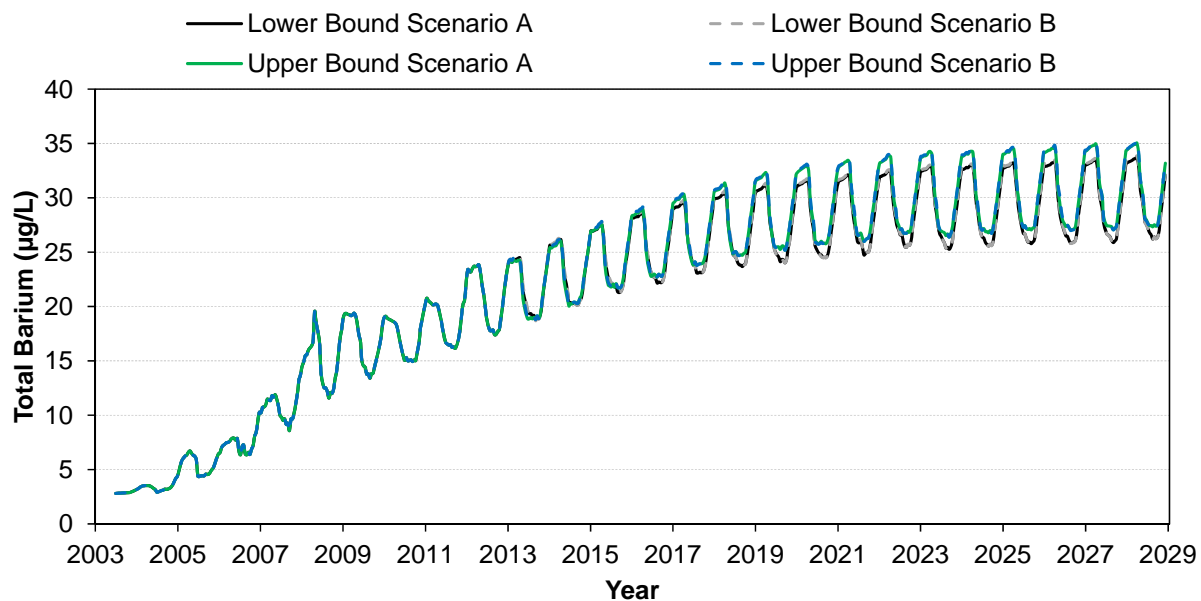mg/L = milligrams per litre; SNP = Surveillance Network Program.

Figure V-10   Predicted Depth-Averaged Sodium Concentrations in Snap Lake

(a) Near diffuser, SNP 02-20e
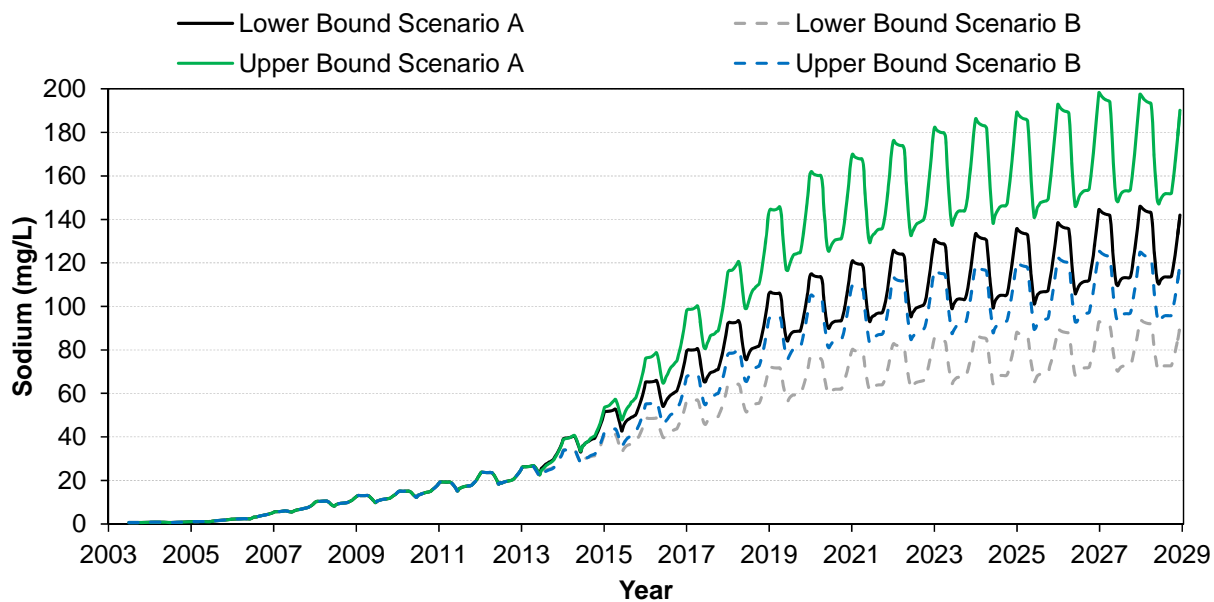
(b) Outlet, SNAP07

mg/L = milligrams per litre; SNP = Surveillance Network Program.

Figure V-11   Predicted Depth-Averaged Sulphate Concentrations in Snap Lake

(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

Note: The BCMOE WQG for sulphate is hardness dependent.

mg/L = milligrams per litre; SSWQO = site-specific water quality objective; SNP = Surveillance Network Program.

Figure V-12   Predicted Depth-Averaged Total Aluminum Concentrations in Snap Lake

(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

µg/L = micrograms per litre; CCME = Canadian Council of Ministers of the Environment; SNP = Surveillance Network Program; WQG = water quality guideline.

Figure V-13   Predicted Depth-Averaged Total Antimony Concentrations in Snap Lake


(a) Near diffuser, SNP 02-20e
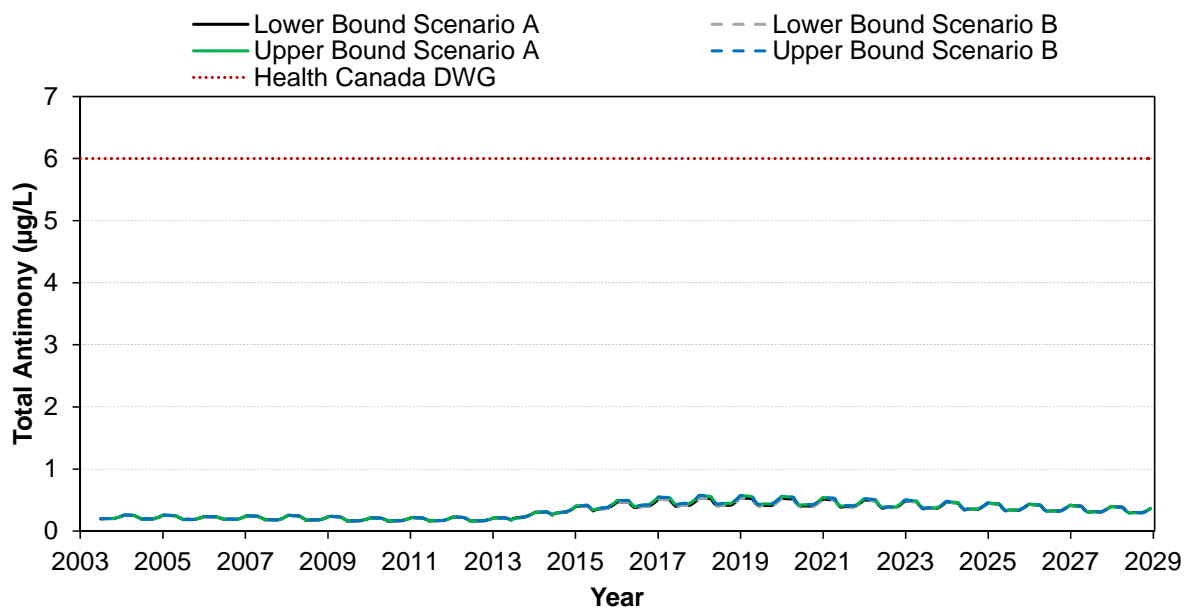
(b) Outlet, SNAP07

The Canadian drinking water guideline for antimony was obtained from Health Canada (2012).   The guideline concentration is the Maximum Acceptable Concentration.

µg/L = micrograms per litre; DWG = drinking water guideline; SNP = Surveillance Network Program.

Figure V-14   Predicted Depth-Averaged Total Arsenic Concentrations in Snap Lake
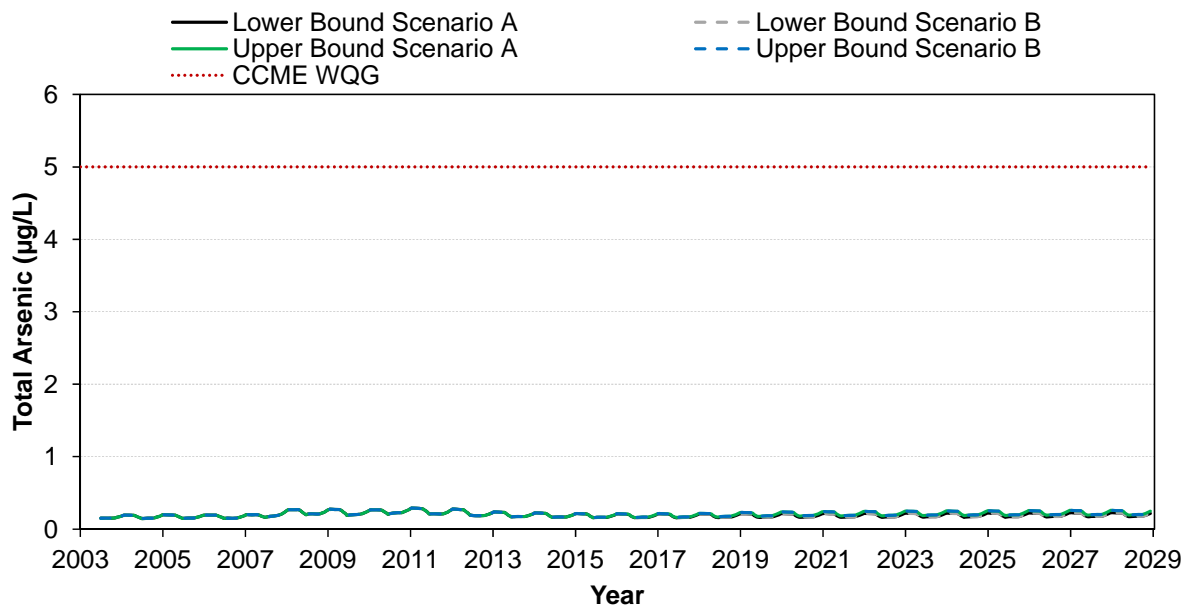
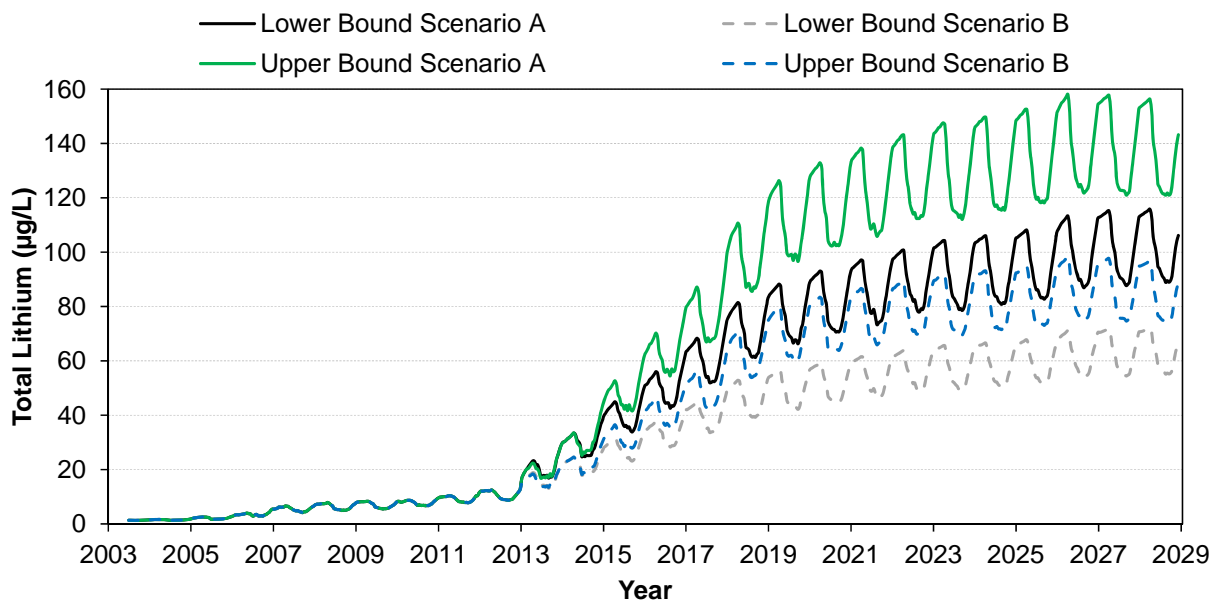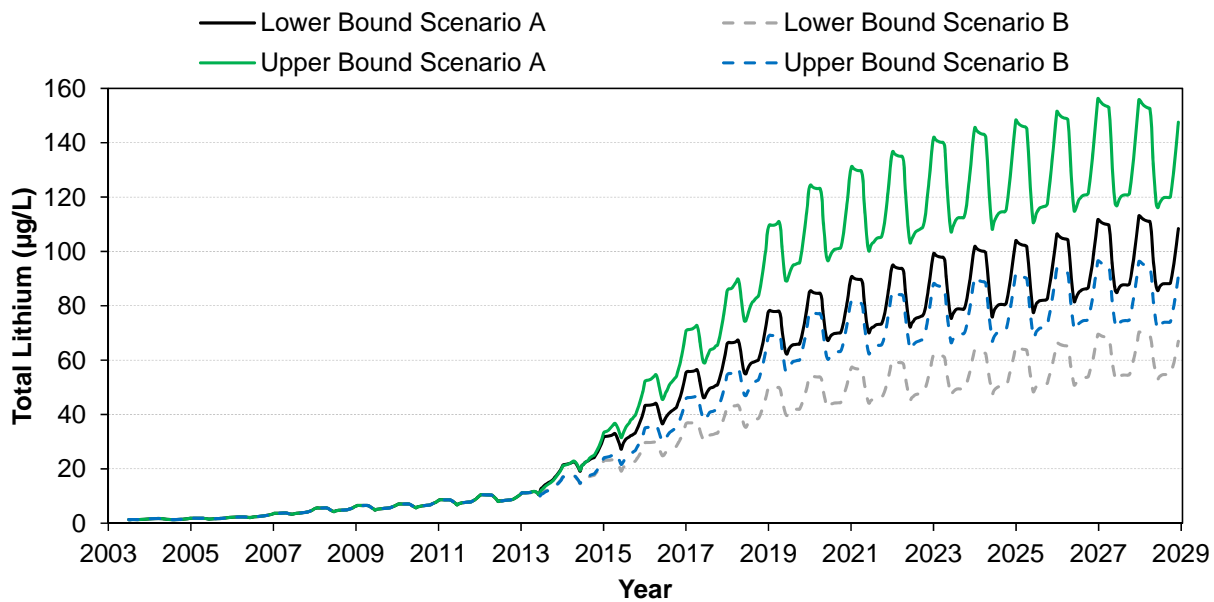(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

µg/L = micrograms per litre; CCME = Canadian Council of Ministers of the Environment; SNP = Surveillance Network Program; WQG = water quality guideline.
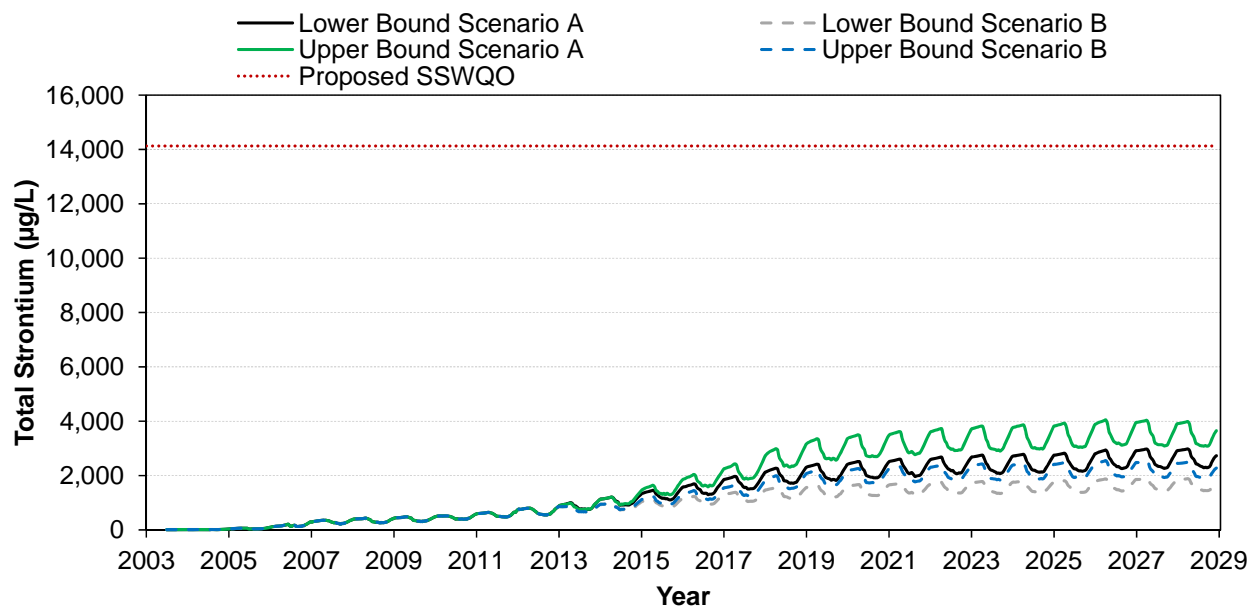
Figure V-15   Predicted Depth-Averaged Total Barium Concentrations in Snap Lake
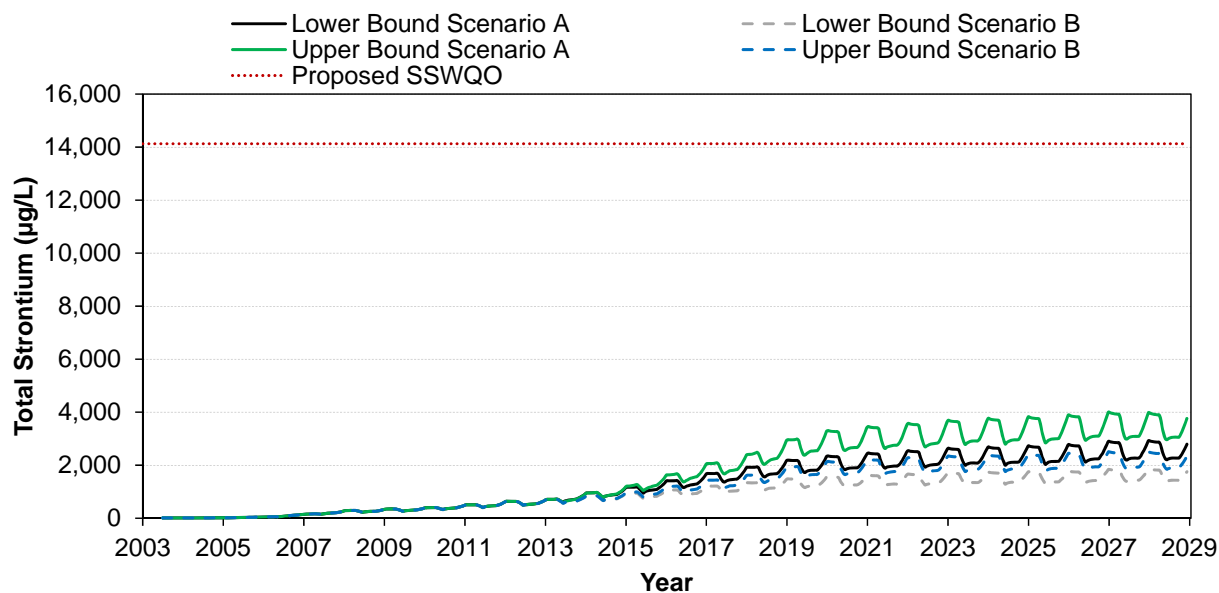

(a) Near diffuser, SNP 02-20e
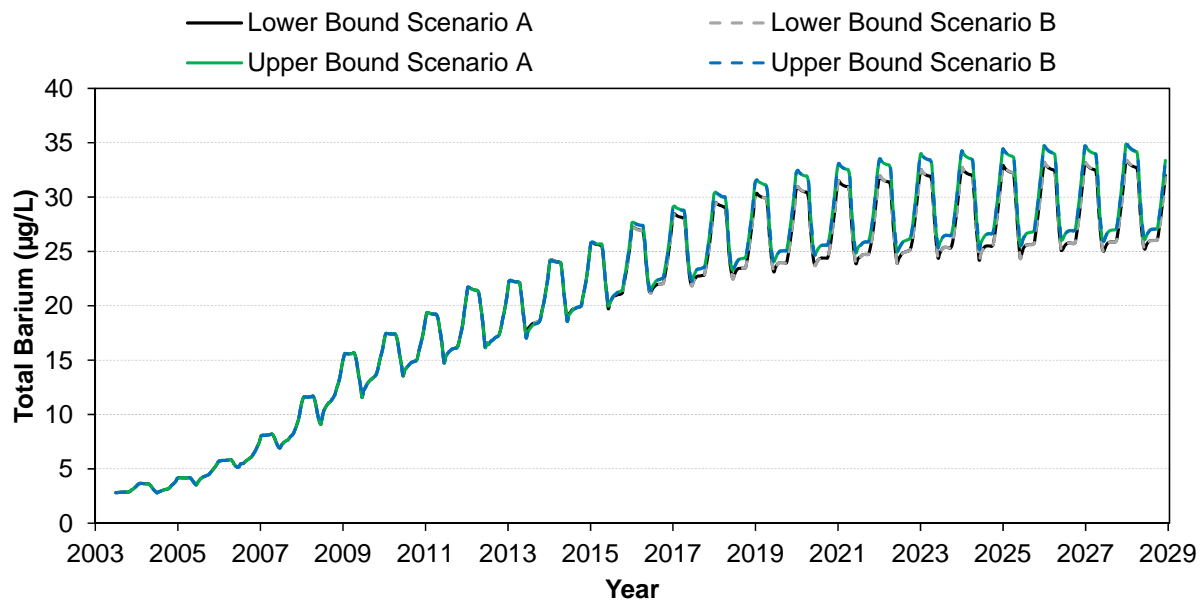
(b) Outlet, SNAP07

µg/L = micrograms per litre; SNP = Surveillance Network Program.

Figure V-16   Predicted Depth-Averaged Total Copper Concentrations in Snap Lake
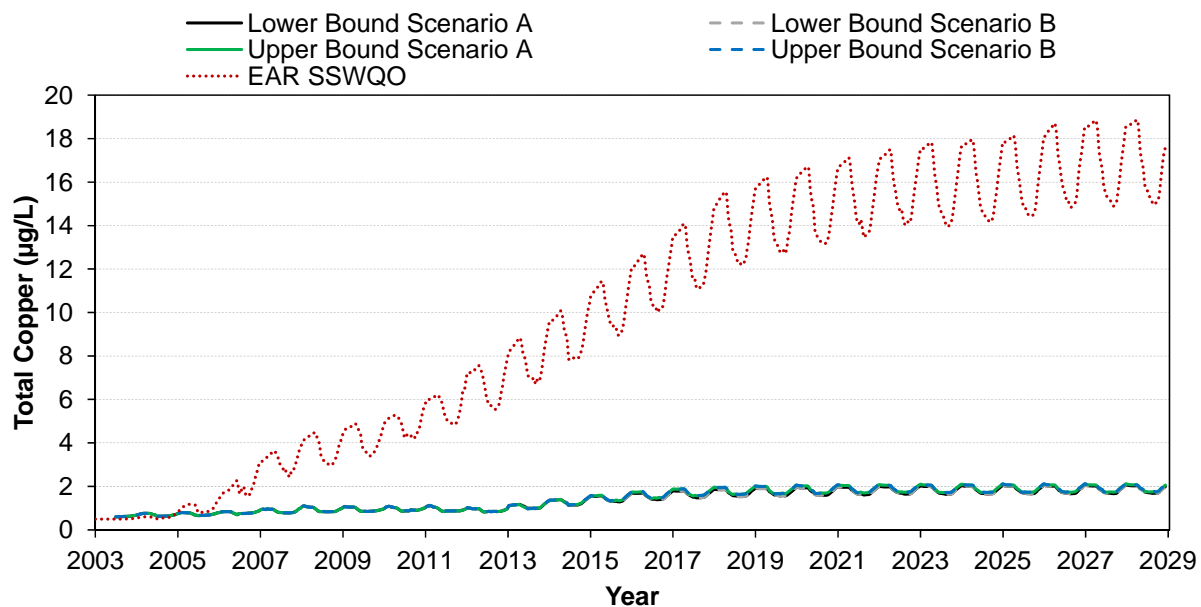
(a) Near diffuser, SNP 02-20e
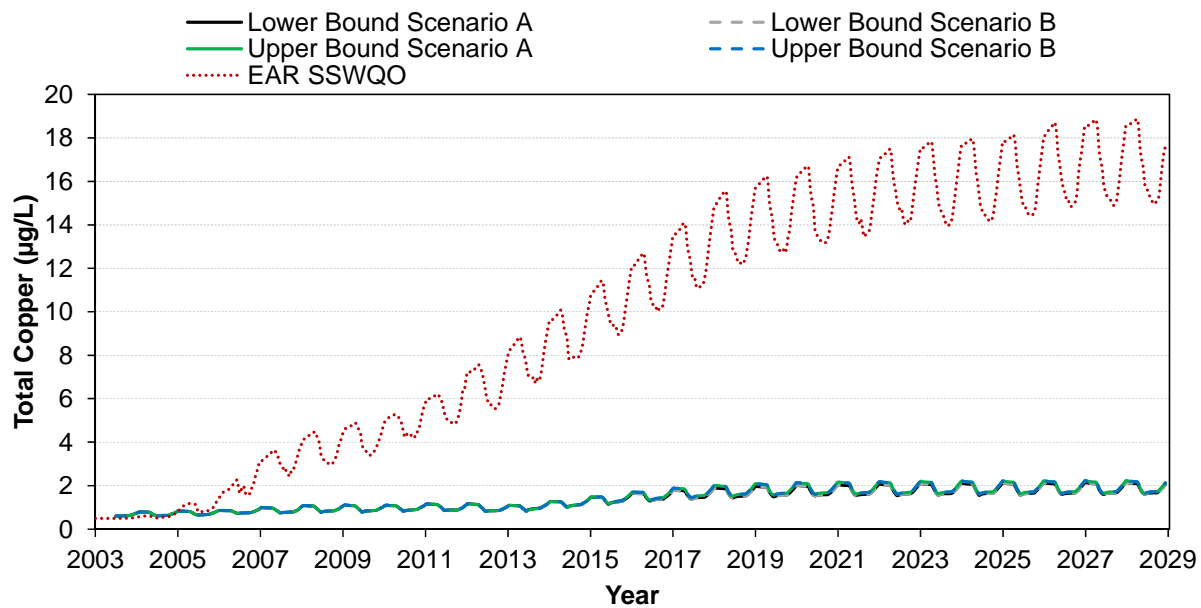
(b) Outlet, SNAP07

Note: The EAR SSWQO for copper is hardness dependent.

μg/L = micrograms per litre; EAR = Environmental Assessment Report; SNP = Surveillance Network Program; SSWQO = site-specific water quality objective.

Figure V-17   Predicted Depth-Averaged Total Lithium Concentrations in Snap Lake

(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

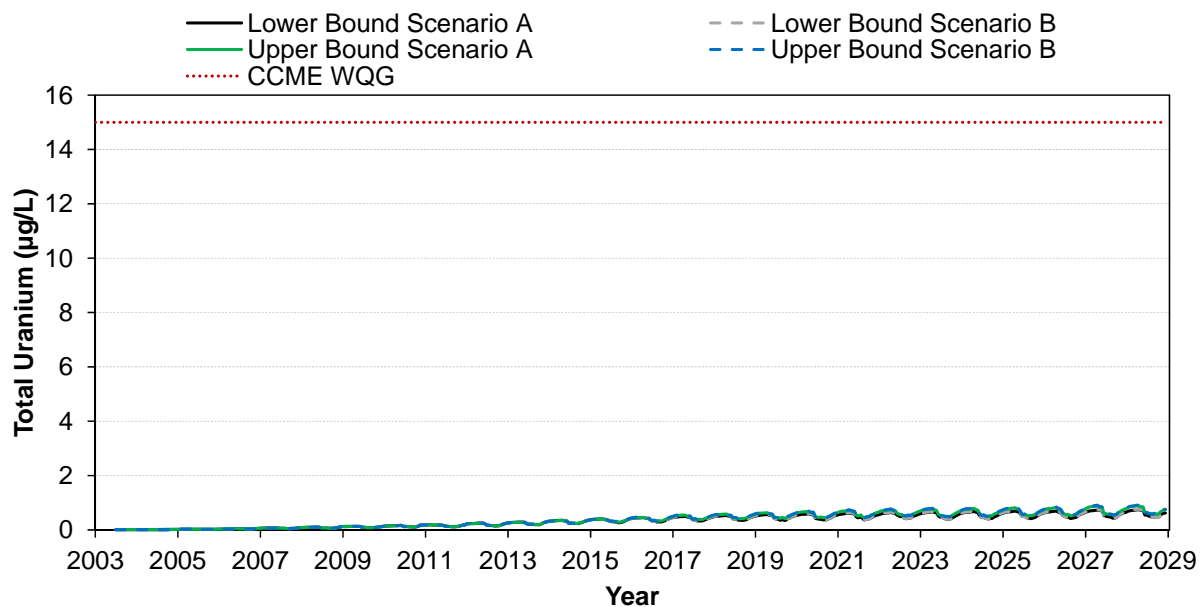µg/L = micrograms per litre; SNP = Surveillance Network Program.

Figure V-18   Predicted Depth-Averaged Total Strontium Concentrations in Snap Lake
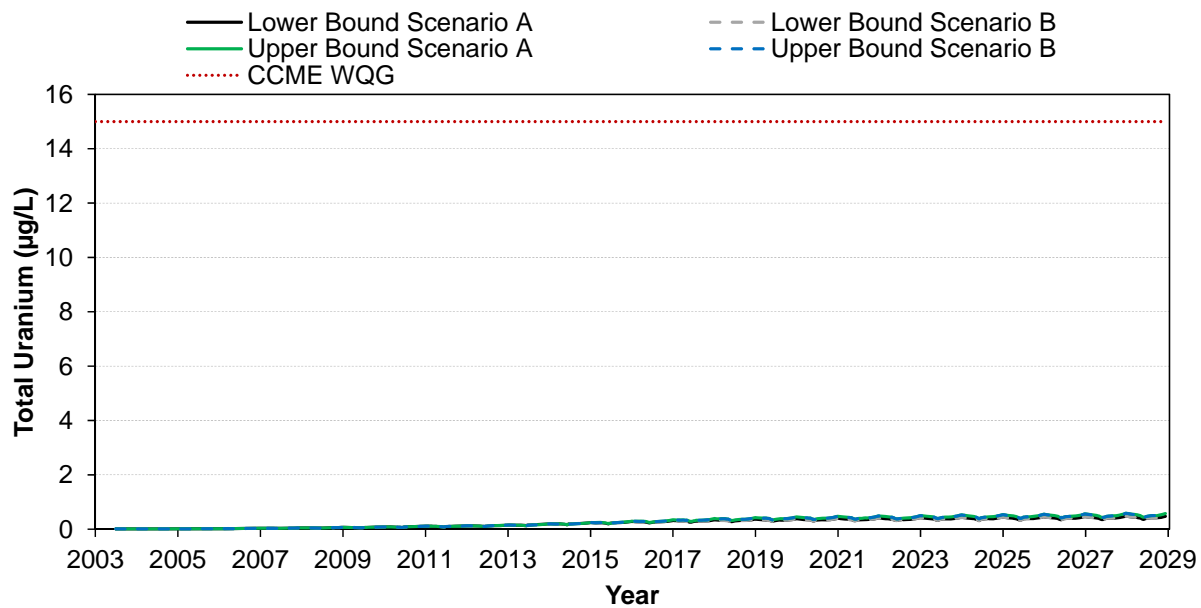

(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

µg/L = micrograms per litre; SNP = Surveillance Network Program; SSWQO = site-specific water quality objective.

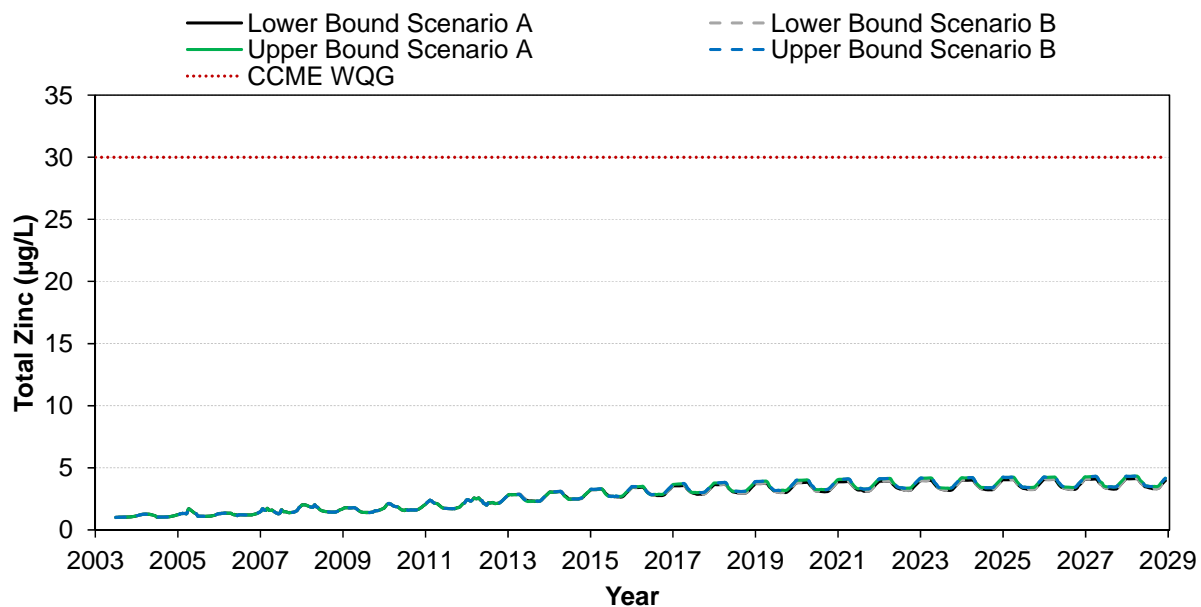**Figure V-19   Predicted Depth-Averaged Total Uranium Concentrations in Snap Lake**
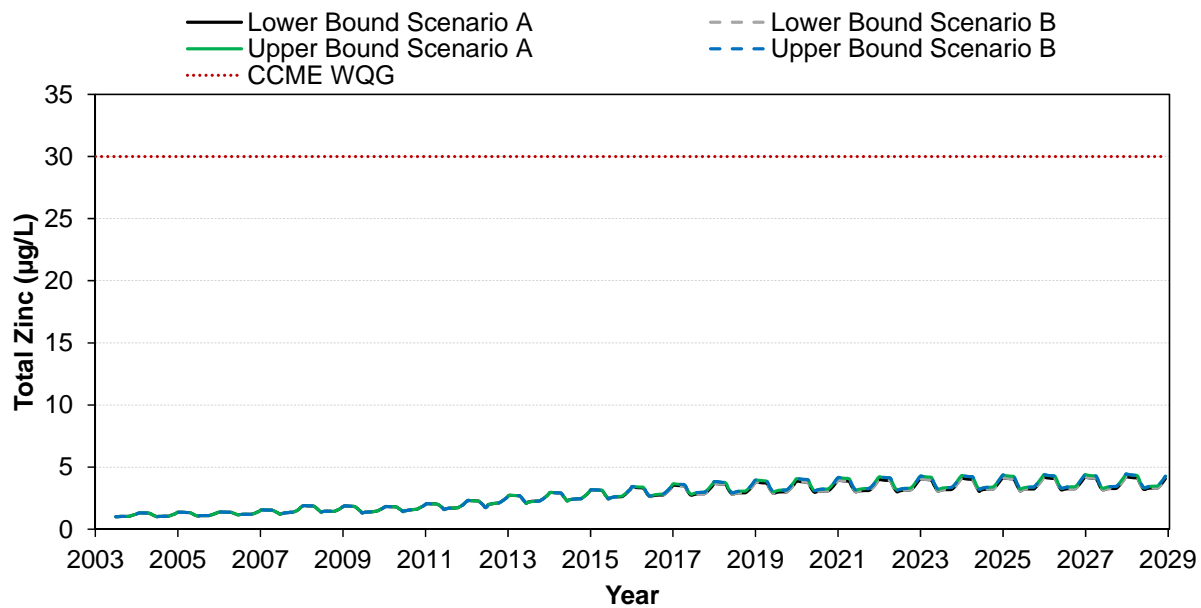

(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

µg/L = micrograms per litre; CCME = Canadian Council of Ministers of the Environment; SNP = Surveillance Network Program; WQG = water quality guideline.

Figure V-20 Predicted Depth-Averaged Total Zinc Concentrations in Snap Lake

(a) Near diffuser, SNP 02-20e

(b) Outlet, SNAP07

µg/L = micrograms per litre; CCME = Canadian Council of Ministers of the Environment; SNP = Surveillance Network Program; WQG = water quality guideline.