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EKATI Diamond Mine

Water Quality Modelling of the Koala Watershed

April 2012

EKATI DIAMOND MINE

WATER QUALITY MODELLING OF THE KOALA WATERSHED

April 2012
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Executive Summary

Engineers and Scientists

Executive Summary

The Long Lake Containment Facility (LLCF) is the Process Kimberlite Containment Area (PKCA) for the EKATI Diamond Mine (EKATI). A water quality prediction model for the LLCF was originally developed in 2004 and has been used to identify potential water quality concerns and to evaluate water management options for the EKATI site.

This report presents the results of a comprehensive update of the existing model of the LLCF that includes;

- analysis of observed data from EKATI mine (flow and water quality data) up to at least the end of 2010 and in some cases to include data from 2011;
- a method of modelling future Process Plant Discharge (PPD) quality for 30 water quality parameters;
- a model of the chain of lakes lying downstream of the LLCF;
- the current preferred water and Fine Processed Kimberlite (FPK) management option including Beartooth pit; and
- development of Water Quality Benchmarks for 30 parameters.

The model was calibrated against observed data and run for a Base Case future scenario to February 2020. The model predictions were compared to recently developed Water Quality Benchmark values for receiving waters.

For most parameters the model produces predictions for the historical period (2000 to end 2010) that match very well with observed concentrations in Cell D, Cell E, Leslie Lake, Moose Lake, Nema Lake and Slipper Lake. The model is able to predict the inter-annual variations in concentrations (i.e., modelling the rate of increase of concentrations over time) and it also provides good fits to the seasonal variations in water quality throughout the year; with dilution and lower concentrations in freshet (June, July); rising concentrations in summer months with lower natural runoff (August, September); and rising concentrations in winter months due to ice exclusion processes (October through April after which ice begins to melt).

In total water quality predictions were made for 30 parameters. The model results indicate that for eight parameters there is a risk that concentrations in the lakes lying downstream of the LLCF could exceed at least 75% of the Water Quality Benchmark from end 2010 to February 2020. Of these, seven are predicted to exceed 100% of the Water Quality Benchmark in this period. However, of those that are predicted to exceed the benchmark; phosphate predictions are impacted by a recent fertilization study in LLCF that has ended; the cadmium benchmark is known to be very low (and below baseline concentrations in the lakes); and chloride, chromium, potassium and selenium concentrations exceed their benchmarks only in winter months when ice exclusion processes raise concentration temporarily in the free under-ice water. Concentrations of aluminium are predicted to exceed Water Quality Benchmarks in open water months and for multiple years during the remaining life time of the mine.

The model is data driven in that nearly all parameters and inputs are based on analysis of observed data at the EKATI mine. Given that there are generally around 10 years of data at EKATI, for most parameters there is a reasonably high degree of confidence that the historical data provide a good basis for future predictions. However, as with all modelling there remain uncertainties in simulating the behaviour of managed and natural systems.

Acknowledgements

Engineers and Scientists

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Table of Contents

EKATI DIAMOND MINE

WATER QUALITY MODELLING OF THE KOALA WATERSHED

Table of Contents

List of Figures

List of Tables

List of Appendices

Glossary and Abbreviations

Glossary and Abbreviations

Terminology used in this document is defined where it is first used. The following list will assist readers who may choose to review only portions of the document.

BOD	Biological Oxygen Demand
EKATI	EKATI Diamond Mine
FPK	Fine Processed Kimberlite
LLCF	Long Lake Containment Facility
LOA	Life of Asset
PK	Processed Kimberlite
PKCA	Processed Kimberlite Containment Area
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solids

1. Introduction

1. Introduction

The Long Lake Containment Facility (LLCF) is the Process Kimberlite Containment Area (PKCA) for the EKATI Diamond Mine (EKATI) and has been in operation since 1998. The Long Lake drainage basin is at the headwater of the western Koala watershed which feeds into the Lac de Gras watershed. The LLCF encompasses Long Lake, which was a large, deep lake, and the former headwater lakes within the Long Lake drainage basin, including Nancy Lake, Brandy Lake and Willy Lake. Down gradient of the LLCF in the Koala watershed are Leslie Lake, Moose Lake, and Nero, Nema, Martine and Slipper Lakes.

The LLCF is divided into a number of compartments or 'cells' for the management Fine Processed Kimberlite (FPK) (Figure 1-1). FPK and other mine waters are discharged into Cells A, B and C, the upstream cells of the LLCF. Solids are retained in Cell C by an dike that separates Cells C and D; however, liquids are able to infiltrate through the dam and enter Cell D. Mixing of FPK supernatant and other mine waters occurs in Cells D and E, before water is discharged from Cell E to the receiving environment in Leslie Lake. There is a permeable dike between Cells D and E and an impermeable frozen core dam at the downstream end of Cell E, preventing uncontrolled releases from Cell E to the receiving environment. Water is released from Cell E by pumping, and discharges are controlled under the EKATI site Water License (Water License W2009L2-0001).

The water discharged from the LLCF flows into Leslie Lake, and then through Moose, Nero, Nema, Martine, Rennie and Slipper Lakes before flowing to Lac de Gras. Within the chain of lakes water discharged from the LLCF is mixed with lake water and natural runoff that enters the lakes from surrounding land. A more detailed review of the history of the LLCF is provided by McKenzie et al. (2011).

A water quality prediction model for the LLCF was developed by Rescan Environmental Services Ltd. for BHP Billiton in 2004 and reported in Rescan (2006a). The model has developed incrementally over the last seven years. During this time the model contributed to identifying potential water quality concerns and to the evaluation of potential water management options, such as the option to discharge underground water to Beartooth pit (to lower chloride concentrations in LLCF) and to undertake fertilization work within Cell D of the LLCF (to lower nitrate concentrations in LLCF).

This report presents the results of a comprehensive update of the LLCF water quality prediction model (LLCF Load Balance Model) and of a model representing the chain of lakes lying downstream of the LLCF (LLCF Downstream Model). For the purpose of this report the two models are collectively called the LLCF Model (the Model). The model update was undertaken to support ongoing site water management.

The modelling was developed within the GoldSim modelling suite, Version 10.11. GoldSim is an industry standard modelling package used for mass balance modelling of FPK storage facilities and mine site water balances at many other mine sites worldwide.

The report outlines key modelling assumptions, describes key model inputs and outputs and provides water quality predictions for a number of key water quality parameters. Water quality predictions are provided for the LLCF and downstream lakes over an operational period to February 2020. These predictions are compared to Water Quality Benchmark values developed for the purpose of this study.

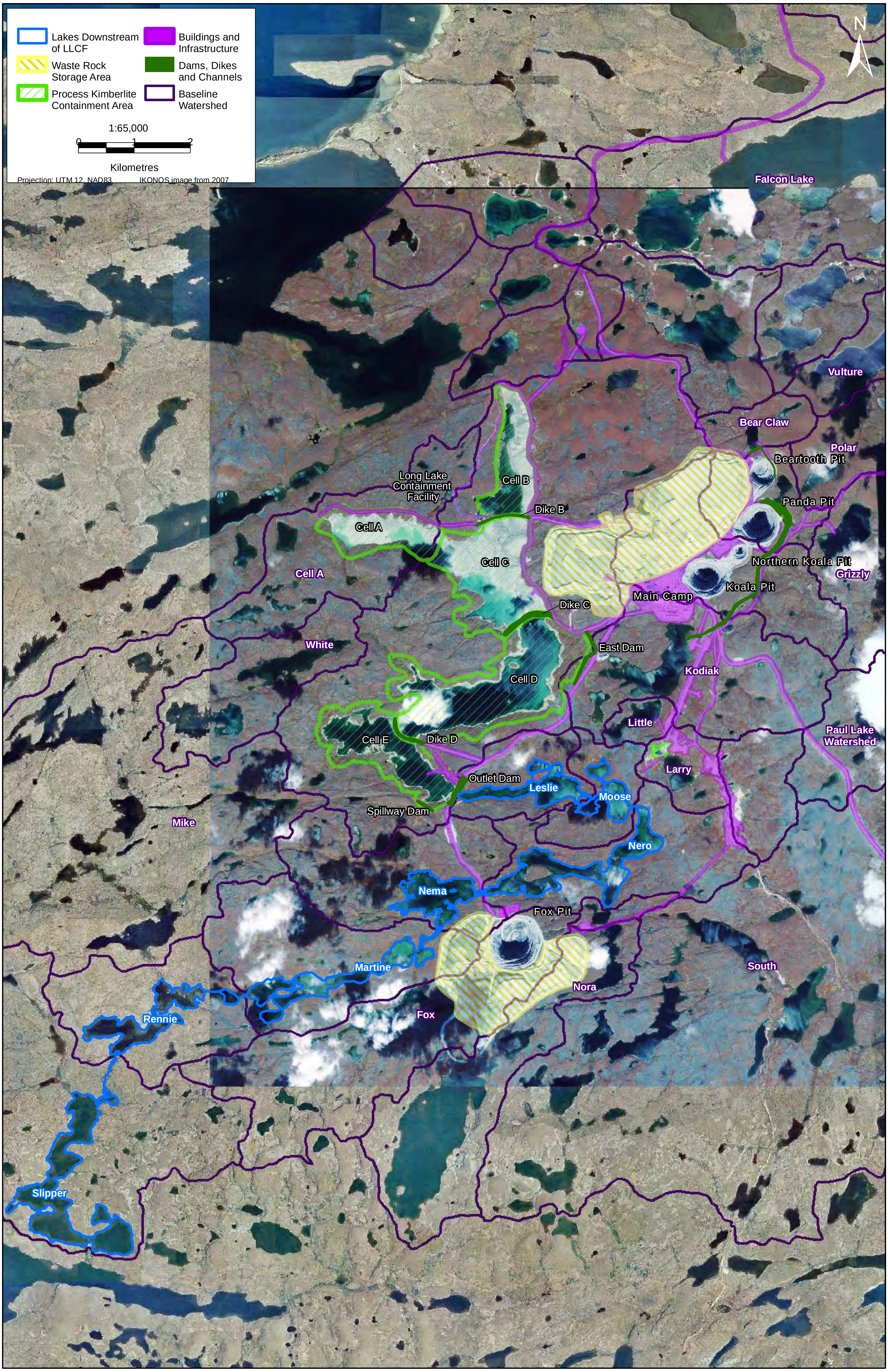

FIGURE 1-1

Long Lake Containment Facility and Downstream Lakes

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2. Overview of Modelling Work

2. Overview of Modelling Work

This report describes the development and testing of a model that predicts water quality in the LLCF and downstream lakes. This report focuses on the Base Case, which is the currently planned and approved operation of mine water and processed kimberlite. The model continues to be a tool to help evaluate different potential site water management options.

The model predictions are compared to observed water quality in the LLCF and downstream lakes during the historical period of mine operations to evaluate the fit of the model to the real world. The model predicts seasonal and annual variations in water quality in the LLCF and in downstream lakes to improve the fit to observed data.

A conservative mass balance modelling approach was adopted to run on a sub-monthly time step which was adequate to evaluate the model against observed data their seasonal trends. The model provides sufficient complexity to represent key processes in LLCF and downstream lakes, while retaining a simple modelling approach that allows it to be run rapidly to test different water management options.

This chapter provides more details of the modelling approach taken, a description of the modelled area (model domain), a discussion of key model assumptions and a summary of the mine plan used in the model.

2.1 MODELLING APPROACH AND MODEL DOMAIN

This report presents the results of a comprehensive update of the LLCF water quality prediction model (LLCF Load Balance Model) and of a model representing the chain of lakes lying downstream of the LLCF (LLCF Downstream Model).

Two models were developed; (i) LLCF Load Balance Model; (ii) LLCF Downstream Model. The models can be run separately or linked together in a single model (LLCF Model). The results presented in this report are based on running the two models separately for flows, but with predicted water quality in Cell E of the LLCF Load Balance Model used as a boundary input to the LLCF Downstream Model. This approach was taken to provide flexibility in terms of running different water management scenarios, while maintaining model stability. The LLCF Downstream Model is run with a user-defined outflow hydrograph from the LLCF (typically based on the average outflow hydrograph from observed data). However, with such a tight constraint on timing of discharges from the LLCF Load Balance Model there was a risk of Cell E becoming dry and the model crashing at certain times (as the volume of Cell E is low relative to the annual flow volume passing through the LLCF). As a result, the LLCF Load Balance Model was run with a more flexible outflow routine that mimics closely the observed hydrograph but is not constrained to the hydrograph shape. Model runs undertaken with the linked and separate models were compared and showed little difference in predicted concentrations between the two approaches, with any differences less than observed annual variation. However, the separation of the models allows for more flexible operation of the models.

The LLCF Load Balance Model contains a representation of all the cells within the LLCF; Cells A, B and C are modelled as a separate unit; Cell D has two vertical units (upper and lower layers) and Cell E is a separate unit. The LLCF Load Balance Model also contains a sub-model representing the inflows, outflows and water quality of Beartooth pit. The model includes all inflows and outflows from the LLCF including inflowing catchments surrounding the facility, precipitation on and evaporation from lake surfaces and all pumped inflows and outflows from the LLCF (i.e., FPK inputs, reclaim water outflows, other mine water inflows). Figure 2.1-1 presents a schematic overview of the key aspect of water and wastewater management considered in the LLCF Load Balance Model.

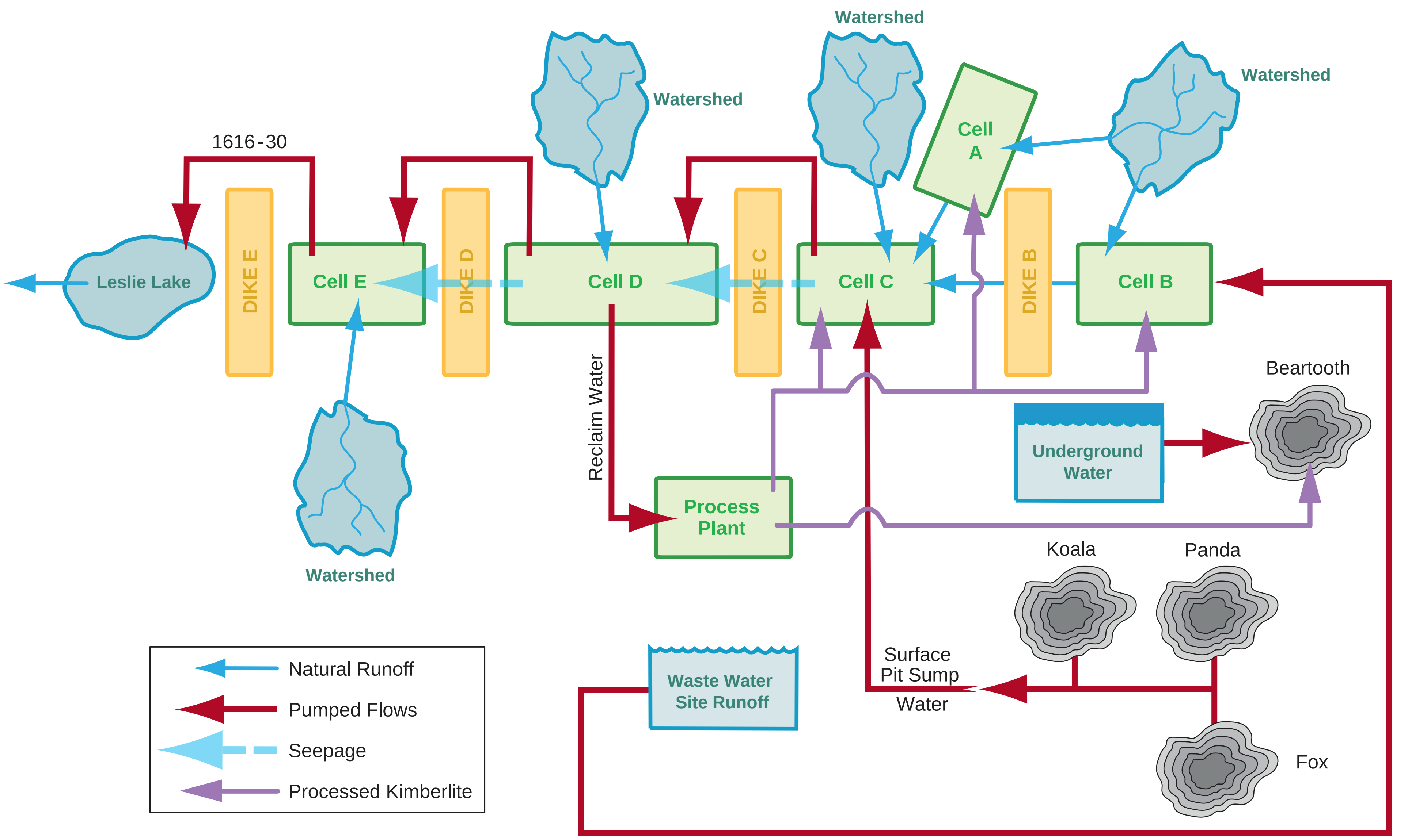


Figure 2.1-1

Schematic of Water and Wastewater Management in the Long Lake Containment Facility

The LLCF Downstream Model contains a representation of lakes lying downstream of the LLCF; Leslie, Moose, Nero, Nema, Martine, Rennie and Slipper Lakes (Figure 1-1). The model predicts outflows to Lac de Gras from Slipper Lake, but does not provide water quality predictions for Lac de Gras. The type of mass balance modelling approach considered for the downstream lakes is not suitable for modelling the large Lac de Gras. The model predicts flow through the lakes and inputs to the lakes from natural runoff from surrounding catchments as well as precipitation on, and evaporation from, lake surfaces.

Both the LLCF Load Balance Model and the LLCF Downstream Model include an ice formation routine that simulates loss of free water to ice during winter months.

All inputs to the model are based on modelling approaches developed using observed data at the EKATI site. This includes representation of catchment runoff, pumped discharges to the LLCF (quality and quantity) and outflow hydrographs.

Key assumptions of the model approach are:

- Assumption of full mixing of water bodies;
- Assumption of non-reactive parameters (except nutrients);
- Assumption of equivalence of dissolved and total metals in EKATI water quality dataset; and
- Assumption of sub-monthly model time step.

More details related to each assumption are provided in the following sections.

2.1.1 Assumption of Full Mixing of Water Bodies

The model assumes that all water bodies are fully mixed after each model time step (i.e., the concentration of any parameter is constant throughout the water body and there are no horizontal and vertical variations within each cell), although the model can be adjusted to allow the development of two layers within Cell D.

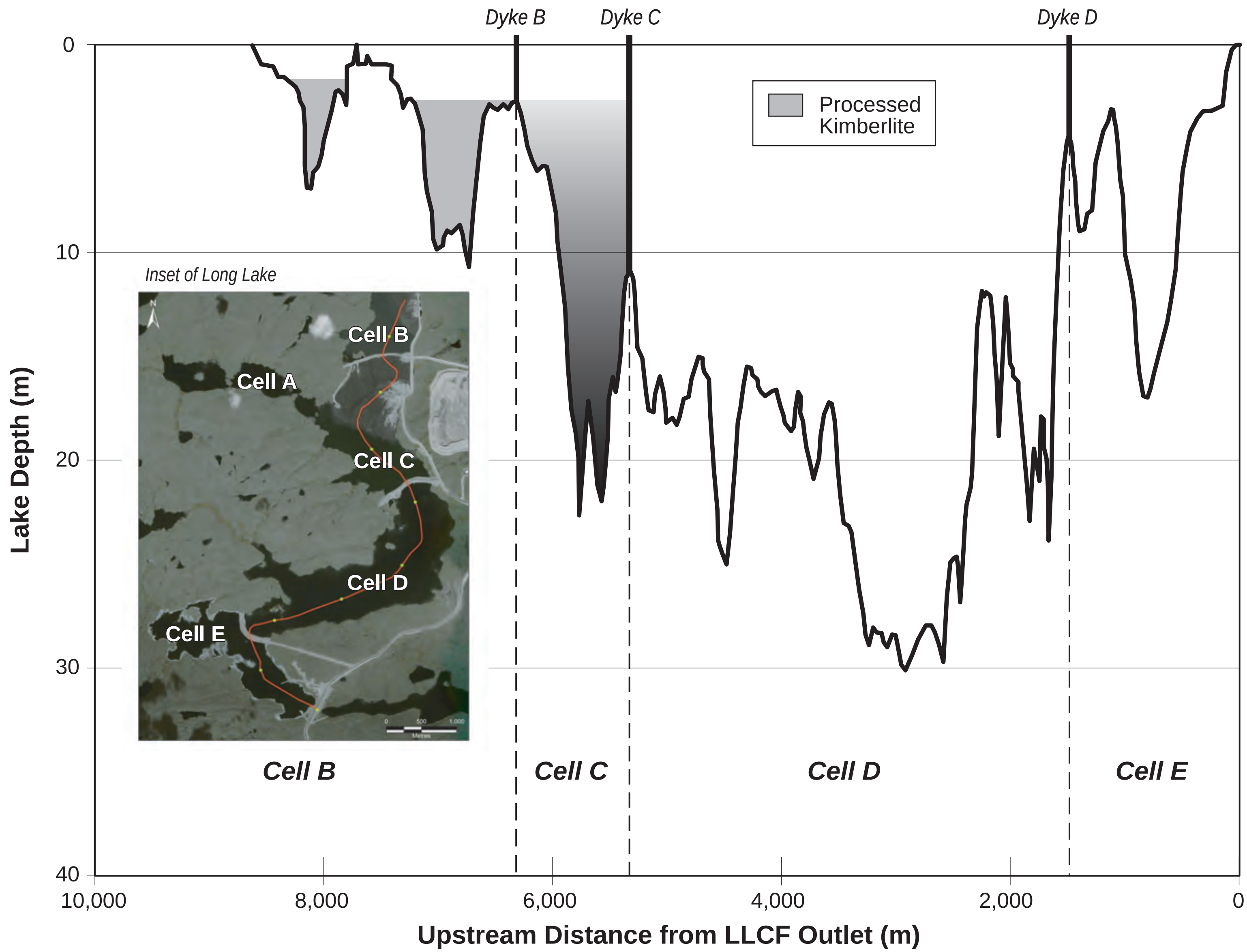
For the downstream lakes the assumption of full mixing is considered appropriate, as the lakes are relatively small and shallow so mixing throughout the water bodies should be attained on a timescale that is short compared to each model time step. Data reported in Rescan (2011b) suggests some weak temperature stratification in July and August for deeper lakes (e.g., observed in Leslie Lake). In addition, some of the downstream lakes (e.g., Nema, Martine, Rennie and Slipper) have embayments that are partially isolated from the main flow pathway through the lakes. If there is limited mixing between these isolated areas and the main flow path through the lakes, some spatial variation in concentrations within the might be expected. However, based on a detailed study of spatial variations of EKATI lakes (Rescan 2008) these variations would appear local in space and time and would not be expected to impact long-term trends in water quality within the lakes. As the results of the LLCF Downstream Model provide good fits to observed data in the downstream lakes (see Section 6.2) any horizontal or vertical variations in mixing within the lakes appear to be of minor importance when interpreting the modelling results.

Cell E is a relatively small water body, but has water depths up to 17 m near its mid-point, Figure 2.1-1. The volume of water flowing through Cell E annually is of the same order as the total water volume of Cell E. Hence, although Rescan (2011b) identifies the presence of minor vertical stratification in salinity and solute concentrations in Cell E during early summer (July) since 2007, these short lived differences in concentrations appear to be too short in duration and small in magnitude to impact the overall water chemistry and solute loadings within Cell E. Over the majority of the year the data indicate that Cell E is fully mixed, consistent with the model assumption of a fully-mixed cell.

Cell D is significantly larger than the other water bodies (Figure 2.1-2) and there may be some vertical and horizontal variations in concentrations within this water body. Field investigations in 2005 and 2006 indicated marked vertical stratification within Cell D, with higher salinity at depth within Cell D than observed close to the surface. The stratification remained in place for most of the year, with full mixing of the layers occurring in autumn due to breakdown of thermal stratification caused by surface cooling. The difference in salinity between the upper and lower layers in Cell D was highest in 2005 and decreased in 2006. Ongoing measurements in Cell D (Rescan 2011b) indicate more limited stratification in Cell D after 2006, with measurements available up to autumn 2010. Hence, it would appear that the strongly defined stratification observed in 2005 and 2006 may have been a transient feature. However, data presented in Rescan (2011b) does indicate differences in salinity and solute concentrations between the upper and lower layers of Cell D, primarily due to the effects of ice exclusion (with denser solute rich water excluded from ice sinking through the water column) and during freshet (with less dense melt water forming a surface layer). Both of these processes would lead to a surface layer in the LLCF with lower solute concentrations than predicted by a fully mixed box model.

The LLCF Load Balance Model represents Cell D as two layers with full mixing of the layers during freshet and autumn. The model can be adjusted to allow only one period of mixing in each year (e.g., autumn mixing only), but the Base Case model run assumes full mixing twice a year. Although this represents the general mixing processes in Cell D the LLCF Load Balance Model is not a hydraulic model and does not model the flow to depth of more dense solute rich water excluded during ice formation. In addition, although the model has two layers, these layers have a fixed depth and do not predict a fresh water layer that changes in thickness during ice melt. In practice, these limitations would tend to result in the LLCF Load Balance Model over-predicting concentrations near the surface of Cell D in the LLCF during freshet, when there is the largest rate of flow between Cell D and Cell E due to influxes of natural runoff from snow melt. Hence, the LLCF Load Balance Model could over-predict loadings passing from Cell D to Cell E during freshet. This effect was seen during the development and set-up of the LLCF Load Balance Model. Predicted freshet concentrations in Cell D were higher than observed concentrations with the opposite in Cell E. However, later in the year, due to the flushing of loadings from Cell D to Cell E during freshet, concentrations in Cell D were lower than observed. To resolve the difference some natural flows from catchments around Cell D were routed to Cell E to provide additional dilution in Cell E during freshet. This approach replicates the overall effect of the freshwater layer in Cell D, although it does not model the exact mixing processes. In order to model horizontal and vertical variations in concentrations a more detailed modelling approach would be required (e.g., 3D hydro-dynamic model). More detailed models might provide improved estimates of the spatial variation in water quality within Cell D, but they would be more difficult to set up, longer to run and would be more limited in their ability to undertaken rapid scenario runs to assess water management options. It was noted that although the calibration of watershed inflows to Cell D and Cell E produced noticeable changes in concentrations in Cell D throughout the year, this produced minor changes in concentrations in Cell E at all times apart from freshet. Given the excellent fit between observed and predicted concentrations in Cell D and Cell E (outlined in Section 6.2) the modelling approach is considered suitable for the purpose of long-term predictions in the LLCF.

Cell C is impacted by discharges of FPK slurry and other mine waters. Within the model Cell C is modelled as a single unit that allows the mixing of mine water with natural runoff and allows the resultant water to flow to Cell D. There is limited information on vertical and horizontal variation in concentrations in Cell C; however, due to the active discharges of water to the cell the assumption of full mixing is considered reasonable for the purpose of this modelling study.



Note: Bathymetry based on Baseline bathymetry data

Figure 2.1-2

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Profile Cross-Section of Long Lake Containment Facility

Figure 2.1-2

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2.1.2 Assumption of Non-reactive Parameters

The model assumes that most water quality parameters are conservative and do not decay or react over time. The exception to this assumption is for nutrients (ammonia, nitrate, nitrite and phosphate) which are modelled using a first order decay function to account for losses as these parameters are cycled by organisms (i.e., taken up by living plankton and released by decaying plankton) in natural water bodies or volatilized at the lake surface (ammonia).

The assumption that most water quality parameters are conservative is reasonable for water bodies where the pH is close to neutral and concentrations are relatively low. Reactions among parameters are anticipated to be of lesser importance than the uncertainties associated with estimating inflows and outflows from the system. Attempting to model chemical reactions among metals and other related species would require complex geochemical modelling and such models are demanding to set-up and calibrate. In addition, these models typically can only be run effectively for quite narrowly defined conditions and ranges of parameter concentrations. The benefits of the non-reactive assumption for the model appear to out weight the benefits of using more complex geochemical models given the generally good fit of the model predictions to observed data.

2.1.3 Assumption of Equivalence of Dissolved and Total Metals in EKATI Water Quality Dataset

The model is a mixing model and does not predict hydraulics within any of the water bodies. The model cannot therefore explicitly simulate the transport or deposition of suspended sediment. All modelled parameters are in the dissolved state and this is assumed to be equivalent to total metals. This is important as some water quality benchmarks are for total metals.

The assumption of equivalence of dissolved and total metals is reasonable for the LLCF because PK solids in the facility are retained within Cell C, with a dike preventing migration of solids to Cell D. As a result suspended solids concentrations in the LLCF are close to zero. As suspended solids concentrations are close to zero it is reasonably assumed that dissolved metals concentrations predicted by the model are equivalent to total metals concentrations.

In addition, many water quality samples from the EKATI field monitoring programs are analysed only as total metals. Hence, to use these data in the model a similar assumption that total metals are equivalent to dissolved metals is made. However, care is taken to exclude samples which might contain anomalously high suspended solids concentrations (e.g., samples from pit sumps).

2.1.4 Assumption of Sub-monthly Model Time Step

The resolution of most available model inputs are monthly (e.g., totals for FPK inflows, averaged watershed inflows, records of mine water volumes). The model is run on a sub-monthly time step for model stability and to smooth the transition from month to month. This approach is reasonably consistent with the model input data and is assumed to adequately represent the time dependent processes in the LLCF and downstream system. This time step also allows seasonal trends to be predicted and evaluated against the observed data.

2.2 MODEL DURATION

The model has been developed based on the environmental operating plan for the mine. The model considers the current management strategy of using Beartooth pit as a store for underground water from early 2009 and for solids and water associated with the secondary stream of FPK starting in September 2012 (BHP Billiton 2011). Beartooth pit is represented as a sub-model within the LLCF water quality prediction model and the operation of the pit is described in more detail in Section 3.2.5.

The current processed kimberlite and water management strategy, including the use of Beartooth pit for underground water and processed kimberlite, is considered the Base Case in the model. The Base Case is the focus of this report, and other scenarios runs representing other potential management scenarios are not considered in this report.

2.3 WATER QUALITY BENCHMARKS

Through a review of water quality guidelines in North America and of literature in the Ecotox database a set of Water Quality Benchmarks were developed as a screening tool for identifying the relevance of modelled water quality trends (Appendix 1). These benchmarks were developed to be appropriate for application to receiving environments at EKATI. The review focussed on identifying benchmarks that are risk-based and that provide environmental safety. These benchmarks are not meant to replace regulatory instruments that are in place for the site as part of on-going monitoring activities; rather, the focus of the review was to identify benchmarks that are both ecologically relevant and scientifically defensible, and provide a reasonable estimate of a concentration above which risk of adverse effects may become elevated. The water quality benchmarks are shown in Table 2.3-1, and are used to interpret the model results. For reference, the table also includes the Effluent Quality Criteria (EQCs) under the site's Water Licence (W2009L2-0001).

Table 2.3-1. Summary of Water Quality Benchmark Values Used to Interpret Modelling Results

		W2009L2-0001	
Parameter	**Water Quality Benchmark (mg/L)**	**LLCF and KPSF**	**Sable Area**
Chloride	116.6 x ln(hardness) - 204.1, to maximum hardness of 160 mg/L $CaCO_3$		
Sulphate	$e^{(0.9116 \times \ln(\text{hardness}) + 1.712)}$, to maximum hardness of 250 mg/L $CaCO_3$		
TDS	None Proposed. Parameter is modelled as it relates to key consituents		
Phosphate	Leslie Lake 0.0096 , Moose Lake 0.0077, Nema Lake 0.0091, Slipper Lake 0.01	0.2	
Nitrate-N	$e^{(0.9518[\ln(\text{hardness})]-2.032}$, to maximum hardness of 160 mg/L $CaCO_3$		20
Nitrite-N	0.06		1
Ammonia-N	0.59[a]	2	4
Aluminium	0.1	1.0	1.0
Antimony	0.02		
Arsenic	0.005	0.5	0.05
Barium	1		
Boron	1.5		
Cadmium	$10^{(0.86[\log10(\text{hardness})]-3.2)}$ /1,000		0.0015
Calcium	None Proposed. Parameter is modelled as it contributes to water hardness		
Total Chromium			0.02
Chromium (III)	0.0089		
Chromium (VI)	0.001		
Copper	0.2 x $e^{(0.8545[\ln(\text{hardness})]-1.465)}$ /1,000, with minimum benchmark of 0.002	0.1	0.02
Iron	0.3		

(continued)

Table 2.3-1. Summary of Water Quality Benchmark Values Used to Interpret Modelling Results (completed)

		W2009L2-0001	
Parameter	**Water Quality Benchmark (mg/L)**	**LLCF and KPSF**	**Sable Area**
Lead	$e^{(1.273[\ln(\text{hardness})]-4.705)}$ /1,000		0.01
Magnesium	None Proposed. Parameter is modelled as it contributes to water hardness		
Manganese	(4.4 x hardness + 605) /1,000		
Molybdenum	19		
Nickel	$e^{0.76[\ln(\text{hardness})]+1.06}$ / 1,000, to maximum hardness of 350 mg/L $CaCO_3$	0.15	0.05
Potassium	41		
Selenium	0.001		
Sodium	None Proposed. Parameter is modelled as it contributes to TDS		
Strontium	6.242		
Uranium	0.015		
Vanadium	0.03		
Zinc	0.03		0.03

Note: W2009L2-0001 also includes EQCs for total suspended solids (TSS), total petroleum hydrocarbons (TPH), Biological oxygen demand (BOD) and turbidity. These are not included in the table as they are not modelled. See Appendix 1 for details on the derivation of Water Quality Benchmarks.

[a] Ammonia benchmark is based on total ammonia value equivalent to CCME guideline for unionized ammonia of 0.019 mg/L, at temperature = 15℃ and pH = 8, which are upper (conservative) values for the EKATI site.

The model simulates variations in un-speciated Chromium over time. Modelled Chromium concentrations are then post-processed and converted into Chromium (III) and Chromium (VI) species based on the proportions given below:

- Cell E and Leslie Lake; Chromium = 23% Chromium (III) and 78% Chromium (VI); and
- Moose, Nero, Nema, Martine, Rennie and Slipper Lakes; Chromium = 41% Chromium (III) and 59% Chromium (VI).

These values were derived based on chromium speciation analyses undertaken on three water quality samples from close to the outflow from Cell E and three samples from Nero-Nema stream (Appendix 1). The post-processed values for Chromium (III) and Chromium (VI) can then be compared to the chromium benchmarks given in Table 2.3-1.

3. Water Balance Inputs

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3. Water Balance Inputs

The water balance components of the LLCF Load Balance Model and the LLCF Downstream Model control the flow of water through the LLCF and downstream lakes.

This chapter provides a summary of key water balance inputs to the models:

- Hydrological inputs (precipitation, watershed runoff and lake evaporation);
- Mining water inputs and outflows (including FPK, underground water, sump water and reclaim);
- Flows between LLCF cells and discharges from the LLCF; and
- Pumped flows out of the LLCF.

3.1 HYDROLOGICAL INPUTS

3.1.1 Available Data

EKATI data records since 1994 are available for meteorological conditions (i.e., precipitation, temperature, evaporation) and stream flows. Data are reported annually as part of the AEMP or form part of baseline datasets. Precipitation and evaporation records are available for the Koala Meteorological Station located near the main EKATI site. Stream flow gauges are operated on eight streams and lake outflow channels across the EKATI site, including a station on the outflow of Slipper Lake, located downstream of the LLCF. There are a limited number of Environment Canada (meteorology) and Water Survey of Canada (stream flow) monitoring stations in northern Canada. Hence, the EKATI dataset is one of the best available for small northern catchments as it provides a reasonably long period of record and flow measurements focussed on small catchments of the type that drain to the LLCF and downstream lakes. Hence, although there is a degree of uncertainty associated with estimation of surface water runoff from small northern watersheds, the methods used in this assessment are considered as being reasonably robust and based on good quality field data.

Periodically, detailed analyses of the available meteorological and hydrological data are undertaken for the EKATI site with the purpose of developing site specific averages and return period estimates for key meteorological and hydrological variables. The latest update was undertaken using data up to and including 2009 and these values are used in this assessment (Appendix 2). Annual rainfall, snowfall and precipitation totals for the Koala Meteorological Station from 1994 to 2009 are summarized in Table 3.1-1. Flow data for 1995 to 2009 for the gauge on the outflow channel from Slipper Lake are summarized in Table 3.1-2.

3.1.2 Estimation of Runoff Rates from Natural Watersheds

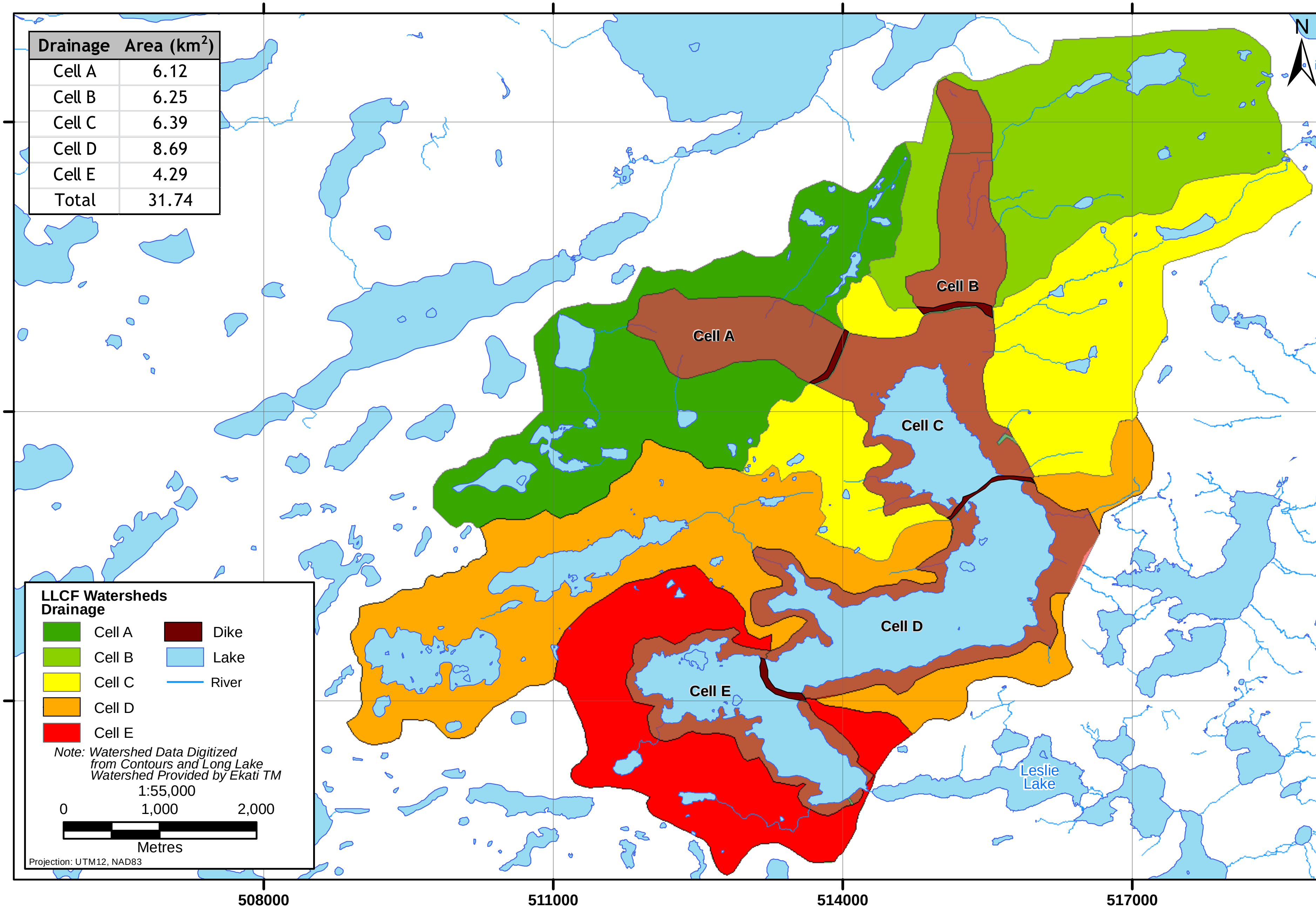
Annual natural runoff totals for watersheds within the study area are calculated using the equation:

Total Annual Runoff (mm) = Total Annual Precipitation (mm) x Runoff Coefficient.

Monthly inflows to water bodies are modelled as:

Average Monthly Inflow (m^3/mon) = Total Annual Runoff (m) x Watershed Area (m^2) x Percentage of Annual Flow Occurring in Month (/mon).

The watershed areas flowing to each water body within the model are summarized in Table 3.1-3 and shown in Figure 3.1-1.



Drainage	Area (km^2)
Cell A	6.12
Cell B	6.25
Cell C	6.39
Cell D	8.69
Cell E	4.29
Total	31.74

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FIGURE 3.1-1

Watershed Areas of the Long Lake Containment Facility

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Table 3.1-1. Summary of Observed Annual Rainfall, Snowfall and Precipitation Totals at the Koala Meteorological Station

	Koala		
Year	Annual Rainfall Total (mm)	Annual Snowfall Total (mm)	Annual Precipitation (mm)
1994	-	-	280
1995	259	260	519
1996	244	266	510
1997	166	57	223
1998	92	279	371
1999	254	204	458
2000	156	116	272
2001	152	184	336
2002	246	75	321
2003	121	171	292
2004	150	72	222
2005	151	97	248
2006	293	133	426
2007	119	138	257
2008	307	115	422
2009	127	124	251
Average	**189**	**153**	**338**

Table 3.1-2. Summary of Flow Data for Gauge on Outflow Channel of Slipper Lake

Year	Runoff Depth (mm)	Precipitation (mm)	Observed Runoff Coefficient	Runoff Volume (Mm^3)	Discharge from LLCF (Mm^3)	Outflow from LLCF as Percentage of Total Flow at Slipper Gauge
1994	-	280	-	-	-	-
1995	123	519	0.24	22.8	-	-
1996	77	510	0.15	14.3	-	-
1997	195	223	0.87	36.1	-	-
1998	-	371	-	-	-	-
1999	298	458	0.65	55.1	17.9	32%
2000	181	279	0.65	33.3	6.8	20%
2001	194	336	0.58	35.9	8.1	23%
2002	84	321	0.26	15.1	3.2	21%
2003	88	288	0.31	16.2	5.2	32%
2004	84	222	0.38	15.7	8.6	55%
2005	113	248	0.46	21.1	4.2	20%
2006	268	430	0.62	49.5	10.1	20%
2007	88	257	0.34	16.3	8.7	53%
2008	130	422	0.31	24.0	5.8	24%
2009	96	251	0.38	17.7	5.6	32%
Average	144	338	0.44	26.6	7.7	30%

Table 3.1-3. EKATI Lake and Catchment Areas

	Lake Area (m^2)	Lake Volume (m^3)	Local Catchment (km^2)
LLCF			42.3 (incl. lakes)
Cells A, B and C	6,300,000	4,000,000	18.7
Cell D	2,810,000	27,000,000	[a]8.7
Cell E	1,480,000	6,800,000	[a]4.3
Leslie Lake	620,000	1,400,000	3.4
Moose Lake	440,000	660,000	39.5
Nero Lake	1,400,000	3,700,000	24.4
Nema Lake	780,000	1,500,000	7.1
Martine Lake	1,000,000	1,800,000	14.5
Rennie Lake	940,000	1,500,000	28.2
Slipper Lake	1,900,000	6,100,000	25.5
Total at Slipper Outflow			***185***
Beartooth pit	150,000	12,100,000	0.21

[a] For calibration of water quality parameters in Cell D, the watershed flowing to Cell E was increased to 8.3 km² and Cell D decreased to 4.7 km² to account for limited mixing of freshet water in Cell D, see Chapter 5 for more details.

Return period annual precipitation totals are provided in Table 3.1-4 with the monthly distribution of the annual totals provided in Table 3.1-5.

Table 3.1-4. EKATI Return Period Precipitation Estimates

Return Period	[a]Annual Precipitation (mm)
1 in 100 dry year	234
1 in 50 dry year	242
1 in 20 dry year	256
1 in 10 dry year	270
Average year	338
1 in 10 wet year	451
1 in 20 wet year	495
1 in 50 wet year	554
1 in 100 wet year	598

[a] Return period analysis was undertaken based on on-site Koala data supplemented by Environment Canada Lupin data. For the period 1994 to 2009 data from Koala was used. For the period 1982 to 1994 Lupin data was used scaled by the average ratio of Koala and Lupin annual precipitation totals for the period of overlapping data (1994 to 2005). This gives a combined dataset of 28 years.

Table 3.1-5. EKATI Monthly Precipitation, Runoff and Evaporation Estimates

	Percentage by Month (%)						
Parameter	May	Jun	Jul	Aug	Sep	Oct	Total
Effective Precipitation[a]	5	55	9	21	6	4	100
Runoff[b]	7	53	23	8	8	1	100
Evaporation[c]	0	40	30	22	7	1	100

[a] Based on EKATI data from 2004 to 2009, assuming that precipitation in winter is retained as snow and melts during freshet.
[b] Based on EKATI stream flow data from 1994 to 2009.
[c] Based on observed EKATI data from 2004 to 2007.

The value for the runoff coefficient for natural catchments surrounding the LLCF is set at 0.65, based on calibration of the LLCF model water balance as outlined in Section 5-1.

The value for the runoff coefficient for natural catchments flowing to the downstream lakes is set at 0.44, which is the average runoff coefficient for observed flows at the Slipper Outflow gauge (Table 3.1-2).

The average runoff coefficient for catchments in the EKATI area based on all flow records is 0.5; however, from year to year and gauge to gauge runoff coefficient values can range from 0.17 to 0.87. The available flow records were analysed to assess whether there were relationships between runoff coefficient and precipitation total (e.g., higher runoff coefficients could be associated with wet years and lower values for dry years), watershed area and/or annual snowfall. However, it was not possible to determine any clear relationships using the available data at the EKATI site. The lack of any relationships of this form may be due to a lack of data, but it may also indicate that such simple relationships do not exist due to the complexity in runoff generating processes in northern Canada. As a result, constant runoff coefficients are used within the LLCF models for all years, with values summarized in Table 3.1-6.

Table 3.1-6. Runoff Coefficients for Different Watersheds/Source Areas

Input	Runoff Coefficient	Comment
Catchment flowing to LLCF	0.65	Value based on calibration of LLCF water balance, as outlined in Section 5.
Catchments flowing to downstream lakes	0.44	Average runoff coefficient from observed data at Slipper gauge outflow.
Runoff on pit walls	0.85	Used in Beartooth pit sub-model. Tested/calibrated against observed sump flow data at Misery pit (Appendix 3)
Precipitation on lake surface	1	Losses from lakes due to evaporation are accounted separately.

Although return period annual totals are developed for precipitation, the modelled Base Case scenario considers average precipitation and runoff in every year.

3.1.3 Estimation of Precipitation and Evaporation for Lake Surfaces

Annual net inflows due to precipitation on, and evaporation from, the surface of a lake or pond are based on:

Annual Net Input to Lake Surface (mm) = Total Annual Precipitation (mm) – Total Annual Evaporation (mm).

Monthly contributions are modelled as:

Average Monthly Inflow/Outflow (m^3/mon) = ((Total Annual Precipitation (m) x Percentage of Effective Precipitation Occurring in Month (/mon)) – (Total Annual Evaporation (m) x Percentage Evaporation Occurring in Month (/mon)) x Lake Area (m^2).

Lake areas are provided in Table 3.1-3. The runoff coefficient for precipitation landing on a pond is considered as 1, with losses due to evaporation modelled separately as shown in the above equations.

Return period annual precipitation totals are provided in Table 3.1-4. There are insufficient evaporation data to develop return period estimates and comparison of annual precipitation and evaporation data did not allow the development of a suitable relationship between the two parameters. Hence, model runs assume annual average evaporation in all years.

The monthly distribution of the annual totals is provided in Table 3.1-5. It should be noted that an ‘effective’ precipitation monthly distribution is defined in Table 3.1-5. These percentages reflect the impact of snowmelt and rainfall on the lake surface. All precipitation falling in the winter months is assumed to be snow, and that this snow melts during May and June. Hence, in Table 3.1-5 the winter monthly percentages equal zero (i.e., precipitation is stored as snow) and the high monthly percentages in May and June reflect snowmelt.

Although return period annual totals are developed for precipitation, the modelled Base Case scenario considers average precipitation in every year.

3.1.4 Modelling of Ice Formation

Lake ice at EKATI can thicken to 2 m by the middle of winter. For small water bodies, the volume of water held as ice in winter can be a significant proportion of the total lake water volume. Ice formation and melting has a limited net impact on the annual lake water balance, as water frozen during winter months is returned to the lake in spring. However, ice is nearly pure water, with chemical constituents in the lake water excluded from the ice and left in the un-frozen lake water below the ice. This can have a major impact on concentrations of parameters in lake water during winter months as the volume of free water decreases, but the total mass of chemical constituents in the water remaining the same; resulting in increased concentrations in winter months.

The rate of ice formation in the LLCF and downstream lakes is based on field measurements taken during winter water quality sampling during two winters in the LLCF. Table 3.1-7 shows how the depths of ice varies linearly over time.

Table 3.1-7. Ice Thickness Values used in Model Based on Measurements at the LLCF from Winters 2005/2006 and 2006/2007

Date	Ice Thickness (m)
September 15	0
October 15	0.25
December 15	1.25
January 15	1.7
April 15	1.7
May 15	1
June 1	0

3.1.5 Groundwater Flows to Natural Water Bodies

The EKATI area is underlain by permafrost. Groundwater flows to the modelled water bodies are considered to be zero. Groundwater flows to underground workings and Fox pit are considered in Section 3.2.4.

3.2 LLCF MINE WATER INPUTS AND OUTPUTS

The LLCF receives mine water from the following sources:

- FPK water discharged from the Process Plant;

- o Sump water from open pits;
- o Water from underground workings; and
- o Sewage.

Reclaim water is pumped from the LLCF for use in the Process Plant.

In June 2009 a plan was put in place to discharge underground water to Beartooth pit (see BHP Billiton 2010). In time (after September 2012) the PK slurry will also be discharged to Beartooth pit (BHP Billiton 2011). This will continue until a target water level in Beartooth pit is reached, whereupon a balance will be maintained between discharges of underground water and FPK to the pit and the pumping of excess water to the Process Plant as reclaim or discharge to the LLCF. More details of the modelling of the water balance of Beartooth pit are provided in Section 3.2.5.

Water is pumped from the LLCF to Leslie Lake. Details of the pumping rates are provided in Section 3.4.

3.2.1 Process Plant Discharge

FPK slurry from the Process Plant is discharged to Cells A, B and C within the LLCF. Within the LLCF model, Cells A, B and C are represented as a single unit. Although solids totals are accounted for in the model, the key variable for the model water balance is the volume of free water within Cell C that is not held within the pores of the settled FPK. This is calculated as:

$$\textit{Free Water } (m^3/mon) = \textit{Total Water with FPK Slurry } (m^3/mon) - \textit{Pore Water in Settled FPK } (m^3/mon)$$

Historical annual totals related to FPK discharges to the LLCF are summarized in Table 3.2-1. Based on data presented in Table 3.2-1, around 4.2 Mt of kimberlite ore has been processed annually. Of this, between 40% and 70% of the ore is discharged to the LLCF as FPK (i.e., solids <0.5 mm). The rest of the processed kimberlite (coarser material) is deposited for the most part in the waste rock storage areas. A similar tonnage was used for the LLCF Load Balance Model.

Table 3.2-1. Observed Processed Kimberlite and Reclaim Discharge Data

Year	Ore Processed (tonnes)	Coarse Kimberlite Rejects (tonnes)	% Ore is FPK to LLCF	Total Solids to LLCF (m^3)	Process Plant FPK Discharge (m^3)	% Solids by Volume in FPK Slurry	Reclaim Water (m^3)	Reclaim as % of Water by Volume in FPK Slurry
[a]1999	1,861,576	494,511	73	506,320	[d]-	-	2,559,278	-
2000	3,013,489	824,182	73	817,259	[d]-	-	4,392,644	-
2001	3,310,930	879,832	73	900,407	[d]-	-	4,581,661	-
2002	3,794,841	1,224,990	68	951,797	[d]-	-	4,389,158	-
2003	4,447,795	1,589,200	64	1,058,739	[d]-	-	4,580,418	-
2004	4,519,871	2,245,853	50	842,229	[d]-	-	5,158,936	-
2005	4,430,414	2,251,052	49	807,171	[d]-	-	5,139,299	-
2006	4,497,852	2,545,347	43	1,171,382	6,312,800	18.6	4,877,592	95

(continued)

Table 3.2-1. Observed Processed Kimberlite and Reclaim Discharge Data (completed)

Year	Ore Processed (tonnes)	Coarse Kimberlite Rejects (tonnes)	% Ore is FPK to LLCF	Total Solids to LLCF (m^3)	Process Plant FPK Discharge (m^3)	% Solids by Volume in FPK Slurry	Reclaim Water (m^3)	Reclaim as % of Water by Volume in FPK Slurry
2007	4,331,604	2,362,071	45	1,181,980	6,232,998	19.0	4,297,647	85
2008	4,342,047	2,572,637	41	1,126,112	5,873,065	19.2	4,163,717	88
2009	5,097,630	2,962,168	42	1,328,140	6,358,323	20.9	4,663,563	93
[b]2010	2,133,666	1,319,019	38	515,373	2,446,077	21.1	1,818,731	94
Average	[c]*4,178,647*	[c]*1,945,733*	[c]*55*	[c]*1,018,521*	[e]*6,194,297*	[e]19.7	[c]*4,624,463*	[e]90.9

[a] *Data available up to end of June 1999 only*
[b] *Data available up to end of May 2010 only*
[c] *Average of 2000-2009*
[d] *Data not included in EKATI spreadsheets*
[e] *Average of 2006-2009/10*

The observed data suggest that the FPK slurry is around 20% solids by volume. This is consistent with data presented in EBA (2002), and summarized in Table 3.2-2.

Table 3.2-2. Estimated Water Content of FPK

State of **FPK**	Solids Content (% by mass)	Solids Content (% by volume)	Density of FPK Slurry (tonnes/m^3)	Void Ratio (e)
At Discharge	30 – 40	14 - 20	0.37 - 0.53	6.3 - 4.0
Settled	45	23	0.63	3.3
Partially Consolidated	56	32	0.86	2.1
90% Consolidated	62	38	1.02	1.7
Dry	100	100	2.7	-

The key assumptions used in the LLCF Load Balance Model regarding FPK discharges to the LLCF are based on historical data (Table 3.2-3).

Table 3.2-3. Summary of Key Parameters Used in Model for PFK Discharges to LLCF

Modelled Input	Solids Content (% by mass)
Processed Kimberlite (PK) solids discharge rate	Observed PK solids volumes are used for period June 1999 to May 2010. For period post May 2010 the model is based on information provided by BHP Billiton
Dry Density of PK ore	2.7 tonnes/m^3
Percentage loss to coarse kimberlite	33%
Slurry water content	81.5% water by volume and 62% water by mass
Water content in settled FPK	62.3% water by volume and 38% water by mass

3.2.2 Reclaim Water

From 2000 to 2009 the annual average reclaim volume was 4.6 Mm^3/year (Table 3.2-1), which was approximately 90% of the water discharged to the LLCF with FPK. Hence, within the LLCF Load Balance Model the reclaim volume is calculated as;

$$\text{Reclaim Water } (m^3) = \text{Water Content of FPK Slurry } (m^3) \times 0.9$$

Pre-2007 reclaim water was taken from Cell C and Cell D in the LLCF. There are no clear records of the timing of movements of the reclaim barge from Cell C to Cell D. However, it is understood that the reclaim barge was placed in Cell C during summer months or when there was a sufficiently deep pond in Cell C, with the barge moved to Cell D at other times. Within the model (pre-January 2007) reclaim water is taken from Cell C in the period June to September and from Cell D in other months. Sometime around 2007 the reclaim barge was permanently placed in Cell D and within the model reclaim is taken from Cell D as default from January 2007 onwards. However, it is noted that in the later years of the mine life reclaim water will also be taken from Beartooth pit and details of the model approach to Beartooth pit are outlined in Section 3.2.5.

3.2.3 Sump Water

Water accumulating at the bottom of open pits is pumped to the LLCF and discharged to Cell C. Historical sump water volumes pumped to the LLCF are summarized in Table 3.2-4.

Table 3.2-4. Summary of Historical Mine Water Inflows to LLCF, as Annual Total Pumped Flows

	Annual Total Pumped Flow (m^3)							
Year	From Fox Pit	From Beartooth Pit	From Panda Pit	From Koala Pit	From Underground	From Koala N Open Pit	Mine Water to Beartooth Pit	From LLCF
1999	0	0	272,034	1,819,398	0	0	0	17,912,450
2000	0	0	167,549	1,252,454	0	0	0	6,755,546
2001	0	0	336,840	403,776	0	0	0	8,121,894
2002	0	0	221,275	140,522	0	0	0	3,236,880
2003	2,825,767	52,036	177,509	105,080	54,631	0	0	5,211,576
2004	139,349	39,048	94,929	82,295	302,045	0	0	8,645,352
2005	68,483	37,419	32,621	82,819	438,015	0	0	4,219,779
2006	389,720	82,440	41,545	251,091	535,001	0	0	10,092,221
2007	169,530	33,705	33,802	120,591	325,598	0	0	8,695,085
2008	335,107	27,335	149,989	37,339	503,067	0	0	5,824,577
2009	137,109	0	2	94,971	352,772	3,395	2,692	5,582,205
2010	353,909	0	65,073	87,309	401,611	0	401,611	7,840,050
2011	471,883	0	0	161,052	562,411	26,336	562,411	8,505,902
[a]Average	258,136	45,331	152,809	125,081	427,565	26,336	482,011	6,894,256

[a] *Averages based on annual totals shaded orange for each parameter.*

Within the model for the period 1999 to 2011 observed monthly inputs are used for each open pit. For future years (2012 to 2020) average monthly pumped flows from analysis of the historical data are used, with values as defined in Table 3.2-5. It is assumed that once mining operations within a pit cease there will be no further pumping from the pit sump and water will be allowed to pond at the bottom of the pit.

For pits that are not yet in operation (Pigeon) the sump inflows are based on modelling work previously undertaken (unpublished). Monthly flow volumes are summarized in Table 3.2-6.

Table 3.2-5. Summary of Historical Mine Water Inflows to LLCF, as Average Monthly Pumped Flows

Year	Average Monthly Pumped Flow (m^3)							
	From Fox Pit	From Beartooth Pit	From Panda Pit	From Koala Pit	From Underground	From Koala N Open Pit	Mine water to Beartooth Pit	From LLCF
Jan	1,190	0	2,247	771	20,260	0	16,611	86,439
Feb	0	0	6,076	836	14,745	0	15,508	96,108
Mar	0	0	2,696	0	15,397	0	16,577	55,609
Apr	20	0	5,351	2	17,627	0	18,541	0
May	35,499	8,683	21,160	16,592	48,151	66	36,821	0
Jun	48,258	14,169	39,128	27,259	60,242	2,626	53,652	919,470
Jul	39,146	8,214	20,292	24,291	57,899	922	71,941	1,655,031
Aug	43,540	4,235	28,180	17,869	51,474	7,115	68,372	815,147
Sep	54,718	8,824	20,453	21,926	58,162	8,726	68,158	1,106,516
Oct	30,983	1,206	12,173	9,703	46,066	5,617	76,978	1,107,284
Nov	3,453	0	4,433	4,058	19,466	721	20,499	788,363
Dec	1,330	0	2,038	1,774	18,076	543	18,355	264,289

Table 3.2-6. Predicted Monthly Flows from Pigeon Sump

Year	[a]Average Monthly Pumped Flow Total (m^3)from Pigeon Pit
Jan	0
Feb	0
Mar	0
Apr	0
May	3,600
Jun	35,300
Jul	8,600
Aug	11,100
Sep	4,100
Oct	2,100
Nov	0
Dec	0

[a] *Based on unpublished modelling work.*

3.2.4 Underground Water

Observed annual totals of water pumped from underground workings are outlined in Table 3.2-7 with annual totals converted into flow rates (L/s). From 2004 to 2009 annual average flow rates from underground have ranged between 9.6 L/s to 17.8 L/s, with an average of 13.6 L/s over these years.

Table 3.2-7. Annual Totals of Water Discharged from Underground

Year	Underground Water (m^3)	Underground Water (L/s)
1999	0	0
2000	0	0
2001	0	0
2002	0	0
2003	54,631	[a]-
2004	302,045	9.6
2005	438,015	13.9
2006	535,001	17.0
2007	325,598	10.3
2008	503,067	16.0
2009	352,772	11.2
2010	401,611	12.7
2011	562,411	17.8
AVERAGE	[b]427,565	[b]13.6

[a] *Not full year.*
[b] *Average of years 2004 to 2011.*

There is a high degree of uncertainty associated with future predictions of underground flow rates, with flow rates likely to increase as underground workings extend deeper and become larger. EBA (2006) estimates peak underground flow rates from groundwater modelling work as:

- Panda, inflow to underground = 14 L/s and through the pit base = 7.5 L/s. Note Rescan (2006b) estimated an average rate for Panda pit of 11.3 L/s;
- Koala North, inflow of 4 L/s;
- Koala, inflows assumed the same as Panda (i.e., inflow to underground = 14 L/s; through the pit base = 7.5 L/s) although Klohn Crippen updated their estimate of groundwater flow into Koala to 20 L/s in 2005 (reported in Rescan 2006b); and
- Fox, inflow only through base of the pit = 7.5 L/s.

This gives a total inflow rate of 32 L/s for Panda/Koala/Koala North, which is significantly higher than the present day flow rate. Based on EBA (2006) the annual volume of underground water from Panda/Koala/Koala North would be around 1.4 Mm^3/year, compared to an observed average of around 0.43 Mm^3/year.

Within the model for the period 1999 to 2011 observed monthly inputs are used for underground water. For future years (January 2012 to February 2020) the underground flow rate is set equal to the average of the historical data (i.e., 13.6 L/s average) and not values obtained by modelling (EBA 2006).

A further consideration is that underground water inflows to the Panda/Koala/Koala North workings would be expected to be constant over time if they were primarily sourced from groundwater. However, the available pumped flow data show a high degree of monthly variation (Figure 3.2-1 and Table 3.2-7), suggesting that surface water runoff is able to enter the underground workings and impact the monthly volumes that need to be pumped to surface. The monthly distribution of flows used in the LLCF Load Balance Model are based on the average monthly flows from the historical data set, with values as defined in Table 3.2-8. Hence, the modelled underground flow rate includes a representation of the observed seasonal variation in underground flow rates.

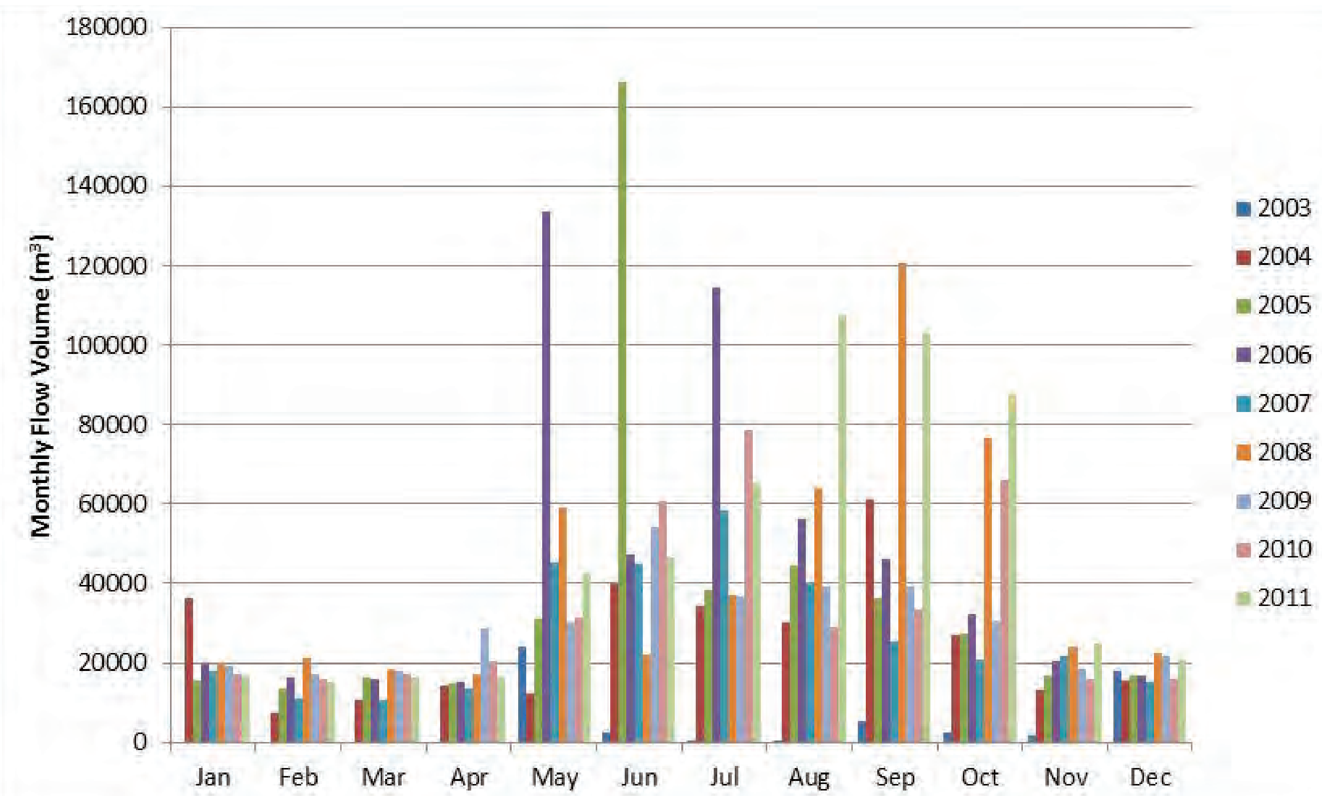

Figure 3.2-1

Monthly Underground Flows

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Table 3.2-8. Monthly Underground Water Flow as Percentages over the Year

	Percentage of Annual Flow in Each Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Underground Water	5	3	4	4	11	14	13	12	14	11	5	4

3.2.5 Beartooth Pit

Processing of kimberlite from Beartooth pit commenced in 2005 and continued until early 2009. Mining at Beartooth pit ceased in 2009 and the pit is currently being used as a store for mine water pumped from underground workings. Permission to discharge mine water to Beartooth pit was obtained in June 11, 2009, as an amendment to the Wastewater and Processed Kimberlite Management Plan. A limited volume of water was discharged in 2009 (18,280 m^3), with underground water discharged from December 2009 onwards. In 2010 approximately 420,000 m^3 of water was discharged into the pit and in 2011 the volume was around 540,000 m^3.

EKATI plan to discharge a secondary stream of FPK to Beartooth pit, to reduce the required storage of FPK in the LLCF, which is the main sink for FPK and mine water at the EKATI site (BHP Billiton 2011). The current plan has underground water placed in Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once water in Beartooth pit approaches 30 m from spill level, free water will be decanted to the Process Plant for use as reclaim water. This is the Base Case used in the LLCF model, where Beartooth pit is represented as a sub-model within the LLCF Load Balance Model.

Key physical characteristics of Beartooth pit are provided in Table 3.2-9. Recent EKATI estimates staff would suggest that the full pit level is at 457 masl, with an operation freeboard of 2 m bringing the maximum operating level to 455 masl (BHP Billiton 2011). However, once FPK solids reach a level 30 m below the full level of the pit (i.e., 427 masl), excess water above this target level will be pumped from the pit and either discharged to LLCF directly or used for reclaim water. FPK solids will be allowed to fill up to 30 m below the spill level with the space above the solids filled with a freshwater cap at closure. The Beartooth pit sub-model does not predict water quality in the pit lake at closure.

Table 3.2-9. Key Physical Characteristics of Beartooth Pit

Pit Diameter (m)	Pit Depth (m)	Pit Surface Area (m^2)	Full Pit Volume (m^3)	Inflowing Catchment (km^2)	Full Pit Lake Level (m)
420	200	200,000	13,400,000	[a]0.21 (1.87)	[b]455

[a] 0.21 km^2 is local catchment surrounding pit and flows to pit during operations. At closure the connection between Beartooth pit and Bearclaw Lake will be re-established so the total catchment at closure will increase to 1.87 km^2.
[b] From BHP Billiton (2011).

Rules considered in the Beartooth pit sub-model include:

- Discharge of underground water to Beartooth pit started in December 2009 and is ongoing;
- Discharge of FPK slurry to commence in September 2012 and to be continuous. In the model FPK solids and supernatant water are discharged to the Beartooth pit sub-model and not to the LLCF;

- When water levels are suitable, water is be pumped to the Process Plant as reclaim from June to October. During this time FPK slurry is discharged to the LLCF. However, in winter months (November to May) the FPK slurry is discharged to Beartooth pit and reclaim taken from the LLCF. There is no discharge of FPK or pumping of reclaim to Beartooth pit in May. At this time FPK discharge and reclaim are directed to the LLCF. However, underground water continues to be discharged to Beartooth pit in all months; and
- There are natural inflows to the pit from precipitation and runoff and losses due to evaporation from the water surface in the pit.

3.2.6 Other (Sewage)

Treated sewage water from the mine site is discharged to the LLCF at a rate of around 100,000 m^3/year.

3.3 FLOWS THROUGH DIKES BETWEEN CELLS

Water flows from Cell C to Cell D and from Cell D to Cell E by seepage through the dikes that divide the cells. Within the model flows between the cells are modelled using the equation;

Flow Rate Through Dike (m^3/s) = (Water Level Upstream Cell (m) – Water Level Downstream Cell (m))/Dam Width (m) x Area of Dike Where Flow Passes Through (m^2) x Hydraulic Conductivity (m/s)

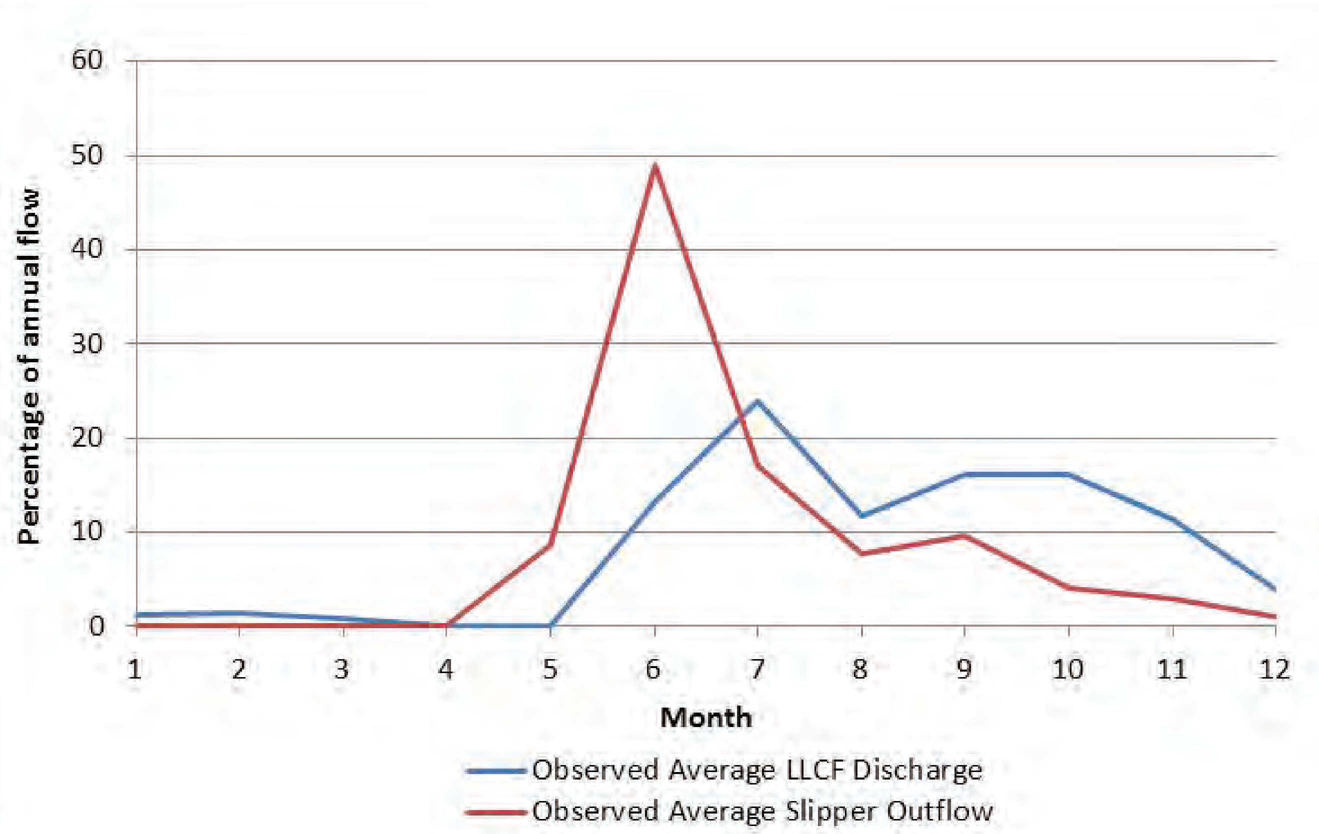
There are limited data available to parameterise or calibrate the flow routine between cells of the LLCF. The model predicts water levels in each cell and estimates were made of the flow area available within each dike. The value of the hydraulic conductivity for each dike was varied until a reasonable fit was obtained between observed and predicted pond level data in Cell D and a reasonable fit was obtained for the bulk water balance for the LLCF. It is likely that a range of flow area/hydraulic conductivity values would produce similar flow rates and there is scope to improve these flow routines with additional field measurements. However, due to a good fit between observed and predicted water quality within the LLCF and downstream lakes (as will be seen in Chapter 6), uncertainties with these flow routines are not anticipated to adversely impact the ability of the model to simulate the evolution of water quality in the LLCF. As a result, these routines are considered a reasonable approximation of the real flow processes through the dikes and are sufficient for the requirements of the modelling study.

3.4 PUMPED OUTFLOWS FROM LLCF TO LESLIE LAKE

Water is discharged from the LLCF to Leslie Lake by pumping. Monthly discharge volumes from the LLCF are recorded at EKATI and are presented in Table 3.4-1. The average monthly flow distribution for historical discharges from the LLCF is provided in Table 3.4-2, where it is compared to the average monthly flow hydrograph for the gauge on Slipper Lake outflow.

The results indicate that the shape of the hydrograph for releases from the LLCF does not exactly match the natural flow hydrograph at Slipper Outflow. The highest discharge rates from the LLCF occur on average in July with a second peak in fall. This compares to the peak of the natural flow hydrograph which occurs in June (Figure 3.4-1).

The difference between the timing of the LLCF discharge hydrograph and the natural flow hydrograph is important as the LLCF discharge does not make best use of the mixing potential in the natural catchment, where the maximum dilution will occur after freshet in June. In addition, discharging water in late summer (September) and into winter months (October to December) provides limited dilution in downstream lakes for the LLCF discharge.



Comparison of Observed Monthly Totals for Slipper Outflow and LLCF Discharge

Figure 3.4-1

Table 3.4-1. Monthly Observed Discharge Volumes from LLCF to Leslie Lake

Month	Monthly Discharge Volume (m^3/mon)												
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
January	1,473,120	0	0	0	0	1,037,263	0	0	0	0	0	0	0
February	1,257,984	0	0	0	0	1,153,299	0	0	0	0	0	0	0
March	1,392,770	0	0	0	0	667,302	0	0	0	0	0	0	0
April	1,347,840	0	0	0	0	0	0	0	0	0	0	0	0
May	1,177,632	0	0	0	0	0	0	0	0	0	0	0	0
June	3,084,480	1,077,291	1,885,028	0	523,848	0	3,071,103	2,690,228	1,786,143	0	0	0	0
July	3,502,656	1,801,152	2,867,880	527,068	657,317	937,992	0	2,382,225	2,439,884	0	1,674,382	2,796,356	3,776,117
August	1,392,768	1,292,739	745,841	1,398,380	458,101	295,964	0	311,294	1,229,794	120,177	1,241,969	1,407,137	1,280,371
September	1,296,000	502,591	1,403,411	0	829,185	937,249	1,148,676	1,347,552	1,231,314	2,296,136	1,294,461	1,220,977	1,066,643
October	1,296,000	745,127	1,160,591	486,251	1,481,073	1,507,431	0	1,346,034	1,247,624	1,343,292	1,281,390	1,382,858	1,305,732
November	691,200	1,201,805	59,143	825,181	905,133	848,774	0	1,310,861	760,326	1,349,368	90,003	1,032,722	1,077,039
December	0	134,841	0	0	356,919	1,260,078	0	704,027	0	715,604	0	0	0
TOTAL	17,912,450	6,755,546	8,121,894	3,236,880	5,211,576	8,645,352	4,219,779	10,092,221	8,695,085	5,824,577	5,582,205	7,840,050	8,505,902

Table 3.4-2. Monthly Flow Percentages for LLCF Discharge and Slipper Outflow Gauge

Month	Percentage Flow Each Month		
	LLCF Discharge	Slipper Outflow as Gauged	Natural Slipper Outflow with LLCF Discharge Removed
January	1.3	0	0
February	1.4	0	0
March	0.8	0	0
April	0.0	0	0
May	0.0	8.7	9.3
June	13.3	48.9	59.5
July	24.0	17.1	15.4
August	11.8	7.8	6.5
September	16.0	9.6	7.3
October	16.0	4.1	1.0
November	11.4	2.9	0
December	3.8	1.0	0

When the LLCF Load Balance Model and LLCF Downstream Model are run separately the LLCF Load Balance Model is run a with pumping routine that maintains a target water level in the pond of 447.5 m (target level used by EKATI staff) with average pumping rates defined to produce a discharge hydrograph that is consistent with observed LLCF discharge and is based on the monthly flow distribution as outlined in Table 3.4-2.

The LLCF Downstream Model is run with an inflow hydrograph (from LLCF) set equal to the average discharge hydrograph from the LLCF based on monthly flow percentages as outlined in Table 3.4-2. This forms part of the Base Case, where the LLCF discharge volumes in the model mimic the long term average monthly discharge practices at EKATI.

4. Water Quality Model Inputs

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4. Water Quality Model Inputs

This chapter outlines the water quality inputs to the LLCF Load Balance Model and the LLCF Downstream Model.

4.1 NATURAL RUNOFF

The quality of natural runoff from catchments surrounding the LLCF and the downstream lakes is based on analysis of data within the AEMP data set. For most catchments the quality of natural runoff is based on the median of observed concentrations at the Vulture Outflow stream monitoring station, which is considered as a stream unaffected by mining activity. However, water quality from the Kodiak Lake site is used for inflows to Moose Lake. Kodiak Lake lies upstream of Moose Lake and inflows to this lake were previously impacted sewage inputs from the main EKATI site (Rescan 2005).

The concentrations used in the modelling work are summarized in Table 4.1-1. Concentrations are considered constant over time.

Table 4.1-1. Natural Runoff Water Quality Estimates of Selected Parameters

	Concentration (mg/L)	
Parameter	**Vulture Stream**	**Kodiak Lake**
Chloride	0.5	0.665
Sulphate	1.265	3.15
TDS	7	14.2
Phosphate	0.006	0.00715
Nitrate	0.0095	0.0307
Nitrite	0.001	0.0005
Ammonia	0.0093	0.014
Aluminium	0.037	0.0375
Antimony	0.0005	0.0005
Arsenic	0.0002	0.000235
Barium	0.00336	0.00782
Boron	0.001	0.001
Cadmium	2.50E-05	2.50E-05
Calcium	0.6715	1.4
[a]Chromium	0.00021	0.0002
Copper	0.001	0.0015
Iron	0.01	0.01
Lead	2.50E-05	2.50E-05
Magnesium	0.563	0.992
Manganese	0.0042	0.0066
Molybdenum	3.00E-05	1.23E-04
Nickel	0.00066	0.00173

(continued)

Table 4.1-1. Natural Runoff Water Quality Estimates of Selected Parameters (completed)

	Concentration (mg/L)	
Parameter	**Vulture Stream**	**Kodiak Lake**
Potassium	1	1
Selenium	5.00E-05	5.00E-05
Sodium	0.45	0.7
Strontium	0.00539	0.012
Uranium	3.60E-05	8.10E-05
Vanadium	0.0001	0.0001
Zinc	0.001	0.00205

[a] Modelled Chromium concentrations are post-processed to Cr(III) and Cr(VI) species based on ratios outlined in Section 2.3

4.2 PROCESS PLANT DISCHARGE

For most parameters (except those with high concentrations in underground water) Processed Kimberlite supernatant water from the Process Plant is the largest source of loadings to the LLCF. Hence, a large amount of effort was expended in trying to prepare good quality estimates of future loadings from the Process Plant to the LLCF.

Observed Process Plant Discharge (PPD) water quality data is available for the period 2000 to mid-2010. During this period there were changes in the proportions of different kimberlite ore passing through the Process Plant (Figure 4.2-1). The available data were analysed to try and develop relationships between PPD concentrations and ore type. Simple relationships could not be identified between changes in PPD water quality and changes in the type of ore processed. It appears that internal variability within each kimberlite (e.g., changes in composition with depth or even between ore samples) is greater than, or at least as great as, variability between kimberlite types, or that other factors obscure clear trends.

As a result, it was not possible to develop time series water quality inputs for the PPD. Instead inputs were developed based on statistical distributions calculated from historical data. Although clear relationships could not be identified between PPD quality and kimberlite ore type, there were general trends that allowed parameters to be divided into three main groups based on the variation in PPD quality over time:

- Group 1. Parameters with marked increase or decrease in concentrations associated with onset of processing of underground ore in 2005/2006;
- Group 2. Parameters with marked change in average concentrations and variability post 2007/2008. There appear to be no reason related to ore type in the Process Plant that would explain the change in concentrations observed in 2007/2008; and
- Group 3. Parameters with no discernible trend, gaps in data or with substantial number of samples below detection limit (masking any trends in data).

A list of parameters within each grouping and the methodology used to develop statistical relationships for input to the LLCF Load Balance Model are outlined in Table 4.2-1. Statistical approaches used for each parameter within the model are described in Table 4.2-2 and graphical examples of the analyses undertaken on PPD data are provided in Figures 4.2-2 and 4.2-3 for two contrasting parameters. Similar approaches were taken for other parameters and results are presented in the Mode Summary Sheets in Appendix 4.

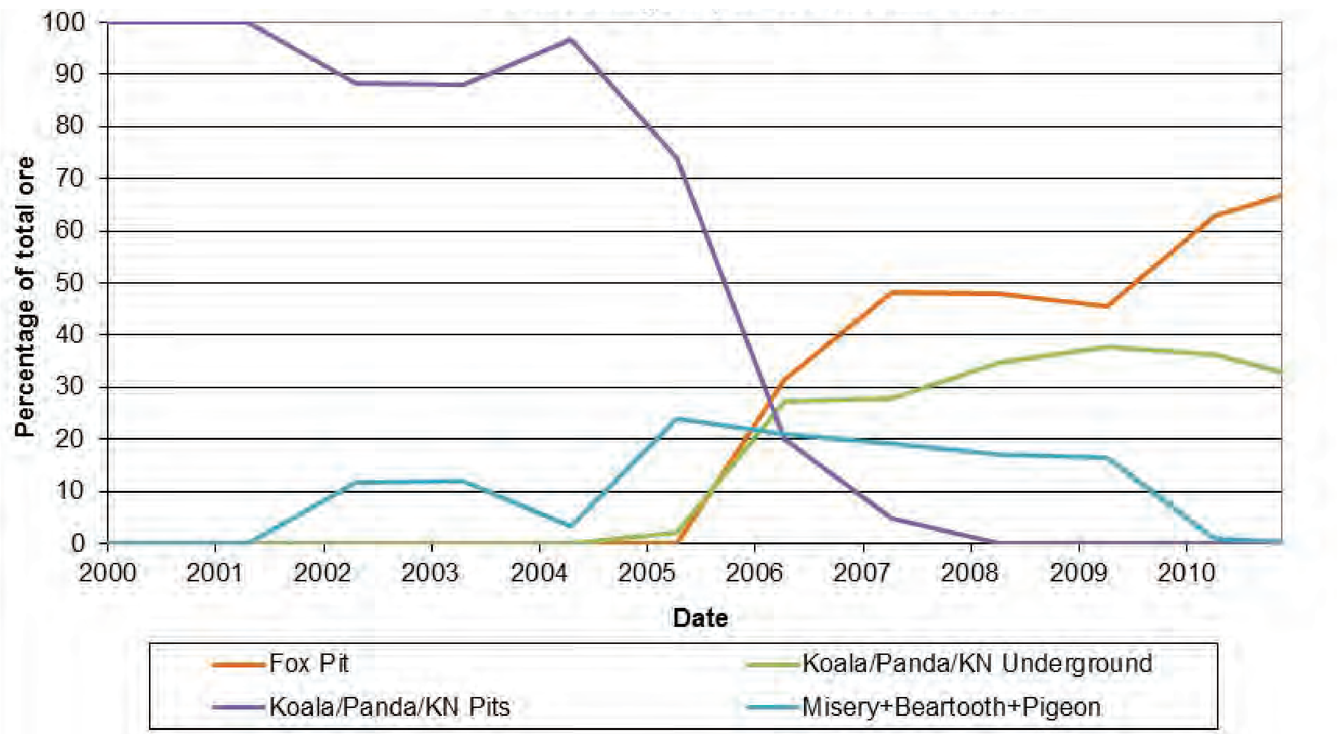

Figure 4.2-1

Percentages of Ore Sent to Process Plant

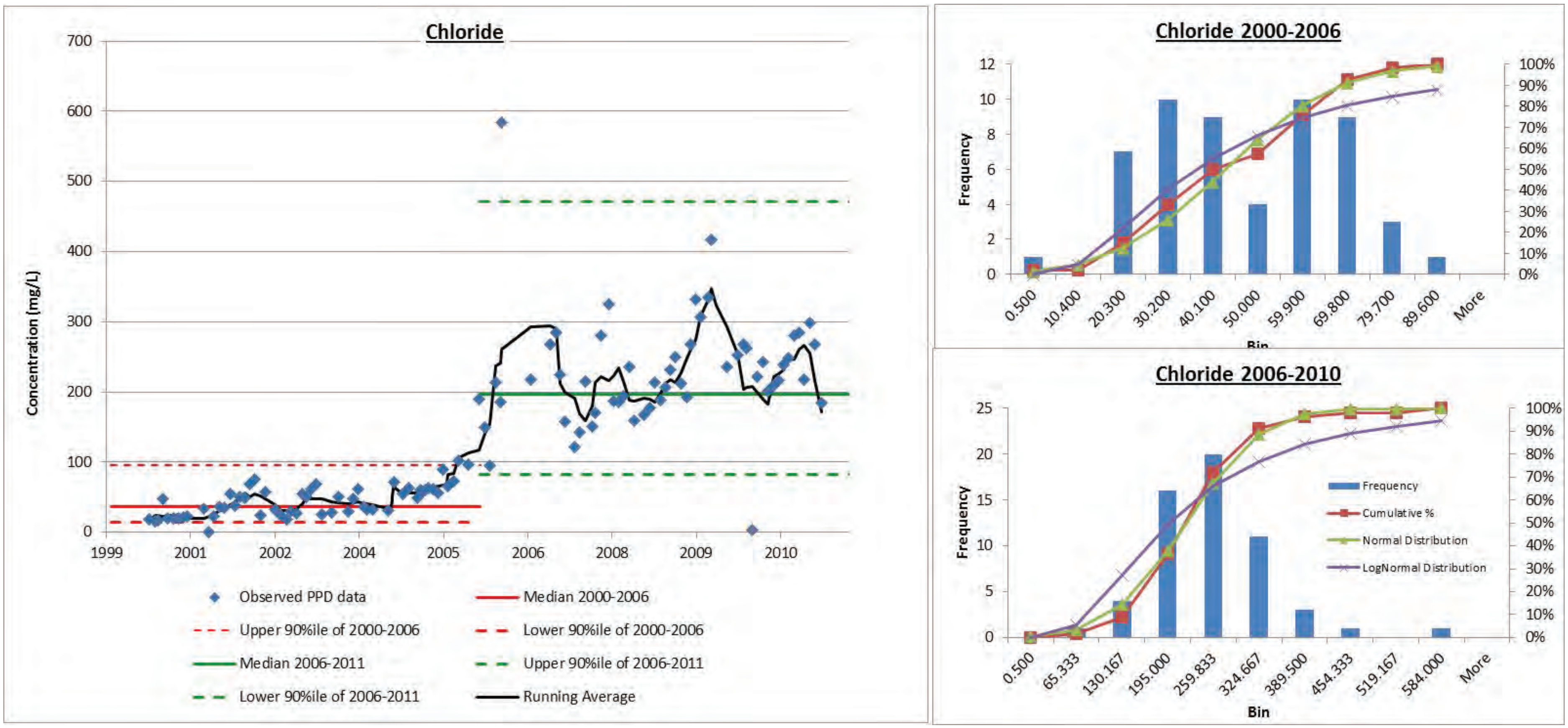

Figure 4.2-2

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Example of Statistical Analysis of PPD Water Quality Data (Chloride)

Figure 4.2-2

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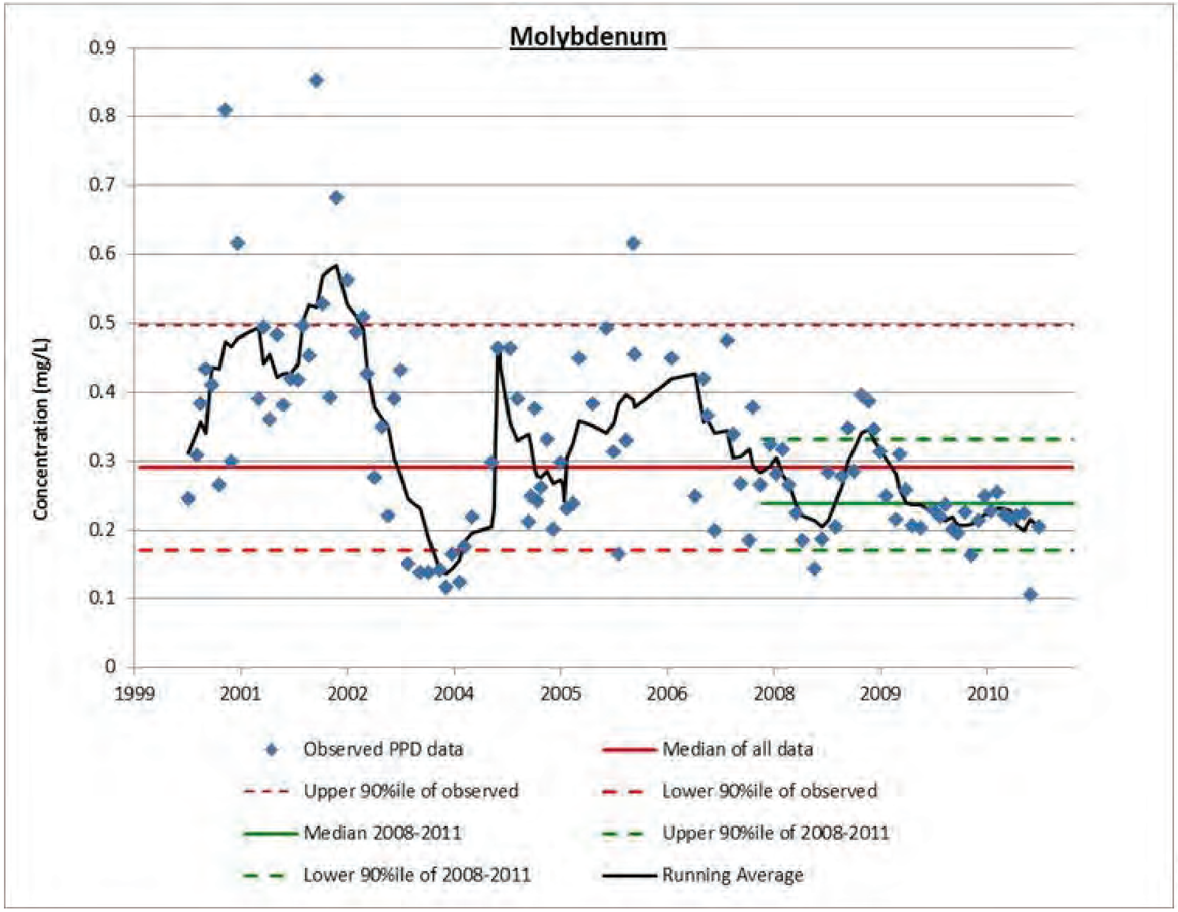

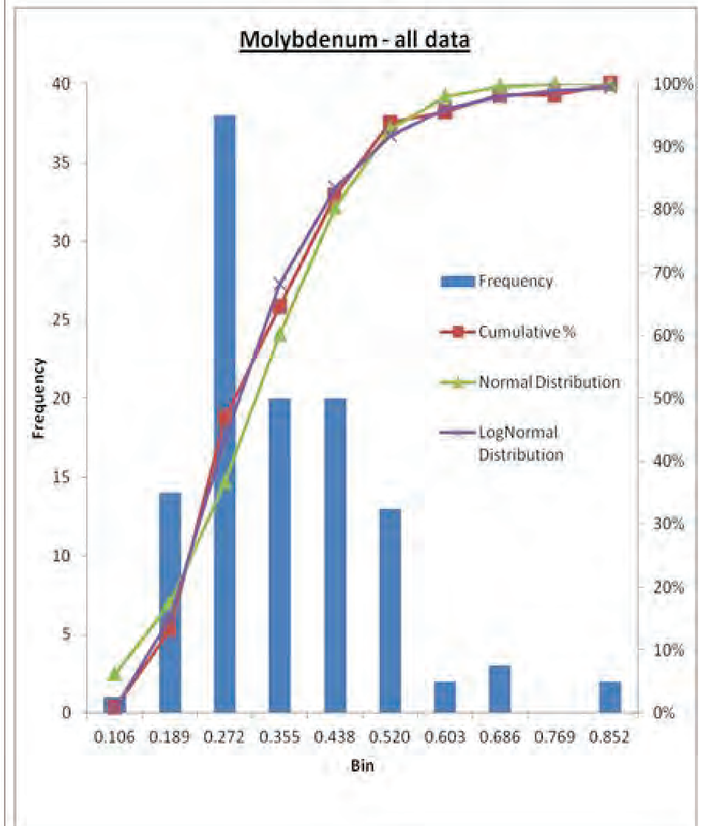

Figure 4.2-3

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Example of Statistical Analysis of PPD Water Quality Data (Molybdenum)

Figure 4.2-3

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Table 4.2-1. Summary of Parameter Groupings and Method used to Estimate PPD Concentrations

Group	Definition	Parameters	Modelling Method
Group 1	Parameters with marked increase or decrease associated with onset of processing of underground ore in 2005/2006.	Chloride, Potassium, TDS, Ammonia, Nitrate, Barium, Magnesium and Sodium.	For the years prior to onset of processing of underground ore, PPD quality is based on statistical analysis of available data from 2000 to 2005 using either normal or lognormal distributions, depending on which distribution provides best visual fit to data. For the years after the onset of processing of underground ore, PPD quality is based on statistical analysis of available data from 2006 to 2010 using either normal or lognormal distributions, depending on which distribution provides best visual fit to data. The LLCF Load Balance Model data uses PPD quality from 2004 to 2010 for the period from 2004 to 2020, except for one year (assumed to be 2018) when input data are based on 2000 to 2004 PPD data to simulate a lack of groundwater influence for a short period, as recommended by BHP Billiton.
Group 2	Parameters with marked change in average concentrations and variability post 2007/2008.	Sulphate, Aluminium, Antimony, Arsenic, Calcium, Copper, Iron, Manganese, Magnesium, Molybdenum, Nickel, Strontium, Vanadium and Zinc.	Data analyzed for: Full period of record (2000 to 2010); and Period 2008 to 2010. A conservative approach is taken whereby the distribution covering the widest range of parameters is considered for the period of 2010 to 2020. As no relationship between change in concentrations with ore type could be determined the approach assumes that the most appropriate distribution (pre or post 2008) cannot be determined to predict future PPD concentrations. Therefore, the more conservative distribution (the one resulting in higher concentrations) is chosen.
Group 3	Parameters with no discernible trend, gaps in data or with substantial number of samples below detection limit (masking any trends in data).	Nitrite, Cadmium, Chromium, Lead, Selenium and Uranium.	Future predictions are based on statistical distribution developed from analysis of all historical data.

Table 4.2-2. Summary of Approach for Predicting PPD Concentrations for Each Parameter

Variables	Approach for Predicting PPD Concentrations for 2010 to 2020
Chloride	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Potassium	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Sulphate	Based on lognormal distribution of all observed data.
Total Dissolved Solids	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Total Ammonia	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Nitrate	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Nitrite	Based on normal distribution of all observed data.
Aluminium	Based on lognormal distribution of observed 2008 to 2010 data.
Antimony	Based on lognormal distribution of all observed data.
Arsenic	Based on lognormal distribution of all observed data.
Barium	2011 to 2020 (except 2018), lognormal distribution based on observed post 2006 data. For 2018, based on lognormal distribution for observed 2000 to 2006 data.
Calcium	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Cadmium	Based on lognormal distribution of all observed data.
Chromium	Based on lognormal distribution of all observed data.
Copper	Based on lognormal distribution of all observed data.
Iron	Based on lognormal distribution of observed 2008 to 2010 data.
Lead	Based on lognormal distribution of all observed data.
Manganese	Based on lognormal distribution of all observed data.
Magnesium	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Molybdenum	Based on lognormal distribution of all observed data.
Nickel	Based on lognormal distribution of all observed data.
Selenium	Based on lognormal distribution of all observed data.
Sodium	2011 to 2020 (except 2018), normal distribution based on observed post 2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Strontium	Based on lognormal distribution of all observed data.
Uranium	Based on lognormal distribution of all observed data.
Vanadium	Based on lognormal distribution of observed 2008 to 2010 data.
Zinc	Based on lognormal distribution of all observed data.

In addition, although there were no clear relationship between ore type and PPD quality, there are clear relationships and correlations between selected water quality parameters in the PPD, i.e., concentrations of some parameters rise and fall together in the PPD. A correlation analysis was undertaken using the Pearson product moment correlation coefficient. An assessment was undertaken to identify parameters that were correlated to one another (i.e., concentrations of one parameter vary in a consistent manner in tandem with another parameter). Parameters were grouped based on their correlation using the following approach:

- Based on full time series data set all water quality parameters with a positive correlation >0.5 are considered related to one another;

- If there are parameters that are un-correlated based on analysis of the full data set, correlation factors were re-calculated based on 2008 to 2010 data only. Parameters are considered correlated if there is a positive correlation >0.5 from the 2008 to 2010 data; and
- A set of core parameters are identified to which the most parameters are correlated. Groupings of parameters are then developed, focused on a single core parameter.

Groupings identified in the analysis are illustrated in Figures 4.2-4a and 4.2-4b, with appropriate correlation coefficients. It is noted that no parameters are related through a negative correlation, as all parameters that have a negative correlation also have a stronger positive correlation.

Within the LLCF Load Balance Model the following process occurs every time step:

- The model randomly selects a probability to be used for calculations. This value is assigned to a core parameter. This probability value is used to select a concentration for the core parameter based on its assigned probability distribution; and
- Parameters correlated to the core parameter use the same probability value, adjusted by the correlation coefficient (based on Iman and Conover method used by the Goldsim software).

The approach outlined above maintains correlations between parameters, although it does not maintain the exact loading balance between parameters seen in the PPD. However, as the method used to estimate PPD concentrations involves stochastic modelling where inputs are based on a statistical distribution of historical data, the effects of uncertainties in the correlation coefficients are likely to be less than the spread of possible concentrations generated by the stochastic inputs.

4.3 SUMP WATER

Sump water quality within the LLCF Load Balance Model is based on analysis of available sump water quality samples from EKATI. There were insufficient samples to allow time varying concentrations to be modelled and as a result sump quality is based on the median concentration of available data, with values summarized in Table 4.3-1.

Sump quality for Pigeon pit, that is yet to go into operation, is based on results of a water quality modelling exercise undertaken for the potential Pigeon development (unpublished). However, the Pigeon modelling work considered a limited number of parameters compared to those considered in the LLCF Load Balance Model (i.e., the Pigeon pit model predicted concentrations of ammonia, chloride, nitrate, sulphate, aluminium, arsenic, chromium, copper, lead, molybdenum, nickel and zinc). For other parameters the median observed sump water quality from Misery pit was used as a surrogate for Pigeon sump quality. Nickel concentrations were also based on Misery pit water quality as the Pigeon pit has many similarities in pit all rock type with Misery pit and both pits have some reactive meta-sediment (schist) rock in their pit walls. Data used for Pigeon pit sump is provided in Table 4.3-1 along with the sump data from the other pits.

4.4 UNDERGROUND WATER

Underground water quality used in the LLCF Load Balance Model is based on analysis of a dataset of 93 groundwater quality samples. This dataset includes grab samples (33 samples) taken from underground workings during 2004 and 2005 and samples taken during an intensive sampling program (60 samples) in October 2005. The October 2005 sampling program was planned and executed to provide reliable data using a consistent methodology (Rescan 2006b). In contrast grab samples taken as part of general monitoring work at EKATI typically have very high suspended solids concentrations and it is unclear if the sumps recorded groundwater inputs or were influenced by any surface inflows. Based on the underground water sample dataset, median concentrations were used as inputs to the LLCF model, with values shown in Table 4.3-1.

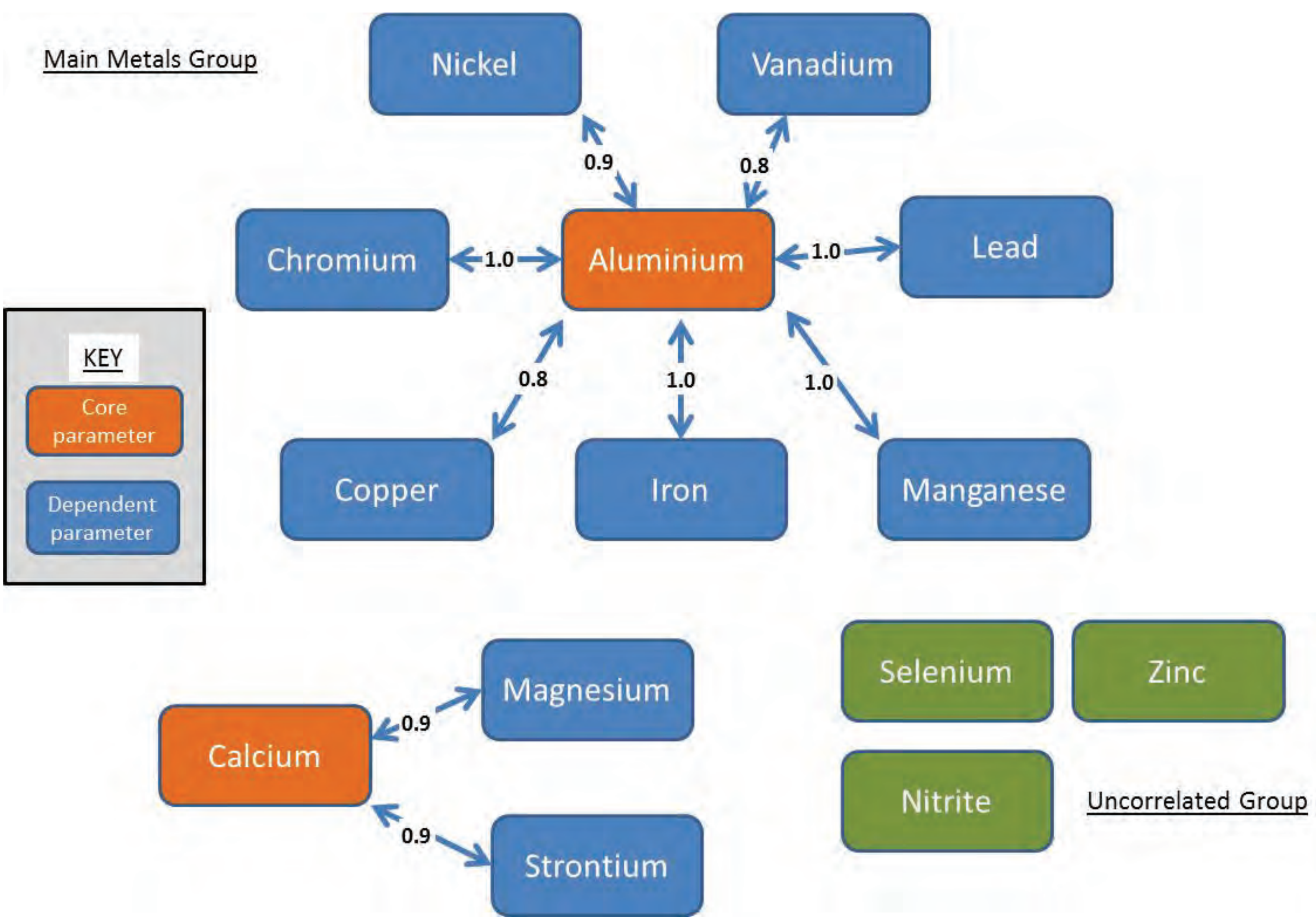
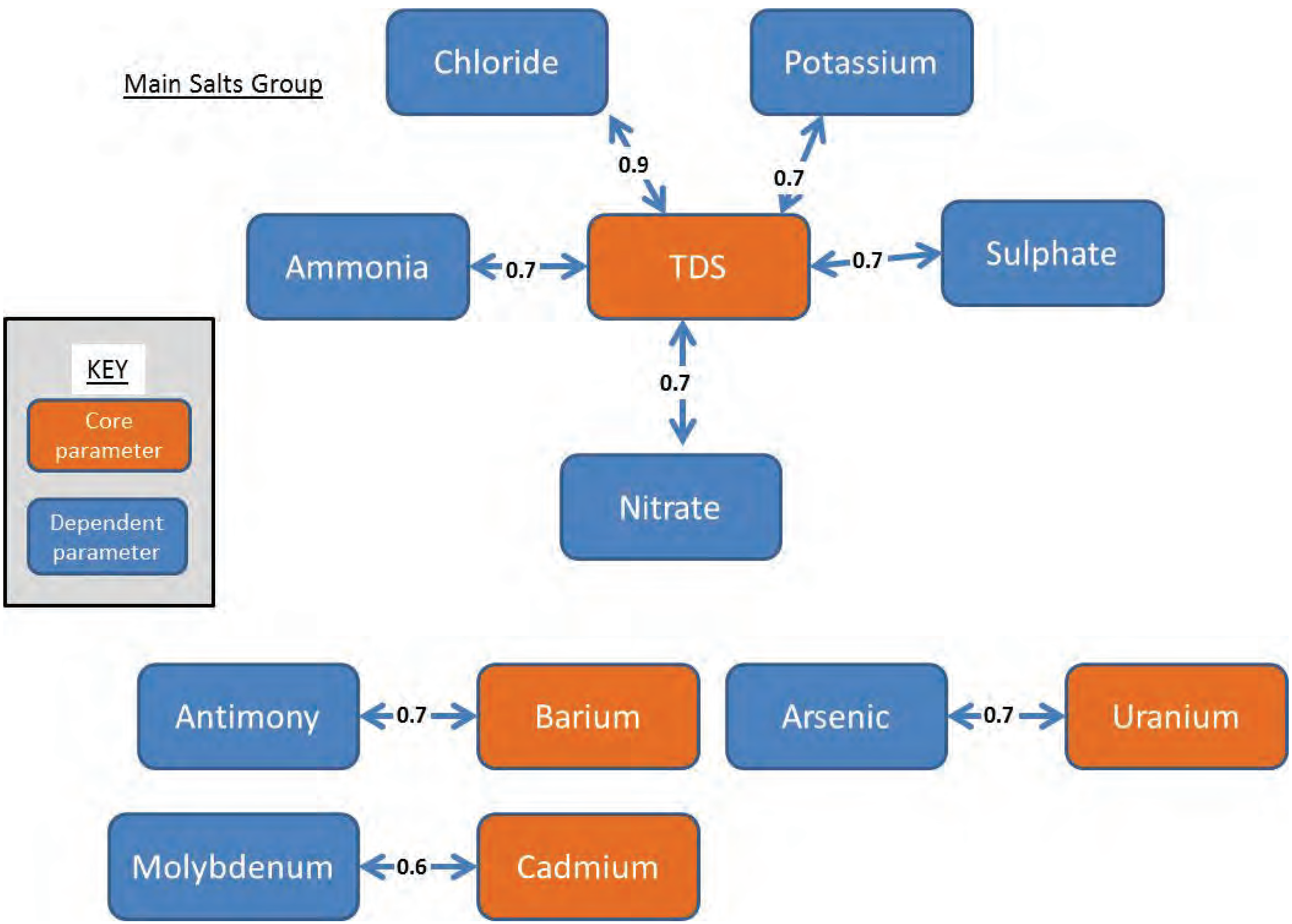


Figure 4.2-4a

Correlations between Selected Parameters



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Correlations between Selected Parameters

Figure 4.2-4b

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Table 4.3-1. Table of Sump Water Concentrations for Selected Parameters

Parameter	Concentration (mg/L)					
	Underground Water	Beartooth Sump	Panda Sump	Koala Sump	Fox Sump	Pigeon Sump
Chloride	6640	22.5	448	1060	35.2	390
Sulphate	639	158	386	322	102	60.5
TDS	10900	1690	599	1440	1200	800
Phosphate	0.450	0	0.0344	0	0.15	0.046
Nitrate	17.6	47.4	45.6	59.8	18.8	28.8
Nitrite	1.47	2.93	1.28	2.74	1.50	0.833
Ammonia	12.95	17.4	4.605	24.8	3.52	8.94
Aluminium	0.015	0.117	0.0046	0.0154	0.015	0.00927
Antimony	0.005	0.00410	0.00408	0.00408	0.0011	0.004
Arsenic	0.0007	0.00179	0.00145	0.00232	0.00648	0.00164
Barium	0.45	0.0667	0.06668	0.0667	0.059	0.065
Boron	0.100	0.0400	0.0400	0.0400	0	0.0400
Cadmium	0.00125	5.43E-05	0.000125	0.000253	0.000172	0.00026
Calcium	2100	160	86.9	216	30.15	57.0
[a]Chromium	0.011	0.000404	0.00125	0.00108	0.00432	0.0285
Copper	0.0022	0.0228	0.00192	0.00687	0.008	0.000662
Iron	0.045	0.015	0.015	0.0150	0.015	0.015
Lead	0.00125	0.000198	0.000125	0.000392	2.50E-05	0.948
Magnesium	255	75.0	130	120	14.0	51.7
Manganese	0.197	0.937	0.1	0.100	0.063	0.204
Molybdenum	0.481	0.0517	0.153	0.151	0.184	0.127
Nickel	0.011	0.0355	0.04375	0.0497	0.0122	0.053
Potassium	180	38.6	21.9	31.9	9.31	29.8
Selenium	0.0005	0.00290	0.0025	0.00147	0.00140	0.0042
Sodium	1100	800	800	800	269	27.2
Strontium	50.9	1.07	1.066	1.07	0.940	1.05
Uranium	0.00349	0.0015	0.00278	0.00278	0.0160	0.002
Vanadium	0.0002	0.005	0.005	0.005	0.0089	0.005
Zinc	0.01	0.00195	0.0025	0.00445	0.00500	0.505

[a] *Modelled Chromium concentrations are post-processed to Cr(III) and Cr(VI) species based on ratios outlined in Section 2.3*

The key loadings from underground water are associated with high concentrations of TDS and its constituent parameters such as chlorides. The deep groundwater in many areas of northern Canada, including the EKATI area, is known to have high salinity values (Dickin, Mills and Freed 2008). The results indicate that TDS concentrations commonly exceed 10,000 mg/L.

4.5 BEARTOOTH PIT

Beartooth pit is modelled as a separate sub-model within the LLCF Load Balance Model. The water balance for Beartooth pit was described in Section 3.2-5. Key sources of loadings to Beartooth pit are summarized in Table 4.5-1. Water quality in Beartooth pit is modelled based on a similar conservative mass balance modelling approach used for the LLCF. The Beartooth sub-model does not model the potential for physical or chemical stratification in Beartooth pit during infilling. However, due to the energy input into the pit lake as it fills (due to inflow of pumped liquids and solids) any stratification is expected and assumed to break down during infilling.

Table 4.5-1. Water Quality Inputs to Beartooth Pit

Water Quality Input	Source
Natural Runoff	Based on Vulture stream data, as per LLCF Load Balance Model (Table 4.1-1)
Sump Water Quality	Based on median concentrations of observed Beartooth sump water quality (Table 4.3-1). Constant value used over time.
Pit Wall Runoff	Based on unpublished geochemical predictions for chemistry of runoff from pit wall rock. Constant values used over time.
Underground Water	Based on analysis of underground water quality data, as per LLCF Load Balance Model (Table 4.3-1).
FPK Water	Based on analysis of PPD quality, as per LLCF Load Balance Model (Section 5.2)
Reclaim	Predicted by Beartooth sub-model and pumped to LLCF.

Loadings accumulating in Beartooth pit are able to be passed to the LLCF either when Beartooth pit water is used for reclaim or if excess water needs to be pumped to the LLCF in the case that water levels in the pit exceed the target level. The key sources of loadings to Beartooth pit will be from underground water and the secondary FPK stream from the Process Plant and as a result the water quality in the pit will be dominated by these sources. The main effect of discharging FPK and underground water to Beartooth on water quality in the LLCF will be a decrease in loadings from 2009 (start of discharge of underground water) to around 2014, when water levels in the pit are expected to reach target levels and water will need to be used as reclaim or pumped to the LLCF. After this time loadings stored in Beartooth pit will be steadily passed to the LLCF and this is likely to result in an increase in concentrations in the LLCF at this time.

4.6 OTHER INPUTS

Sewage provides an insignificant input to the LLCF and the model does not explicitly model loadings from sewage with sewage considered to have chemistry of natural runoff.

Concerns over rising nitrate concentrations in the LLCF led to the initiation of a nutrient amendment program, consisting of the addition of monopotassium phosphate fertiliser to Cell D and a monitoring program. Fertilizer addition was undertaken in the summer of 2009 and 2010 (Rescan 2010, 2011) and 2011. The rate of addition is summarized in Table 4.6-1. The phosphorus content of the fertiliser was calculated as 22.2% and the potassium content was calculated as 28.2% by weight (calculations were based on the information provided on the product label). Within the LLCF Load Balance Model potassium and phosphorus loadings were made to Cell D at the dates shown in Table 4.6-1. In terms of phosphorus the loadings from the nutrient amendment program are a dominant loading to the LLCF, while for potassium the additional loadings due to fertilizer addition are minor compared to potassium loadings from other sources.

Table 4.6-1. Summary of the Fertiliser Additions Made to Cell D of the LLCF

Date of Fertiliser Addition	Amount of Fertiliser Added to Cell D (kg)	Cumulative Amount of Fertiliser Added to Cell D (kg)	Cumulative Amount of Phosphorus Added to Cell D (kg)
July 7, 2009	50	50	11
July 9, 2009	450	500	111
July 14, 2009	875	1,375	305

(continued)

Table 4.6-1. Summary of the Fertiliser Additions Made to Cell D of the LLCF (completed)

Date of Fertiliser Addition	Amount of Fertiliser Added to Cell D (kg)	Cumulative Amount of Fertiliser Added to Cell D (kg)	Cumulative Amount of Phosphorus Added to Cell D (kg)
July 15, 2009	225	1,600	355
July 20, 2009	2,000	3,600	799
July 27, 2009	2,175	5,775	1,282
August 3, 2009	2,175	7,950	1,765
August 11, 2009	825	8,775	1,948
August 12, 2009	1,350	10,125	2,248
August 17, 2009	2,175	12,300	2,731
August 27, 2009	841	13,141	2,917
August 28, 2009	1,334	14,475	3,213
September 2, 2009	1,567	16,042	3,561
July 17, 2010	1,500	17,542	3,894
July 23, 2010	2,000	19,542	4,671
July 30, 2010	2,000	21,542	5,892
July 29, 2011	590	22,132	6,023
August 6, 2011	1,404	23,536	6,466
August 12, 2011	1,326	24,862	7,203
August 20, 2011	1,000	25,862	8,162

5. Water Balance Results

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5. Water Balance Results

Water quality predictions are the key outputs from the LLCF Load Balance Model and LLCF Downstream Model. However, it is important that the water balance for the two models produces results that are consistent with observed flows and which reproduce key features of the flow hydrographs within the modelled systems. Hence, results from the water balance components of the LLCF and downstream lakes models are discussed in this chapter and compared to observed outflows from the LLCF and at the flow monitoring station at the outlet of Slipper Lake.

As discussed in Chapter 2, it should be noted that the LLCF Load Balance Model and the LLCF Downstream Model are run separately to allow the LLCF Load Balance Model to run stably (i.e., so Cell E does not dry out) and to allow control over outflows from the LLCF to Leslie Lake in the LLCF Downstream Model.

5.1 WATER BALANCE RESULTS FOR THE LLCF LOAD BALANCE MODEL

The LLCF Load Balance Model was run for the period 2000 to end 2010 and model-predicted outflows from the LLCF were compared to observed flows. The runoff coefficient for watersheds flowing to the LLCF was varied until a good fit was obtained between the observed and predicted average annual outflow volume over the eleven year period. A good fit was obtained with a runoff coefficient of 0.65, which is higher than the average runoff coefficient for gauged watersheds at EKATI, which is 0.5. Most key mine water inputs to the model are based on observed flow data, with the volume of free water from settled FPK based on assumptions of settled FPK densities that are obtained from observed data. Hence, natural runoff is one of the only free variables that can be adjusted during calibration.

A comparison of predicted and observed annual outflow volumes for the calibrated model is shown in Table 5.1-1. There is a very good correspondence of predicted and observed flows at the outlet of the LLCF over the observed data record period, with the predicted average annual outflow volume only 2% below the observed volume. From year to year; however, there are differences between the predicted and observed outflow volumes for the following reasons:

- Uncertainties associated with pumped flow measurements at outflow from LLCF and for all pumped flows to the facility;
- The model is run with a constant runoff coefficient for runoff from natural catchments although the EKATI dataset indicates that the coefficient will vary year from year; and
- Actual discharges from the LLCF are controlled manually and there is flexibility as to when water can be discharged from the facility, while the outflow routine in the model is based on a deterministic rule which attempts to key water levels in Cell E at a target level. For example, water entering the LLCF in 2003 was not pumped out of the facility until January to March 2004, resulting in lower observed outflows in 2003 and higher flows in 2004. In addition, very limited water was pumped from the facility in 2005 and additional water was discharged in 2006 to compensate.

Figure 5.1-1 provides an illustration of the average contribution of annual inflows to the LLCF. It is clear from the figure that flows from catchments surrounding the LLCF and from FPK water are the dominant contributors to the water balance for the LLCF.

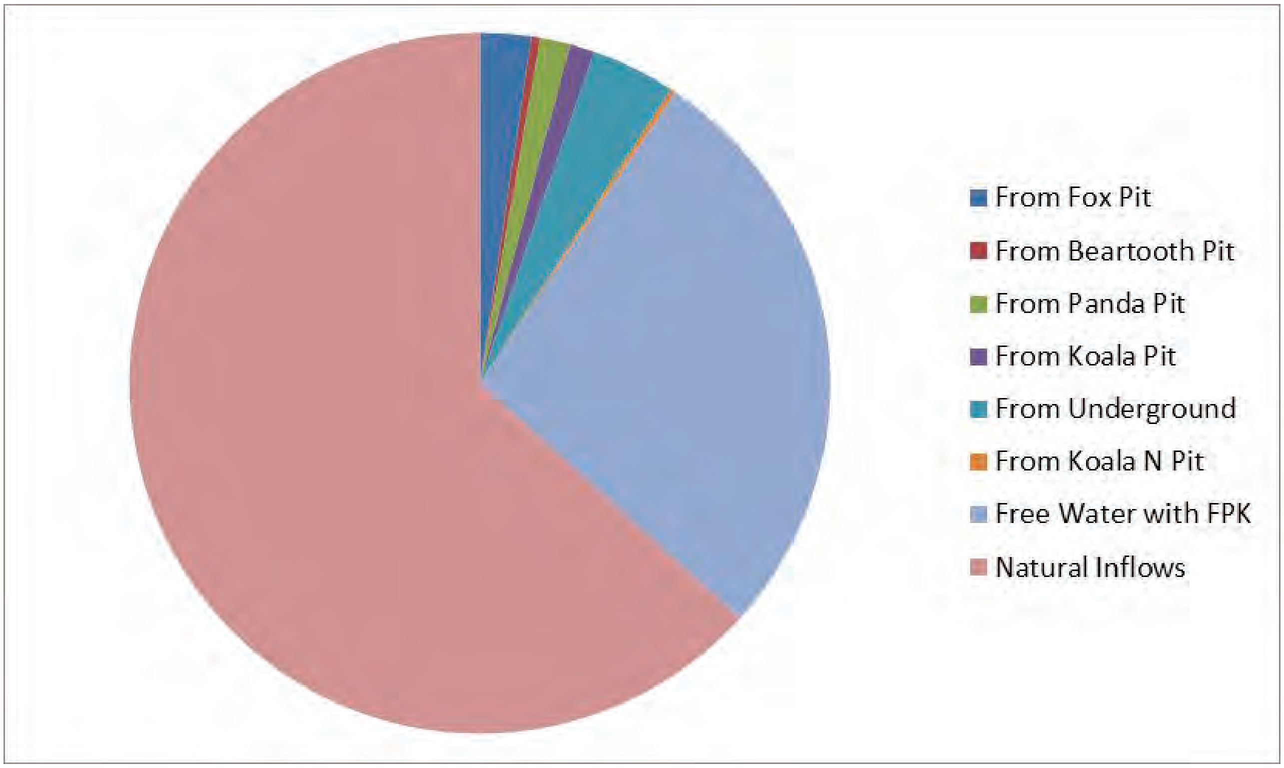

Figure 5.1-1

Summary of Sources of Inflows to LLCF

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Table 5.1-1. Comparison of Observed and Predicted LLCF Outflows

Year	Observed Outflow from LLCF (Mm^3)	Model Predicted Outflow from LLCF (Mm^3)
2000	6.76	6.32
2001	8.12	6.70
2002	3.24	6.90
2003	5.21	6.75
2004	8.65	6.22
2005	4.22	5.68
2006	10.09	7.45
2007	8.70	6.79
2008	5.82	7.18
2009	5.58	6.20
2010	7.84	6.48
Average	6.75	6.61

In addition to the calibration of runoff coefficients, some calibration of the internal water balance of the LLCF Load Balance Model was undertaken. Within the LLCF Load Balance Model, calibration of water quality predictions in Cell D and Cell E resulted in the routing of runoff from the catchment of Cell D to Cell E to account for observations that un-calibrated predictions of concentrations in Cell D were too low after freshet (i.e., model predicted too high a flow of loadings from Cell D to Cell E during freshet). This was interpreted as an effect of incomplete mixing in Cell D during freshet with formation of upper fresher layer with natural runoff and ice melt, which was able to flow to Cell E. By routing the runoff to Cell E this improved Cell D predictions, but made marginal difference to Cell E concentrations (slight lowering in June). This change impacted the internal water balance of the LLCF, but did not impact the overall water balance of the facility, with no impact on the overall annual water balance or on timing of flows to downstream lakes which are controlled by a pumping routine.

Annual lake residence times are calculated for Cell D and Cell E based on the equation:

$$\textit{Annual residence time (yr)} = \textit{Cell volume } (m^3) / \textit{Total Flow through Cell } (m^3/yr)$$

The residence time for a water body provides an estimate of the time required for the entire lake volume to be replaced with inflowing water. A low residence time (e.g., inflows would replace total lake volume in a matter of days or weeks) would suggest that the water quality of the lake would be dominated by the quality of the inflowing water. In contrast, a lake with a high residence time (e.g., inflows would need to occur for number of months or years to replace lake volume) would have a buffering capacity resisting changes to the lake water quality as a result of inflows.

The volume of Cell D is around 27 Mm^3, with the volume of Cell E around 6.8 Mm^3 (Table 3.1-3). The annual average discharge from the LLCF is around 6.9 Mm^3 (Table 3.2-4). Hence, the annual lake residence time for Cell D is around 3.9 years, indicating that the annual flow through the cell is significantly less than the total water volume. This indicates there is a buffering capacity within Cell D against changes in water quality inputs. For Cell E the residence time is of the order of 1 year, indicating that water quality in this cell will respond more quickly to any changes in inflows from Cell D. However, as Cell D lies upstream of Cell E water quality inputs to Cell E will be buffered through mixing within Cell D.

5.2 WATER BALANCE RESULTS FOR LLCF DOWNSTREAM MODEL

The LLCF Downstream Model was run for the period 2000 to end 2010, consistent with available flow data for the outflow at Slipper Lake. The model was run with observed runoff coefficients from the Slipper gauge and using observed pumped outflows from the LLCF. Hence, as observed data were used as inputs to the key hydrological inputs to the model, it is not unexpected that the modelled annual outflows form Slipper are very similar to the observed flow volumes at the Slipper gauge station (Table 5.2-1). Differences between the modelled and observed data reflect uncertainties and errors with gauged data (pumped flows and at Slipper gauge) and may also be impacted by assumptions related to precipitation on and evaporation from the lake surfaces.

Table 5.2-1. Comparison of Observed and Predicted Flows at Slipper Lake Outflow

	Annual Outflow Volumes (Mm^3)	
Year	**Observed**	**Modelled**
2000	34.68	31.40
2001	35.97	29.49
2002	15.91	16.42
2003	17.46	19.50
2004	20.65	21.15
2005	21.13	22.71
2006	51.52	39.36
2007	17.05	20.26
2008	26.06	27.01
2009	17.77	19.85
2010	20.81	26.86
Average	24.43	24.26

Annual lake residence times are calculated for each of the downstream lakes in Table 5.2-2. The residence time for a lake or water body calculated on an annual basis is defined as:

$$\textit{Annual residence time (yr) = Lake volume } (m^3) / \textit{Total Inflow to Lake } (m^3/yr)$$

Monthly or weekly residence times can be calculated by varying the time over which the inflow acts. As noted in Section 5.1, the residence time for a lake provides an estimate of the time required for the entire lake volume to be replaced with inflowing water. A low residence time (e.g., inflows would replace total lake volume in a matter of days or weeks) would suggest that the water quality of the lake would be dominated by the quality of the inflowing water. In contrast a lake with a high residence time (e.g., inflows would need to occur for number of months or years to replace lake volume) would have a buffering capacity resisting changes to the lake water quality as a result of inflows.

The downstream lakes are generally relatively small and shallow with lake volumes lower than the average annual discharge volume from the LLCF (6.9 Mm^3, from Table 3.2-4). If natural runoff from local catchments surrounding each lake is also added, the total annual inflow to each lake is significantly more than the lake volumes. This is illustrated in Table 5.2-2 for years with average precipitation, 1 in 100 dry year precipitation and 1 in 100 wet year precipitation. The annual residence time for a year with average precipitation ranges from only 19 days for Moose Lake to 77 days for Nero Lake.

Table 5.2-2. Calculation of Annual Residence Times for Lakes Lying Downstream of LLCF

Lake	Local Catchment Flowing to Water Body (km^2)	Total Catchment (Excluding Lake Areas) (km^2)	Lake Area (km^2)	Annual Inflow for Year with Average Annual Runoff (Mm^3)	Lake Volume (Mm^3)	[c]Average Residence Time (days)		
						[d]Year with Average Annual Runoff	[d]Year with 100 Year Dry Runoff	[d]Year with 100 Year Wet Runoff
LLCF	31.7	31.7	10.7	[a]6.4				
Leslie	3.4	35.1	0.62	[b]7.0	1.4	73	180	47
Moose	39.5	74.6	0.44	[b]13.5	0.7	19	42	11
Nero	24.4	99	1.4	[b]17.6	3.7	77	168	44
Nema	7.1	106.1	0.78	[b]18.8	1.5	29	64	17
Martine	14.5	120.6	1	[b]21.2	1.8	31	67	18
Rennie	28.2	148.8	0.94	[b]25.9	1.5	21	45	12
Slipper	25.5	174.3	1.9	[b]30.1	6.1	74	158	41

[a] *Average of observed LLCF discharge*

[b] *Calculated as Total Catchment downstream of LLCF (km^2) x annual average runoff total (166.5 mm), added to the discharge from the LLCF. The contribution from direct precipitation on lake is balanced by evaporation from the lake surface.*

[c] *Average residence time = Lake Volume / Annual Inflow*

[d] *Average annual runoff = 166.5 mm, 1 in 100 dry year runoff = 81 mm, 1 in 100 wet year runoff = 310.5 mm ; values based on statistical analysis of Koala Meteorological Station precipitation data multiplied with runoff coefficient of 0.5.*

The annual flow hydrograph for streams at EKATI shows a marked seasonality. Nearly all the annual flow occurs soon after snow melt, typically in June, with flows decreasing through the year, see Table 3.1-5. There are zero flows in winter months as most streams at EKATI freeze to their beds in winter. As a result, an assessment of residence times in response to average monthly flows is also useful with results provided in Table 5.2-3. The results indicate that during June and July the total average monthly inflows to all lakes lying downstream of the LLCF are greater than lake volumes (i.e., residence times are less than 1 month). For other months monthly inflows are typically less than the lake volume.

Note that care should be taken in interpreting and using the results of this residence time assessment. The concept of residence time assumes that all inflowing water to a lake effectively displaces (pushes out) existing lake water. However, in reality mixing and flow processes within lakes are more complex. However, the assessment clearly shows that residence times for the chain of lakes lying downstream of the LLCF are low, with lake inflow volumes during freshet (June and July) typically larger than the volume of water in the lakes at the onset of freshet. These results indicate that the lakes have limited buffering capacity with respect to the water quality of inflows to the lakes and that on an annual basis the water quality of the lakes will respond rapidly to any change in inflow water quality. Note also that the annual discharge volume from the LLCF is a significant percentage of the total inflow to upstream lakes (i.e., it is 92% of the total annual inflow to Leslie lake and 47% of the total annual inflow to Moose lake), with the percentage falling to around 21% for Slipper Lake due to dilution with runoff from natural catchments draining to the lakes.

Table 5.2-3. Calculation of Monthly Residence Times for Lakes Lying Downstream of LLCF, Year with Average Annual Runoff

Lake	Monthly Residence Time (days)					
	May	June	July	August	September	October
Leslie	>1 month (20% of lake volume in 1 month)	11	27	>1 month (40% of lake volume in 1 month)	>1 month (40% of lake volume in 1 month)	>1 month (5% of lake volume in 1 month)
Moose	>1 month (80% of lake volume in 1 month)	3	7	20	20	>1 month (20% of lake volume in 1 month)
Nero	>1 month (20% of lake volume in 1 month)	12	28	>1 month (40% of lake volume in 1 month)	>1 month (40% of lake volume in 1 month)	>1 month (5% of lake volume in 1 month)
Nema	>1 month (50% of lake volume in 1 month)	5	11	31	30	>1 month (10% of lake volume in 1 month)
Martine	>1 month (50% of lake volume in 1 month)	5	11	>1 month (90% of lake volume in 1 month)	>1 month (90% of lake volume in 1 month)	>1 month (10% of lake volume in 1 month)
Rennie	>1 month (70% of lake volume in 1 month)	3	8	22	22	>1 month (20% of lake volume in 1 month)
Slipper	>1 month (20% of lake volume in 1 month)	11	27	>1 month (40% of lake volume in 1 month)	>1 month (40% of lake volume in 1 month)	>1 month (5% of lake volume in 1 month)

6. Water Quality Results

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6. Water Quality Results

6.1 OBSERVED CONCENTRATIONS

There is a long data record of water quality for the LLCF and downstream lakes, with the period of record and number of samples summarized in Table 6.1-1. The samples outlined in Table 6.1-1 are the key water quality data used to test and calibrate the LLCF Load Balance Model and the LLCF Downstream Model. There are other samples from within Cell C, Cell D and Cell E that have been taken as part of other monitoring programs for the LLCF and which are not listed in Table 6.1-1. Where relevant, reference is made throughout the report to some of these additional water quality data.

Table 6.1-1. Available Water Quality Data

Station	Years of Operation	Number of Samples	Typical Sampling Frequency
Cell E LLCF (1616-30)	1998 - 2010	198	Monthly
Leslie Lake	1994 - 2010	32	3 to 4 times per year during open water season
Moose Lake	1994 - 2010	54	3 to 4 times per year during open water season
Stream between Moose and Nero	1996 - 2010	48	3 times per year during open water season
Nema Lake	1995 - 2010	52	3 times per year during open water season
Stream between Nema and Martine	1995 - 2010	51	3 times per year during open water season
Slipper Lake	1994 - 2010	54	4 times per year during open water season
Stream between Slipper and Lac de Gras	1994 - 2010	51	4 times per year during open water season

6.2 MODEL RESULTS FOR HISTORICAL PERIOD (JANUARY 2000 TO END 2010)

The LLCF Load Balance Model and the LLCF Downstream Model were run for the period January 2000 to end 2010. This is the period for which there are historical data to constrain all model inputs, and observed concentrations in the LLCF and downstream lakes to which model predictions can be compared. At the time of writing this report selected and yet unpublished 2011 water quality data were made available (e.g., Cell D and E water quality) and data were extracted for key parameters used in calibration (TDS, chloride, hardness, nutrients). However, for most parameters and for results presented in the Model Summary Sheets (Appendix 4) the historical period is defined as 2000 to end 2010.

A calibration exercise was not undertaken for all water quality parameters. Calibration involved the adjustment of key model input parameters until a reasonable fit was obtained between observed and predicted data. Reasonable fit was qualitatively based on experience with the EKATI data set and the model. The model was then run for the future period using the calibrated parameters. Some calibration of the model water balance was undertaken and is reported in Chapter 5. However, for most water quality parameters no adjustments of model inputs were made to try and improve the modelled fit to observed data; best estimates were made of key inputs based on observed data (as outlined in Chapter 4) and the model was run using these parameters without further adjustment.

Calibration was undertaken for key non-conservative parameters; ammonia, nitrate, nitrite and phosphate. Load losses of these parameters were modelled using a first order decay function, with calibration of the decay rate or half-life until a reasonable fit was obtained with observed data. Some calibration was also undertaken on freshet flows from Cell D and Cell E to improve the quality of predictions in Cell D.

The following sections present comparison of modelled and observed concentrations in the LLCF and downstream lakes for the period 2000 to end 2010. A discussion is also provided of the calibration work undertaken for key non-conservative parameters. Results are also provided for key non-conservative parameters; chloride, hardness and TDS, for which there was no calibration of decay rates or changes to model inputs to produce better fits to observed data. Results for these parameters are presented here as concentrations of these parameters have varied over the historical period of operations of the LLCF and a comparison of modelled and observed data provides a clear indication of how model predictions vary within and among years and of the quality of model fits to observed data. Furthermore, results are presented for hardness as this is a key parameter in terms of its influence on Water Quality Benchmarks for selected parameters (Table 2.3-1).

It should be noted when comparing model predictions to observed water quality data that there are some ‘outliers’ within the observed water quality data set. Outliers fall into a number of categories:

- High concentrations during winter months. Ice on lake surfaces is almost 100% pure water and when it forms it excludes (leaves behind) solutes into the unfrozen ice below. Hence, in the ice-free water, concentrations of parameters increase during winter months until the ice melts and dilutes the water. The model has a routine that predicts ice exclusion processes and produces high concentrations in winter months. However, there are cases where observed data have some anomalously high winter concentrations that may indicate years with thicker ice than average or reflect samples taken in locally poorly mixed under-ice water.
- Low concentrations in spring months. During ice and snow melt a layer of cleaner melt water can form on a lake surface. If water quality samples are taken on this layer instead of the lake water beneath low concentrations can be recorded.
- High concentrations of some metals due to samples with high TSS. In the EKATI dataset only results from total metals samples are available (no dissolved metals). This is intentional because guidelines and site specific water quality objectives are defined for total metals. At EKATI most samples have very low TSS so that total metals concentrations are effectively equal to dissolved metals concentrations. However, there are some samples with higher than normal TSS and for these some common metals (e.g., aluminium, iron) can record high concentrations. These concentrations do not reflect underlying dissolved metals in the water but rather reflect the presence of sediment particles in the sample.
- Unexplained. Some samples are outliers that do not fit into the above groupings. These are few but their origin is unexplained and may reflect problems with sampling or analysis of the water quality data.

6.2.1 LLCF Load Balance Model

The LLCF Load Balance Model was run for the historical period with observed pumped inflows to the LLCF and observed water quality for underground water, sumps and natural runoff. However, the model was run using the statistical approach to predicting PPD water quality as outlined in Section 4.2. The PPD is the primary source of loadings for many parameters. Hence, using the stochastic PPD input to the model for the historical period provides a test of the PPD methodology to estimate PPD water quality.

During the model calibration work it was determined that full mixing in Cell D may not occur during freshet. This is likely caused by water from a freshwater layer passing to Cell E during freshet without mixing through Cell D. A more detailed description of the process and modelling approach is provided in Section 2.1.1. However, the model approach produced good fits to the observed data and mimicked the gross effect of a fresh water upper layer passing to Cell E during freshet. This calibration work is primarily internal to the LLCF in that it resulted in changes to concentrations in Cell D (improved predictions), but it did not substantially impact predictions in Cell E, with variation in concentrations from the un-calibrated model significantly less than the typical annual variation of concentrations in the cell. Hence, the adjustment for Cell D flows does not impact concentrations passed to the LLCF Downstream Model.

Conservative Parameters

All parameters bar ammonia, nitrate and phosphate are modelled as conservative. Model predictions for Cell D and Cell E for TDS, chloride and hardness are shown in Figures 6.2-1, 6.2-2 and 6.2-3 including observed data for 2011. Note that TDS is modelled because it is a conservative parameter that is suitable for model calibration because observed concentrations in LLCF and downstream lakes have been consistently detectable and variable.

The model produces predicted trends that match very well with observed concentrations in Cell D and Cell E. The results not only provide a good match to the inter-annual variations in concentrations (increase over time) they provide good fits to the seasonal variations in water quality throughout the year; with dilution and lower concentrations in freshet (June, July), rising concentrations in summer months with lower natural runoff (August, September) and rising concentrations in winter months due to ice exclusion processes (October through April after which ice begins to melt).

Model fits for all parameters for the historical period are provided in the Model Summary Sheets (Appendix 4).

Non-conservative Parameters

Ammonia, nitrate, nitrite and phosphate are considered non-conservative parameters and are modelled using a first order decay equation of the type:

$$\textit{Concentration at Time } t = \textit{Initial Concentration } x\ (0.5)^{t/half\text{-}life}$$

The value of the decay rate for each of these parameters was varied until a good fit was obtained between observed and predicted concentrations in Cell D and Cell E. Calibrated model predictions for Cell D and Cell E for the four non-conservative parameters are shown in Figures 6.2-4 to 6.2-7. Calibrated model decay rates are provided in Table 6.2-1.

Table 6.2-1. Calibrated Decay Rates for Non-conservative Water Quality Parameters

Parameter	Calibrated Half-life for Parameter
Phosphate	2.1 months during period of active fertiliser addition (2009, 2010 and 2011) and 11.1 months for all other times
Nitrate	No decay
Nitrite	8.3 months
Ammonia	4.2 months

These four non-conservative parameters can experience losses within the LLCF due to their uptake as a nutrient. Ammonia can also decay through volatilisation at the water/air interface. Residence times for Cell D and Cell E were calculated in Section 5.1 and indicate residence times for Cell D of 3.9 years and Cell E of 1 year. The residence times for the LLCF are significantly larger than the calibrated decay half-lives for the non-conservative parameters, indicating that there is sufficient residence time within the LLCF for decay of these parameters due to biogeochemical processes to occur and to be modelled.

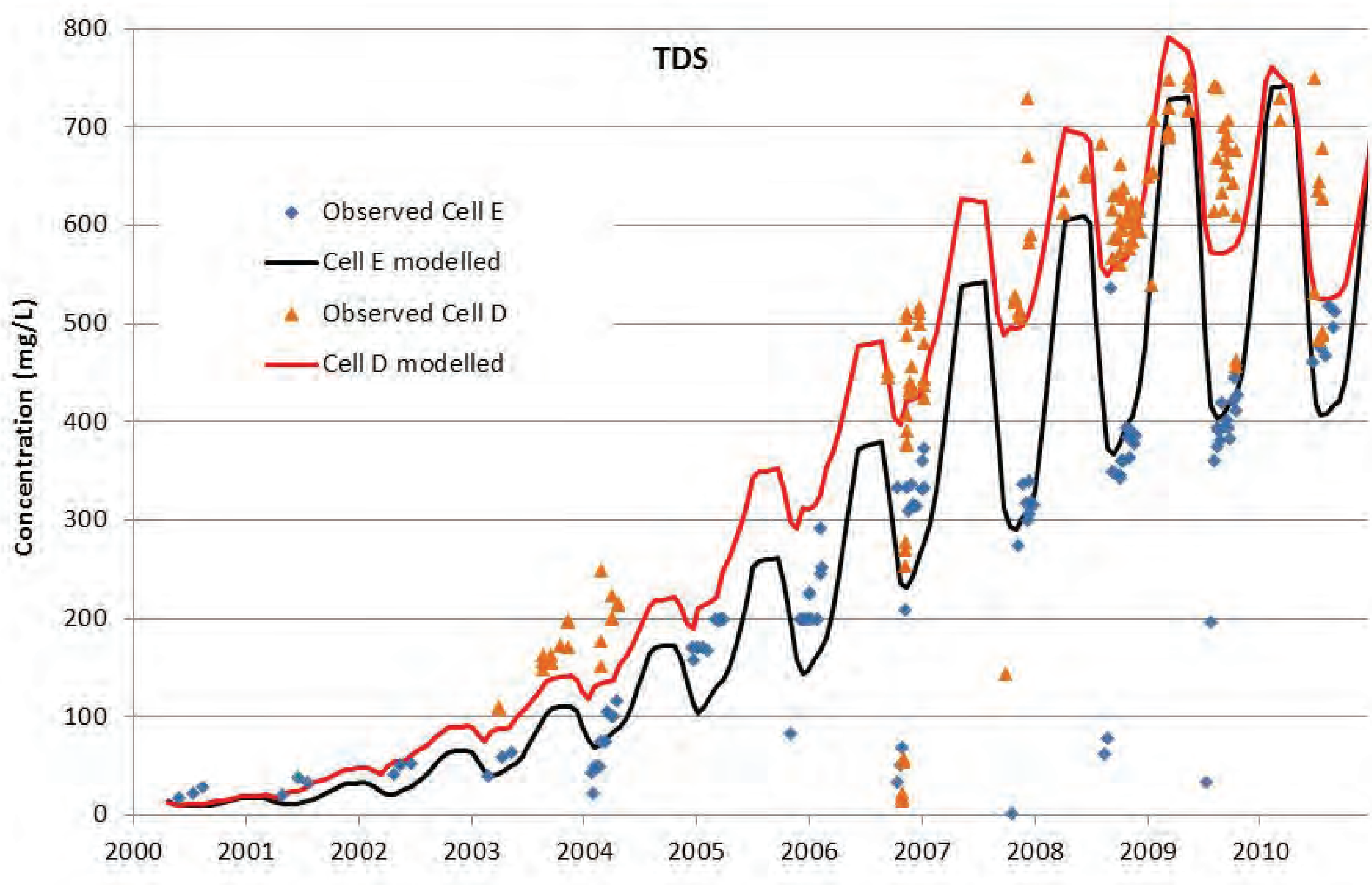

Figure 6.2-1

Comparison of Predicted and Observed TDS Concentrations for Cell D and Cell E

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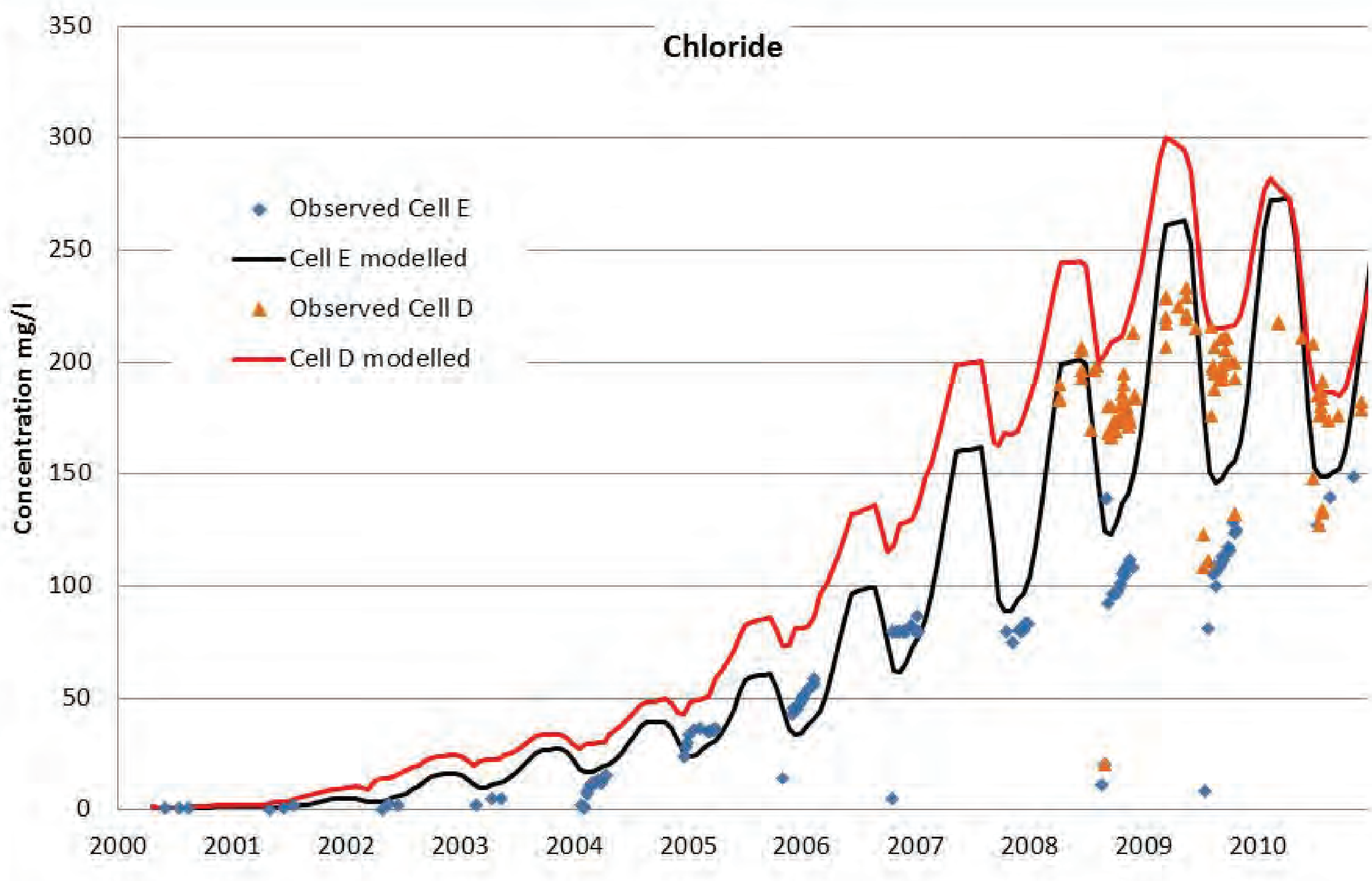

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Comparison of Predicted and Observed Chloride Concentrations for Cell D and Cell E

Figure 6.2-2

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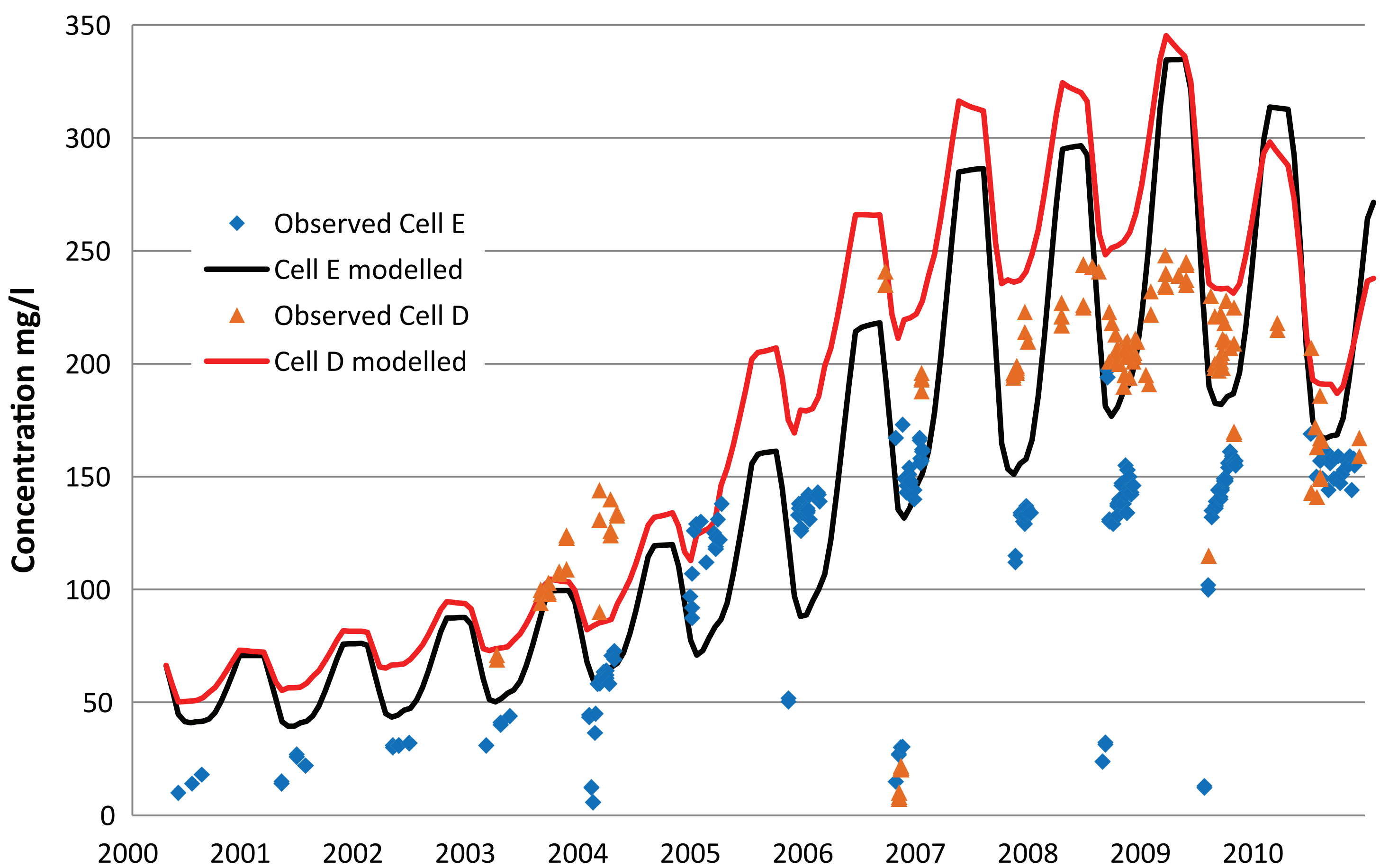

Figure 6.2-3

Comparison of Predicted and Observed Hardness Concentrations for Cell D and Cell E

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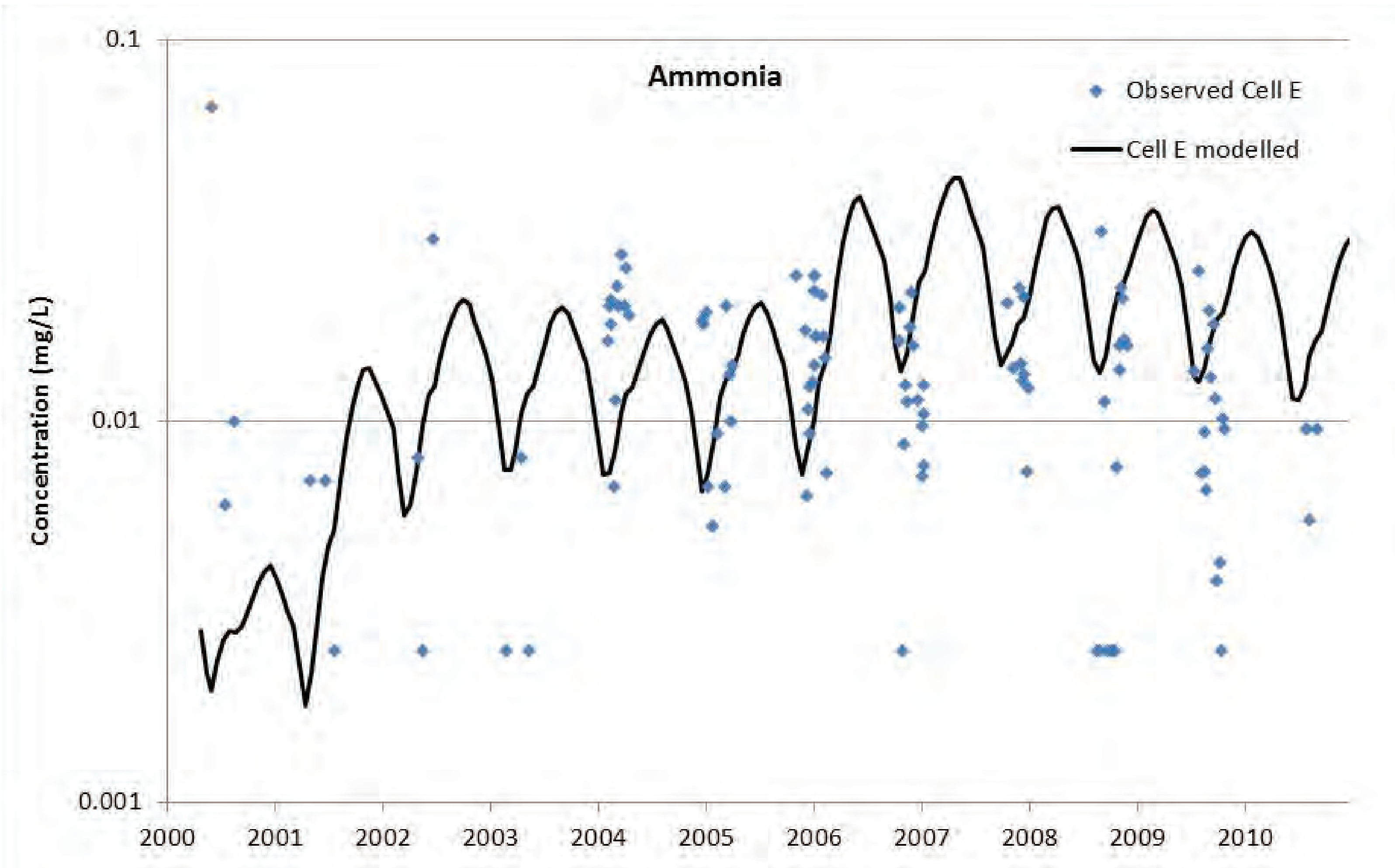

Figure 6.2-4

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Comparison of Predicted and Observed Ammonia Concentrations for Cell E (No Observed Ammonia Data for Cell D)

Figure 6.2-4

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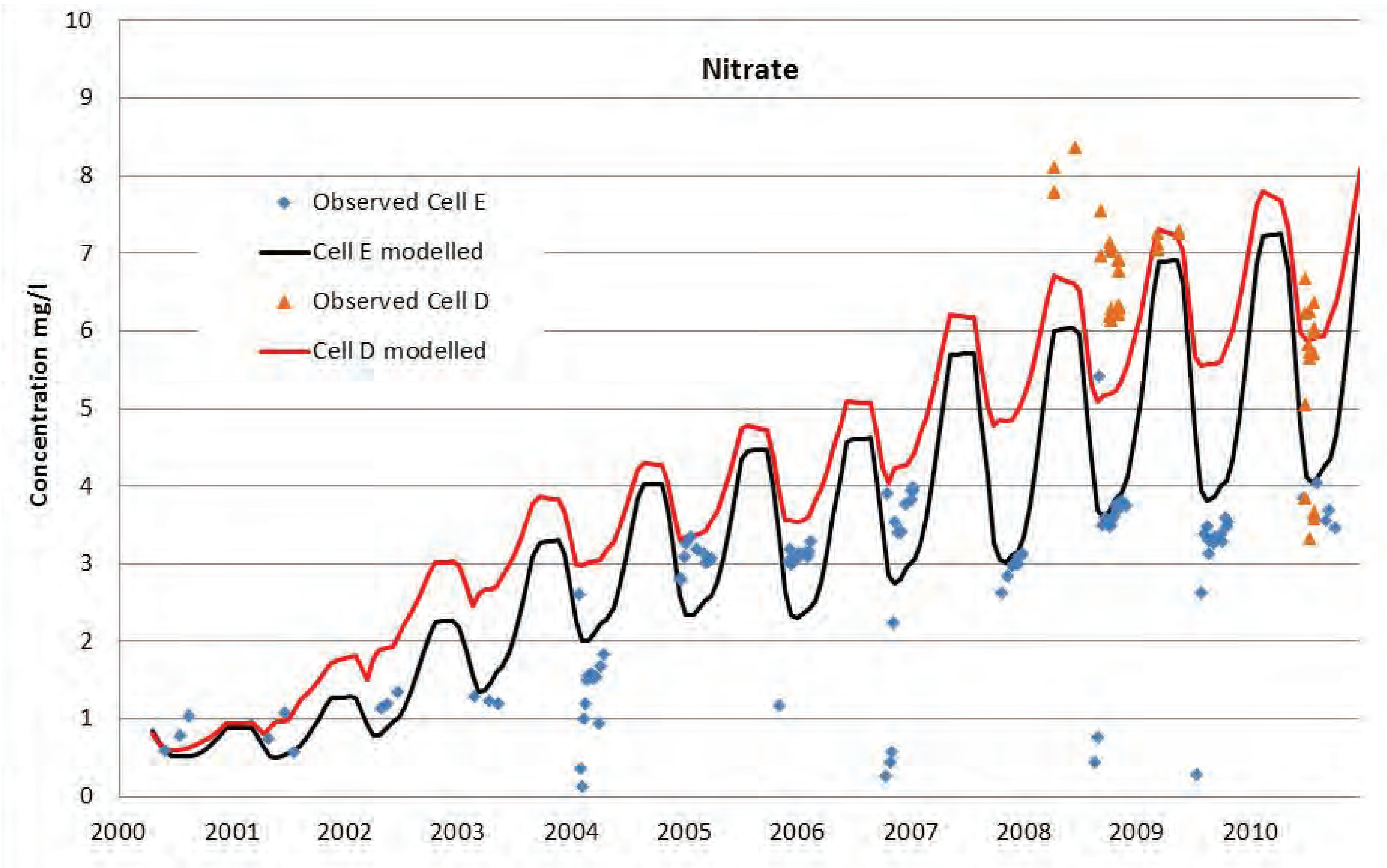

Figure 6.2-5

Comparison of Predicted and Observed Nitrate Concentrations for Cell D and Cell E

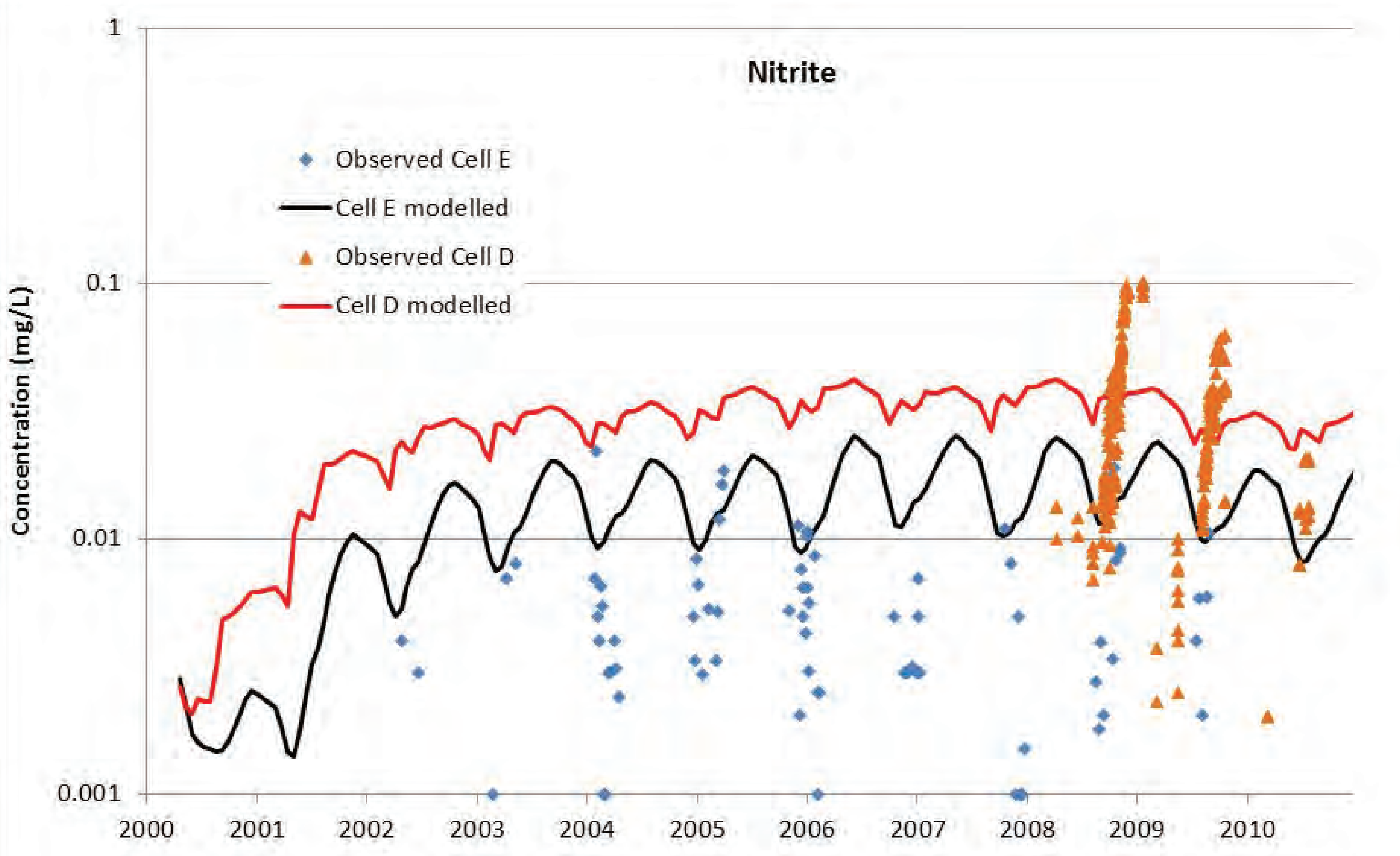

Figure 6.2-6

Comparison of Predicted and Observed Nitrite Concentrations for Cell D and Cell E

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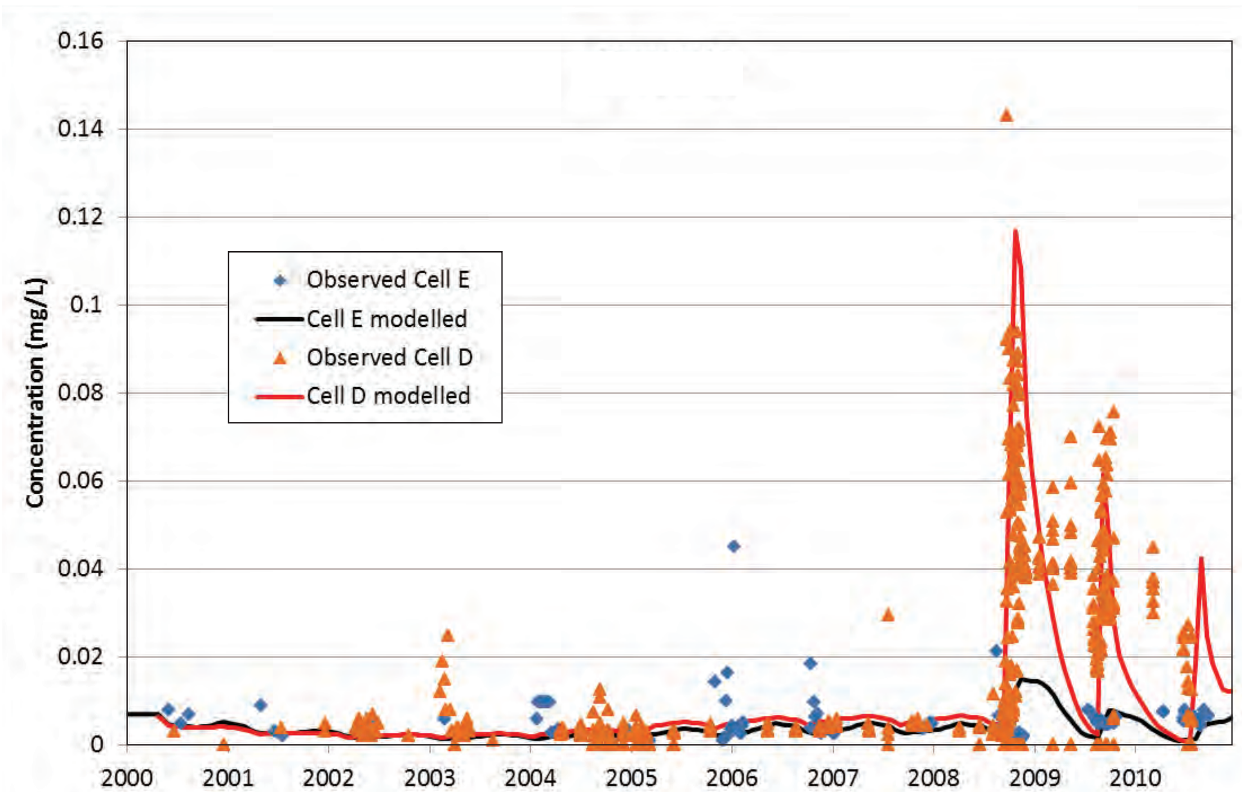

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Comparison of Predicted and Observed Phosphate Concentrations for Cell D and Cell E

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Model predictions for ammonia with a decay half-life of 4.2 months produced a good fit with observed data (Figure 6.2-3).

A reasonable fit was obtained between predicted and observed nitrate concentrations with a zero decay rate (Figure 6.2-5).

Although the model was able to predict concentrations that were consistent with observed nitrite data, it did not predict the large annual variations in nitrite concentrations observed in Cell D and Cell E (Figure 6.2-5).

For phosphate a time varying decay rate was required in order to provide a good fit to observed data. A higher rate of decay (half-life of 2.1 months) was required during the period of time when there was active addition of fertiliser to the LLCF (summer 2009, 2010 and 2010, see Section 4.6). A lower rate was found to be acceptable at other times; half-life of 11.1 months. A time varying decay rate can be is reasonable as overall dynamics of phosphate uptake by plankton are expected to be different during an induced bloom (i.e., following additional of fertiliser) compared to the natural oligotrophic state of the LLCF. The lower natural decay rate is used in the model for the full modelled period post-2012, when no additional fertiliser addition is modelled.

Overall the non-conservative parameters show similar seasonal variations as seen for the conservative parameters; however, seasonal variations in concentrations are dampened by the decay rate. Model results are considered reasonably good given the use of a relatively simple decay equation. In reality, losses of nutrients will be controlled by a number of physical factors (e.g., water temperature and stratification, sunlight) and will vary in time. However, the results would suggest that the approach is adequate for the model to predict trends in water quality for these non-conservative parameters.

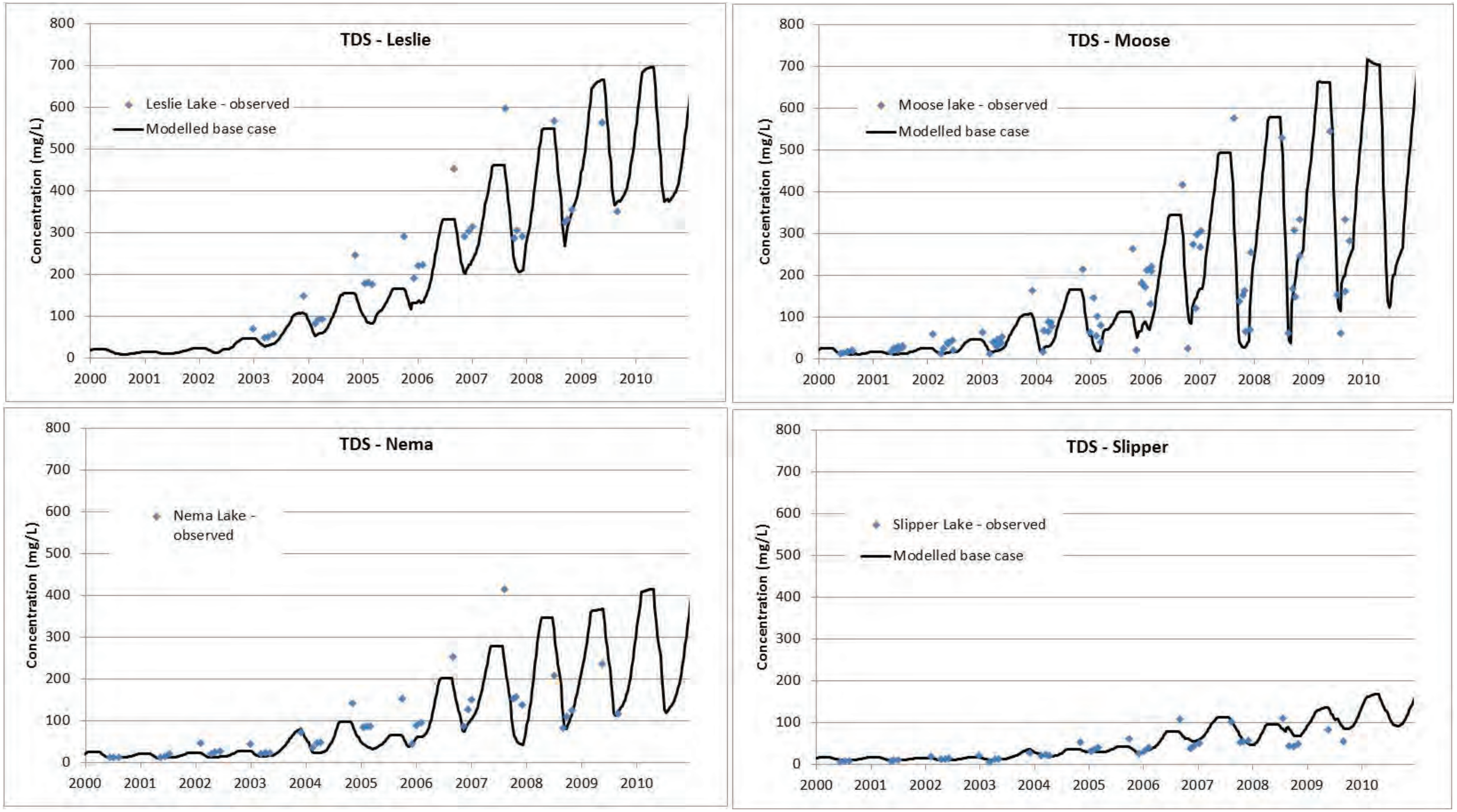
6.2.2 LLCF Downstream Model

The LLCF Downstream Model was run for the period 2000 to end 2010. The model used Cell E predicted concentrations from the LLCF Load Balance Model as upstream inputs, i.e., it did not use observed Cell E water quality as a test of the quality of the LLCF Load Balance Model predictions. No calibration or adjustment of parameters was undertaken in the LLCF Downstream Model. Within the downstream model no decay of nutrients was modelled as the residence times of these lakes (see Section 5.2) were too low compared to the decay half-lives of the non-conservative parameters (Table 6.2-1) for any significant losses to occur or to be modelled.

<u>Conservative Parameters</u>

All parameters bar ammonia, nitrate, nitrite and phosphate are modelled as conservative. Model predictions for Cell D and Cell E for TDS, chloride and hardness are shown in Figures 6.2-8 to 6.2-10.

The model produces predictions that match very well with observed concentrations in and the downstream lakes. The results not only provide a good match to the inter-annual variations in concentrations (increase over time) they provide good fits to the seasonal variations in water quality throughout the year, similar to patterns predicted for Cell E by the Load Balance Model.



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Comparison of Predicted and Observed TDS Concentrations for Downstream Lakes

Figure 6.2-8

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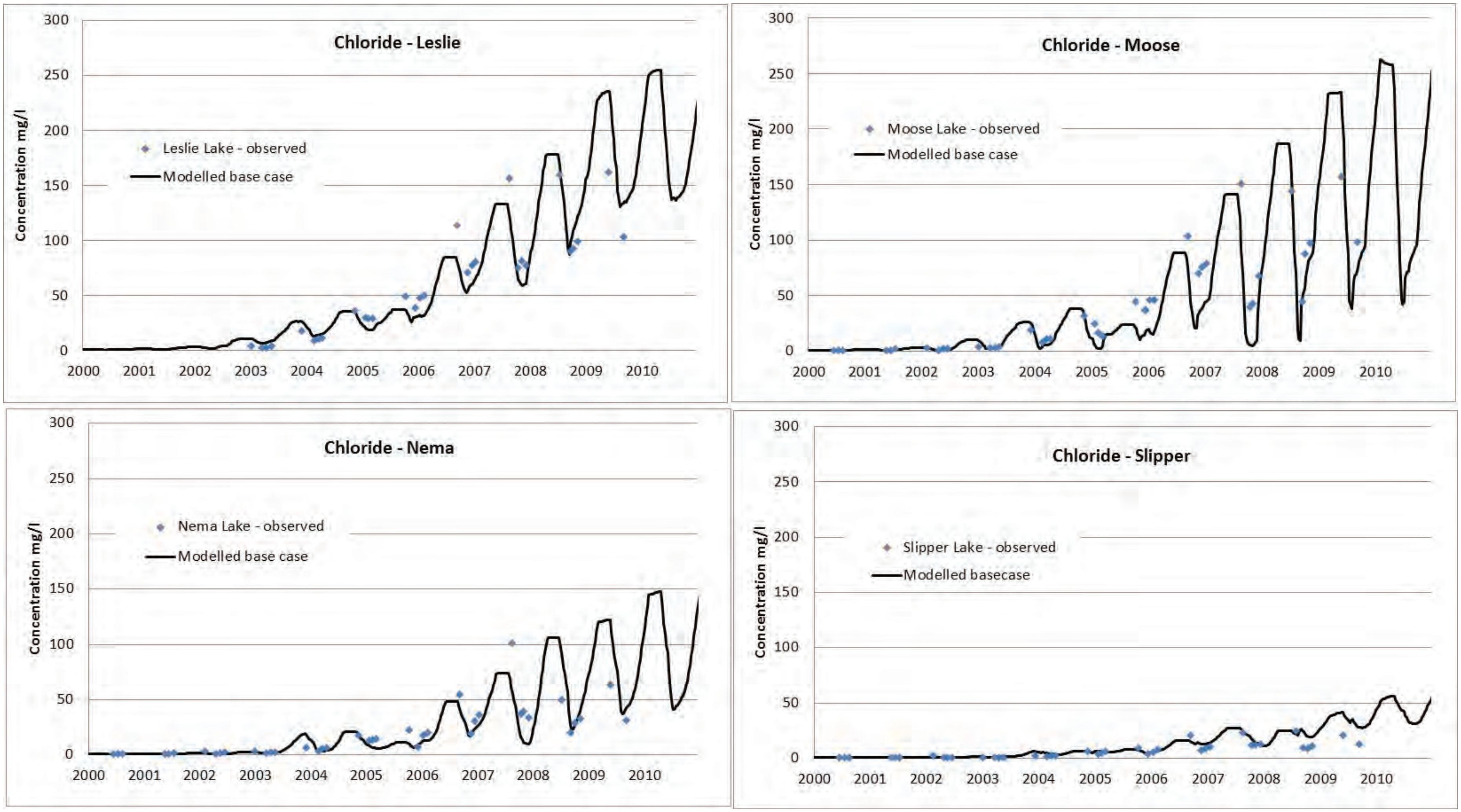

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Comparison of Predicted and Observed Chloride Concentrations for Downstream Lakes

Figure 6.2-9

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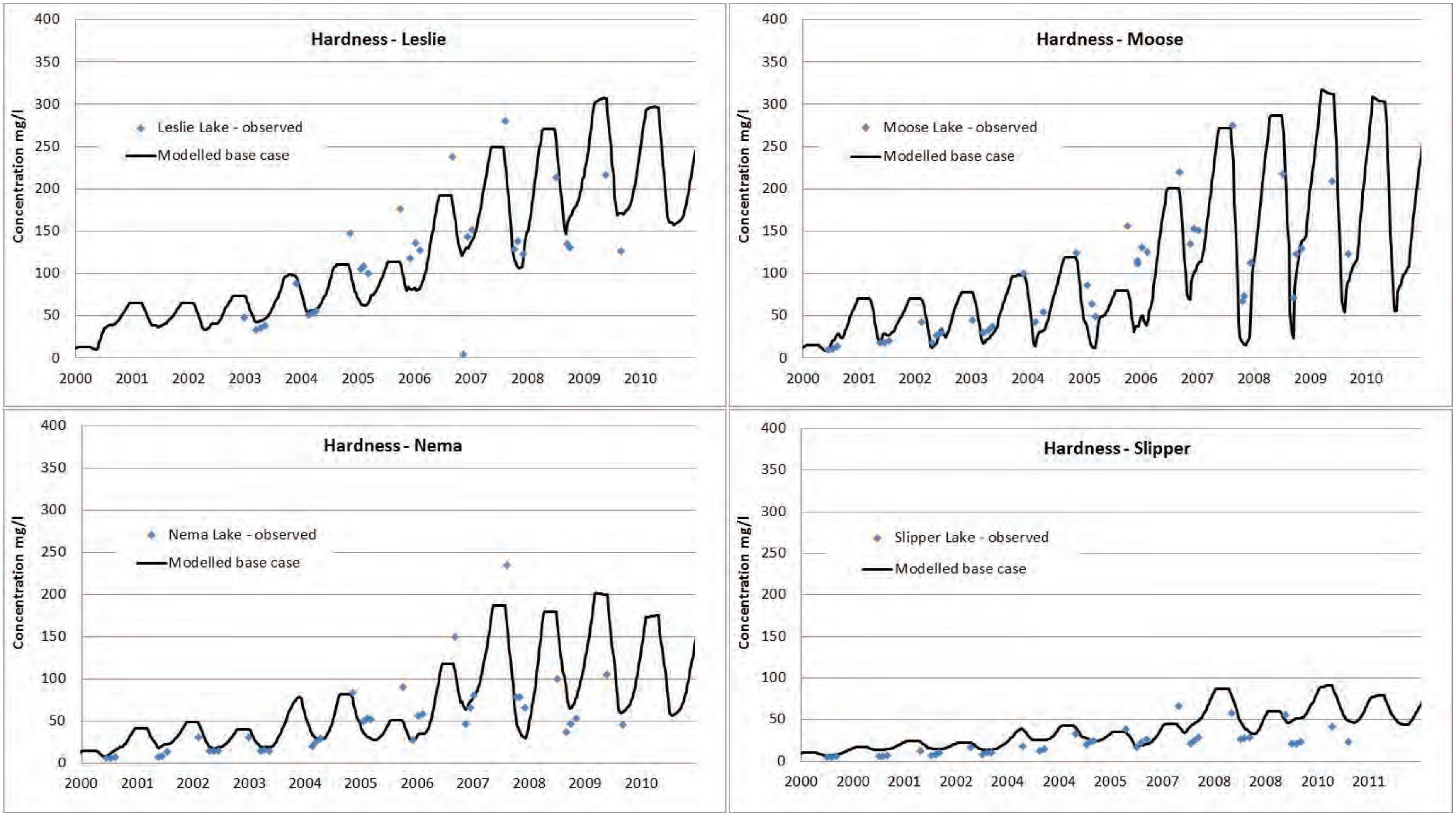

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Comparison of Predicted and Observed Hardness Concentrations for Downstream Lakes

Figure 6.2-10

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The seasonal range in concentrations (from peak in winter to low after freshet) varies from lake to lake and is most marked for Moose Lake where there is a large inflowing catchment that provides substantial dilution in freshet. However, Moose Lake is relatively small so that in winter ice formation removes a substantial volume (approximately 45% of Moose Lake) of the lake water resulting in increased concentrations in the under-ice free water during winter months.

The model represents well the dilution processes from Leslie Lake to Slipper Lake. The quality of the fit with observed data is excellent, particularly given that the results are presented with no calibration.

Model fits for all parameters for the historical period are provided in the Model Summary Sheets (Appendix 4).

<u>Non-conservative Parameters</u>

Ammonia, nitrate, nitrite and phosphate are modelled as non-conservative parameters. Within the LLCF Load Balance Model these parameters are modelled with a first order decay rate. However, in the LLCF Downstream Model no decay rate is modelled as the flow time within the downstream lakes is considered small. Figures 6.2-11 to 6.2-14 show that the model predictions for these nutrients are acceptable without the need for a decay rate. The poorest fit between observed and predicted data is for nitrate, where the model over-predicts observed concentrations. However, nitrate in the LLCF is modelled with a zero decay rate, so including a decay equation for the downstream lakes would have no effect for nitrate. For phosphate the peaks in loadings in 2009 to 2011 were a result of additional of phosphate to the LLCF during a nutrient amendment study undertaken in 2009, 2010 and 2011 (Section 4.6).

6.3 FUTURE PREDICTIONS OF WATER QUALITY IN LLCF AND DOWNSTREAM LAKES (JANUARY 2011 TO 2025)

The LLCF Load Balance Model and LLCF Downstream Model were run for the period of January 2011 to end 2025 to predict the evolution of water quality over the mine's lifetime. For the purpose of evaluating modelled trends into the future an operational period to early 2020 was assumed. Post-closure modelling of water quality in LLCF and downstream lakes has not been fully tested for this report and will be the subject of subsequent modelling studies to support reclamation research.

Predictions for all modelled parameters are provided in Model Summary Sheets in Appendix 4. However, results are presented in the main body of the report for parameters of concern, which are those predicted to rise to more than 75% of their Water Quality Benchmark (see Section 2.3) in the downstream lakes during the period 2011 to February 2020. A summary of the peak concentrations (expressed as percentage of Water Quality Benchmark) in downstream lakes for all parameters for the historical period and future period is provided in Table 6.3-1. Note that TDS results are presented because it is a conservative parameter that is suitable for model calibration and provides a context for its key constituents. TDS has no proposed benchmark.

Cell E results for parameters of concern are provided in Figures 6.3-1 to 6.3-9. Graphs are provided which:

- show predicted concentrations over time compared to Water Quality Benchmarks and observed water quality data; and
- show predicted and observed concentrations converted to a time series representing percentage of the Water Quality Benchmark that is reached.

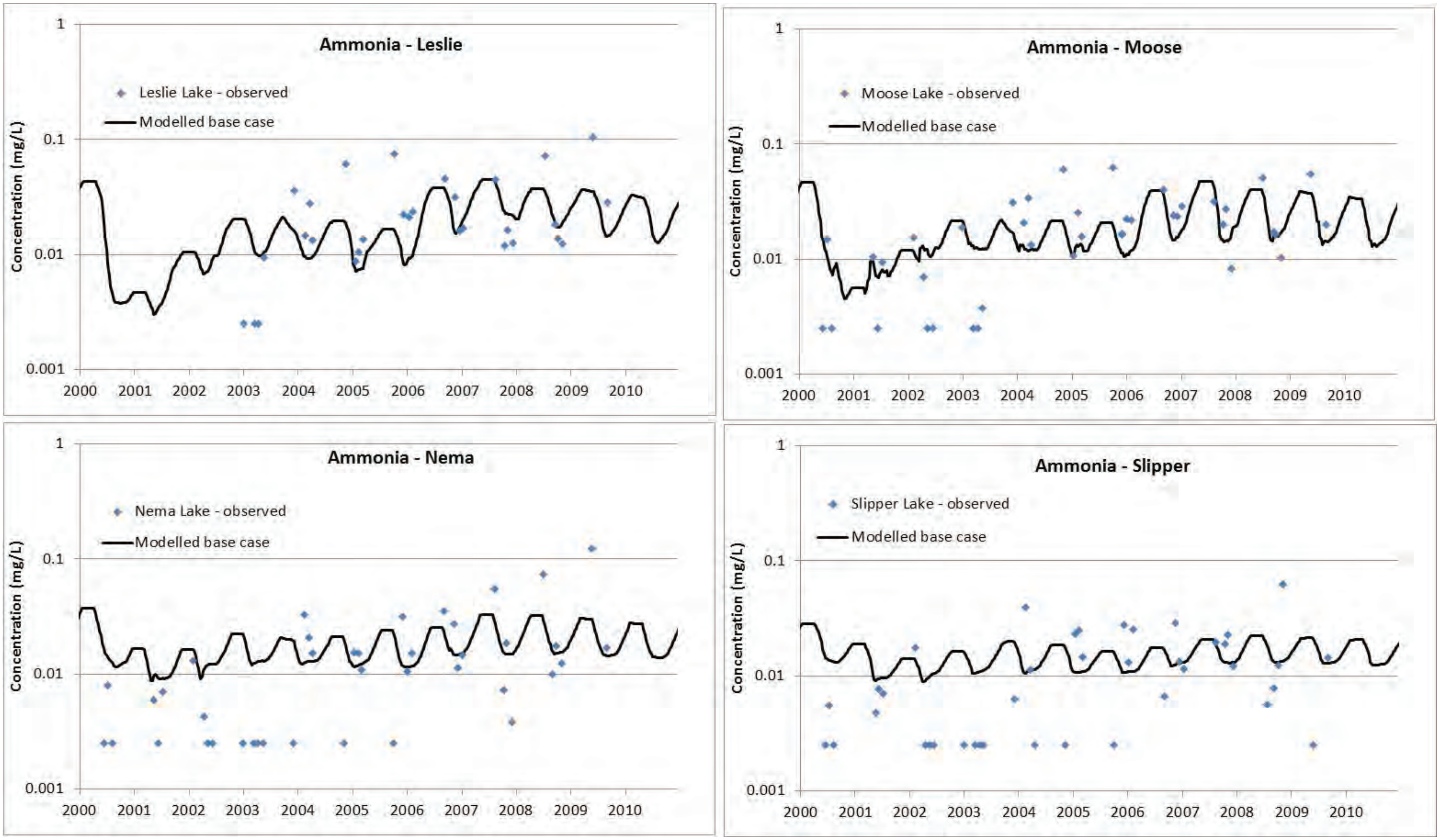

Figure 6.2-11

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Comparison of Predicted and Observed Ammonia Concentrations for Downstream Lakes

Figure 6.2-11

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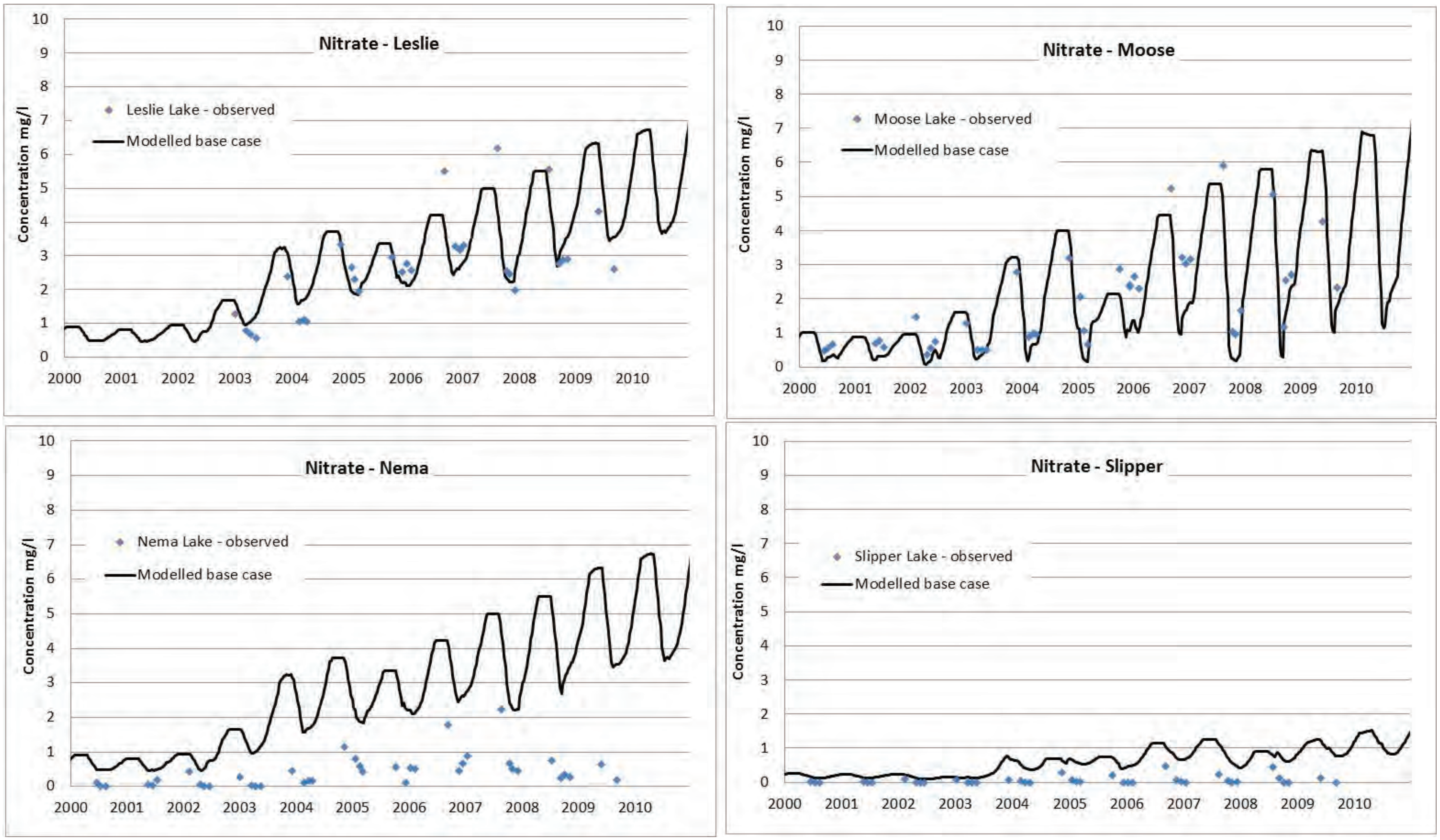

Figure 6.2-12

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Comparison of Predicted and Observed Nitrate Concentrations for Downstream Lakes

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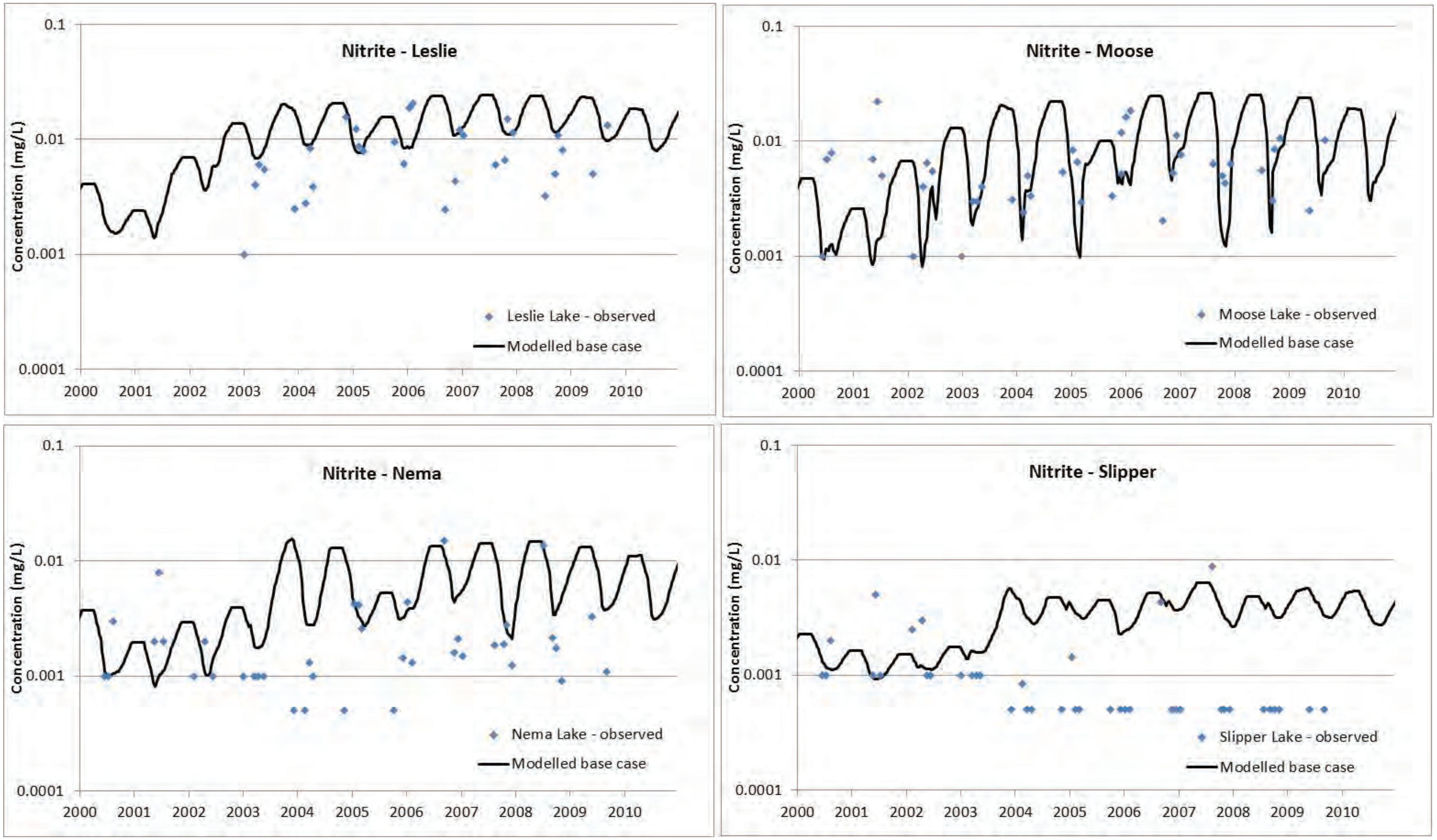

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Comparison of Predicted and Observed Nitrite Concentrations for Downstream Lakes

Figure 6.2-13

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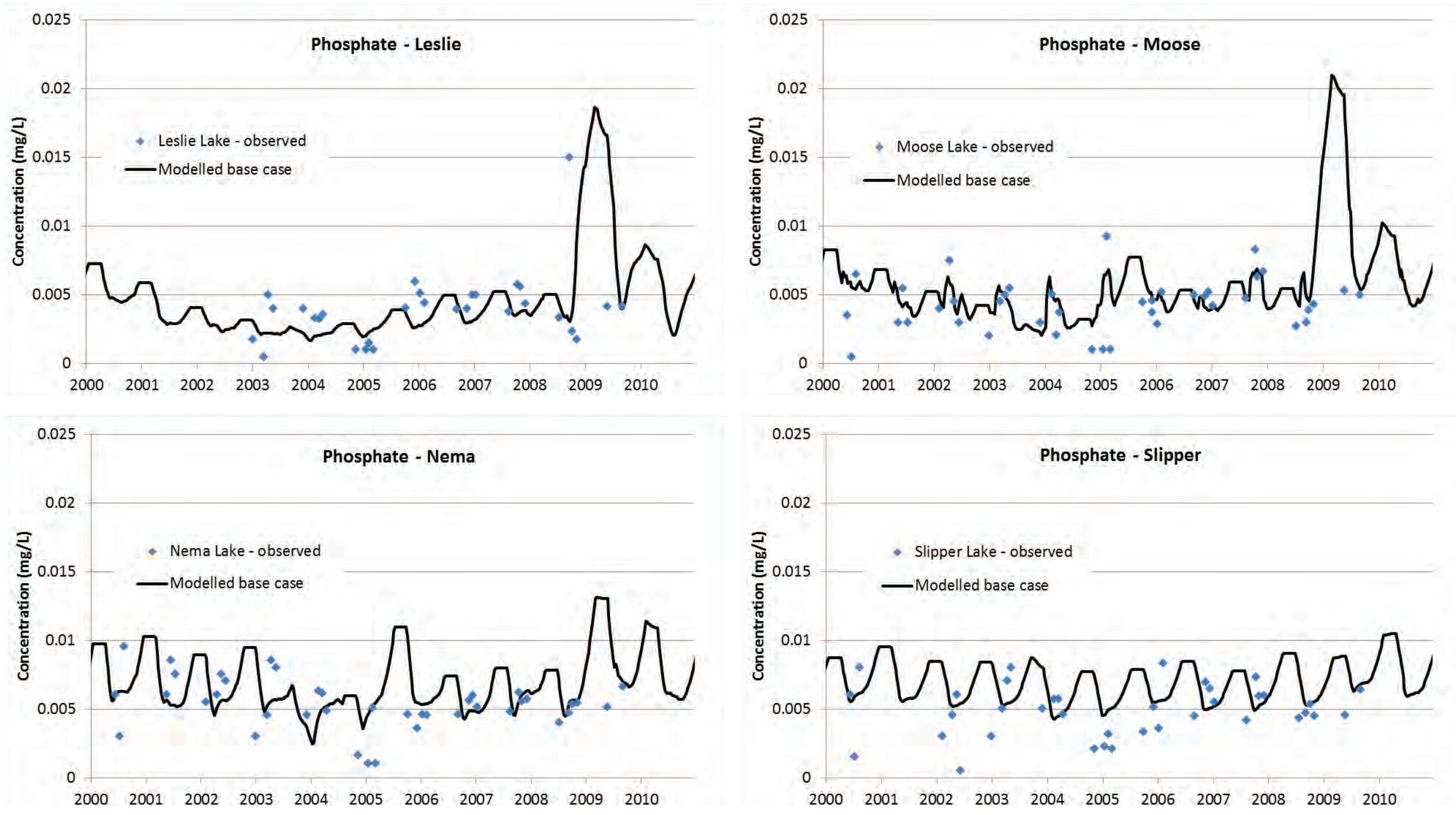

Figure 6.2-14

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Comparison of Predicted and Observed Phosphate Concentrations for Downstream Lakes

Figure 6.2-14

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Table 6.3-1. Model Predicted Maximum Concentration and Percentage of Water Quality Benchmark Value for Downstream Lakes for Period Jan 2011 to Feb 2020

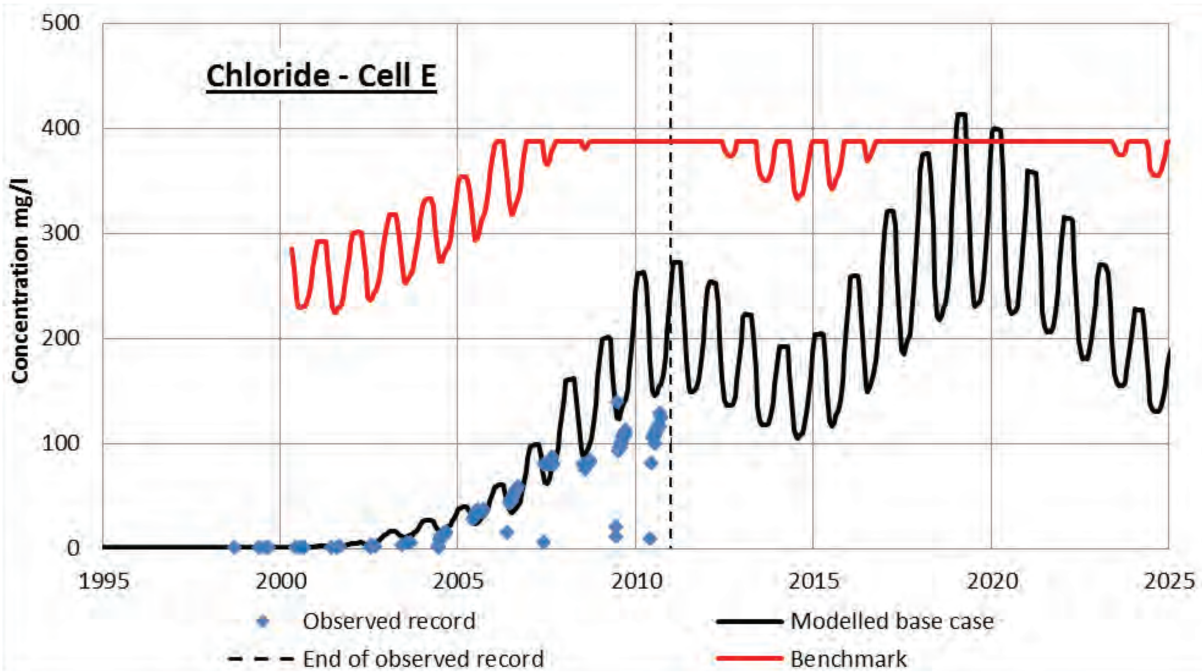
Parameter	Leslie Lake		Moose Lake		Nema Lake		Slipper Lake	
	Maximum Predicted (mg/L)	% of Benchmark	Maximum Predicted (mg/L)	% of Benchmark	Maximum Predicted (mg/L)	% of Benchmark	Maximum Predicted (mg/L)	% of Benchmark
Aluminum	0.143 *Mar. 2014*	143 *Mar. 2014*	0.150 *Jan. 2015*	150 *Jan. 2015*	0.113 *Jan. 2015*	113 *Jan. 2015*	0.0771 *Apr. 2016*	77 *Apr. 2016*
Ammonia-N	0.0337 *Jan. 2013*	6 *Jan. 2020*	0.0349 *Jan. 2013*	6 *Jan. 2013*	0.0277 *Jan. 2011*	5 *Jan. 2011*	0.0212 *Apr. 2011*	4 *Apr. 2011*
Antimony	0.00572 *Feb. 2020*	29 *Feb. 2020*	0.00592 *Jan. 2020*	30 *Jan. 2020*	0.00355 *Feb. 2020*	18 *Feb. 2020*	0.00185 *Feb. 2020*	9 *Feb. 2020*
Arsenic	0.00359 *Feb. 2020*	72 *Feb. 2020*	0.00372 *Jan. 2020*	74 *Jan. 2020*	0.00216 *Feb. 2020*	43 *Feb. 2020*	0.00105 *Feb. 2020*	21 *Feb. 2020*
Barium	0.0638 *Mar. 2011*	6 *Feb. 2020*	0.0671 *Jan. 2011*	7 *Jan. 2011*	0.0439 *Jan. 2011*	4 *Jan. 2011*	0.0239 *Apr. 2011*	2 *Apr. 2011*
Boron	0.0575 *Feb. 2020*	4 *Feb. 2020*	0.0591 *Jan. 2020*	4 *Jan. 2020*	0.0320 *Feb. 2020*	2 *Feb. 2020*	0.0136 *Feb. 2020*	<1 *Feb. 2020*
Cadmium	0.000293 *Feb. 2020*	420 *Mar. 2014*	0.000305 *Jan. 2020*	491 *Jul. 2014*	0.000184 *Feb. 2020*	429 *Jan. 2015*	0.0000948 *Feb. 2020*	464 *Jan. 2015*
Chloride	383 *Mar. 2019*	99 *Mar. 2019*	392 *Jan. 2020*	101 *Jan. 2020*	212 *Feb. 2020*	55 *Feb. 2020*	85.8 *Feb. 2020*	28 *Feb. 2020*
Chromium$_{(III)}$	0.000284 *Mar. 2019*	3 *Jan. 2019*	0.000552 *Jan. 2020*	6 *Jan. 2020*	0.000366 *Jan. 2020*	4 *Jan. 2020*	0.000218 *Feb. 2020*	2 *Feb. 2020*
Chromium$_{(VI)}$	0.00101 *Mar. 2019*	101 *Jan. 2019*	0.000794 *Jan. 2020*	79 *Jan. 2020*	0.000526 *Jan. 2020*	53 *Jan. 2020*	0.000314 *Feb. 2020*	31 *Feb. 2020*
Copper	0.00193 *Feb 2019*	51 *Aug. 2014*	0.00209 *Jan. 2019*	70 *May 2015*	0.00239 *Jan. 2019*	99 *Dec. 2014*	0.00196 *Apr. 2019*	98 *Apr. 2019*
Iron	0.0975 *Mar. 2014*	33 *Feb. 2014*	0.100 *Jan. 2014*	33 *Jan. 2014*	0.062 *Apr. 2015*	21 *Apr. 2015*	0.0341 *Apr. 2015*	11 *Apr. 2015*
Lead	0.000134 *Mar. 2011*	2 *Aug. 2014*	0.000140 *Jan. 2015*	4 *Jul. 2014*	0.0000978 *Jan. 2011*	4 *Sep. 2014*	0.0000626 *Apr. 2011*	5 *Dec. 2015*

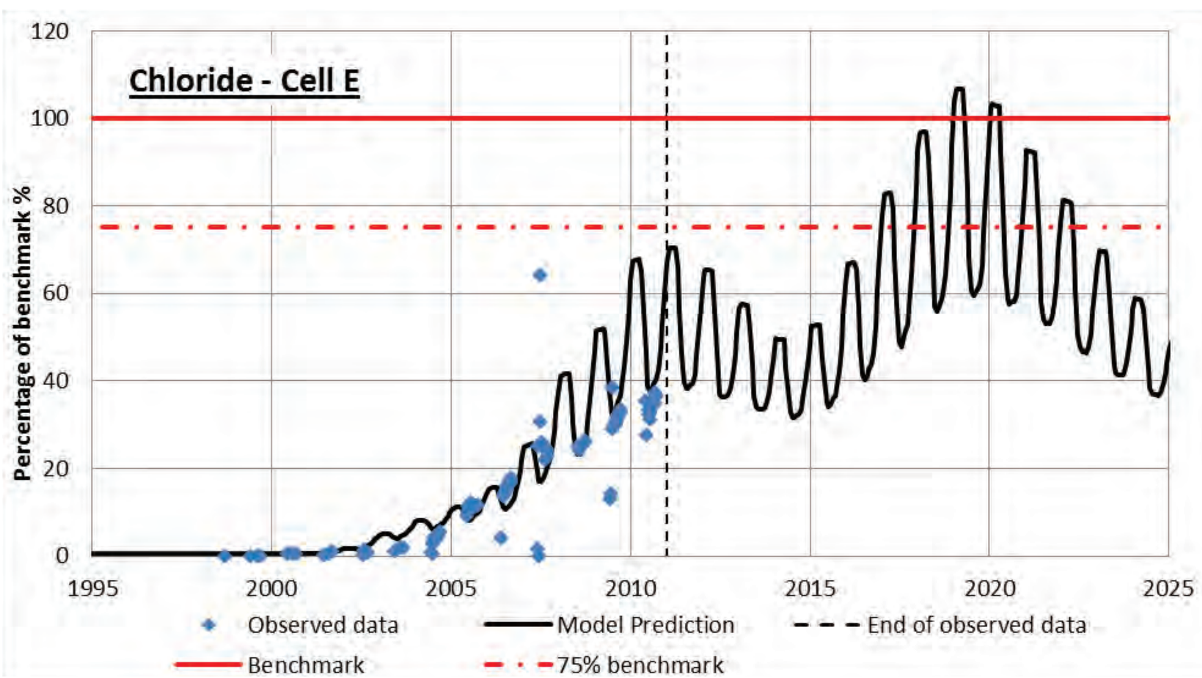
(continued)

Table 6.3-1. Model Predicted Maximum Concentration and Percentage of Water Quality Benchmark Value for Downstream Lakes for Period Jan 2011 to Feb 2020 (completed)

Parameter	Leslie Lake		Moose Lake		Nema Lake		Slipper Lake	
	Maximum Predicted (mg/L)	% of Benchmark	Maximum Predicted (mg/L)	% of Benchmark	Maximum Predicted (mg/L)	% of Benchmark	Maximum Predicted (mg/L)	% of Benchmark
Manganese	0.0215 *Mar. 2011*	1 *Jan. 2014*	0.0227 *Jan. 2011*	1 *Jan. 2015*	0.0178 *Jan. 2011*	1 *Jan. 2015*	0.0118 *Apr. 2011*	1 *Apr. 2016*
Molybdenum	0.163 *Feb. 2020*	<1 *Feb. 2020*	0.168 *Jan. 2020*	<1 *Jan. 2020*	0.0885 *Feb. 2020*	<1 *Feb. 2020*	0.0354 *Feb. 2020*	<1 *Feb. 2020*
Nickel	0.00733 *Feb. 2020*	4 *Mar. 2015*	0.00762 *Jan. 2020*	6 *Jun. 2015*	0.00545 *Jan. 2020*	5 *Jul. 2015*	0.00311 *Apr. 2019*	5 *Feb. 2016*
Nitrate-N	9.22 *Feb. 2020*	56 *Feb. 2020*	9.50 *Jan. 2020*	35 *Jan. 2020*	5.09 *Feb. 2020*	41 *Apr. 2015*	2.08 *Feb. 2020*	36 *Jan. 2015*
Nitrite-N	0.0213 *Feb. 2020*	35 *Feb. 2020*	0.0211 *Feb. 2020*	35 *Feb. 2020*	0.0107 *Apr. 2011*	18 *Apr. 2011*	0.00578 *Apr. 2011*	10 *Apr. 2011*
[a]Phosphate-P	0.00663 *Feb. 2012*	69 *Feb. 2012*	0.00721 *Jan. 2012*	94 *Jan. 2012*	0.00965 *Jan. 2013*	106 *Jan. 2013*	0.00929 *Aug. 2012*	92 *Apr. 2013*
Potassium	41.1 *Feb. 2020*	100 *Feb. 2020*	42.4 *Jan. 2020*	103 *Jan. 2020*	23.3 *Feb. 2020*	57 *Feb. 2020*	9.89 *Feb. 2020*	24 *Feb. 2020*
Selenium	0.00117 *Mar. 2015*	117 *Mar. 2015*	0.00120 *Jan. 2015*	120 *Jan. 2015*	0.000685 *Apr. 2015*	68 *Apr. 2015*	0.000327 *Apr. 2016*	33 *Apr. 2016*
Strontium	2.40 *Mar. 2019*	38 *Mar. 2019*	2.46 *Jan. 2020*	39 *Jan. 2020*	1.33 *Feb. 2020*	21 *Feb. 2020*	0.543 *Feb. 2020*	9 *Feb. 2020*
Sulphate	133 *Feb. 2020*	24 *Feb. 2020*	137 *Jan. 2020*	24 *Jan. 2020*	74.2 *Feb. 2020*	15 *Apr. 2015*	31.1 *Feb. 2020*	13 *Apr. 2015*
Uranium	0.000916 *Mar. 2019*	6 *Jan. 2019*	0.000944 *Jan. 2019*	6 *Jan. 2019*	0.000569 *Apr. 2019*	4 *Apr. 2019*	0.000278 *Apr. 2019*	2 *Apr. 2019*
Vanadium	0.00622 *Feb. 2020*	21 *Feb. 2020*	0.00640 *Jan. 2020*	21 *Jan. 2020*	0.00347 *Feb. 2020*	12 *Feb. 2020*	0.00148 *Feb. 2020*	5 *Feb. 2020*
Zinc	0.00318 *Feb. 2020*	11 *Feb. 2020*	0.00338 *Jan. 2020*	11 *Jan. 2020*	0.00350 *Jan. 2020*	12 *Jan. 2020*	0.00258 *Apr. 2011*	9 *Apr. 2011*

[a] *Phosphate maxima are provided for period Jan 2012 to Feb 2020, to avoid period of active fertiliser addition to the LLCF which was a short-term management measure that has now ceased.*





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Chloride Predictions in Cell E for 2000 to 2025

Figure 6.3-1

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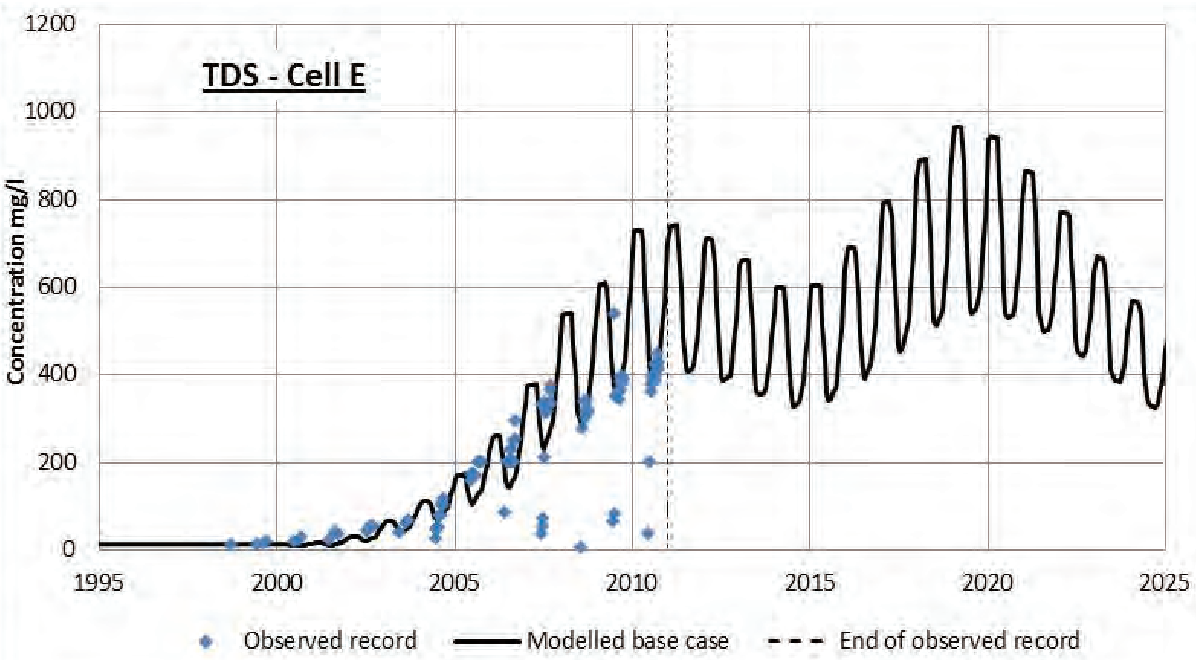
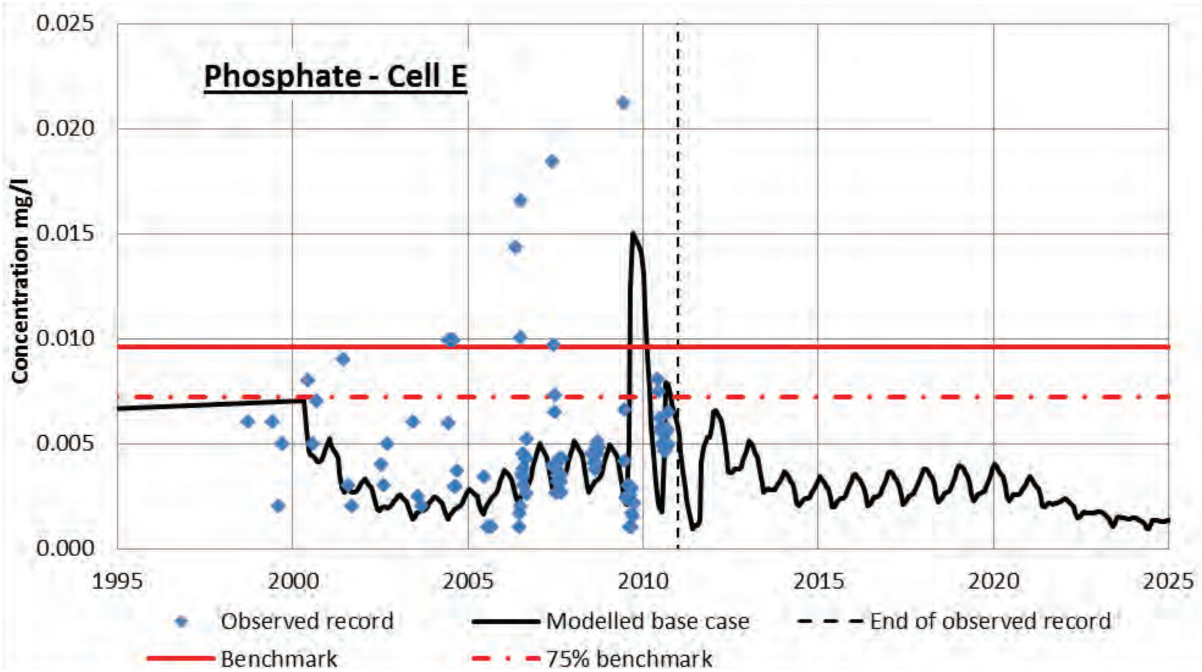


Figure 6.3-2

TDS Predictions in Cell E for 2000 to 2025



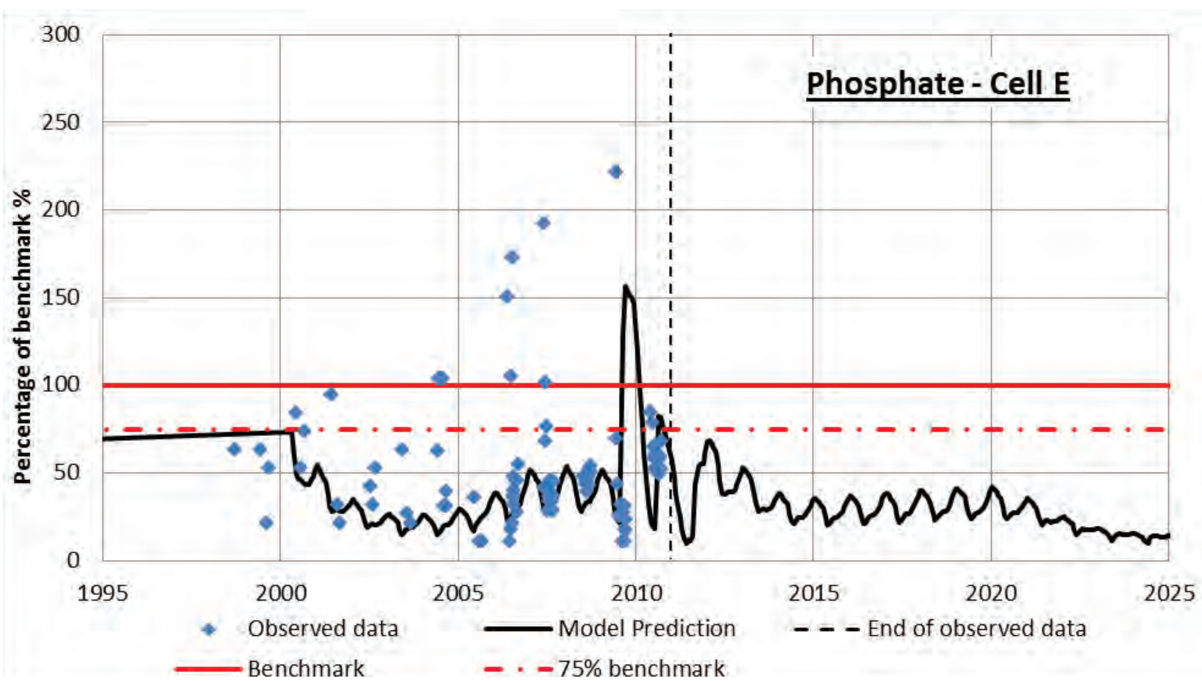


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Figure 6.3-3

Phosphate Predictions in Cell E for 2000 to 2025

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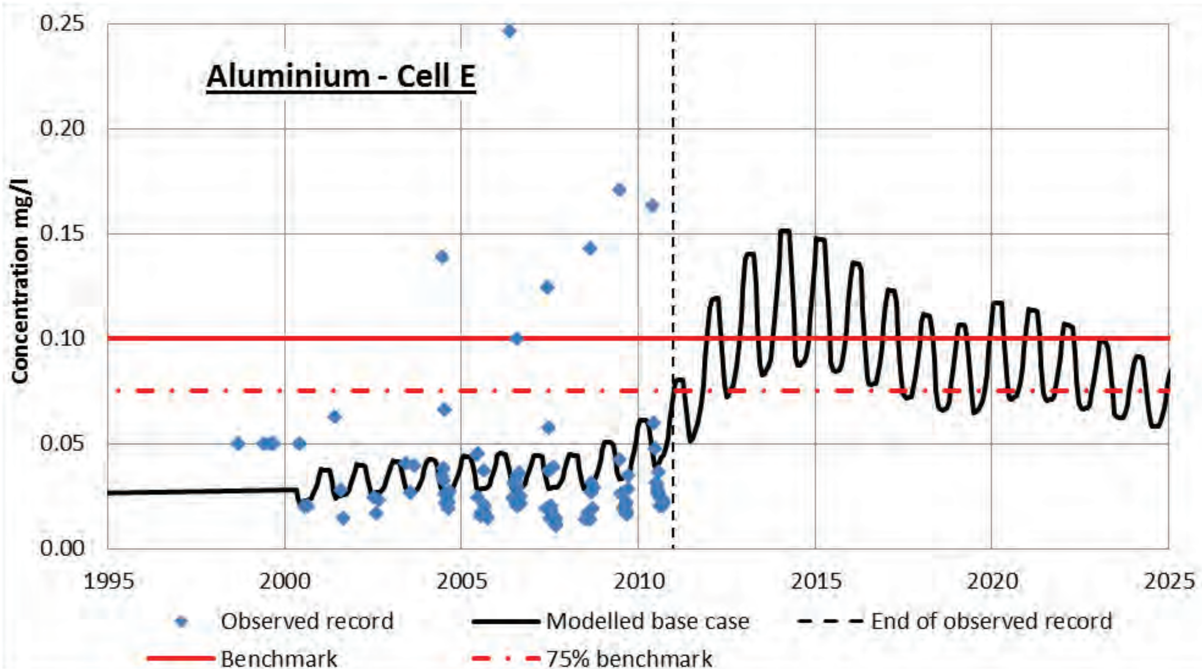

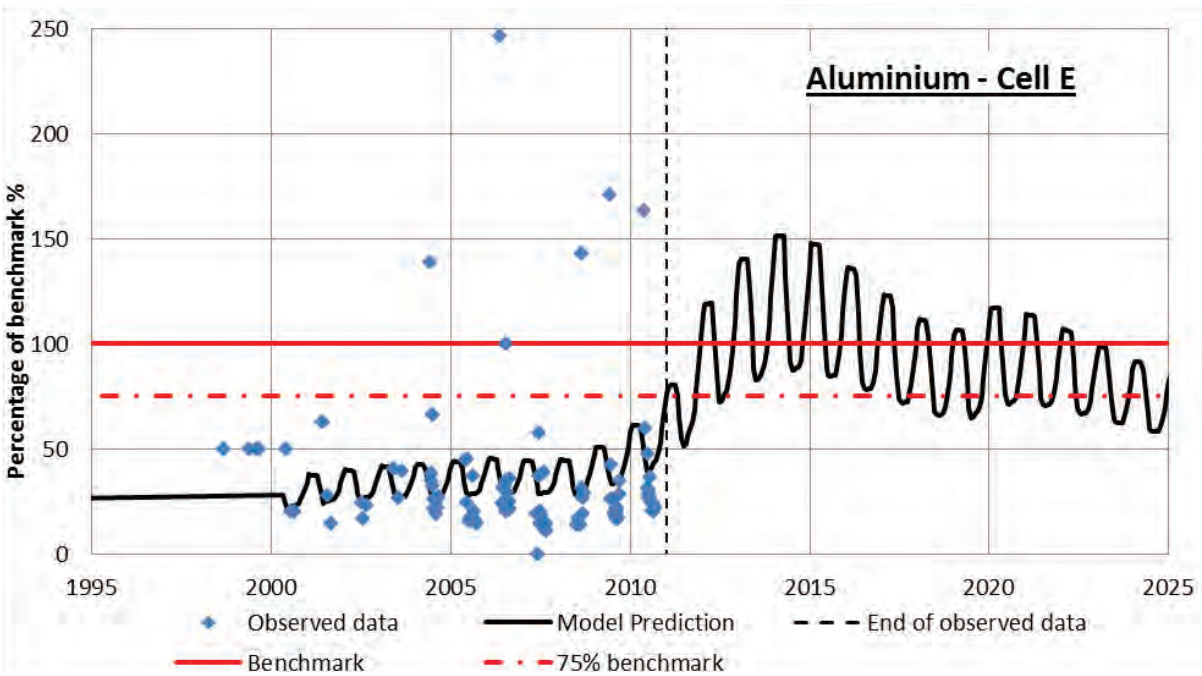

Figure 6.3-4

Aluminium Predictions in Cell E for 2000 to 2025

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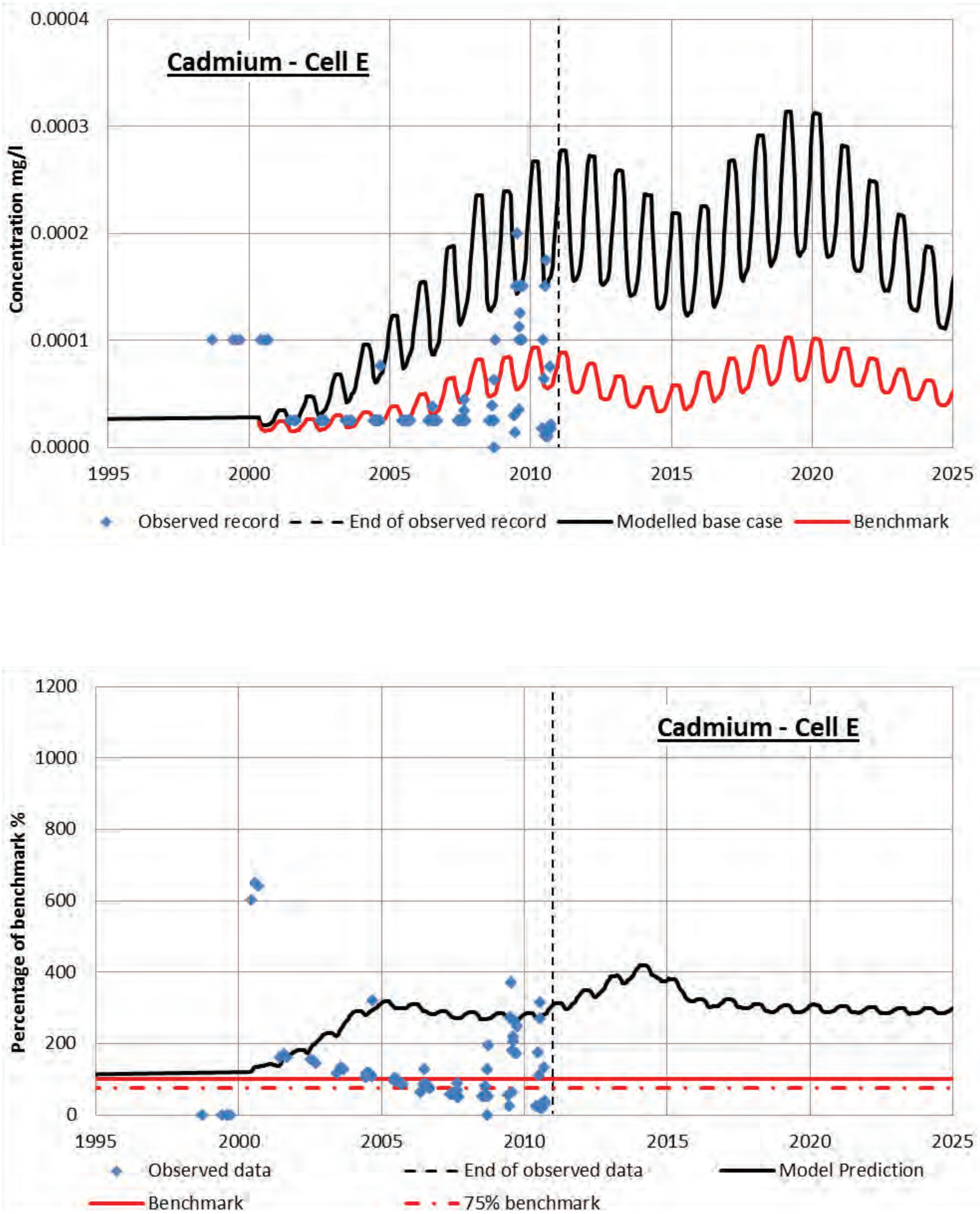

Figure 6.3-5

Cadmium Predictions in Cell E for 2000 to 2025

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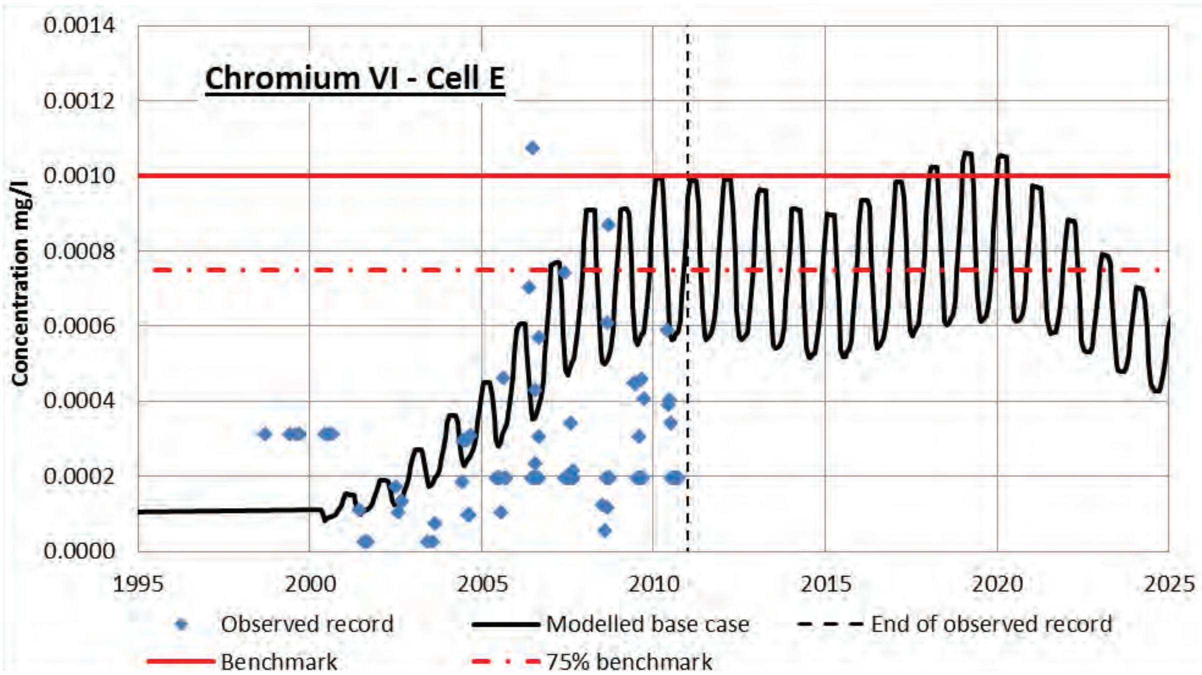

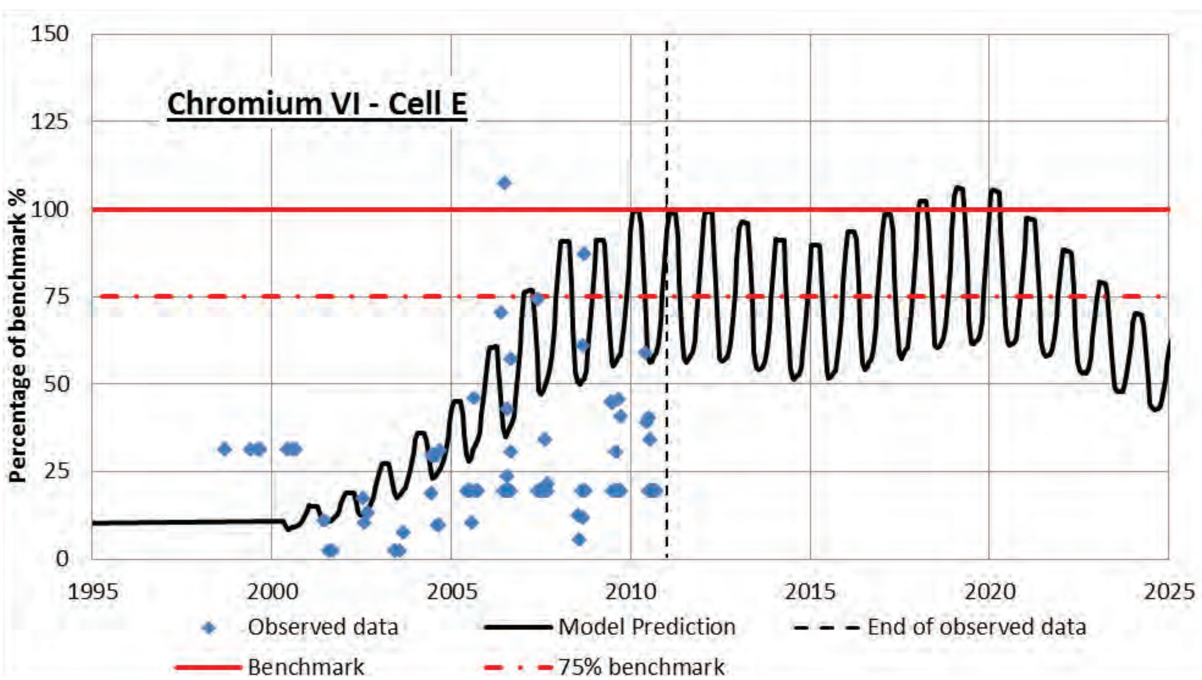

Figure 6.3-6

Chromium(VI) Predictions in Cell E for 2000 to 2025

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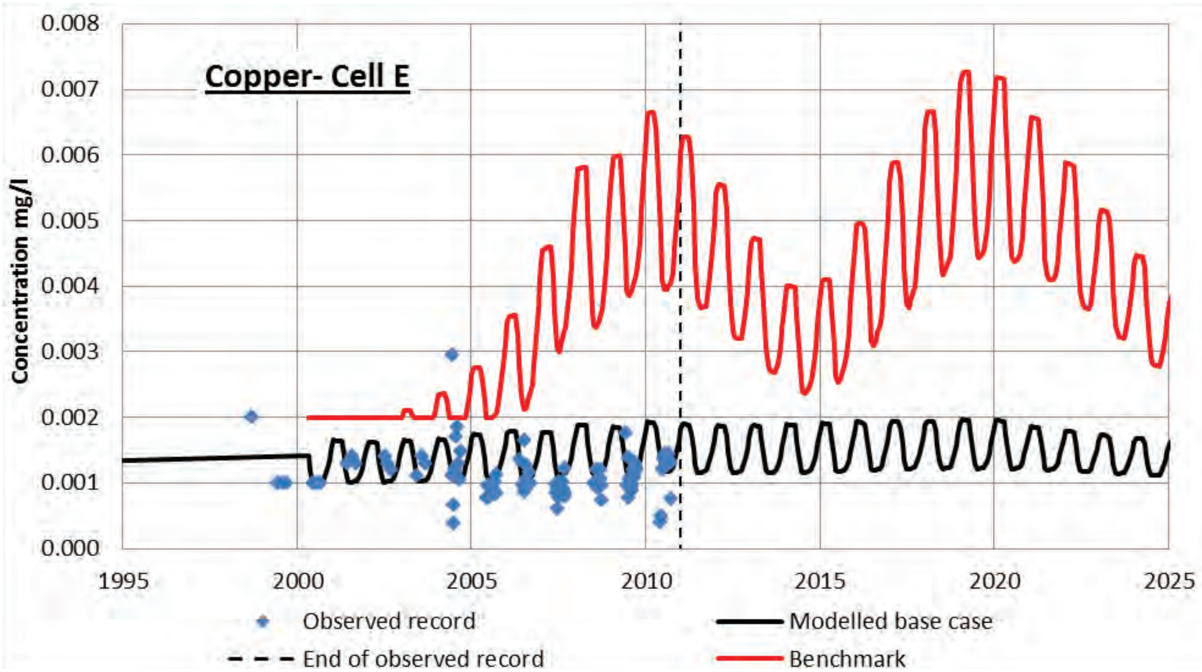

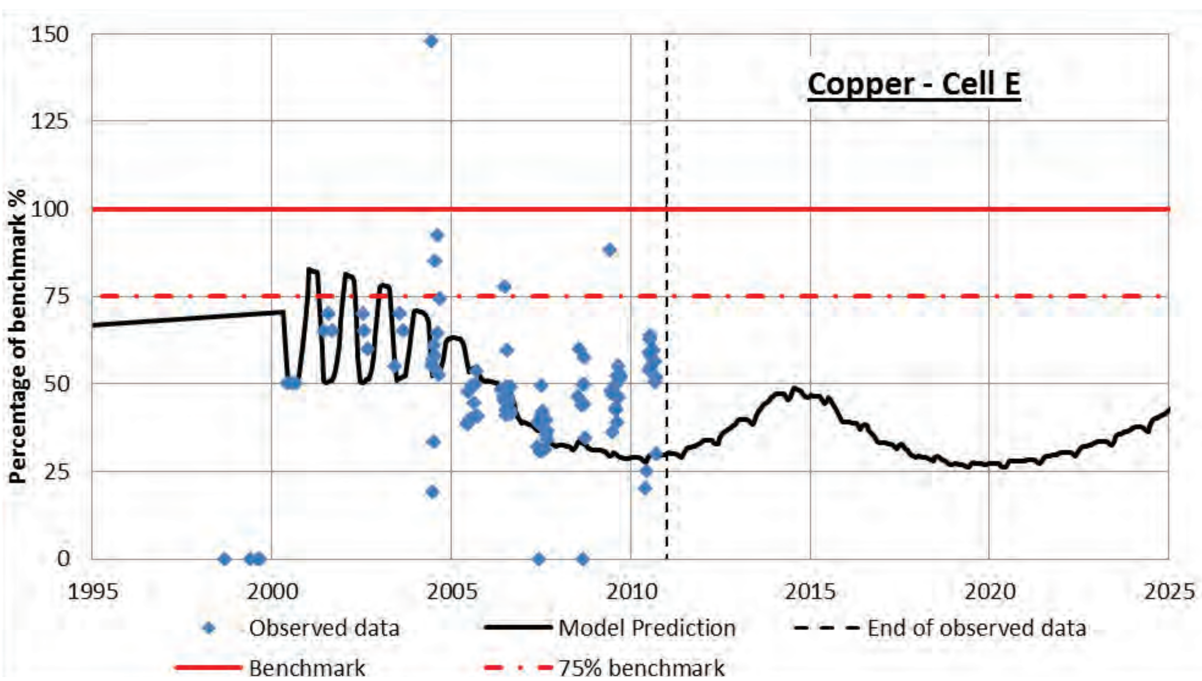

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Copper Predictions in Cell E for 2000 to 2025

Figure 6.3-7

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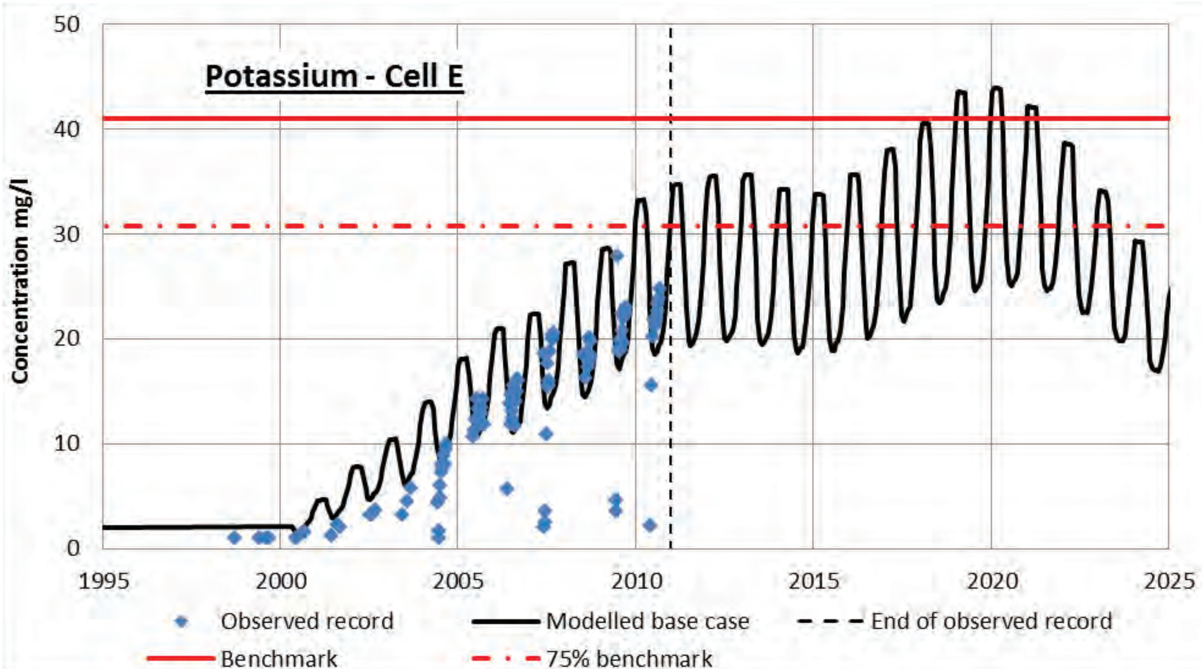

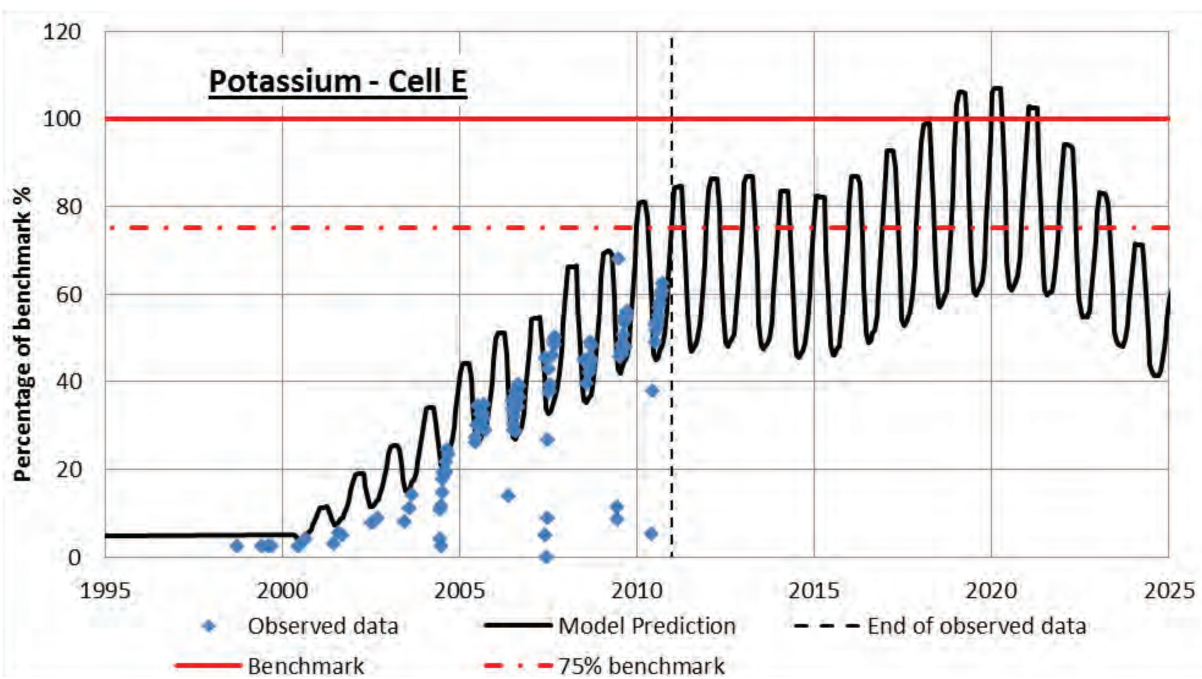

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Potassium Predictions in Cell E for 2000 to 2025

Figure 6.3-8

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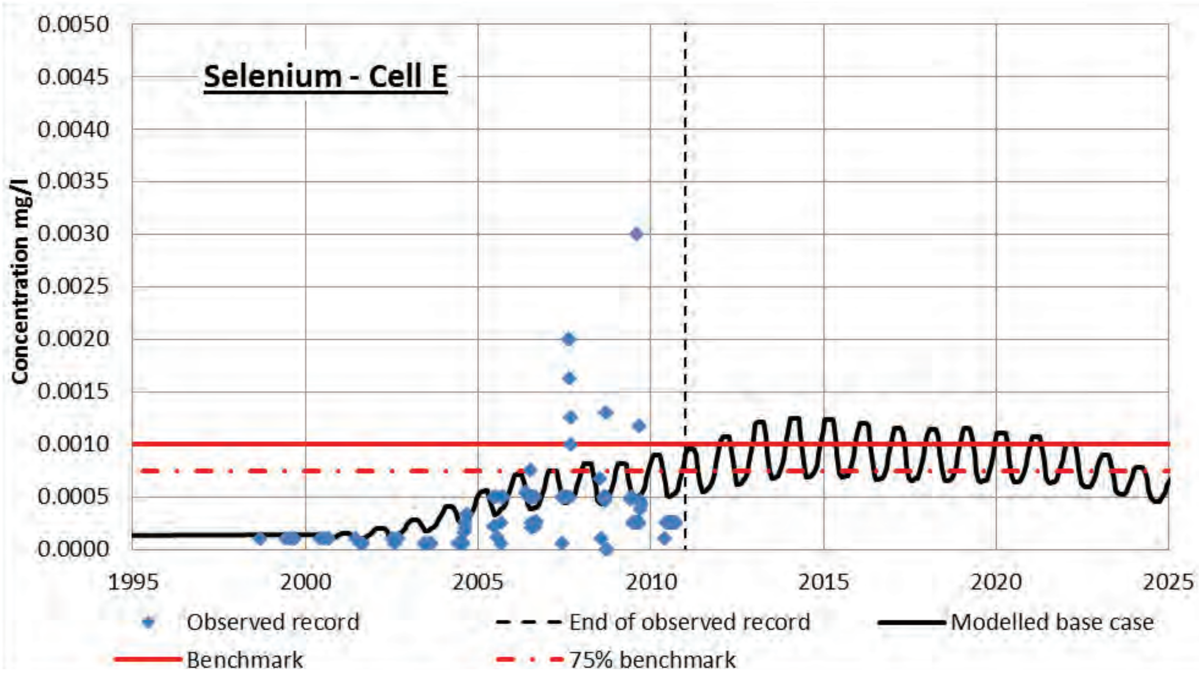

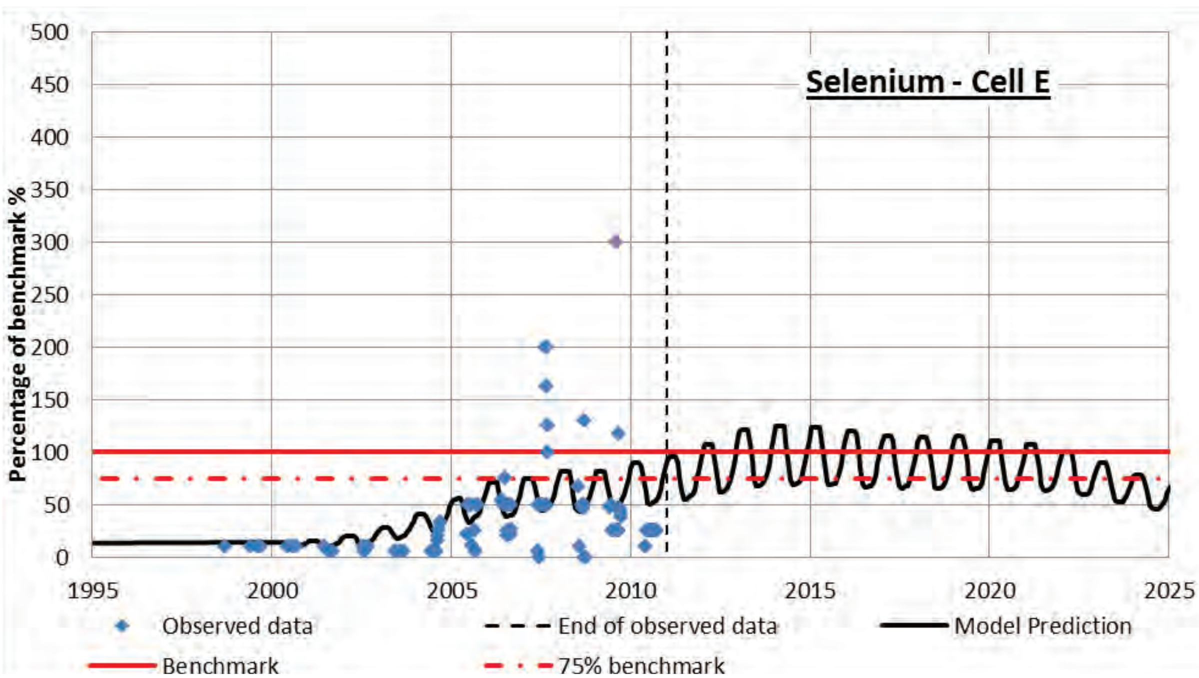

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Selenium Predictions in Cell E for 2000 to 2025

Figure 6.3-9

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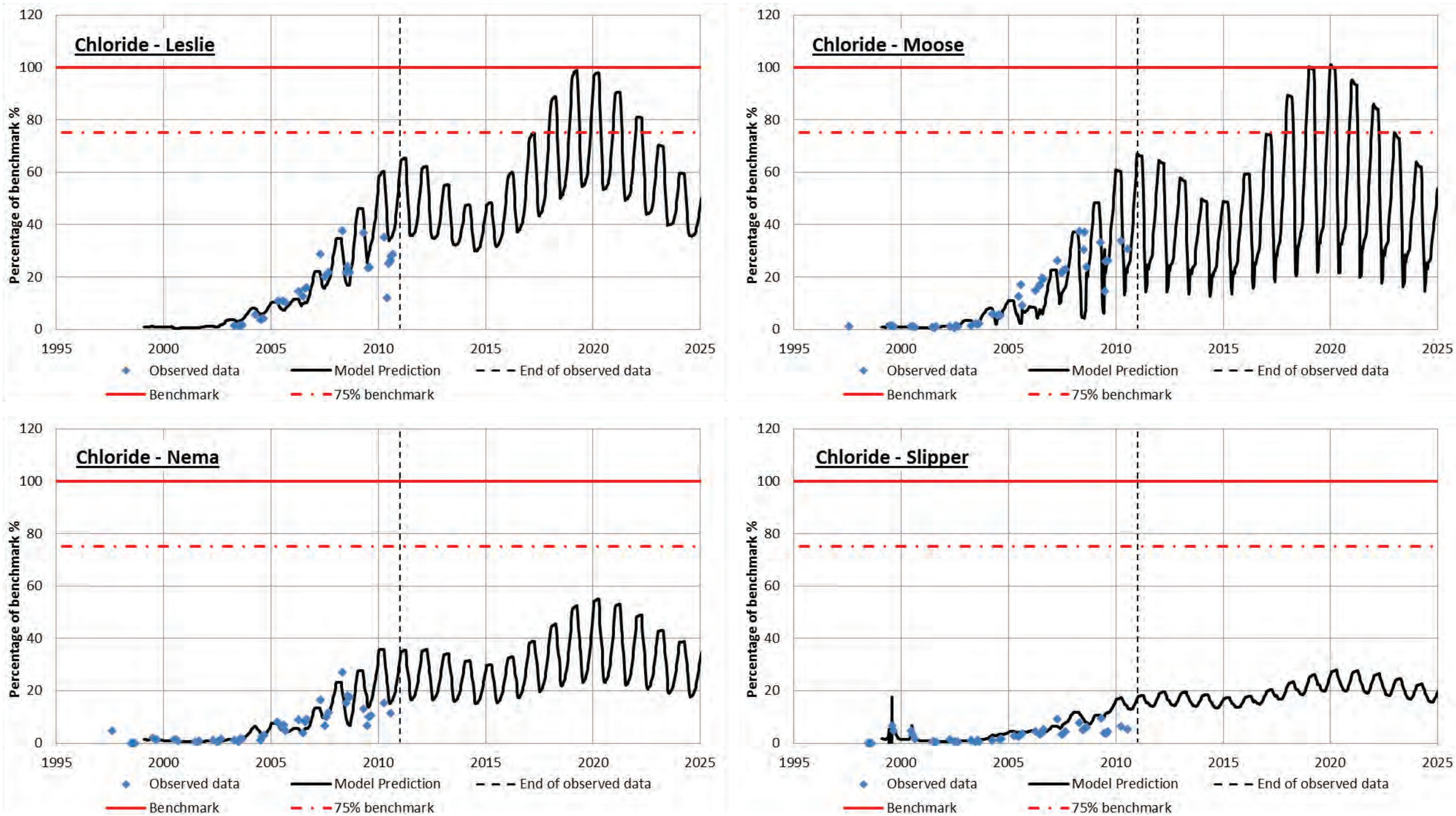
Results for parameters of concern in downstream lakes are provided in Figures 6.3-10 to 6.3-18. Graphs are provided that show predicted and observed concentrations converted to a time series representing percentage of the Water Quality Benchmark that is reached. TDS results are presented because it is a conservative parameter that is suitable for model calibration and provides a context for its key constituents. TDS has no proposed benchmark.

Water Quality Benchmarks that are a function of hardness are estimated using model predicted hardness. A comparison of modelled hardness to observed hardness (Section 6.2) shows that the model provides a good fit to observed hardness data for the historical period, although the model slightly over-predicts observed hardness for recent years. Uncertainties or errors in the hardness predictions have the potential to impact Water Quality Benchmarks for some parameters (chloride, sulphate, nitrate, cadmium, copper, lead, manganese and nickel, see Table 2.3-1). Hence, an assessment was undertaken whereby hardness values were varied by ±25% to assess the impact of changes in Water Quality Benchmarks on the maximum percentage of the benchmark predicted by the Model for these parameters. An uncertainty of ±25% was considered a reasonable estimate of the likely uncertainty for hardness predictions, based on comparison of observed and predicted hardness values in Cell E and downstream lakes (Figures 6.2-3 and 6.2-10). The results indicate that:

- For nitrate, sulphate and chloride the peak predicted hardness concentrations exceed the upper limit for the Water Quality Benchmark and as a result the benchmarks are not sensitive to ±25% uncertainties in the hardness predictions;
- For copper there is a lower threshold for the Water Quality Benchmark which is the critical value for calculating the maximum percentage of the benchmark predicted by the model. Changes in hardness by ±25% do not impact this lower threshold value;
- For cadmium the model predictions are substantially above the Water Quality Benchmark and the results are not sensitive to changes in the hardness predictions; and
- For sulphate, lead, manganese and nickel the model predictions are substantially below the Water Quality Benchmark so that the results are not sensitive to changes in the hardness predictions.

Hence, although some Water Quality Benchmarks are dependent on hardness predictions, the key conclusions of the model (maximum percentage of benchmark reached during life time of mine and identification of parameters where maximum percentage exceeds a 75% threshold) are not affected by likely uncertainties in hardness predictions. Hence, the conclusions of the study are considered to be reasonably robust to changes in hardness predictions.



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Chloride Predictions in Downstream Lakes for 2000 to 2025

Figure 6.3-10

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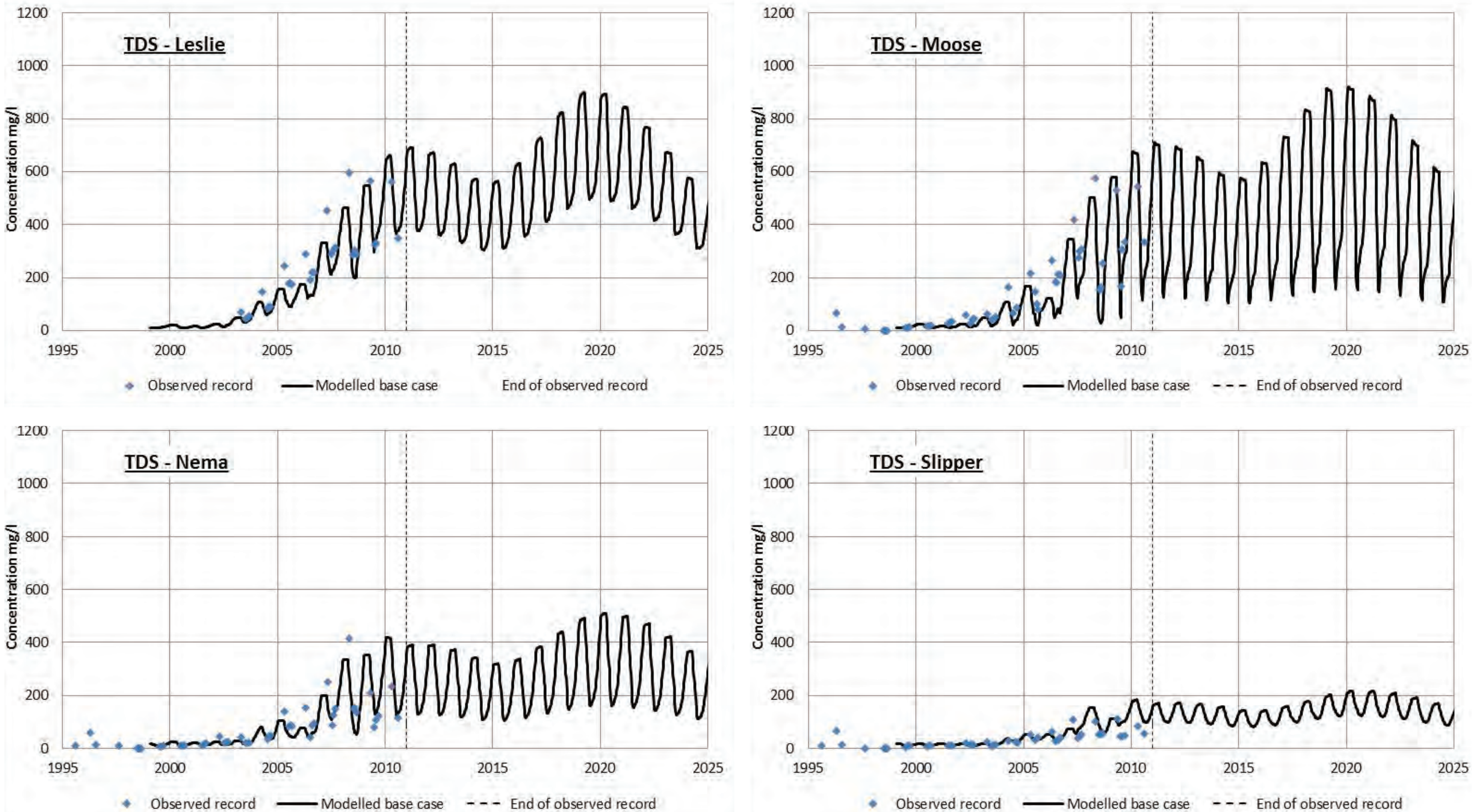

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TDS Predictions in Downstream Lakes for 2000 to 2025

Figure 6.3-11

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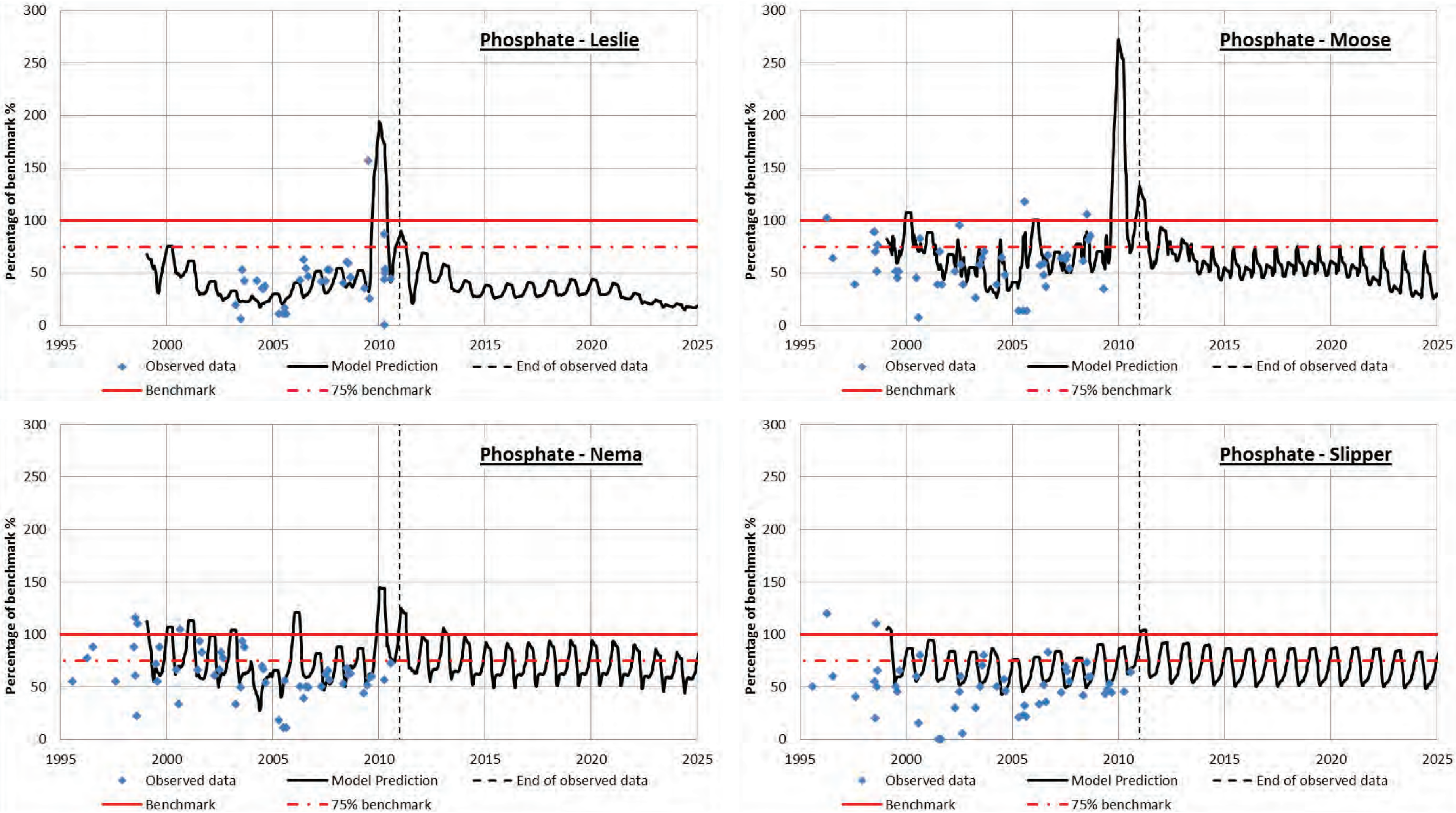

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Phosphate Predictions in Downstream Lakes for 2000 to 2025

Figure 6.3-12

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PROJECT # 0648-127 ILLUSTRATION # a36512w April 3, 2012

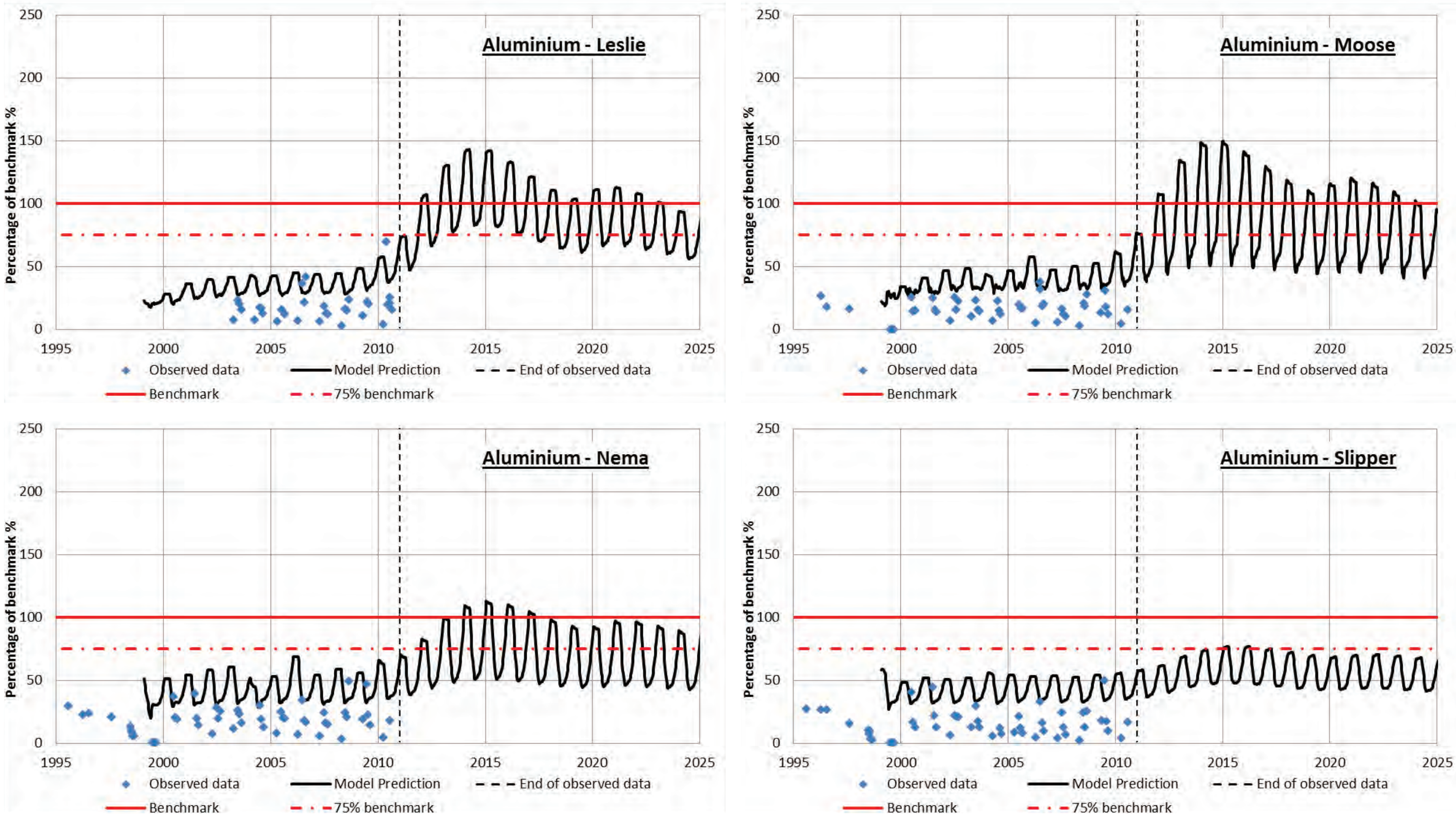

Figure 6.3-13

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Aluminium Predictions in Downstream Lakes for 2000 to 2025

Figure 6.3-13

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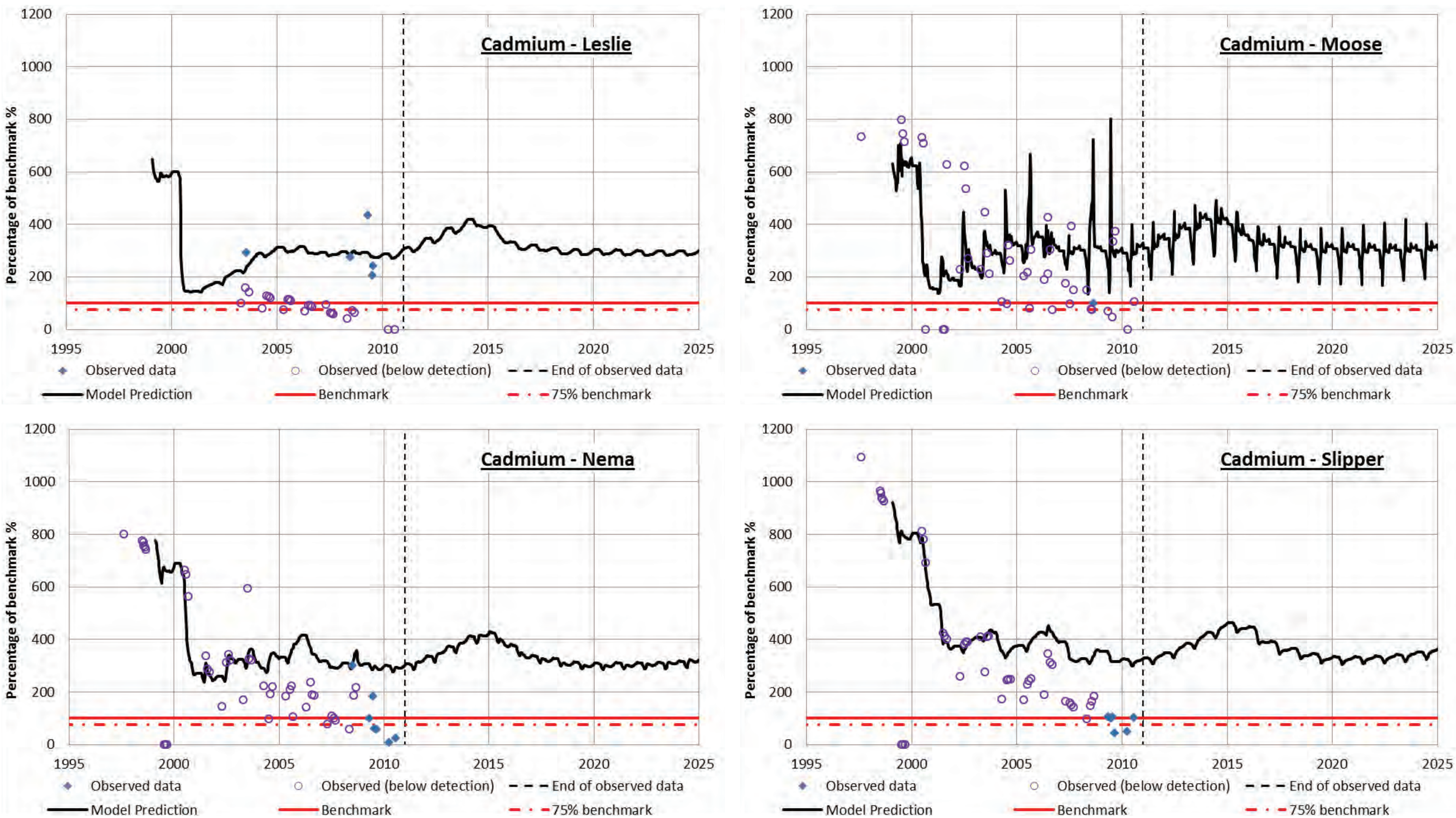

Figure 6.3-14

Cadmium Predictions in Downstream Lakes for 2000 to 2025

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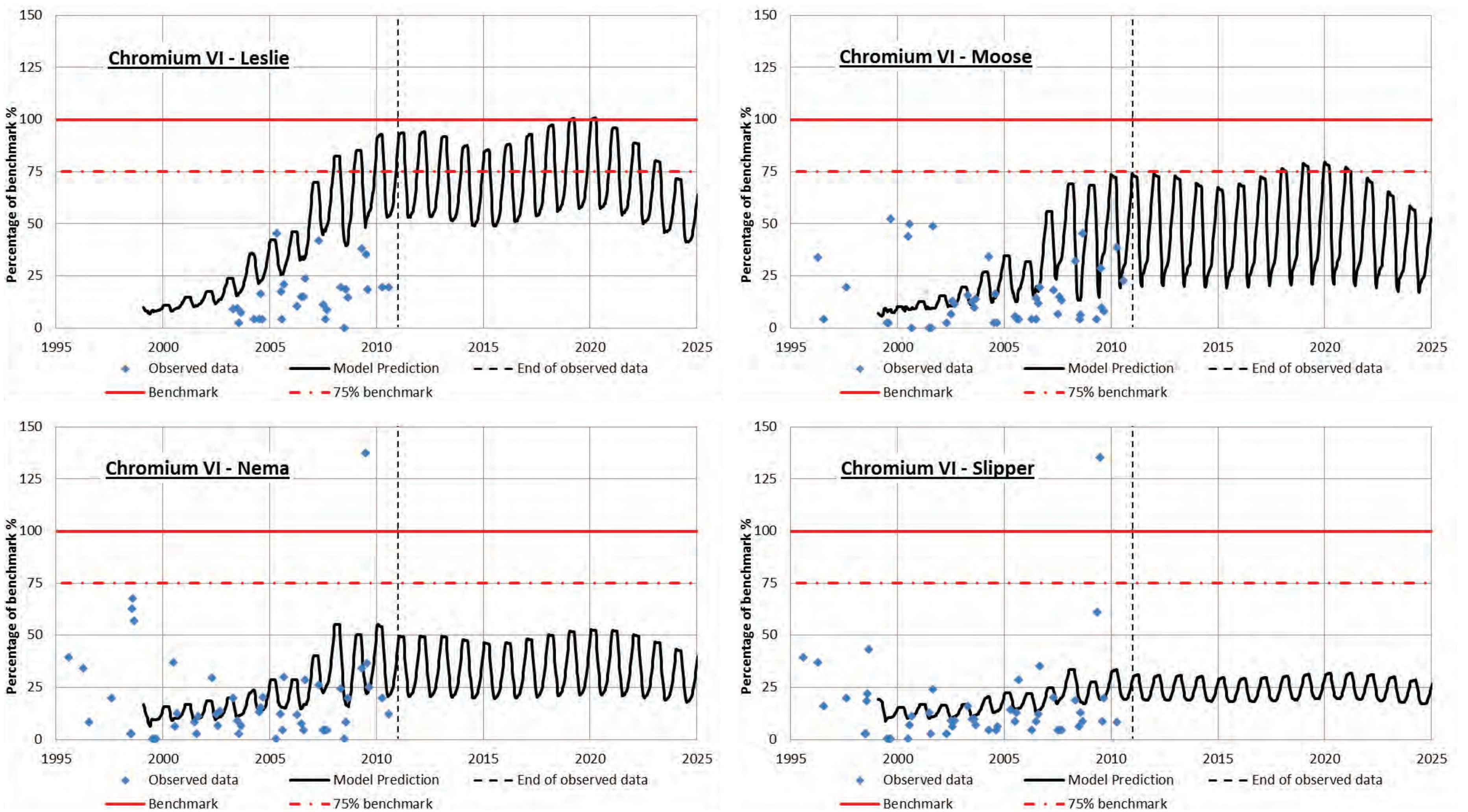

Figure 6.3-15

Chromium(VI) Predictions in Downstream Lakes for 2000 to 2025

PROJECT # 0648-127 ILLUSTRATION # a36515w April 3, 2012

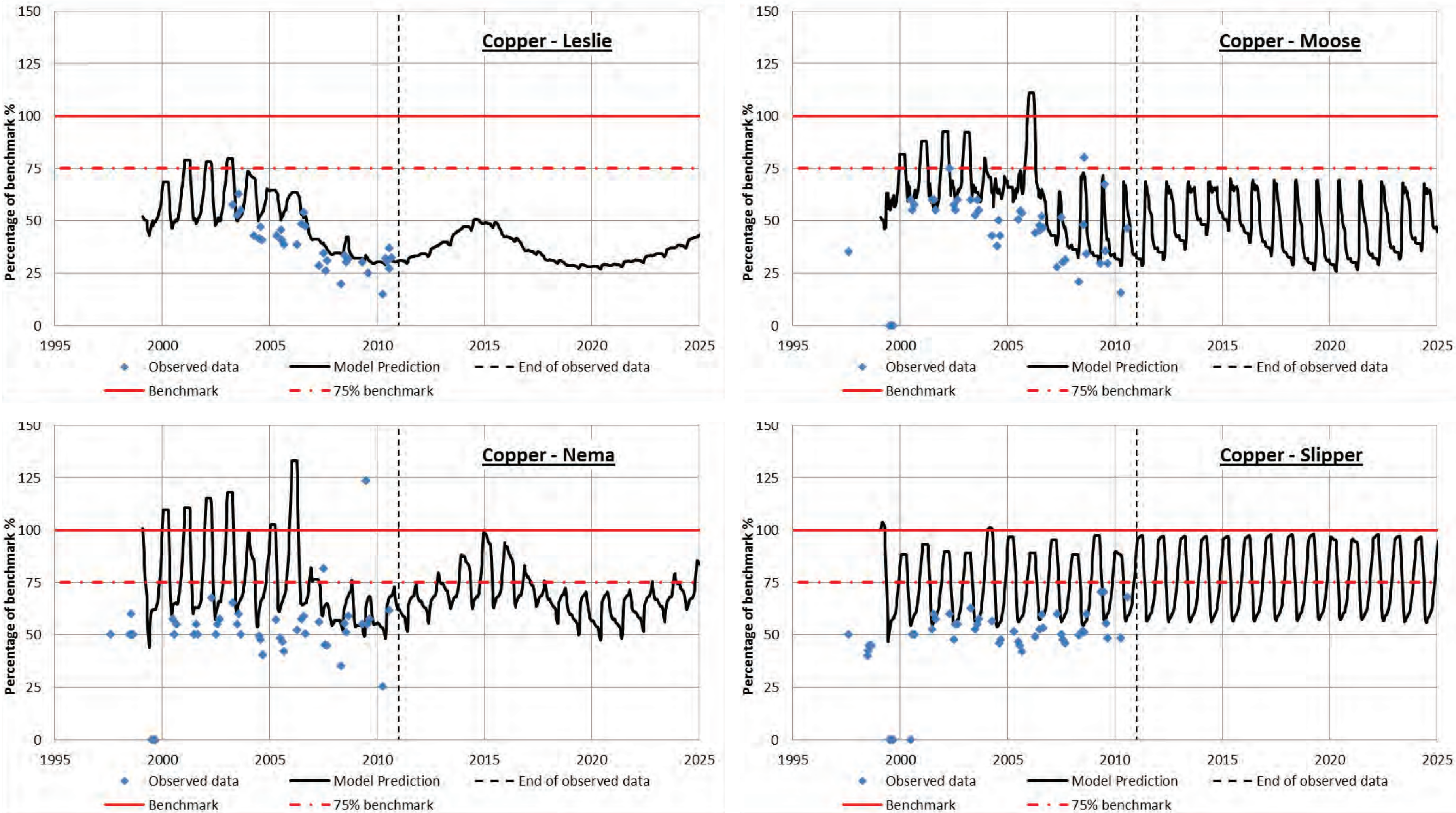

Figure 6.3-16

Copper Predictions in Downstream Lakes for 2000 to 2025

Figure 6.3-16

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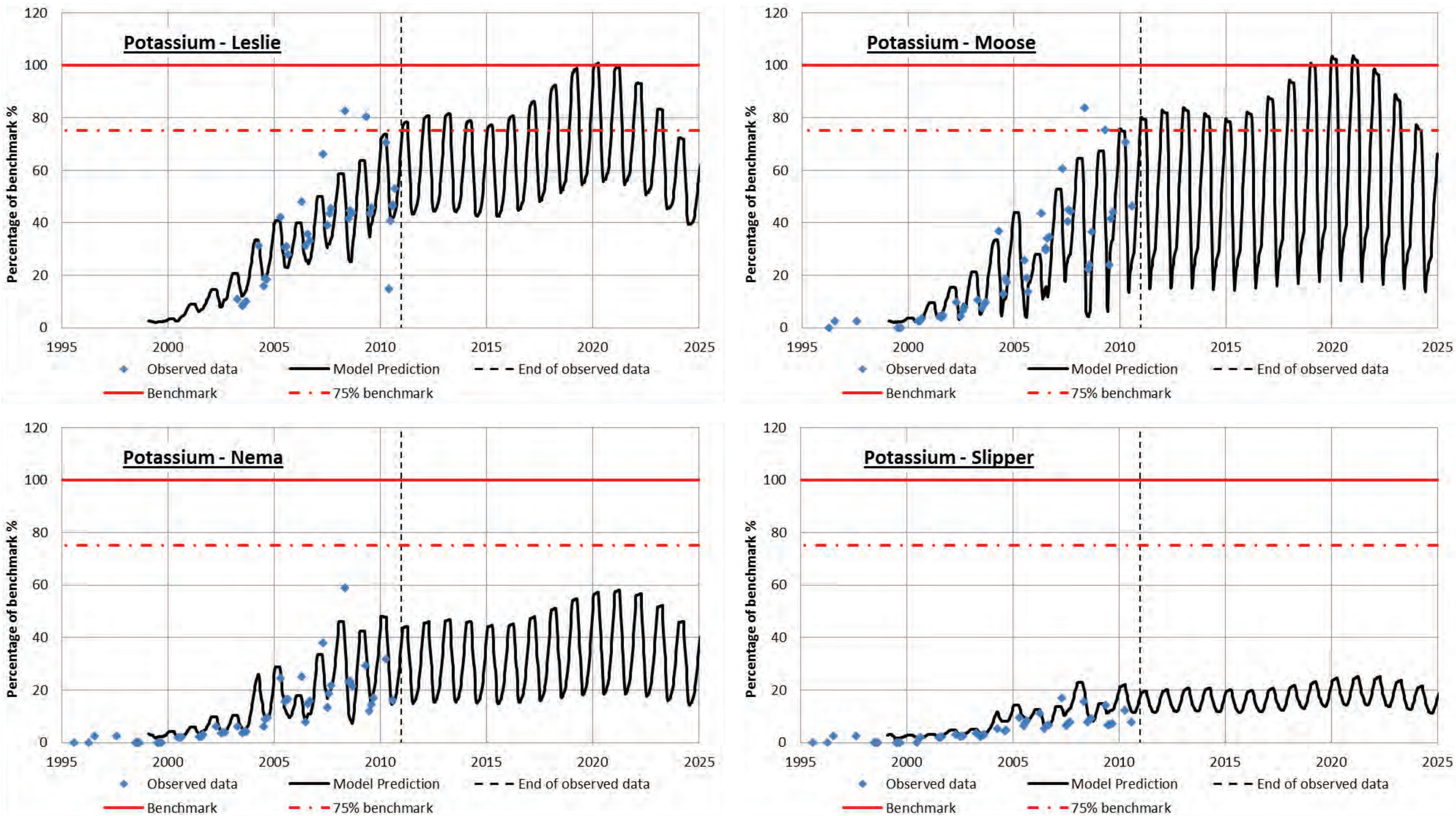

Figure 6.3-17

Potassium Predictions in Downstream Lakes for 2000 to 2025

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PROJECT # 0648-127 ILLUSTRATION # a36517w April 3, 2012

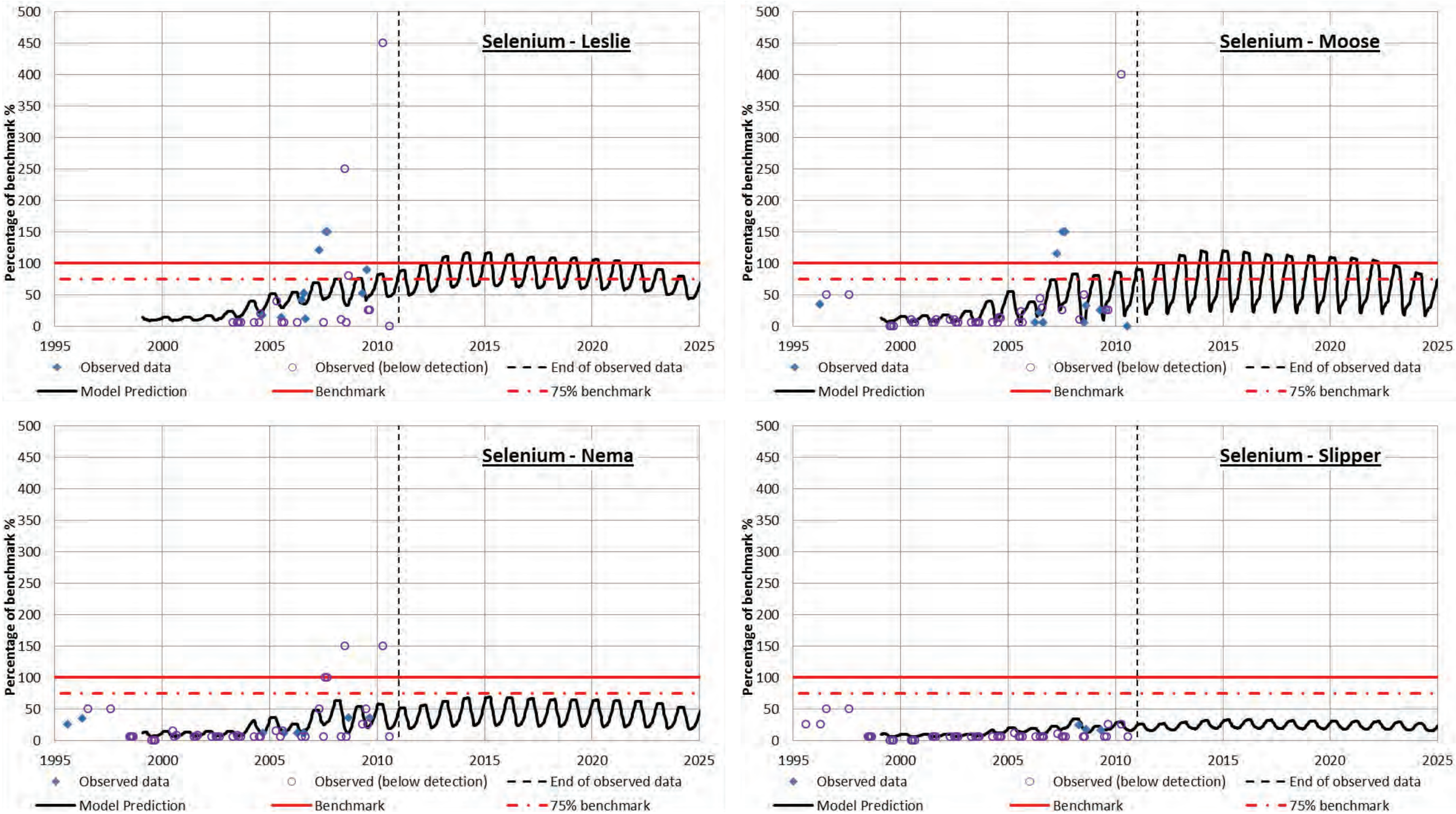

Figure 6.3-18

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Selenium Predictions in Downstream Lakes for 2000 to 2025

Figure 6.3-18

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7. Uncertainty and Summary

7. Uncertainty and Summary

7.1 UNCERTAINTY

The model is data driven in that nearly all parameters and inputs are based on analysis of observed data at the EKATI mine. Hence, uncertainties associated with the model predictions are primarily associated with how well historical trends predict future conditions in the LLCF. Given that there are generally around 10 years of data at EKATI, for most parameters there is a reasonably high degree of confidence that the historical data provide a good basis for future predictions. For some parameters there are longer periods of record, e.g., there are over 15 years of precipitation data at EKATI, providing a constraint on average precipitation at the site. However, key areas of uncertainty are outlined below.

7.1.1 Key Uncertainties as a Result of Model Inputs or Model Assumptions

Underground Water Flow Rate and Chemistry

Underground water has high loadings of certain salts (e.g., TDS, chloride).There is uncertainty associated with the future rate of groundwater flows to underground workings with predicted flows around three times higher than observed underground flow rates. The LLCF Load Balance Model assumes that future underground flow rates will be consistent with the historical average. If the flow rate were to increase and the chemistry remain the same there is a risk of higher concentrations of salts in the LLCF.

There is reasonable confidence in modelled underground water quality. Although the estimates used in the model are based on a limited number of samples, the data are consistent and groundwater chemistry is not expected to greatly over time. However, any future change in groundwater chemistry would impact the model predictions.

Future Predictions of Process Plant Discharge Quality

The LLCF Load Balance Model bases predictions of future PPD quality on statistical distributions of historical PPD water quality data. A conservative approach is taken in that if there is uncertainty in terms of trends in historical data the model is run assuming distributions from the historical period with the highest PPD concentrations. However, if future PPD water quality is markedly worse than seen to date the model would not be able to predict these future changes. The risk of this occurring is considered relatively low because for most parameters the historical PPD concentrations have been relatively consistent, with the major observed change being associated with a shift to underground mining. In addition, ore from most of the kimberlites at the site has been processed so there are data on the response of PPD quality to the processing of these ores. However, there remains the potential for there to be kimberlite with a higher content of certain parameters that would take future PPD concentrations above what has been seen to date.

Prediction of Ice Thickness and Ice Exclusion Processes

The model predicts the growth of ice on lake surfaces and predicts the impact that ice growth has on concentrations of parameters in the under ice water; as ice grows it excludes solutes resulting in raised concentrations in free water below the ice. This real process impacts observed concentrations with lakes during winter months and accounts for the high concentrations seen in lakes during this period.

The model considers that ice grows at the same rate and to the same thickness in every year of operations. In reality, if ice thickness varies or the rate of growth varies, this will impact winter water quality in downstream lakes. As peak predicted concentrations of all parameters occur in winter months, variations in ice thickness could impact modelled peak values. However, ice thickness is not expected to vary substantially year over year, with ice expected to reach thicknesses ranging from of 1.5 to 2 m annually.

7.1.2 Key Uncertainties as a Result of Mine Site Water Management

Future Operations of Beartooth Pit

The Base Case model considered in this report has Beartooth pit being used as a sink for underground water and FPK. Once the pit is filled to a target level, excess water will be used as reclaim or pumped directly to the LLCF. To date, reclaim water has been taken from the LLCF and has been relatively 'clean' water. Water in Beartooth pit will be a mix of FPK supernatant and underground water; hence it is not clear how this would impact PPD quality. In the model, a conservative assumption is made that loadings in reclaim water from Beartooth pit will add to loadings obtained from the kimberlite in the Process Plant before being discharged to the LLCF with FPK.

Timing of Discharges from LLCF to Leslie Lake

Discharges from the LLCF to downstream lakes are modelled based on observed discharge data. As outlined in Section 3.4, observed discharges from the LLCF do not mimic the natural flow hydrograph in the EKATI area, with LLCF discharging a higher percentage of the annual flow total outside the freshet period compared to natural flows. In addition, the discharge data set has years where there have been winter discharges from the LLCF to the downstream lakes. Hence, the average LLCF discharge hydrograph used in the Base Case includes discharges late in the summer months and discharge of a small volume of water to downstream lakes in winter months. During these periods there is limited dilution through natural runoff in the downstream lakes.

If discharges from the LLCF in the future were controlled to better mimic the natural hydrograph and to avoid winter discharges this has the potential to improve water quality in the lakes. This is important in winter months as ice exclusion processes in winter produce the highest predicted and observed concentrations of solutes in lake water. The results of the model are therefore sensitive to the assumption of discharge timing.

7.1.3 Key Uncertainties as a Result of Model Calibration and Model Predictions

Nutrient Parameter Decay Rates

Selected nutrients (ammonia, nitrite and phosphate) are modelled as non-conservative parameters that decay over time using a first order decay equation. The decay rate used in the model is calibrated for the historical period by fitting model predictions in Cell D and Cell E of the LLCF with observed data. However, a first order decay equation is a simplification of the actual process of loss of nutrients as the equation simulates a constant loss rate over time, while in reality the rate of loss of nutrients will vary over time in response to climatic factors such as temperature. There is reasonable confidence in the modelled approach for nutrients as the model predictions are calibrated against observed data. In addition, nutrient concentrations in downstream lakes are typically below Water Quality Benchmarks. However, there is a risk that the model may over- or under-predict future nutrient concentrations as a result of the simplified approach to modelling nutrient decay.

Flows between Cells within LLCF

The model has been shown to have a robust water balance for outflows from the LLCF and within downstream lakes. However, there is less confidence related to modelled predictions of flows between cells within the LLCF. Given the ability of the model to make good quality predictions of water quality in Cell E (good fit to observed data), it is clear that the model representation of flows between cells must provide a good approximation to the actual process. However, in order to improve predictions of water quality in Cell D, calibration of natural flow rates to Cell E and Cell D had to be undertaken. Observed data indicate that there may be incomplete mixing in the upper layer in Cell D during freshet, with a surface layer of snowmelt runoff passing from Cell D to Cell E without fully mixing in Cell D. The model was adjusted to represent this effect, but there is uncertainty with the process that causes the fresh surface layer and the process is likely to vary from year to year depending on snow depth and rate of snowmelt in spring. Although the calibration does impact concentrations in Cell D it does not appear to impact Cell E freshet concentrations significantly.

Impact of Model Predicted Hardness on Water Quality Benchmarks

A number of Water Quality Benchmarks are a function of hardness. Model predicted hardness is used to calculate the Water Quality Benchmarks and as a result, uncertainties or errors in hardness predictions have the potential to impact benchmark values. However, model predictions of hardness were shown to provide a goof fit to observed data in the LLCF and downstream lakes, which provides confidence in the models ability to accurately predict this parameter. In addition, a sensitivity analysis (discussed in Section 6.3) indicates that changes in hardness predictions of around ±25% would not impact the key conclusions of the modelling work; namely, maximum percentage of benchmark reached during life time of mine and identification of parameters where maximum percentage exceeds a 75% threshold.

7.2 SUMMARY

Version 3 of the existing water quality prediction model of the LLCF was updated to Version 4, to include:

- observed data up to at least end 2010 and in some cases to include data from 2011;
- a method of modelling future PPD quality for 30 water quality parameters;
- a model of the chain of lakes lying downstream of the LLCF;
- the current and approved water and FPK management option including Beartooth pit; and
- development of Water Quality Benchmarks for 30 parameters.

The Model was calibrated against observed data and run for a Base Case future scenario. The model predictions were compared to recently developed Water Quality Benchmark values for receiving waters.

In total, predictions were made for 30 parameters. The model results indicate that for eight parameters there is a risk that concentrations in the lakes lying downstream of the LLCF could exceed at least 75% of their respective Water Quality Benchmark. Of these, seven are predicted to exceed 100% of the Water Quality Benchmarks from end 2010 to February 2020. However, of those that are predicted to exceed their benchmark:

- phosphate predictions are impacted by a recent fertilization study in LLCF that has ended. From January 2012 the model predicts concentrations in excess of 100% of benchmark only in Name Lake;

- the cadmium benchmark is known to be very low (and below baseline concentrations in the lakes); and
- chloride, chromium, potassium and selenium concentrations only exceed their benchmark in winter months when ice exclusion processes raise concentration temporarily in the free under-ice water. Concentrations in open water months are significantly below 100% of the Water Quality Benchmark.

Concentrations of aluminum are predicted to exceed Water Quality Benchmarks in open water months and for multiple years during the remaining life time of the mine.

The model results indicate that the use of Beartooth pit produces a decrease in concentrations of most parameters in the LLCF during the period that underground and/or FPK are being discharged to the pit. However, once liquid and solids in Beartooth pit reach their target level water will be used as reclaim or pumped to the LLCF. At that time most concentrations will rise in the LLCF and for many parameters the peak predicted concentrations is attained close to the end of the mine life, partly as a result of the discharge of Beartooth pit water to the LLCF.

This modelling study also presents indicative results for the closure period, after the end of mine operations. However, the model was not tested for the closure period and a detailed assessment of concentrations during closure will be undertaken in a separate reclamation research study.

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Appendix 1
Water Quality Benchmarks

Rescan™
Engineers and Scientists

Memorandum

DATE:	April 27, 2012
TO:	Eric Denholm, BHP Billiton EKATI
FROM:	Marc Wen
CC:	Tonia Robb, Eric Denholm, James Elphick, Peter Chapman, Charity Clarkin, Mike Stewart
SUBJECT:	Water Quality Benchmarks for the EKATI Watershed
PROJECT:	0648-127

Through a review of water quality guidelines in Canada and the United States, and of literature in the Ecotox database, this technical memorandum identifies preliminary water quality benchmark values for consideration as a screening tool for identifying the relevance of observed and modelled water quality trends. This memorandum was developed with technical input from James Elphick at Nautilus Environmental.

The objective of the following review was to identify water quality benchmarks that are appropriate for application to receiving environments at EKATI. The review focussed on identifying benchmarks that are risk-based, and provide environmental safety. The proposed benchmarks are not meant to replace regulatory instruments that are in place for the site as part of on-going monitoring activities; rather, the focus of the review was to identify benchmarks that are both ecologically relevant and scientifically defensible, and provide a reasonable estimate of a concentration above which risk of adverse effects may become elevated.

Water quality guidelines in Canada have historically been developed by application of a safety factor to the lowest effect level published in the literature. However, in 2007, the CCME updated its methodology for developing water quality guidelines to utilize a Species Sensitivity Distribution approach, which employs all of the acceptable toxicity data for the constituent of interest and establishes the water quality guideline based on the 5th percentile of the cumulative distribution of those values (CCME 2007). This approach is considered appropriate in cases where there are sufficient data and representation from major classes of organisms, including fish, invertebrates and plants or algae. In general, this approach might be expected to result in a less conservative water quality guideline than the safety factor approach; however, since substantially more toxicological data are available now for most constituents than in prior decades, toxicological datasets are considerably more robust in most cases, and application of SSDs has become standard practice for development of water quality guidelines in Australia, Europe and the USA, as well as in Canada.

The SSD approach provides a more useful tool for assessing environmental risk, compared to benchmarks developed using safety factors, since it is based on concentrations above which effects might be expected to occur. Guidelines that are calculated using a safety factor can be highly conservative and ecological risk associated with exceedances may be over-stated. Historical CCME water quality guidelines applied a safety factor of between of 5 and 10 or more in establishing the guidelines and, consequently, the extent to which these guidelines are overly conservative is not clear. In some cases, the safety factor used may appropriately accommodate species that are sensitive to the chemical, but have not been tested. However, in other cases, the safety factor may be unnecessarily conservative.

From the standpoint of selection of water quality benchmarks for application to the site, it is ideal to utilize values that are relevant from a regulatory perspective. Consequently, site specific water quality objectives and Canadian-based guidelines are generally most appropriate for application at EKATI. From a risk assessment standpoint, risk-based water quality guidelines provide a scientifically defensible tool for assessing ecological risk. Risk based guidelines include CCME guidelines (or others) produced using the SSD approach, since these guidelines establish effects associated with risk to a specific percentage of species (typically 5%). An additional factor in selection of appropriate water quality benchmarks is the date when promulgated. The toxicological dataset is continually increasing as a result of efforts to characterize toxicants and, consequently, more recent benchmarks are more likely to have incorporated a larger dataset and, consequently, would be expected to be more robust.

Site specific water quality objectives have been developed at EKATI for chloride, nitrate, and molybdenum. These values are the most relevant objectives for application at EKATI. The CCME has published one guideline using the SSD approach (for uranium) and has presented draft guidelines for a number of others, including cadmium, zinc and silver (Roe et al. 2010). These guidelines may be the most appropriate guidelines in the absence of site-specific objectives, although the Draft guidelines were not considered appropriate at this time for EKATI because they have not yet been formally endorsed.

Table 1 (located after the References portion of this memo) shows the list of preliminary Candidate Parameters for the development of benchmarks. Candidate Parameters were chosen on the basis of existing trends in the data, and whether they are currently existing Effluent Quality Criteria (EQC) parameters, and whether they are evaluated parameters in the EKATI Aquatic Effects Monitoring Program (AEMP). Water quality benchmarks are presented in the table for those parameters that that may be a risk to the aquatic receiving environment at EKATI. The information in Table 1 is subject to change as new site information or scientific literature become available.

Table 2 (located at the end of this memo) provides additional information related to short-term “acute” water quality benchmarks where this information is available from regulatory bodies.

It should be noted that the review conducted here focussed on benchmarks for individual constituents and, consequently, does not take into consideration the potential for antagonistic, additive or synergistic effects between them.

1. Long-term Exposure Benchmarks

1.1 Major ions

Chloride: A site-specific water quality objective has been developed for chloride at EKATI (Elphick et al. 2011), and is the most appropriate tool for assessing environmental risk at the site. The work by Elphick et al. (2011) provides an update to an earlier site-specific objective for chloride (Rescan 2008). The 2011 publication benefited from a peer review as part of the manuscript review process, and was published as a site specific objective. The 2011 site specific objective applies across a range of water hardnesses of up to 160 mg/L as $CaCO_3$; a guideline was not established at levels higher than this because the dataset used to establish the site-specific guideline was limited to this range of hardnesses. Based on the current ratio of ions at the site, it appears likely that the water hardness would reach the upper end of this range (i.e., hardness of 160 mg/L) before the chloride concentration would approach its objective. At this point in time, it will be necessary to establish safe concentrations for the combination of major ions present at the site.

Sulphate: A site-specific water quality objective has been developed for sulphate at EKATI (Rescan 2012c) across a range of hardness values up to 160 mg/L as $CaCO_3$.

Alkalinity: Alkalinity is a measure of bicarbonate and carbonate, which is an anionic component of total dissolved solids. There are no water quality criteria for maximal concentrations of carbonate alkalinity and this is generally substantially lower than chloride concentrations at the site. Thus, no water quality benchmark for alkalinity appears necessary.

Hardness: Hardness is comprised primarily of calcium and magnesium ions. In general, increasing water hardness reduces the toxicity of a variety of other ions, such as some metals and major anions (e.g., SO_4, Cl, NO_3). There are no Canadian or US water quality guidelines for these cations, with toxicity typically ascribed to the anionic counter-ions to these cations (e.g., SO_4, Cl). The proposed benchmarks for chloride and sulphate are expected to result in sufficient protection against toxicity from hardness-causing cations and, consequently, an objective for water hardness does not appear necessary.

Potassium: There are currently no water quality guidelines for potassium published in Canada or the USA and, consequently, a site specific water quality objective for potassium was developed for EKATI (Rescan 2012d). The site specific benchmark (41 mg/L as K) was calculated using the SSD approach and employed data available in peer-reviewed publications, as well as from reference toxicant tests conducted by laboratories using potassium chloride.

Sodium: There are no water quality guidelines for sodium, and none are proposed for EKATI. This cation is relatively low in toxicity, and limits proposed for sulphate and chloride are expected to also be protective of risk of sodium toxicity, since these values are based on results from toxicity tests conducted using sodium sulphate and sodium chloride, respectively.

Total Dissolved Solids: TDS is a measure of all dissolved ions, and is typically comprised of the major ions, Cl, Na, SO_4, Ca, Mg, K, HCO_3 and NO_3 with minor contributions from other ions. There are currently no federal Canadian or US water quality guidelines or criteria for TDS. Alaska has implemented a State guideline of 1,000 mg/L. A similar guideline (i.e., 1,000 mg/L TDS) used in Iowa has recently been replaced with individual benchmarks for sulphate and chloride, which are considered more appropriate for assessing environmental risk. A site-specific objective of 500 mg/L has been established for the Red Dog Mine in Alaska during the spawning period in order to protect spawning Arctic Grayling, although recently published data indicate that this species is protected at TDS concentrations exceeding 1,000 mg/L TDS (Brix et al. 2010).

Table 3 shows the ionic contributions to the TDS in Leslie Lake in 2011. Under ice concentrations are greater than during the open water season, as expected due the effects of ice exclusion of solutes. TDS is dominated by Cl and Na; these ions contribute, on a molar basis, approximately 35 and 28% of ions.

Figure 1 shows the trend towards an ionic composition more dominated by Cl and Na in recent years in Leslie Lake, compared to reference lakes. Note that outliers in the reference lakes result from changes in detection limits that affect measurements at very low concentrations of certain ions in reference lakes. The change towards a more Cl/Na dominated composition is the result of inputs of saline groundwater to the Process Plant Discharge that reported to the LLCF, and ultimately downstream.

The proposed site specific benchmarks for chloride, sulphate, potassium, and nitrate are expected to result in sufficient protection from TDS and, consequently, a benchmark for TDS does not appear necessary.

Table 3. TDS Composition in Leslie Lake

	Under Ice		Open Water	
	mM	**mg/L**	**mM**	**mg/L**
Calculated TDS	16.56	664.5	10.6	428.2
	mM	**% TDS**	**mM**	**% TDS**
Chloride	5.75	34.7%	3.85	36.3%
Sodium	4.61	27.8%	3.10	29.2%
Sulphate	1.83	11.0%	1.16	11.0%
Calcium	1.41	8.5%	0.72	6.8%
Magnesium	1.02	6.2%	0.55	5.2%
Potassium	0.93	5.6%	0.58	5.4%
Bicarbonate	0.69	4.1%	0.42	4.0%
Nitrate	0.33	2.0%	0.23	2.2%

Conductivity: No water quality guidelines have been produced for conductivity, and a screening tool based on this parameter does not appear necessary for the site.

pH: The CCME water quality guideline for pH indicates an acceptable pH range of 6.5 to 9; this range appears appropriate for application at EKATI.

Total Suspended Solids: The CCME water quality guideline for TSS indicates a maximum average increase of 5 mg/L from background levels for longer term exposures. This appears to be an appropriate screening tool for EKATI.

Turbidity: The CCME water quality guideline for turbidity indicates a maximum average increase of 2 NTU from background levels for longer term exposures. This appears to be an appropriate screening tool for EKATI.

Total Petroleum Hydrocarbons: There are no Canadian water quality guidelines for total petroleum hydrocarbons; however, guidelines do exist for individual components, including benzene, toluene, and ethylbenzene, of which the lowest individual guideline is for toluene (2 µg/L), as well as a variety of polycyclic aromatic hydrocarbons, of which the lowest individual guideline is for anthracene (0.012 µg/L). As a result of the wide range of toxicities associated with the individual components of total petroleum hydrocarbons, no screening benchmark is proposed.

Biological Oxygen Demand: There are no Canadian water quality guidelines for BOD, and none are proposed as a screening benchmark for EKATI.

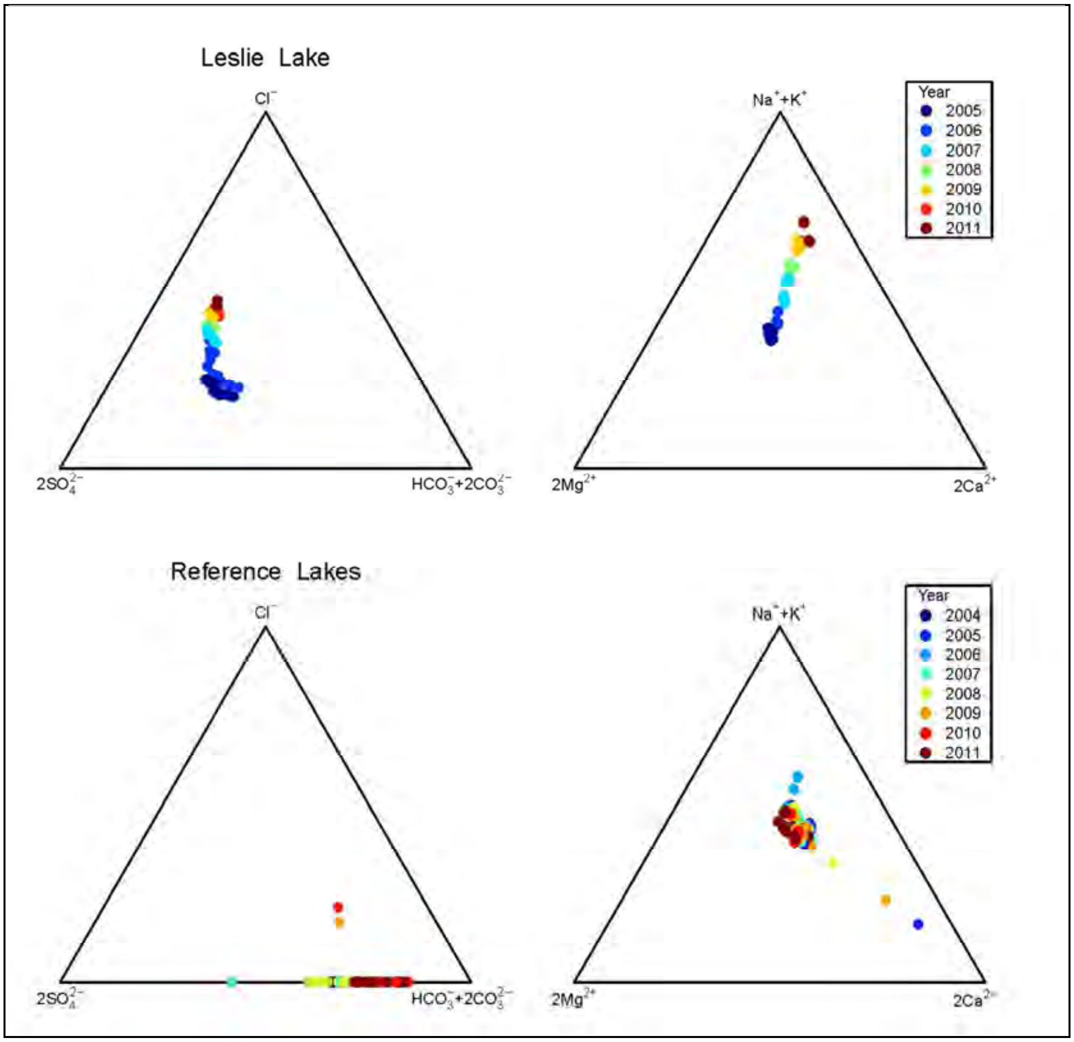

Figure 1. Ternary Plot of Relative Composition of Major Ion in Leslie Lake and at EKATI Reference Lakes.

1.2 Nutrients

Ammonia: The CCME water quality guideline for unionized ammonia (0.019 mg/L as NH_3) is the most appropriate tool for application to the site. Since this is based on the unionized fraction, it accommodates the role of pH, ionic strength and temperature in affecting the toxicity of ammonia. An alternative guideline that could be applied would be the USEPA criteria for total ammonia, which have previously been used at EKATI (Golder Associates 2008); however, these benchmarks are relatively similar at the pH of interest. For example, the CCME guideline, calculated as total ammonia, is 2.7 mg/L as N at pH 7.5 and 10°C, whereas the USEPA criterion is 4.4 mg/L as N under these conditions. In addition, the USEPA water quality criterion is currently under revision and is expected to be lowered in cases where freshwater mussels are present. Thus, the slightly more conservative value associated with the CCME guideline appears to be appropriate. The CCME water quality guideline for total ammonia is shown in Table 1a as a function of pH and temperature; note that all of the values for total ammonia in Table 1a correspond to an unionized ammonia of 0.019 mg/L under the temperature and pH values specified. Table 1a presents the corresponding total ammonia concentrations as NH_3, whereas Table 1b shows the corresponding total ammonia concentrations as NH_3-N which is more typically reported in the EKATI Aquatic Effects Monitoring Program (AEMP) and Surveillance Network Program (SNP).

Based on a review of water quality data for Cell E and downstream lakes, pH in the lakes typically varies as shown in Table 4.

The typical monthly air temperatures at EKATI are shown in Table 5. Assuming that water temperatures equilibrate to some degree to air temperatures, a summer maximum water temperature is typically about 13°C.

Table 4. pH in EKATI Lakes and LLCF

Location	pH		
	Mean	Median	90%ile Fit to Normal Distribution
Cell E	7.31	7.41	7.79
Leslie	7.54	7.62	7.96
Moose	7.15	7.10	7.73
Nema	7.04	7.00	7.53
Slipper	6.79	6.70	7.26

Table 5. Monthly Temperatures at EKATI

Month	EKATI Mean Monthly Temperature (°C)
January	-30.3
February	-27.3
March	-23.0
April	-13.4
May	-3.5
June	9.0
July	12.6
August	10.5
September	3.7
October	-6.6
November	-17.8
December	-24.5

Based on the typical pH (about 8) and temperature (about 15°C) data for EKATI lakes, an ammonia-N concentration of 0.59 mg/L is equivalent to an unionized ammonia concentration of 0.019 mg/L as NH3. Therefore, based on the CCME guideline, 0.59 mg/L NH3-N appears to be a reasonable benchmark for EKATI lakes.

<u>Nitrate</u>: A site specific water quality objective has been developed for nitrate and this is considered the most relevant tool for assessing risk at EKATI (Rescan 2012b).

<u>Nitrite</u>: The Canadian water quality objective for nitrite is 60 µg/L, and is based on potential for effects on salmonids. This benchmark is appropriate as a screening tool for EKATI, where

concentrations of nitrite have typically been well below this value. The BC water quality guideline for this anion accommodates the ameliorating effect of chloride on toxicity of nitrite (BCMoE 2009); chloride reduces toxicity of nitrite because these anions share the same uptake pathway. Chloride concentrations are elevated at EKATI and, consequently, accommodating the effect of chloride on nitrite toxicity would be appropriate. Thus, in the event that elevated concentrations of nitrite are observed in future, the BC water quality guidelines for nitrite, which range from 20 to 200 µg/L depending on chloride concentration, would be an appropriate tool to further evaluate the risk of any observed exceedances.

Total Kjeldahl Nitrogen (TKN): TKN is a measure of the ammonia and the organic forms of nitrogen. There are no Canadian water quality guidelines for TKN, and none are proposed as a screening benchmark for EKATI.

Orthophosphate, Total Phosphorus (TP): Risk associated with phosphorus is related to eutrophication, rather than toxicity. Thus, a benchmark for phosphorus is established below using the Canadian Guidance Framework for the Management of Phosphorus in Freshwater Systems (CCME 2004; Environment Canada 2004). This Framework uses a tiered approach where predefined trigger ranges are based on the trophic status for the lakes being addressed (Table 6). The trigger ranges are based on the range of Total Phosphorus concentrations in water that define the reference trophic status for a site. These ranges are therefore system-specific.

Table 6. Phosphorus Trigger Ranges for Lakes

Trophic Level	Total Phosphorus (mg/L)
Ultra-oligotrophic	< 0.004
Oligotrophic	0.004 – 0.01
Mesotrophic	0.01 – 0.02
Meso-eutrophic	0.02 – 0.035
Eutrophic	– 0.10
Hypereutrophic	> 0.10

Under this Framework, further assessment is required if these trigger ranges are exceeded or are likely to be exceeded, because of the risk of an impact occurring or having occurred. Should the assessment suggest that it is likely that phosphorus levels will result in an unwanted change then an adaptive management decision should be made.

EKATI data show that the average baseline total phosphorus concentrations for AEMP lakes downstream of the LLCF fall within the oligotrophic category (Table 7). In their analysis of Kodiak Lake data Environment Canada (2004) categorized this lake as mesotrophic with an average baseline concentration of 0.011 mg/L TP. Therefore the oligotrohic category for nearby lakes and lakes downstream of the LLCF appears to be a conservative classification based on this Framework.

The Framework requires further assessment if the trigger value of 0.01 mg/L (for oligotrophic lakes) is exceeded or phosphorus concentrations increase more than 50% over the historical reference levels (baseline). This 50% increase was deemed by the Ontario Ministry of Environment (1997) as an acceptable increase, beyond which deterioration of water quality from excessive phosphorus levels was observed in Pre-Cambrian Shield lakes. It was also deemed sufficient to protect Arctic lakes (Environment Canada 2004).

Table 7. EKATI Total Phosphorus Concentrations for Baseline Years in AEMP Lakes (mg/L)

	Baseline Average				
Lake	**April**	**August**	**Open Water[1]**	**April & August**	**All Dates**
Counts	NA	0.0083	0.0083	0.0083	0.0083
Nanuq	NA	0.0017	0.0017	0.0017	0.0017
Vulture	0.0070	0.0027	0.0029	0.0029	0.0030
Kodiak	0.0090	0.0114	0.0120	0.0114	0.0119
Grizzly	NA	0.0036	0.0095	0.0036	0.0095
Leslie	NA	0.0064	0.0064	0.0064	0.0064
Moose	0.0080	0.0055	0.0051	0.0058	0.0053
Nema	0.0070	0.0061	0.0061	0.0062	0.0062
Slipper	0.0120	0.0062	0.0068	0.0065	0.0069
Lac de Gras (S2 and S3)	NA	0.0035	0.0036	0.0035	0.0036
All Lakes[2]	0.0085	0.0046	0.0049	0.0048	0.0050

	Mean Baseline + 50%					
Lake	**April**	**August**	**Open Water[1]**	**April & August**	**All Dates**	**Benchmark**
Counts	-	0.0125	0.0125	0.0125	0.0125	0.01
Nanuq	-	0.0025	0.0025	0.0025	0.0025	0.0025
Vulture	0.0105	0.0040	0.0043	0.0043	0.0045	0.0043
Kodiak	0.0135	0.0172	0.0180	0.0171	0.0179	0.0180
Grizzly	-	0.0054	0.0142	0.0054	0.0142	0.01
Leslie	-	0.0096	0.0096	0.0096	0.0096	0.0096
Moose	0.0120	0.0083	0.0077	0.0086	0.0079	0.0077
Nema	0.0105	0.0091	0.0091	0.0093	0.0093	0.0091
Slipper	0.0180	0.0093	0.0101	0.0098	0.0104	0.01
Lac de Gras (S2 and S3)	-	0.0053	0.0054	0.0053	0.0054	0.0054
All Lakes[2]	0.0128	0.0069	0.0073	0.0071	0.0075	0.0073

[1] *Includes July and August when applicable.*
[2] *Grizzly and Kodiak Lakes not included.*

Based on the Framework the values shown in Table 7 as Mean Baseline + 50% for the Open Water season are appropriate benchmarks for the management of phosphorus at the majority of EKATI in lakes downstream of the LLCF. However, the benchmark for Counts, Grizzly and Slipper lakes was set at 0.01 (the upper limit of the oligotrophic range) because Mean Baseline + 50% was greater than the upper limit.

Total Phosphorus (TP) is the amount of phosphate that is in the water sample as any form of phosphate molecule (PO_4), typically considered "nutrient" phosphorus. Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate. Laboratory analysis of TP is by combined digestion/colorimetric technique. For the purpose of the benchmark value, TP is equivalent to Total Phosphate-P reported in the AEMP as measured by ALS Laboratory.

Silicon: There are no Canadian water quality guidelines for silicon, and none are proposed as a screening benchmark for EKATI. This material is a nutrient for diatoms, and increased reactive silicon may result in increased diatom populations.

Total Organic Carbon (TOC): There are no Canadian water quality guidelines for TOC, and none are proposed as a screening benchmark for EKATI.

1.3 Metals, Metalloids and Non-Metals

Aluminum: The CCME water quality guideline for aluminum is linked to pH, with substantially lower thresholds for effects expected for conditions in which the pH is less than 6.5. Waterbodies at EKATI typically exceed pH 6.5 and, consequently, the guideline of 0.1 mg/L appears to be appropriate, and is based on a species (rainbow trout) that is representative of other salmonid species that are present at the site. It should be noted, however, that many factors can alter the toxicity of aluminum in site-specific manner, and the actual threshold for adverse effects may be higher than this. An appropriate evaluation of risk associated with this metal would need to consider site-specific factors.

Antimony: There are no Canadian water quality guidelines for antimony. The Ontario Ministry of Environment developed an interim water quality guideline for this metal in 1996 by applying an uncertainty factor of 14.5 to the most sensitive endpoint of 0.3 mg/L, resulting in a proposed objective of 0.02 mg/L (Fletcher et al. 1996). There is relatively little confidence in assessing risk based on exceedance of this value as a result of the relatively large uncertainty factor and the paucity of data for this metal. However, this provides the most appropriate available objective for assessing water quality at EKATI.

Arsenic: The CCME water quality guideline for arsenic was based on effects on algae at a concentration of 50 µg/L. However, a 10-fold safety factor was applied resulting in a guideline of 5 µg/L. Thus, exceedance of the guideline may not result in significantly elevated risk of ecological effects. For comparison, the USEPA water quality criterion for arsenic is 150 µg/L, which is substantially higher than the CCME guideline. However, since the CCME guideline is based on effects on a species that occurred at a concentration that is lower than the USEPA criterion, it would appear to be inappropriate to employ the CCME criterion at the site. Consequently, the CCME guideline is proposed for application to the site; however, the safety factor employed in developing this guideline should be considered in any consideration of risk associated with exceedance of this value.

Barium: The BC water quality guidelines for aquatic life utilize an interim value of 1 mg/L, which was based on a literature review conducted by Haywood and Drinnan (1983). This value is proposed as a screening tool for EKATI, although the reliability of this benchmark is uncertain.

Boron: The CCME water quality guideline for the protection of aquatic life for boron is 1.5 mg/L. This appears to be an appropriate screening tool for EKATI.

Cadmium: The current CCME interim guideline for cadmium is proposed as a benchmark for this metal at the site. However, the on-going scientific validity of the interim WQG is questionable. McGeer et al. (2012) show that the CCME guideline for total cadmium is lower than criteria established in the US for dissolved cadmium. In 2010 CCME circulated a draft revised water quality guideline for cadmium using the SSD approach with hardness incorporated as a toxicity modifying factor (Roe et al. 2010). Upon formal release, this revised guideline should be used as the screening level guideline for assessing risk at the site. The current interim water quality guideline is used here on an interim basis pending finalization of the update by CCME.

Chromium: The CCME water quality guidelines for chromium (III) (8.9 µg/L) and chromium (VI) (1.0 µg/L) are based on data for cladocerans and rainbow trout (a surrogate for other salmonids present at the site), respectively, which are relevant to the site. However, these guidelines employed a ten-fold safety factor and may overstate the risk associated with this metal. For comparison, USEPA water quality criteria for Cr(III) and Cr(VI) are 74 (at a hardness of 100 mg/L) and 10 µg/L, respectively. The CCME guidelines are proposed as the most useful tool to assess risk at the site; however, exceedances of these values may overstate risk as a result of the large safety factor employed.

The following brief discussion on the environmental geochemistry of chromium is provided as context to understand what chromium species are anticipated to dominate in EKATI waters.

Chromium in natural waters typically originates from rock weathering, atmospheric fallout, and surface runoff (Kotas and Stasicka 2000). The environmental geochemistry and toxicity of chromium is highly dependent on the redox species. The dominant stable forms are hexavalent (Cr(VI)) and trivalent (Cr(III)) chromium. In natural waters, Cr(VI) forms oxyanions (e.g. $HCrO_4^-$ or CrO_4^{2-}) and is more soluble, mobile, and toxic than Cr(III) (Beaubien et al. 1994). Cr(VI) is readily reduced to Cr(III) under moderately oxidizing to highly reducing conditions by ΣH_2S, Fe (II), fulvic acids, and low molecular weight organic compounds (Rai et al. 1989). Cr(III) exists as a cation or hydroxide (e.g. Cr^{3+}, $Cr(OH)^{2+}$, $Cr(OH)_3$) in natural waters and has a strong affinity for particles and organic colloidal complexes (Beaubien and others 1994). Oxidation of Cr(III) to Cr(VI) is kinetically sluggish with dissolved oxygen as the oxidizing agent, but may be rapid in the presence of manganese oxides. The nature and concentration of potential reductants, oxidants, and complexants may result in significant proportions of Cr(III) in oxygenated surface waters (Kotas and Stasicka 2000). It has been noted that Cr(III) proportions in streams may be higher than in lakes due to higher particulate loadings and increased availability of organic complexants (Swietlik 2002).

The analysis of chromium commonly measures total and hexavalent chromium and trivalent chromium is calculated as the difference. These methods assume that colloidal or organic chromium does not contribute significantly to the total chromium concentration. Notably, however, while Cr(VI) was consistently found to be the dominant form of chromium in the Great Lakes across a range of trophic statuses, about 10% of the dissolved chromium was colloidal or organic chromium and Cr(III) was typically below the detection limit (Beaubien et al. 1994). Organic-complexed Cr(III) is relatively stable and unreactive and concentrations typically reflect conservative chemical behaviour downstream. In suboxic waters, as may be expected under ice, Cr(III) is the expected form of chromium (Kotas and Stasicka 2000).

Water samples taken as part of the AEMP and SNP are analysed for total chromium. Recent water samples taken in Cell E of the LLCF, at the Nero-Nema Stream and in Grizzly Lake (October 17 and 18, 2011) were analysed for chromium speciation by Applied Speciation and Consulting LLC. These samples were taken to provide preliminary information on the concentration and proportion of Cr(III) and Cr(VI) EKATI water bodies which is not available from the AEMP and SNP. Samples from 1616-30 (Cell E) were taken to understand the speciation of chromium in the effluent discharge. At the time of sampling, Nero-Nema was still accessible whereas other water bodies that form part of the AEMP were iced over or not accessible logistically. Samples from Grizzly Lake were taken because the AEMP reference lakes could not be accessed. The results of the speciation analysis are presented in Table 8.

The data from Nero-Nema Stream and Grizzly Lake indicate higher than expected Cr(III) proportions based on data from southern lakes (e.g., Balistrieri et al. 1992; Beaubien et al. 1994) but there are little to no published data on chromium speciation from Arctic lakes. The higher proportion of Cr(III) in Nero-Nema compared to Cell E of the LLCF may reflect in-stream particulate loads or higher organic carbon concentrations in the stream, but that does not explain the unexpectedly high Cr(III) proportion in Grizzly Lake. Under ice conditions are expected to be lower in oxygen for some lakes in the EKATI watershed (i.e., in some cases suboxic); however, this should only result in increased proportions of Cr(III) relative to Cr(VI). Confirmatory sampling in the open water season and during the winter is required to improve the understanding of chromium speciation in these waters.

Table 8. Results of Chromium Speciation from EKATI Lakes

Sample ID	Units	Cr(VI)	Total Cr	Cr(III)	% as Cr(VI)	% as Cr(III)
LLCF Cell E, upstream of decant structure to Leslie Lake.						
1616-30	ug/L	0.076	0.108	0.032	70	30
1616-30	ug/L	0.081	0.106	0.025	76	24
1616-30	ug/L	0.085	0.099	0.014	86	14
Mean		0.081	0.104	0.024	78	22
Nero-Nema Stream						
Nero-Nema	ug/L	0.037	0.068	0.031	54	46
Nero-Nema	ug/L	0.047	0.091	0.044	52	48
Nero-Nema	ug/L	0.048	0.068	0.019	71	28
Mean		0.044	0.076	0.031	59	41
Freshwater intake from the Grizzly Lake Pumphouse						
1616-11	ug/L	0.025	0.107	0.082	23	77
1616-11	ug/L	0.017	0.109	0.092	16	84
1616-11	ug/L	0.023	0.095	0.072	24	76
Mean		0.022	0.104	0.082	21	79
Max Overall Value	ug/L	0.085	0.109	0.092		
Percentage of CCME Guideline Reached	%	8.5		1.0		
Field Blank	ug/L	0.019 U	0.013 U	0.019 U		

Samples taken between October 17 and 18, 2011
Laboratory analysis by Applied Speciation and Consulting LLC.
U = Not detected. Concentration is below the eMDL
Cr(III) Calculated by difference (total Cr - Cr(VI)).

Copper: The CCME water quality guideline appears to be the most appropriate for application at EKATI and incorporates hardness as a toxicity modifying factor. However, it should be noted that a number of factors, in particular, dissolved organic carbon, may substantially reduce toxicity of this metal on a site-specific basis. The USEPA has incorporated the Biotic Ligand Model into water quality criteria for copper in order to accommodate some of these factors, and this tool may be useful to establish benchmarks for copper at the site in the event that a more robust measure of potential effects is needed in future.

Iron: The CCME water quality guideline for iron appears to be appropriate for application to the site. This guideline is based on effects on developing eggs of fathead minnows, which is a cyprinid fish and is considered relevant to the site because of the presence of other cyprinids, and provides approximately a five-fold safety factor. It should be noted that solubility of iron is limited and risk would be reduced in cases where it is present as particulate, rather than in the dissolved phase, although particulate iron has the potential to cause adverse effects as a result of physical effects.

Lead: The CCME water quality guideline for lead is considered appropriate for application to the site. This guideline incorporates water hardness as a toxicity modifying factor. This guideline is similar to the criterion employed by the USEPA for this metal.

Manganese: There are no CCME water quality guidelines for manganese. The guideline proposed by the BC Ministry of Environment for this constituent (Reimer 1988) is proposed for the site.

Molybdenum: A site specific water quality objective has been proposed for the site, and is considered the most appropriate tool for assessing environmental risk (Rescan 2012a).

Nickel: The CCME water quality guideline for nickel is considered appropriate for application to site. The guideline incorporates water hardness as a toxicity modifying factor; however, there is a minimum guideline of 0.025 mg/L regardless of water hardness.

Selenium: Water quality guidelines for selenium are a topic of ongoing research and establishing a water-based limit for selenium is problematic, since effects are generally associated with tissue concentrations of organic selenium in fish and birds, rather than dissolved inorganic selenium in the water column. Tissue-based guidelines for selenium are considered to be the most appropriate measure of risk to aquatic organisms in long-term exposures because of the highly variable nature of the relationship between water column concentrations of inorganic selenium and body burdens, and the fact that effects are typically expressed in offspring of egg-laying vertebrates (e.g., fish, amphibians and birds). Consequently, the USEPA draft water quality criteria for selenium include a chronic limit based on a whole body concentration of 7.91 mg/kg, dry weight. Recently, an SSD for effects of selenium on fish that are relevant to Canadian environments has been calculated by deForest et al. (2011) based on tissue concentrations in fish ovaries and eggs; the HC_5 of 20 mg/kg dry weight in ovaries appears to provide a useful tool for predicting effects associated with this constituent and is proposed as a benchmark in the event that exceedances of the CCME water column guideline are observed. It should be noted that the Province of British Columbia was anticipated to release a revised water quality guideline for selenium in November 2011, and the relevance of this guideline to EKATI should be evaluated once it is released.

Strontium: There are currently no federal Canadian or US water quality guidelines for strontium. Snap Lake has undertaken a review of the available information on potential toxicity of strontium to freshwater aquatic life and has proposed a chronic effects toxicity benchmark of 6,242 µg/L (Golder 2011). This benchmark value is lower than the chronic threshold adopted for strontium (21,000 µg/L) by the US states of Michigan and Ohio (MDEQ 2008, Ohio EPA 2009) and subsequently by Quebec (Chowhury and Blust 2011). Snap Lake is undertaking additional testwork to reduce uncertainties related to this proposed toxicity benchmark and EKATI proposes to update this benchmark as new information becomes available.

Uranium: CCME has published a water quality guideline for uranium using an SSD approach, with the most sensitive species being the freshwater amphipod, *Hyalella azteca*, which is considered relevant to the site. This is considered to be the most appropriate tool for evaluating risk at the site.

Vanadium: A site specific water quality objective has been proposed for the site, and is considered the most appropriate tool for assessing environmental risk (Rescan 2012e).

Zinc: The current CCME guideline for zinc is proposed as a benchmark for EKATI. CCME has developed a draft revised water quality guideline for zinc using an SSD approach (Roe et al. 2010) which may be considered to be a more appropriate tool for assessing risk at the site once it is released.

2. Short-term Exposure Benchmarks

Canadian water quality guidelines have historically been calculated as a concentration of a material that would be expected to have no effect on aquatic life for indefinite exposure periods. However, revised guidance for calculation of Canadian water quality guidelines has incorporated guidelines for both short-term and long-term exposure periods. This approach is analogous to “maximum” and

"30-day average" benchmarks utilized by the BC Ministry of Environment, or to the "acute" and "chronic" benchmarks published by the USEPA.

Unfortunately, very few short-term exposure benchmarks have been published by the CCME. Consequently, the USEPA "acute" criteria are considered to be the most appropriate tool for assessing potential risk from short-term exposures to contaminants at the site. The USEPA criteria are calculated using a procedure that is analogous to the SSD approach, although the procedure focuses on the most sensitive few taxa, rather than the entire dataset. The short-term "acute" water quality benchmark information is presented in Table 2.

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Table 1. Preliminary Long-term Water Quality Benchmark Values for Consideration as EQCs Screening Tools

			Benchmark Value								
						Hardness Specific Benchmark Value (mg/L as $CaCO_3$)				Water License W2009L2-0001	
Variables	Candidate Parameter?	Rationale	Information Source	Unit	Benchmark Value	40	80	120	160	Max Average	Comment
Physical/Ion											
Total Alkalinity	Yes	AEMP	None Proposed								
Bicarbonate	Yes	TREND	None Proposed								
Carbonate	No		None Proposed								
Conductivity	Yes	TREND	None Proposed								
Hydroxide	No										
pH	Yes	AEMP	CCME	pH Units	6.5 to 9					6 to 9	
Chloride	Yes	AEMP	Site Specific WQO	mg/L	116.6 x ln(hardness) - 204.1[1]	226	307	354	388		Hardness as mg/L $CaCO_3$
Potassium	Yes	AEMP	Site Specific WQO	mg/L	41						
Total Silicon	Yes	TREND	None Proposed								
Sulphate	Yes	AEMP	Site Specific WQO	mg/L	$e^{(0.9116 \times \ln(\text{hardness}) + 1.712)}$[2]	160	301	435	566		Hardness as mg/L $CaCO_3$
Total Suspended Solids	Yes	EKATI, S	CCME	mg/L	Increase of 5 mg/L from Background					15	
Turbidity	Yes	TREND, S	CCME	NTU	Increase of 2 NTU from Background					(10 Sable)	
Hardness	Yes	AEMP	None Proposed								
Ion Balance	No										
Total Dissolved Solids	Yes	AEMP	None Proposed		1,000						
Total Petroleum Hydrocarbons	Yes	EKATI, S	None Proposed							3	
Biological Oxygen Demand	Yes	EKATI, S	None Proposed	mg/L						40	
Nutrients/Organics											
Unionized Ammonia	Yes	AEMP, EKATI, S	CCME	mg/L NH_3	0.019					2 mg/L total (4 Sable)	0.019 mg/L is equivalent to 0.59 mg/L NH_3-N at pH 8 and 15°C.
Nitrate-N	Yes	AEMP, S	Site Specific WQO	mg/L NO3-N	$e^{(0.9518[\ln(\text{hardness})]-2.032)}$[1]	4.4	8.5	12.5	16.4	(20 Sable)	Hardness as mg/L $CaCO_3$
Nitrite-N	Yes	AEMP, S	CCME	mg/L NO2-N	0.060					(1 Sable)	
Orthophosphate	Yes	AEMP	None Proposed								Benchmark not proposed based on toxicity. Potential effects from eutrophication are captured under Total Phosphorus
Total Phosphorus	Yes	AEMP, S	CCME (eutrophication)	mg/L	Leslie Lake 0.0096, Moose Lake 0.0077, Nema Lake 0.0091, Slipper Lake 0.01					(0.2 Sable)	
Total Organic Carbon	Yes	AEMP	None Proposed								
Total Kjeldahl Nitrogen	Yes	TREND	None Proposed								
Total Metals, Metalloids and Non-Metals											
Aluminum	Yes	AEMP, EKATI, S	CCME	µg/L	100					1,000	pH > 6.5
Antimony	Yes	AEMP	Ontario MoE	µg/L	20						
Arsenic	Yes	AEMP, EKATI, S	CCME	µg/L	5					0.5 (0.05 Sable)	
Barium	Yes	TREND	BC MoE	µg/L	1,000						
Beryllium	No										

Variables	Candidate Parameter?	Rationale	Benchmark Value: Information Source	Unit	Benchmark Value	Hardness Specific Benchmark Value (mg/L as $CaCO_3$): 40	80	120	160	Water License W2009L2-0001 Max Average	Comment
Boron	Yes	TREND	CCME	µg/L	1,500						
Cadmium	Yes	S, TREND	Interim CCME	µg/L	$10^{(0.86[\log10(hardness)]-3.2)}$	0.015	0.027	0.039	0.050	(1.5 Sable)	Hardness as mg/L $CaCO_3$
Calcium	Yes	TREND	None Proposed								
Chromium	Yes	S, TREND	CCME	µg/L	8.9 Cr(III) 1 Cr(IV)					(20 Sable)	
Cobalt	No										
Copper	Yes	AEMP, EKATI, S	CCME	µg/L	$0.2 \times e^{(0.8545[\ln(hardness)]-1.465)}$ with minimum benchmark of 2	2.00	2.00	2.76	3.53	100 (20 Sable)	Hardness as mg/L $CaCO_3$
Iron	Yes	AEMP	CCME	µg/L	300						
Lead	Yes	TREND, S	CCME	µg/L	$e^{(1.273[\ln(hardness)]-4.705)}$ with minimum benchmark of 1	1.00	2.39	4.01	5.79	(10 Sable)	Hardness as mg/L $CaCO_3$
Magnesium	Yes	TREND	None Proposed								
Manganese	Yes	TREND	BC MoE	µg/L	4.4 x hardness + 605	781	957	1,133	1,309		Hardness as mg/L $CaCO_3$
Mercury	No										
Molybdenum	Yes	AEMP	Site Specific WQO	µg/L	19,000						
Nickel	Yes	AEMP, EKATI, S	CCME	µg/L	$e^{0.76[\ln(hardness)]+1.06}$ with minimum benchmark of 25[3]	47.6	80.7	109.8	136.6	150 (50 Sable)	Hardness as mg/L $CaCO_3$
Selenium	Yes	AEMP	Water CCME	µg/L	1						
Silver	No										
Sodium	Yes	TREND	None Proposed								
Strontium	Yes	TREND	Golder (2011)	µg/L	6,242						
Uranium	Yes	AEMP	CCME	µg/L	15						
Vanadium	Yes	TREND	Site Specific WQO	µg/L	30						
Zinc	Yes	AEMP	CCME	µg/L	30					(30 Sable)	

Notes:
EKATI=*is an EQC for main EKATI site under water licence W2009L2-0001.*
S=*is an EQC for Sable site under water licence W2009L2-0001.*
AEMP=*is an evaluated parameter in 2011 AEMP, which may also include increasing trends.*
TREND=*is a parameter that shows increasing or inconclusive trend in the dataset relative to baseline and/or reference condition, that was not a 2011 AEMP evaluated parameter.*
[1] *Relationship is limited to a hardness range of up to 160 mg/L hardness.*
[2] *Relationship is limited to a hardness range of up to 160 mg/L hardness.*
[3] *Relationship is limited to a hardness range of up to 350 mg/L hardness.*

Table 1a. Total Ammonia Values (in mg/L as NH_3) as a Function of pH and Temperature

(The values presented are equivalent to an unionized ammonia concentration of 0.019 mg/L as NH_3)

		pH						
		6.0	6.5	7.0	7.5	8.0	8.5	9.0
Temp (°C)	0	231	73.0	23.1	7.32	2.33	0.749	0.25
	5	153	48.3	15.3	4.84	1.54	0.502	0.172
	10	102	32.4	10.3	3.26	1.04	0.343	0.121
	15	69.7	22.0	6.98	2.22	0.715	0.239	0.089
	20	48.0	15.2	4.82	1.54	0.499	0.171	0.067
	25	33.5	10.6	3.37	1.08	0.354	0.125	0.053
	30	23.7	7.50	2.39	0.767	0.256	0.094	0.043

Table 1b. Total ammonia values (in mg/L as NH_3-N) as a function of pH and temperature

(The values presented are equivalent to an unionized ammonia concentration of 0.019 mg/L as NH_3)

		pH						
		6.0	6.5	7.0	7.5	8.0	8.5	9.0
Temp (°C)	0	190	60	19	6.0	1.9	0.62	0.21
	5	126	40	13	4.0	1.3	0.41	0.14
	10	84	27	8.5	2.7	0.86	0.28	0.10
	15	57	18	5.7	1.8	0.59	0.20	0.073
	20	39	13	4.0	1.3	0.41	0.14	0.055
	25	28	8.7	2.8	0.89	0.29	0.10	0.044
	30	19	6.2	2.0	0.63	0.21	0.077	0.035

Table 2. Preliminary Short-term Water Quality Benchmark Values for Consideration as EQCs Screening Tool

Variables	Information Source	Unit	Benchmark Value	Hardness Specific Benchmark Value (mg/L as $CaCO_3$) 40	80	120	160	Water License W2009L2-0001 (Sable values in brackets) Max Grab	Comment
Physical/Ion									
pH	CCME	pH Units	6.5 to 9						
Sulphate	Site Specific WQO	mg/L	$e^{(0.4163 \times \ln(\text{hardness}) + 4.878)}$	610	814	964	1087		Hardness as mg/L $CaCO_3$
Potassium	Site Specific WQO	mg/L	112						
Total Suspended Solids	CCME	mg/L	Increase of 25 mg/L from Background					25	
Turbidity	CCME	NTU	Increase of 8 NTU from Background					(15 Sable)	
Total Petroleum Hydrocarbons		mg/L						5	
Nutrients/Organics									
Total Ammonia-N	BC MoE	mg/L	Dependent on pH and temperature					4 mg/L total (8 Sable)	
Nitrate-N	BC MoE	mg/L NO3-N	32.8					(40 Sable)	
Nitrite-N	BC MoE	mg/L NO2-N	0.18					(2 Sable)	For chloride between 4 and 6 mg/L; can be adjusted for higher and lower chloride
Total Phosphorus		mg/L						(0.4 Sable)	
Total Metals									
Aluminum	USEPA	µg/L	750					2,000	pH > 6.5
Arsenic	USEPA	µg/L	340					1 (0.1 Sable)	
Cadmium	USEPA	µg/L	$e^{(1.0166[\ln(\text{hardness})]-3.924}$	0.84	1.70	2.57	3.44	(3 Sable)	Hardness as mg/L $CaCO_3$
Boron	CCME	µg/L	29,000						
Chromium	USEPA	µg/L	16 Cr(IV)					(40 Sable)	The lower of Cr(III) and Cr(IV)
Copper	BC MoE	µg/L	0.094 x hardness + 2	5.76	9.52	13.28	17.04	200 (40 Sable)	Hardness as mg/L $CaCO_3$
Lead	USEPA	µg/L	$e^{(1.273[\ln(\text{hardness})]-1.46)}$ with minimum benchmark of 1	25.43	61.46	102.97	148.52	(20 Sable)	Hardness as mg/L $CaCO_3$
Molybdenum	Site Specific WQO	µg/L	221,000						
Nickel	USEPA	µg/L	$e^{(0.8460[\ln(\text{hardness})]+2.255)}$	216.11	388.46	547.42	698.26	300 (100 Sable)	Hardness as mg/L $CaCO_3$
Selenium	Draft USEPA	µg/L	258 as selenite 417 as selenate						Selenate value is based on sulphate of 100 mg/L; can be adjusted for higher and lower sulphate
Uranium	CCME	µg/L	33						
Vanadium	Site Specific WQO	µg/L	1,600						
Zinc	USEPA	µg/L	$e^{0.8473[\ln(\text{hardness})]+0.884)}$	55.1	99.2	139.8	178.4	(60 Sable)	Hardness as mg/L $CaCO_3$

Appendix 2

Derivation of Key Hydrologic Parameters

Appendix 2. Derivation of Key Hydrological Parameters

This appendix presents data analyses undertaken to derive key hydrological parameters for the EKATI site. These values are averages for the whole EKATI site.

A2-1 ANNUAL AND MONTHLY PRECIPITATION TOTALS

<u>Data Availability</u>

The Koala meteorological station, located near to the main EKATI site has a continuous precipitation record since 1994, with data summarised in Table A2-1.

Table A2-1. Observed Annual Precipitation Totals

	Koala			Diavik	Lupin		
Year	**Annual Rainfall Total (mm)**	**Annual Snowfall Total (mm)**	**Annual Precipitation (mm)**	**Annual Rainfall Total (mm)**	**Annual Rainfall Total (mm)**	**Annual Snowfall Total (mm)**	**Annual Precipitation (mm)**
1994			280		131	110	241
1995	259	260	519	157	166	144	310
1996	244	266	510		317	148	465
1997	166	57	223		119	97	216
1998	92	279	371		169	152	321
1999	254	204	458		213	182	396
2000	156	116	272		111	144	255
2001	152	184	336	133	103	177	280
2002	246	75	321	217	233	111	344
2003	121	171	292	99	143	120	263
2004	150	72	222	101	179	159	338
2005	151	97	248	135	161	144	305
2006	293	133	426	173			194
2007	119	138	257				
2008	307	115	422				
2009	127	124	251				
Average	**189**	**153**	**338**	**145**	**170**	**141**	**302**

A meteorological station was operated in the Misery area from 1994 to 1996, but there are gaps in the records, so that there are no complete annual data series.

Rainfall data from the meteorological station at the Diavik mine, located south of EKATI were obtained for seven years of record, Table A2-1.

Data from the Environment Canada Class A meteorological station at Lupin, were obtained from Environment Canada and are summarised in Table A2-1.

Annual Average Precipitation

Key conclusions from the available data shown in Table A2-1 are:

- annual average precipitation at the Koala Meteorological Station is 338 mm, with around 45% falling as snow;
- average annual precipitation at Lupin is 302 mm, with around 47% falling as snow; and
- average annual rainfall at Diavik is around 145 mm, compared to 189 mm at Koala and 170 mm at Lupin. Snowfall data is not available for Diavik.

The meteorological station at Diavik is located to the south of most of the pits at EKATI apart from Misery pit. On average rainfall at Diavik is 75% of the total at Koala. Such a large discrepancy would appear unusual as annual precipitation totals in northern Canada might not be expected to vary to such a degree over such a short distance, given the similar topography and climate across the region. The main difference between the two sites may be the relative proximity to Lac de Gras, with the large water body influencing the local weather around Diavik.

As the Koala meteorological station was used for the precipitation inputs to the Long Lake Containment Facility (LLCF) Load Balance Model and the LLCF Downstream Model. The Koala station is located close to the LLCF and has a data record of 16 years. Data from the Environment Canada station at Lupin were used to extend the Koala dataset during the estimate of return period annual precipitation totals.

Return Period Annual Precipitation Totals

Return period annual precipitation totals were calculated based on analysis of records at the Koala meteorological station and the Environment Canada Lupin meteorological station.

There are 16 years of precipitation data from the Koala meteorological station. Meteorological data has been collected near Lupin since 1959; however, the location of the station was moved in 1981. Statistical analysis of mean and standard deviations for the periods 1959 to 1981 and 1982 to 2003 indicated there were differences in the two populations. Hence, only data from 1982 to 2005 (24 years of data) was considered for this assessment.

Return period analysis was undertaken based on Koala data supplemented by Lupin data. For the period 1994 to 2009 data from Koala was used. For the period 1982 to 1994 Lupin data was used scaled by the average ratio of Koala and Lupin annual precipitation totals for the period of overlapping data (1994 to 2005). This gave a combined dataset of 28 years.

A return period analysis was then undertaken for the combined data using Normal and LogNormal probability distributions. These distributions are commonly used for the analysis of annual total precipitation data; see Chow et al. (1988). The best fit between data and distribution was obtained for a three parameter log normal distribution. The results are shown in Table A2-2.

As the return period estimates are based on a dataset of 28 years, it should be noted that although results for return periods of around 10 to 30 years might be expected to be reasonably accurate given the period of observed data, estimates of return period precipitation much in excess of 30 years will have a high degree of uncertainty.

Table A2-2. Return Period Precipitation Estimates

Return Period	Annual Precipitation Based on Combined Koala/Lupin Data (mm)
1-in-100 dry year	234
1-in-50 dry year	242
1-in-20 dry year	256
1-in-10 dry year	270
Average year	[a]338
1-in-10 wet year	451
1-in-20 wet year	495
1-in-50 wet year	554
1-in-100 wet year	598

[a] *Results scaled to provide average annual precipitation values as defined above*

Monthly Precipitation

Monthly average precipitation values were calculated based on analysis of data from the Koala meteorological station. For the purpose of water balance modelling snow is of interest primarily when it is mobilised as melt water. Hence, for water balance purposes 'effective precipitation' is defined, which represents the precipitation available as water, i.e., snow accumulating in winter is released as melt during May and June in freshet. Monthly percentages of effective precipitation are provided in Table A2-3, with a high percentage in June reflecting the period when snow melt occurs.

Table A2-3. Monthly Precipitation, Runoff and Evaporation Percentages

Return Period	May	Jun	Jul	Aug	Sept	Oct	Total
[a]Effective Precipitation	5	55	9	21	6	4	100 %
[b]Runoff	7	53	23	8	8	1	100 %
[c]Evaporation	0	40	30	22	7	1	100%

[a] *Based on EKATI data from 2004 to 2009, assuming that precipitation in winter is retained as snow and melts during freshet.*
[b] *Based on all available EKATI streamflow data.*
[c] *Based on observed EKATI data from 2004 to 2007.*

Data from Lupin was also analysed. These data indicated a higher percentage of precipitation during the period July – October than the Koala data. However, the Koala data is used for water balance modelling.

A2-2 ANNUAL AND RUNOFF TOTALS

Natural runoff from watersheds within the Pigeon pit area is calculated through the simple equation:

Total annual runoff (mm) = Total annual precipitation (mm) x runoff coefficient

where different runoff coefficients can be defined for different watersheds, as outlined in the following sections.

Data Availability

Streams flows have been gauged at a number of sites within the EKATI claim block since 1994. In total 63 flow years of data are available, undoubtedly making this one of the world's largest datasets of gauged flow data from small, northern watersheds.

Annual Average Runoff

For each gauged station, total annual runoff (mm) was calculated by dividing the total observed annual flow volume (m^3) by the watershed area (km^2) upstream of the gauge site. Flow data was used only if flows were measured for the full open-water season. Any years where the freshet peak was missed or where the gauge malfunctioned were not considered in the assessment.

For each dataset the runoff coefficient was calculated by dividing the annual runoff total by the annual precipitation total. The runoff coefficient is a dimensionless factor that describes the fraction of total precipitation falling on a watershed that is converted to stream runoff. It has a value < 1 and accounts for all losses of water within the watershed, including evapo-transpiration, sublimation and soil storage. The calculated runoff coefficients for all the sites are given in Table A2-4. The average runoff co-efficient for the EKATI site was calculated as 0.5, indicating that on average only half of the precipitation landing on a natural watershed in the EKATI area leaves the watershed as stream flow. However, runoff coefficients for watersheds flowing into the LLCF and for watersheds flowing to downstream lakes were calibrated based on observed LLCF discharge data and gauged flows at the Slipper Lake outlet, respectively (Section 5 of main report). Calibrated runoff coefficients for these locations are given in Table A2-5.

Table A2-4. Summary of Observed Stream Flow Data in EKATI Area

Gauge Station	Year	Runoff Depth (mm)	Precipitation (mm)	Runoff Coefficient	Annual Average Runoff Coefficient (Avg. Runoff Depth (mm))
Vulture-Polar	1997	182	223	0.82	
Slipper-Lac de Gras	1997	195	223	0.87	
Martine-Nema	1997	109	223	0.49	0.60
Moose-Nero	1997	51	223	0.23	*134*
Lower PDC	1999	215	458	0.47	
Vulture-Polar	1999	339	458	0.74	
Slipper-Lac de Gras	1999	298	458	0.65	0.52
Counts Outflow	1999	92	458	0.20	*236*
Vulture-Polar	2000	170	279	0.61	
Lower PDC	2000	173	279	0.62	
Slipper-Lac de Gras	2000	181	279	0.65	
Nanuq	2000	148	279	0.53	0.58
Counts Outflow	2000	131	279	0.47	*161*
Upper Exeter	2001	212	336	0.63	0.63
					212
Vulture-Polar	2002	135	321	0.42	
Counts Outflow	2002	167	321	0.52	
Slipper-Lac de Gras	2002	84	321	0.26	

(continued)

Table A2-4. Summary of Observed Stream Flow Data in EKATI Area (continued)

Gauge Station	Year	Runoff Depth (mm)	Precipitation (mm)	Runoff Coefficient	Annual Average Runoff Coefficient (Avg. Runoff Depth (mm))
Pigeon-Fay	2002	177	321	0.55	
Logan Outflow	2002	202	321	0.63	0.43
Horseshoe Outflow	2002	55	321	0.17	*137*
Vulture-Polar	2003	62	288	0.22	
Lower PDC	2003	55	288	0.19	
Slipper-Lac de Gras	2003	88	288	0.31	0.30
Counts Outflow	2003	135	288	0.47	*85*
Vulture-Polar	2004	171	222	0.77	
Lower PDC	2004	80	222	0.36	
Slipper-Lac de Gras	2004	84	222	0.38	
Counts Outflow	2004	115	222	0.52	
Pigeon-Fay	2004	151	222	0.68	
Upper PDC	2004	113	222	0.51	
Ross Outflow	2004	60	222	0.27	
Logan Outflow	2004	75	222	0.34	0.46
Horseshoe Outflow	2004	67	222	0.30	*102*
Vulture-Polar	2005	151	248	0.61	
Lower PDC	2005	171	248	0.69	
Slipper-Lac de Gras	2005	113	248	0.46	
Counts Outflow	2005	130	248	0.52	
Pigeon-Fay	2005	115	248	0.46	
Upper PDC	2005	187	248	0.75	
Ross Outflow	2005	118	248	0.48	0.54
Horseshoe Outflow	2005	77	248	0.31	*133*
Vulture-Polar	2006	259	430	0.60	
Lower PDC	2006	254	430	0.59	
Slipper-Lac de Gras	2006	268	430	0.62	
Counts Outflow	2006	124	430	0.29	
Pigeon-Fay	2006	173	430	0.40	0.52
Upper PDC	2006	269	430	0.63	*225*
Vulture-Polar	2007	156	257	0.61	
Lower PDC	2007	106	257	0.41	
Slipper-Lac de Gras	2007	88	257	0.34	
Counts Outflow	2007	117	257	0.46	0.45
Pigeon-Fay	2007	117	257	0.46	*117*
Vulture-Polar	2008	122	422	0.29	
Lower PDC	2008	153	422	0.36	
Slipper-Lac de Gras	2008	130	422	0.31	

(continued)

Table A2-4. Summary of Observed Stream Flow Data in EKATI Area (completed)

Gauge Station	Year	Runoff Depth (mm)	Precipitation (mm)	Runoff Coefficient	Annual Average Runoff Coefficient (Avg. Runoff Depth (mm))
Cujo Outflow	2008	73	422	0.17	0.27
Counts Outflow	2008	92	422	0.22	*114*
Vulture-Polar	2009	133	251	0.53	
Lower PDC	2009	121	251	0.48	
Slipper-Lac de Gras	2009	96	251	0.38	
Cujo Outflow	2009	112	251	0.45	0.47
Counts Outflow	2009	133	251	0.53	*119*
			Average	0.47	0.48
			Stdev	0.17	
			Max	0.87	
			Min	0.17	

Table A2-5. Runoff Coefficients for Different Watersheds / Source Areas

Input	Runoff Coefficient	Comment
Catchment flowing to LLCF	0.65	Value based on calibration of LLCF water balance, as outlined in Section 5 in the main report.
Catchments flowing to downstream lakes	0.44	Average runoff coefficient from observed data at Slipper gauge outflow.
Runoff on pit walls	0.85	Used in Beartooth pit sub-model. Tested/calibrated against observed sump flow data at Misery pit (Appendix 3)
Precipitation on lake surface	1	Losses from lakes due to evaporation are accounted separately.

Although average runoff coefficients can be defined there is a high degree of variability in observed runoff coefficients. As is shown in Table A2-4, observed runoff coefficients can vary with annual averages ranging from 0.30 to 0.63 and for the full data set values can range from 0.17 to 0.87. It is thought possible that the runoff coefficient could vary with the precipitation total, e.g., higher runoff coefficients could be associated with wet years and lower values for dry years. However, it was not possible to determine any relationship between runoff coefficient and annual precipitation using the available data at the EKATI site. In addition, no relationships could be found between annual runoff and watershed area and/or annual snowfall. The lack of any relationships of this form may be due to a lack of data, but it may also indicate that such simple relationships do not exist due to the complexity in runoff generating processes in northern Canada. There are no standard watershed models for northern Canada, although recent research at the University of Saskatchewan has resulted in the development of a model for northern watersheds, which, if tested further, may result in a more sophisticated method of estimating runoff in the EKATI region, in the future.

However, based on data available at present and using the average runoff coefficient, estimates of annual runoff for any watershed can be made using;

Total annual runoff (mm) = Total annual precipitation (mm) x runoff coefficient

Hence, for an average annual precipitation total of 338 mm, this would indicate annual runoff of 169 mm. The results compare well with previous studies. Maps of average annual runoff for northern Canada prepared by Acres (1982) predicted mean annual runoff in the EKATI area to be around 150 mm.

Return Period Annual Runoff Totals

Return period annual runoff totals are defined as the return period precipitation totals multiplied by runoff coefficients as outlined in Table A2-5.

Monthly Runoff Totals

Estimates of monthly runoff totals are used to assess seasonal variations in flow. For each EKATI flow dataset the percentage of the annual flow total that occurred in each month was calculated. From this data, average monthly percentage values were calculated and are summarised in Table A2-6. It is notable that over 80% of the annual flow total occurs between May to July associated with snowmelt and freshet conditions. Less than 20% of the annual flow occurs during the summer and autumn.

Table A2-6. Monthly Flow Distributions for EKATI Hydrology Stations and Selected WSC Sites

	Percentage of Annual Runoff Total in Each Month					
	May	June	July	August	Sept	October
EKATI Watersheds	7	53	23	8	8	1
WSC Stations	3	58	15	9	13	2

An attempt was made to compare these monthly percentage values to data from Water Survey of Canada (WSC) stations. From an analysis of many stations in Northwest Territories and Nunavut it was found that monthly values were very sensitive to latitude and watershed area. In the Mackenzie valley area and to the south of EKATI freshet occurs earlier with a higher percentage of annual flow occurring in May. For larger basins across the north of Canada there are higher flows in July and August due to flow attenuation and lake storage within the larger watershed areas. However, data for the three watersheds identified as being potentially hydrologically similar to the EKATI watersheds showed a very similar flow distribution to the EKATI sites. Data for these stations are also provided in Table A2-6.

A2-3 ANNUAL AVERAGE AND MONTHLY EVAPORATION

Data Availability

Evaporation has been measured at EKATI since 1994. Annual totals are provided in Table A2-7.

Table A2-7. Observed Annual Precipitation and Evaporation Totals in the EKATI Area

Year	Annual Precipitation (Koala Station) (mm)	Annual Evaporation (mm)
1994	280	270
1995	519	275
1996	510	356
1997	223	279
1998	371	354
1999	458	334
2000	272	376
2001	336	301

(continued)

Table A2-7. Observed Annual Precipitation and Evaporation Totals in the EKATI Area (completed)

Year	Annual Precipitation (Koala Station) (mm)	Annual Evaporation (mm)
2002	321	[a] ***349***
2003	292	[a] ***326***
2004	222	-
2005	248	252
2006	426	340
2007	257	319
2008	422	277
2009	251	244
Average	338	310

[a] *Interpolated from incomplete annual series*

Annual Average Evaporation

Based on the EKATI dataset average annual evaporation is calculated to be 310 mm.

Return period evaporation

An attempt was made to assess whether evaporation totals varied with annual precipitation, i.e., was there lower evaporation during wetter years and higher evaporation during drier years. However, no clear relationship was visible with the EKATI data. As a result, water balance modelling work considers average evaporation is every year of operation.

Monthly Evaporation Totals

Monthly evaporation totals are shown in Table A2-3, based on analysis of the EKATI dataset.

Appendix 3

Calibration of Pit Wall Runoff Rates

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Appendix 3. Calibration of Pit Wall Runoff Rates

The following memo derives appropriate values for runoff coefficients to be used when estimating pit wall runoff into open pits at the EKATI site. Simple water balance models are developed for operational pits at EKATI and a value for the pit wall runoff coefficient is obtained through calibration, with the value of the runoff coefficient varied until a fit is obtained between predicted annual volumes of water accumulating at the bottom of the pit and observed pit sump pumped water volumes.

The purpose of undertaking this exercise for the LLCF Load Balance Model is that estimates of pit wall runoff are required for pits that are currently not in operation at EKATI, but will contribute sump water to the LLCF (i.e., Pigeon pit) and runoff estimates are required for the Beartooth sub-model.

Data on pumped volumes from open pits at EKATI are recorded as monthly totals and this data is reported annually. There is multi-year data for Misery pit, Fox pit, Beartooth pit and Koala pit, which are used to calibrate simple pit water balance models based on catchment and pit areas for these pits. There is data for Panda pit but suitable catchment areas were not available to allow sensible inflow estimates.

The simple pit water balance model considers inflows to the pit from the catchment surrounding the pit and from runoff over the pit walls.

Observed annual precipitation totals are available from the Koala Meteorological Station for the historical period.

Pit areas and catchments were calculated based on site maps, imagery and/or engineering plans.

Groundwater inflows are considered zero for all pits. Groundwater held within mined kimberlite or waste rock and water removed from the pit within kimberlite ore or waste rock is considered negligible compared to other inflows.

Within each pit the surface area of the pit sump is considered negligible and there is assumed to be a balance between precipitation landing directly on the sump (runoff coefficient = 1) and evaporation from the sump.

Runoff totals for the pit walls and natural catchments are estimated based on the following equation;

Total annual runoff (mm) = Total annual precipitation (mm) x runoff coefficient

Different runoff coefficients need to be defined for pit wall runoff and runoff from natural watersheds.

The average runoff coefficient for natural catchments is 0.5 at EKATI, i.e., half of the precipitation total is converted into runoff. This is based on analysis of stream flow data at the site.

The runoff coefficient for precipitation falling on pit walls was not known and was calibrated by varying the runoff coefficient for all pits until a reasonable water balance was obtained for each pit. Given the uncertainties associated with all input parameters (i.e., precipitation at each pit, natural runoff coefficient, pit wall runoff), trying to calibrate a different pit wall runoff coefficient for each year of record would only calibrate the runoff coefficient to the uncertainties in the data and was unlikely to improve our understanding of runoff rates and would not aid prediction of future conditions.

Hence, the pit wall runoff coefficient was calibrated for a single, constant value that would be applicable to all open pits.

The best fit between predicted and observed sump water volumes was obtained for a runoff coefficient of 0.85 (i.e., 85% of precipitation is converted to runoff). Calculations for each open pit based on this value are given below. However, such a value would appear reasonable as runoff from pit walls is expected to be significantly higher than from a natural catchment, but there would still be losses due to evaporation, sublimation and water held in broken rock sitting on benches within the open pit.

A3-1 MISERY PIT SUMP

Records of monthly pumped water totals have been recorded for Misery pit since 2000, Table A3-1.

Table A3-1. Summary of Recorded Annual Pumped Volumes from Misery Pit

Year	Pumped Volume (m^3)	Operational Status	Averages (m^3/year)	
2000	656,277	Lake dewatering		
2001	472,992	Lake dewatering pre-stripping	Pre-stripping	565,000
2002	120,245	Operations		
2003	72,609	Operations		
2004	89,662	Operations	Operations	94,200
2005	55,340 [a]	Temporary closure		
2006	0	Temporary closure		
2007	129,650	Temporary closure		
2008	0	Temporary closure		
2009	0	Temporary closure		
2010	169,000 [b]	Temporary closure		
2011	300,000 [c]	Temporary closure	Closure	93,427
			Operations and closure	93,700

[a] *Water allowed to accumulate in pond and pumped out in October and November 2005*
[b] *Pumping volume for summer 2010 provided by A Conley, BHP Billiton*
[c] *Estimate of future pumping in 2011 (prior to push-back of pit) provided by A Conley, BHP Billiton*

In 2000 and 2001 activities focussed on dewatering of Misery Lake and pit pre-stripping. Pumped volumes at this time reflect pumping of the existing lake and are significantly higher than volumes in later years (i.e., average of 565,000 m^3/year, Table A3-1).

Between 2002 and 2004, the pit was under active mining and during this period pumped totals reflect runoff reaching the sump at the pit bottom. It is assumed that water was not stored at this time and all pumped inflows were quickly pumped to the surface. During this period there was an average pumping rate of 94,200 m^3/year.

From 2005 to the present day, Misery pit has been in temporary closure and water has been allowed to accumulate at the bottom of the pit, being pumped to King Pond Settling Facility (KPSF) periodically. Hence, in some years (e.g., 2006, 2008 and 2009) no water was pumped from the bottom of the pit. In September 2005 water depths at the bottom of the pit reached around 11.4 m, before water was pumped out. Pumping also occurred in 2007 and 2010 and there is already a permitted pumped volume for 2011. Taking all available data the annual average pumping rate during the temporary closure period is 93,400 m^3/year, very similar to the rate during operations.

Taking all data from period of operations and temporary closure (including 2011) the annual average pumped flow rate is 93,700 m^3.

The simple water balance model was run for the period 2002 to 2011 (operations and temporary closure), using observed precipitation and natural watershed runoff coefficients, Table A3-2. The model predicted an average annual inflow to the pit that was very similar to the observed average annual pumping rate from Misery pit.

Table A3-2. Results of Annual Mass Balance Modelling – Misery Pit

				Catchment Area	**300,000 m^2**
				Pit	**200,000 m^2**
Year	**Observed Precipitation (mm)**	**Observed Runoff Coefficient**	**Pit Runoff Coefficient**	**Estimated Annual Runoff (m^3)**	**Observed Annual Pumped Out (m^3)**
2002	321	0.43	0.85	95,979	120,245
2003	292	0.30	0.85	75,920	72,609
2004	222	0.46	0.85	68,273	89,662
2005	248	0.54	0.85	81,985	55,340
2006	426	0.52	0.85	139,143	0
2007	257	0.45	0.85	78,730	129,650
2008	422	0.27	0.85	105,940	0
2009	251	0.47	0.85	78,370	0
2010	338	0.50	0.85	108,160	169,000
2011	338	0.50	0.85	108,160	300,000
Average				**94,066**	**93,651**

A3-2 FOX PIT SUMP

Records of monthly pumped water totals have been recorded for Fox pit since 2003, Table A3-3.

Table A3-3. Summary of Recorded Annual Pumped Volumes from Fox Pit

Year	**Pumped Volume (m^3)**	**Operational Status**	**Averages (m^3/year)**	
2003	2,825,767	Lake dewatering	Lake dewatering	2,825,767
2004	139,349	Operations		
2005	68,483	Operations		
2006	389,720	Operations		
2007	169,530	Operations		
2008	273,570	Operations		
2009	137,109	Operations	Operations	196,293
			Operations	196,293

In 2003 activities focussed on dewatering of Fox Lake and pumped volumes at this time reflect pumping of the existing lake and are significantly higher than volumes in later years.

Between 2004 and 2009, the pit was under active mining and during this period pumped totals reflect runoff reaching the sump at the pit bottom. It is assumed that water was not stored at this time and all pumped inflows were quickly pumped to the surface. During this period there was an average pumping rate of 196,293 m^3/year.

The simple water balance model was run for the period 2004 to 2009 (operations), using observed precipitation and natural watershed runoff coefficients, Table A3-4. The model predicted an average annual inflow to the pit that was very similar to the observed average annual pumping rate from Fox pit.

Table A3-4. Results of Annual Mass Balance Modelling - Fox Pit

				Catchment Area	**280,000 m^2**
				Pit	**575,000 m^2**
Year	**Observed Precipitation (mm)**	**Observed Runoff Coefficient**	**Pit Runoff Coefficient**	**Estimated Annual Runoff (m^3)**	**Observed Annual Pumped Out (m^3)**
2004	222	0.46	0.85	137,000	139,349
2005	248	0.54	0.85	158,380	68,483
2006	426	0.52	0.85	270,483	389,720
2007	257	0.45	0.85	158,313	169,530
2008	422	0.27	0.85	238,173	273,570
2009	251	0.47	0.85	155,996	137,109
Average				**186,391**	**196,293**

A3-3 BEARTOOTH PIT SUMP

Records of monthly pumped water totals have been recorded for Beartooth pit since 2003, Table A3-5.

Table A3-5. Summary of Recorded Annual Pumped Volumes from Beartooth Pit

Year	**Pumped Volume (m^3)**	**Operational Status**	**Averages (m^3/year)**	
2003	52.036	Operations		
2004	39,048	Operations		
2005	37,419	Operations		
2006	82,440	Operations		
2007	33,705	Operations		
2008	54,758 [a]	Operations		
2009	No data	Operations	Operations	49,901
			Operations	49,901

[a] *No data for May and June, so long-term averages for these months used in the assessment*

Between 2004 and 2009, the pit has been under active mining and during this period pumped totals reflect runoff reaching the sump at the pit bottom. It is assumed that water was not stored at this time and all pumped inflows were quickly pumped to the surface. During this period there was an average pumping rate of 49,901 m^3/year.

The simple water balance model was run for the period 2004 to 2009 (operations), using observed precipitation and natural watershed runoff coefficients, Table A3-6. The model predicted an average annual inflow to the pit that was higher than the observed average annual pumping rate from Beartooth pit. It is noted that this is the only pit where a pit wall runoff coefficient of 0.85 did not produce a reasonable fit to the observed data. A value of 0.5 would be required to provide a reasonable fit. It is unclear why Beartooth pit results are anomalous and may indicate that there have been errors in estimating the pit or catchment areas.

Table A3-6. Results of Annual Mass Balance Modelling – Beartooth Pit

				Catchment Area	210,000 m^2
				Pit	157,000 m^2
Year	Observed Precipitation (mm)	Observed Runoff Coefficient	Pit Runoff Coefficient	Estimated Annual Runoff (m^3)	Observed Annual Pumped Out (m^3)
2003	292	0.30	0.85	57,363	52.036
2004	222	0.46	0.85	50,999	39,048
2005	248	0.54	0.85	60,973	37,419
2006	426	0.52	0.85	103,556	82,440
2007	257	0.45	0.85	58,825	33,705
2008	422	0.27	0.85	80,256	54,758
2009	251	0.47	0.85	-	-
Average				**68,662**	**49,901**

A3-4 KOALA PIT SUMP

Records of monthly pumped water totals have been recorded for Koala pit since 1999, Table A3-7.

In 1999 and 2000 activities focussed on dewatering of lakes above Koala pit. Pumped volumes at this time reflect pumping of the existing lake and are significantly higher than volumes in later years (i.e., average of 1,535,926 m^3/year, Table A3-7).

Table A3-7. Summary of Recorded Annual Pumped Volumes from Koala Pit

Year	Pumped Volume (m^3)	Operational Status	Averages (m^3/year)	
1999	1,819,398	Lake dewatering		
2000	1,252,454	Lake dewatering	Lake dewatering	1,535,926
2001	403,776	Operations		
2002	140,522	Operations		
2003	105,080	Operations		
2004	82,295	Operations		
2005	82,819	Operations		
2006	251,091	Operations		
2007	120,591	Operations		
2008	- [a]	Operations		
2009	94,971	Operations	Operations	160,143
			Operations	160,143

[a] *Full year not recorded, gauge malfunction*

Between 2001 and 2009, the pit was under active mining and during this period pumped totals reflect runoff reaching the sump at the pit bottom. It is assumed that water was not stored at this time and all pumped inflows were quickly pumped to the surface. During this period there was an average pumping rate of 160,143 m^3/year.

The simple water balance model was run for the period 2001 to 2009 (operations), using observed precipitation and natural watershed runoff coefficients, Table A3-8. The model predicted an average annual inflow to the pit that was very similar to the observed average annual pumping rate.

Table A3-8. Results of Annual Mass Balance Modelling - Koala Pit

				Catchment Area	320,000 m^2
				Pit	520,000 m^2
Year	Observed Precipitation (mm)	Observed Runoff Coefficient	Pit Runoff Coefficient	Estimated Annual Runoff (m^3)	Observed Annual Pumped Out (m^3)
2001	336	0.63	0.85	216,250	403,776
2002	321	0.43	0.85	186,052	140,522
2003	292	0.30	0.85	157,096	105,080
2004	222	0.46	0.85	130,693	82,295
2005	248	0.54	0.85	152,096	82,819
2006	426	0.52	0.85	259,464	251,091
2007	257	0.45	0.85	150,970	120,591
2008	422	0.27	0.85	-	-
2009	251	0.47	0.85	149,022	94,971
Average				**175,205**	**160,143**

A3-5 SUMMARY

Results from a simple water balance model for four operational pits in the EKATI area were compared to observed pit sump pumping data. Based on the use of a pit wall runoff coefficient of 0.85, the difference between predicted and observed average annual pumped volumes for each pit were:

- Misery: 0%;
- Fox: -5%;
- Beartooth: +50%; and
- Koala: +9%.

For three of the pits the simple model produced results within 10% of the observed. Acknowledging the uncertainties associated with the input parameters, results indicate that the modelling approach probably does represent the main processes affecting inflows to the pits. The Beartooth results are anomalously high and this may reflect uncertainties in the estimation of inflowing natural catchment area and may not reflect any differences in pit wall runoff rates.

However, based on data available, the results indicate that the water balance model can be used to estimate pit inflows for other pits with no available data, i.e., Pigeon pit. The value will also be used for estimates of runoff in the Beartooth sub-model, with caution given the uncertainties associated with estimation of runoff to Beartooth. However, as pit wall and surface runoff are minor inflows to Beartooth compared to the rate of underground water inflow and tailings slurry, these uncertainties are unlikely to have any impact on water balance or water quality predictions.

Appendix 4

Model Summary Sheets

Aluminium

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	54%	Process Plant	50%
Sump	3%	Sump	1%
Underground	0%	Underground	0%
Runoff	42%	Runoff	37%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	11%

Key Comments Related to Modelling Work

Many concentrations in sump and Process Plant discharge are below detection limit making future prediction difficult to quantify accurately. PPD concentrations show increase in loadings of Aluminium since 2008.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.1 mg/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.99	0.025	0.143	143%	0.049	0.016	0.0771	77%

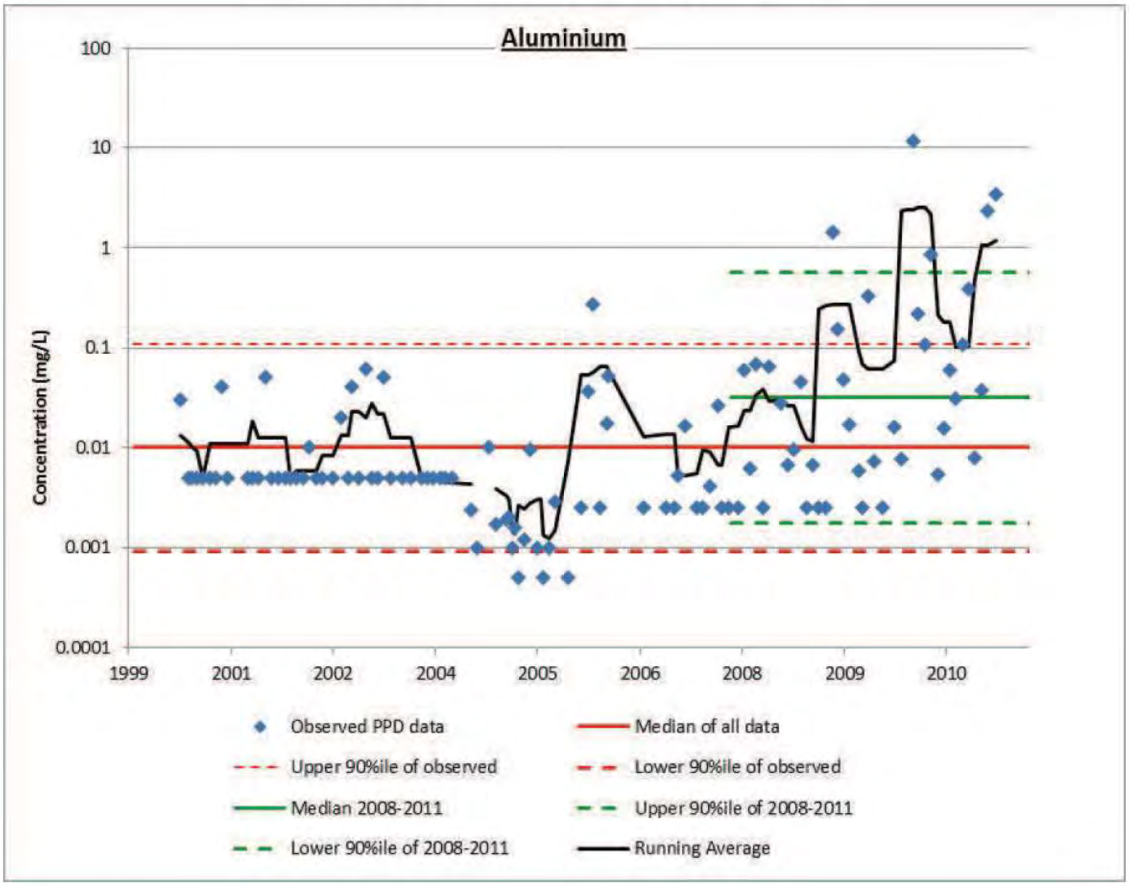
Comment on Model Fit to Observed Data

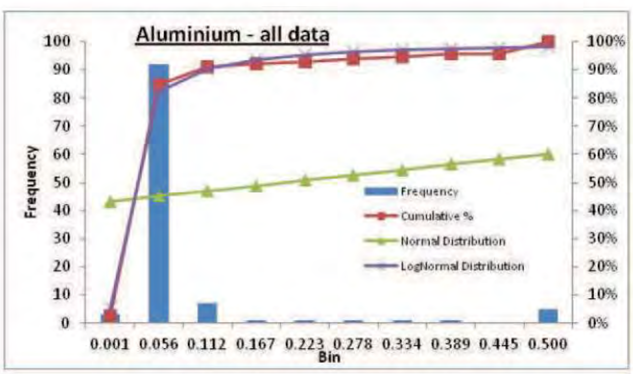
Reasonable fit between observed and predicted concentrations; however, there is variability in observed Aluminium concentrations with some high values. This is likely a result of use of total metals data for observed concentrations. For most metals dissolved metals = total metals at EKATI; however, for some metals such as Aluminium this is not the case and samples with higher than average TSS can produce high particulate metals (and therefore total metals) concentrations. These cannot be predicted by the model.

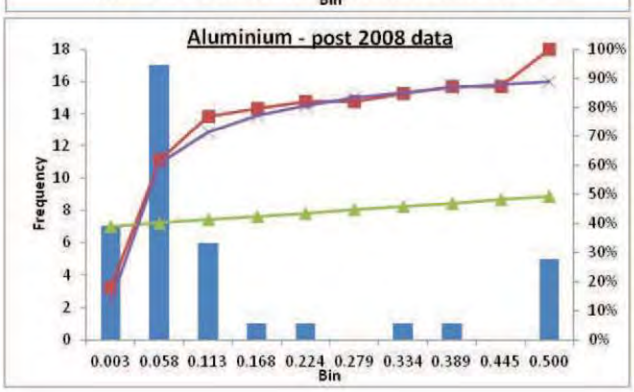
Summary

For Cell E, Leslie, Moose and Nema lakes, the model predicts concentrations of Aluminium that exceed the benchmark value within the lifetime of the mine. For Slipper Lake the model predicts Aluminum concentrations below the benchmark value, but above 75% of the benchmark value within the lifetime of the mine.

Figure 1: Process Plant Inputs to LLCF Model







Comment on Historical Trends in PPD
Higher PPD concentrations and wider spread of data (higher standard deviation) post 2007/2008.

Modelling Approach for Future PPD
Based on lognormal distribution of observed PPD data from 2008 to 2010.

Modelled Correlation between WQ Parameters
Aluminium is correlated to nickel (0.9), vanadium (0.8), chromium (1), copper (0.8), iron (1), manganese (1) and lead (1)

Figure 2: Model Predictions for LLCF

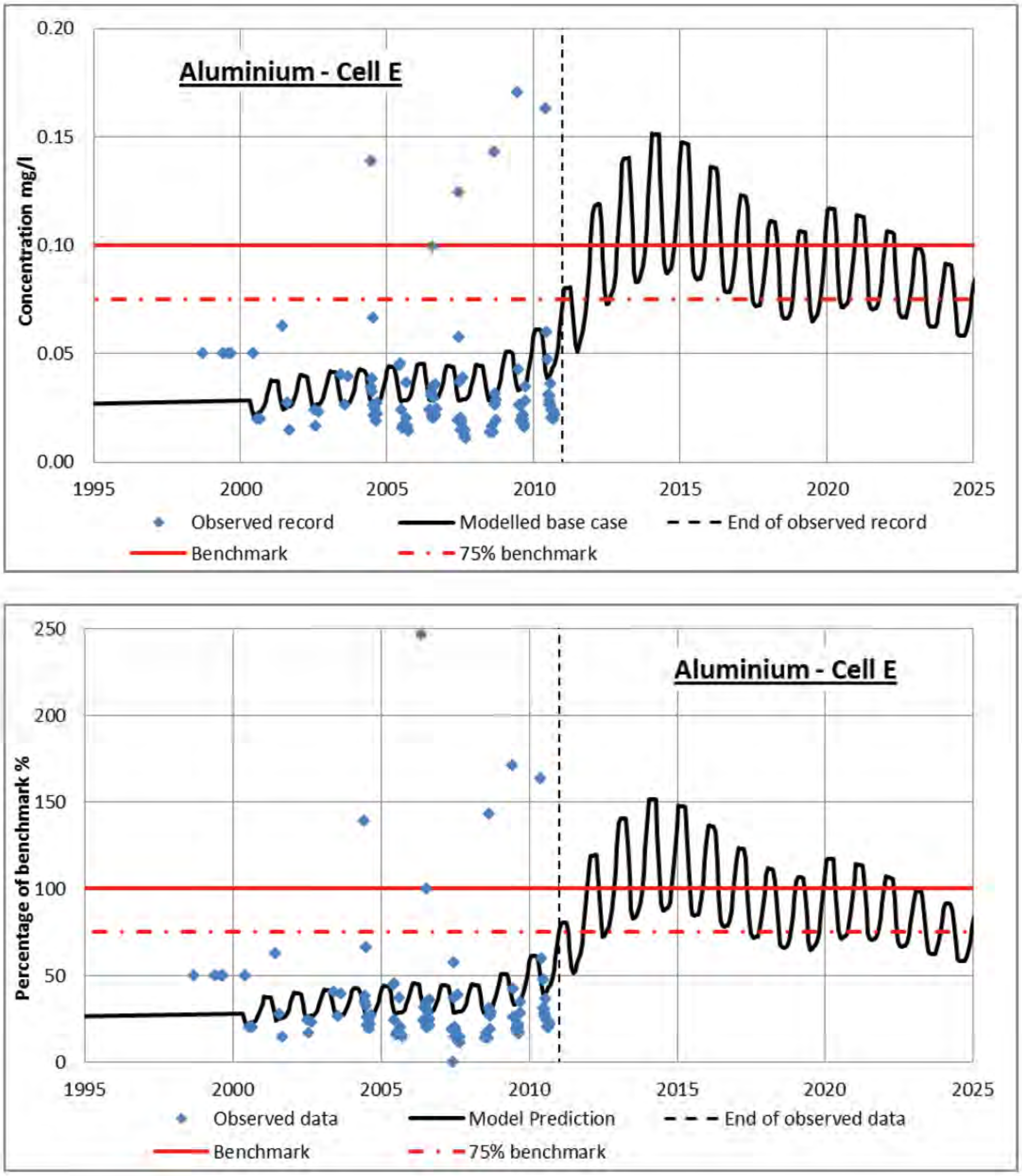


Figure 3: Predictions in Receiving Environment

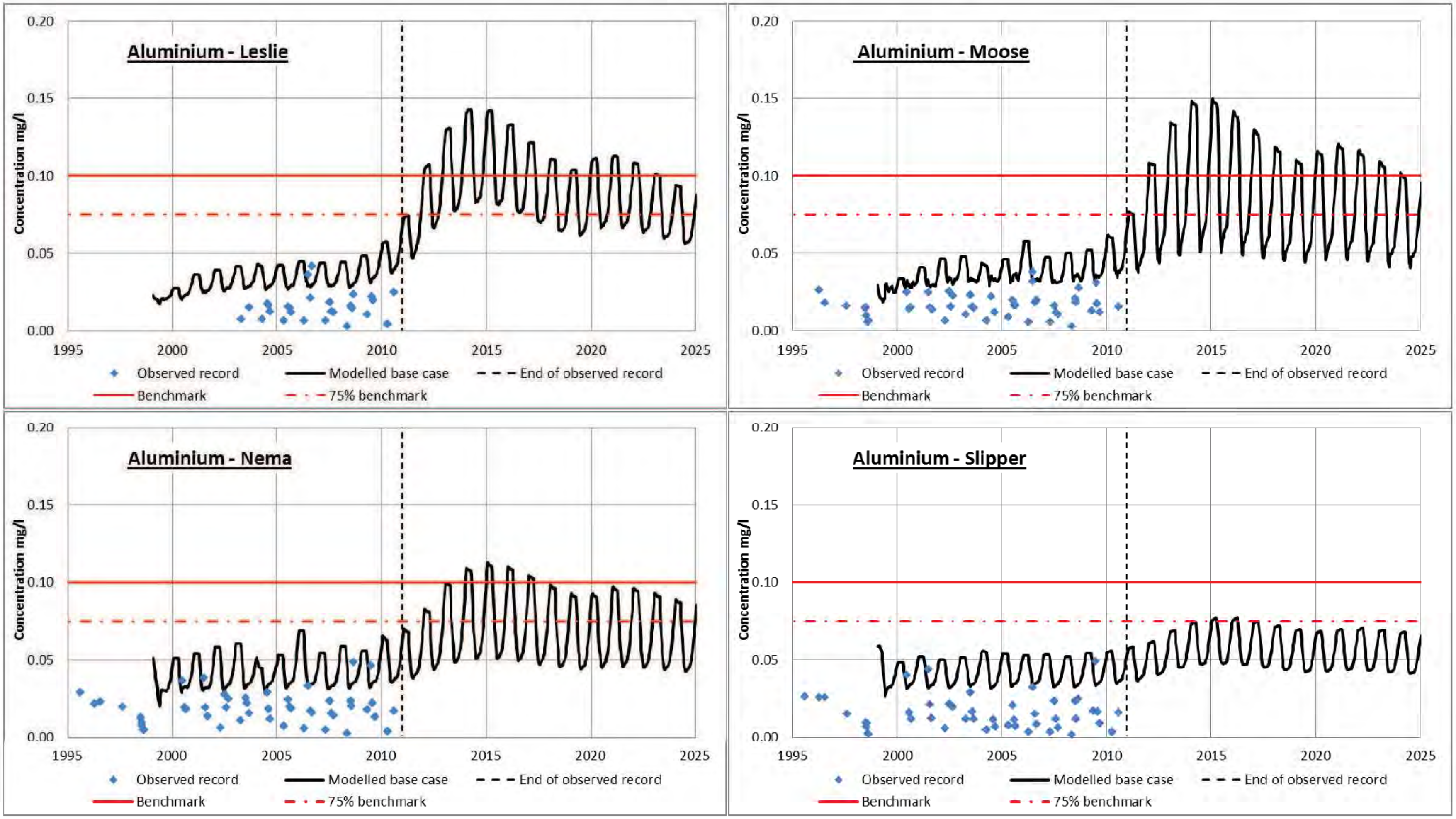
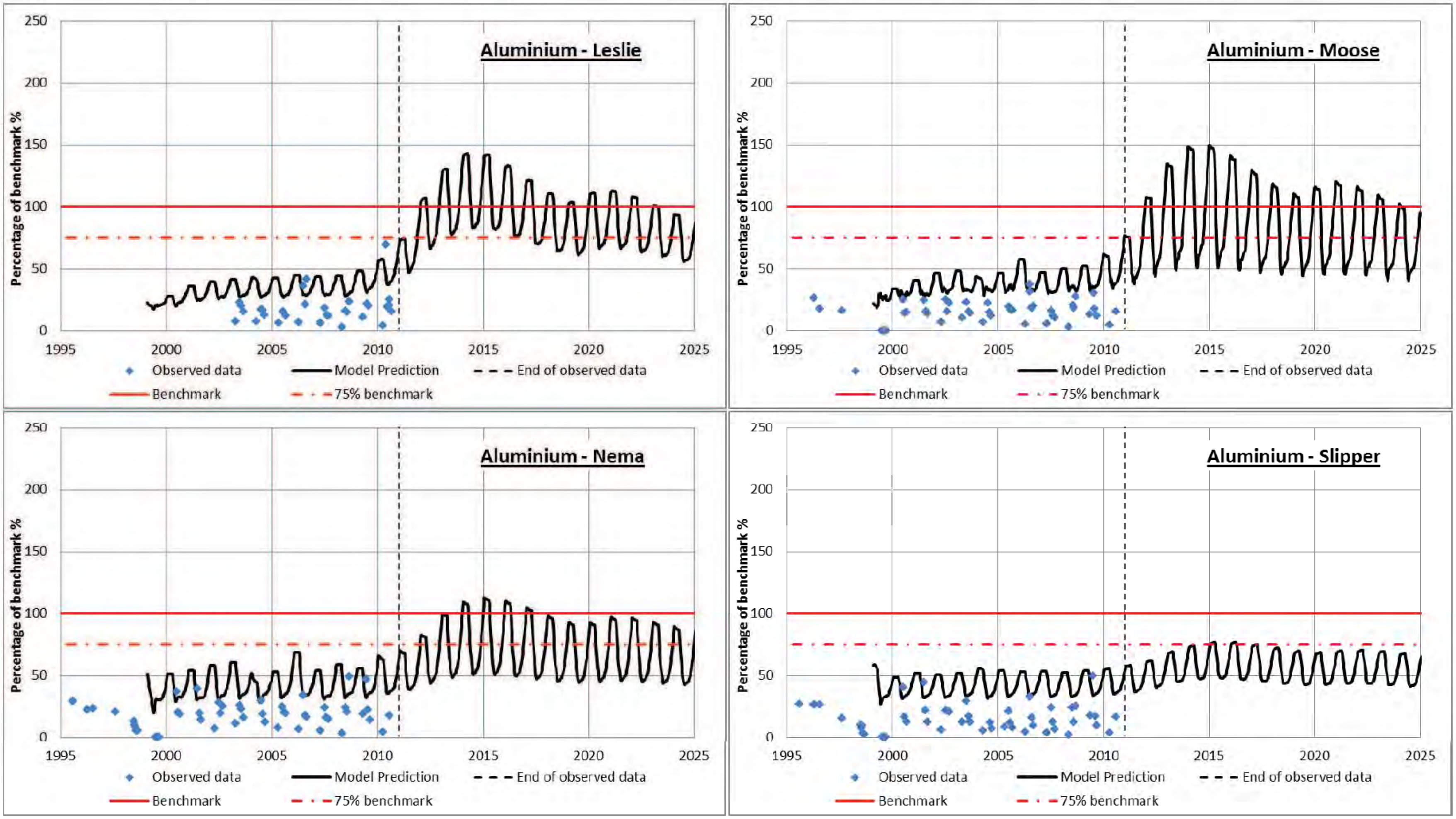


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Ammonia

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	49%	Process Plant	60%
Sump	32%	Sump	33%
Underground	18%	Underground	0%
Runoff	0%	Runoff	1%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	6%

Key Comments Related to Modelling Work

Key loading of Ammonia is from the Process Plant discharge. Ammonia is modelled to decay over time within the model with a calibrated half-life of 4.2 months. Ammonia is modelled as NH_3-N.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.59 mg/L NH_3-N (CCME guideline) (equivalent to 0.019 mg/L unionized ammonia at pH 8 and temperature 15^{o}C

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.11	0.0098	0.0337	6%	0.062	0.014	0.0212	4%

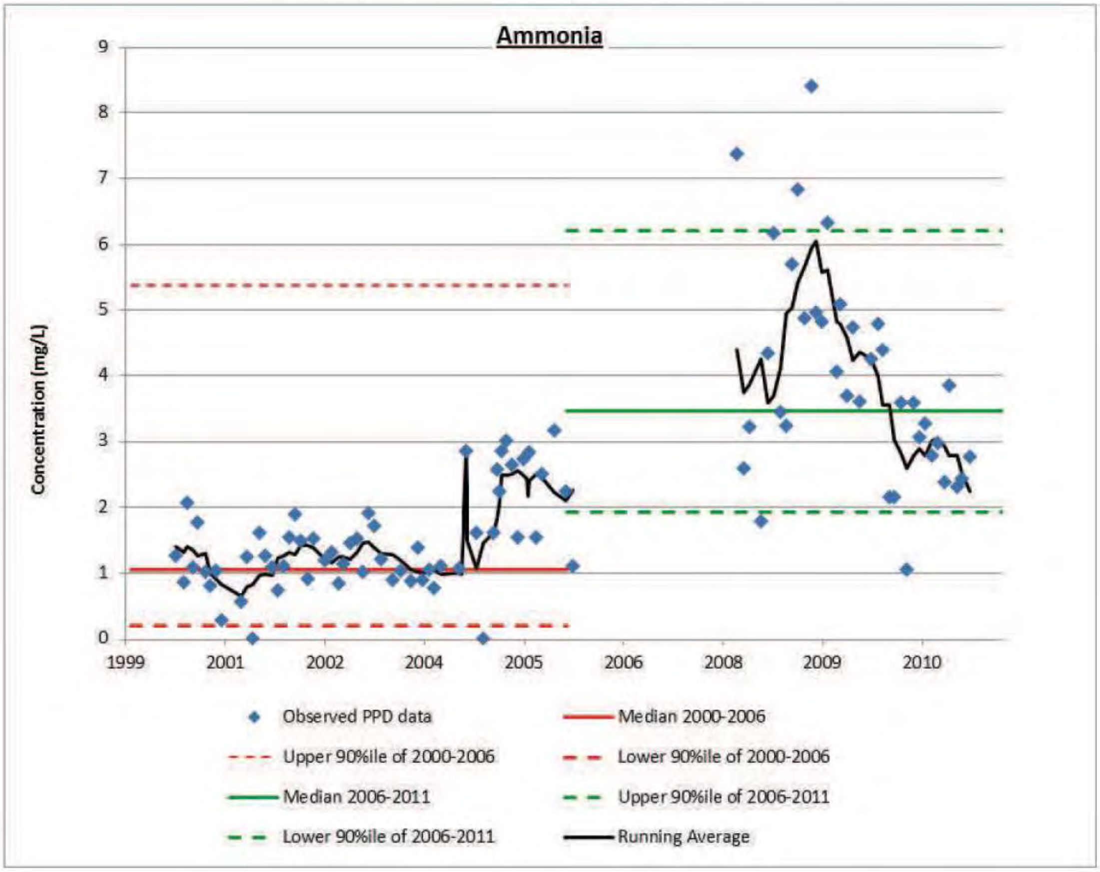
Comment on Model Fit to Observed Data

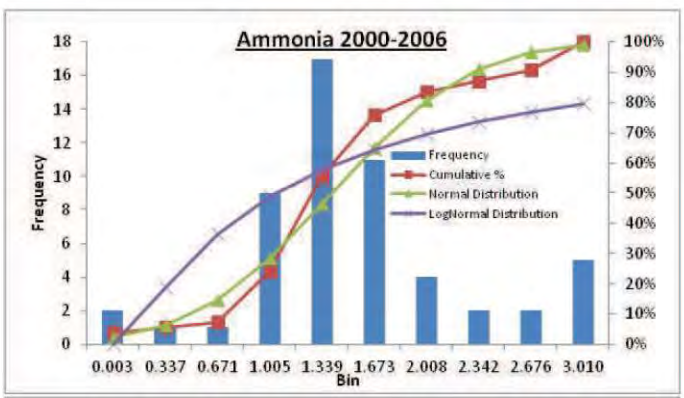
Reasonable calibration with observed data given the uncertainties associated with decay of ammonia.

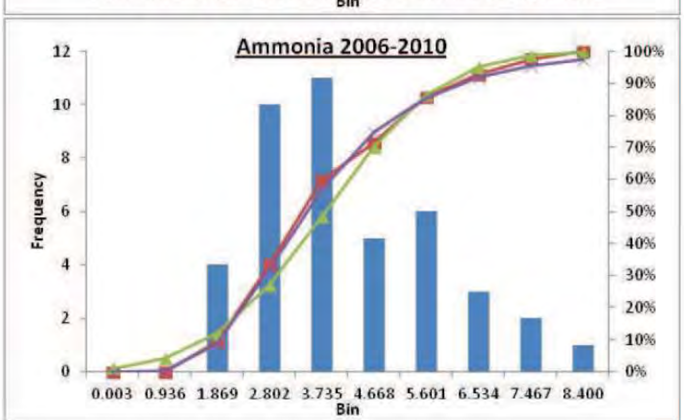
Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model







Comment on Historical Trends in PPD

Gap in PPDF data from 2006 to 2007. There appears to be higher concentrations post-2005, but difficult to define trend due to data gaps.

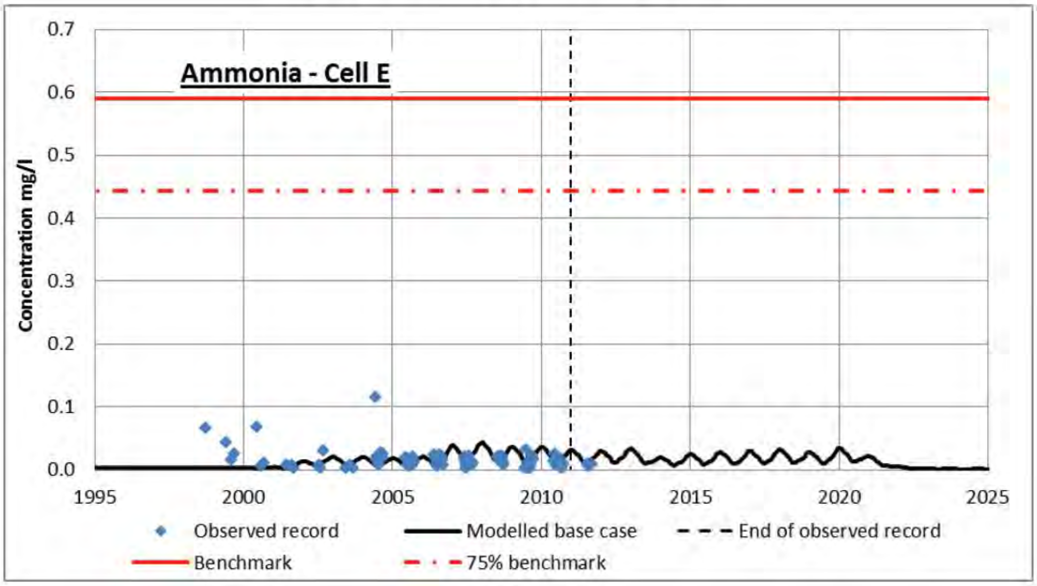
Modelling Approach for Future PPD

2011 to 2020 (except 2018), normal distribution based on observed post-2008 data. For 2018, based on normal distribution for observed PPD data from 2000 to 2006.

Modelled Correlation between WQ Parameters

Ammonia is correlated to TDS with correlation factor 0.7.

Figure 2: Model Predictions for LLCF



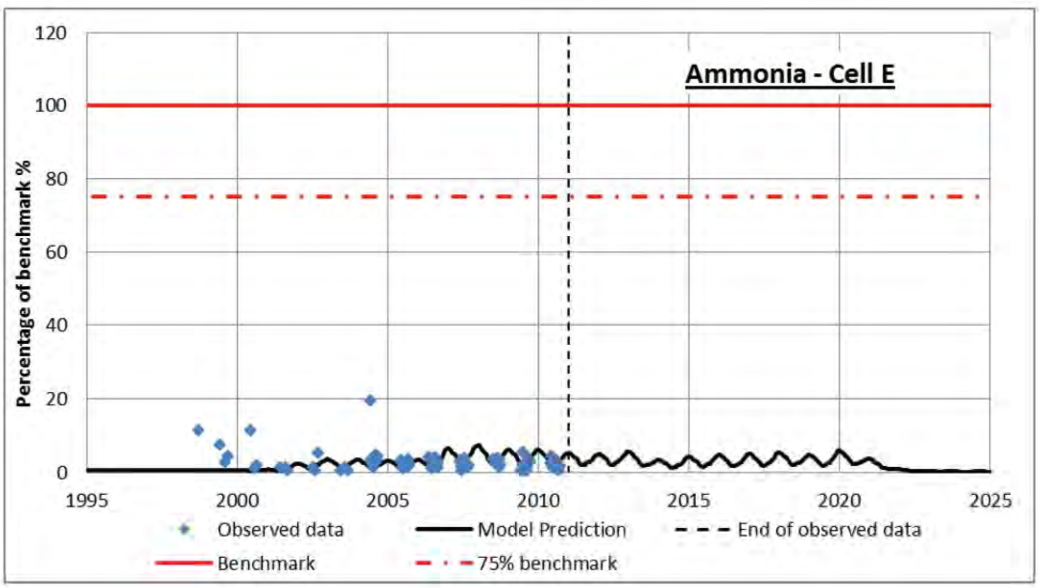


Figure 3: Predictions in Receiving Environment

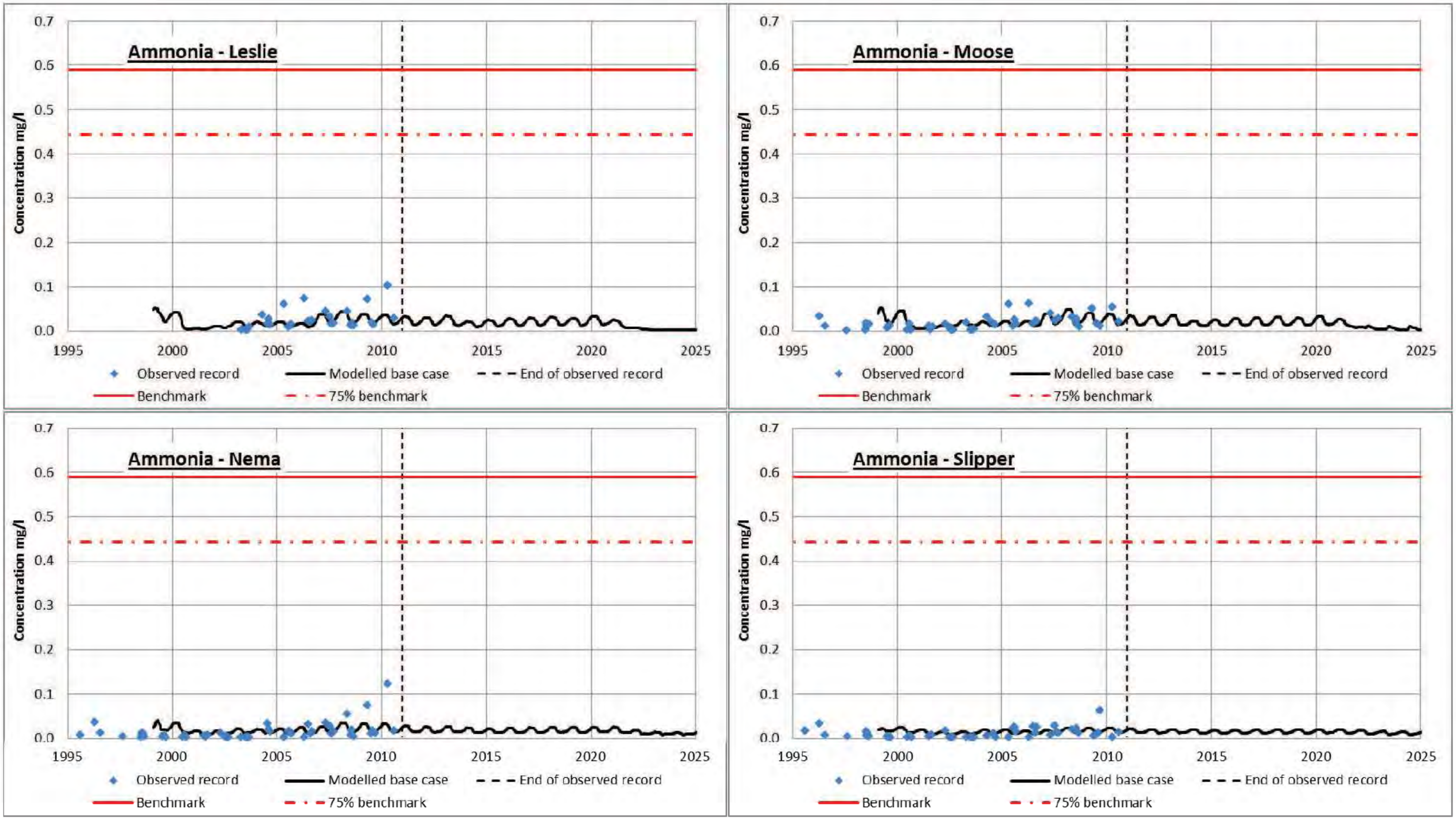
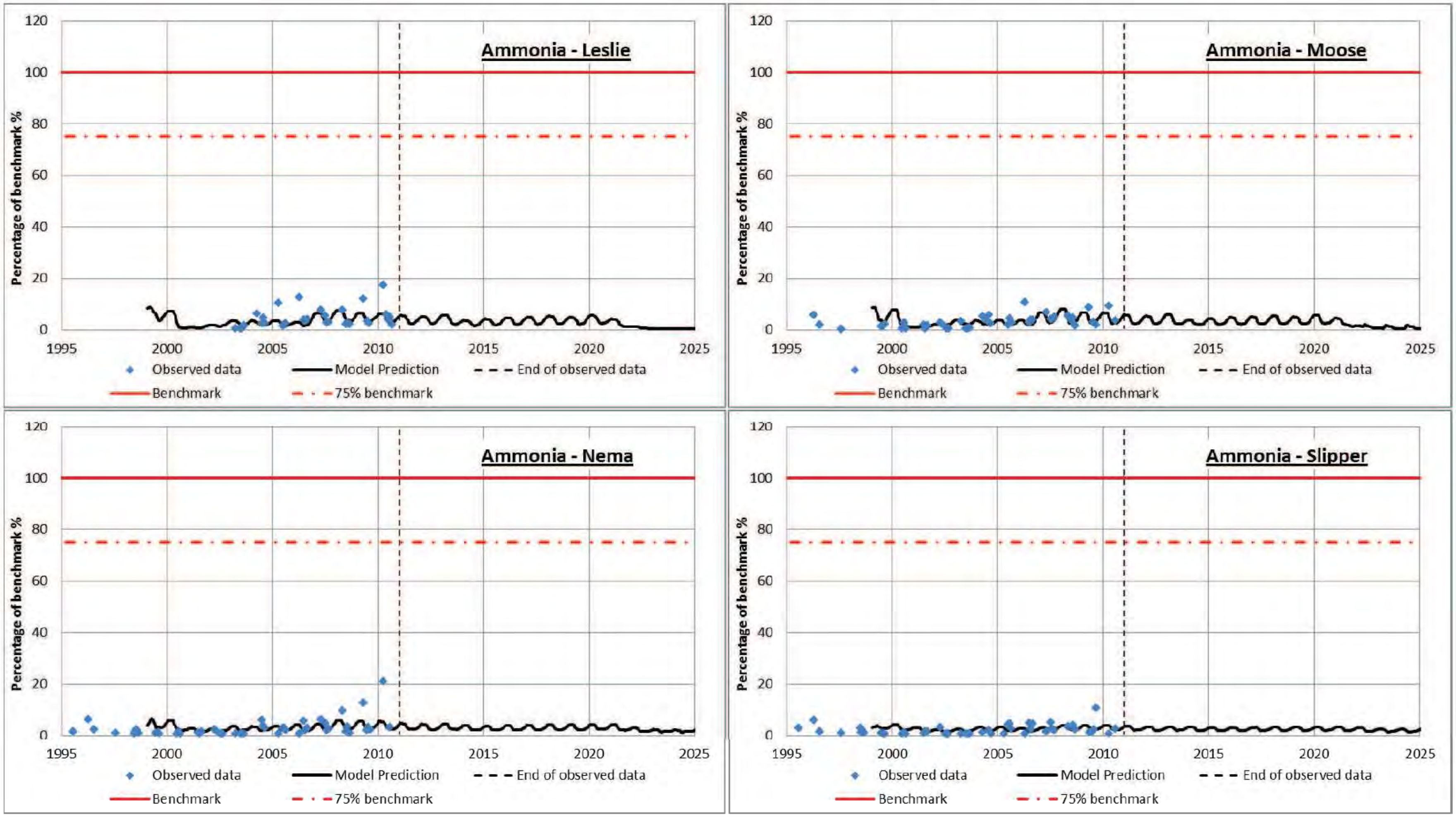


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Antimony

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	85%	Process Plant	68%
Sump	3%	Sump	3%
Underground	2%	Underground	0%
Runoff	9%	Runoff	10%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	18%

Key Comments Related to Modelling Work

Key loading to LLCF is from Process Plant discharge. Concentrations of Antimony in PP discharge have decreased since 2004.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.02 mg/L (Ontario MoE)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.0067	0.0036	0.00572	29%	0.012	0.00093	0.00185	9%

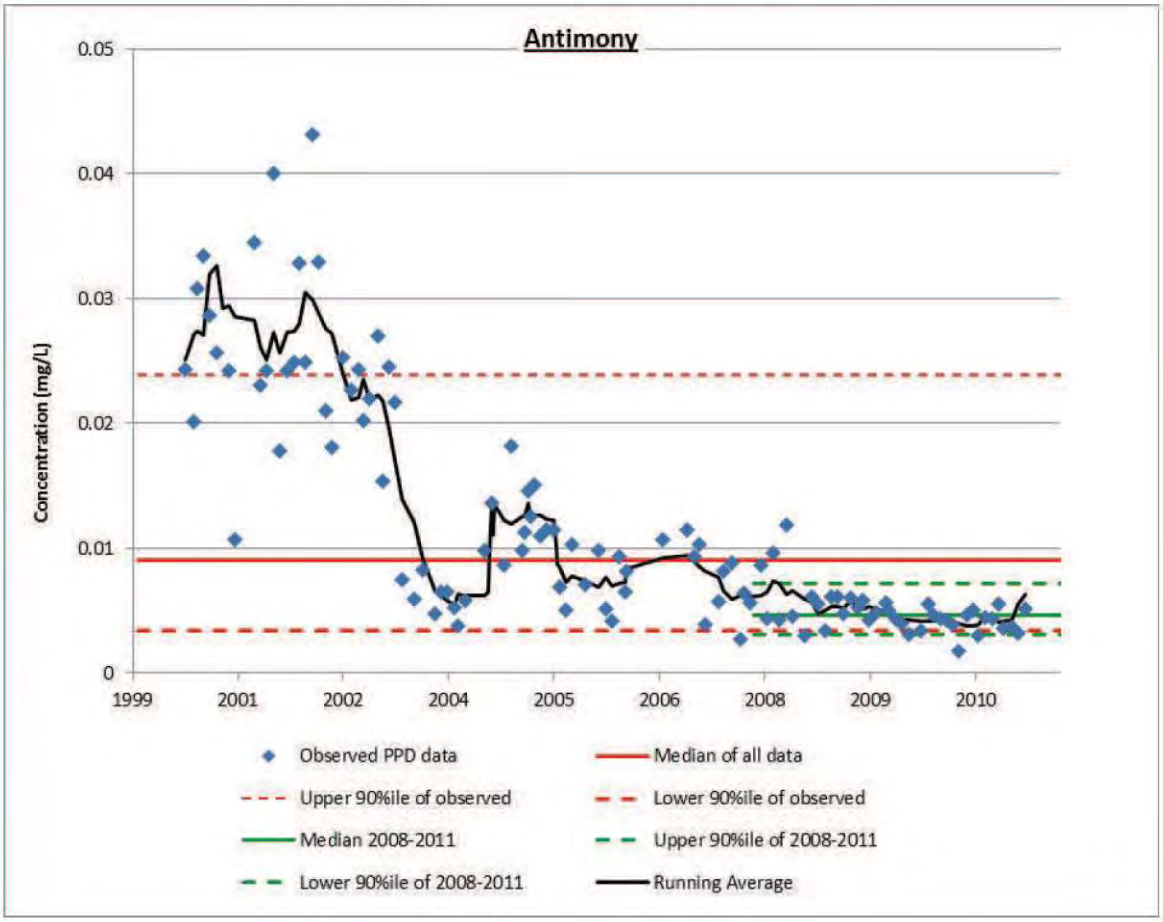
Comment on Model Fit to Observed Data

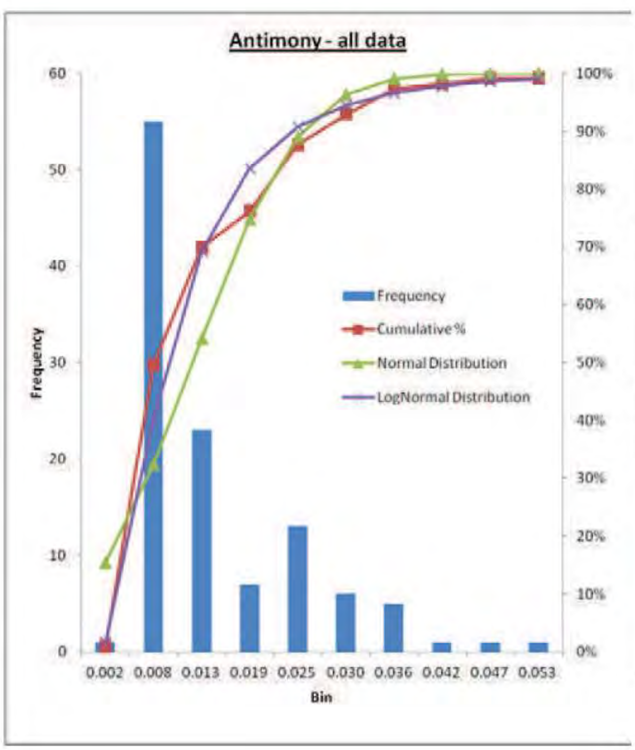
Reasonable fit to observed data, although model over-predicts observed concentrations.

Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

High concentrations in 2003, but consistently lower concentrations post-2008.

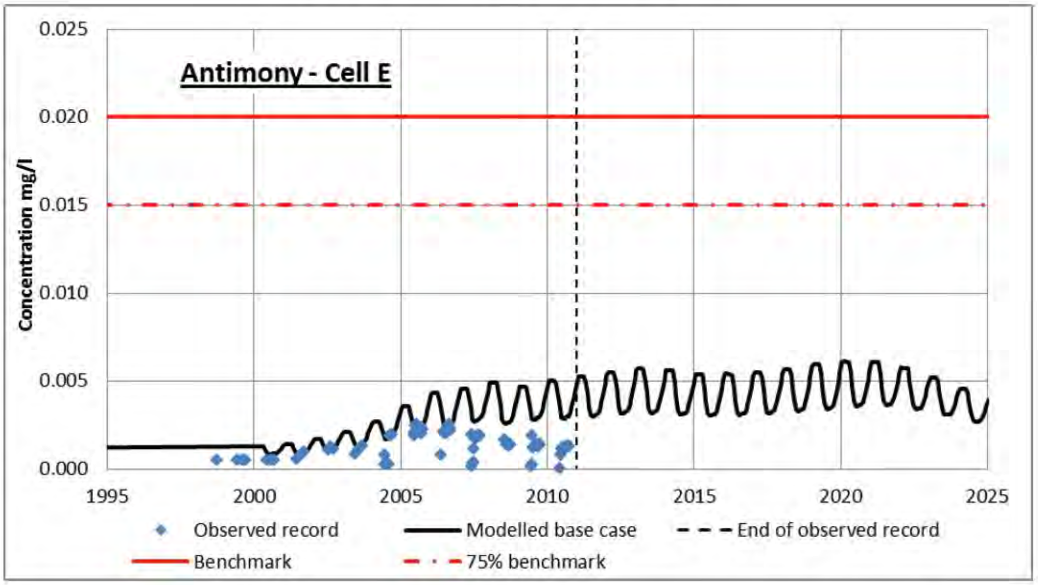
Modelling Approach for Future PPD

Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters

Antimony is correlated to Barium

Figure 2: Model Predictions for LLCF



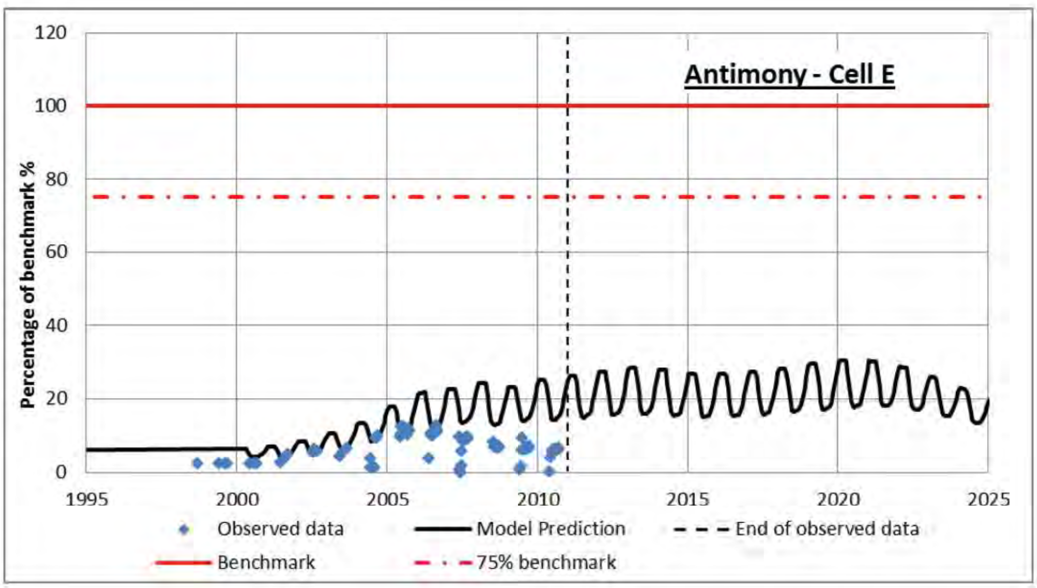


Figure 3: Predictions in Receiving Environment

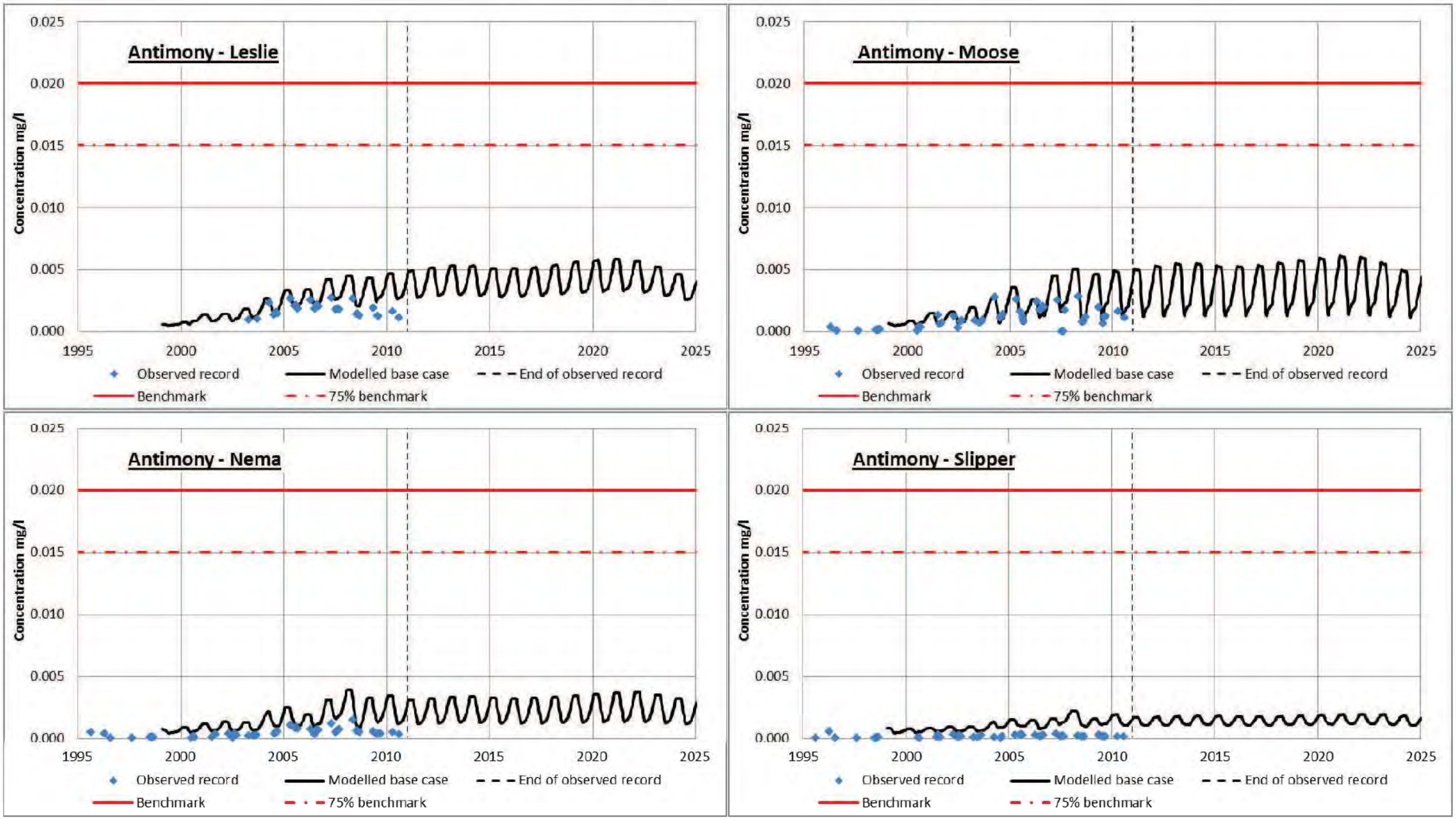
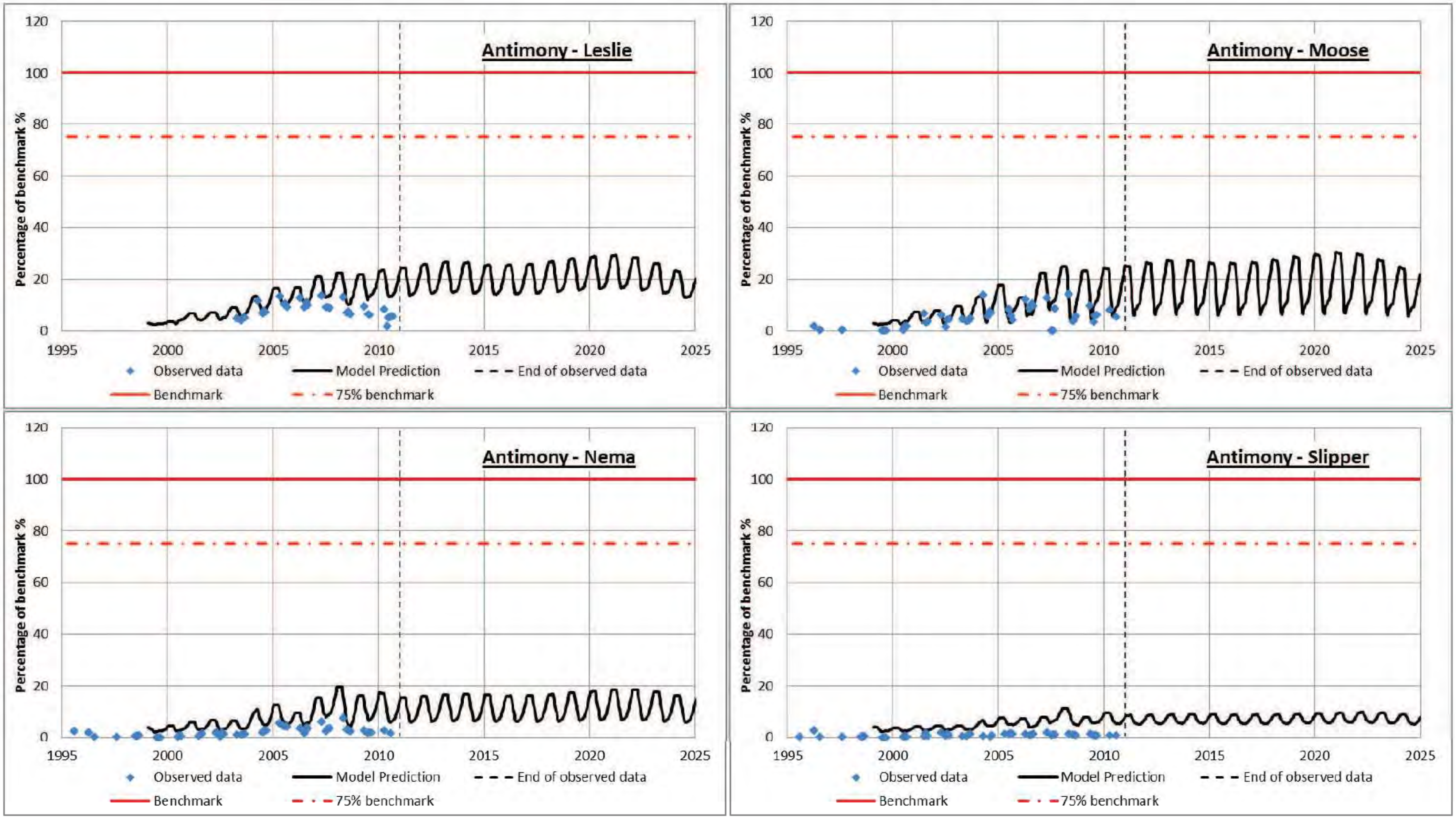


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Arsenic

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	86%	Process Plant	70%
Sump	7%	Sump	9%
Underground	1%	Underground	0%
Runoff	6%	Runoff	7%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	14%

Key Comments Related to Modelling Work

Key input to LLCF model is from Process Plant discharge.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.005 mg/L (CCME guideline)

Leslie Lake (mg/L)				**Slipper Lake (mg/L)**			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.0026	0.00054	0.00359	72%	0.00045	0.00024	0.00105	21%

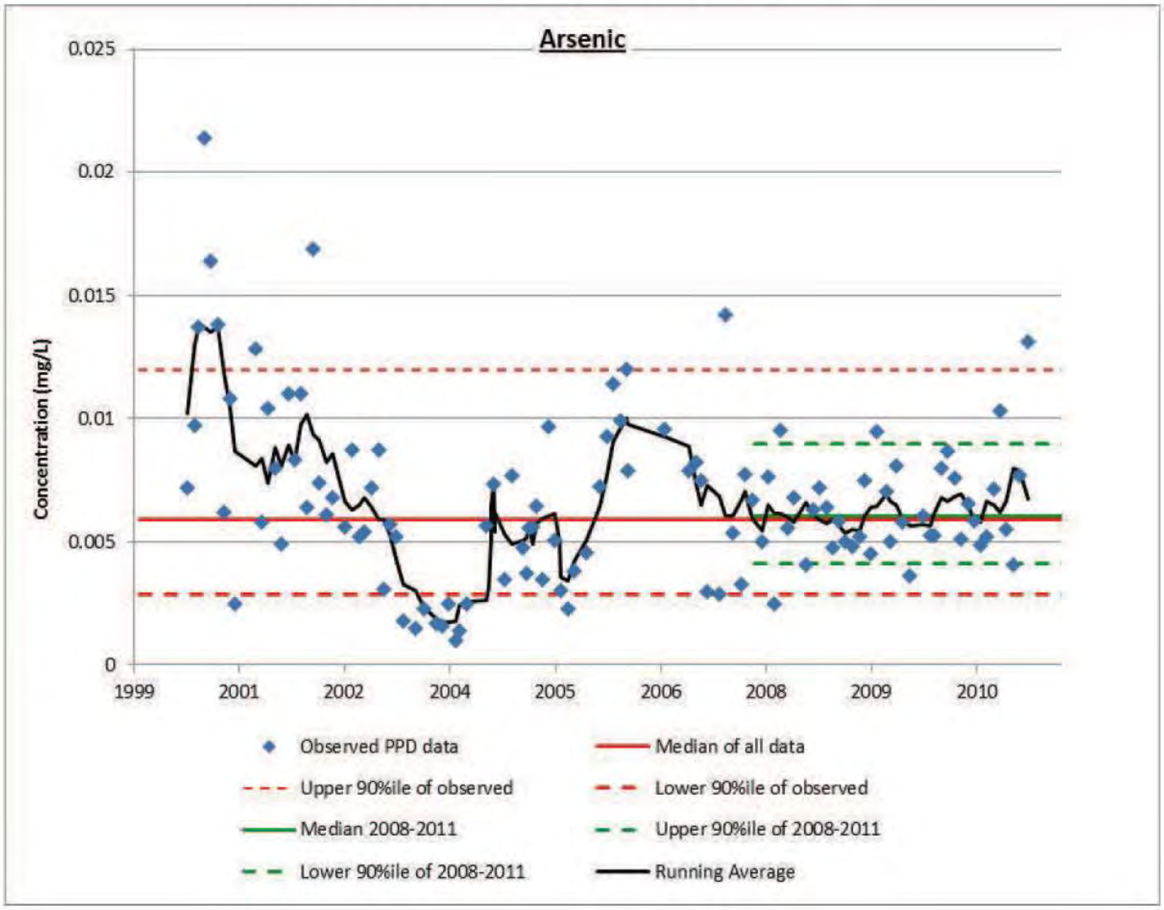
Comment on Model Fit to Observed Data

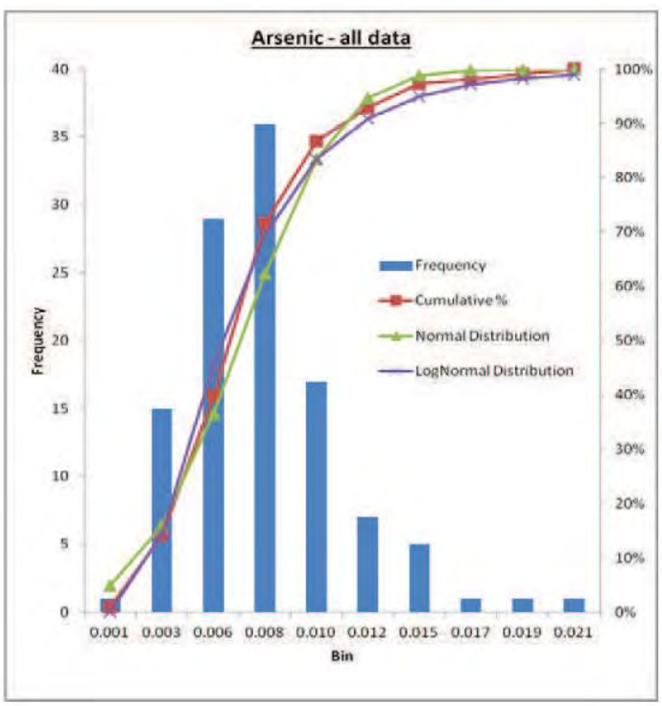
Model over-predicts based on observed concentrations.

Summary

Historical concentrations and model predictions for downstream lakes are below 75% of the benchmark.

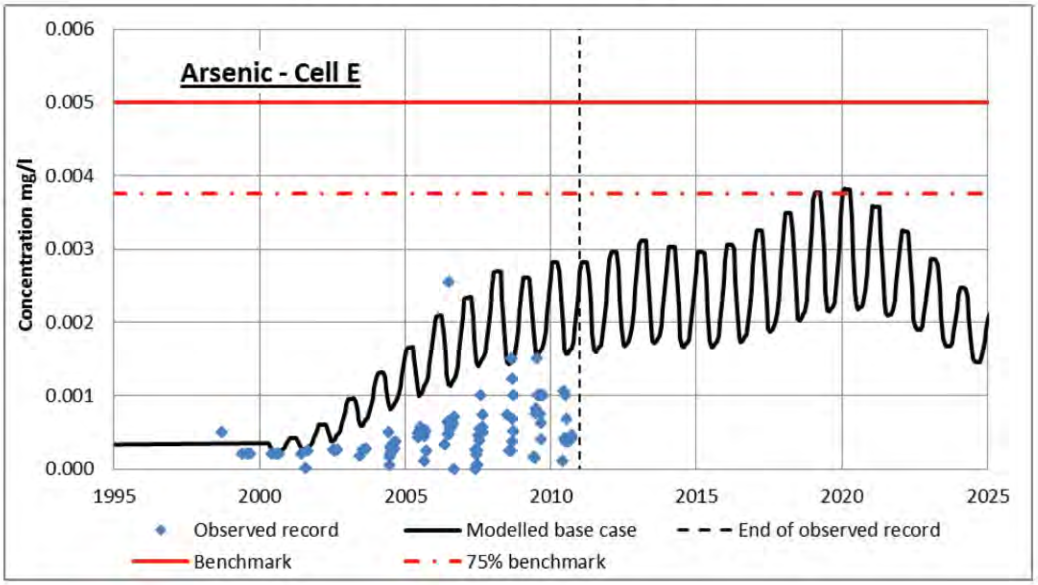
Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD Lower PPD concentrations and lower spread of data post-2008
Modelling approach for Future PPD Based on lognormal distribution of all observed data.
Modelled Correlation between WQ Parameters Arsenic is correlated to uranium

Figure 2: Model Predictions for LLCF



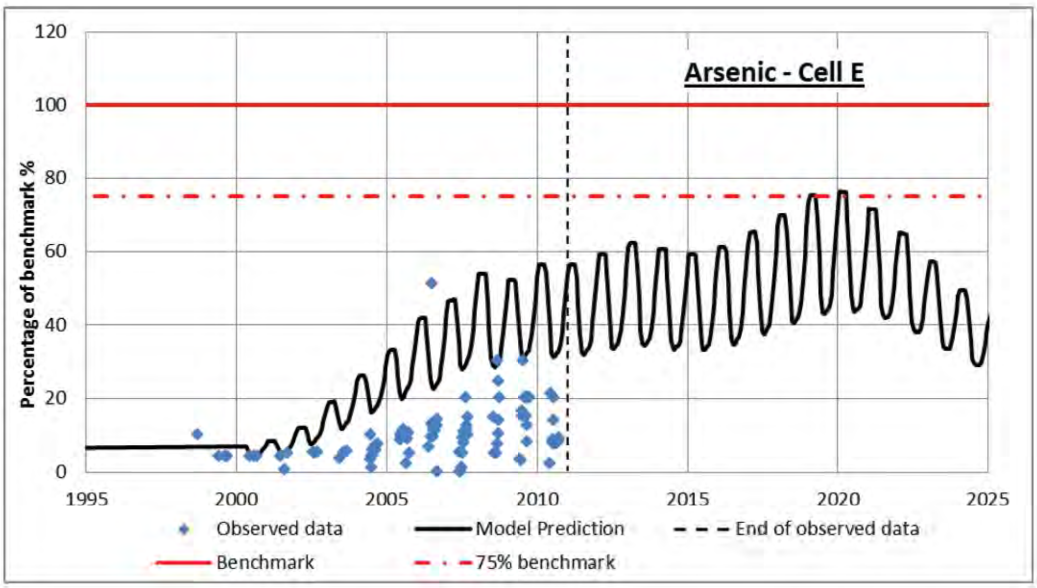


Figure 3: Predictions in Receiving Environment

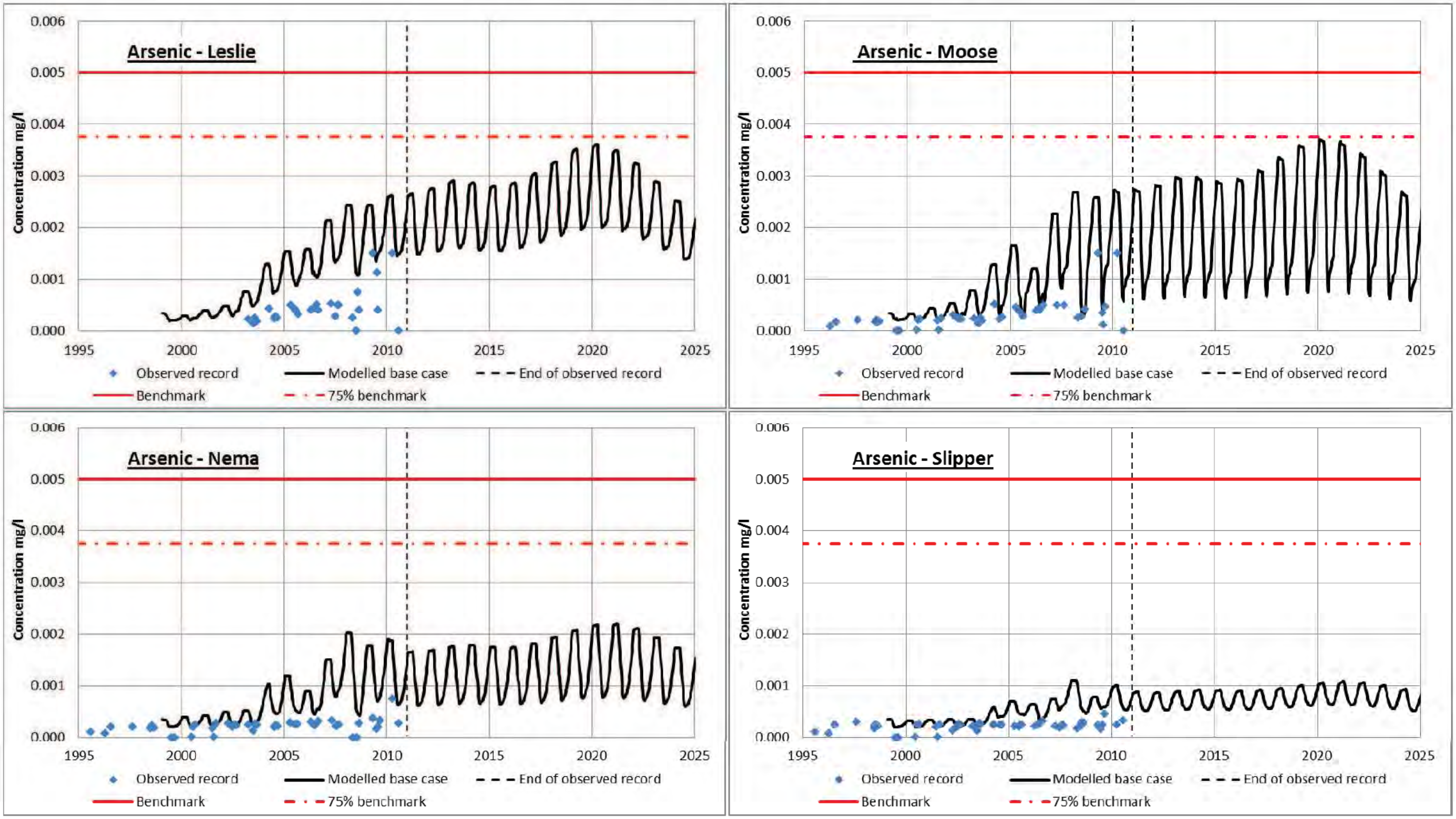
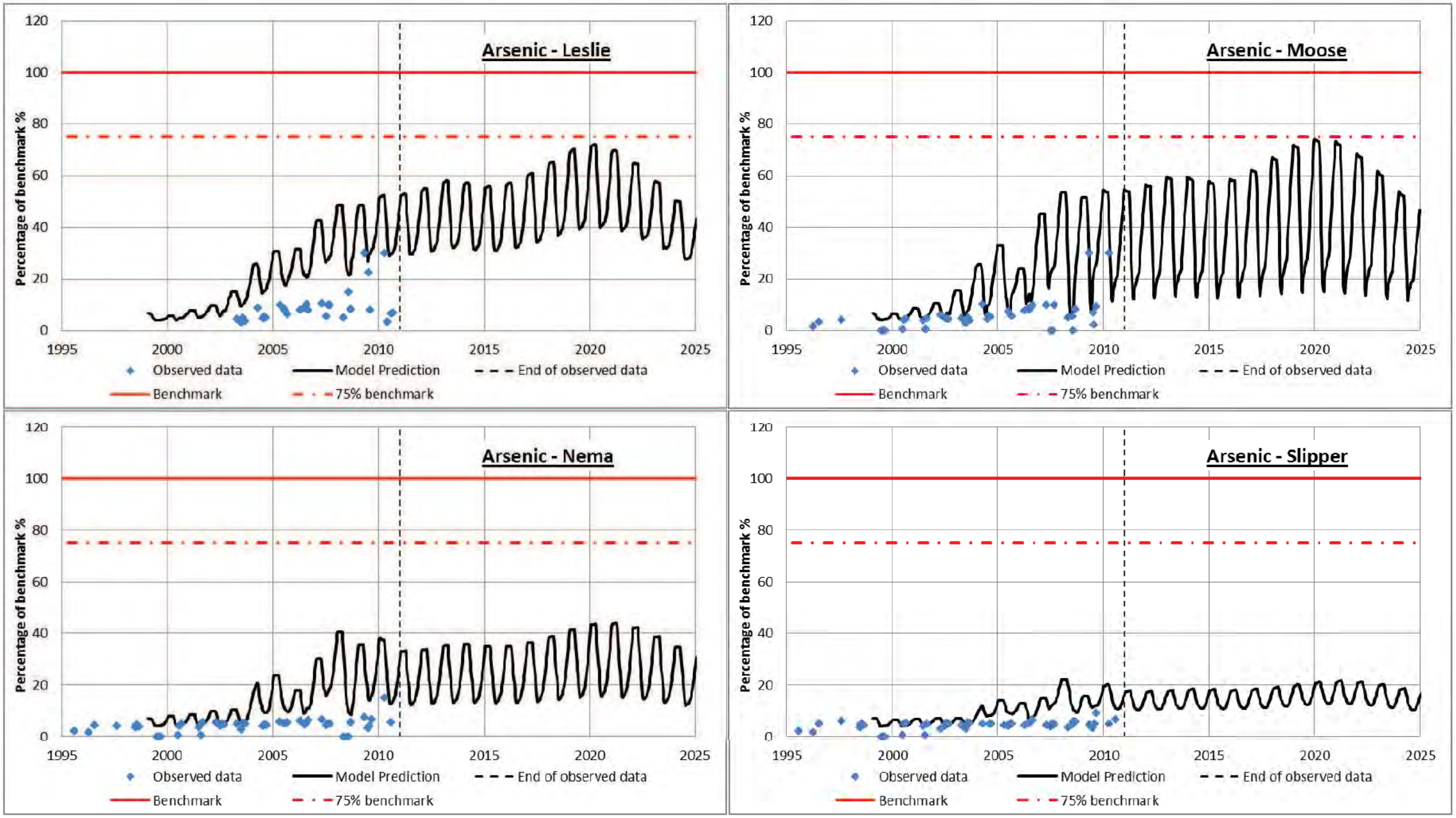


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Barium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	75%	Process Plant	52%
Sump	5%	Sump	8%
Underground	16%	Underground	0%
Runoff	4%	Runoff	6%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	34%

Key Comments Related to Modelling Work

Main source loading for Barium is from the Process Plant discharge. Concentrations in the PP discharge have decreased markedly since 2005.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

1 mg/L (BC MoE guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.13	0.076	0.0638	6%	0.023	0.011	0.0239	2%

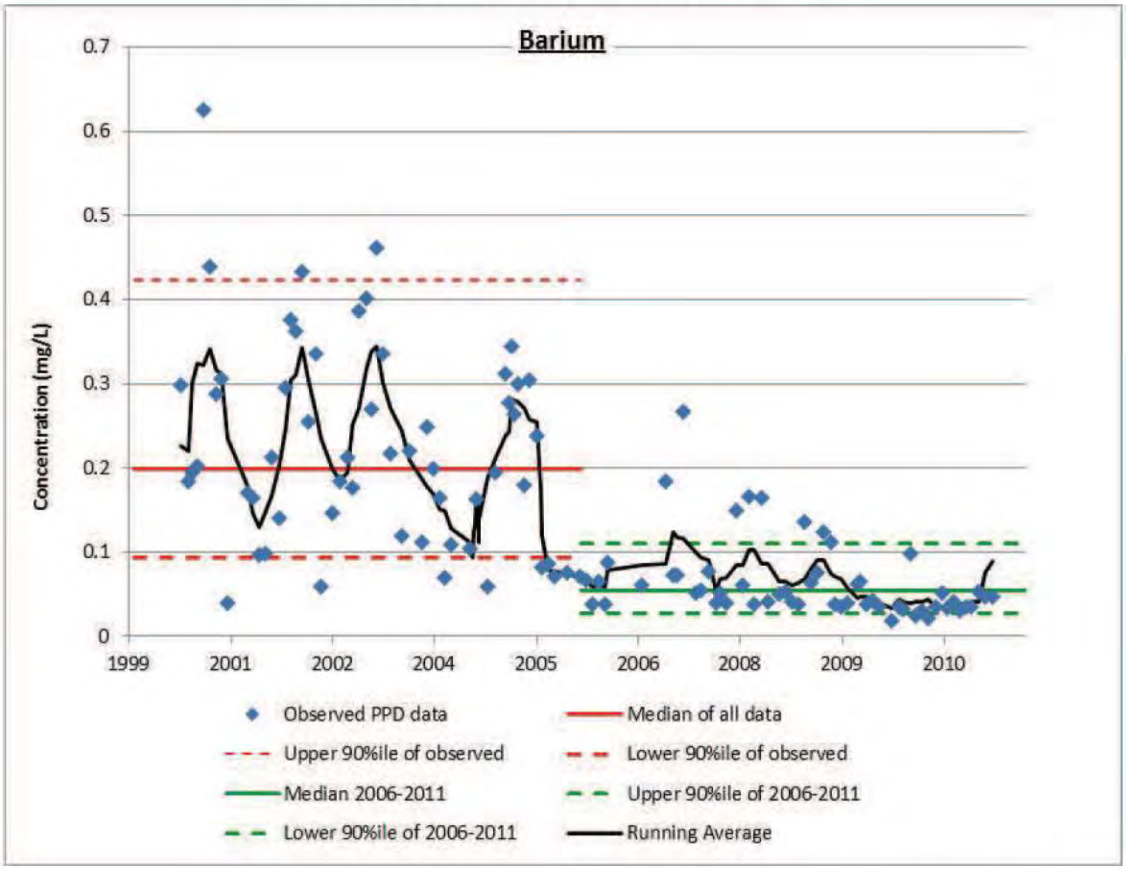
Comment on Model Fit to Observed Data

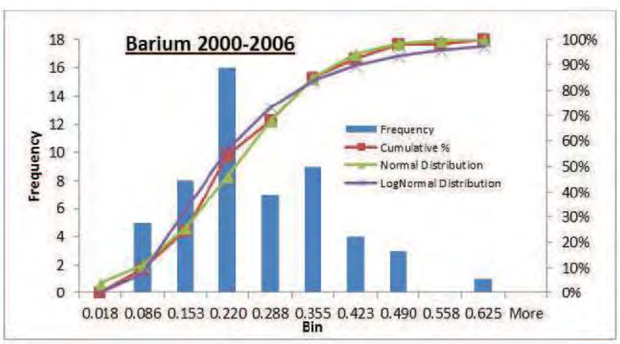
Reasonable calibration results, although model may slightly under predict observed concentrations.

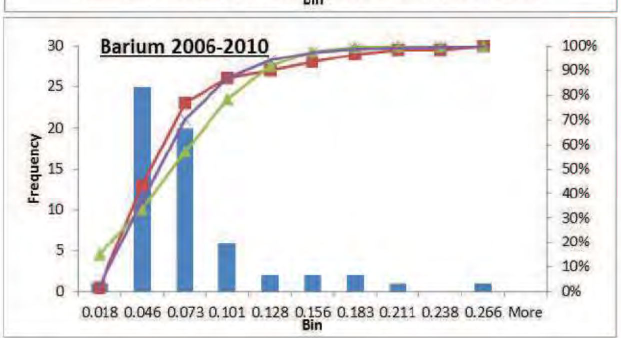
Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model







Comment on Historical Trends in PPD

High PPD concentrations post-2005, consistent with start of processing of underground ore.

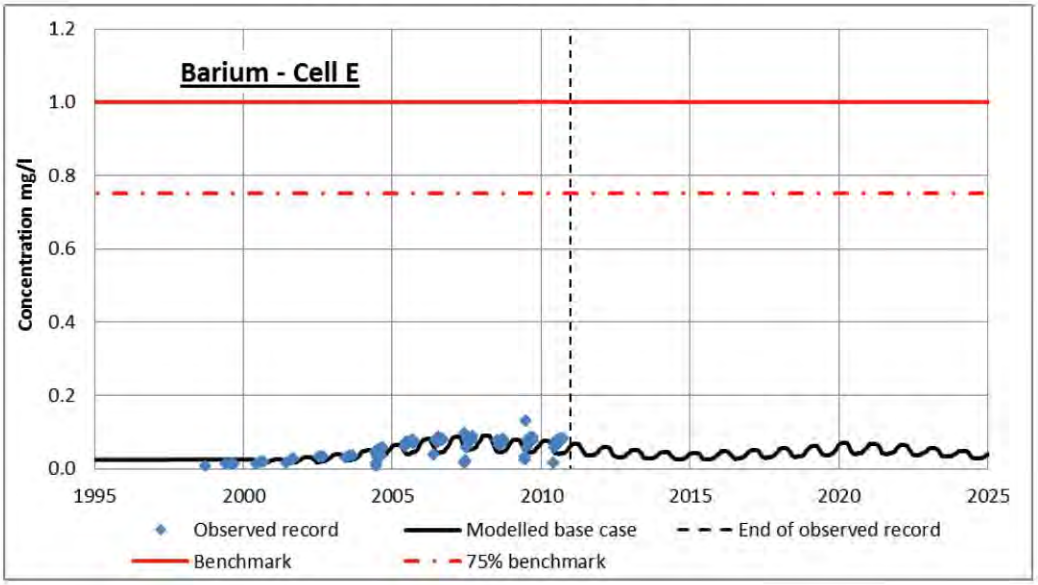
Modelling Approach for Future PPD

For 2011 to 2020 (except 2018), lognormal distribution used based on observed post-2006 data. For 2018, based on lognormal distribution for observed PPD data from 2000 to 2006 data.

Modelled Correlation between WQ Parameters

Barium is correlated with Antimony

Figure 2: Model Predictions for LLCF



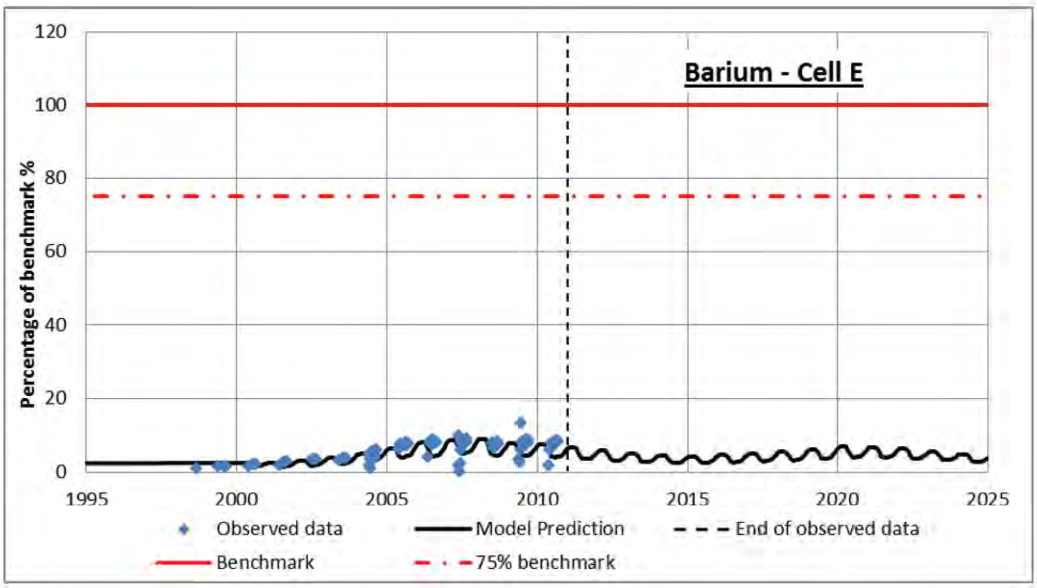


Figure 3: Predictions in Receiving Environment

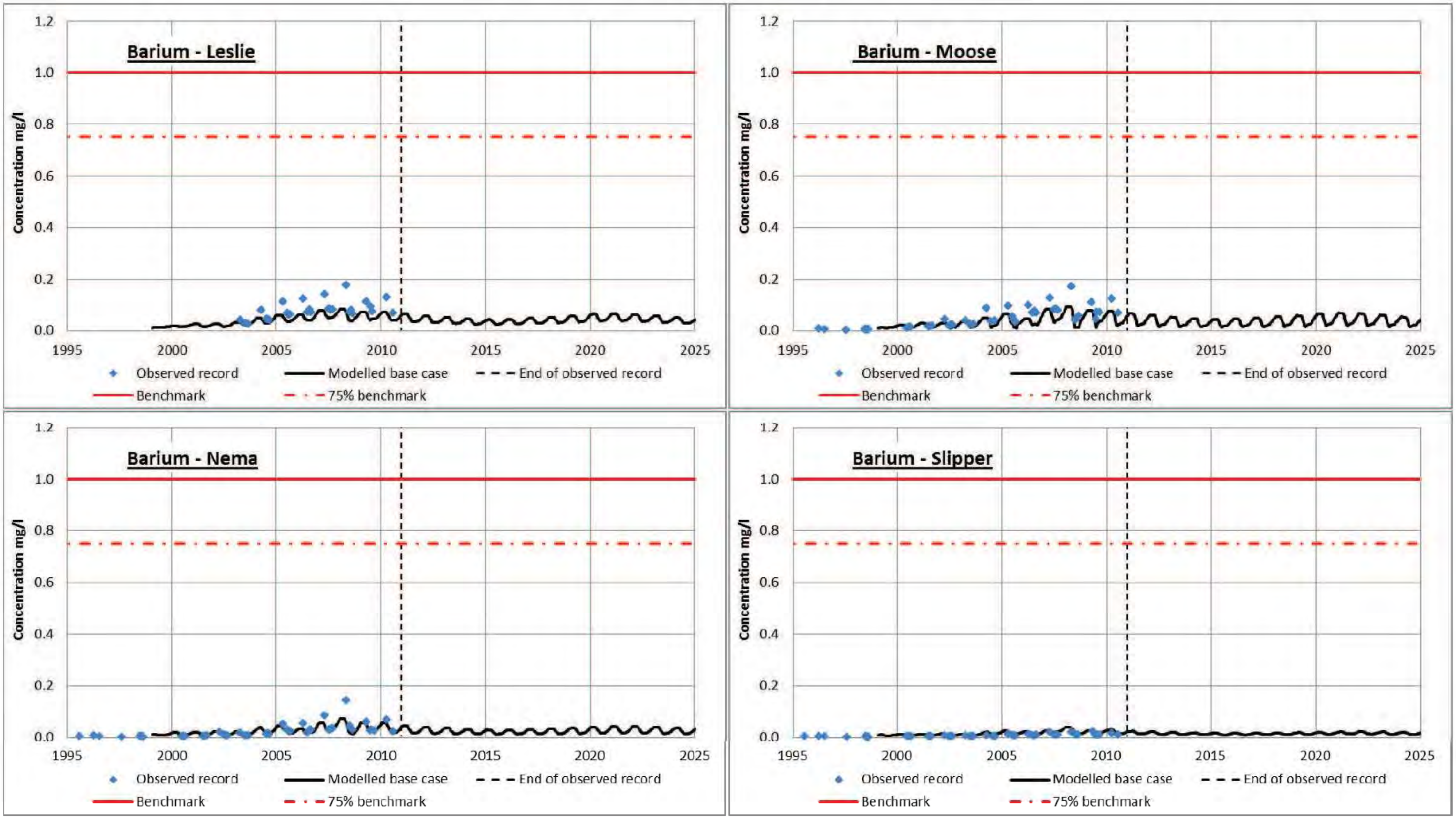
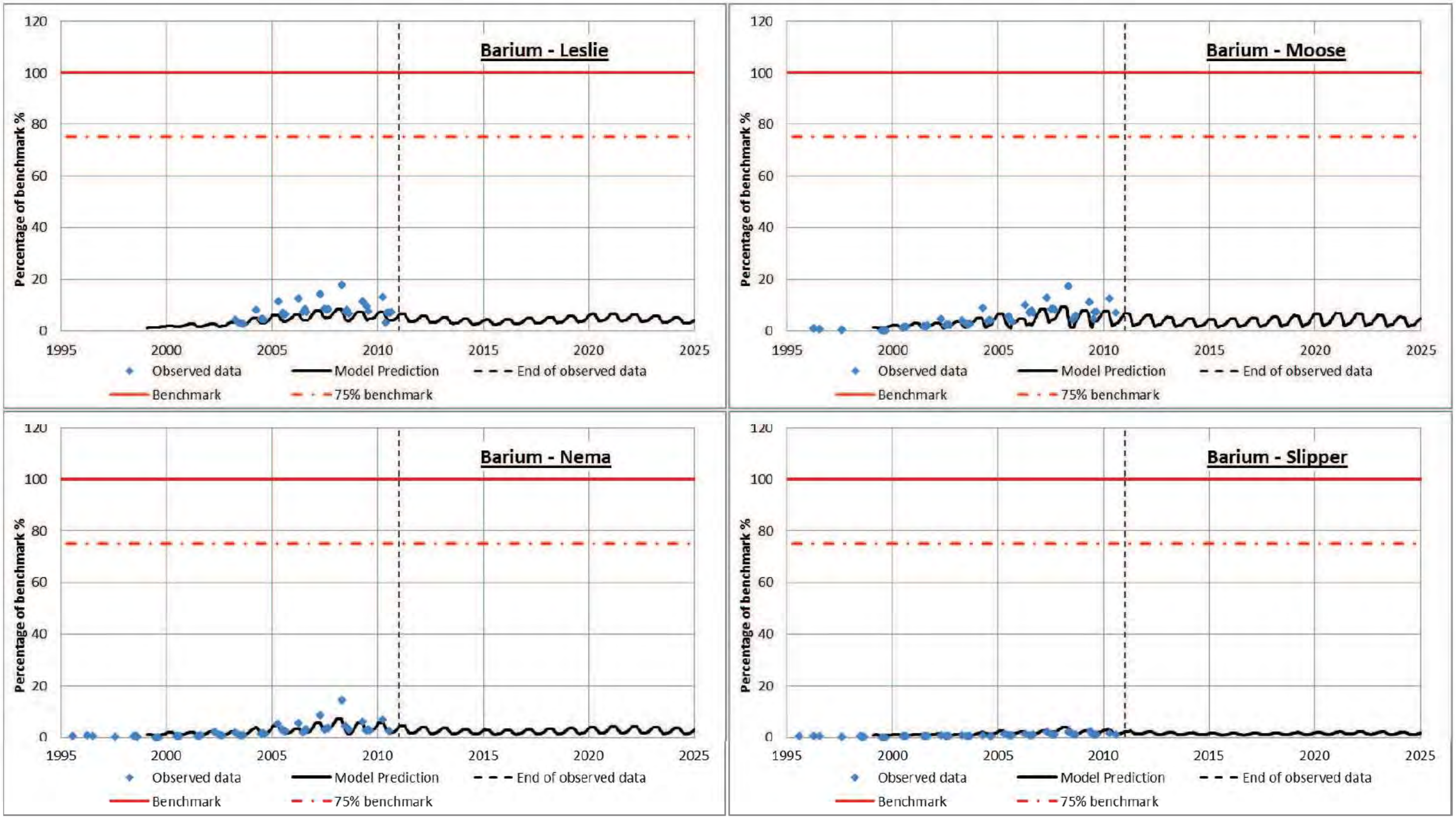


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Boron

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	83%	Process Plant	76%
Sump	6%	Sump	3%
Underground	8%	Underground	0%
Runoff	3%	Runoff	2%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	19%

Key Comments Related to Modelling Work

Historically the key loading for Boron is from the Process Plant discharge. Boron concentrations in the Process Plant discharge have shown a general increasing trend from 2006 to 2009/2010, although the concentrations may have peaked in 2009-2010.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

1.5 mg/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.0011	110	0.0575	4%	0.025	0.0038	0.0136	<1%

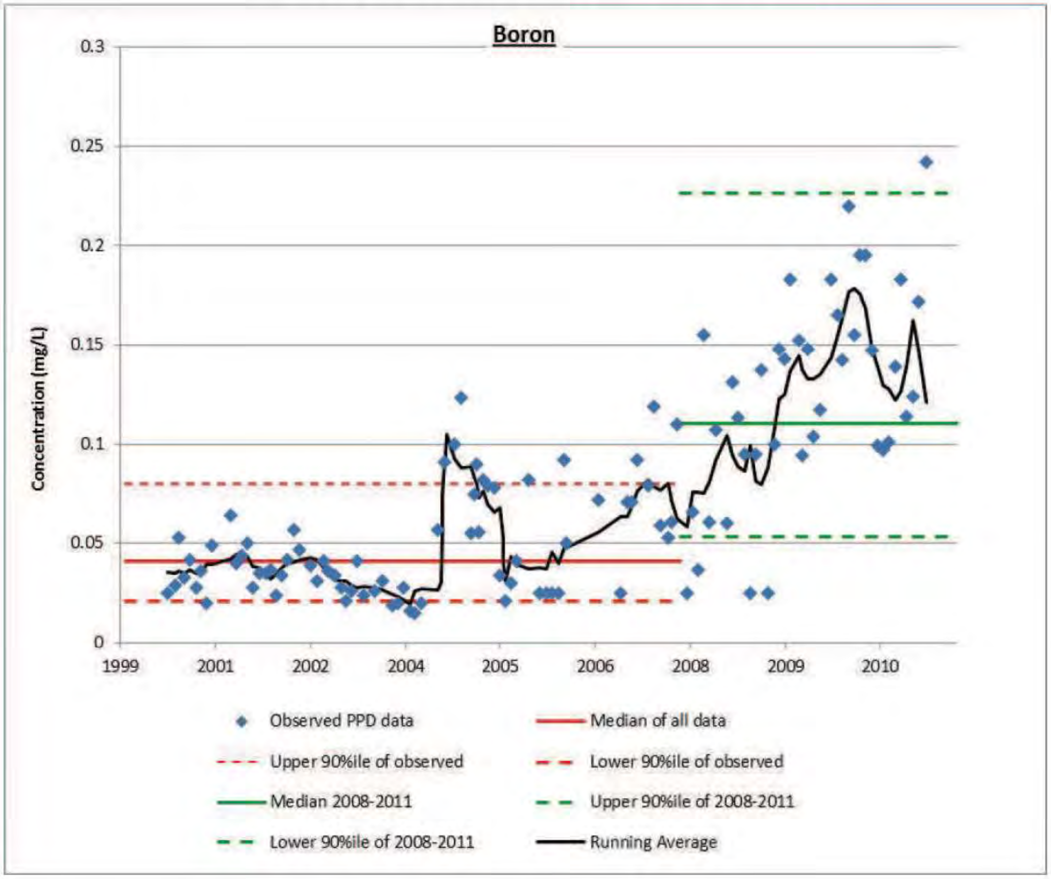
Comment on Model Fit to Observed Data

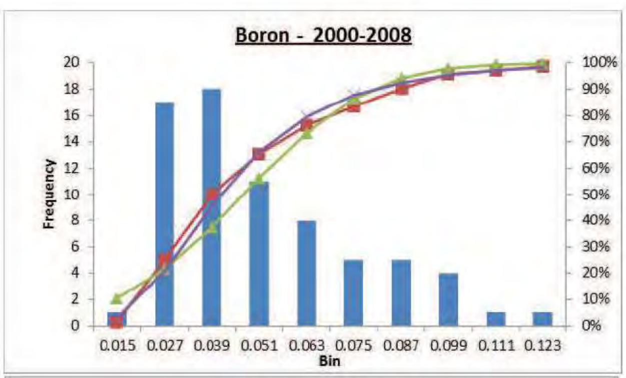
Good quality calibration with observed data.

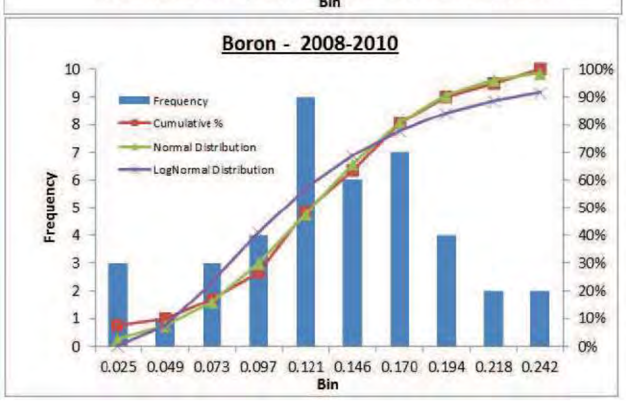
Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model







Comment on Historical Trends in PPD

Concentrations increase post-2008, and there may be an increasing trend over the period 2006 – 2009.

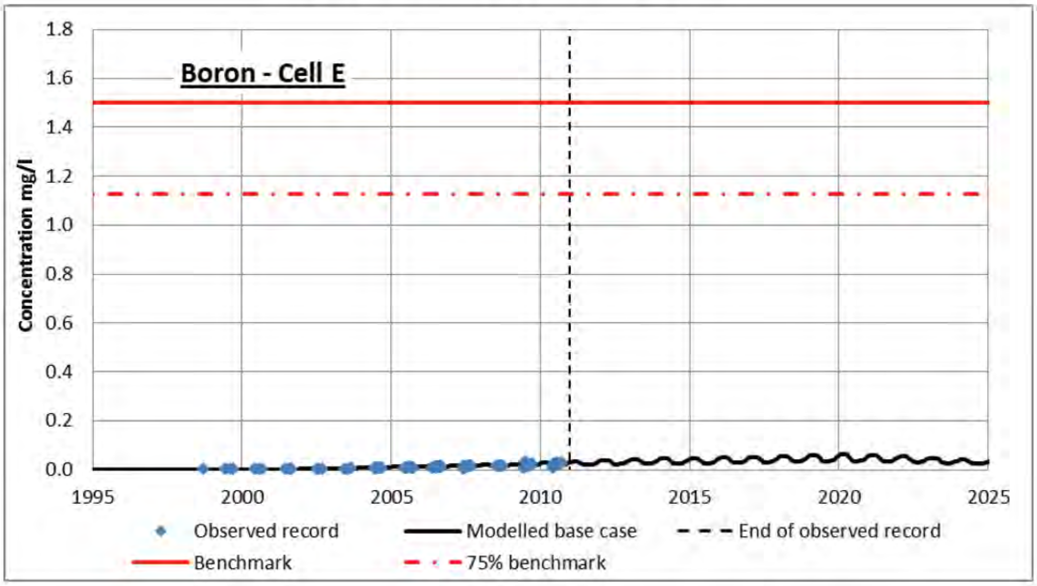
Modelling approach for Future PPD

Based on normal distribution of observed 2008-2010 PPD data.

Modelled Correlation between parameters

Boron is correlated to arsenic (0.65)

Figure 2: Model Predictions for LLCF



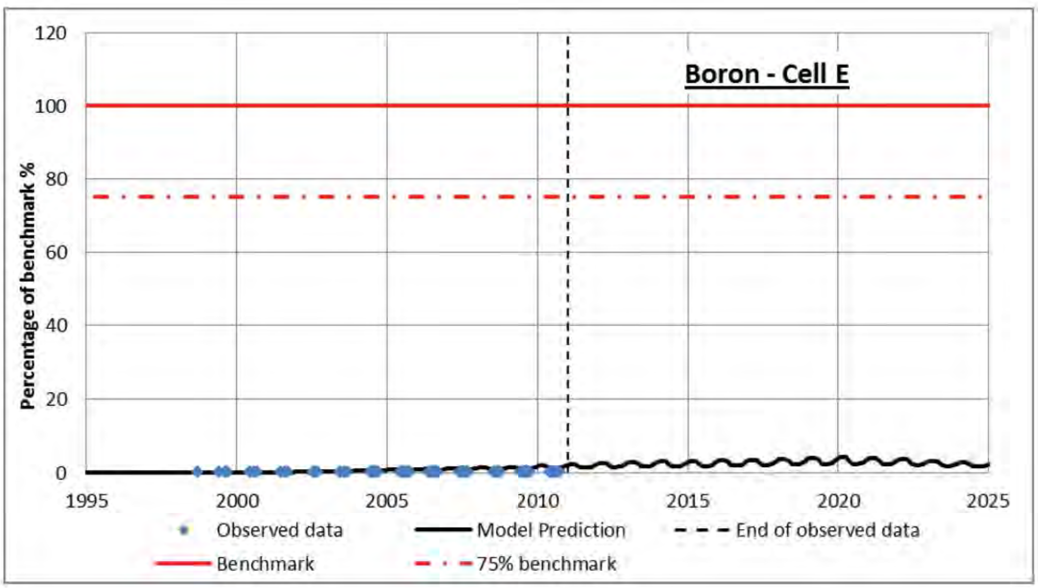


Figure 3: Predictions in Receiving Environment

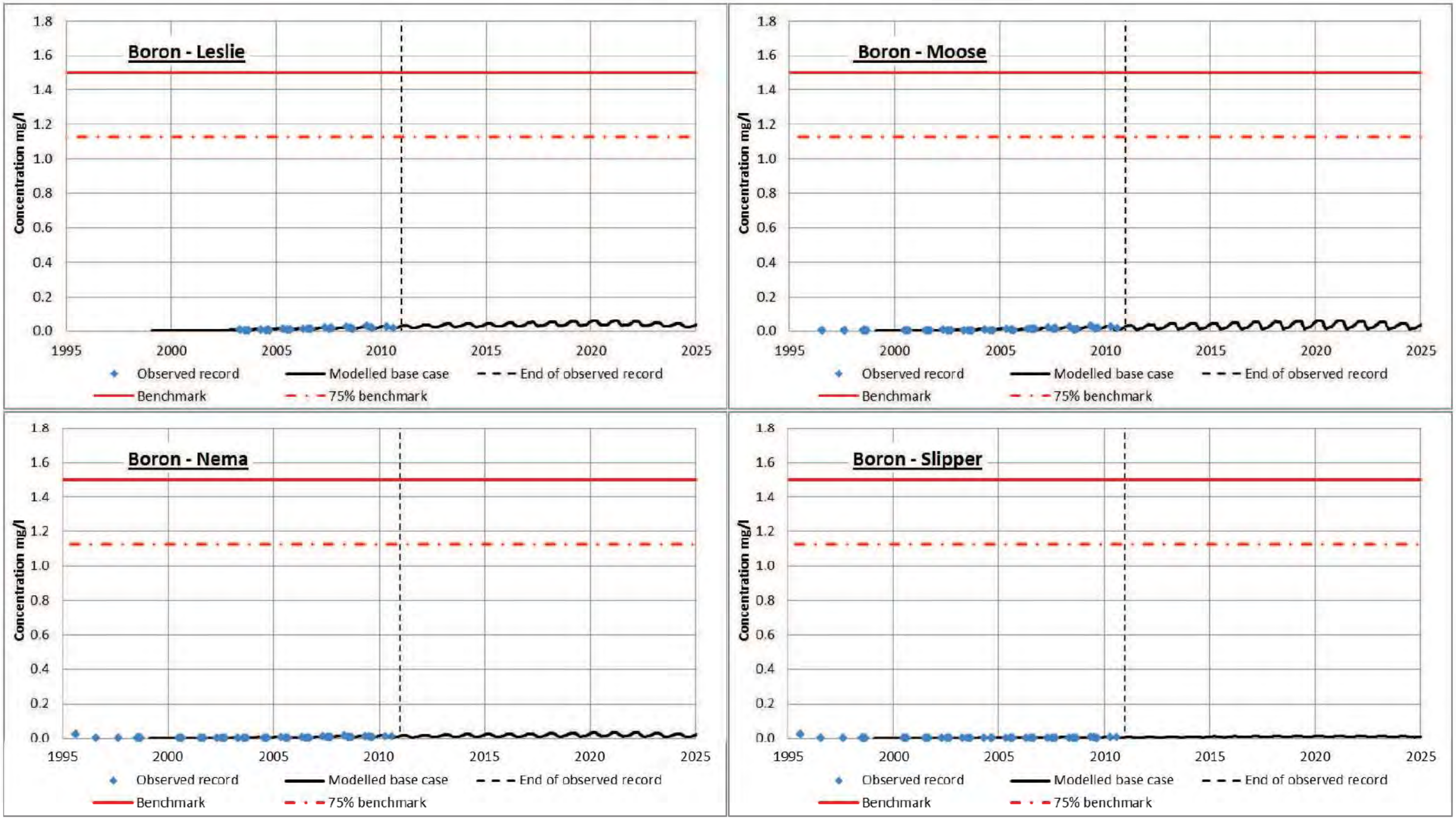
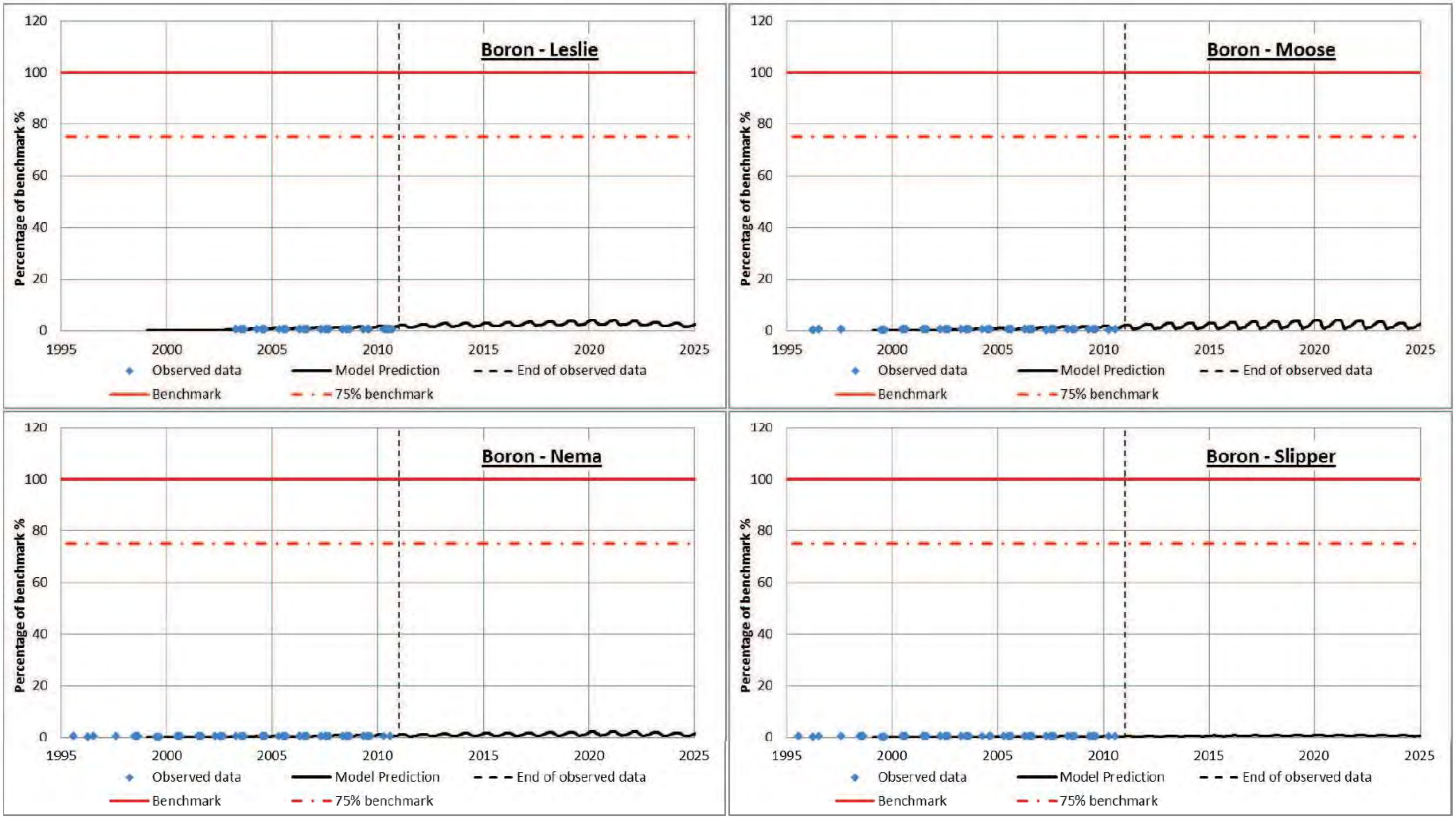


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Cadmium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	70%	Process Plant	48%
Sump	5%	Sump	4%
Underground	12%	Underground	0%
Runoff	13%	Runoff	21%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	27%

Key Comments Related to Modelling Work

Main loading to LLCF is from Process Plant discharge. Many observed Cadmium concentrations in the Process Plant discharge and sump are below detection limit which makes it difficult to develop reliable future predictions based on these data.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

Hardness dependent; $10^{(0.86(\log10(hardness))-3.2)}$ ug/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.0002	0.00009	0.000296	414%	0.0001	0.000018	0.0000953	460%

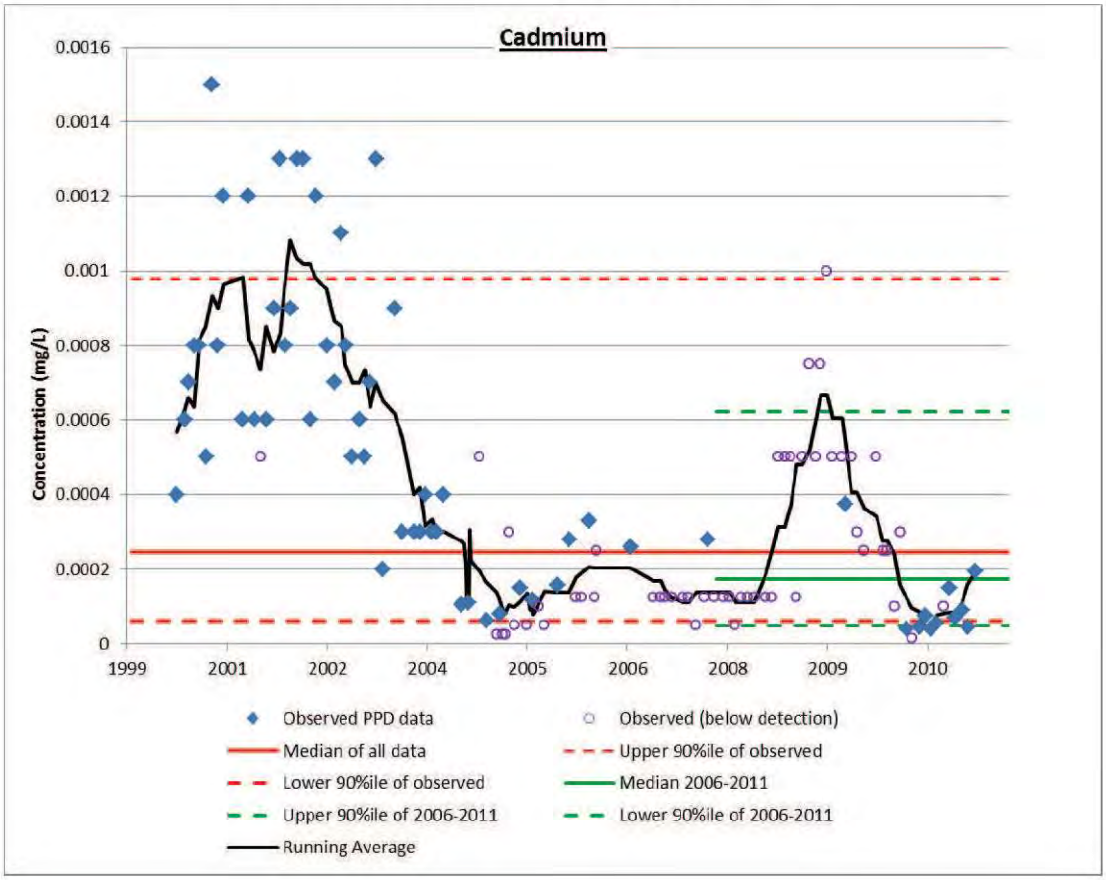
Comment on Model Fit to Observed Data

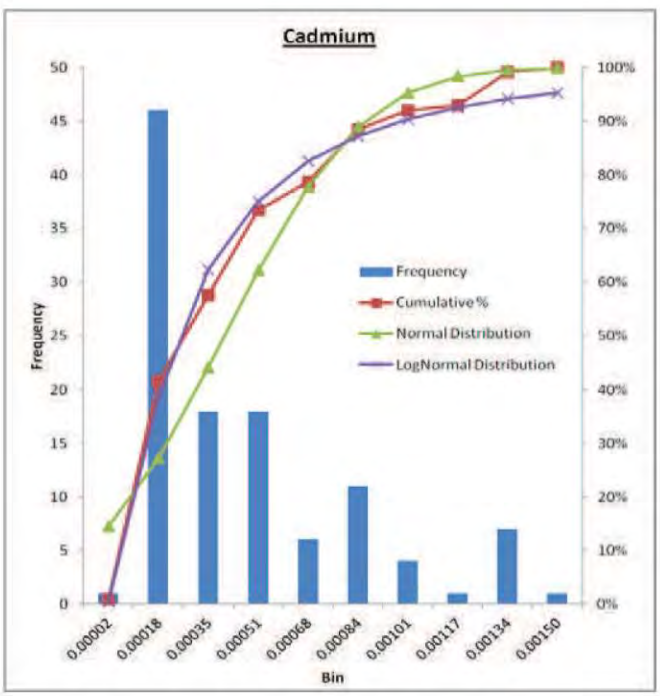
Model over-predicts observed concentrations, likely as many inputs and observed data are below detection limits.

Summary

Historical concentrations and model predictions for downstream lakes are significantly above the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Decrease in PPD concentrations to 2003/2004; then more consistent and low concentrations. After 2006, many PPD concentrations are blow detection limit, making it difficult to identify clear a clear trend.

Modelling Approach for Future PPD

Based on lognormal distribution of all observed PPD data.

Modelled Correlation between Parameters

Cadmium is correlated to Molybdenum

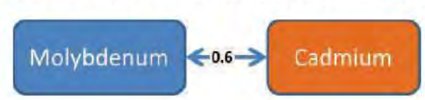
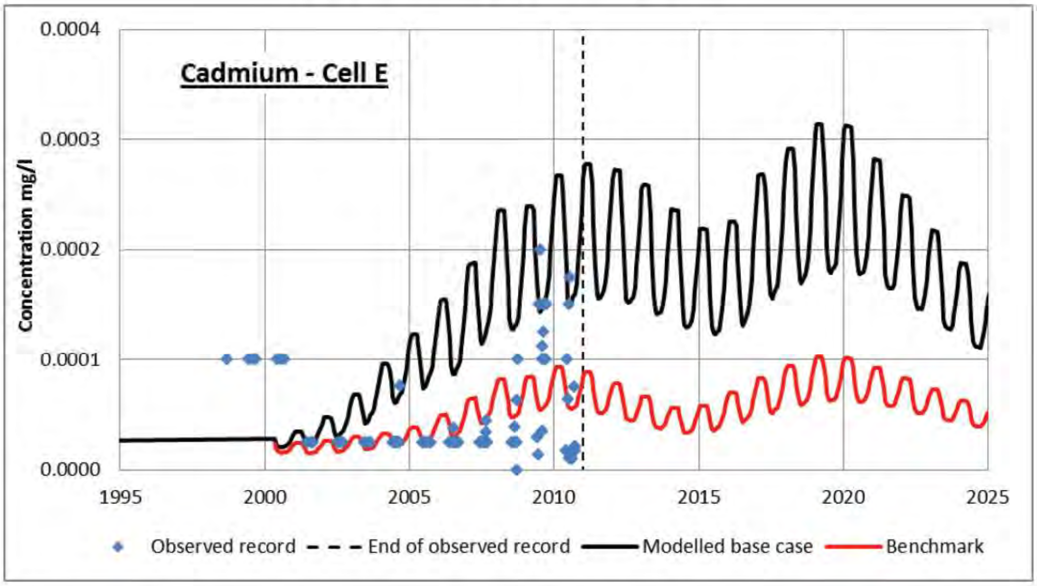


Figure 2: Model Predictions for LLCF



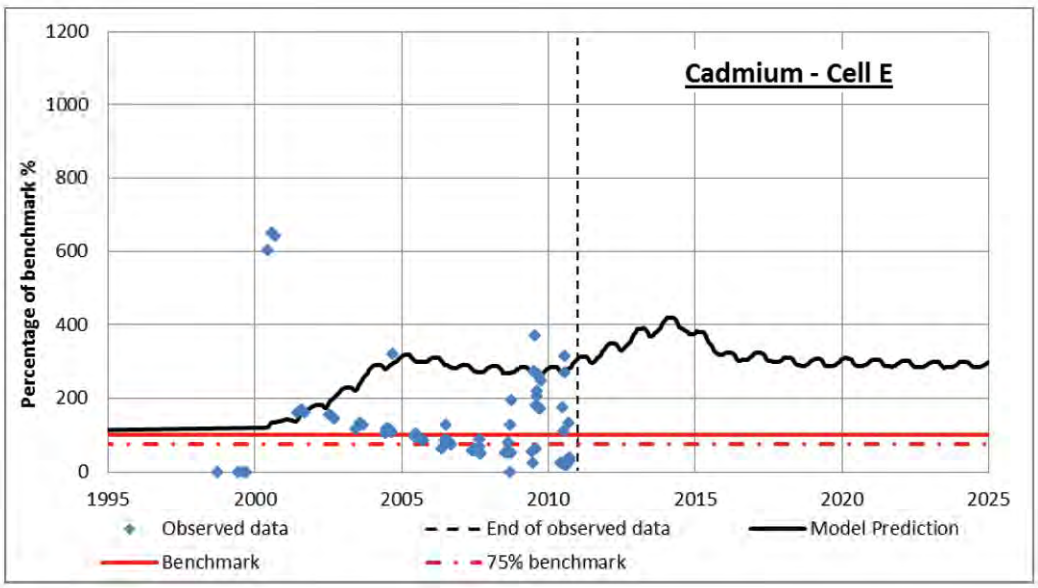


Figure 3: Predictions in Receiving Environment

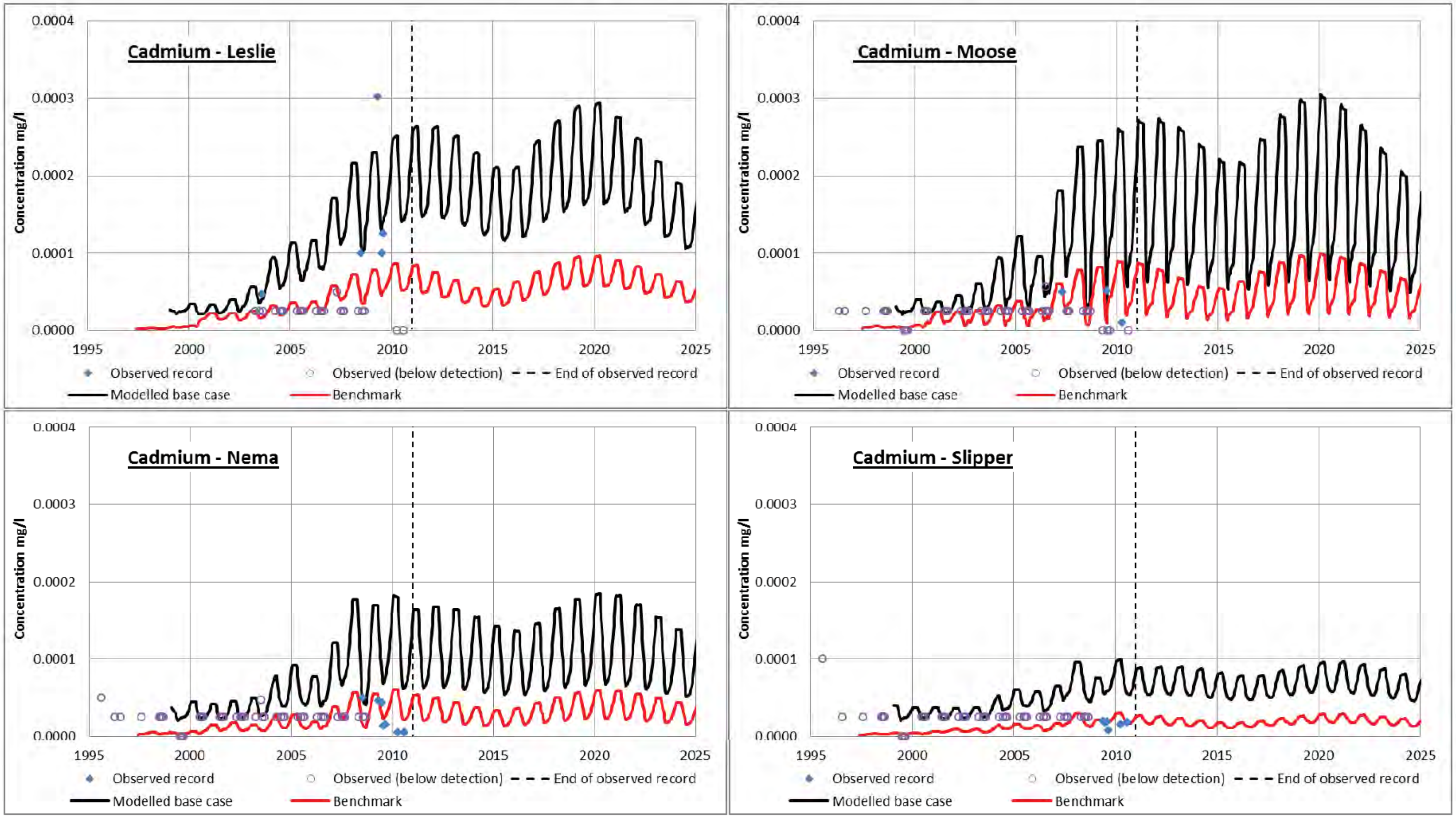
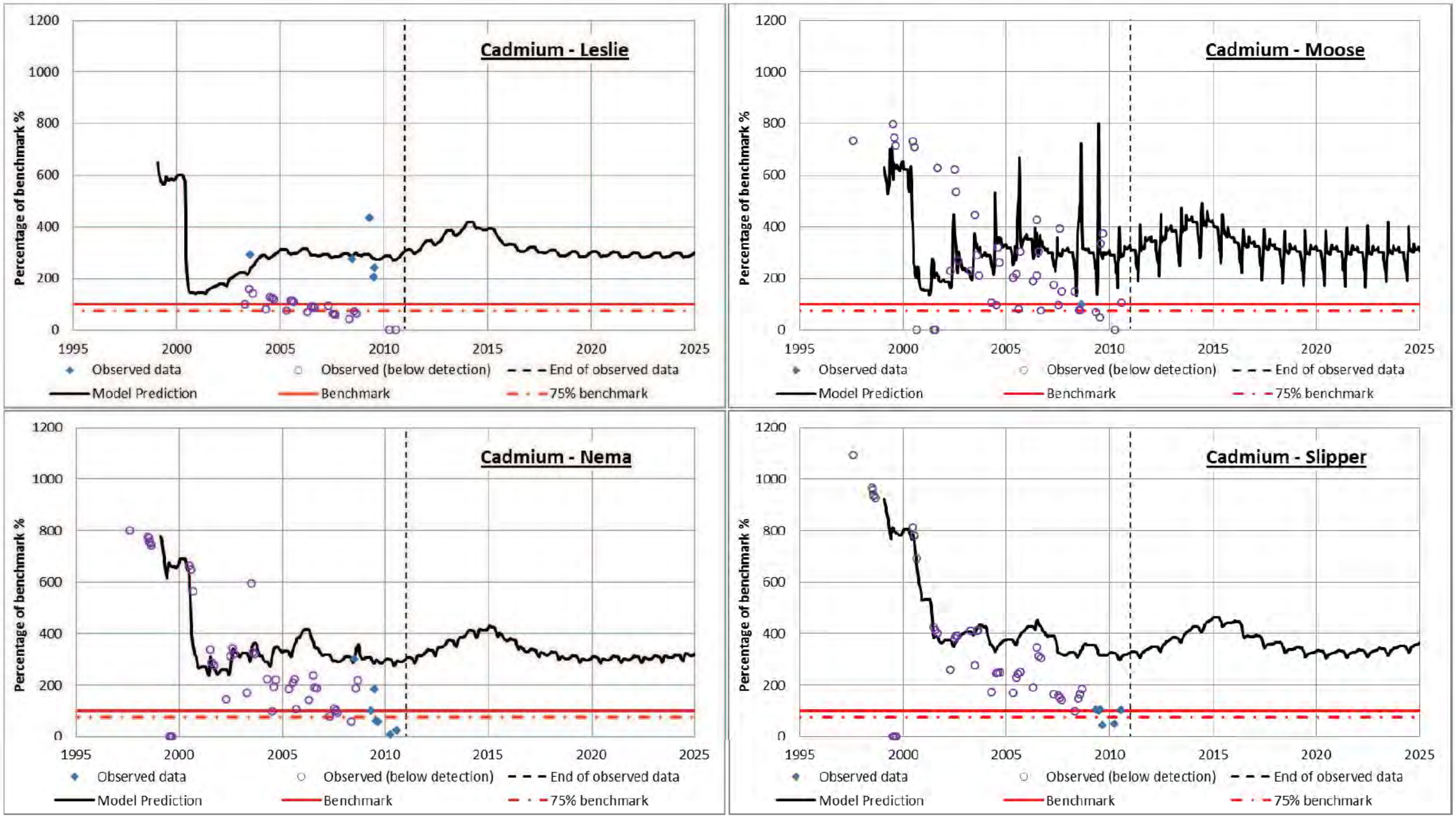


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Calcium

Sources of Parameter in LLCF

Historical 2000 – end 2010

Process Plant	8%
Sump	9%
Underground	82%
Runoff	1%
Beartooth Pit Reclaim	0%

Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)

Process Plant	4%
Sump	8%
Underground	0%
Runoff	1%
Beartooth Pit Reclaim	87%

Key Comments Related to Modelling Work

Shift of main loading from underground water to Process Plant following discharge of underground water to Beartooth. Important parameter for calculation of Hardness.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

None proposed

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
49	21	106..4	-	9.8	4.2	23.1	-

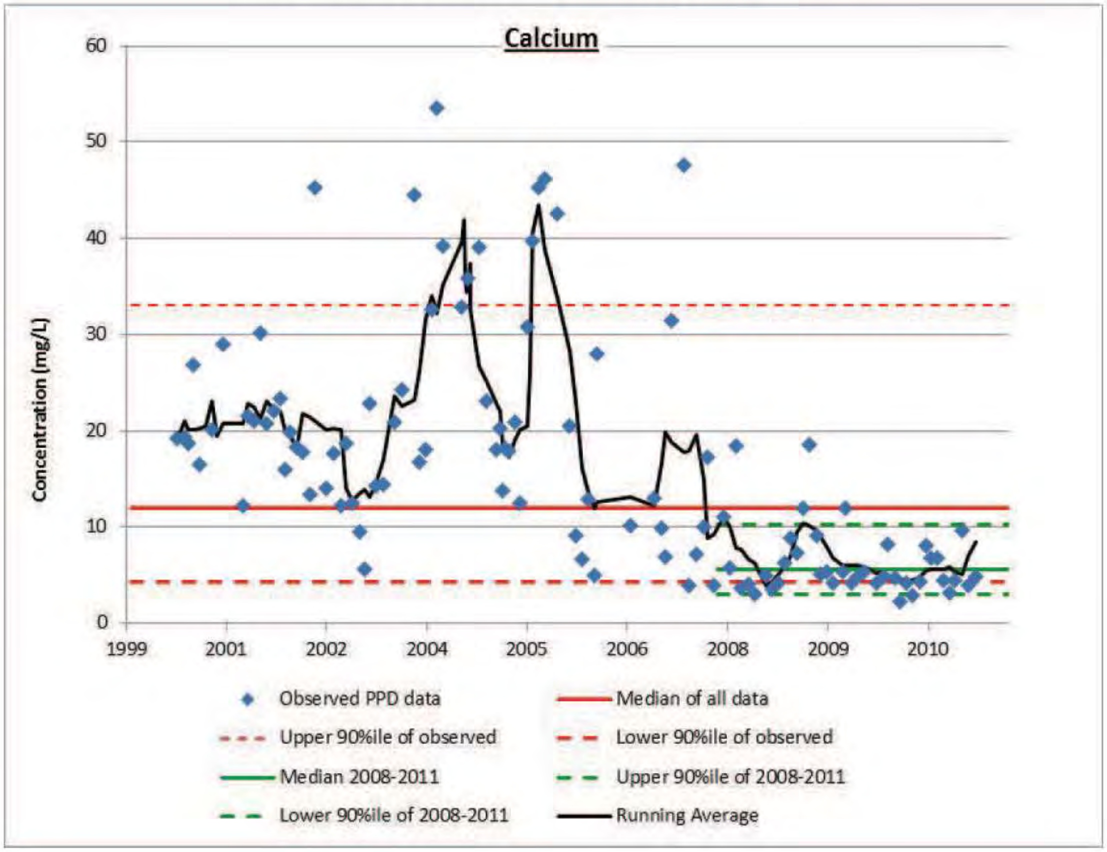
Comment on Model Fit to Observed Data

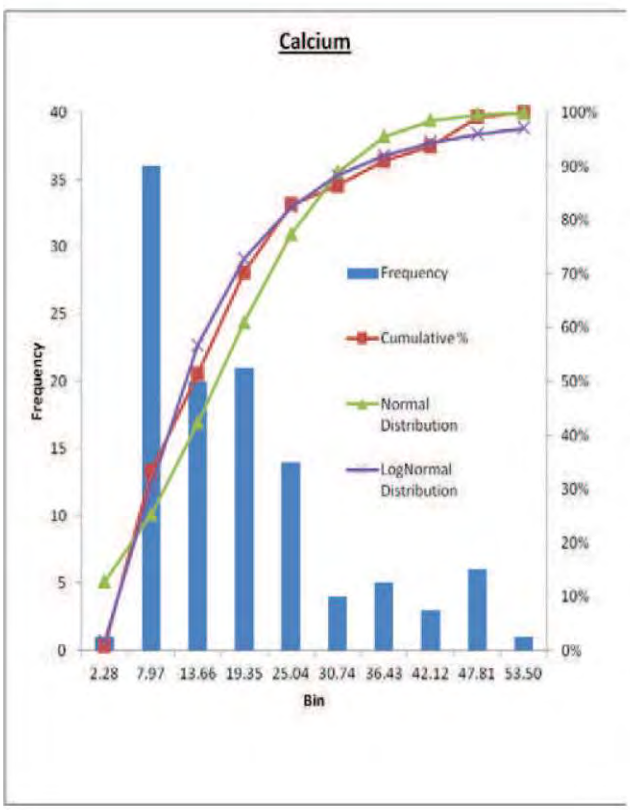
Good fit between predicted and observed data in all lakes, with model over-predicting in Cell E.

Summary

No benchmark proposed.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Concentrations decrease post 2008, with lower spread of data

Modelling Approach for Future PPD

2011 to 2020 (except 2018), normal distribution based on observed post-2008 data. For 2018, based on normal distribution for observed from 2000 to 2008 data.

Modelled Correlation Between Parameters

Calcium correlates with magnesium and strontium

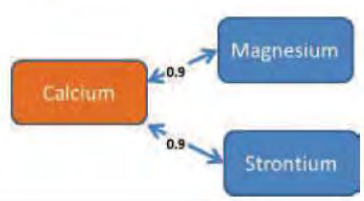


Figure 2: Model Predictions for LLCF

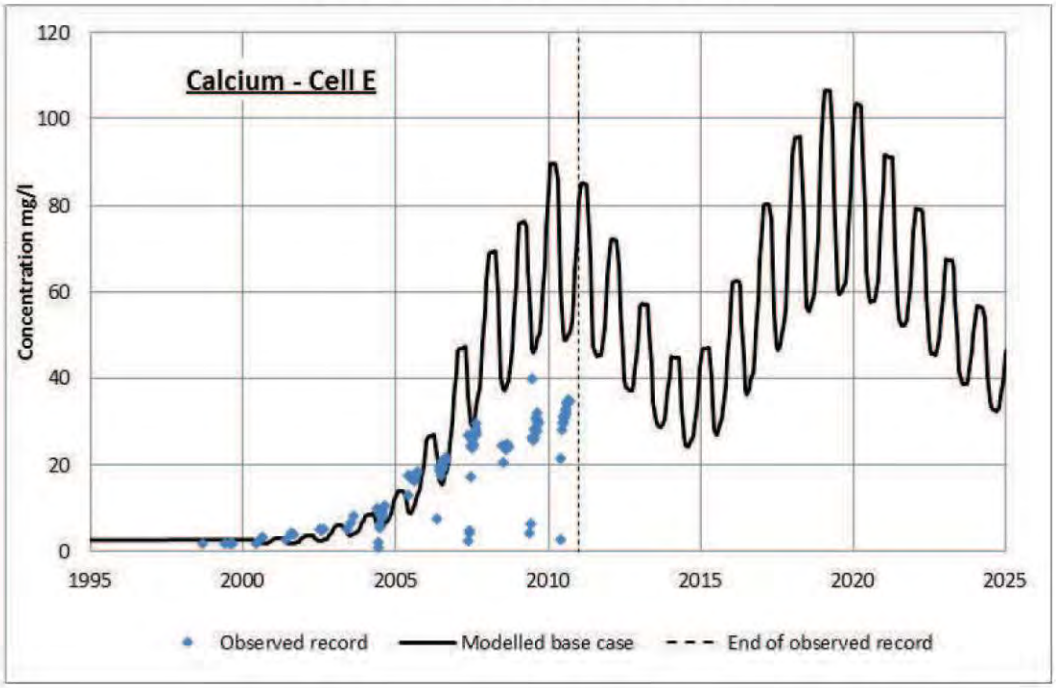
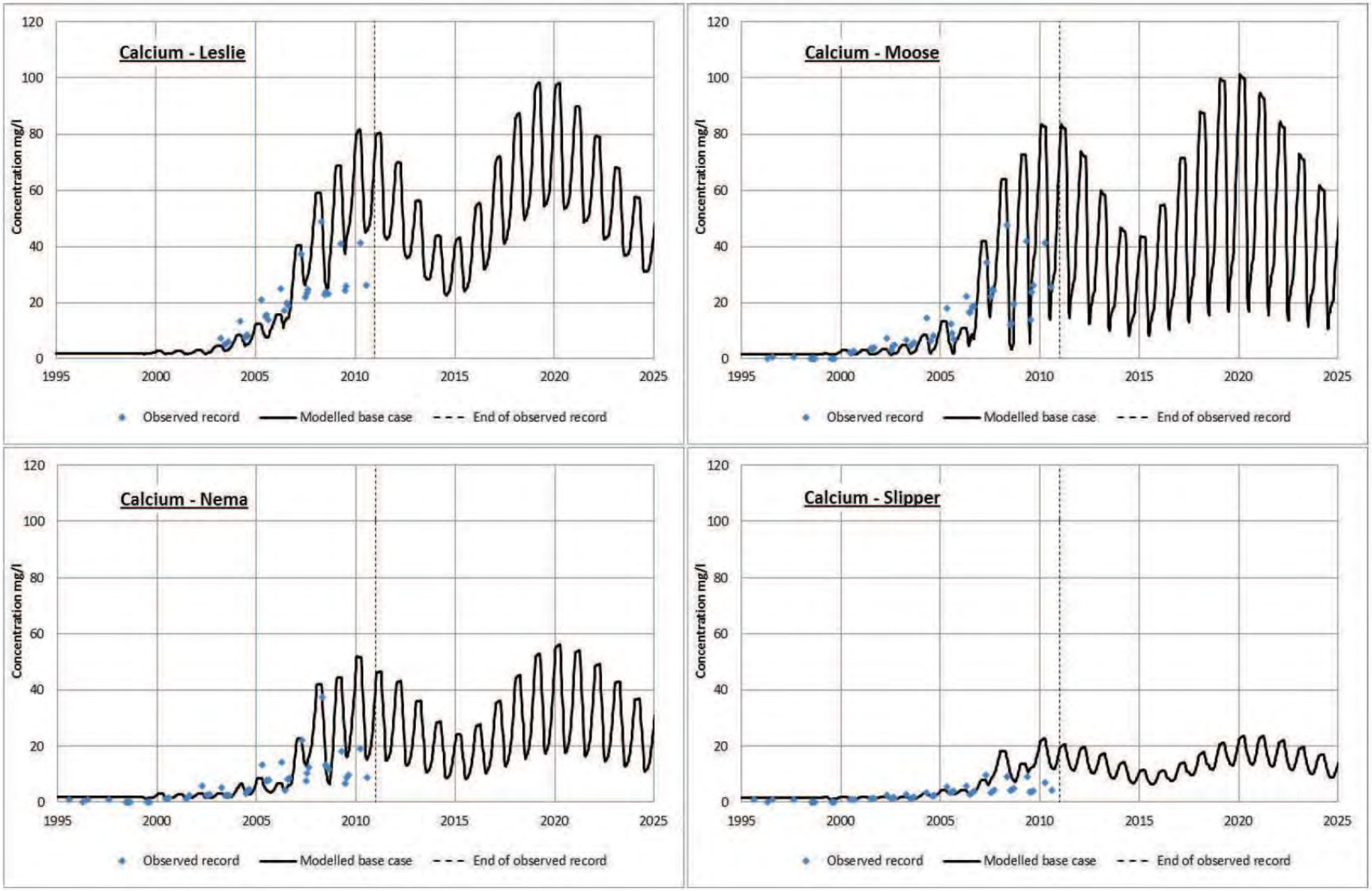


Figure 3: Predictions in Receiving Environment



Chloride

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	22%	Process Plant	20%
Sump	12%	Sump	9%
Underground	66%	Underground	0%
Runoff	0%	Runoff	0%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	71%

Key Comments Related to Modelling Work

Historically the key loading for Chloride has been underground water. However, the Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. At present (2011) the main loading of Chloride is from the Process Plant discharge. Going forward, once Beartooth pit is filled, excess water from the pit will need to be decanted and used in the process Plant as reclaim water. Hence, Chloride loadings stored in Beartooth pit will enter the LLCF with the Process Plant discharge at that time causing the peak in Chloride concentrations in the LLCF and downstream lakes predicted for 2019/2020.

Water Quality Benchmark

116.6 x ln(hardness) - 204.1 mg/L, relationship is limited to hardness range up to 160 mg/L. (Site Specific WQO)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
140	110	383	99%	24.5	12	85.8	28%

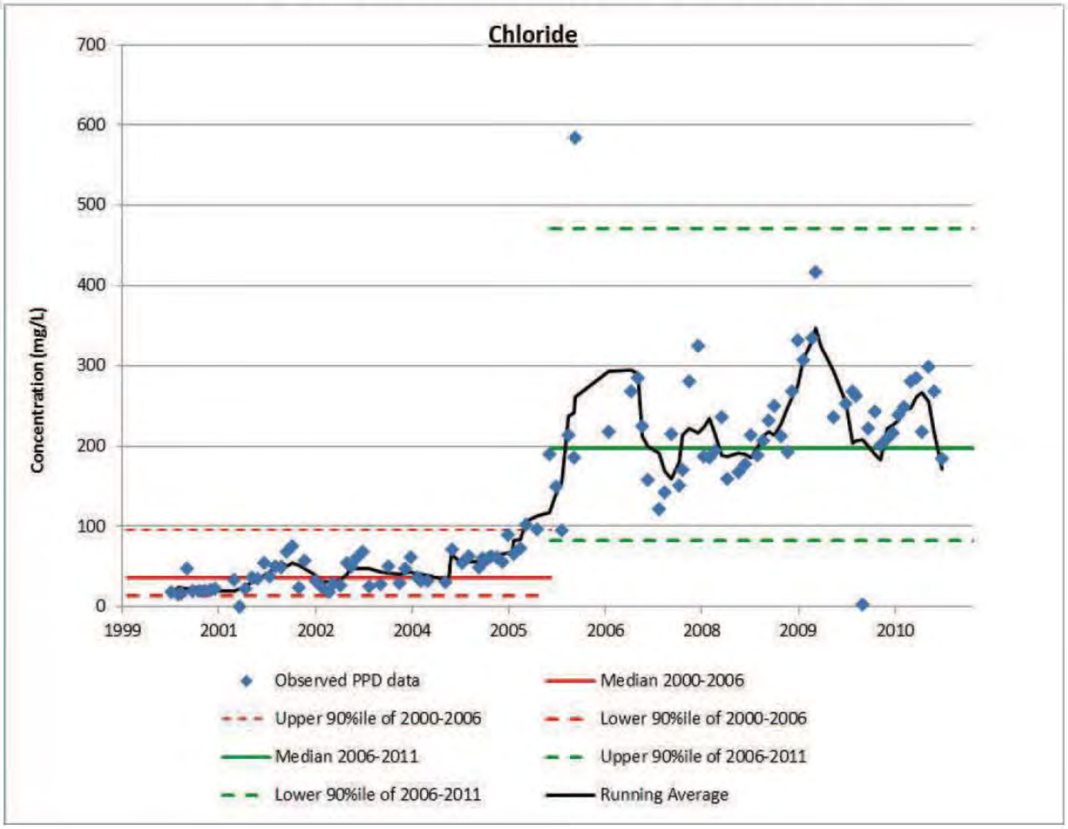
Comment on Model Fit to Observed Data

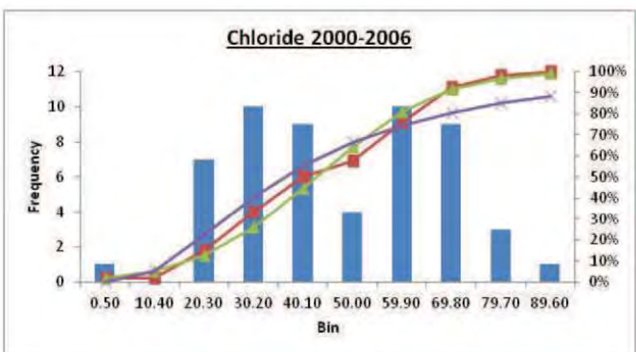
Good quality calibration with observed data, although model over-predicts observed concentrations slightly.

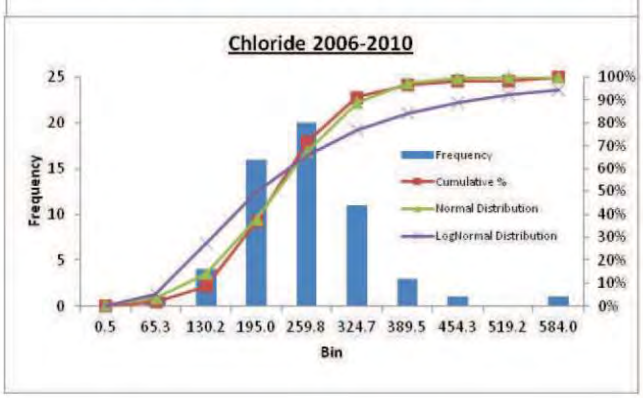
Summary

Historical concentrations for downstream lakes have not exceeded the benchmark. The model predicts concentrations for Leslie and Moose lakes do not exceed the benchmark, but do exceed 75% of the benchmark within the lifetime of the mine. For Nema and Slipper lakes future concentrations are predicted to remain below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model







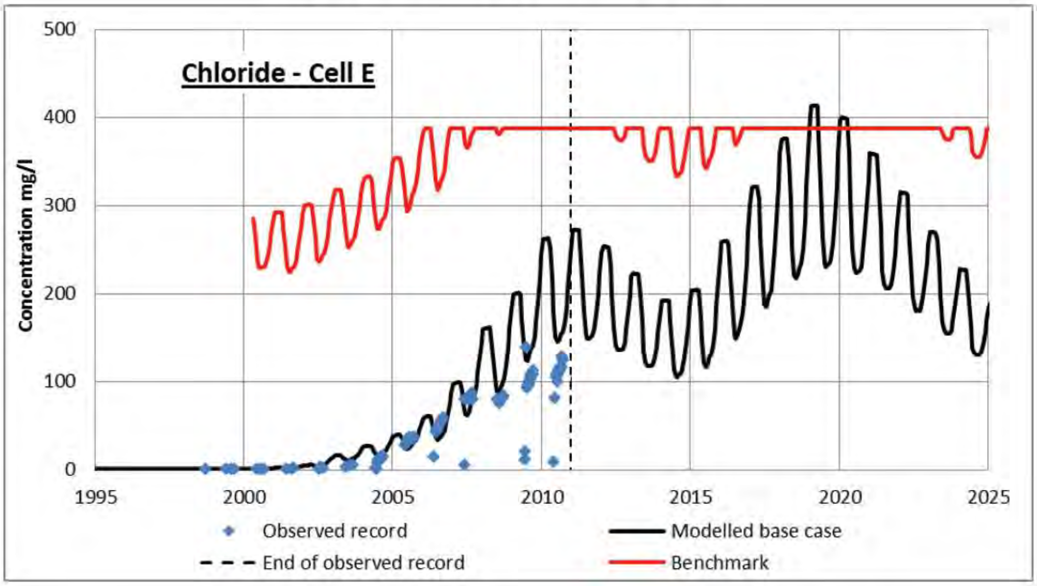
Comment on Historical Trends in PPD

Period of high concentrations observed in PPD from 2006 to 2008, with lower concentrations before and after this period.

Modelling Approach for Future PPD

Based on lognormal distribution of all 2006-2011 observed PPD data.

Figure 2: Model Predictions for LLCF



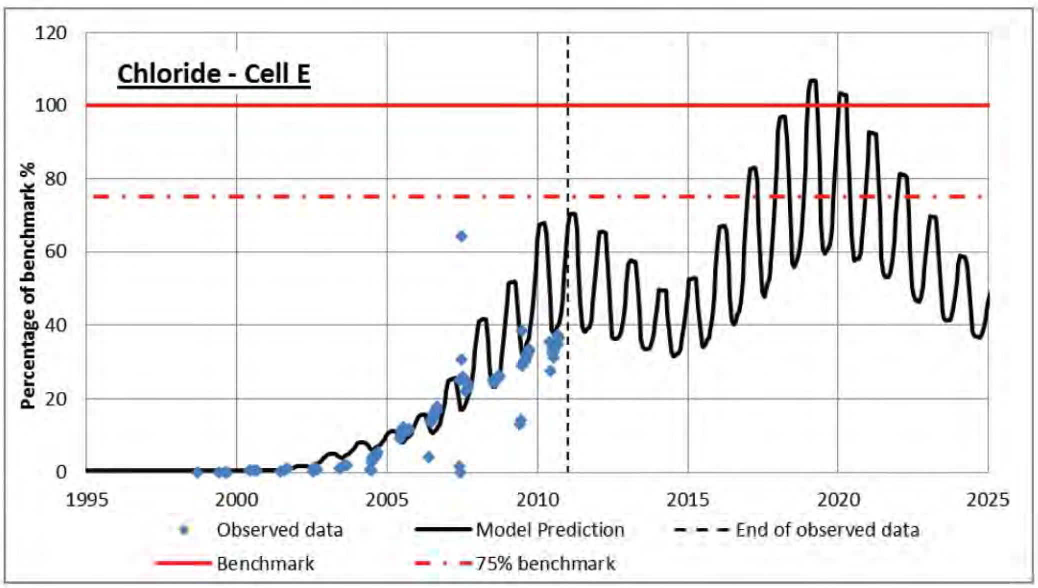


Figure 3: Predictions in Receiving Environment

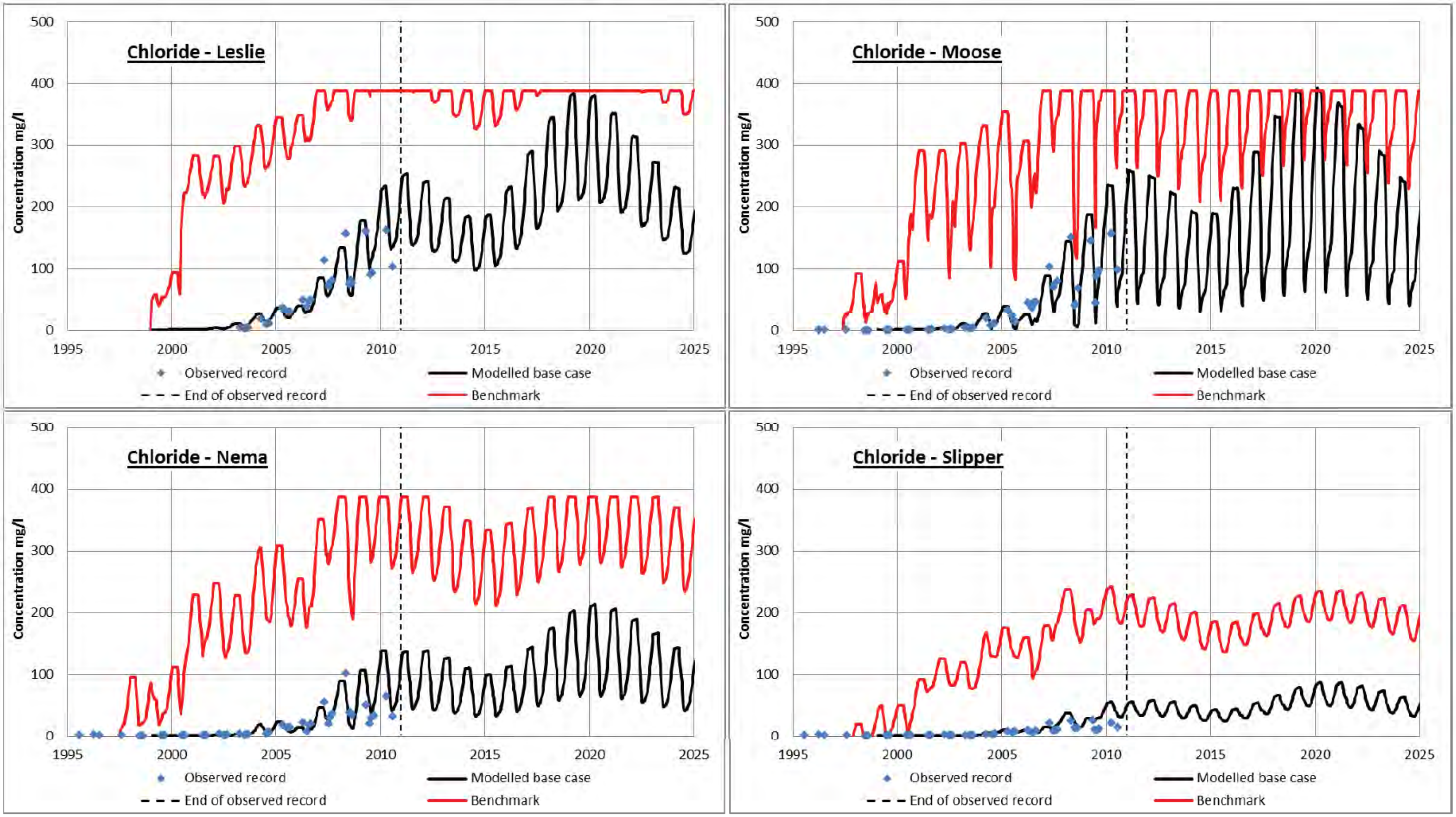
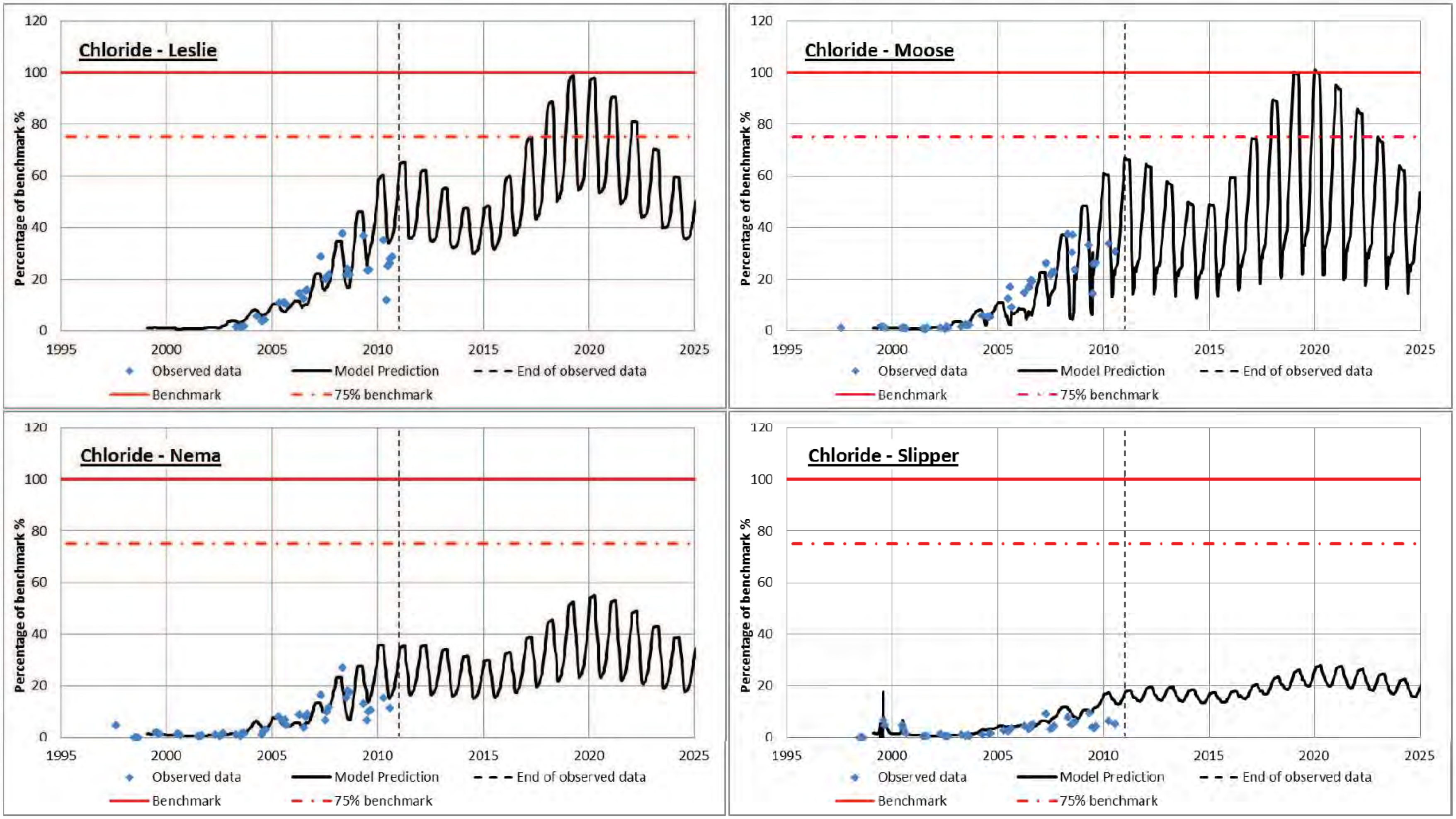


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Chromium

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	49%	Process Plant	26%
Sump	11%	Sump	17%
Underground	24%	Underground	0%
Runoff	16%	Runoff	20%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	37%

Key Comments Related to Modelling Work

Main loading to LLCF is from the Process Plant Discharge, although there are significant inputs from other sources. Many Process Plant discharge observed concentrations are less than detection limit, reducing the accuracy of predictions.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.0089 mg/L for Cr(III) (CCME guideline)

0.001 mg/L for Cr(VI) (CCME guidelines)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
Cr(III) 0.0007	Cr(III) 0.000055	Cr(III) 0.000284	Cr(III) 3%	Cr(III) 0.0011	Cr(III) 0.00021	Cr(III) 0.000218	Cr(III) 2%
Cr(VI) 0.0025	Cr(VI) 0.00020	Cr(VI) 0.00101	Cr(VI) 101%	Cr(VI) 0.0015	Cr(VI) 0.00030	Cr(VI) 0.000314	Cr(VI) 31%

Comment on Model Fit to Observed Data

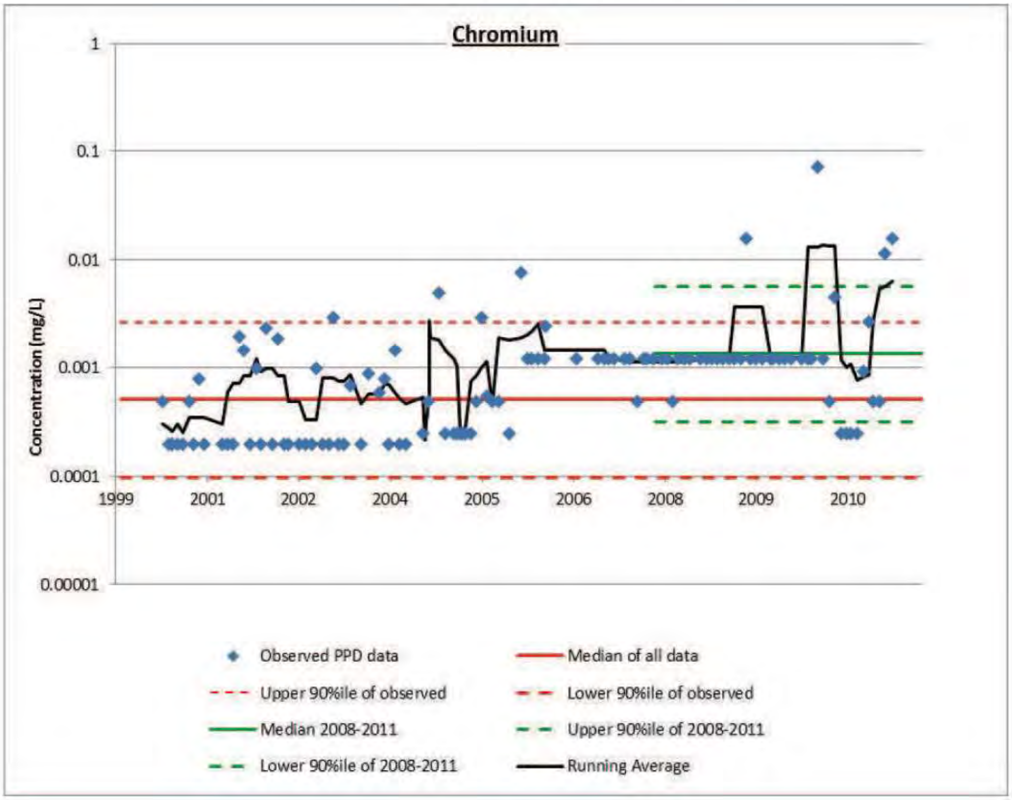
Good fit to observed Chromium data.

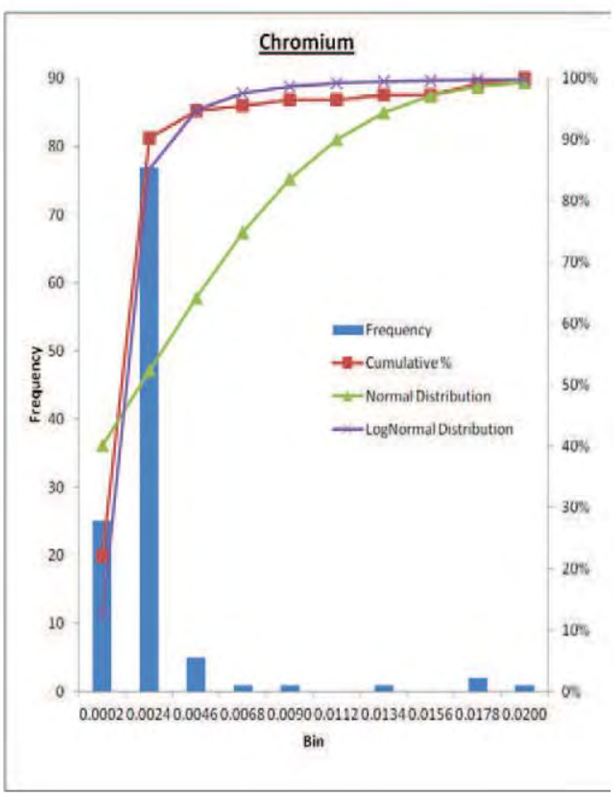
Summary

All predictions for Chromium (III) are below the benchmark.

Model predicts Chromium (VI) concentrations in Leslie Lake above the benchmark and concentrations in Moose Lake predicted to exceed 75% of the benchmark limit. Predicted concentrations of Chromium (VI) in Nema and Slipper lake are below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Most samples are below detection limit. Hence, it is difficult to determine any trend in the data.

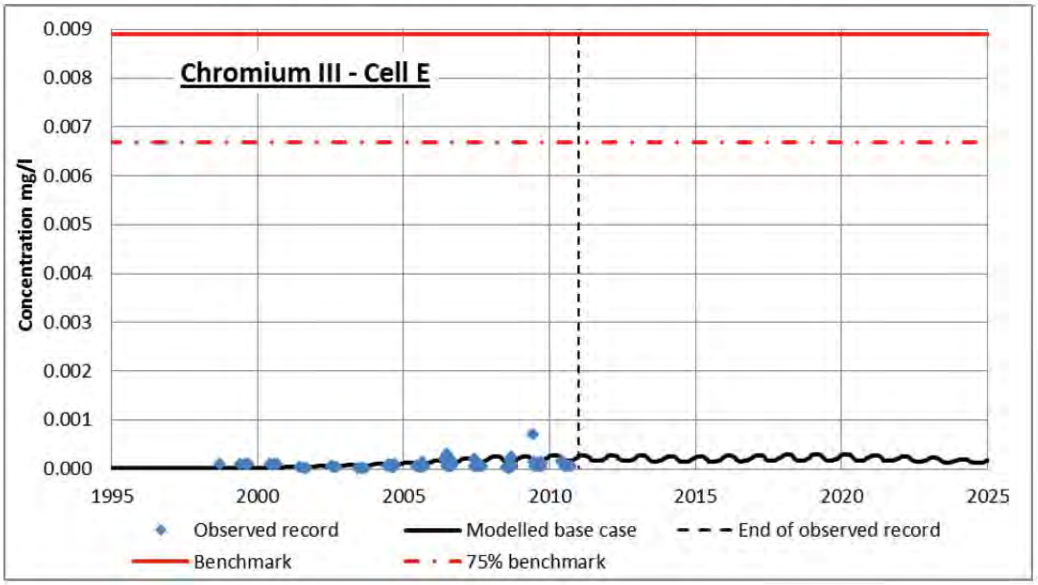
Modelling Approach for Future PPD

Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters

Chromium is correlated to aluminium (1.0)

Figure 2: Model Predictions for LLCF - Chromium III



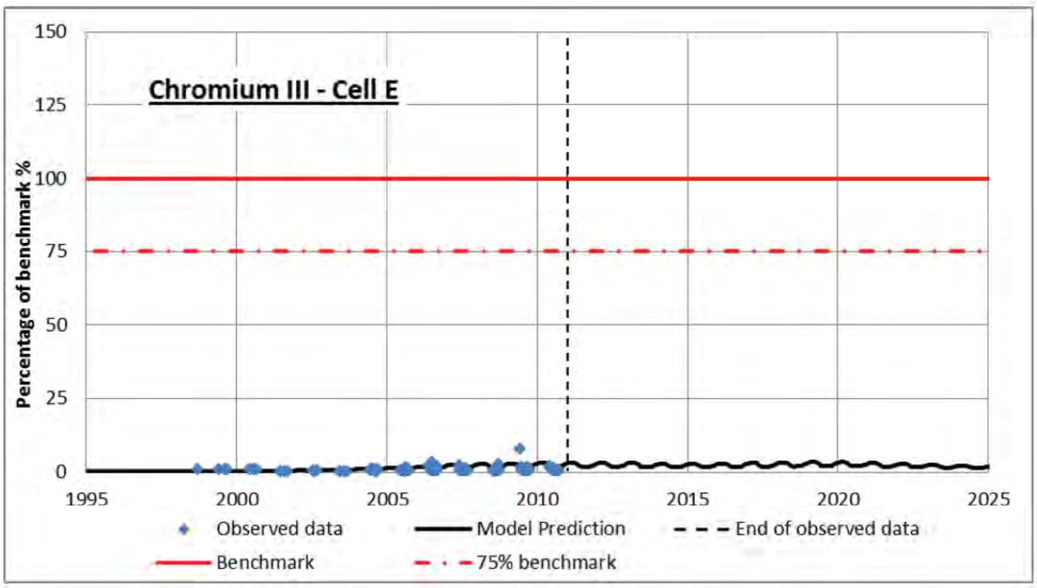
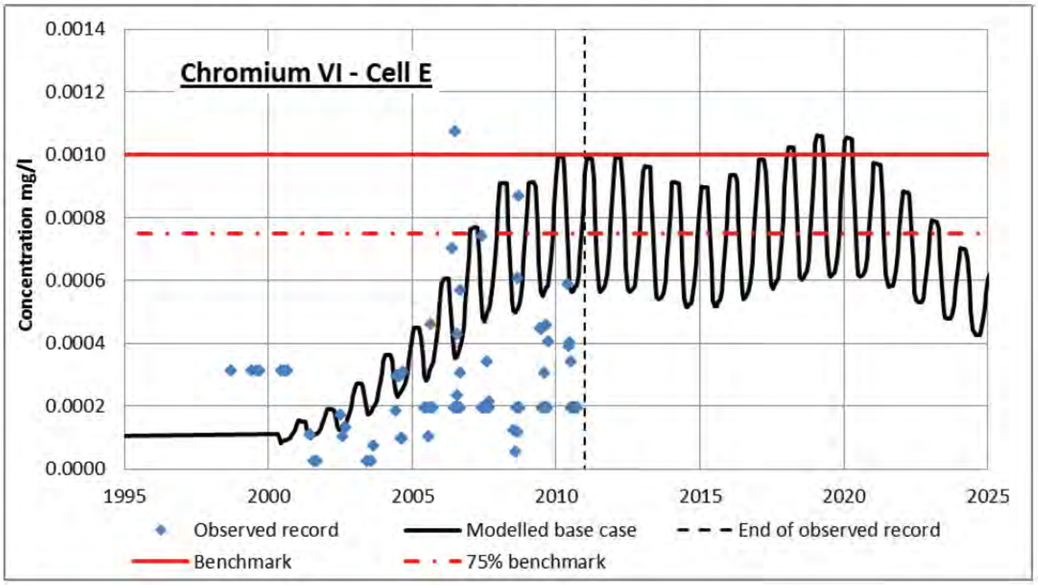


Figure 3: Model Predictions for LLCF - Chromium VI



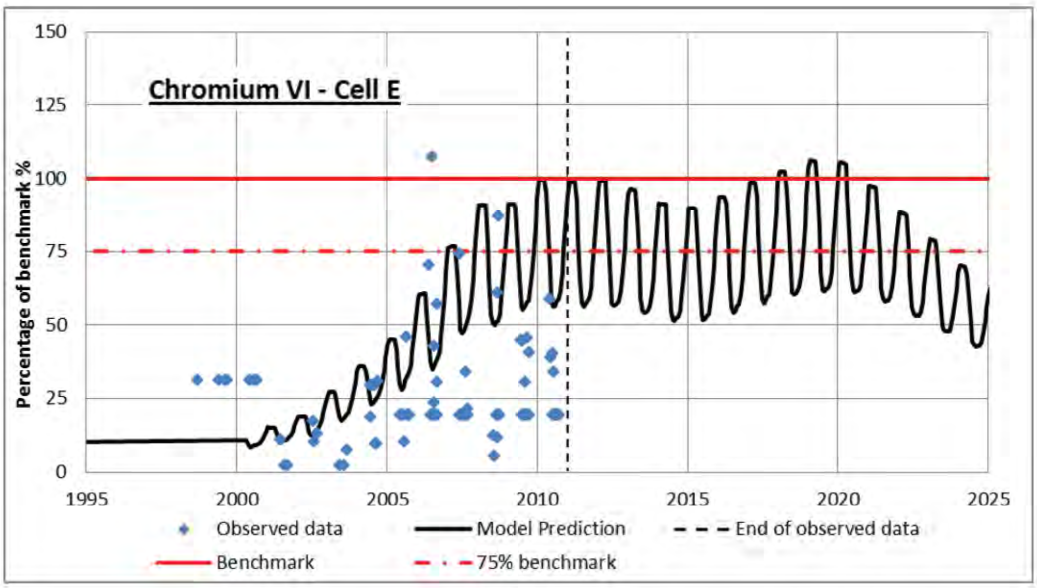


Figure 4: Predictions in Receiving Environment - Chromium III

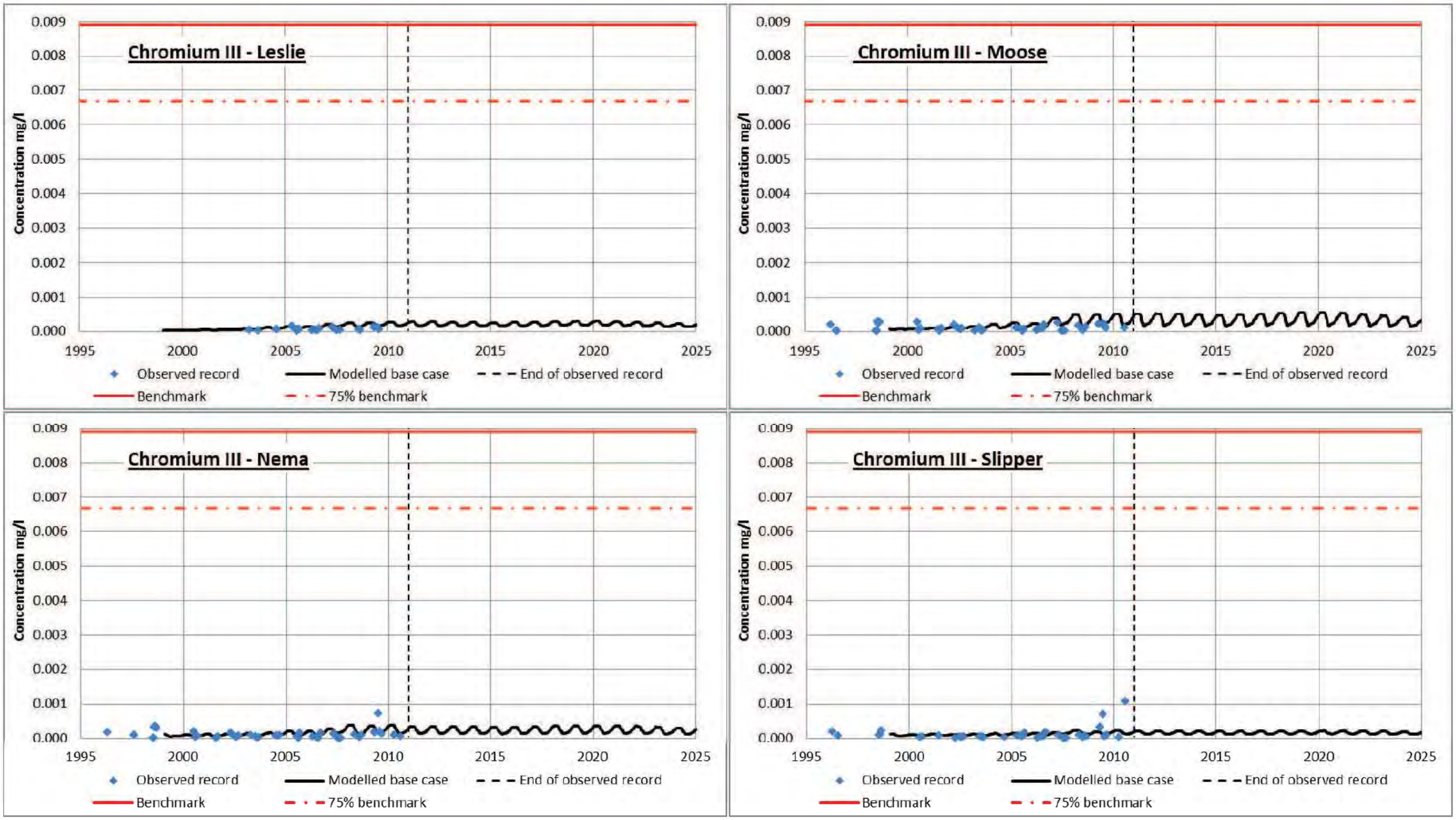


Figure 5: Predictions in Receiving Environment as Percentage of Benchmark - Chromium III

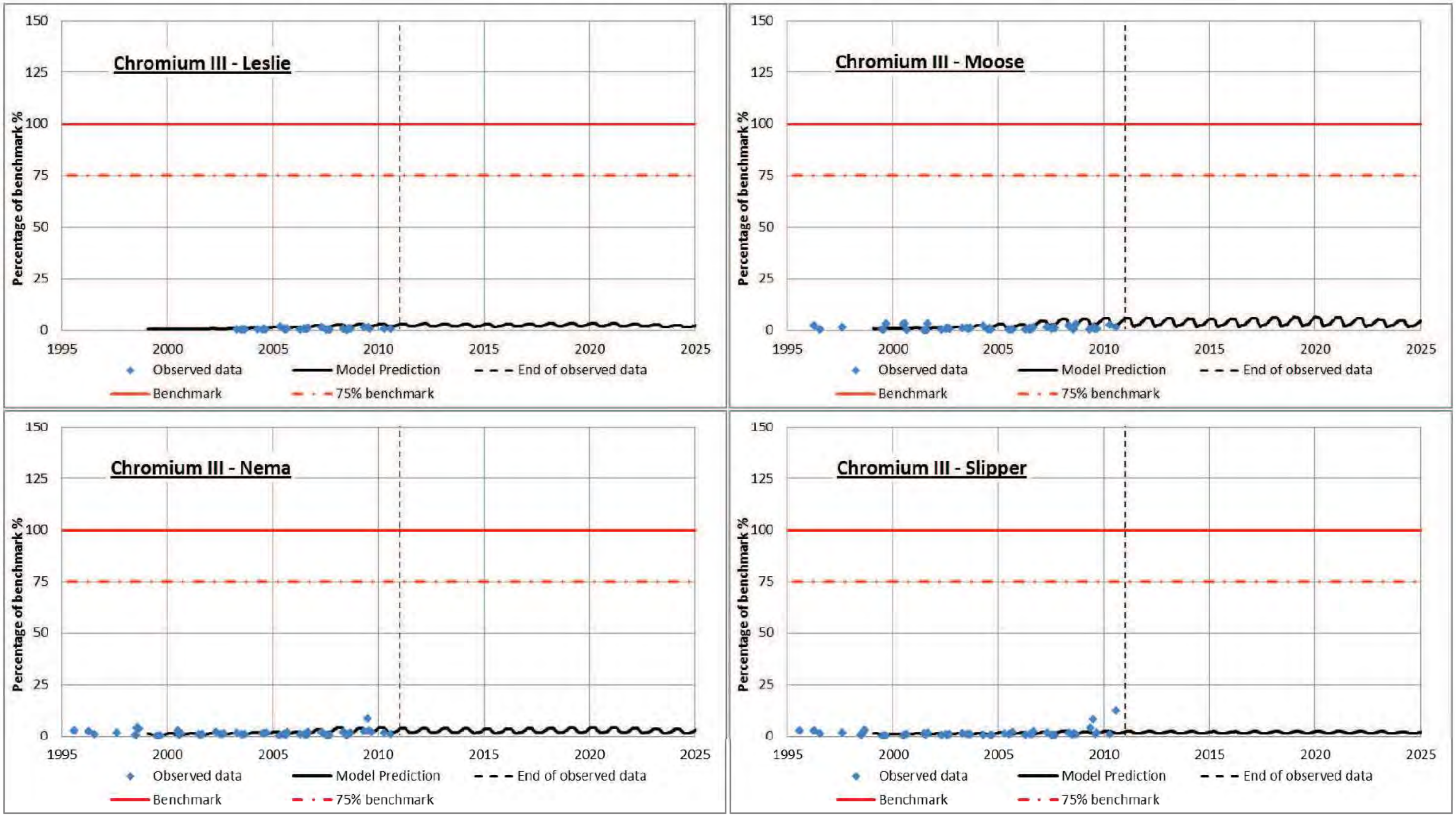


Figure 6: Predictions in Receiving Environment - Chromium VI

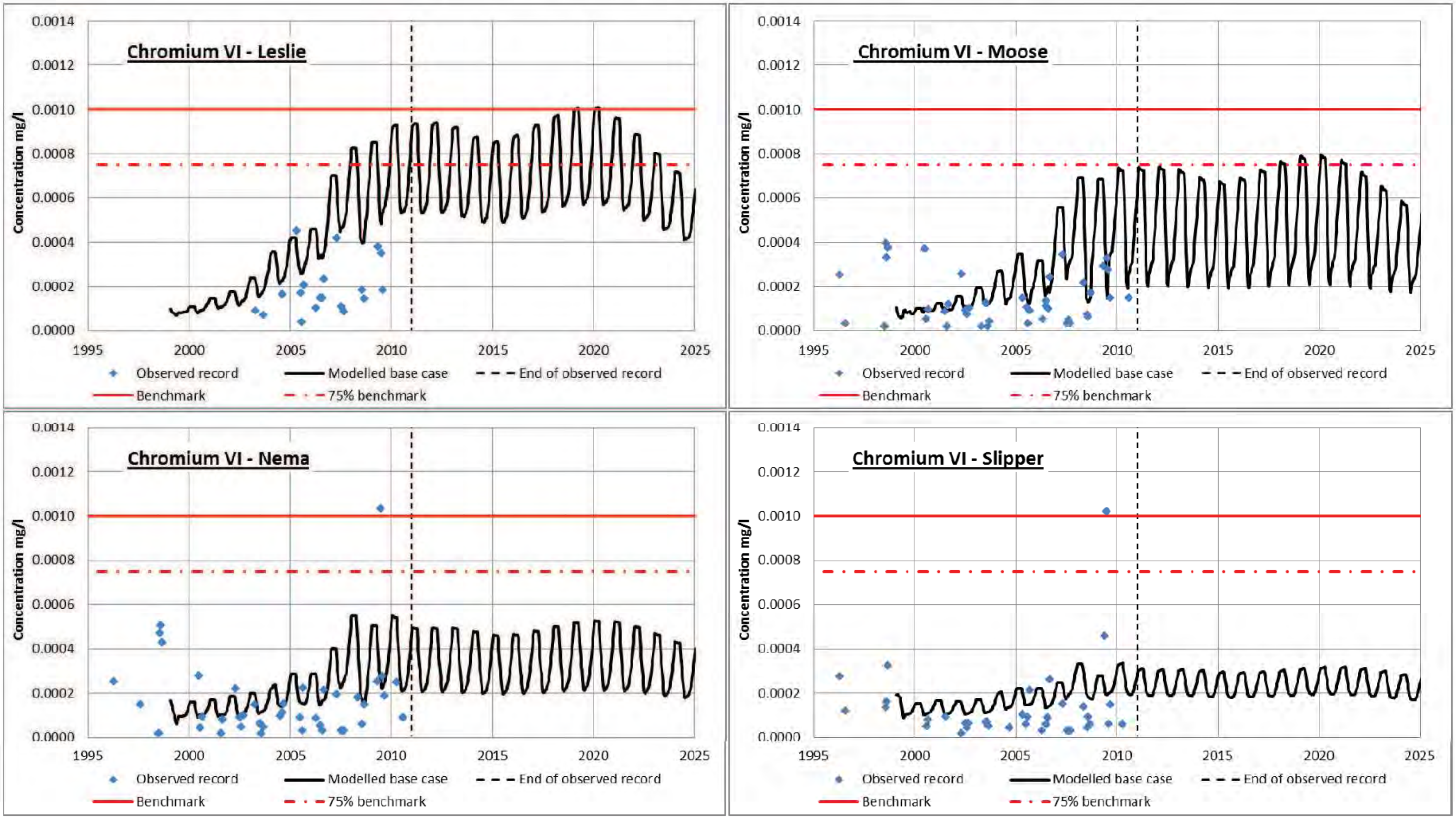
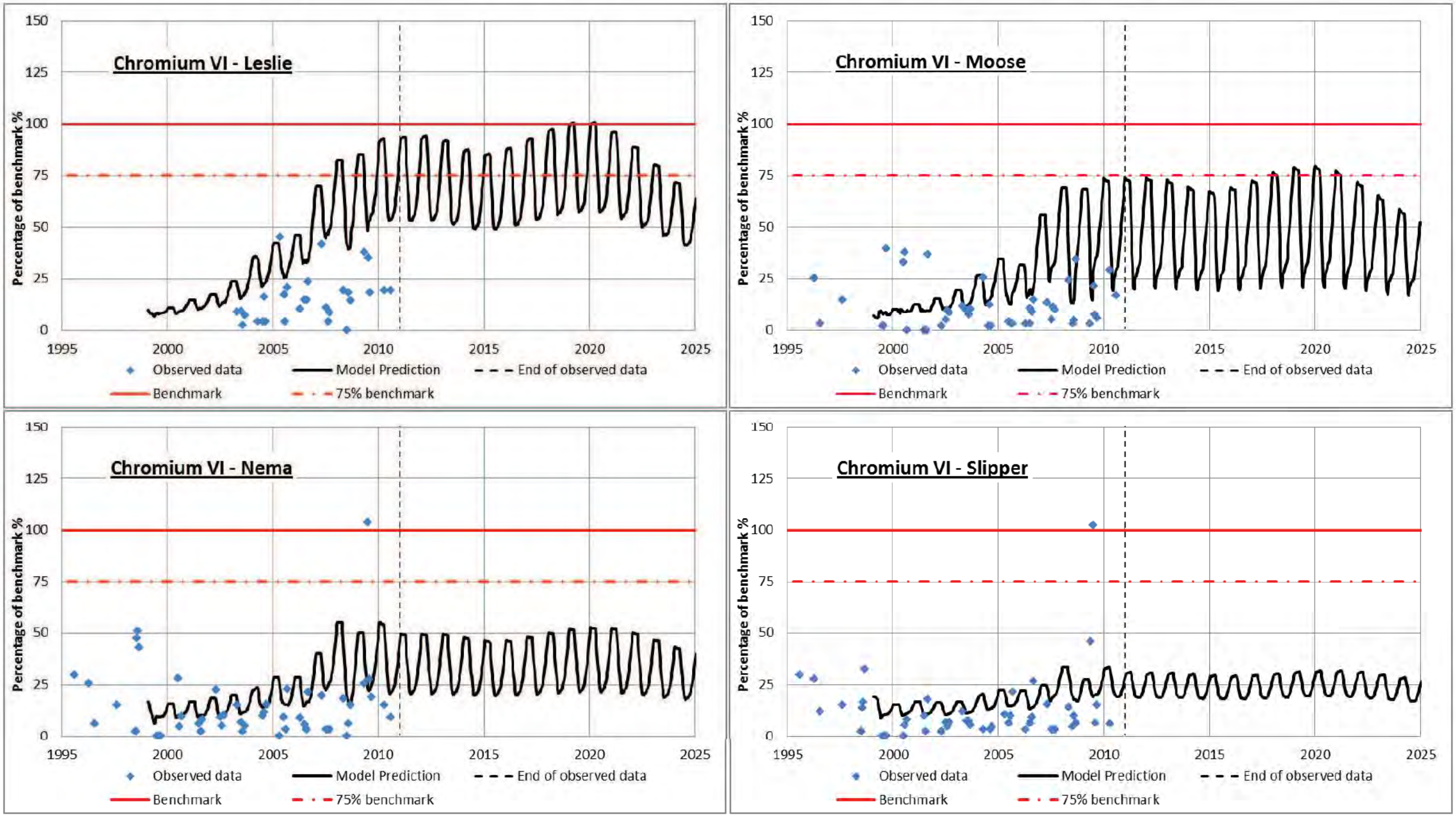


Figure 6: Predictions in Receiving Environment as Percentage of Benchmark - Chromium VI



Copper

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	20%	Process Plant	13%
Sump	24%	Sump	24%
Underground	3%	Underground	0%
Runoff	52%	Runoff	57%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	7%

Key Comments Related to Modelling Work

Many Copper water quality samples from the Process Plant discharge and sumps are below detection limit, making it is difficult to make realistic future predictions based on these data. The main loading of Copper to the LLCF is from natural runoff, although there are contributions from Process Plant discharge and sump water.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

Hardness dependent; $0.2 \times e^{(0.8545[\ln(\text{hardness})]-1.465}$ ug/L, minimum benchmark of 2 ug/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.003	0.0012	0.00193	51%	0.0035	0.00124	0.00196	98%

Comment on Model Fit to Observed Data

Reasonable fit with observed data; however, many of observed copper concentrations are less than detection limits which limits ability to produce a high quality calibration.

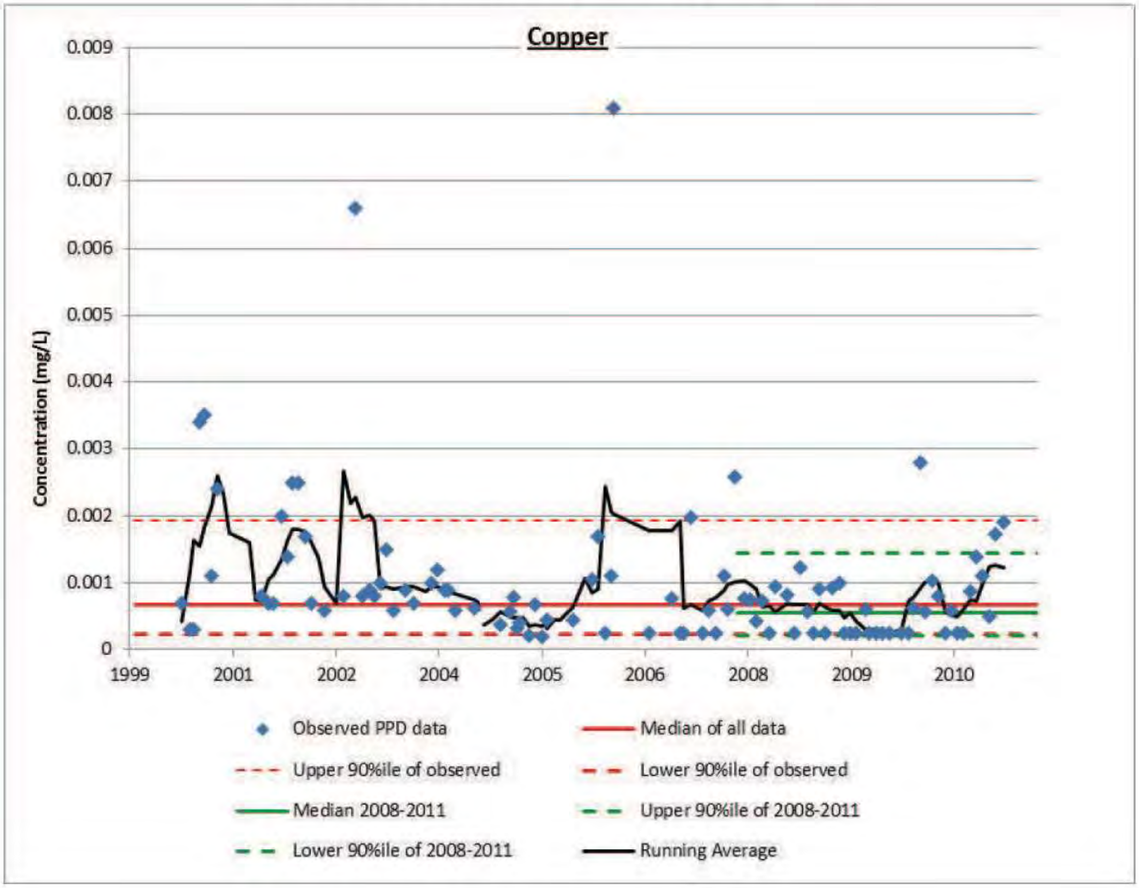
Summary

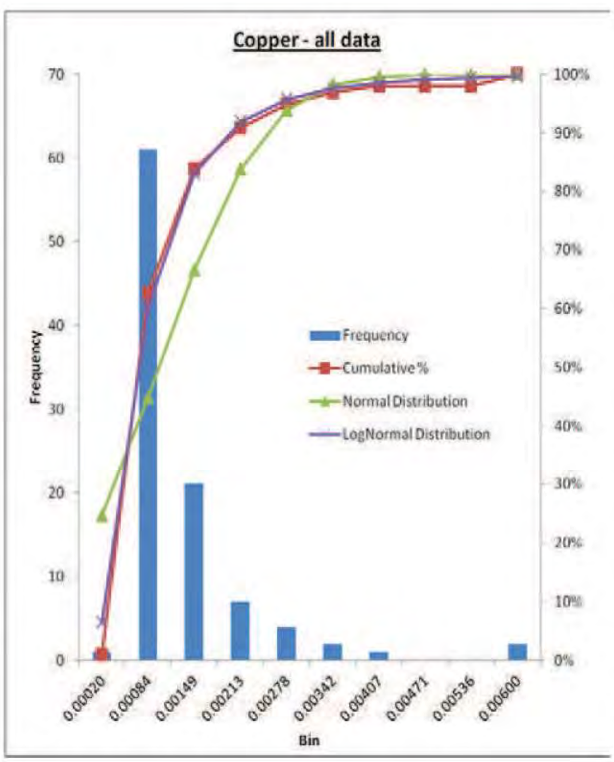
Future concentrations to the end of the operational life of the mine are predicted to be below 75% of the benchmark for Leslie and Moose lakes. Predicted concentrations in 2028/2029 are predicted to exceed 75% of the benchmark due to predicted changes to hardness and the hardness dependence of the benchmark. Concentrations in these lakes are not predicted to exceed the benchmark itself.

For Nema and Slipper lake, the model predicts concentrations above 75% of the benchmark within the operating life of the mine.

It should be noted that, the benchmark is variable due to its dependence on hardness and concentrations of copper in natural runoff can approach the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD
PPD concentrations decrease post 2007/2008, with lower average values and lower variability in data.
Modelling Approach for Future PPD
Based on lognormal distribution of all observed PPD data.
Modelled Correlation between WQ Parameters
Copper is correlated to aluminium, 0.8 correlation coefficient

Figure 2: Model Predictions for LLCF

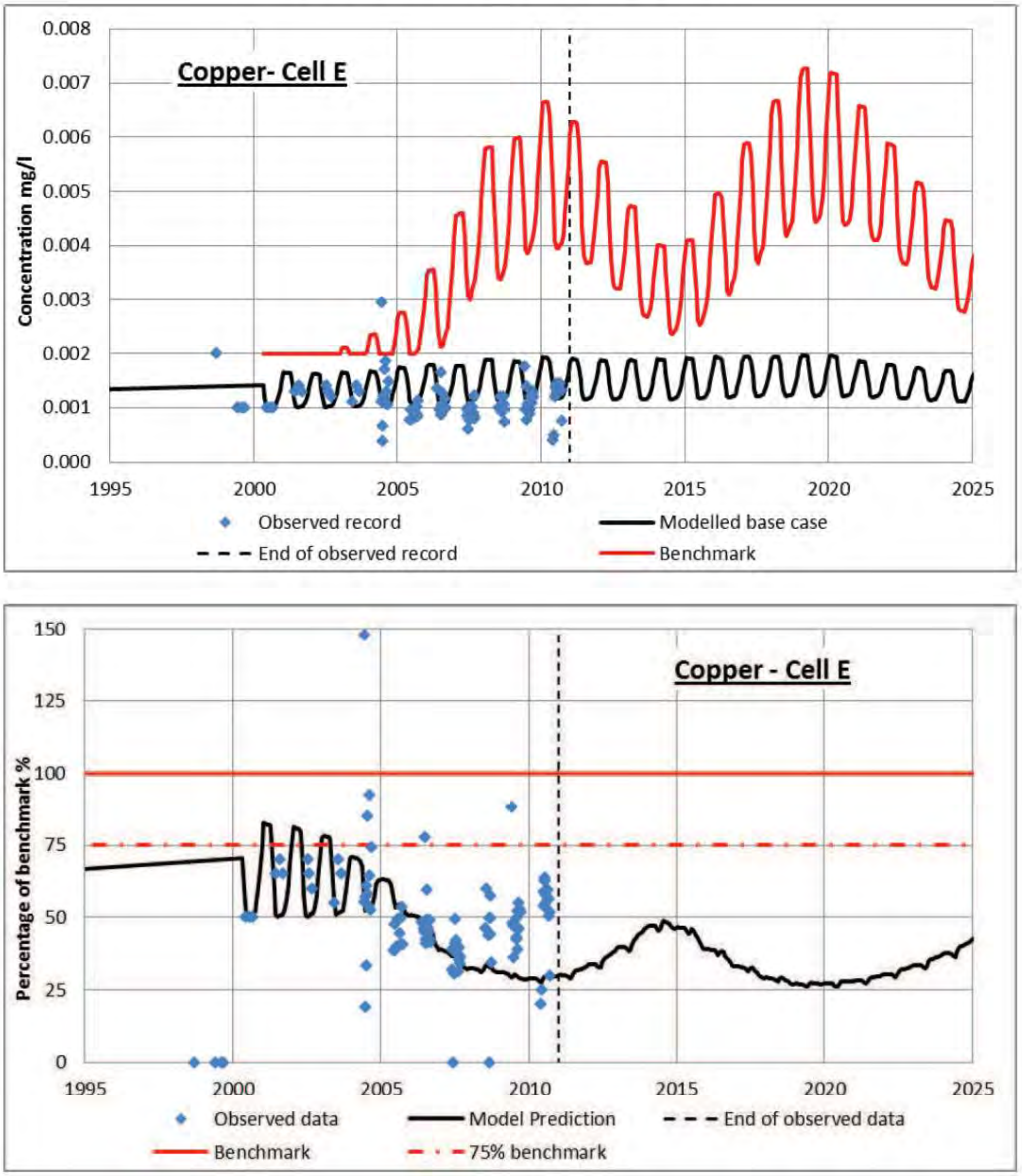


Figure 3: Predictions in Receiving Environment

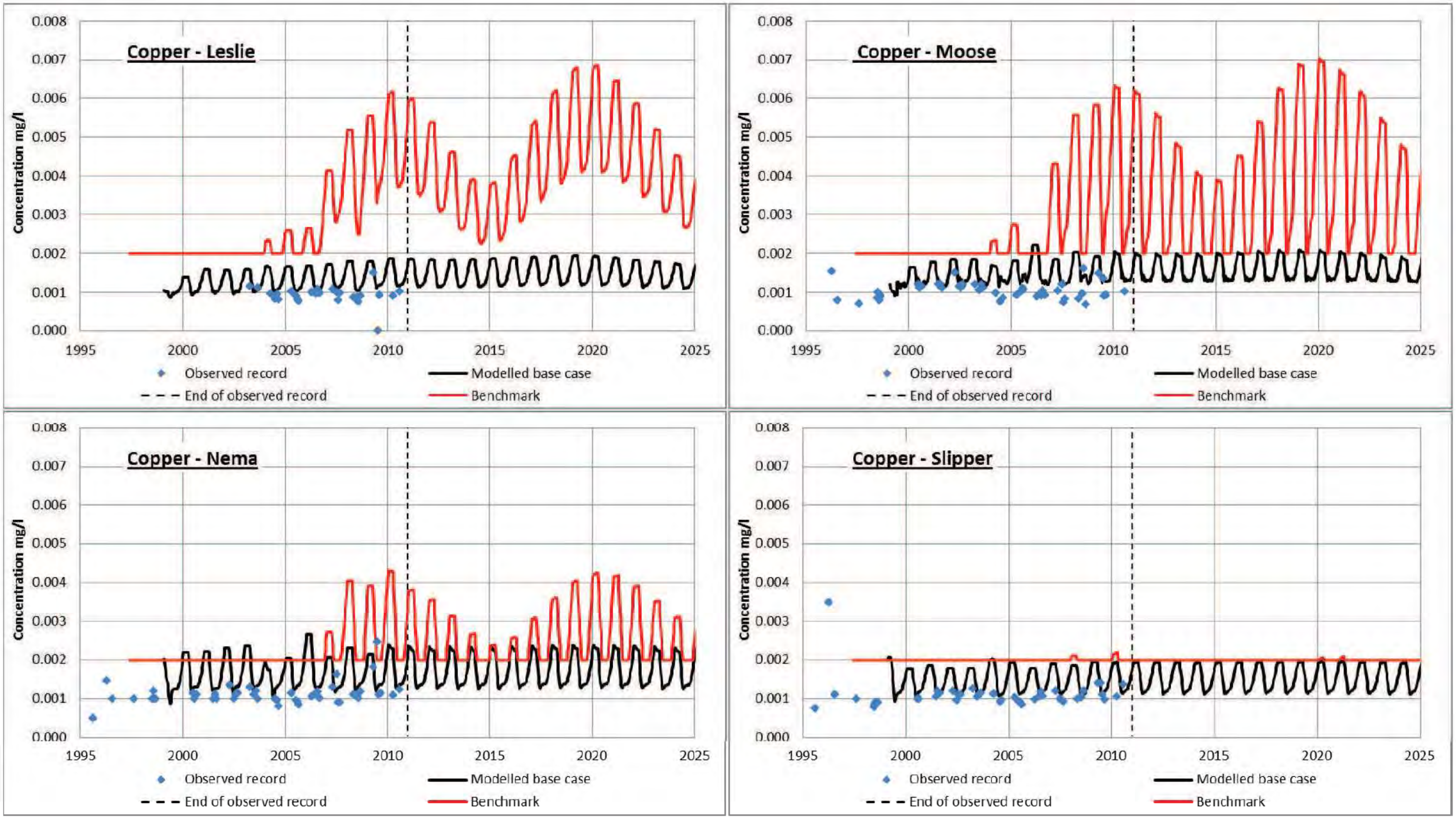
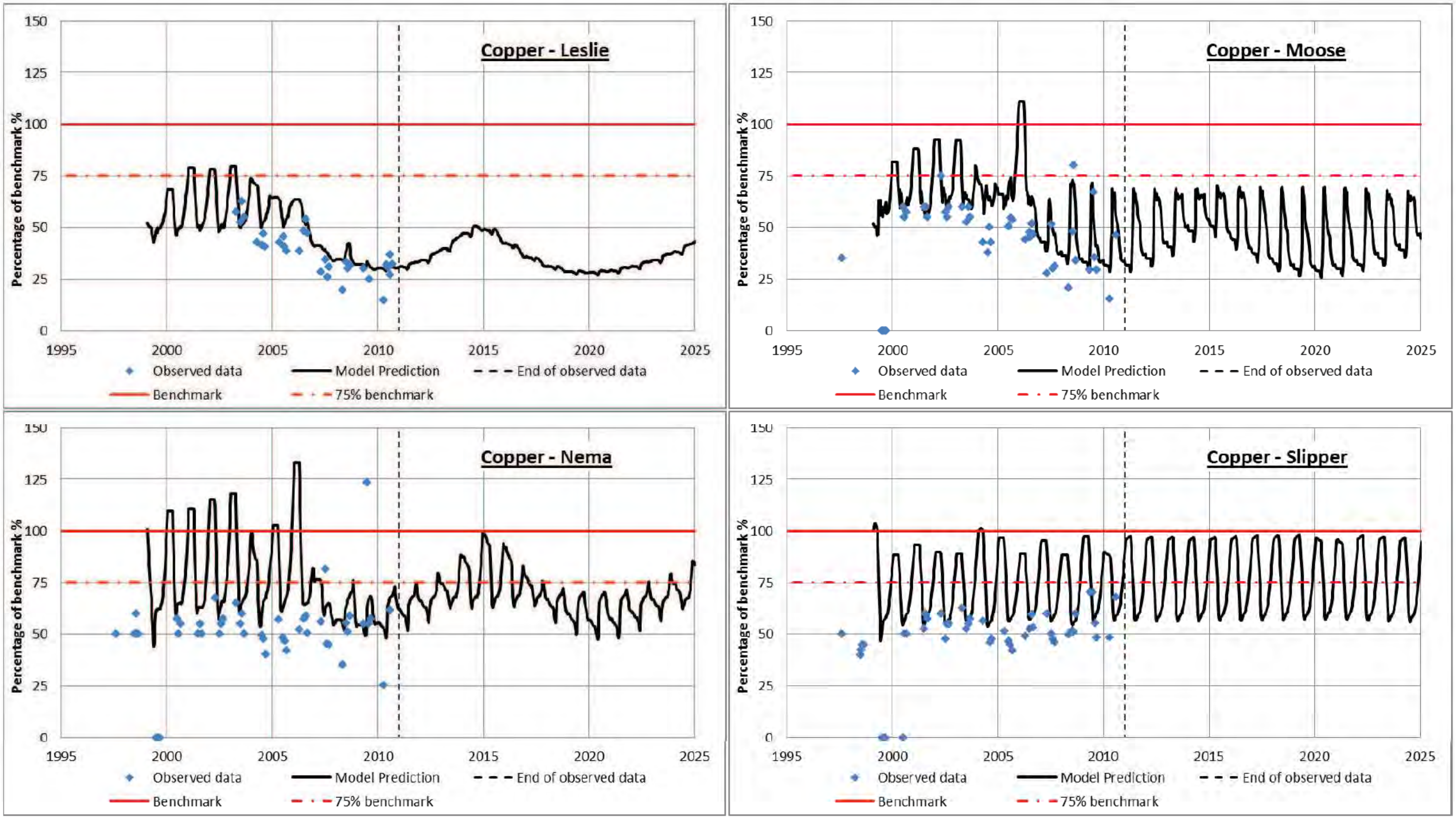


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Hardness

Sources of Parameter in LLCF

Historical 2005 - 2011		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	26%	Process Plant	17%
Sump	17%	Sump	10%
Underground	55%	Underground	0%
Runoff	2%	Runoff	3%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	70%

Key Comments Related to Modelling Work

Key parameter for prediction of hardness for use in some Water Quality Benchmarks.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

None proposed

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
280	125	371.2	-	67	23	83.6	-

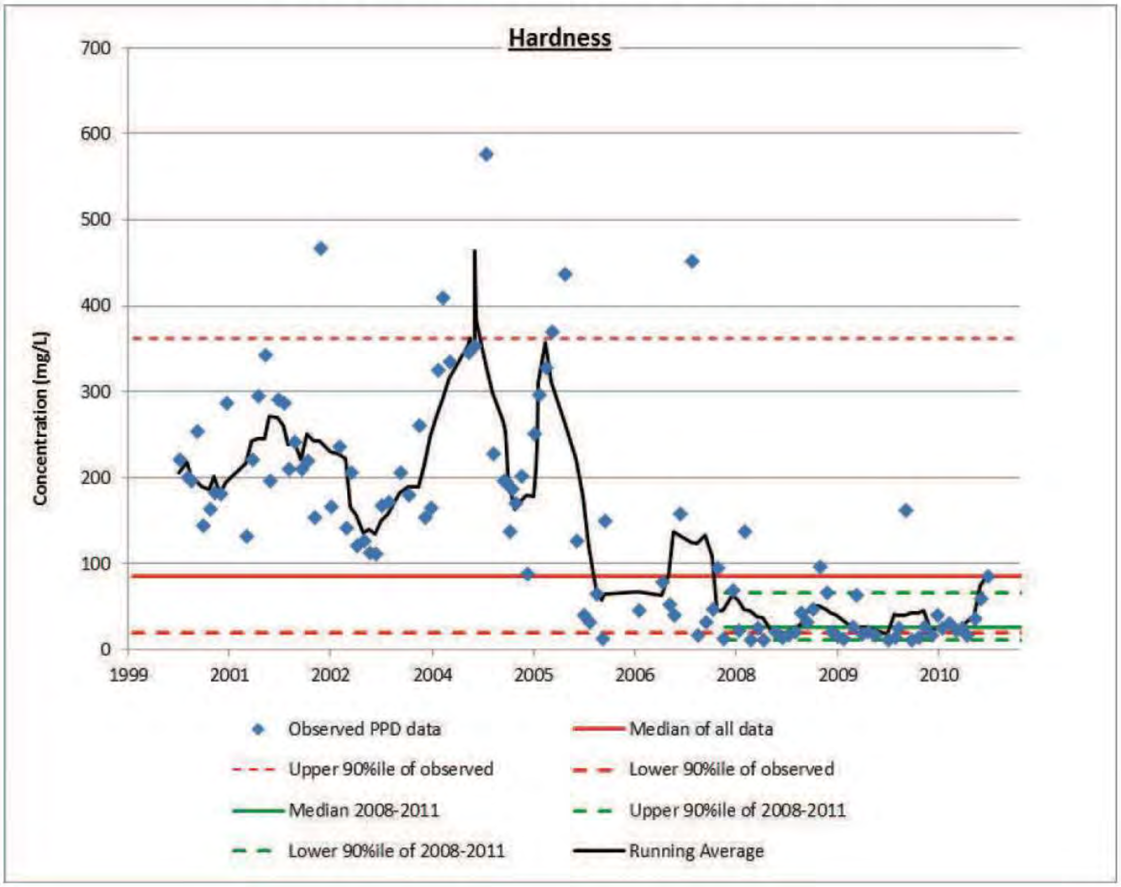
Comment on Model Fit to Observed Data

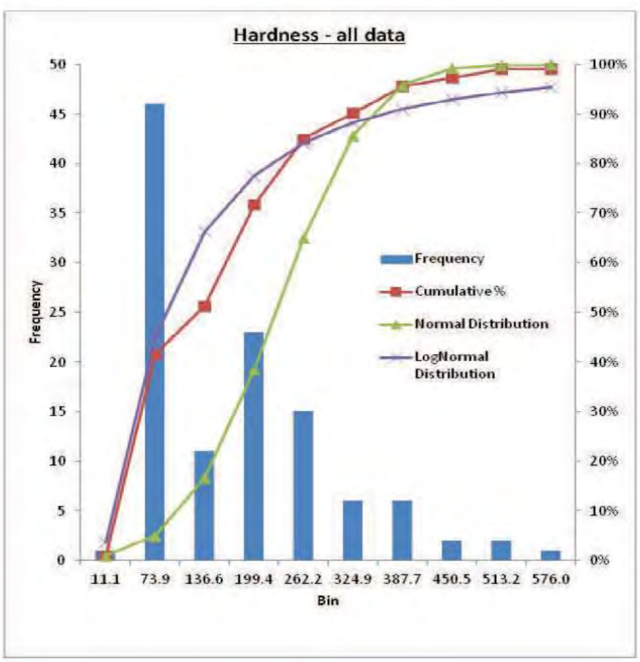
Good fit with observed data, although slight over-prediction in Cell E in recent years.

Summary

No benchmark proposed.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD Concentrations observed to decrease post 2006, with lower average values and lower variability in data; consistent with start of processing of underground ore.
Modelling approach for Future PPD For 2011 to 2020 (except 2018), normal distribution based on observed post-2006 data. For 2018, based on normal distribution for observed 2000 to 2006 data.
Modelled Correlation between parameters Hardness is correlated to magnesium, 1 correlation coefficient.

Figure 2: Model Predictions for LLCF

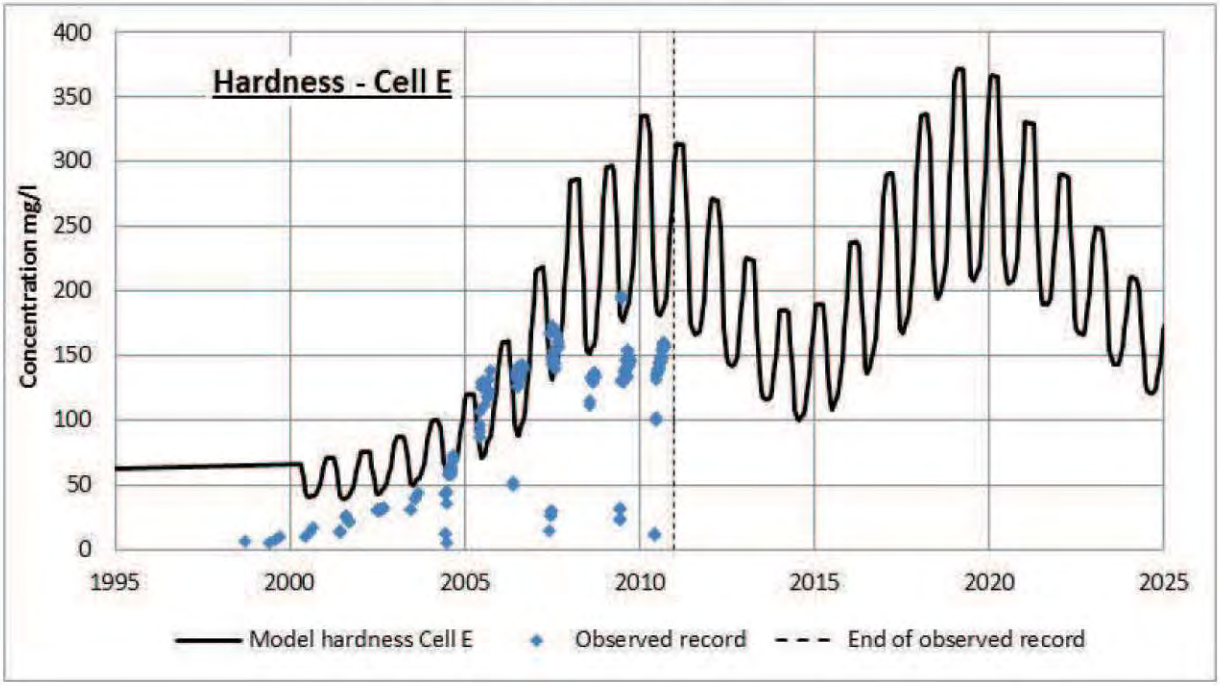
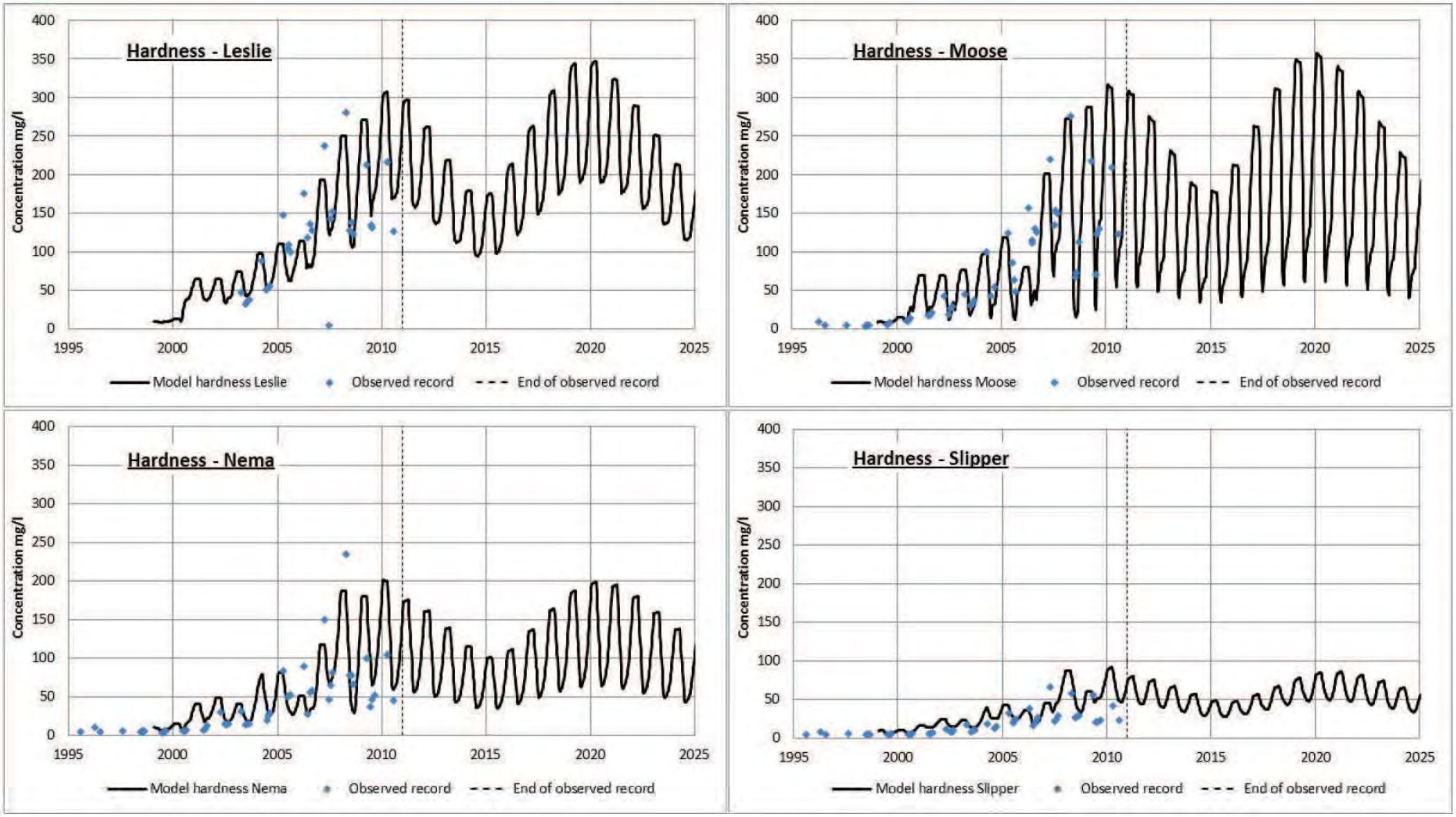


Figure 3: Predictions in Receiving Environment



Iron

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	73%	Process Plant	65%
Sump	8%	Sump	1%
Underground	2%	Underground	0%
Runoff	17%	Runoff	15%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	18%

Key Comments Related to Modelling Work

Many Iron water quality samples from the Process Plant discharge and sumps are below detection limit, making it difficult to make realistic future predictions based on these data.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.3 mg/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.94	0.0015	0.0975	33%	0.094	0.049	0.0341	11%

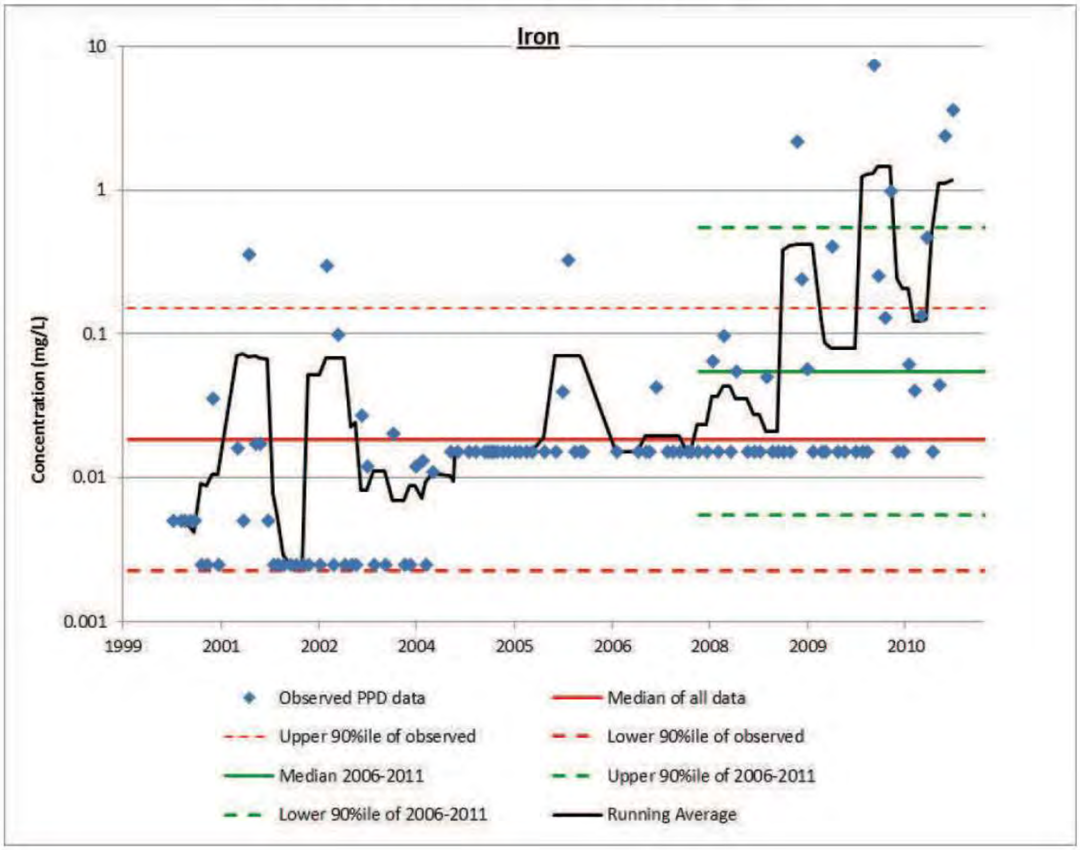
Comment on Model Fit to Observed Data

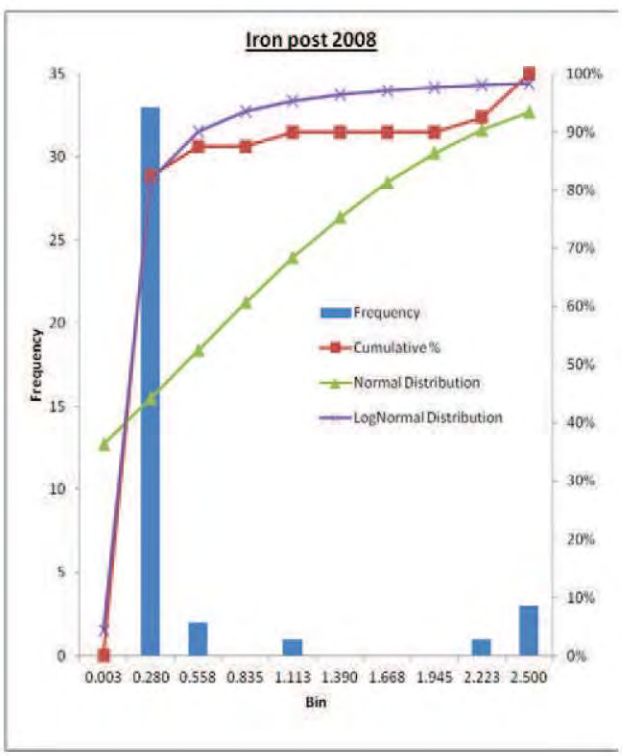
Reasonable fit between observed and predicted concentrations; however, there is variability in observed iron concentrations with some high values. This likely is a result of the use of total metals data for observed concentrations. For most metals dissolved metals = total metals at EKATI; however, for some common metals such as Iron this is not the case and samples with higher than average TSS can produce high particulate metals (and therefore total metals) concentrations. These cannot be predicted by the model.

Summary

Historical concentrations and model predictions for downstream lakes are below 75% of the benchmark.

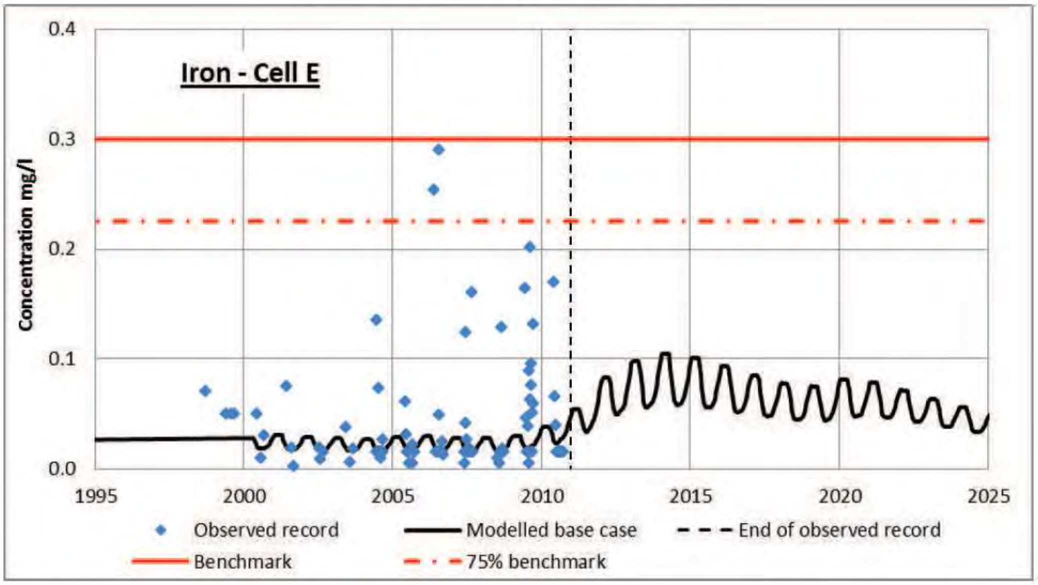
Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD Concentration increase post-2008, but there are a significant number of samples below detection limit.
Modelling approach for Future PPD Based on lognormal distribution of observed 2008-2010 PPD data.
Modelled Correlation between parameters Iron is perfectly correlated to aluminium (1).

Figure 2: Model Predictions for LLCF



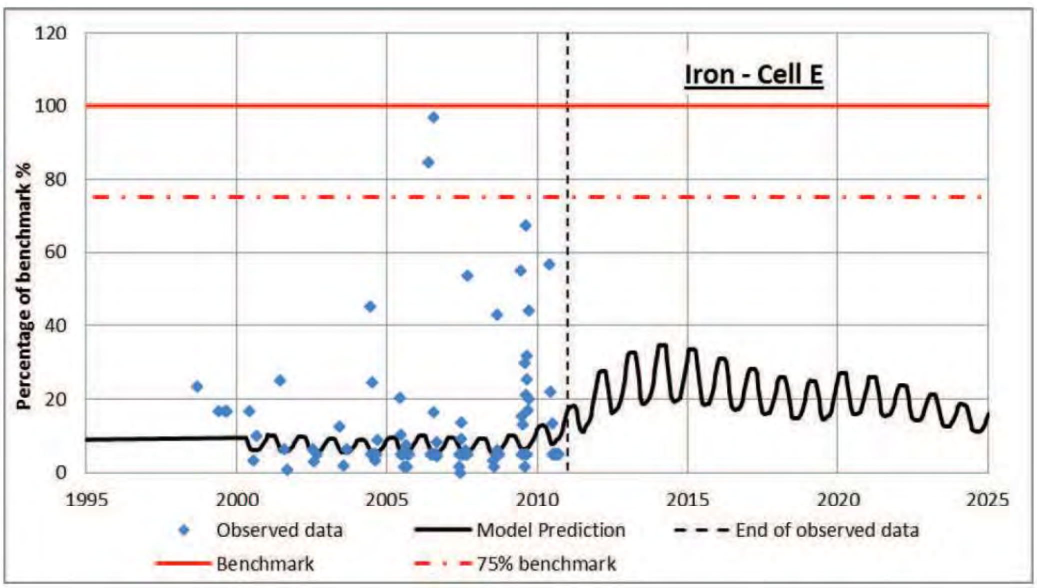


Figure 3: Predictions in Receiving Environment

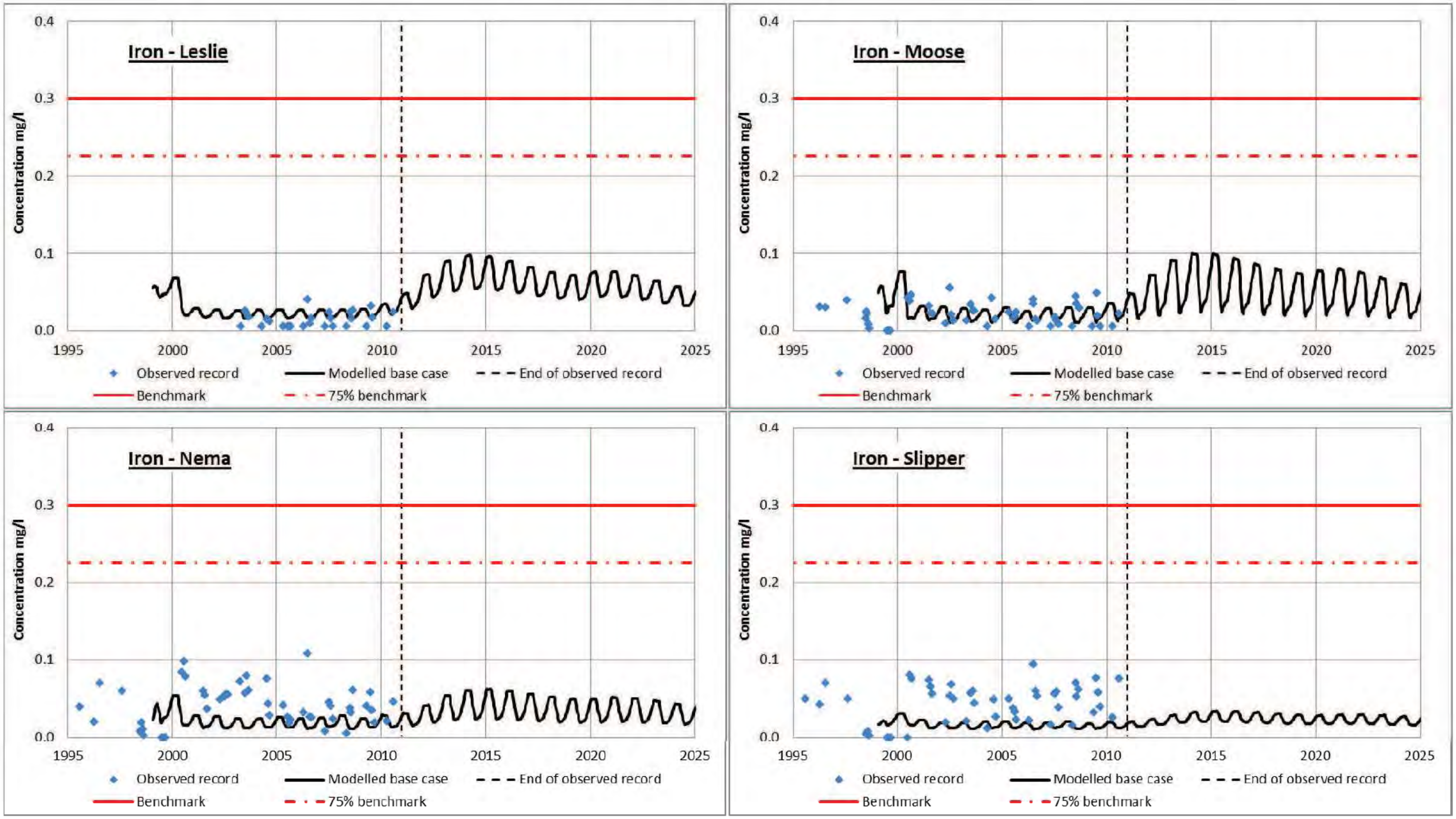
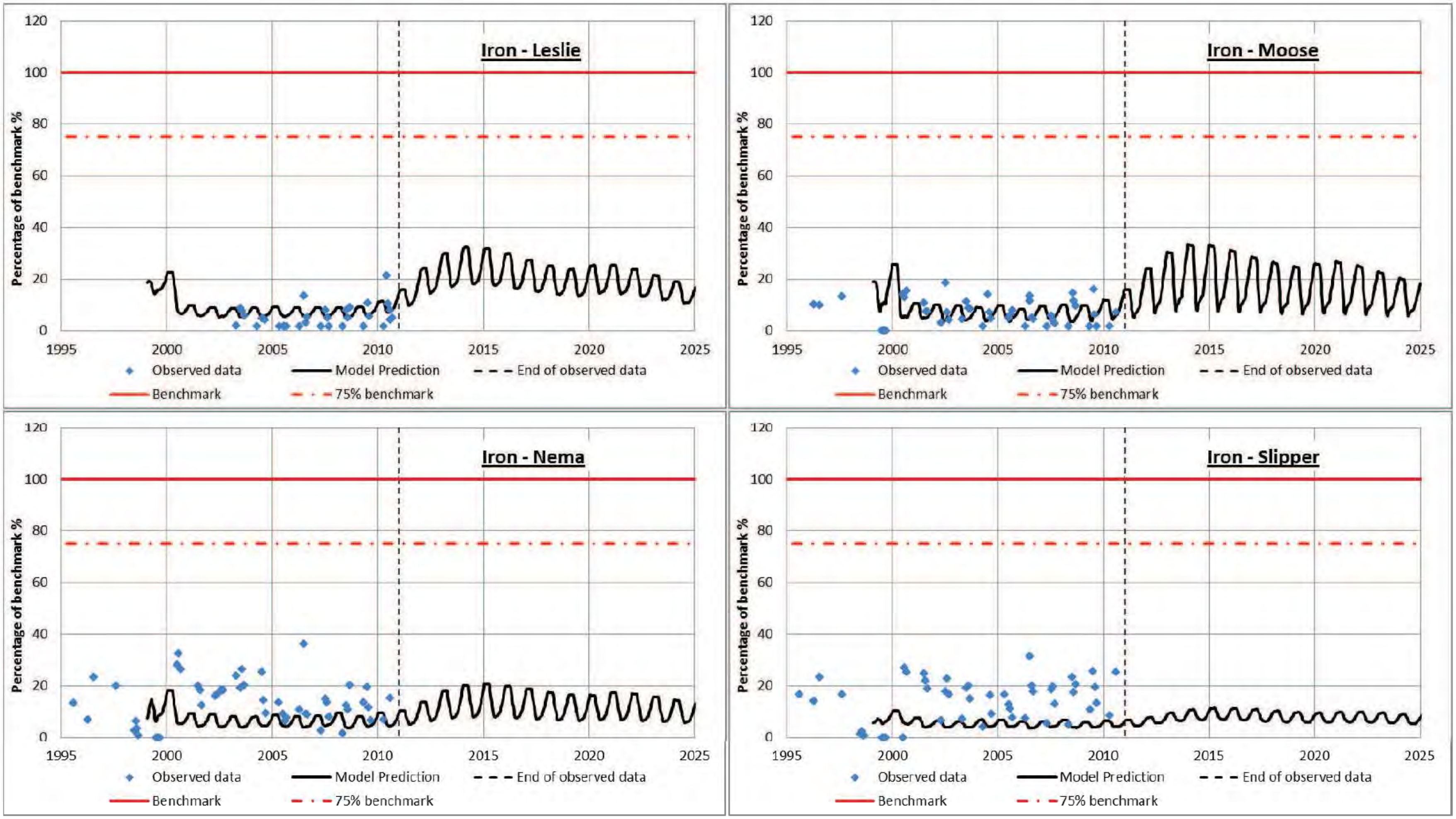


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Lead

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	44%	Process Plant	26%
Sump	9%	Sump	8%
Underground	28%	Underground	0%
Runoff	20%	Runoff	24%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	41%

Key Comments Related to Modelling Work

The majority of Lead water quality samples from the Process Plant discharge and sumps are below detection limit, making it difficult to realistically predict future concentrations based on these data.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

$e^{(1.273[\ln(\text{hardness})]-4.705)}$ ug/L (CCME guideline)

Leslie Lake (mg/L)				**Slipper Lake (mg/L)**			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.00081	0.000025	0.000134	2%	0.0018	0.000058	0.0000626	5%

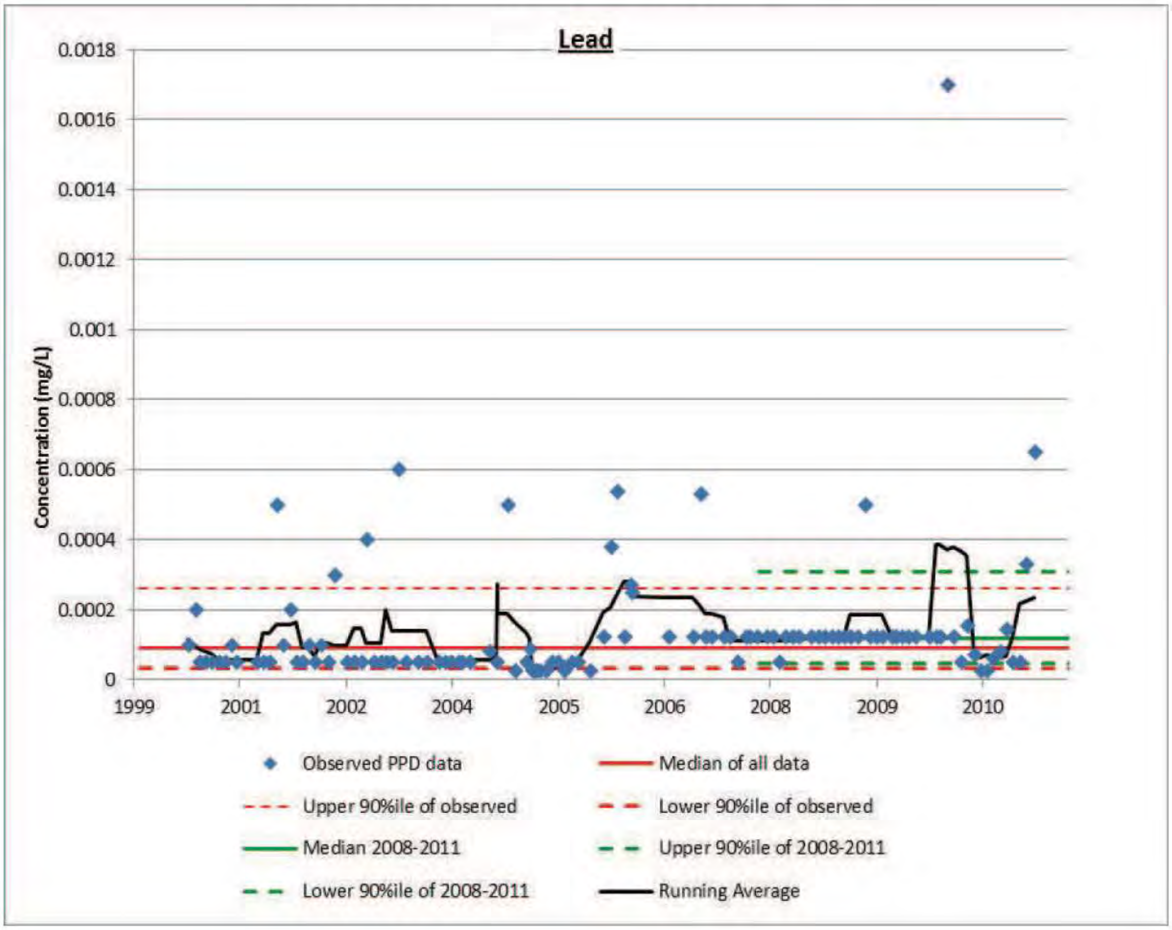
Comment on Model Fit to Observed Data

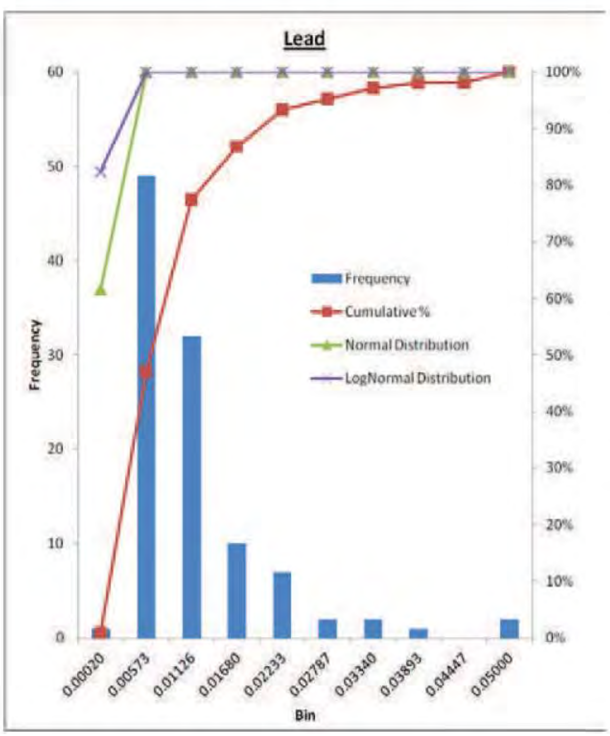
Reasonable fit, but large number of observed concentrations are below detection limit.

Summary

Model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD
No clear trend and majority of of PPD samples are below detection limit.
Modelling Approach for Future PPD
Based on lognormal distribution of all observed PPD data.
Modelled Correlation between WQ Parameters
Lead is correlated to aluminium (1).

Figure 2: Model Predictions for LLCF

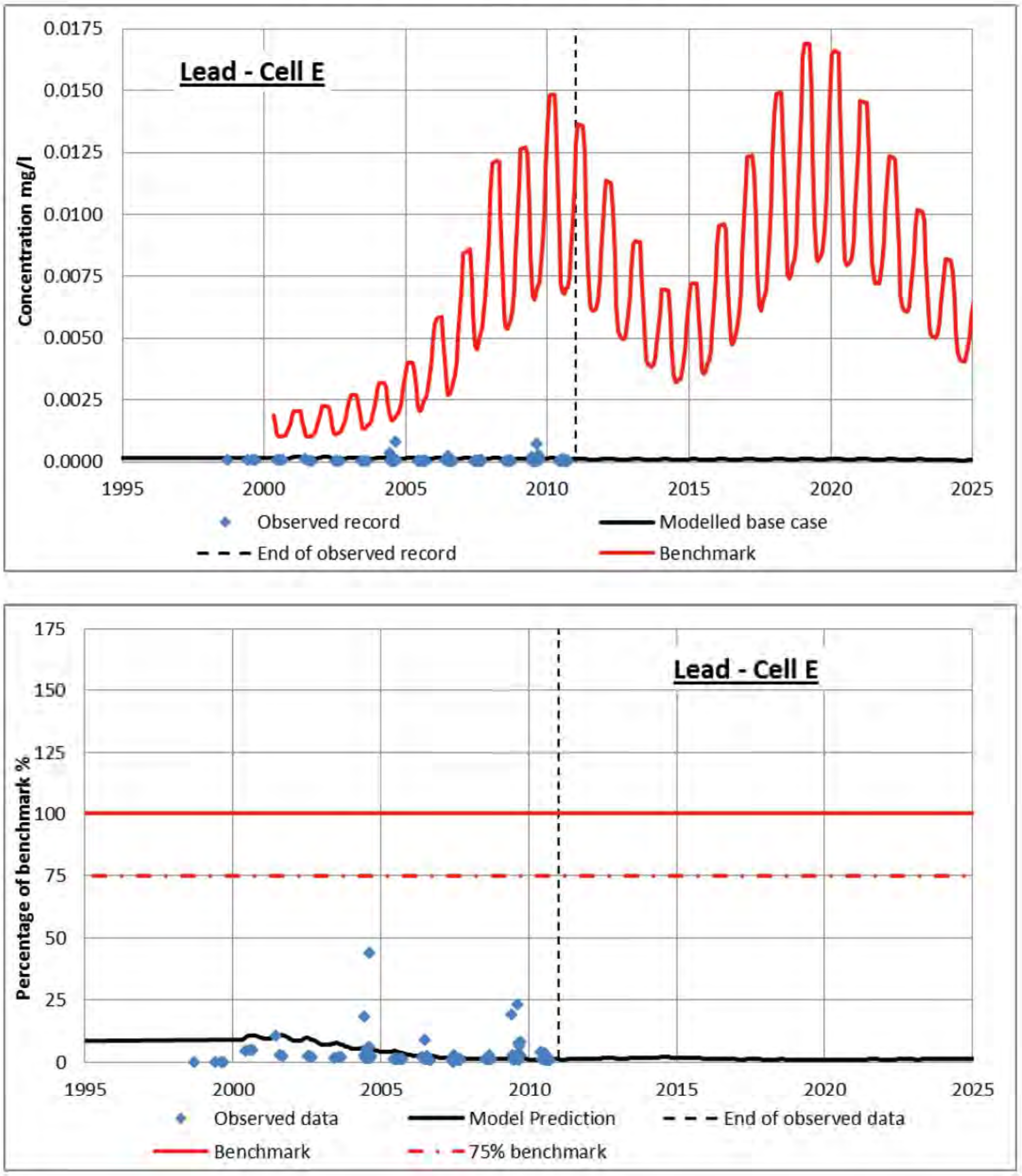


Figure 3: Predictions in Receiving Environment

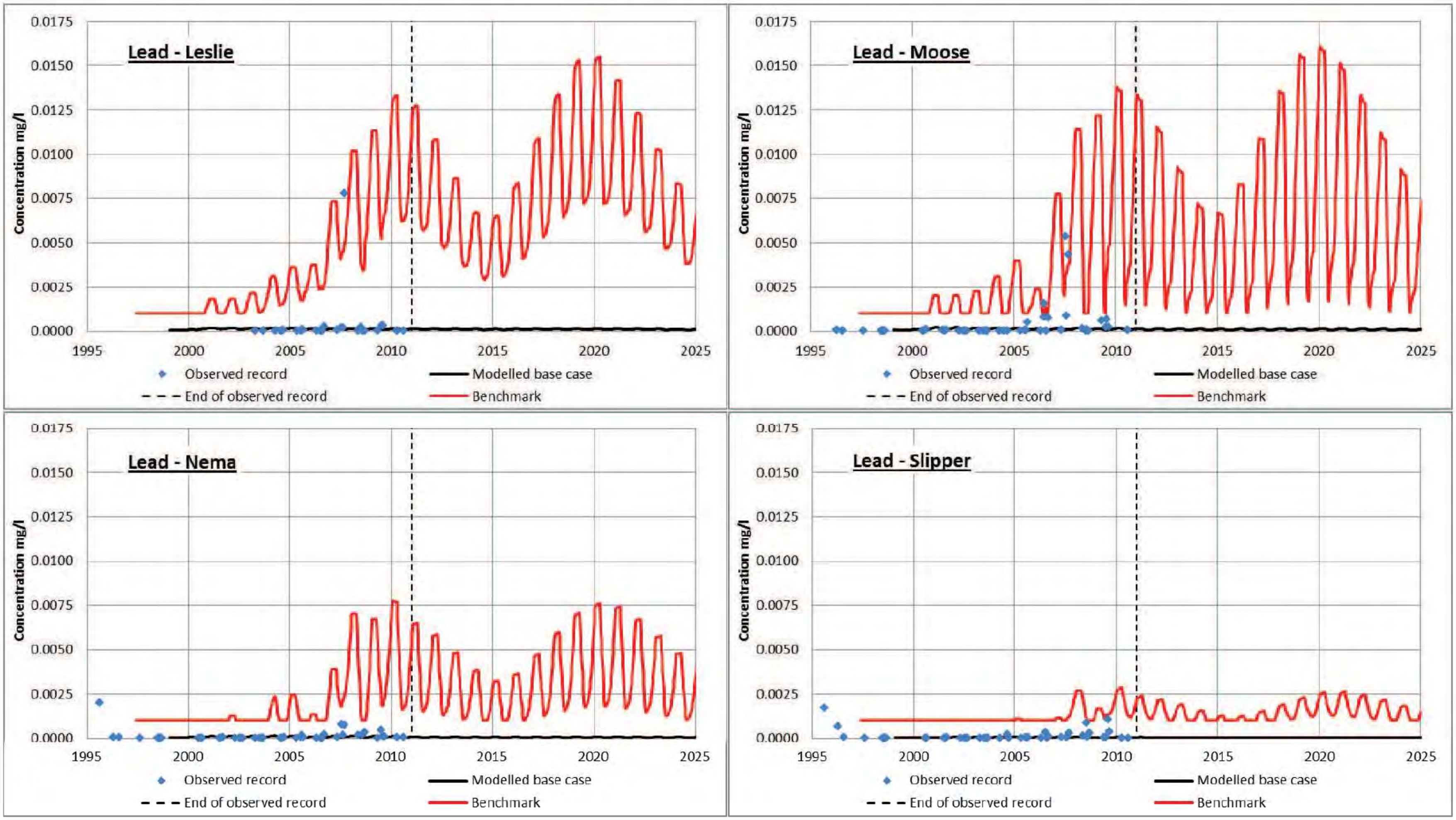
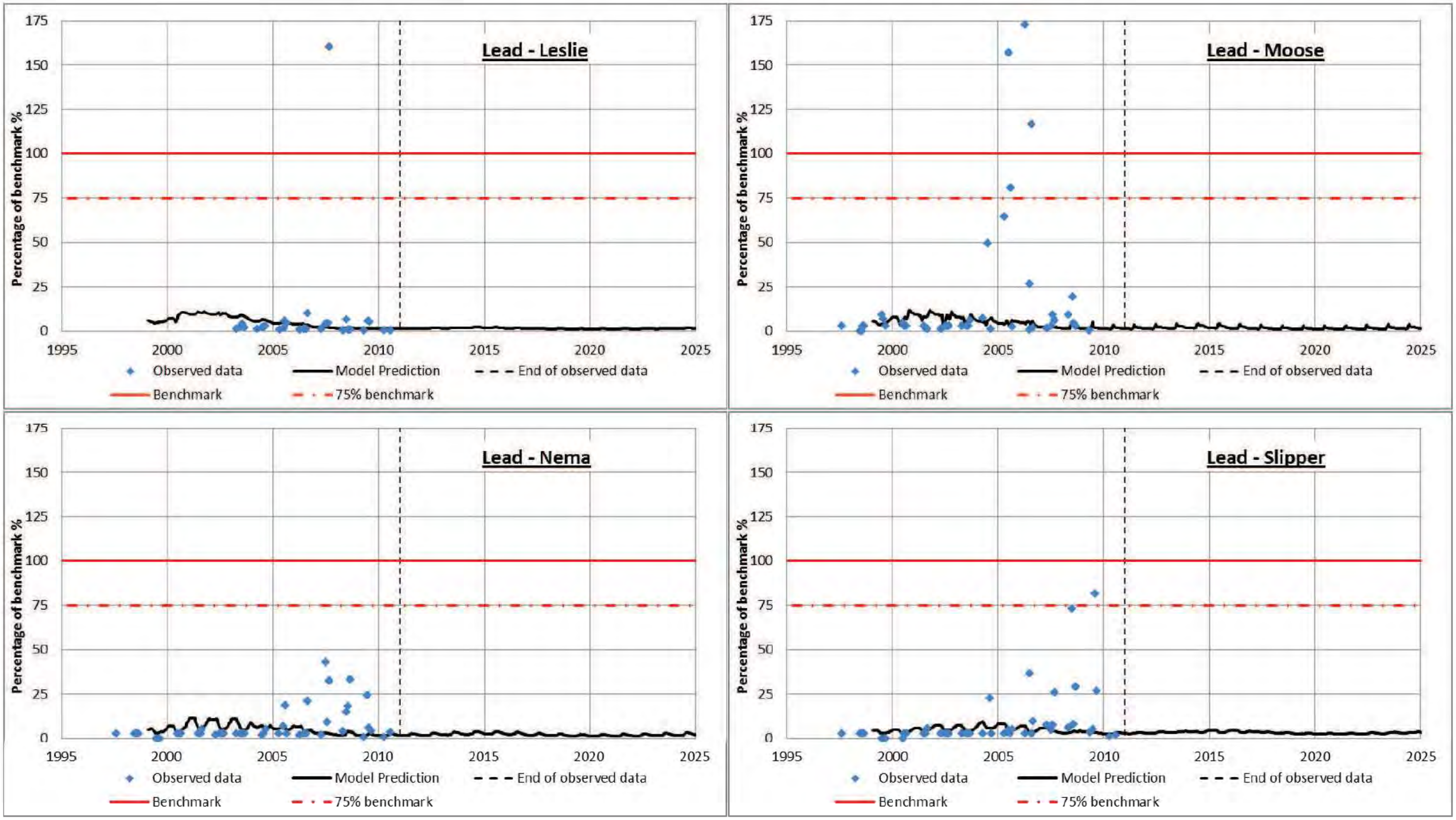


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Magnesium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	49%	Process Plant	30%
Sump	20%	Sump	24%
Underground	29%	Underground	0%
Runoff	2%	Runoff	3%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	43%

Key Comments Related to Modelling Work

Main loading is from PPD, with dramatic decrease in concentrations from PP post-2005. Model predicts decreasing concentrations post-2005.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

None proposed

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
38	16	25.2	-	14	3.2	6.4	-

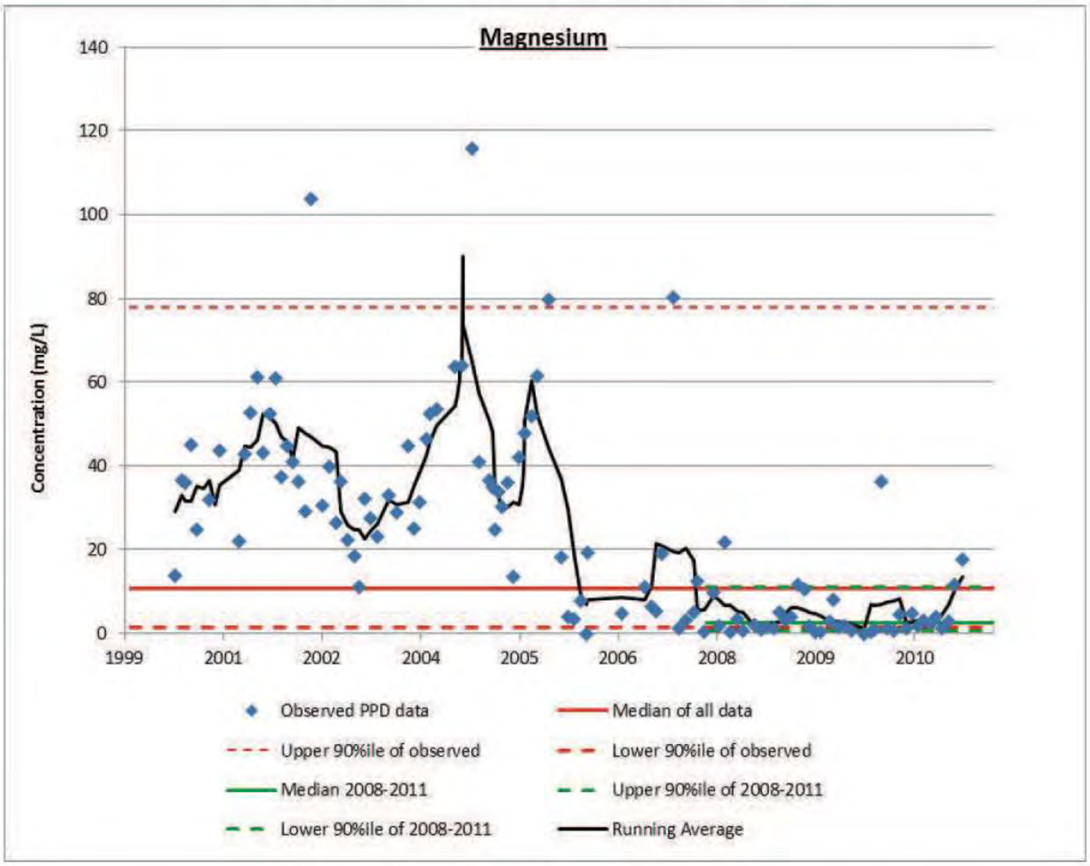
Comment on Model Fit to Observed Data

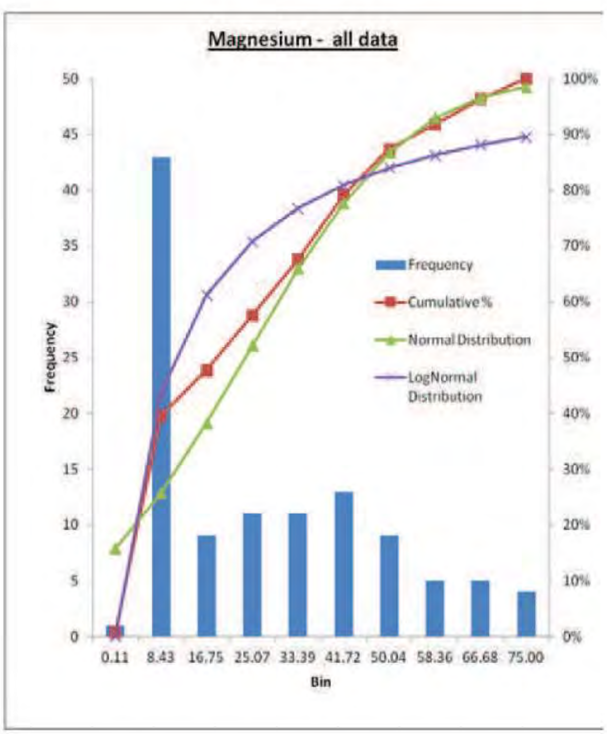
Reasonable fit with observed data. Higher observed values are underestimated.

Summary

No benchmark proposed.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Drop in observed concentrations post-2005, but concentrations are seen to be consistently lower post-2008, with lower average values and lower variability in data.

Modelling Approach for Future PPD

For 2011 to 2020 (except 2018), normal distribution based on observed post-2006 data. For 2018, based on normal distribution for observed from 2000 to 2006 data.

Modelled Correlation between Parameters

Magnesium is correlated to Calcium (0.9)

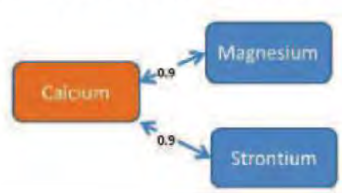


Figure 2: Model Predictions for LLCF

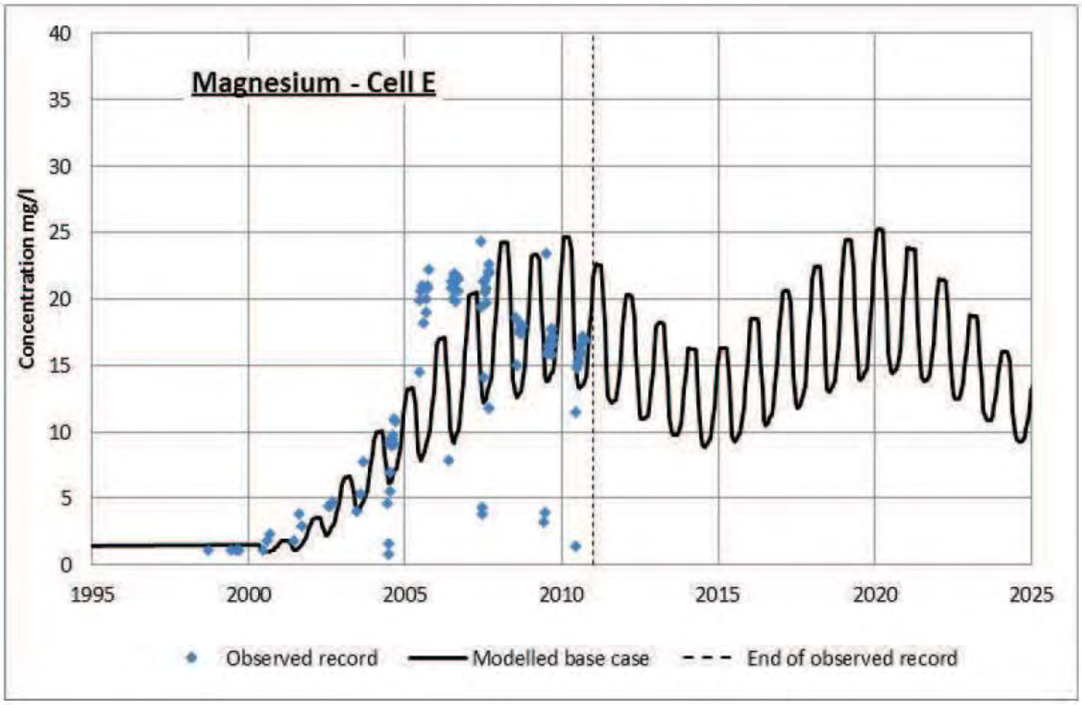
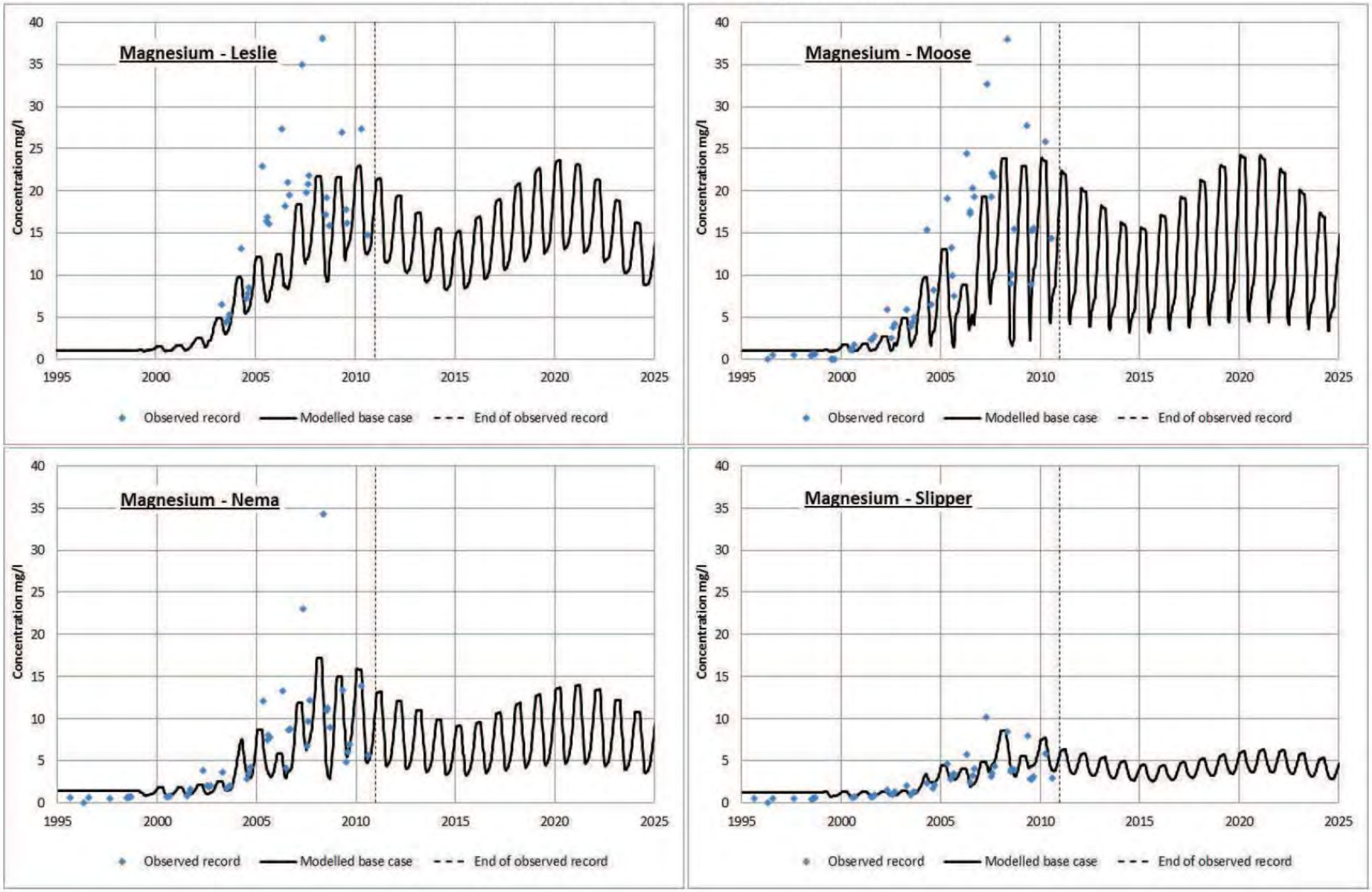


Figure 3: Predictions in Receiving Environment



Manganese

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	21%	Process Plant	11%
Sump	36%	Sump	31%
Underground	25%	Underground	0%
Runoff	19%	Runoff	24%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	35%

Key Comments Related to Modelling Work

Manganese loadings are divided between the Process Plant discharge, sumps, underground and runoff, with no dominant source of this parameter.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

4.4 x hardness + 605 ug/L (BC MoE)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.048	0.0034	0.0215	1%	0.014	0.0089	0.0118	1%

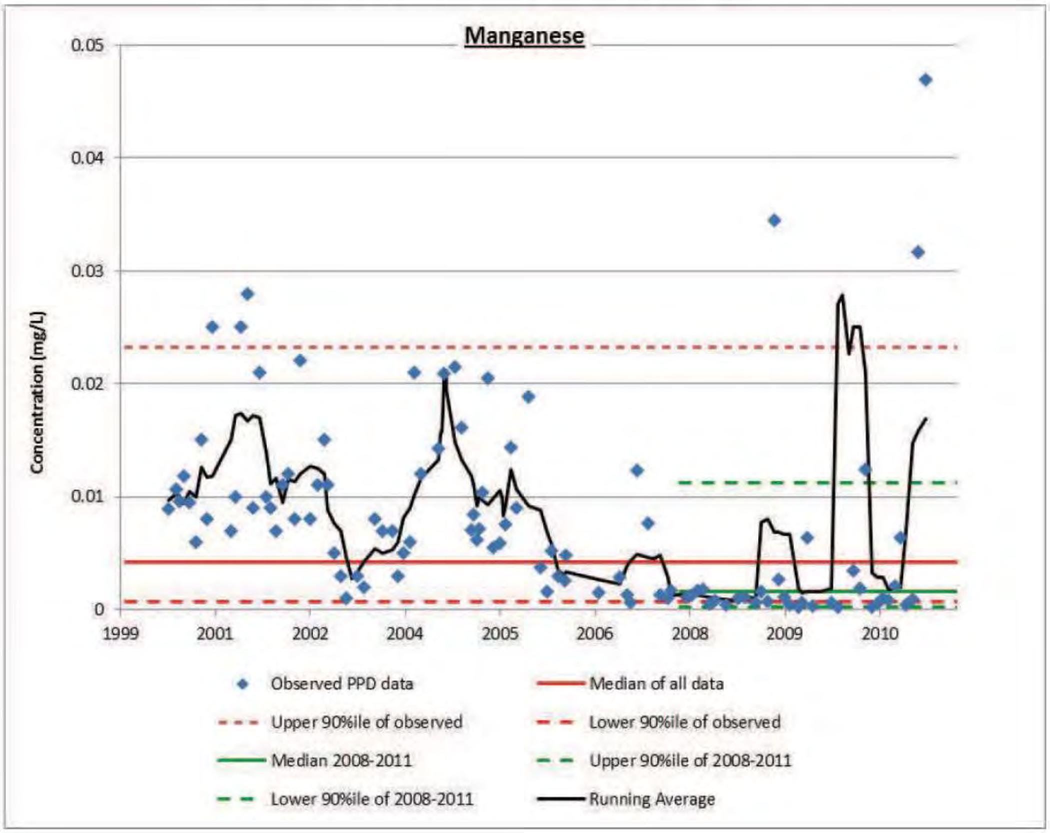
Comment on Model Fit to Observed Data

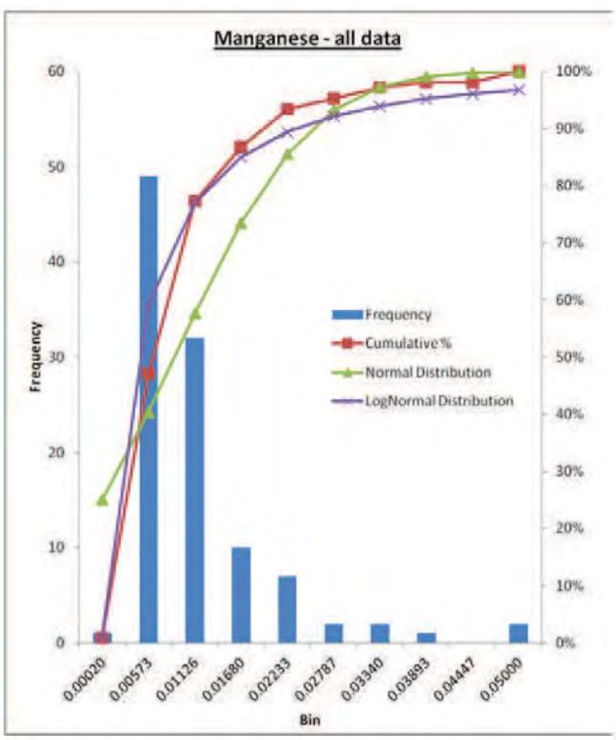
Reasonable fit between observed and predicted concentrations, with model generally over-predicting concentrations.

Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

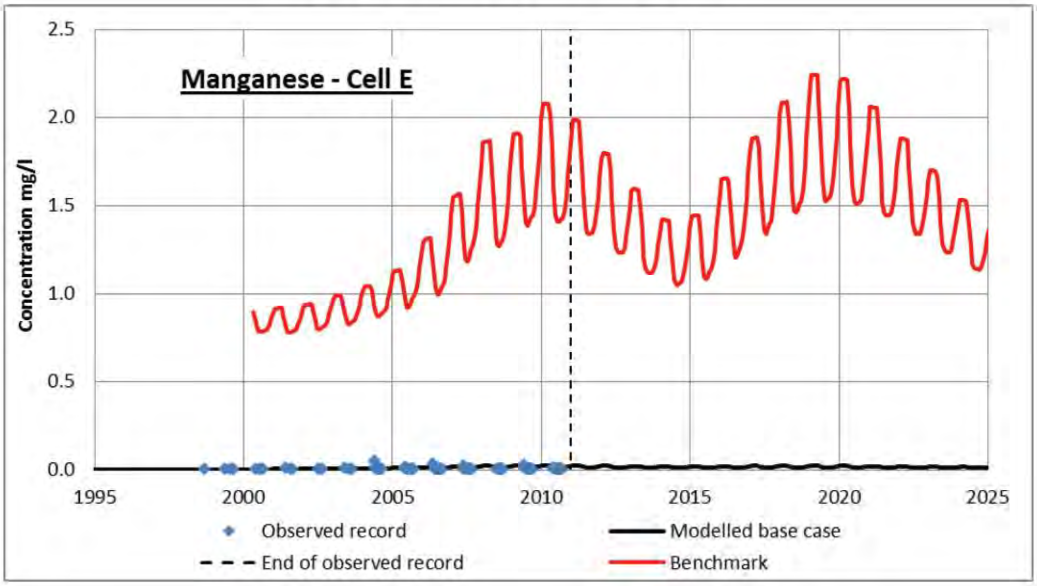
Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD
There is a drop in observed PPD concentrations post-2005, but concentrations are seen to be consistently lower post-2008, with lower average values and lower variability in data.
Modelling Approach for Future PPD
Based on lognormal distribution of all observed PPD data.
Modelled Correlation between WQ Parameters
Manganese is correlated with Aluminium (1)

Figure 2: Model Predictions for LLCF



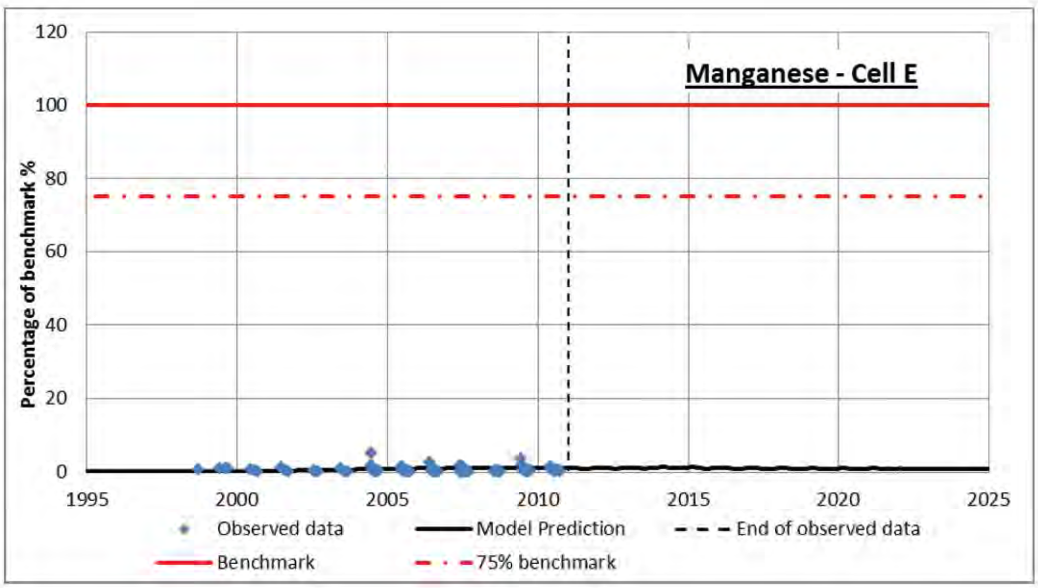


Figure 3: Predictions in Receiving Environment

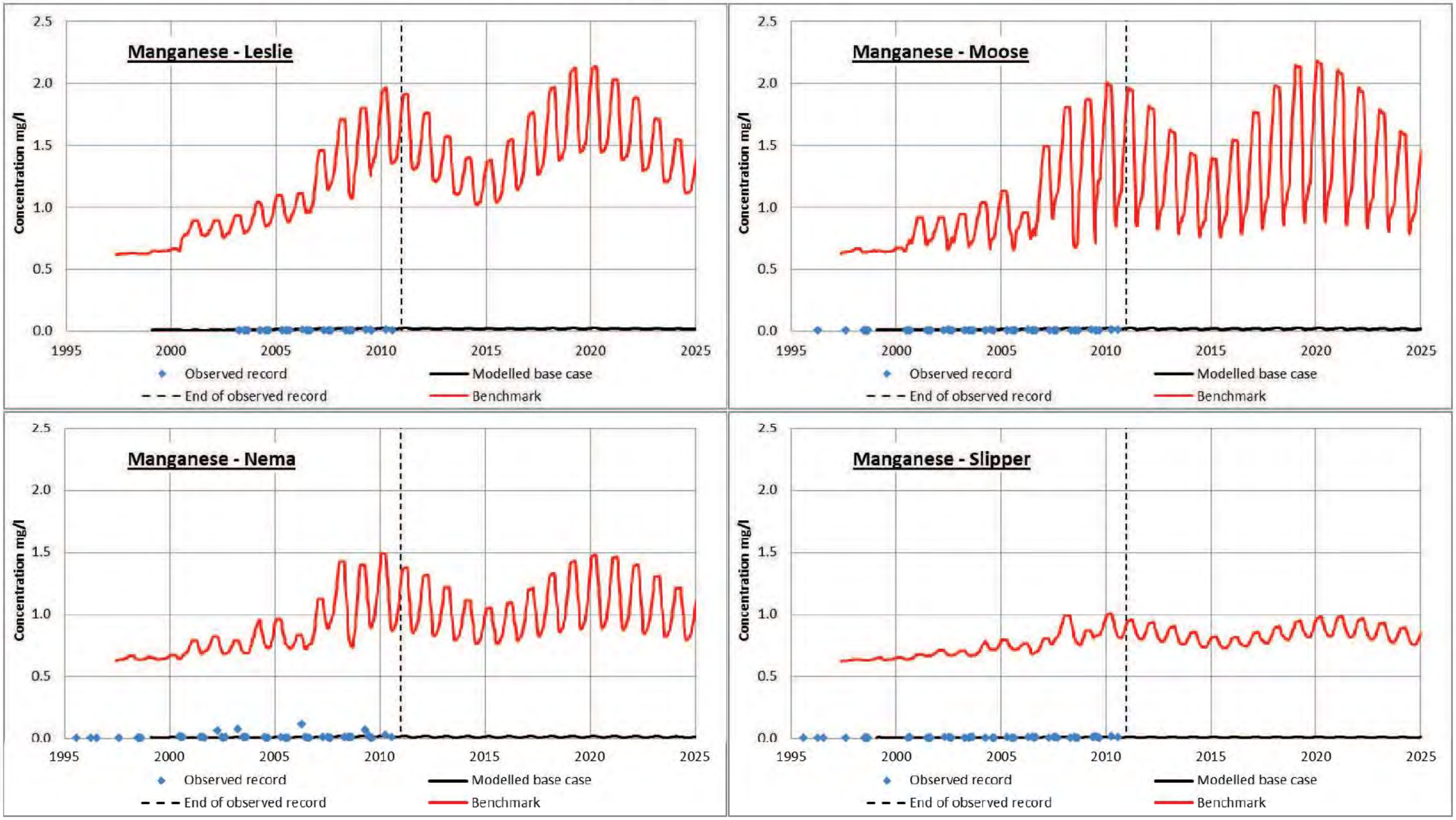
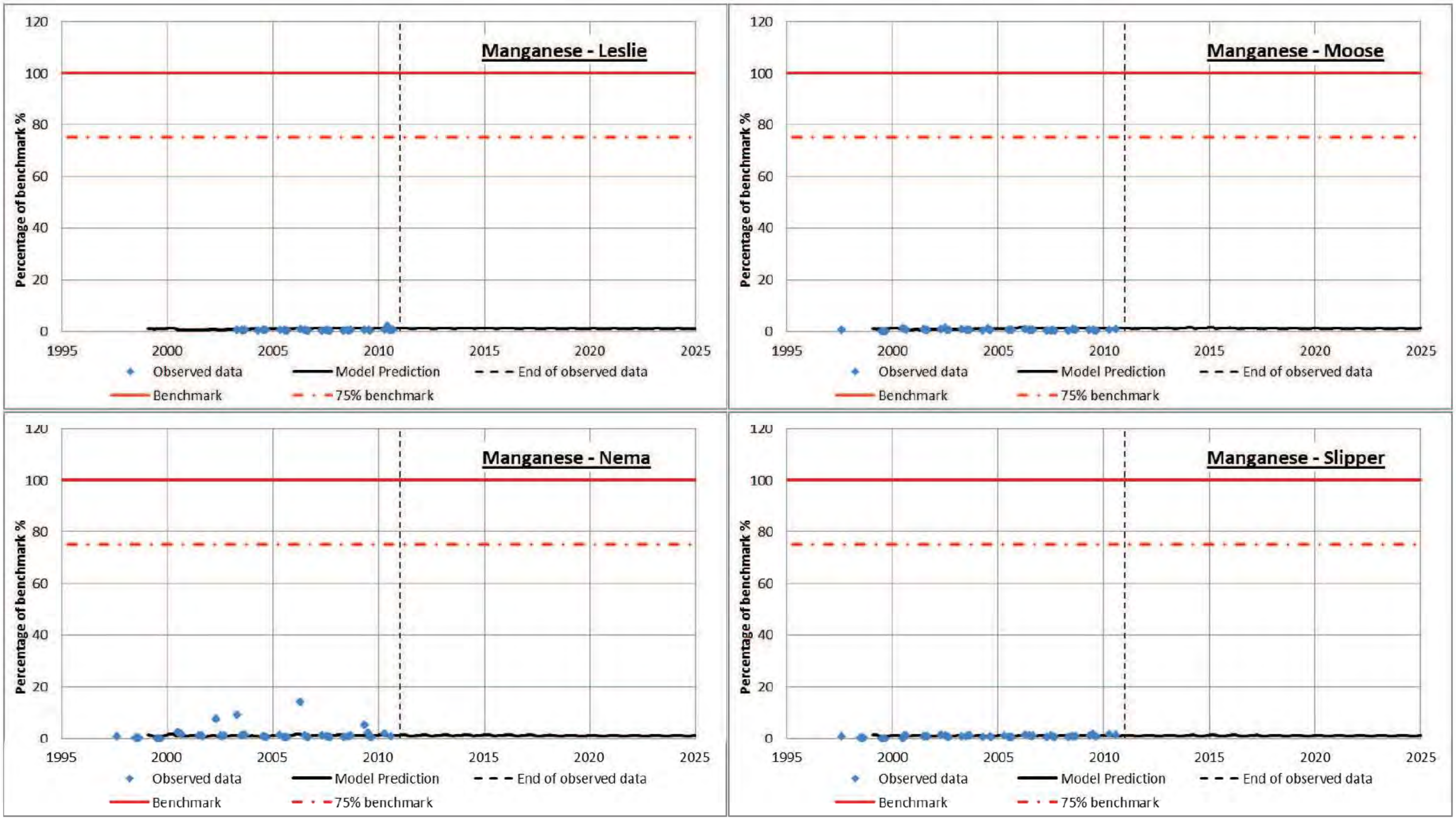


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Molybdenum

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	85%	Process Plant	67%
Sump	6%	Sump	8%
Underground	9%	Underground	0%
Runoff	0%	Runoff	0%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	25%

Key Comments Related to Modelling Work

Nearly all loadings to LLCF are from Process Plant discharge, with Process Plant discharge concentrations having decreased over time.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

19 mg/L (Site Specific WQO).

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.094	0.068	0.163	<1%	0.0075	0.0049	0.03	<1%

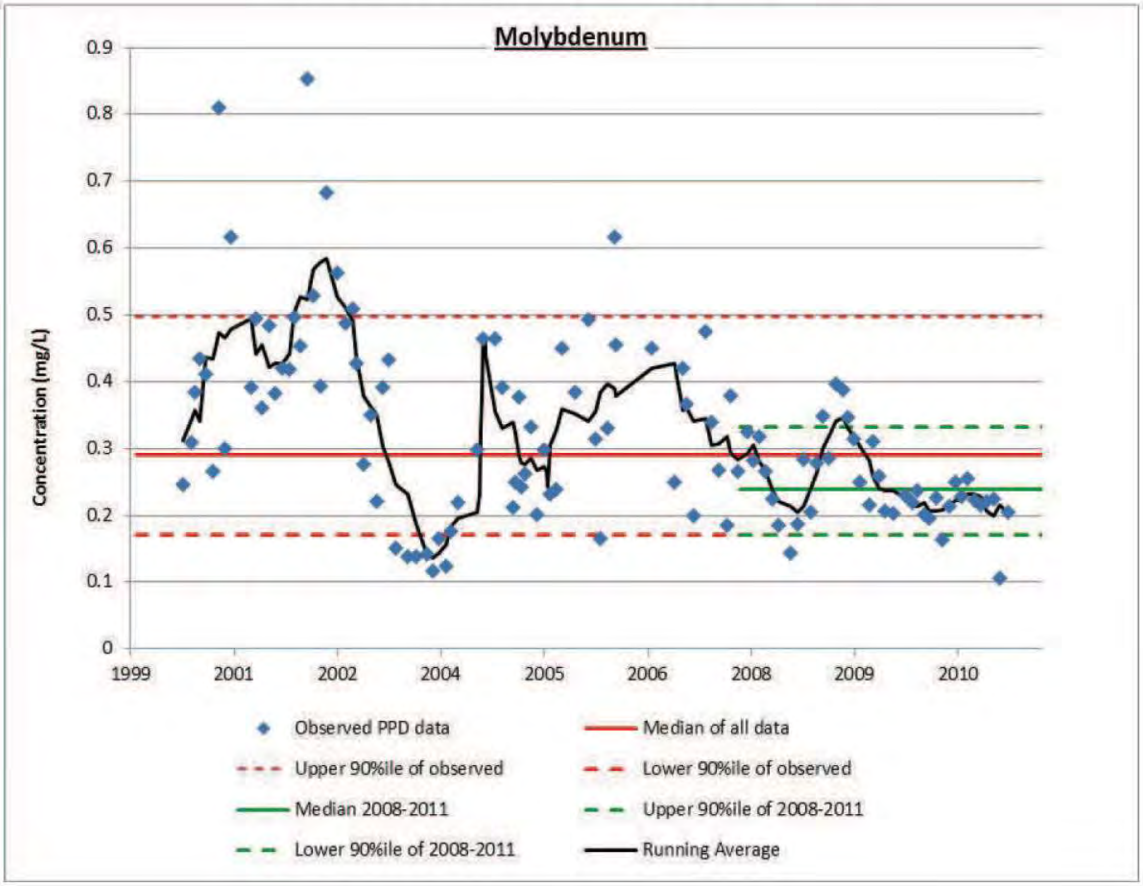
Comment on Model Fit to Observed Data

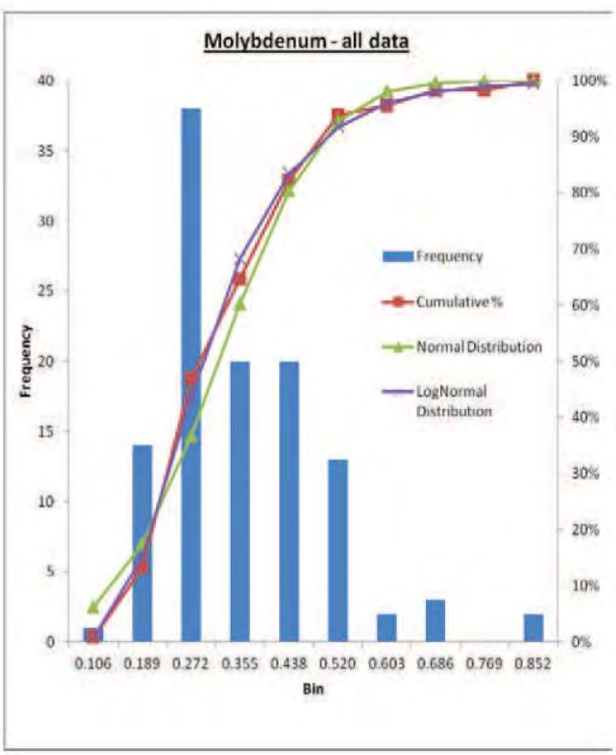
Good fit with historical data in Cell E, Leslie, Moose and Nema. Over-prediction of observed data in Slipper Lake.

Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Lower variability in PPD concentrations post-2008. However, fluctuations in concentrations pre-2008 cannot be related (simply) to changes in ore type.

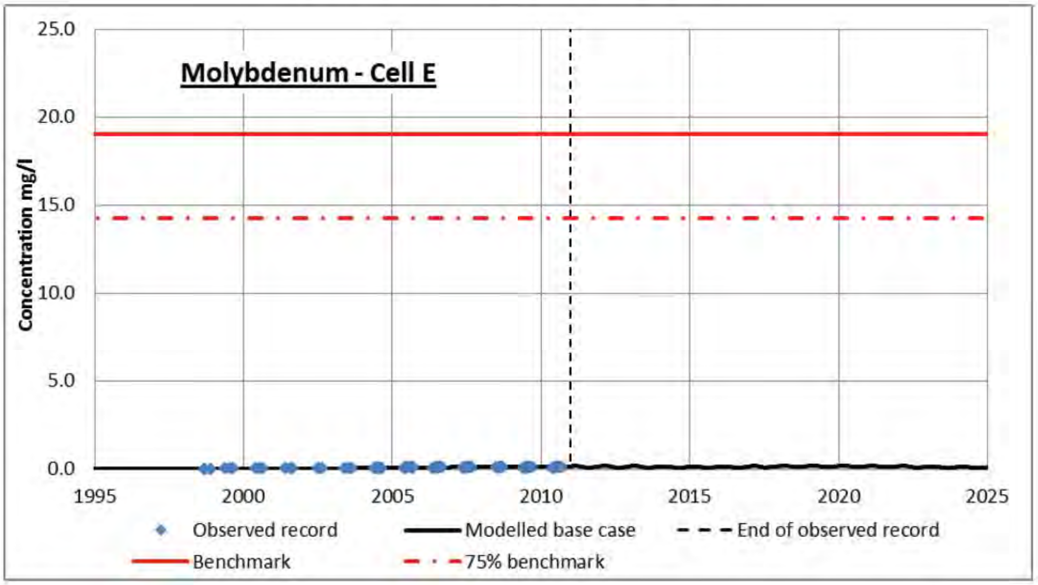
Modelling Approach for Future PPD

Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters

Molybdenum is correlated to cadmium (0.6).

Figure 2: Model Predictions for LLCF



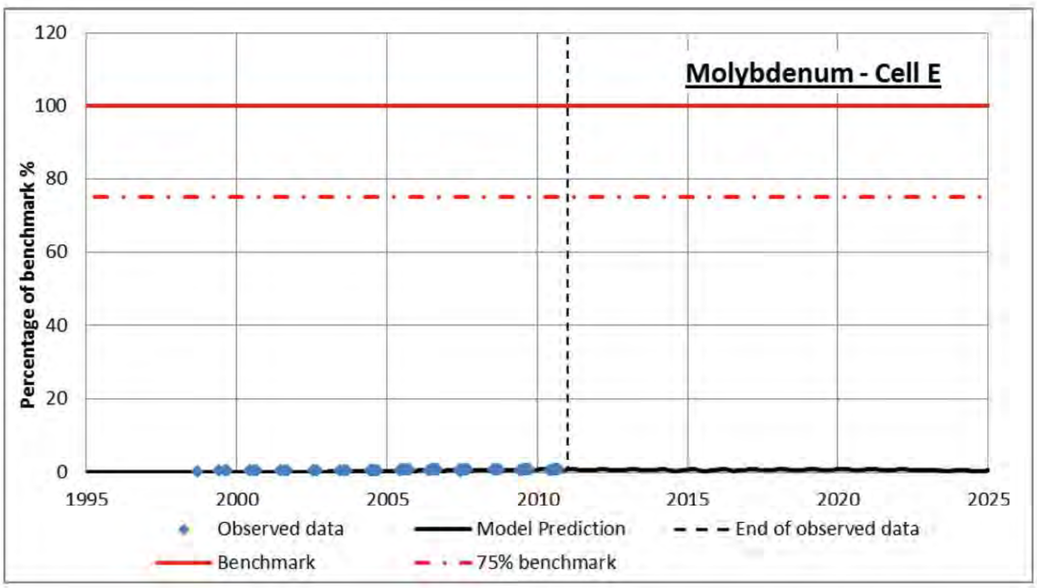


Figure 3: Predictions in Receiving Environment

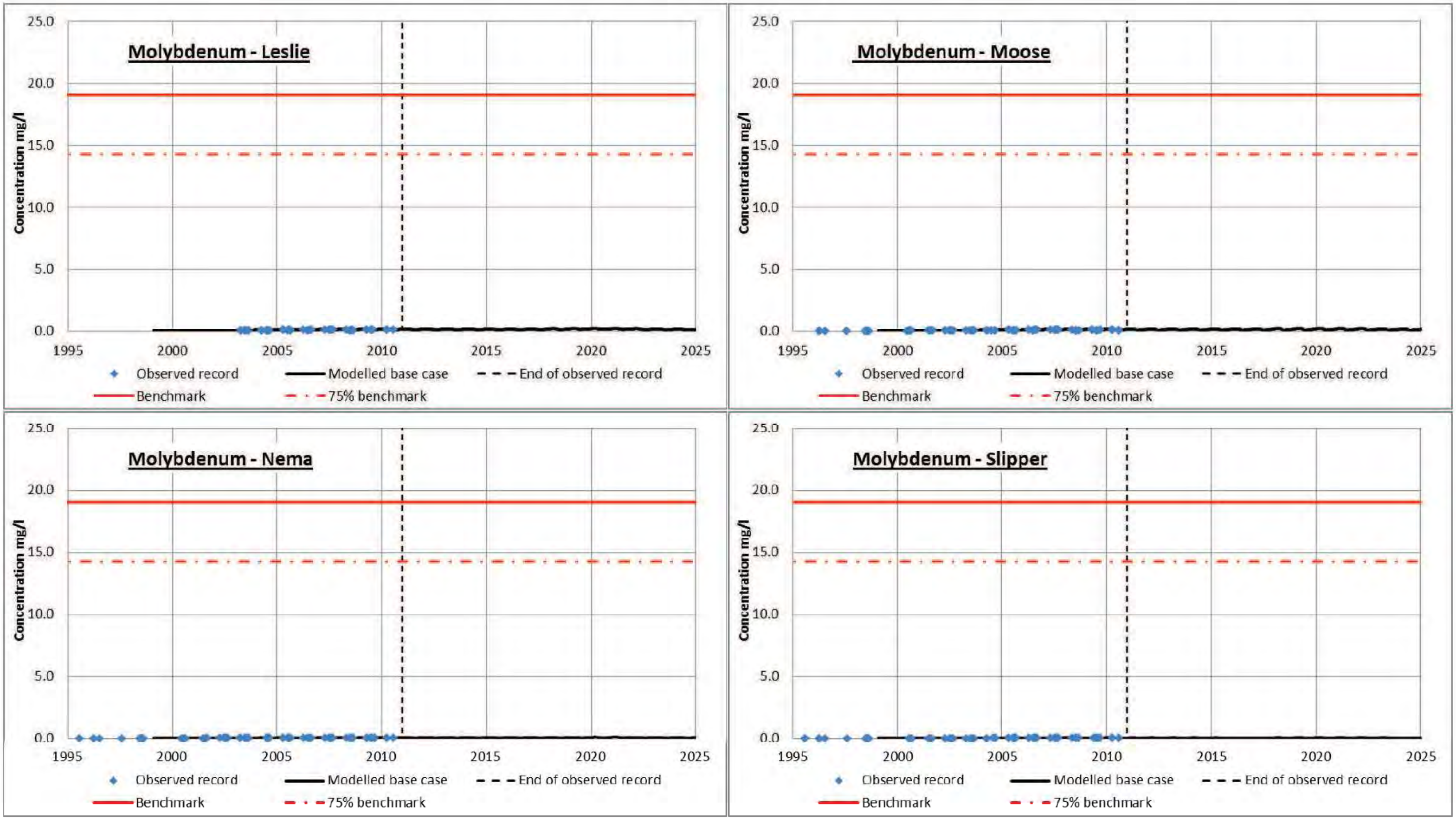
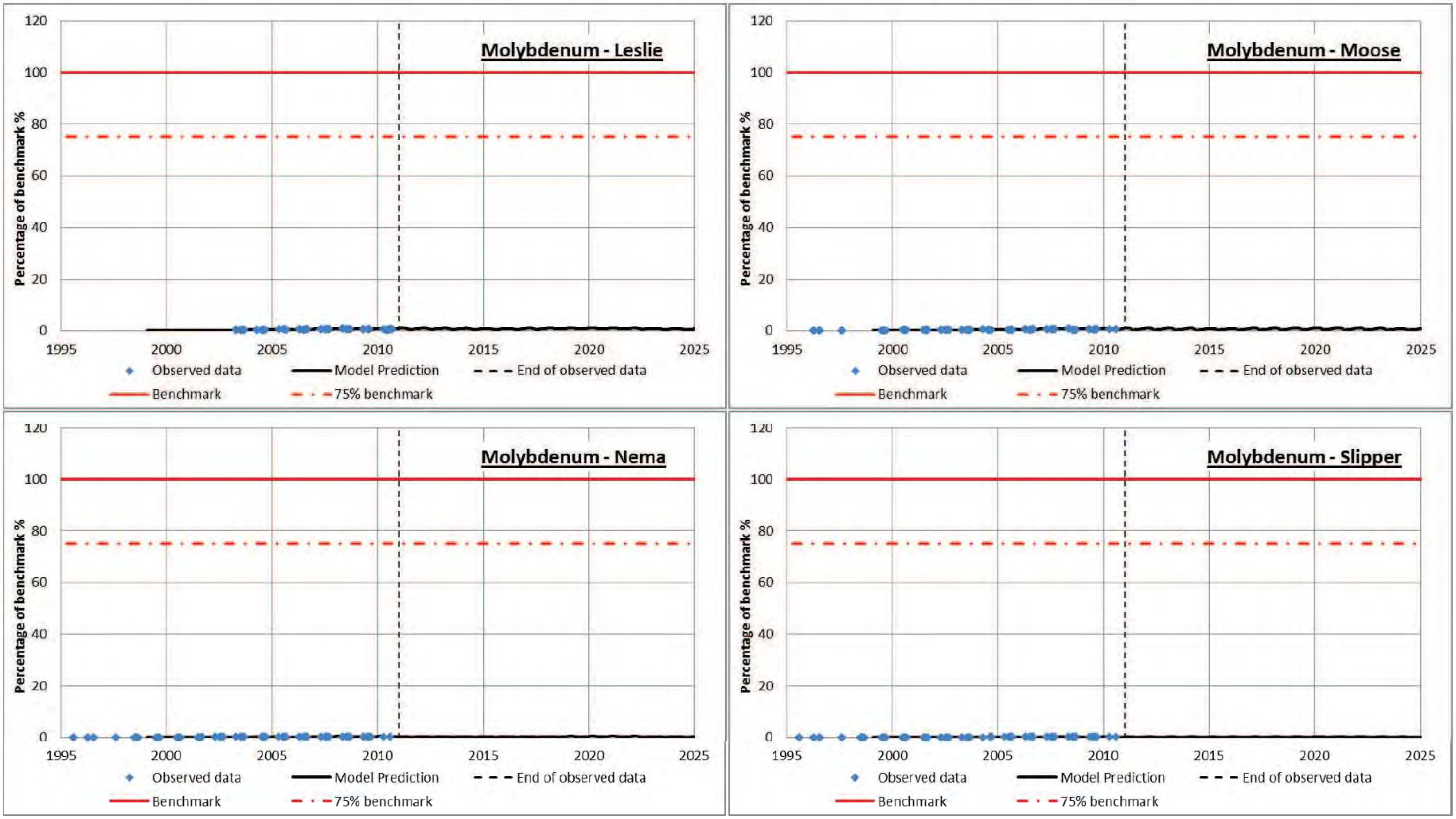


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Nickel

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	59%	Process Plant	44%
Sump	28%	Sump	29%
Underground	4%	Underground	0%
Runoff	9%	Runoff	10%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	16%

Key Comments Related to Modelling Work

Nearly all loadings to LLCF are from Process Plant discharge.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

$e^{(0.76[\ln(\text{hardness})]+1.06)}$ ug/L , with a minimum of 25 ug/L. The relationship is limited to hardness range up to 350 mg/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.0067	0.0036	0.00733	4%	0.012	0.00093	0.00311	5%

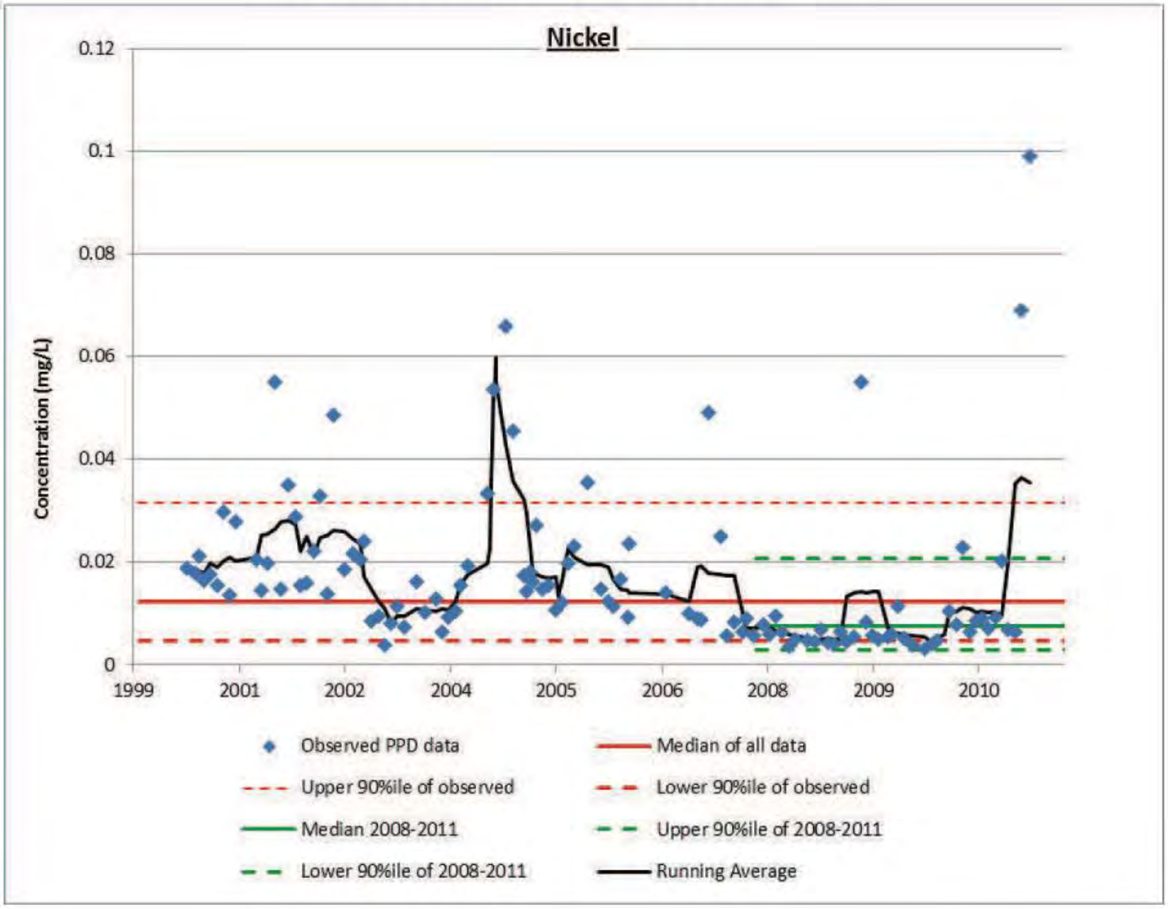
Comment on Model Fit to Observed Data

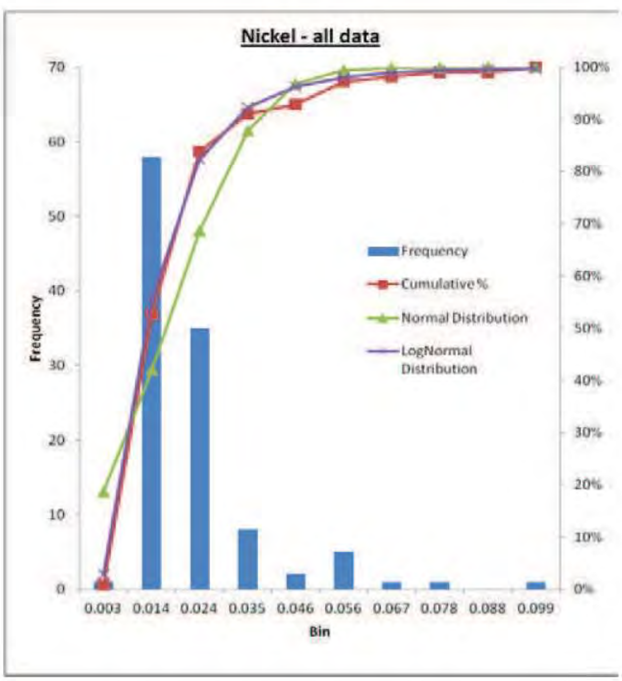
Good fit with historical data in Cell E, Leslie, Moose and Nema. Over-prediction of observed data in Slipper Lake.

Summary

Model predictions for downstream lakes are significantly below 75% of the benchmark. With the exception of outliers, historical concentrations are also significantly below 75% of the benchmark.

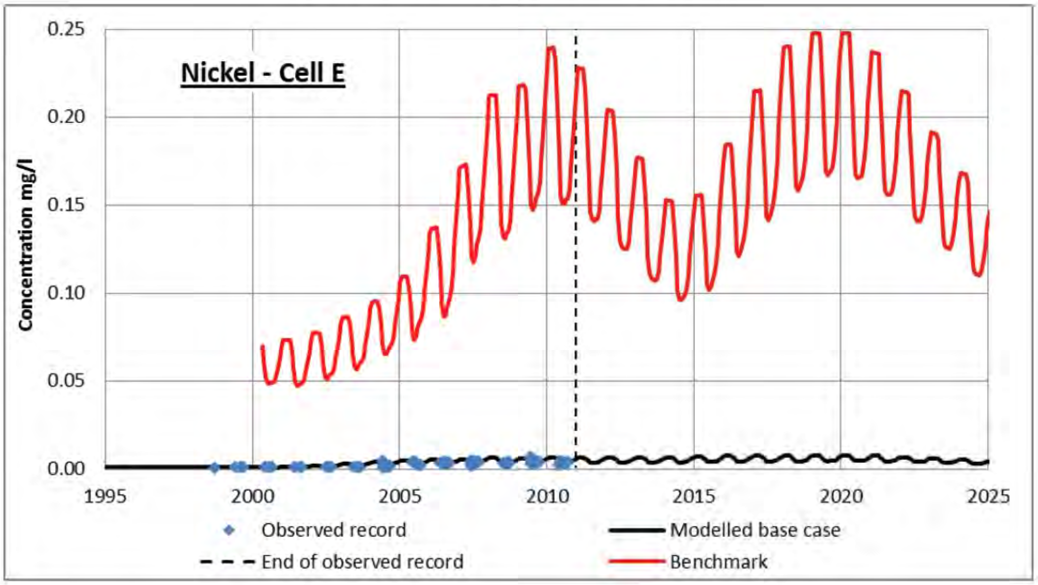
Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD Lower PPD concentrations post 2007/2008, with lower average values and lower variability in data.
Modelling Approach for Future PPD Based on lognormal distribution of all observed PPD data.
Modelled Correlation between WQ Parameters Nickel is correlated to aluminium (0.9)

Figure 2: Model Predictions for LLCF



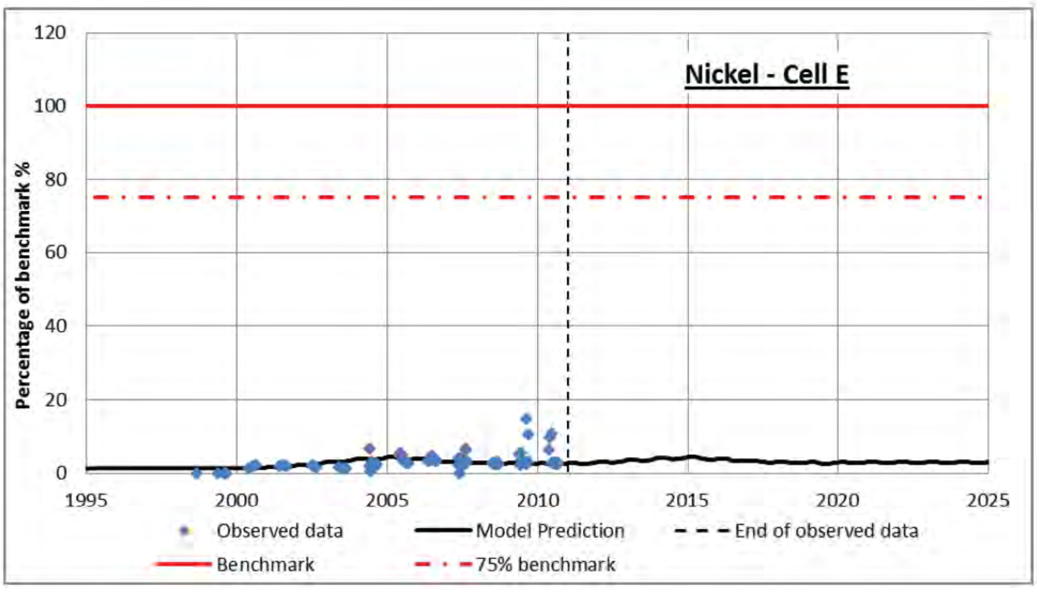


Figure 3: Predictions in Receiving Environment

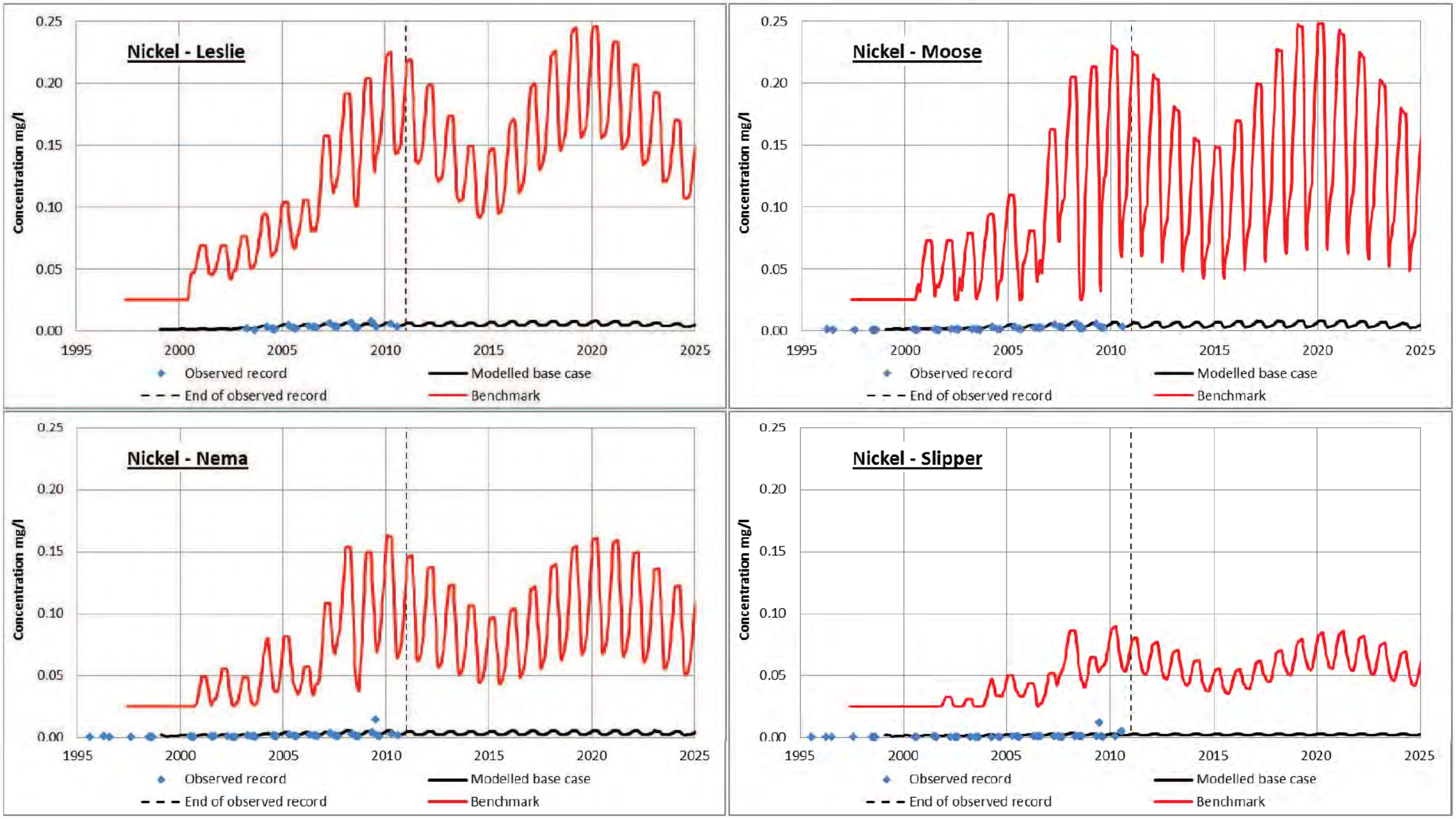
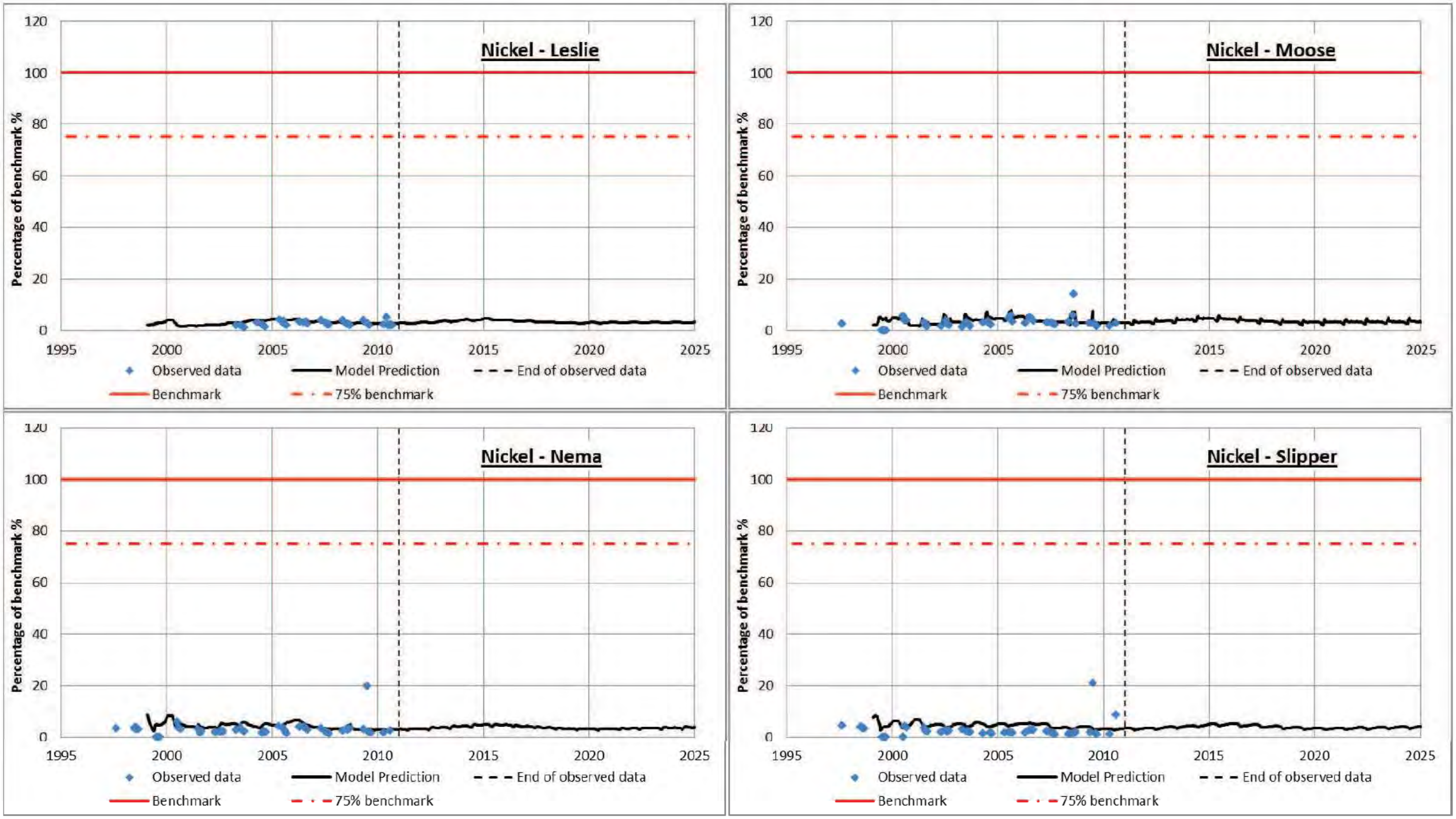


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Nitrate

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	63%	Process Plant	55%
Sump	31%	Sump	27%
Underground	6%	Underground	0%
Runoff	0%	Runoff	0%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	17%

Key Comments Related to Modelling Work

Key loading of Nitrate is from the Process Plant discharge, with concentrations showing an increase since 2005 with processing of underground kimberlite.

Nitrate is not modelled to decay over time as calibration work indicates no requirement for decay of the parameter in the LLCF.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

$e^{(0.9518[\ln(\text{hardness})]-2.032}$ mg/L , relationship is limited to hardness range up to 160 mg/L. (Site specific WQO)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
5.4	3.5	9.22	56%	0.48	0.059	2.08	36%

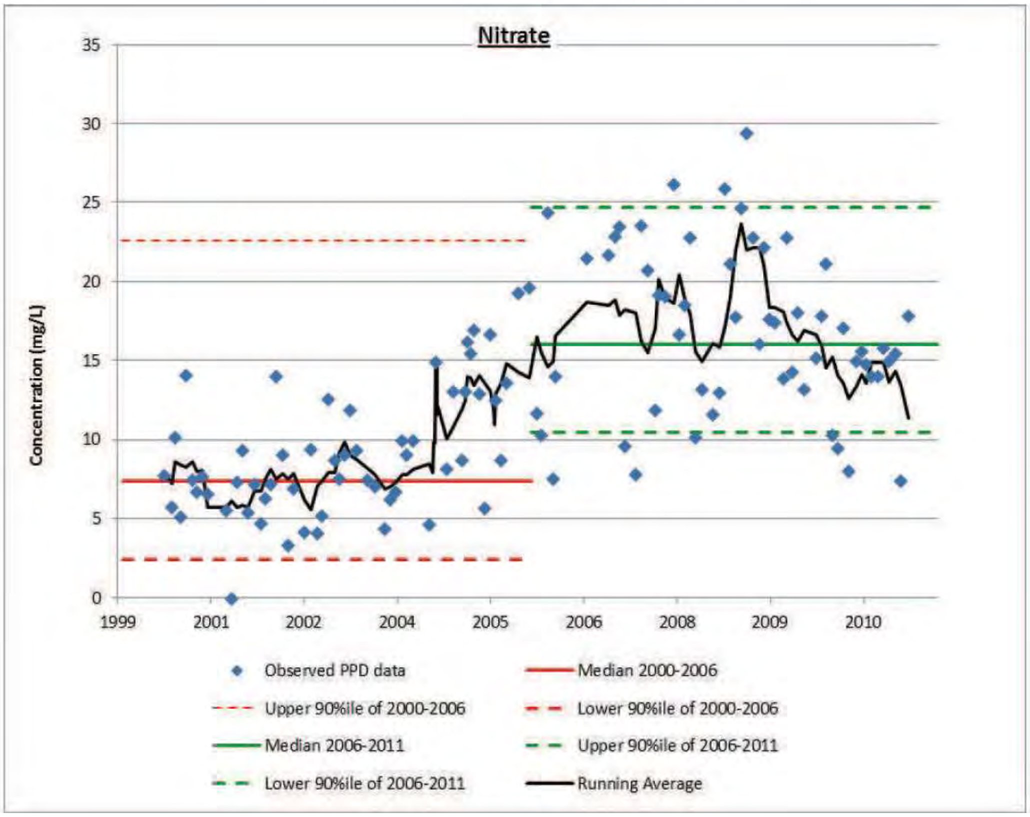
Comment on Model Fit to Observed Data

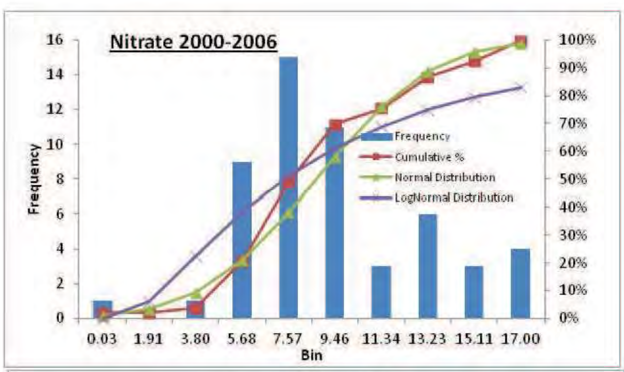
Good fit with observed data.

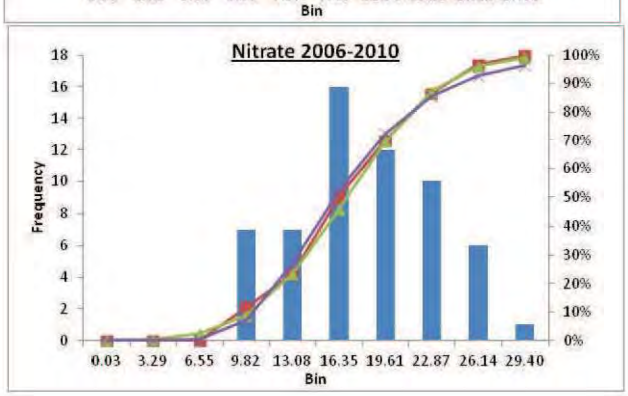
Summary

Historical concentrations and model predictions for downstream lakes are below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model







Comment on Historical Trends in PPD

Observed PPD concentrations increase post-2005, consistent with start of processing of underground ore. May have peaked around 2009/2010.

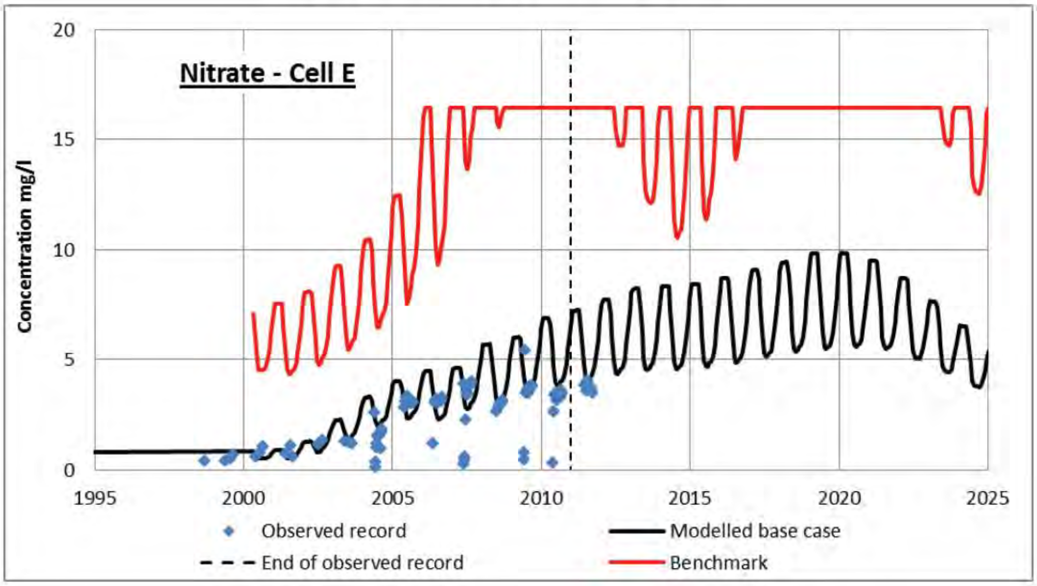
Modelling Approach for Future PPD

2011 to 2020 (except 2018), normal distribution based on observed post-2006 PPD data. For 2018, based on normal distribution for observed 2000-2006 PPD data.

Modelled Correlation between WQ Parameters

Nitrate is correlated with TDS (0.7).

Figure 2: Model Predictions for LLCF



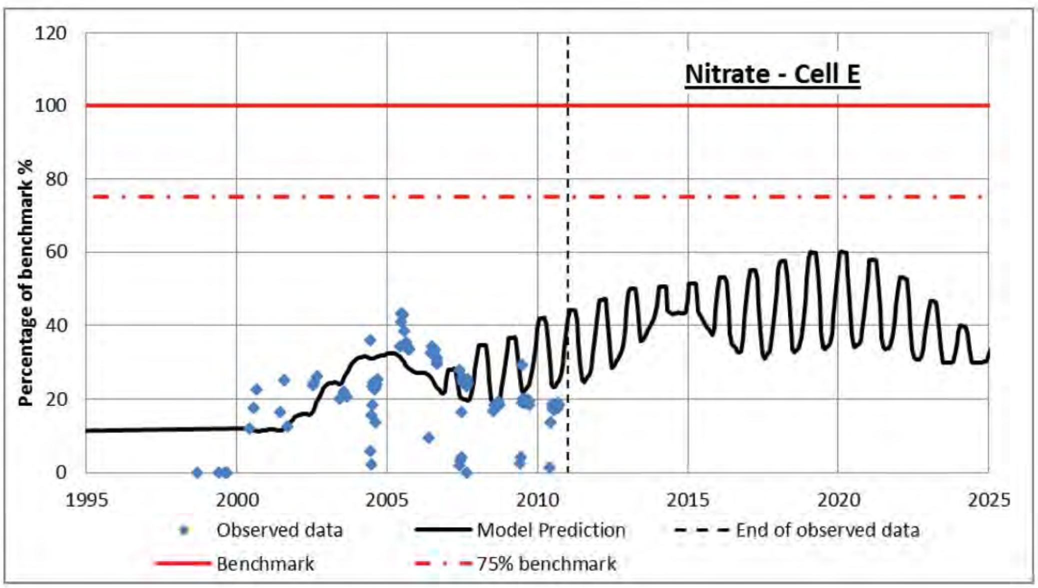


Figure 3: Predictions in Receiving Environment

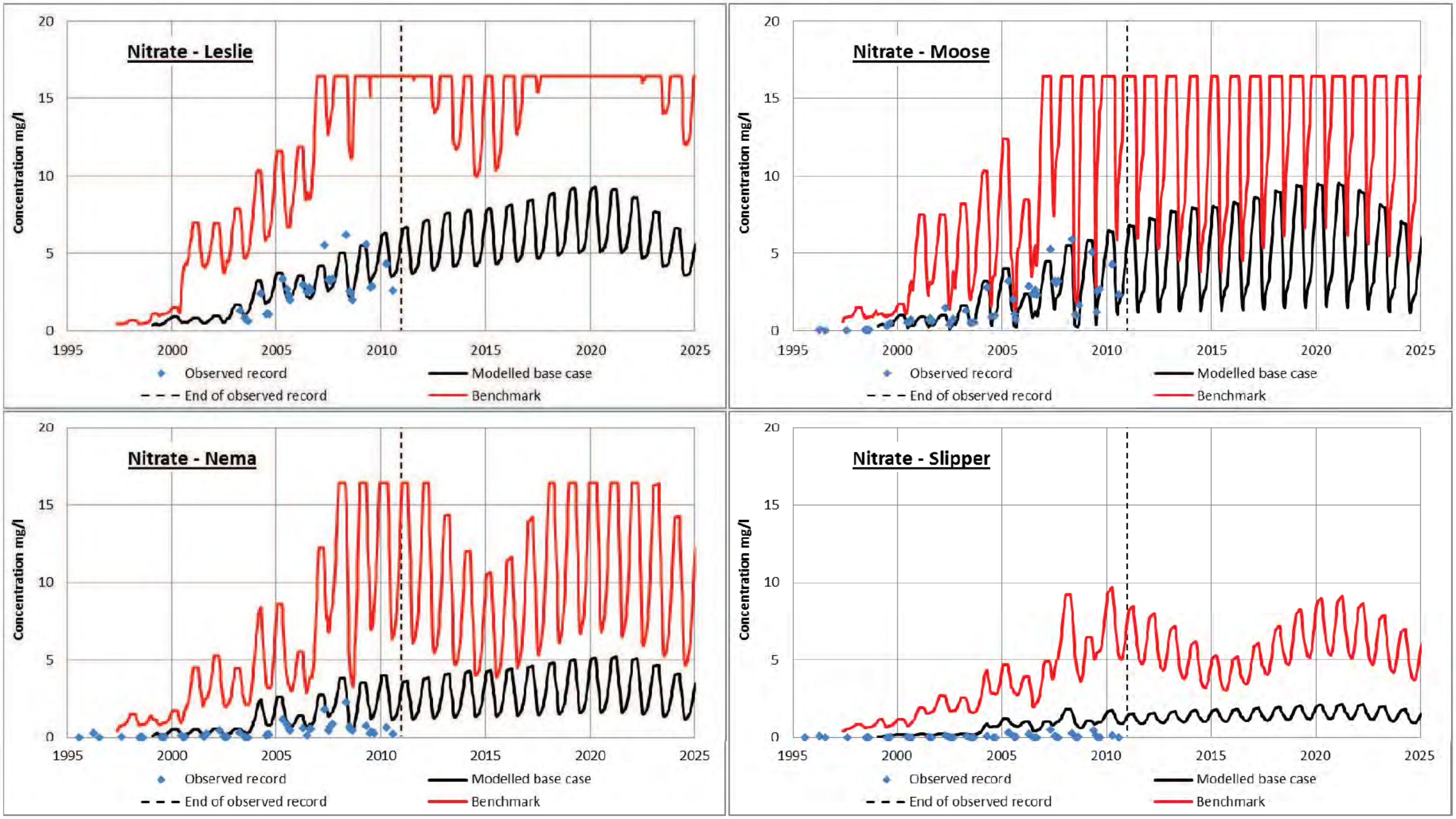
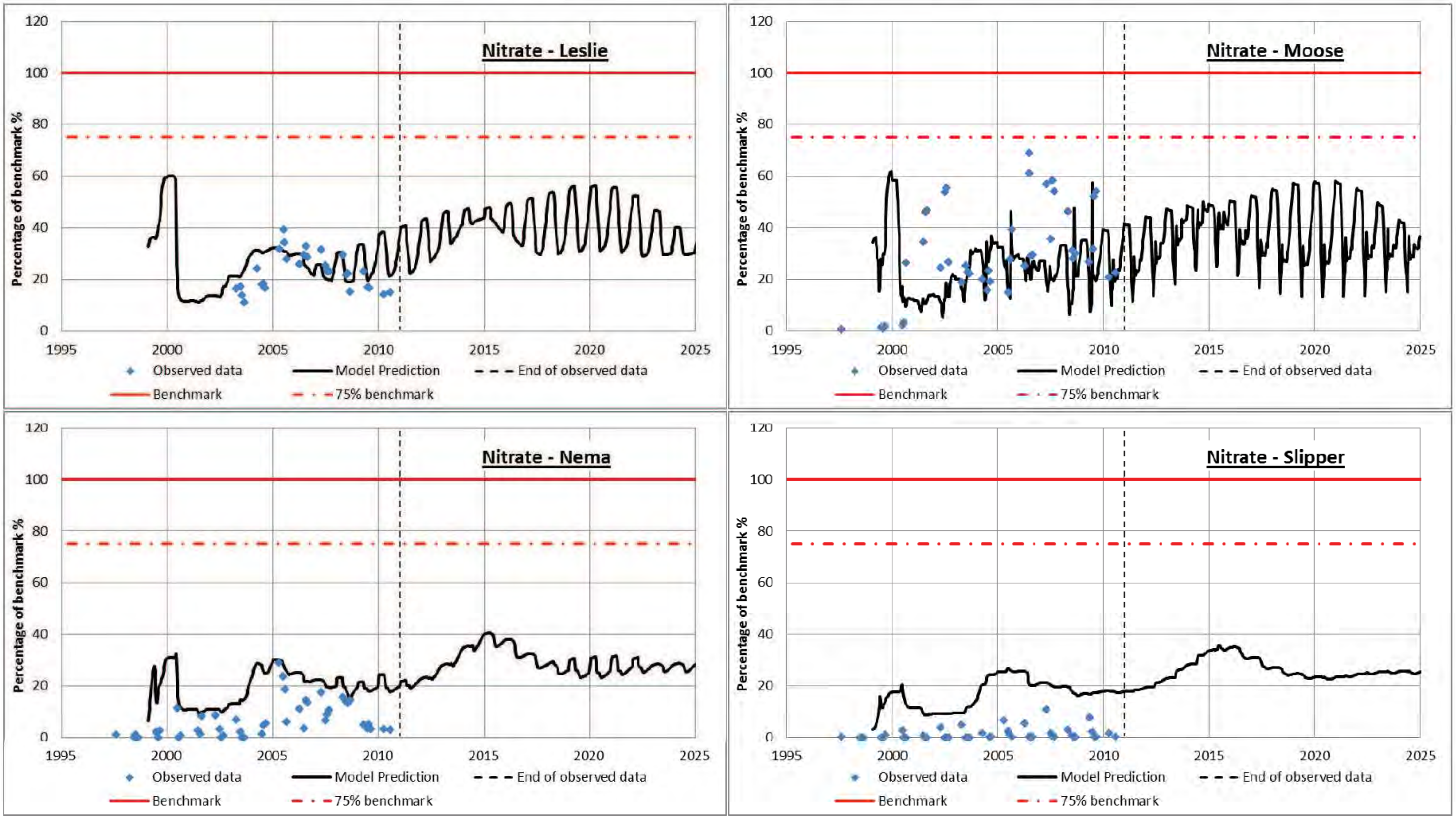


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Nitrite

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	58%	Process Plant	55%
Sump	30%	Sump	38%
Underground	12%	Underground	0%
Runoff	0%	Runoff	0%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	7%

Key Comments Related to Modelling Work

The key loading of Nitrite is from the Process Plant discharge, although there are limited historical data with which to make future predictions.

Nitrite is modelled to decay over time within the model with a calibrated half-life of 8.3 months.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.06 mg/L (CCME)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.022	0.00078	0.0213	35%	0.009	0.0005	0.00578	10%

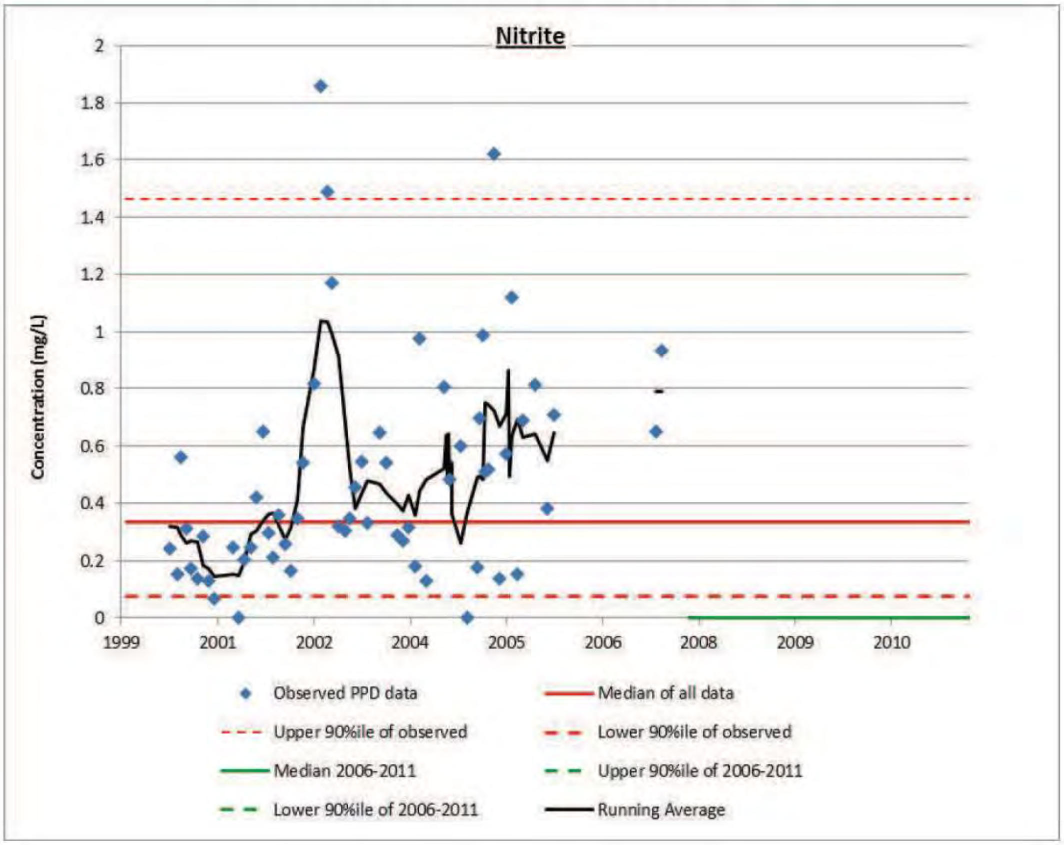
Comment on Model Fit to Observed Data

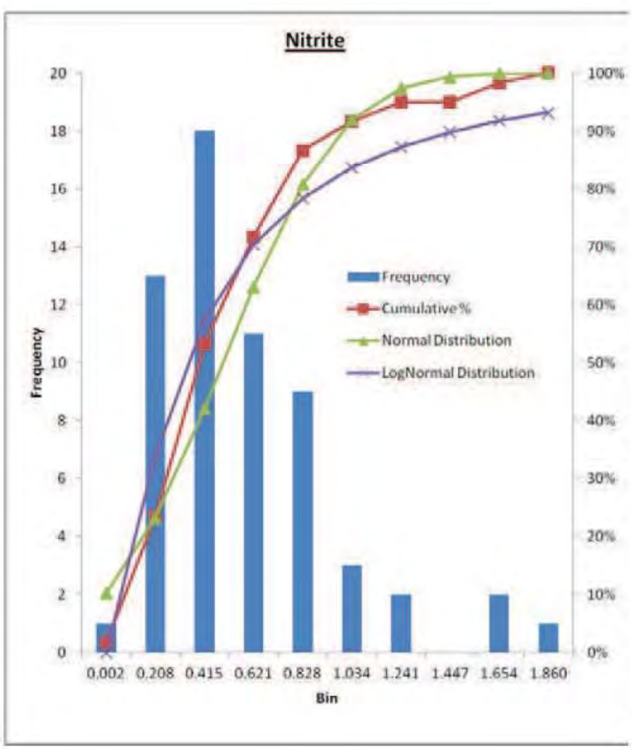
Model results are a good fit with observed data.

Summary

Historical concentrations and model predictions for downstream lakes are below 75% of the benchmark.

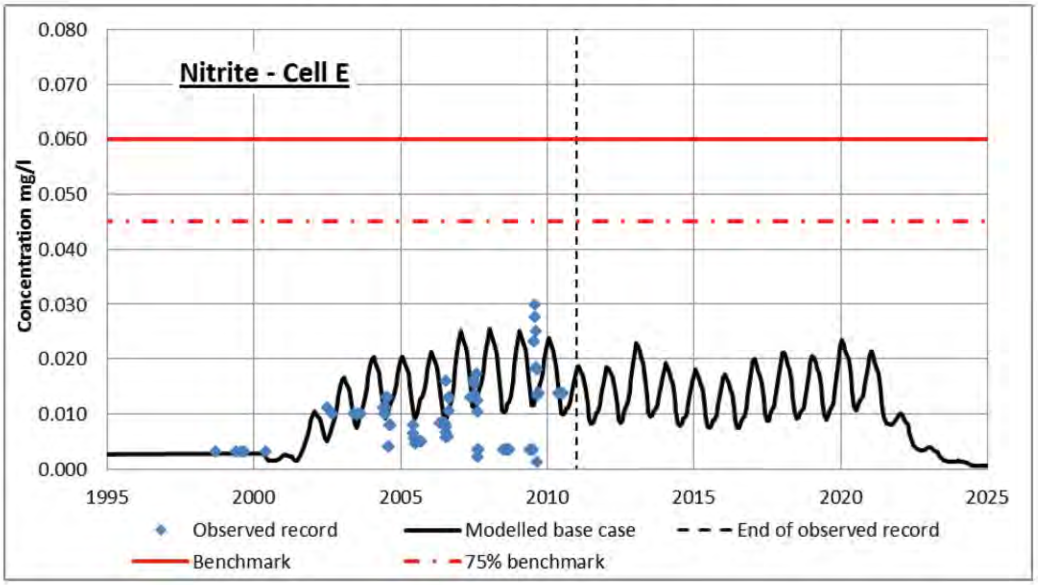
Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD No data post-2005.
Modelling Approach for Future PPD Based on normal distribution of all observed PPD data.
Modelled Correlation between WQ Parameters Nitrite is uncorrelated to any parameter.

Figure 2: Model Predictions for LLCF



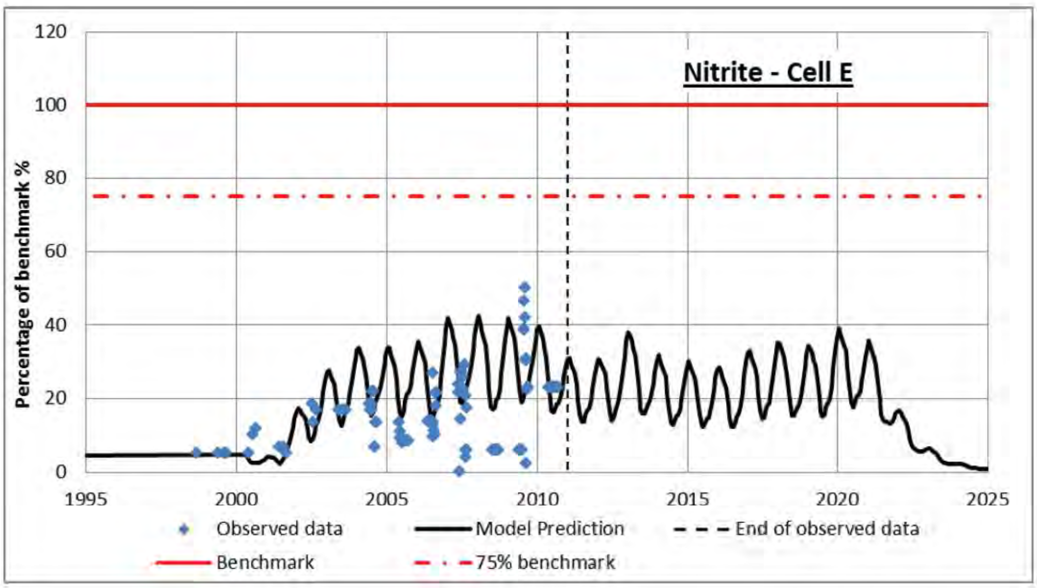


Figure 3: Predictions in Receiving Environment

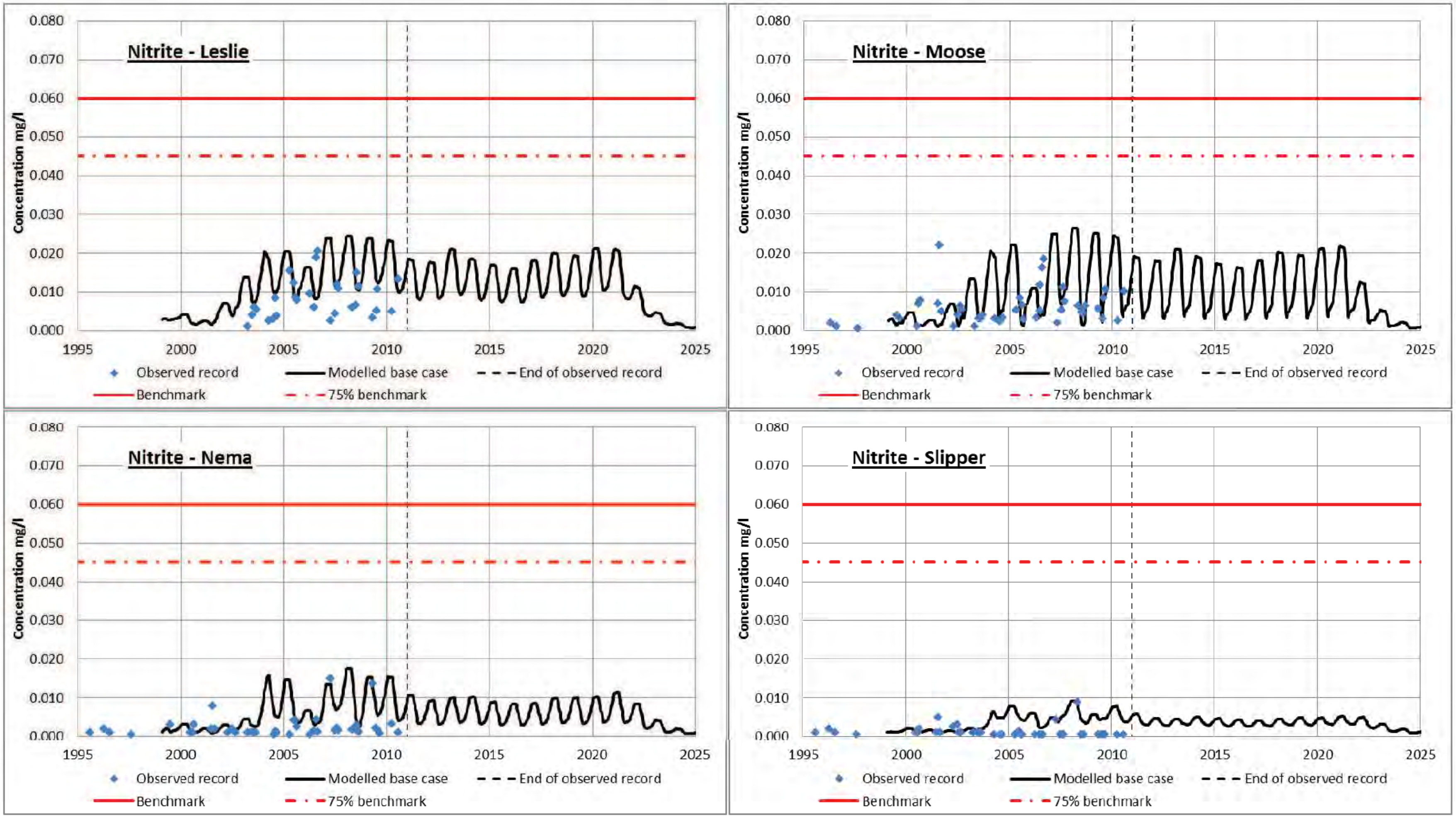
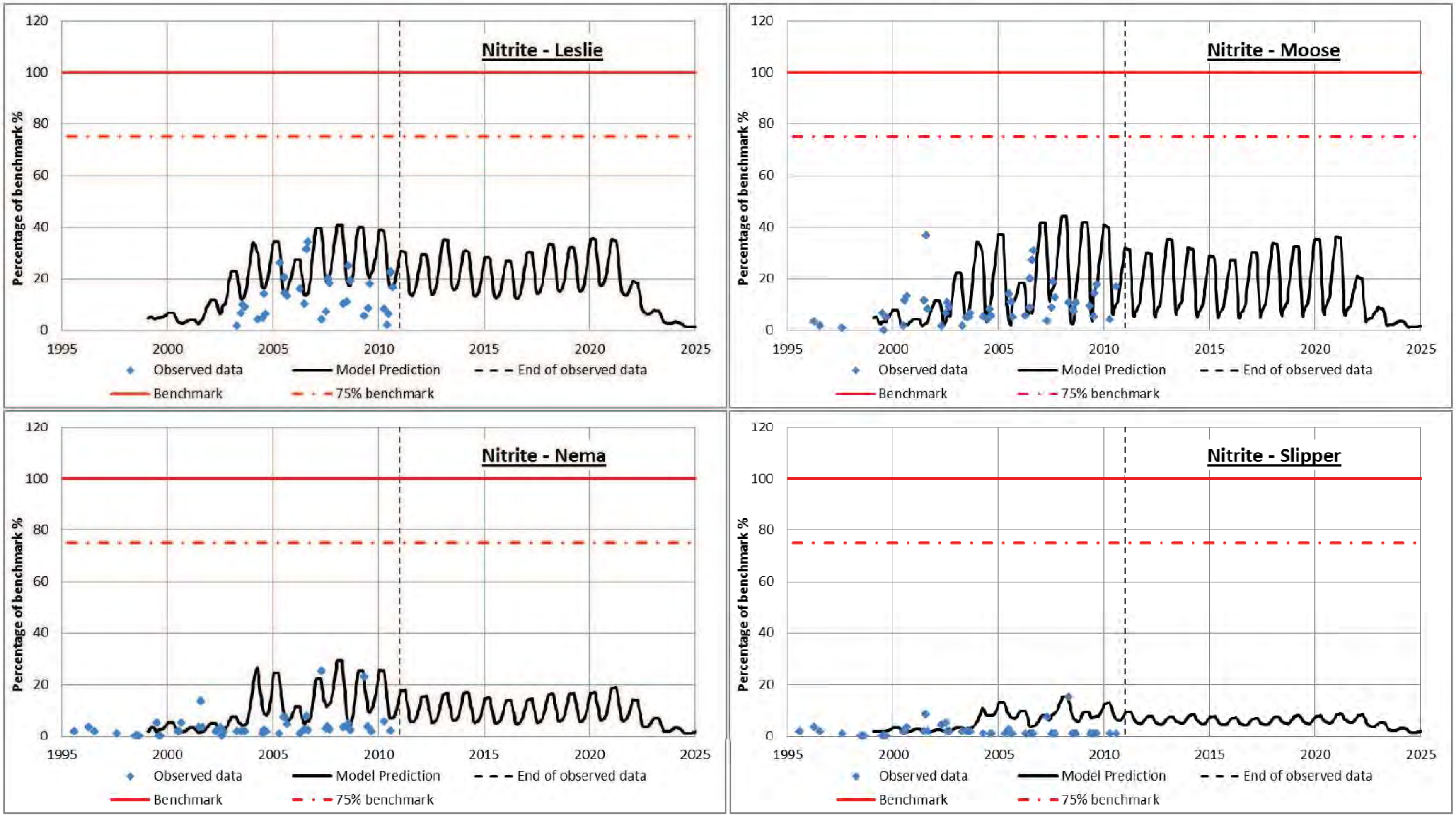


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Phosphate

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	32%	Process Plant	35%
Sump	12%	Sump	25%
Underground	38%	Underground	0%
Runoff	18%	Runoff	27%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	12%

Key Comments Related to Modelling Work

Historically inputs of Phosphate are distributed between the Process Plant discharge, underground water and natural runoff. However, Phosphate was added to Cell D of the LLCF in summer 2009, 2010, 2011 as part of a fertilisation study. These additional loadings produced marked increases in phosphate in Cell D and Cell E.

There are losses of Phosphate within the LLCF due to its uptake as a nutrient and it is modelled using a first order decay equation (similar to that used for ammonia and nitrate). The decay rate used in the modelling was calculated through calibration. A time varying decay rate was required to produce a calibrated model, with a higher rate of decay (half-life of 2.1 months) during the period of fertiliser addition and a lower rate of decay (half-life of 11.1 months) at other times. A time varying decay rate is reasonable as overall update dynamics of Phosphate by plankton will be different during an induced bloom compared to the natural oligotrophic state of the LLCF. The lower natural decay rate is used in the model for the period post-2012, when no additional fertiliser addition is modelled.

It should be noted that Phosphate concentrations have not been monitored in the Process Plant discharge since January 2006.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

Canadian Guidance Framework for the Management of Phosphorus in Freshwater Systems for oligotrophic lakes set out a framework to determine acceptable levels of phosphorous nutrient. These guidelines are based on potential changes to nutrient and trophic status of water bodies and not on toxicity. For oligotrophic lakes total phosphorus should be below 0.01 mg/L and should not be allowed to increase more than 50% over the baseline levels without further assessment; Leslie Lake = 0.0096 mg/L; Moose Lake = 0.0077 mg/L ; Nema Lake = 0.0091 mg/L; Slipper Lake = 0.01 mg/L. It should be noted that these limits are based on baseline monitoring during the open water season and do not take into account winter ice exclusion processes. As a result they are only valid for the open water season.

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.045	0.0043	0.00864	90%	0.012	0.0046	0.0105	104%

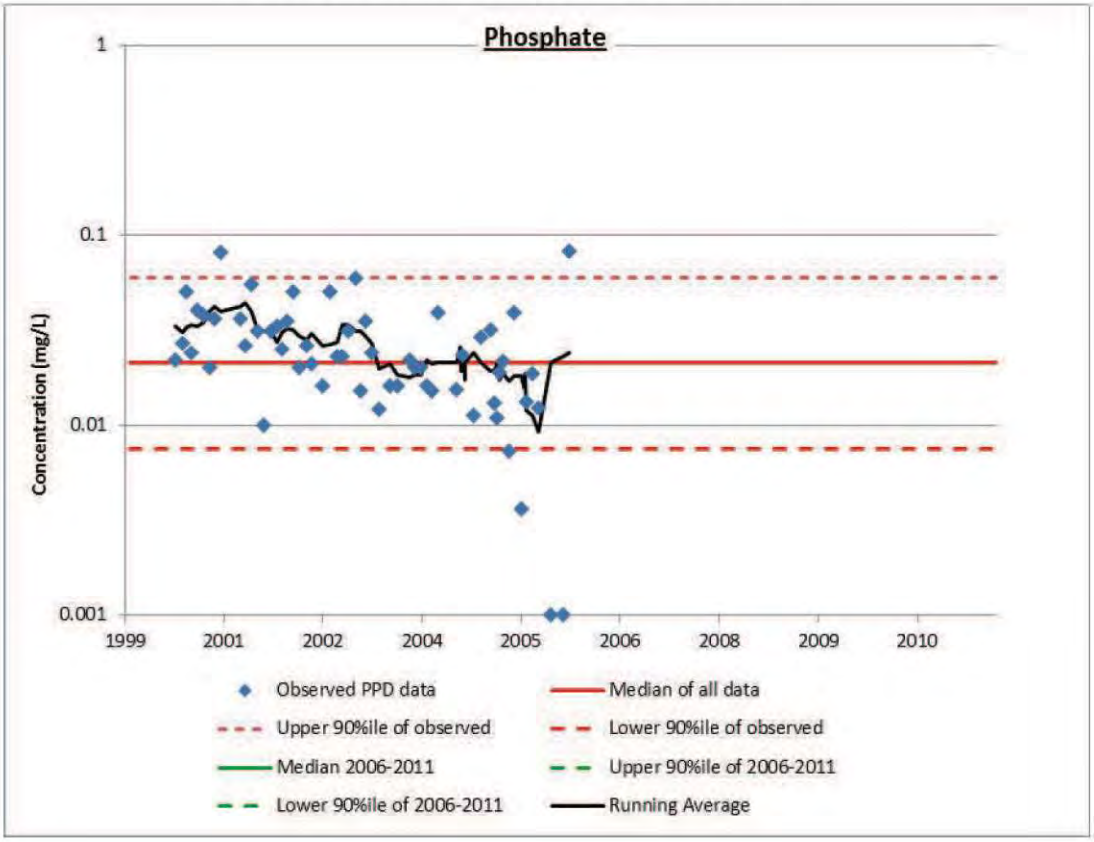
Comment on Model Fit to Observed Data

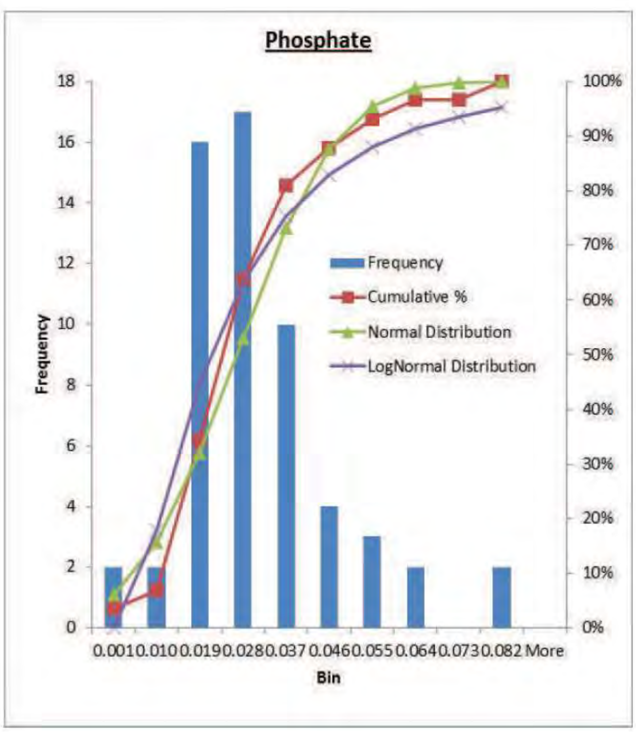
Reasonable calibration with observed data was achieved using first order decay and a calibrated decay rate of 4.2 months, however, predictions for Cell E and downstream lakes for the period of the fertilization study appear to be over predicted compared to observed data.

Summary

Model predictions indicated that results for Cell E and Leslie Lake exceed the benchmark; however; results for Slipper did not exceed 75% of the benchmark. The modelled exceedances of phosphate in downstream lakes are associated with phosphate amendments made to Cell D as part of a fertilization study in 2008, 2009 and 2010. The modeling results indicate that over the short term these phosphate will return to concentrations below 75% of the benchmark.

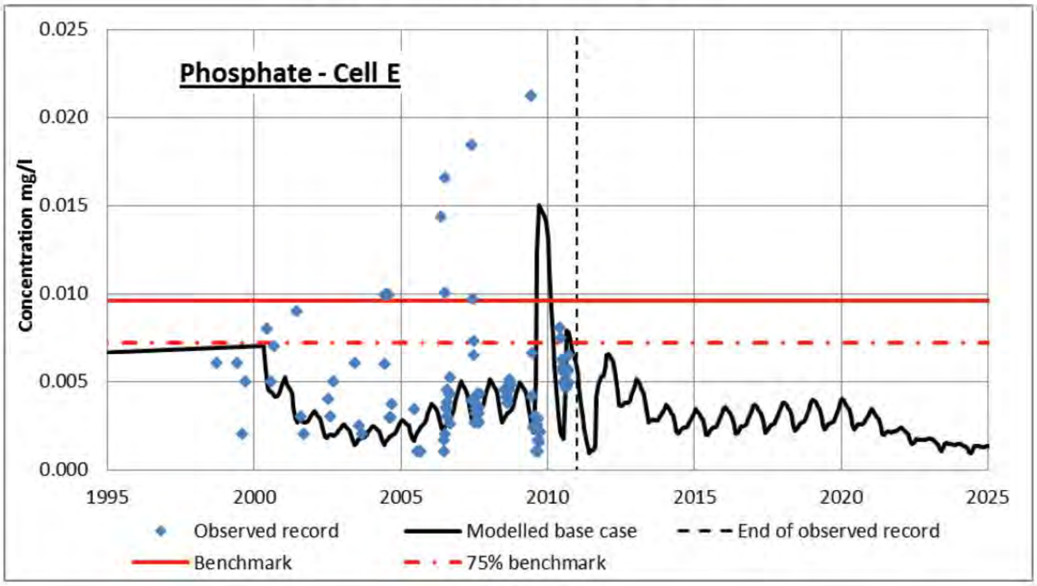
Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD No PPD samples post-Jan 2006. General falling trend was seen from Feb 2000 to Jan 2006; however no data to assess trend in period Jan 2006 to present.
Modelling Approach for Future PPD Based on normal distribution of all available PPD data (i.e., from Feb 2000 to Jan 2006).
Modelled Correlation between WQ Parameters Phosphate is correlated to TDS (0.5).

Figure 2: Model Predictions for LLCF



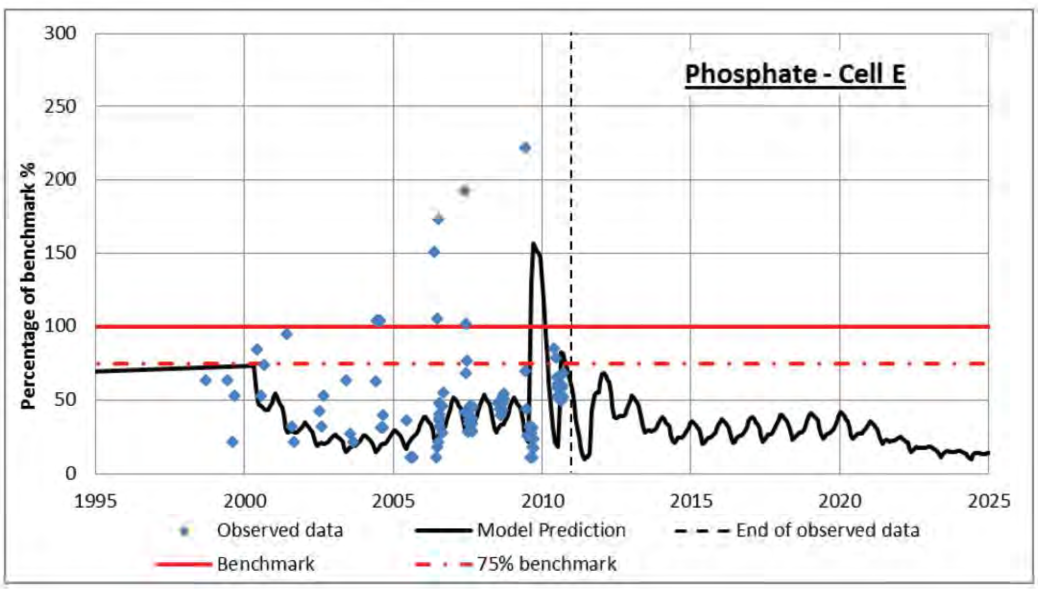


Figure 3: Predictions in Receiving Environment

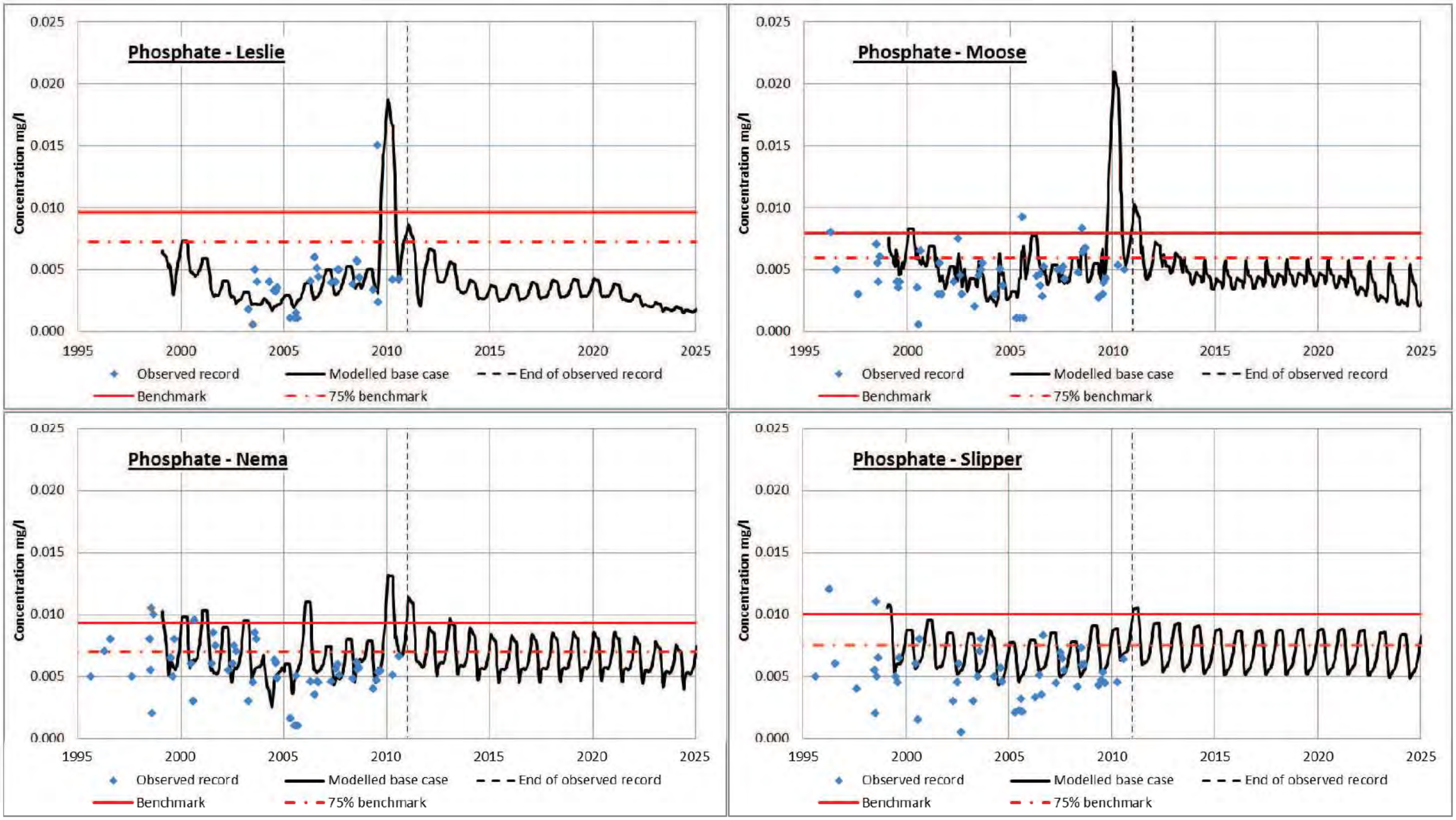
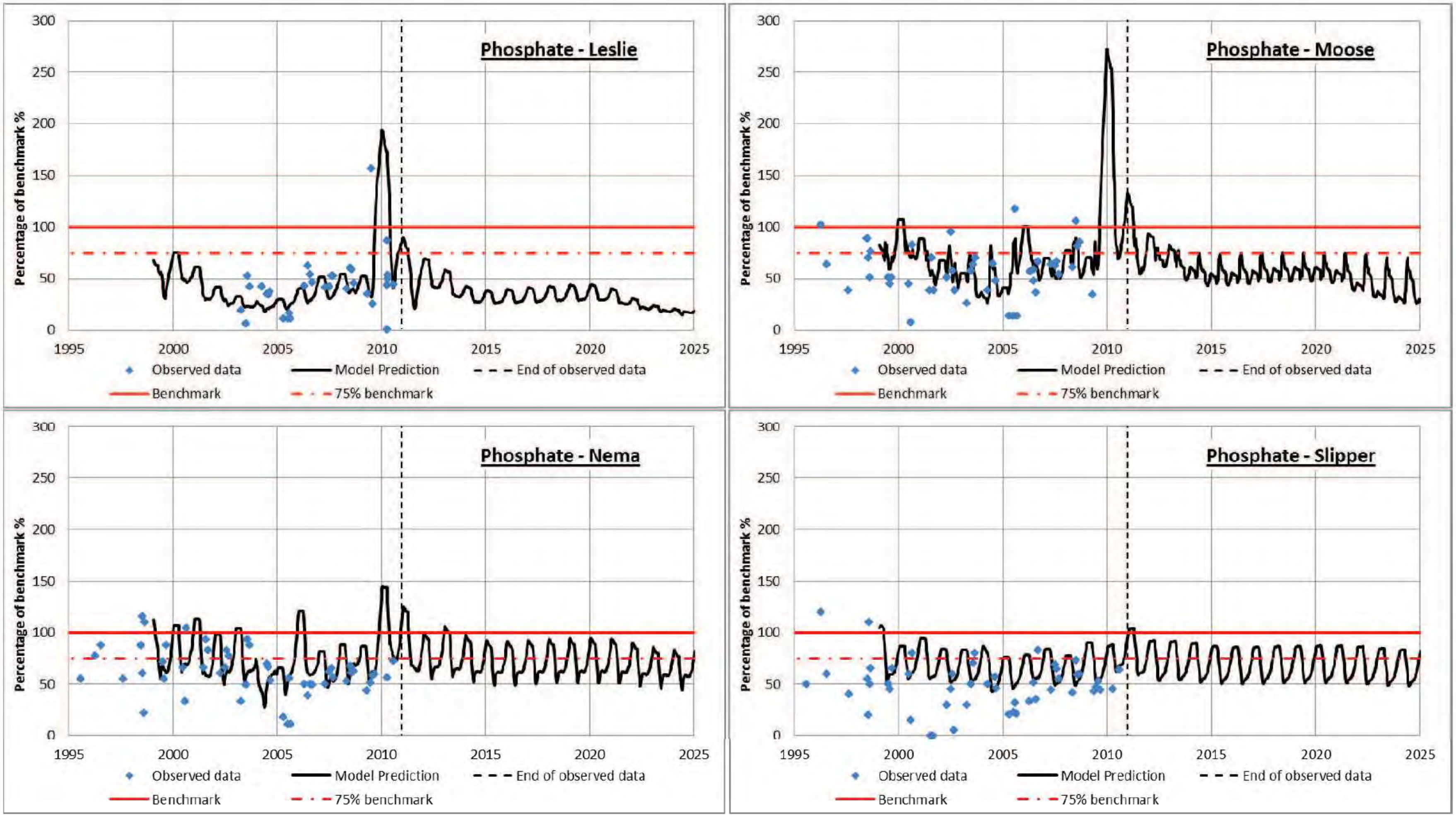


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Potassium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	72%	Process Plant	63%
Sump	11%	Sump	6%
Underground	15%	Underground	0%
Runoff	3%	Runoff	3%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	28%

Key Comments Related to Modelling Work

Key loadings to LLCF are from the Process Plant discharge, with concentrations increasing post-2005 with processing of underground kimberlite. Due to increase in Process Plant discharge concentrations post-2005 future model predictions show concentrations increasing until end of operations.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water. Hence, potassium loadings stored in Beartooth pit will enter the LLCF with the Process Plant discharge at this time causing the peak in Potassium concentrations in the LLCF and downstream lakes predicted for 2019/2020.

Water Quality Benchmark

41 mg/L (Site Specific WQO)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
34	22	41.1	100%	6.9	3.1	9.89	24%

Comment on Model Fit to Observed Data

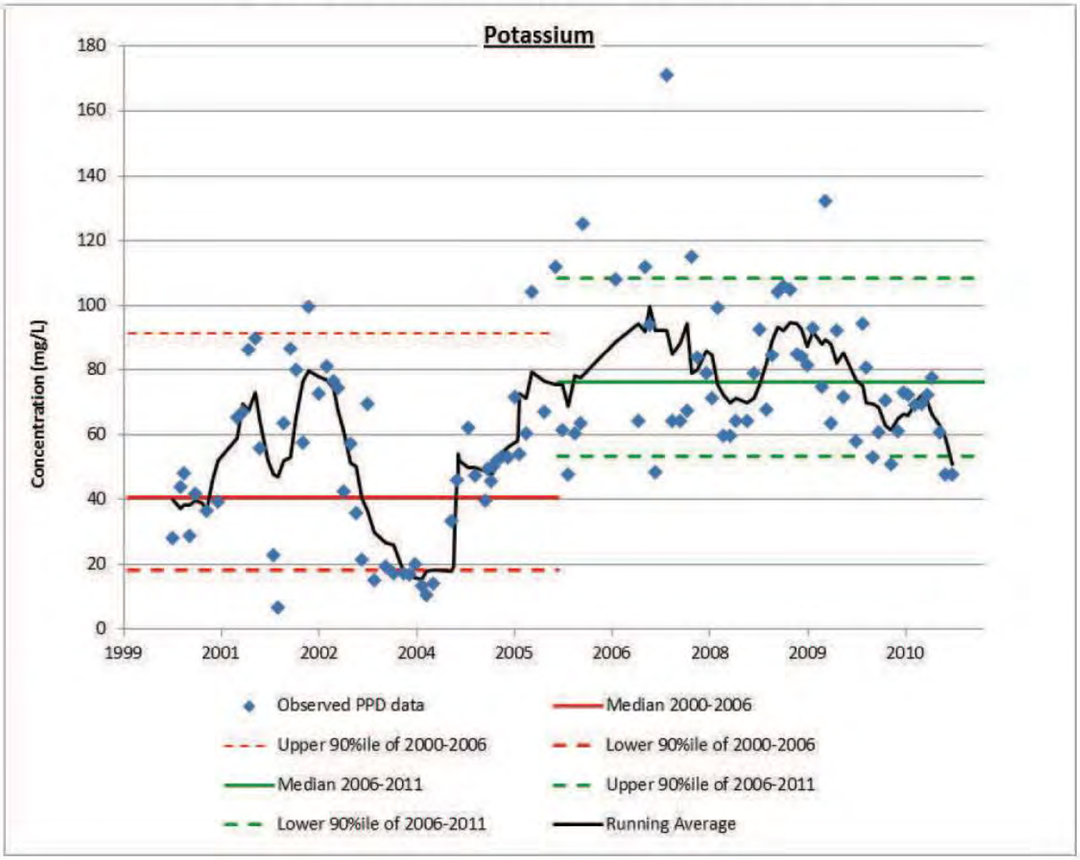
Very good fit to observed data.

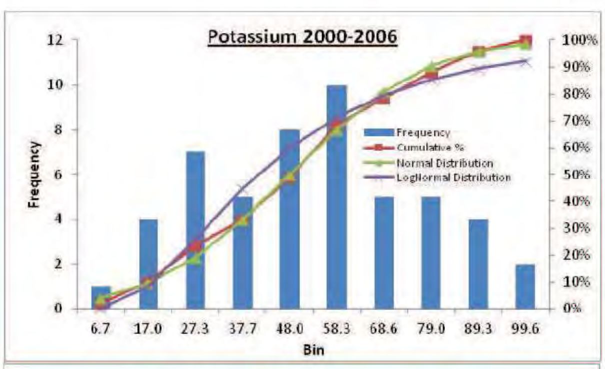
Summary

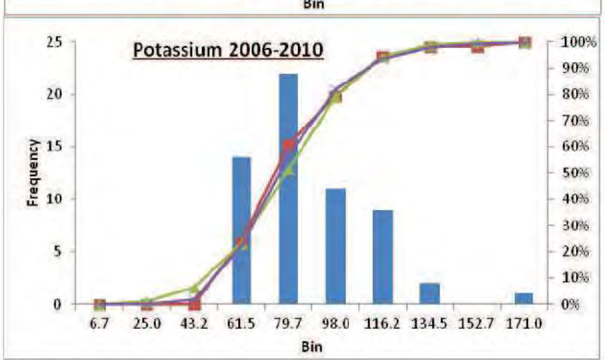
Modelled concentrations reach the benchmark in Leslie Lake and exceed in Moose Lake near end of mine life. Results for Slipper Lake are below 75% of benchmark.

Peak Potassium concentrations are associated with use of water stored in Beartooth pit as reclaim water for the Process Plant. Water stored in Beartooth pit has high Potassium concentrations from underground water.

Figure 1: Process Plant Inputs to LLCF Model







Comment on Historical Trends in PPD

Observed concentrations generally higher post-2006; however, the changes are less marked than other salts.

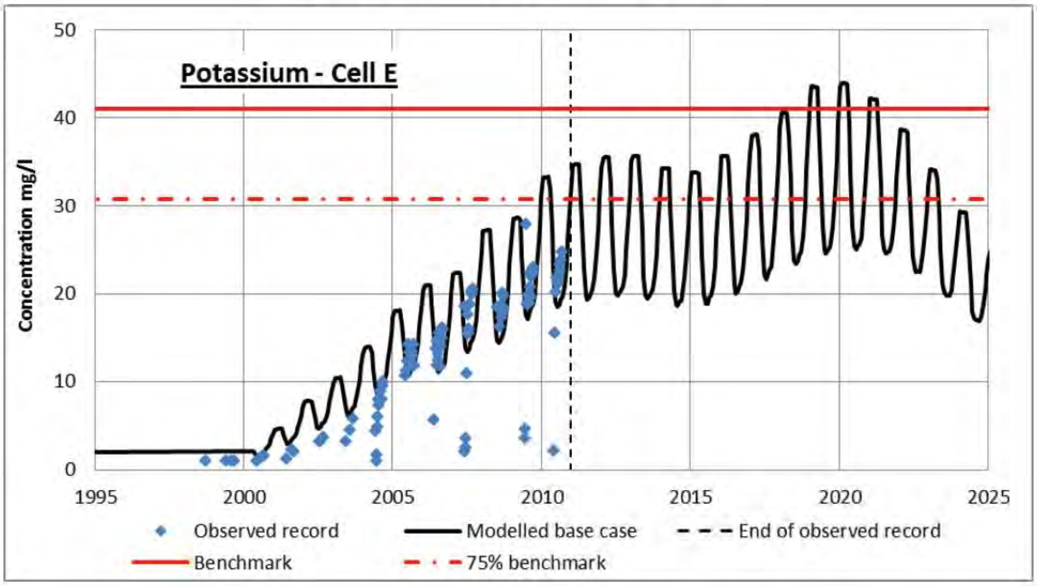
Modelling Approach for Future PPD

2011to 2020 (except 2018), normal distribution based on observed post-2006 PPD data. For 2018, based on normal distribution for observed 2000-2006 PPD data.

Modelled Correlation between WQ Parameters

Potassium is correlated with TDS (0.7)

Figure 2: Model Predictions for LLCF



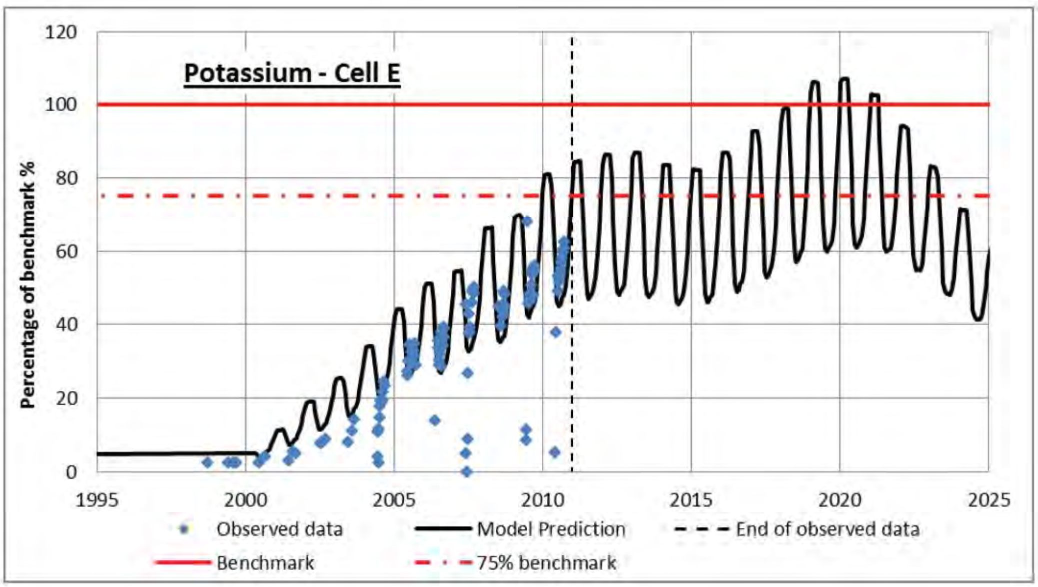


Figure 3: Predictions in Receiving Environment

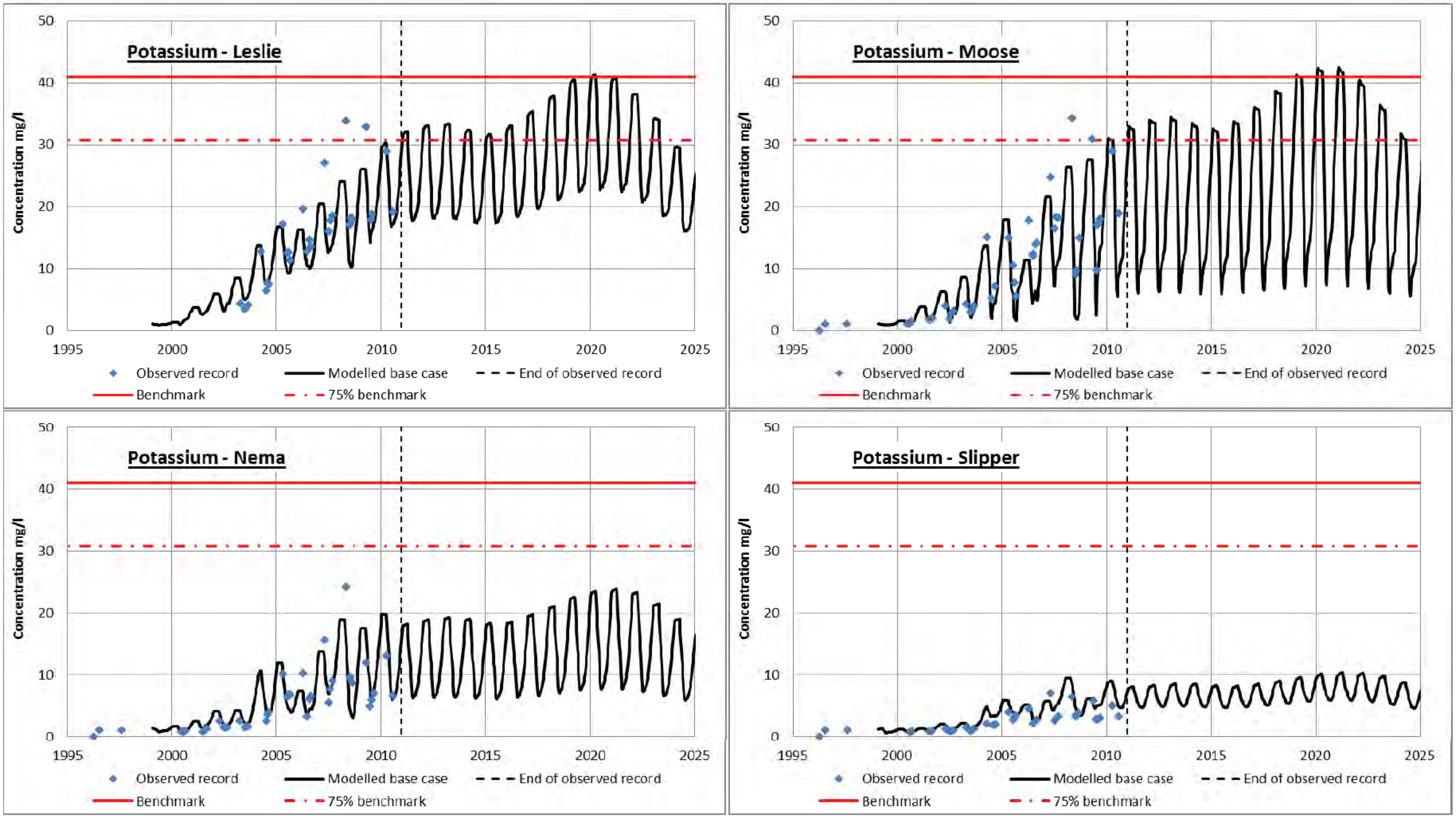
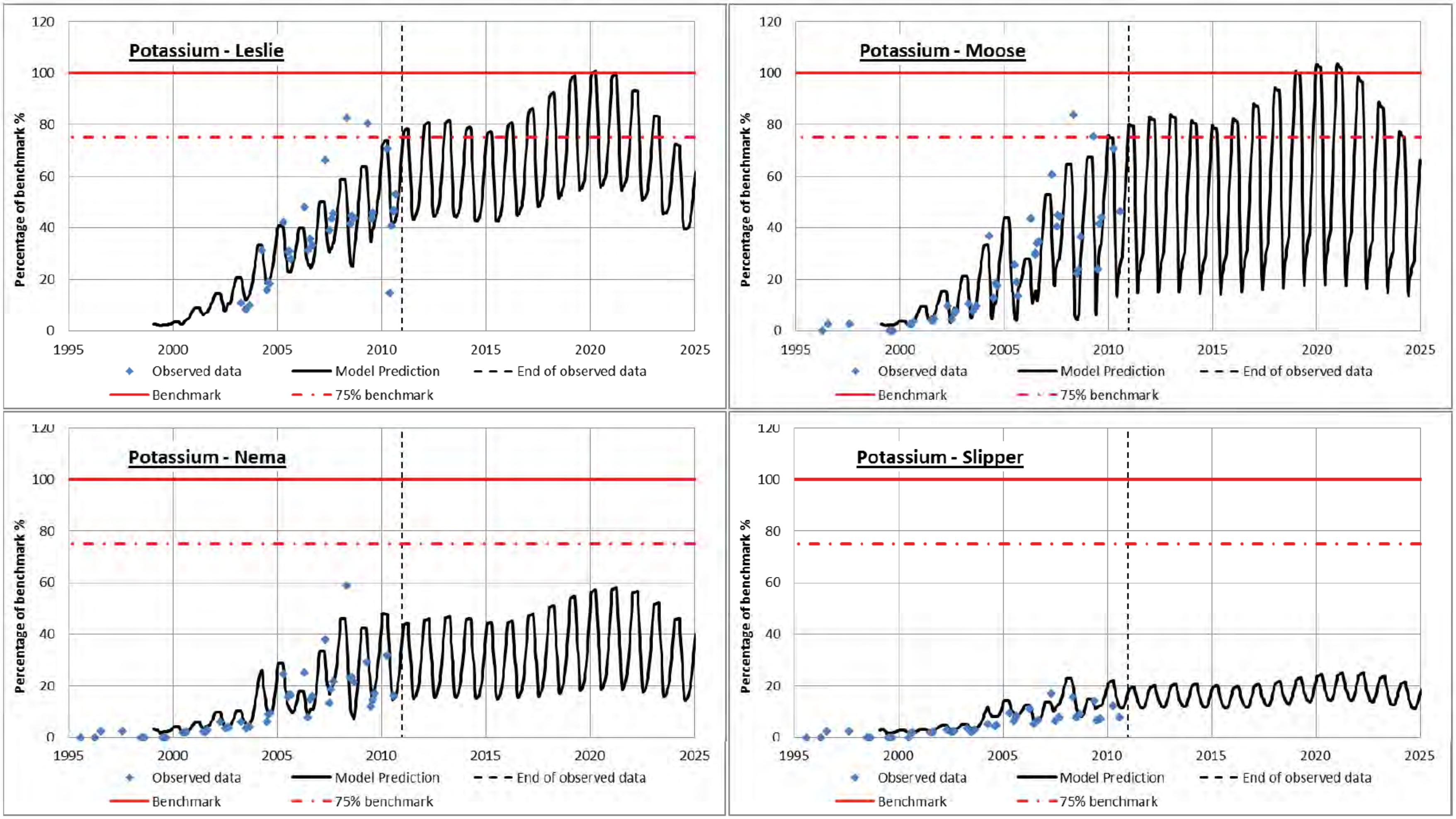


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Selenium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	83%	Process Plant	71%
Sump	10%	Sump	11%
Underground	1%	Underground	0%
Runoff	5%	Runoff	5%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	14%

Key Comments Related to Modelling Work

Nearly all loadings to LLCF are from Process Plant discharge. High concentrations in excess of benchmark have been observed from 2004 to 2007 related to Selenium loadings to the Process Plant during this time. The source of these loadings may be due to high concentrations in Fox ore (as seen in Fox sump data). In recent years concentrations of Selenium in Process Plant discharge have decreased as have concentrations in downstream lakes; hence peak of concentrations may have passed.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.001 mg/L (CCME guideline)

Leslie Lake (mg/L)				**Slipper Lake (mg/L)**			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.003	0.00025	0.00117	117%	0.0005	0.00011	0.000327	33%

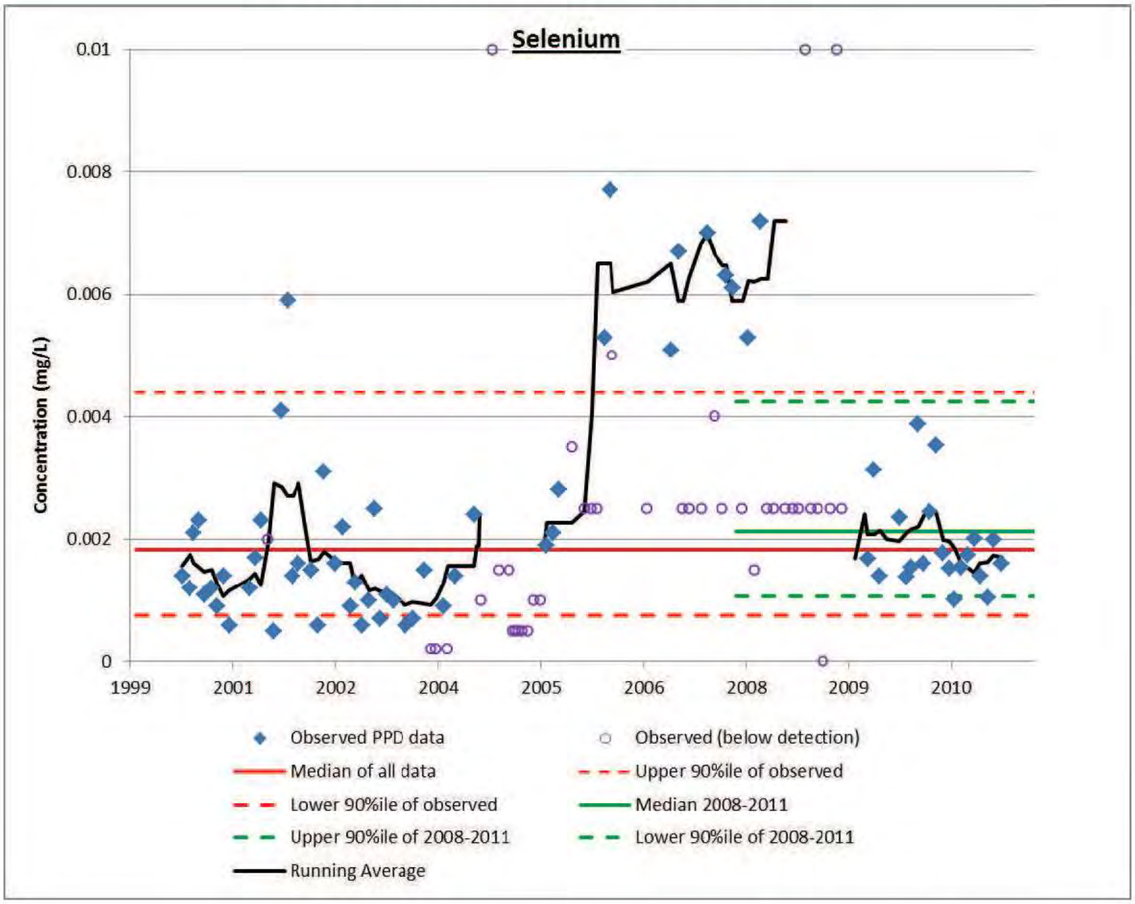
Comment on Model Fit to Observed Data

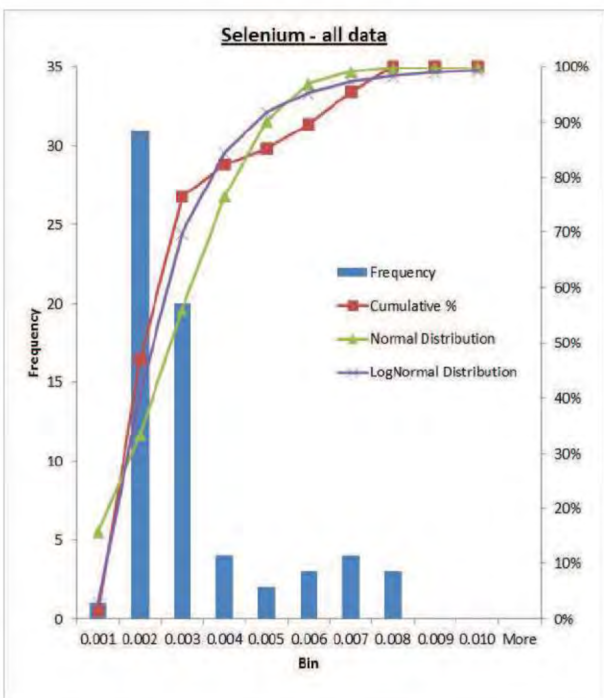
Reasonable fit between observed and predicted concentrations in downstream lakes, although LLCF model is not able to predict peaks of concentrations in from 2004 to 2007. Calibration runs (with observed Process Plant discharge data) produce better results than seen in the following pages.

Summary

Modelled concentrations exceed the benchmark in Leslie and Moose Lakes. Results for Slipper Lake do not exceed 75% of the benchmark within the lifetime of the mine.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Period of high concentrations observed from 2006 to 2008, with lower concentrations pre- and post this period

Modelling Approach for Future PPD

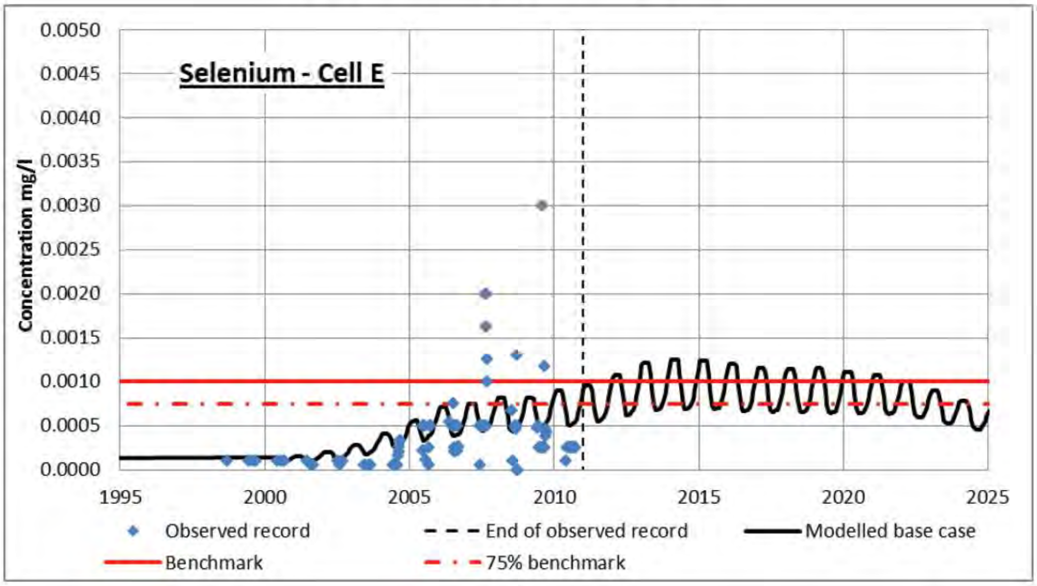
Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters

Selenium is uncorrelated to any parameter

Selenium

Figure 2: Model Predictions for LLCF



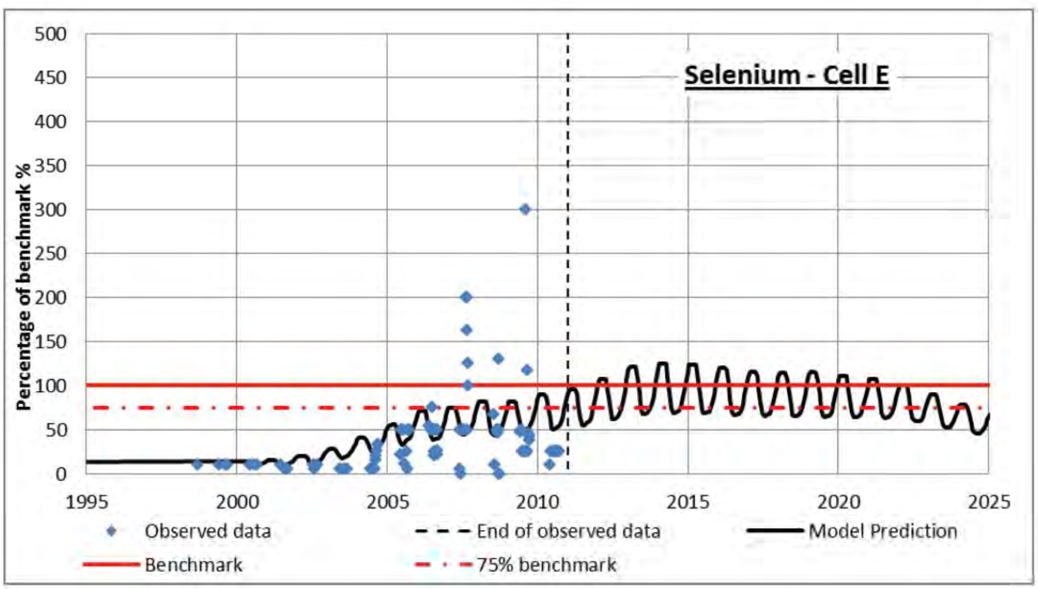


Figure 3: Predictions in Receiving Environment

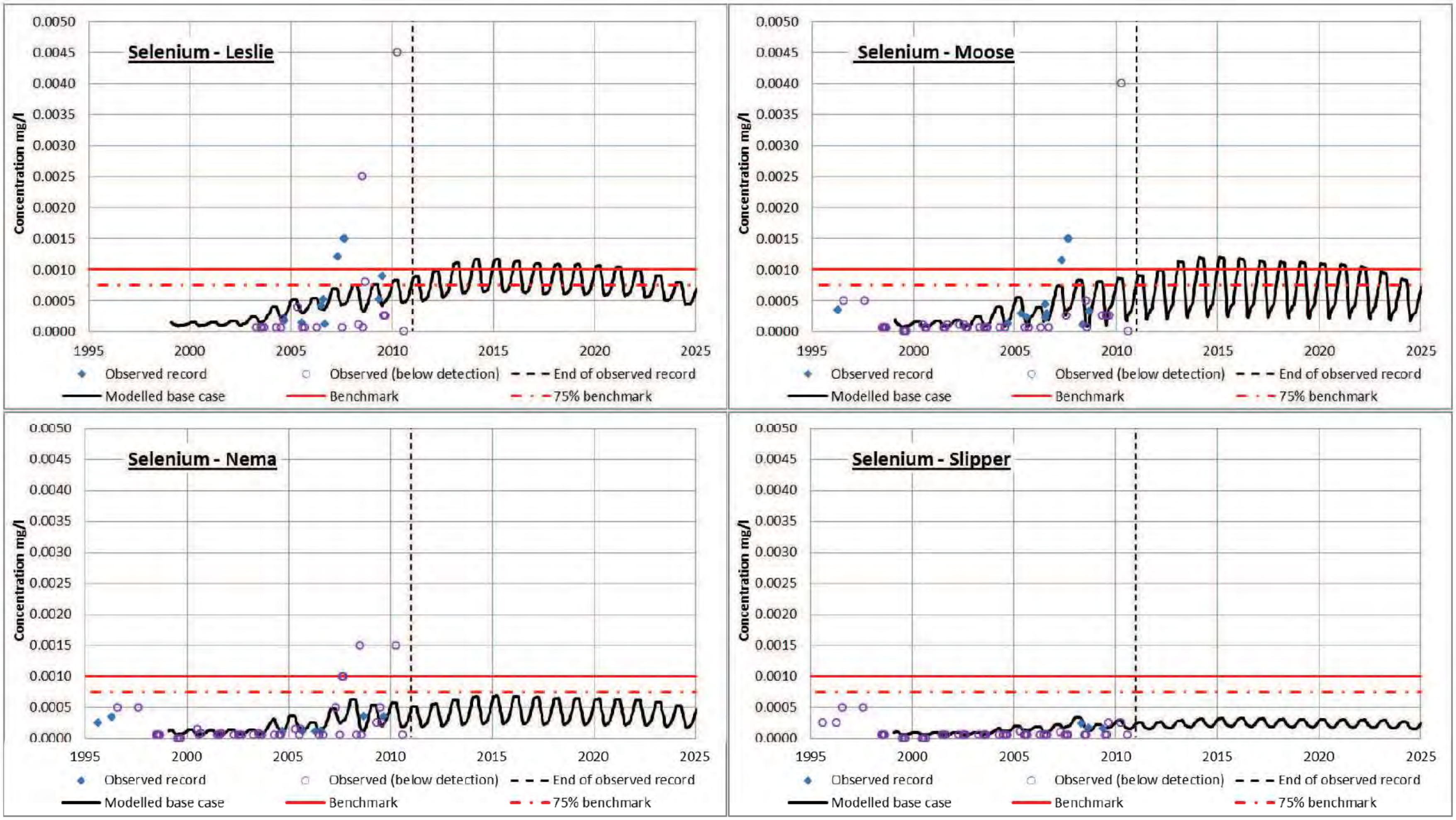
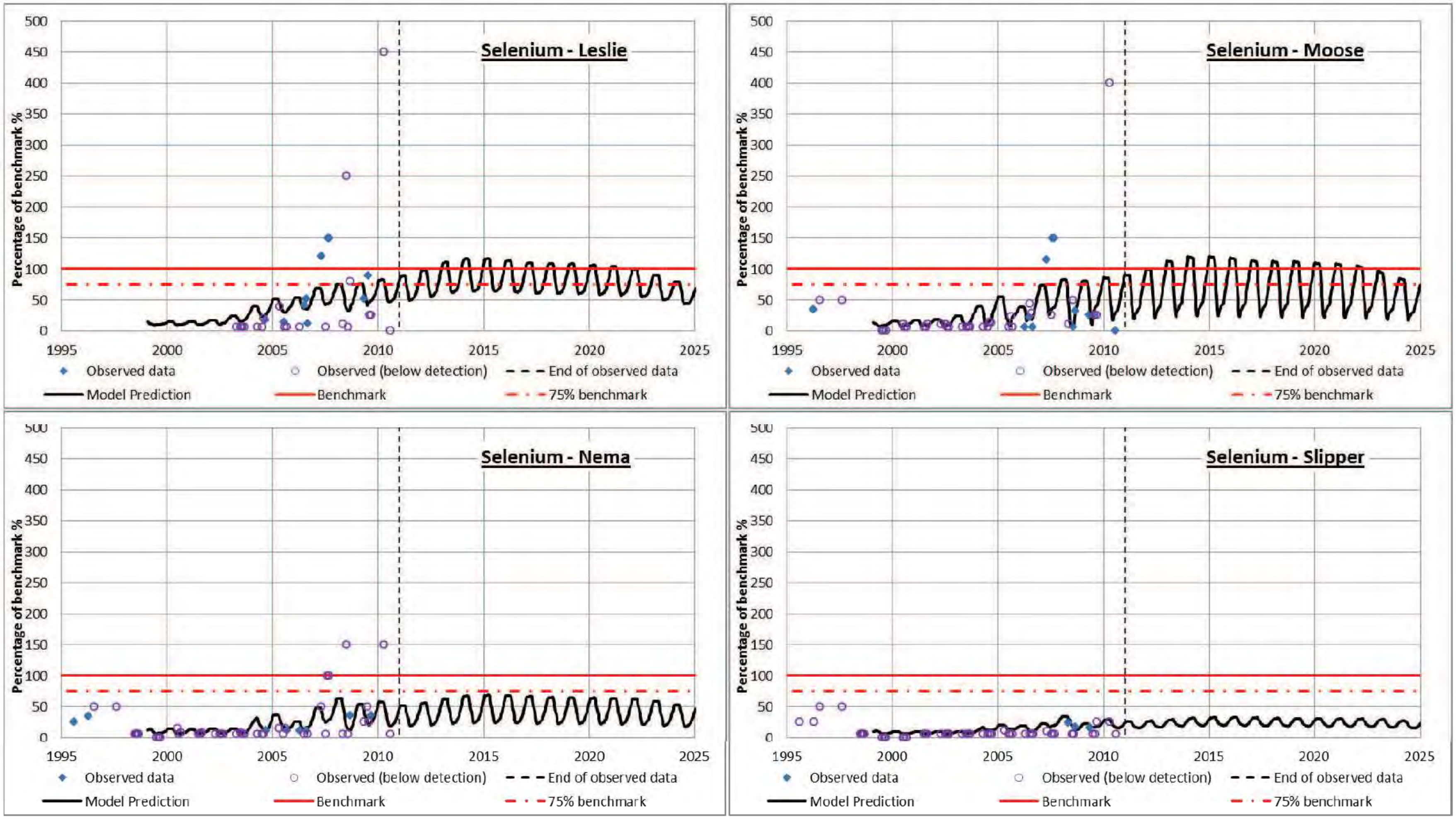


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Strontium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	10%	Process Plant	7%
Sump	4%	Sump	4%
Underground	86%	Underground	0%
Runoff	0%	Runoff	0%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	89%

Key Comments Related to Modelling Work

Historically the key loading for Strontium has been underground water. However, the Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. At present (2011) the main loading of Strontium is from the Process Plant discharge. Going forward, once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water. Hence, Strontium loadings stored in Beartooth pit will enter the LLCF with the Process Plant discharge at this time causing the peak in Strontium concentrations in the LLCF and downstream lakes predicted for 2019/2020.

Water Quality Benchmark

6.242 mg/L (as per the 2011 Golder technical memo for Snap Lake)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.91	0.59	2.40	38%	0.15	0.064	0.543	9%

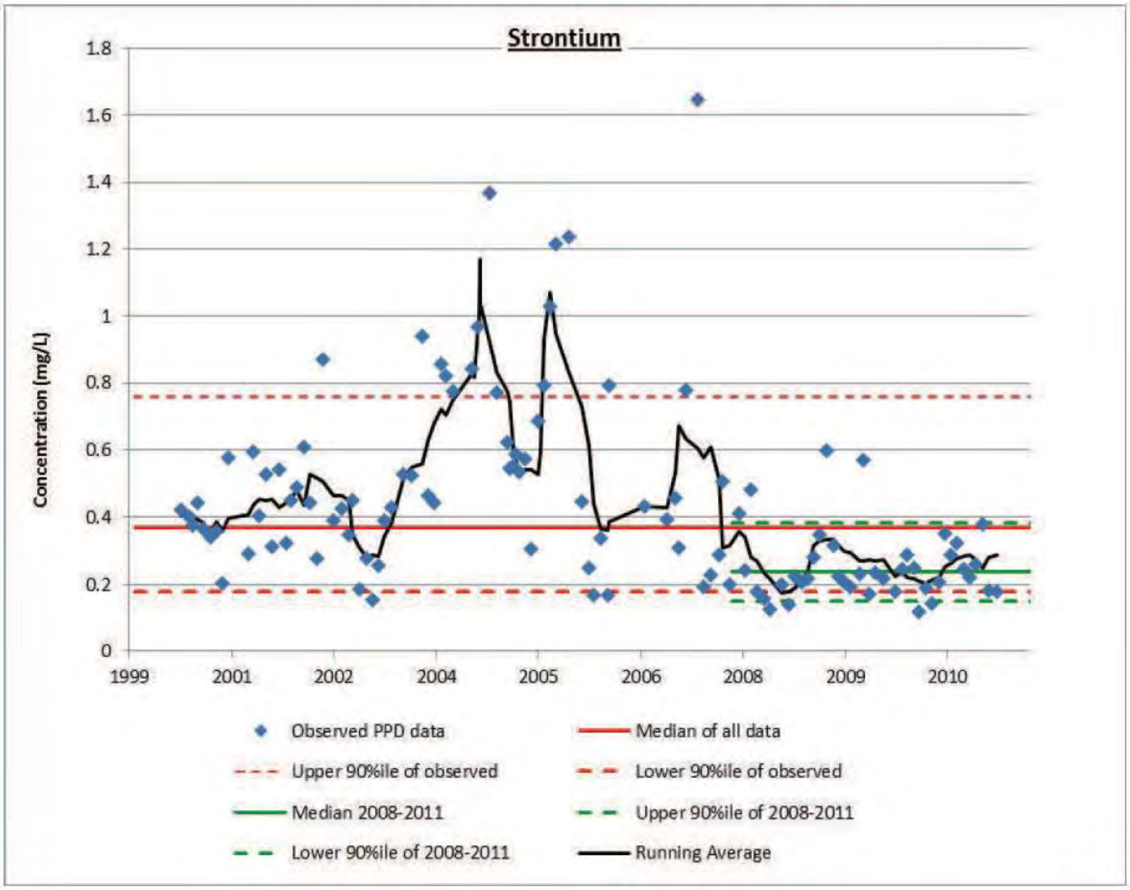
Comment on Model Fit to Observed Data

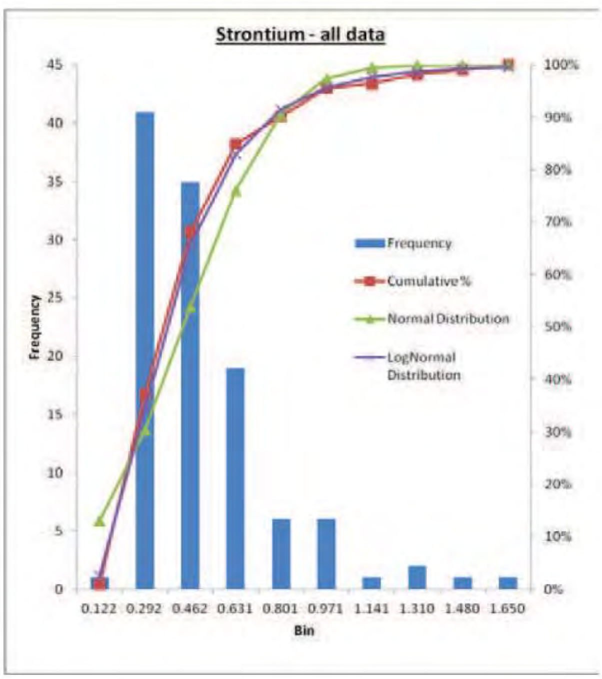
Good fit to observed data.

Summary

Historical concentrations and model predictions for downstream lakes are below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Lower PPD concentrations post-2007/2008, with lower average values and lower variability in data.

Modelling Approach for Future PPD

Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters

Strontium is correlated to Calcium (0.9)

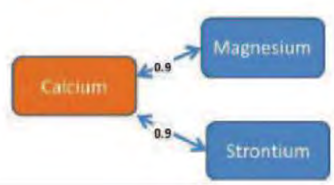
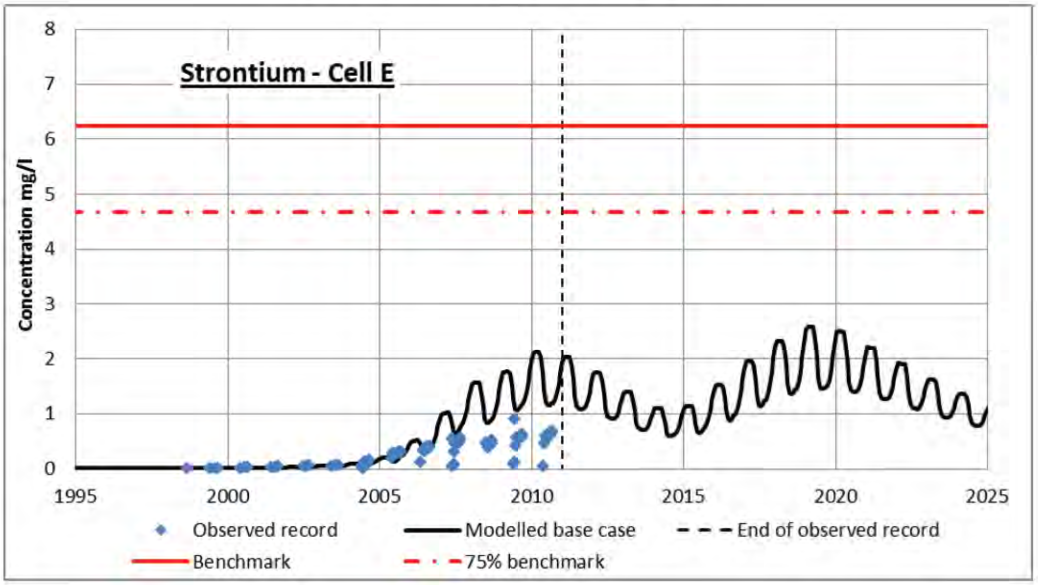


Figure 2: Model Predictions for LLCF



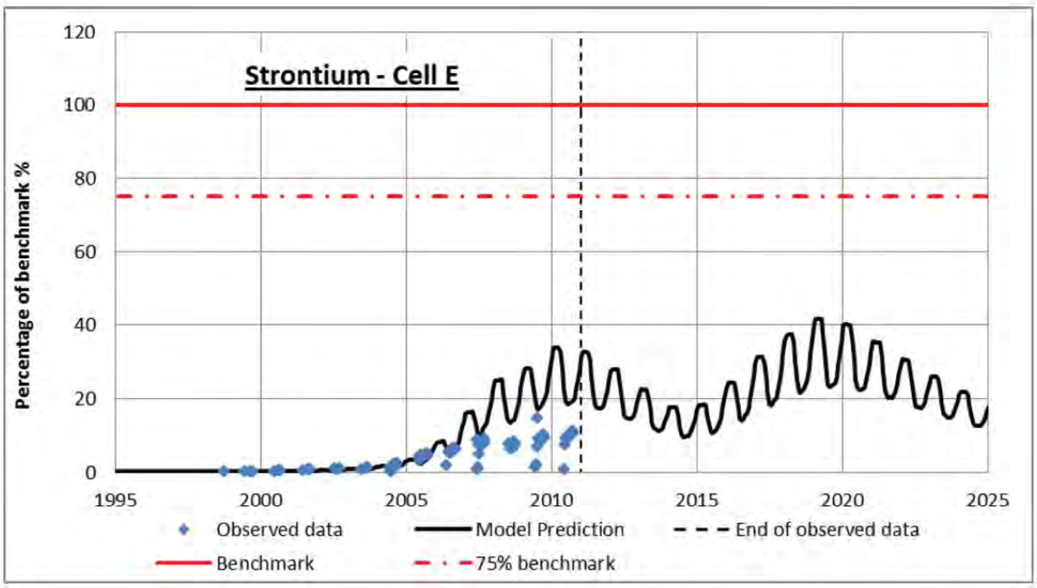


Figure 3: Predictions in Receiving Environment

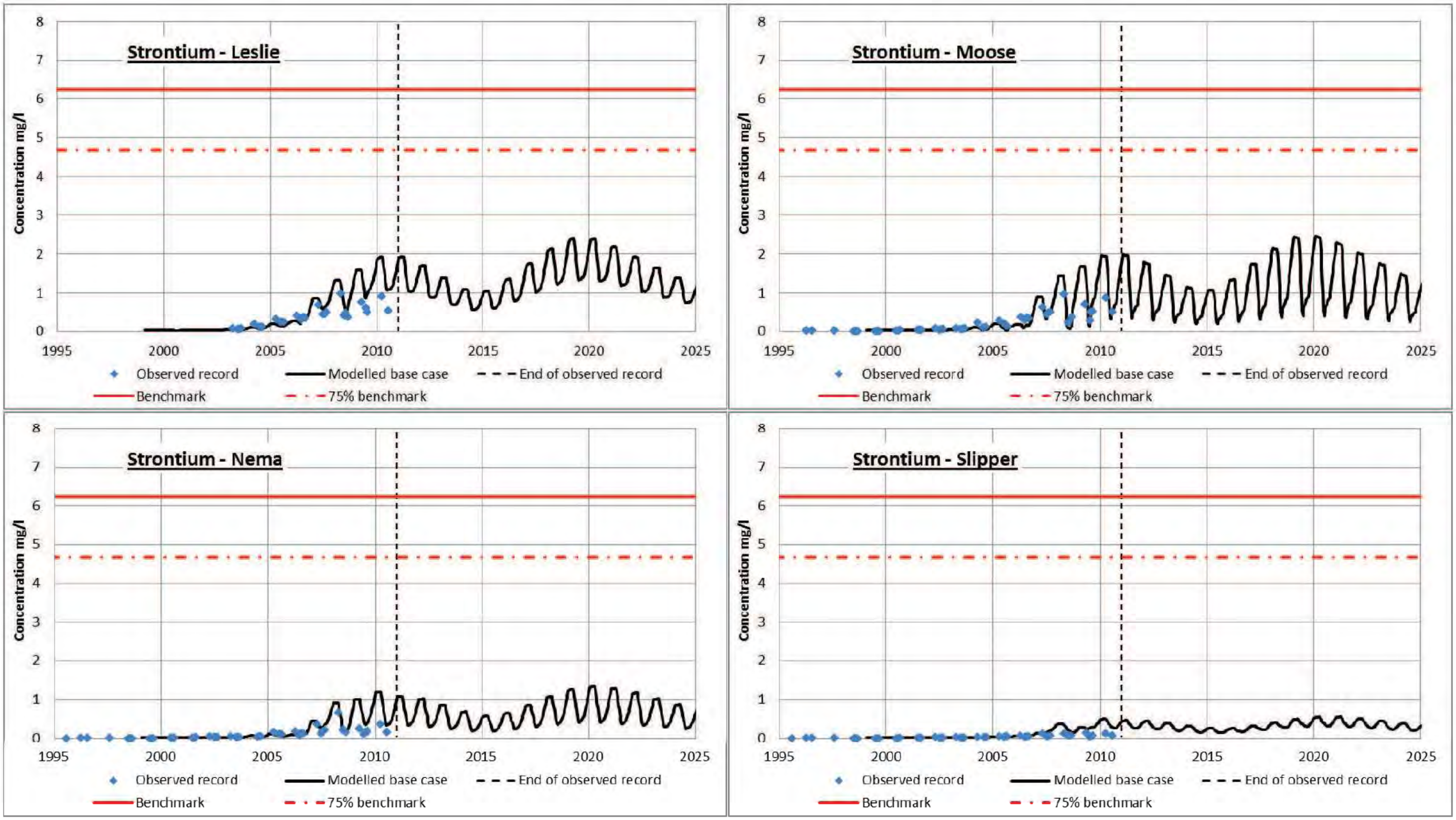
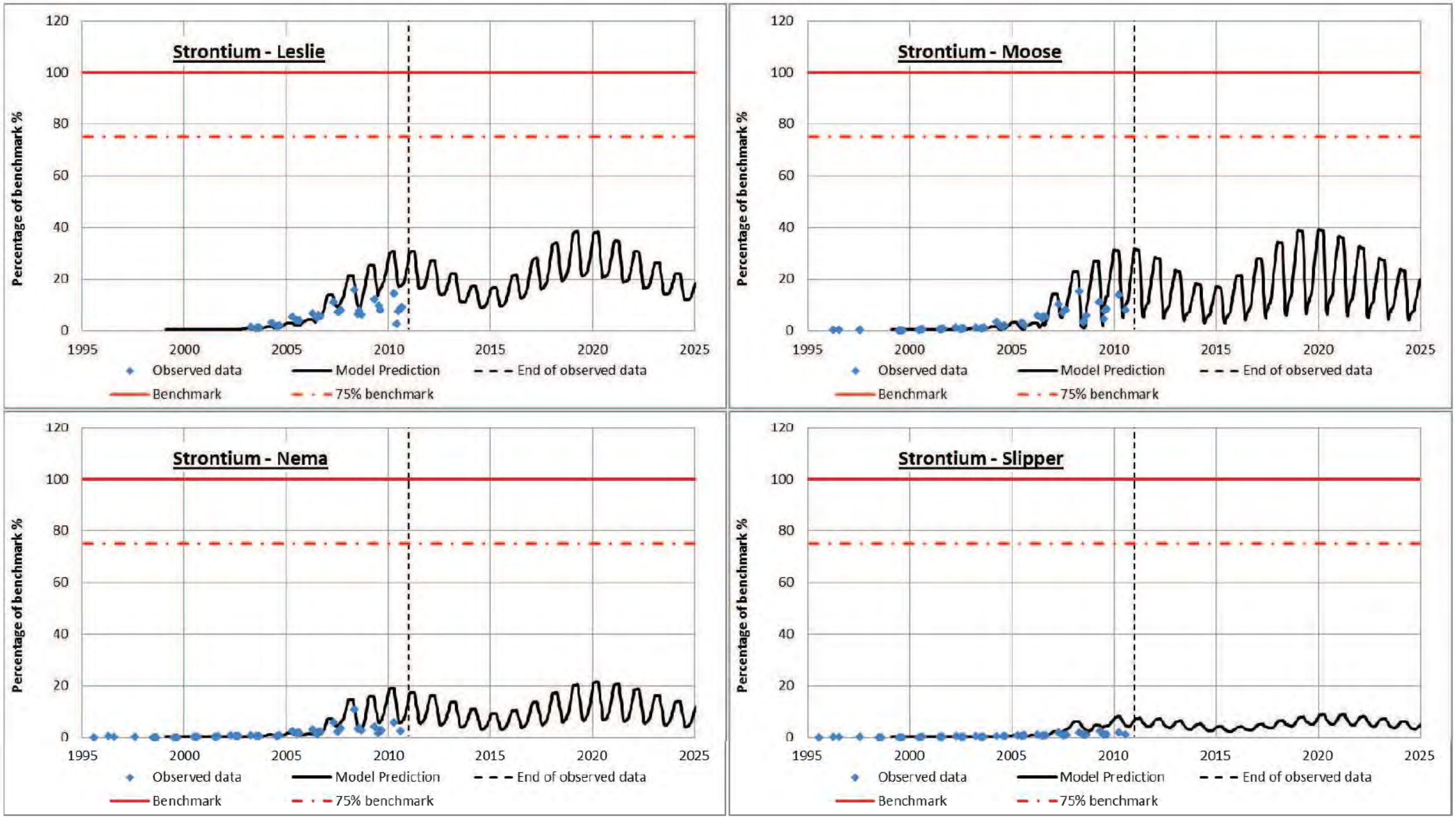


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Sulphate

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	72%	Process Plant	59%
Sump	12%	Sump	13%
Underground	15%	Underground	0%
Runoff	1%	Runoff	1%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	27%

Key Comments Related to Modelling Work

Main loading is from Process Plant discharge. Inputs from process Plant discharge have been highly variable without clear trend related to kimberlite type.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

$0.2 \times e^{(0.9116[\ln(hardness)]+1.712)}$ mg/L , relationship is limited to hardness range up to 250 mg/L (Site Specific WQO)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
169.5	87	133	24%	35	13	31.1	13%

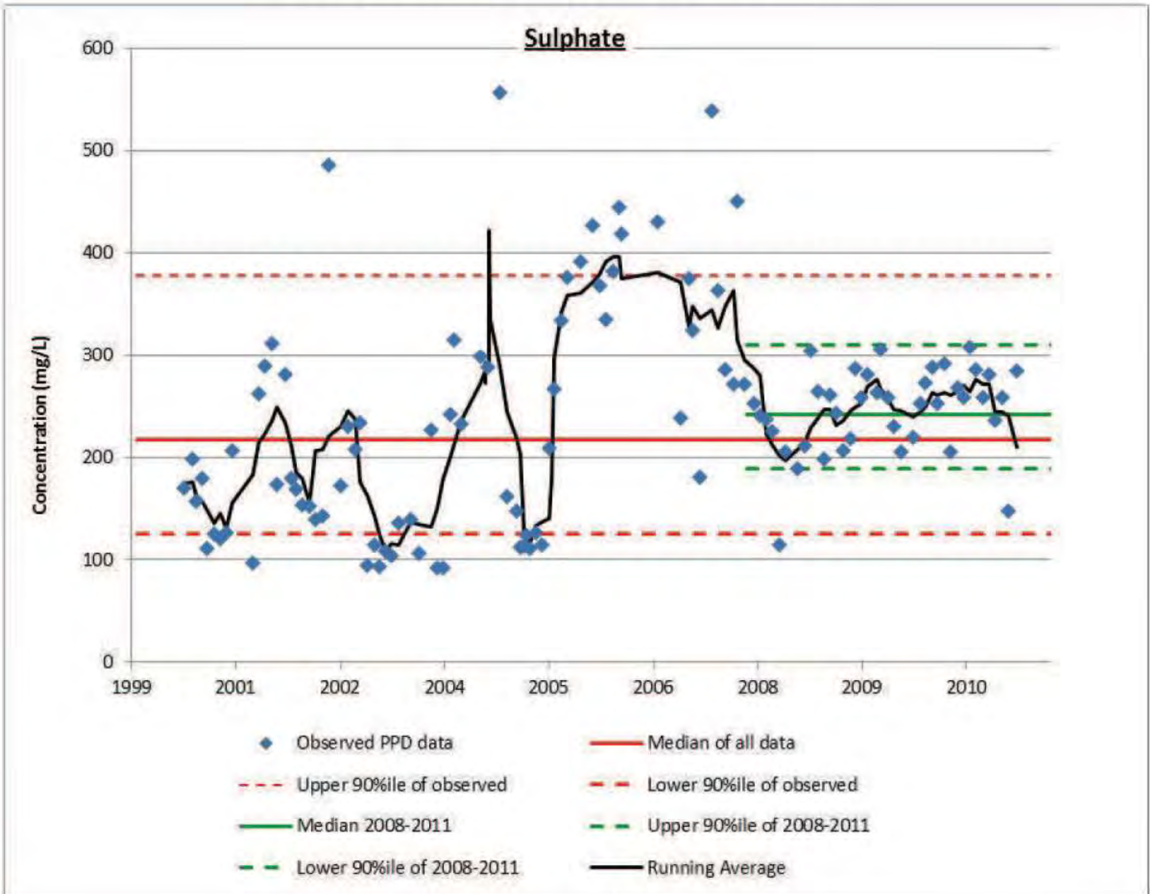
Comment on Model Fit to Observed Data

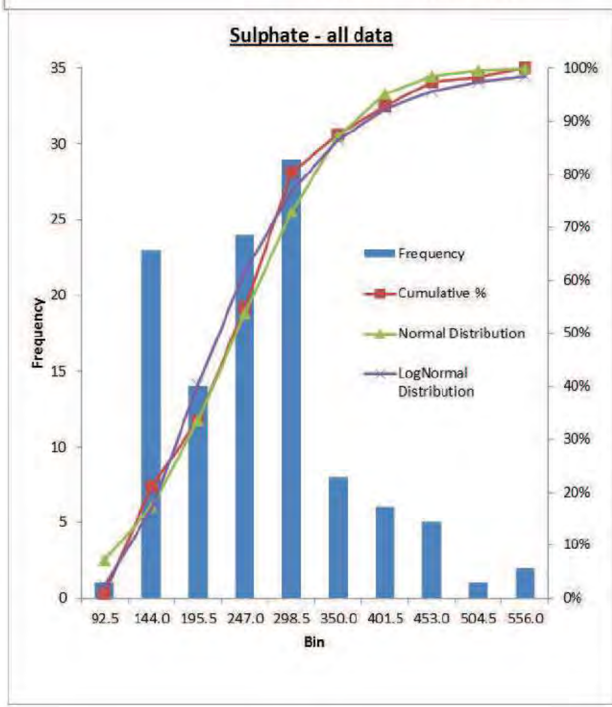
Good overall fit to modelled data in Cell E, although model over-predicts concentrations in early years of operations. Excellent fits to data in downstream lakes.

Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD
PPD concentrations consistently lower post-2005.

Modelling Approach for Future PPD
Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters
Sulphate is correlated with TDS (0.7)

Figure 2: Model Predictions for LLCF

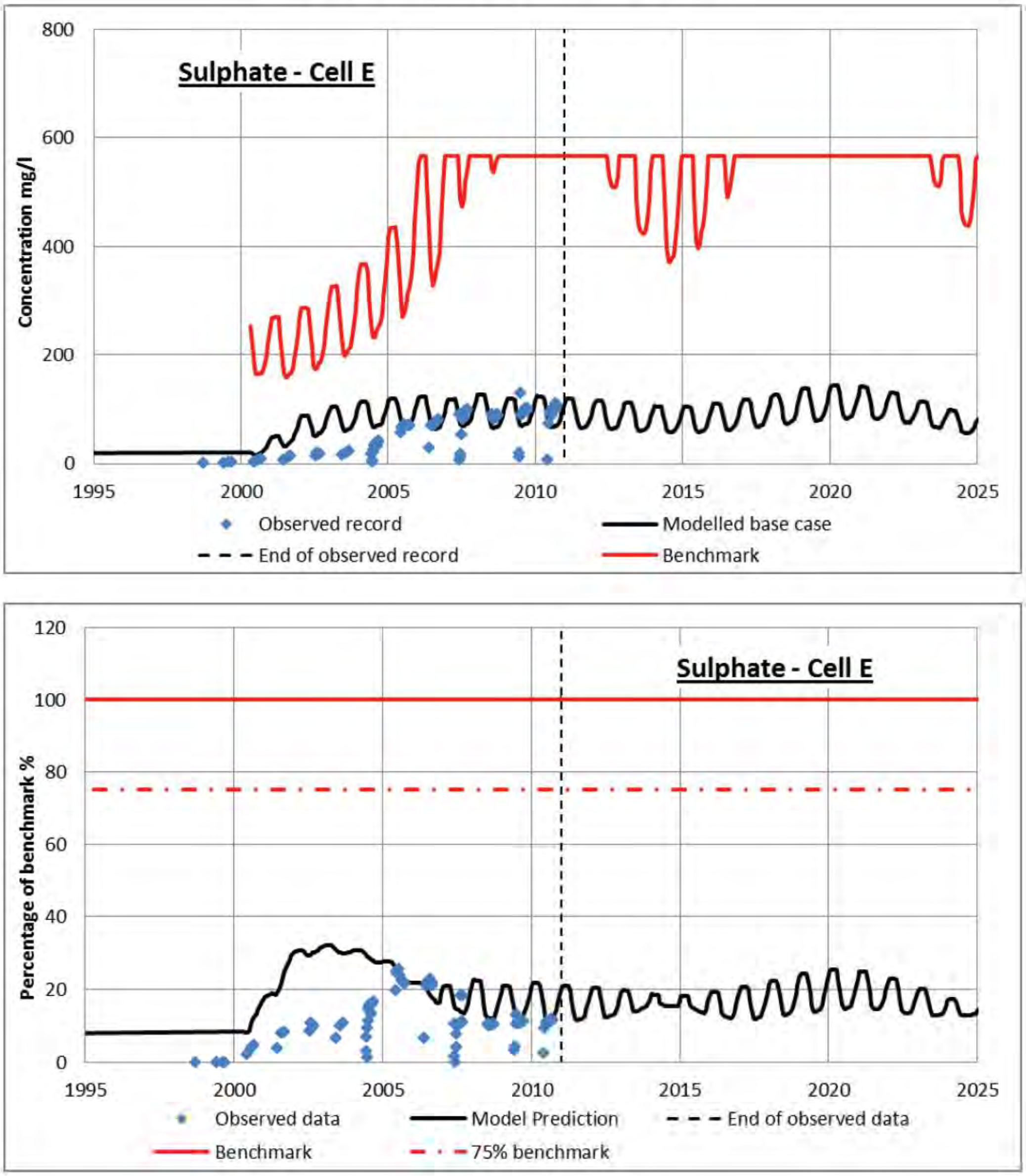


Figure 3: Predictions in Receiving Environment

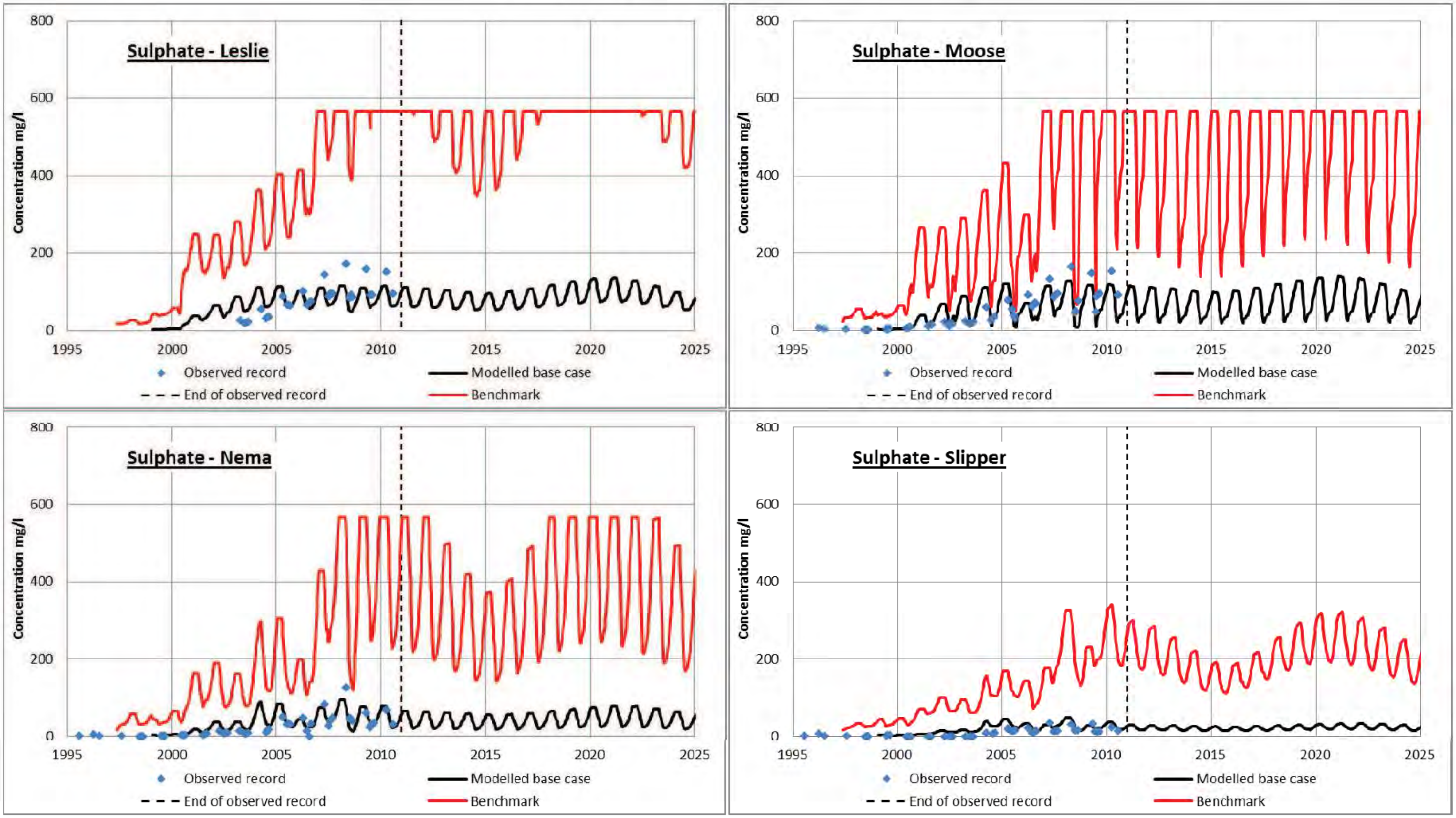
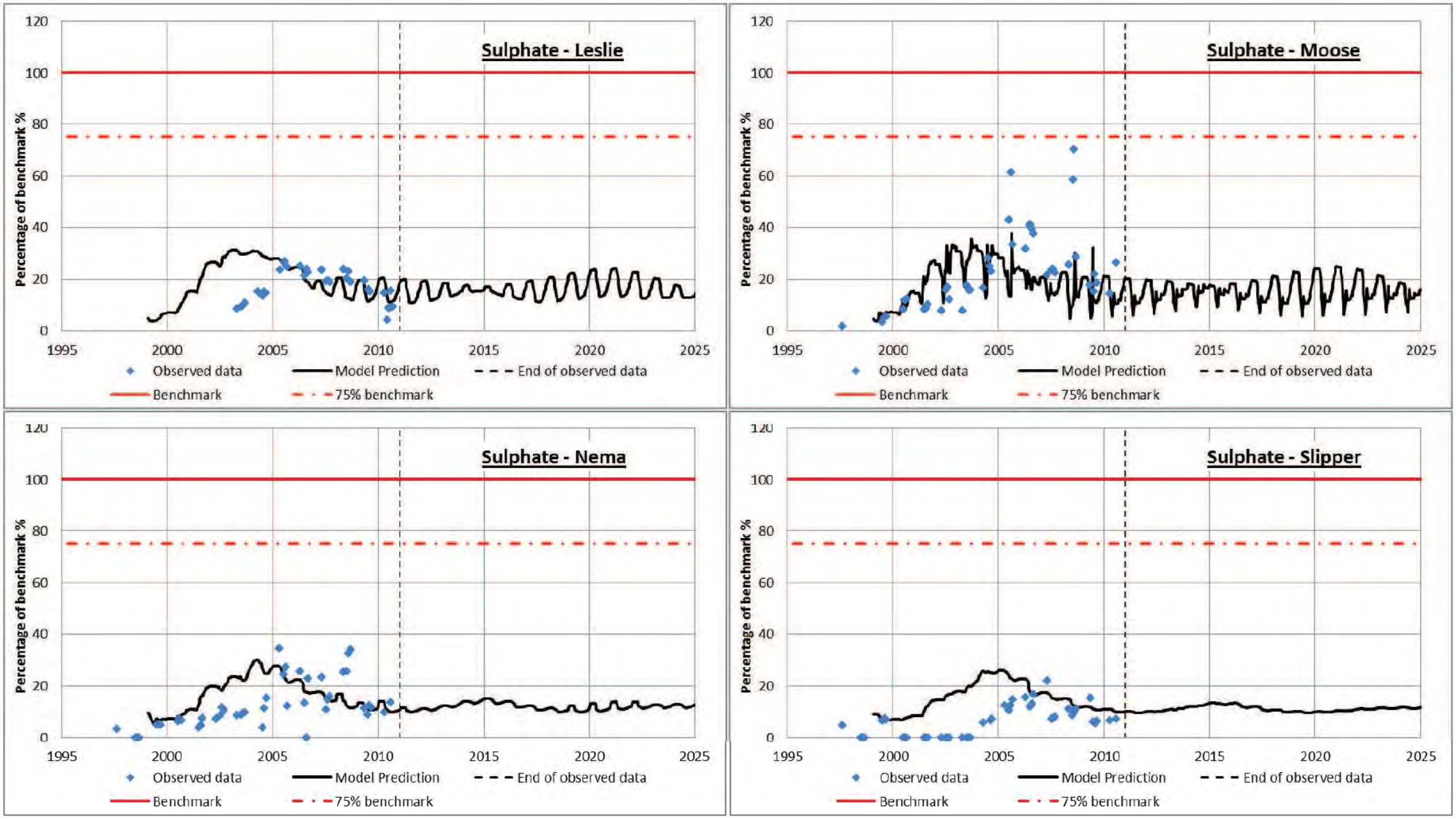


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Total dissolved solids (TDS)

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	41%	Process Plant	37%
Sump	12%	Sump	10%
Underground	46%	Underground	0%
Runoff	1%	Runoff	1%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	52%

Key Comments Related to Modelling Work

The key sources of loadings of TDS are underground water and the Process Plant discharge. TDS concentrations in the Process Plant discharge increased when underground kimberlite was sent to the Process Plant in 2005/2006.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Hence, at present (2011) the main loading of TDS is from the Process Plant Discharge. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water. Hence, TDS loadings stored in Beartooth pit will enter the LLCF with the Process Plant Discharge at this time causing the peak in TDS concentrations in the LLCF and downstream lakes predicted for 2019/2020.

Water Quality Benchmark

None Proposed

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
540	380	899	-	110	52	213	-

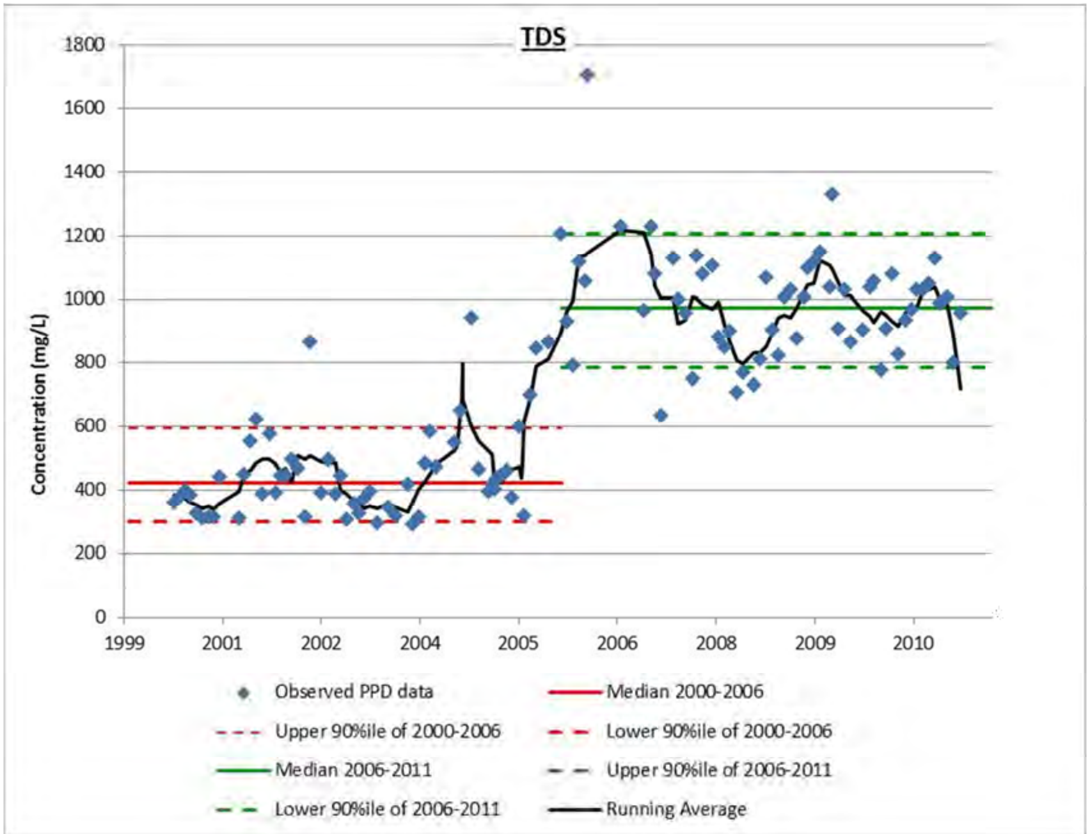
Comment on Model Fit to Observed Data

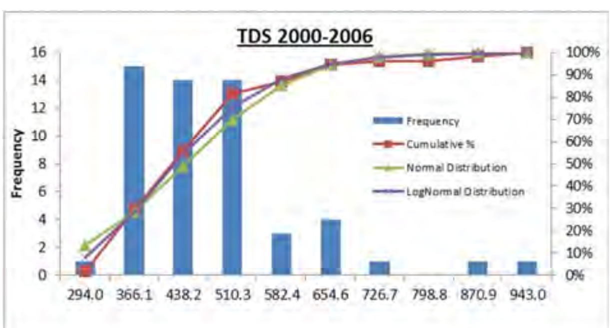
Very good fit with observed data in all lakes.

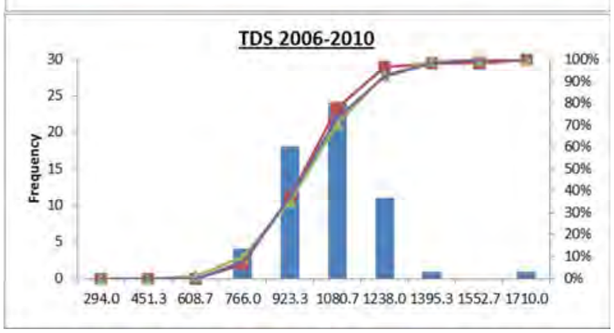
Summary

No benchmark proposed.

Figure 1: Process Plant Inputs to LLCF Model







Comment on Historical Trends in PPD

Rapid increase in PPD concentrations post-2005, consistent with start of processing of underground ore.

Modelling Approach for Future PPD

2011to 2020 (except 2018), normal distribution based on observed post-2006 PPD data. For 2018, based on normal distribution for observed 2000 to 2006 PPD data.

Modelled Correlation between WQ Parameters

TDS is correlated to chloride, ammonia, potassium, sulphate and nitrate

Figure 2: Model Predictions for LLCF

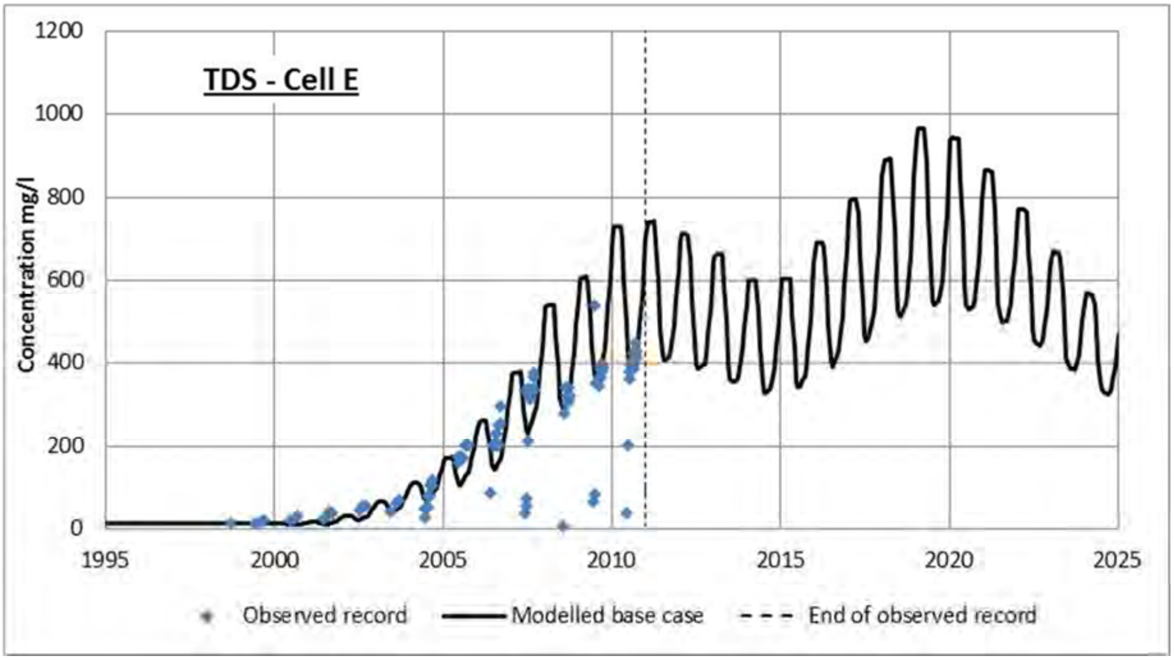
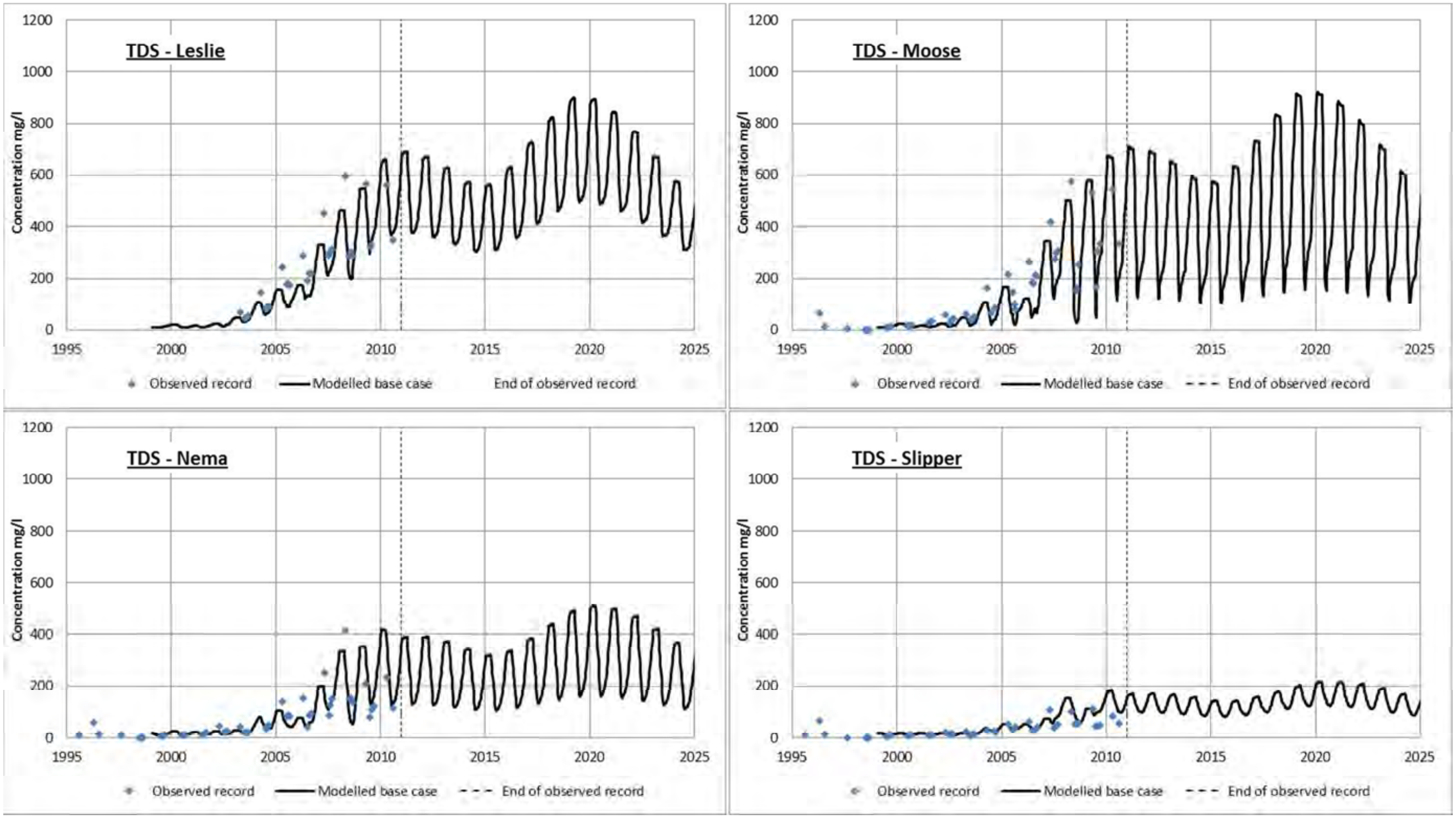


Figure 3: Predictions in Receiving Environment



Uranium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	11%	Process Plant	8%
Sump	68%	Sump	74%
Underground	15%	Underground	0%
Runoff	6%	Runoff	4%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	14%

Key Comments Related to Modelling Work

Key loading of Uranium is from sump water.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.015 mg/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.0029	0.00044	0.000916	6%	0.0001	0.00007	0.000278	2%

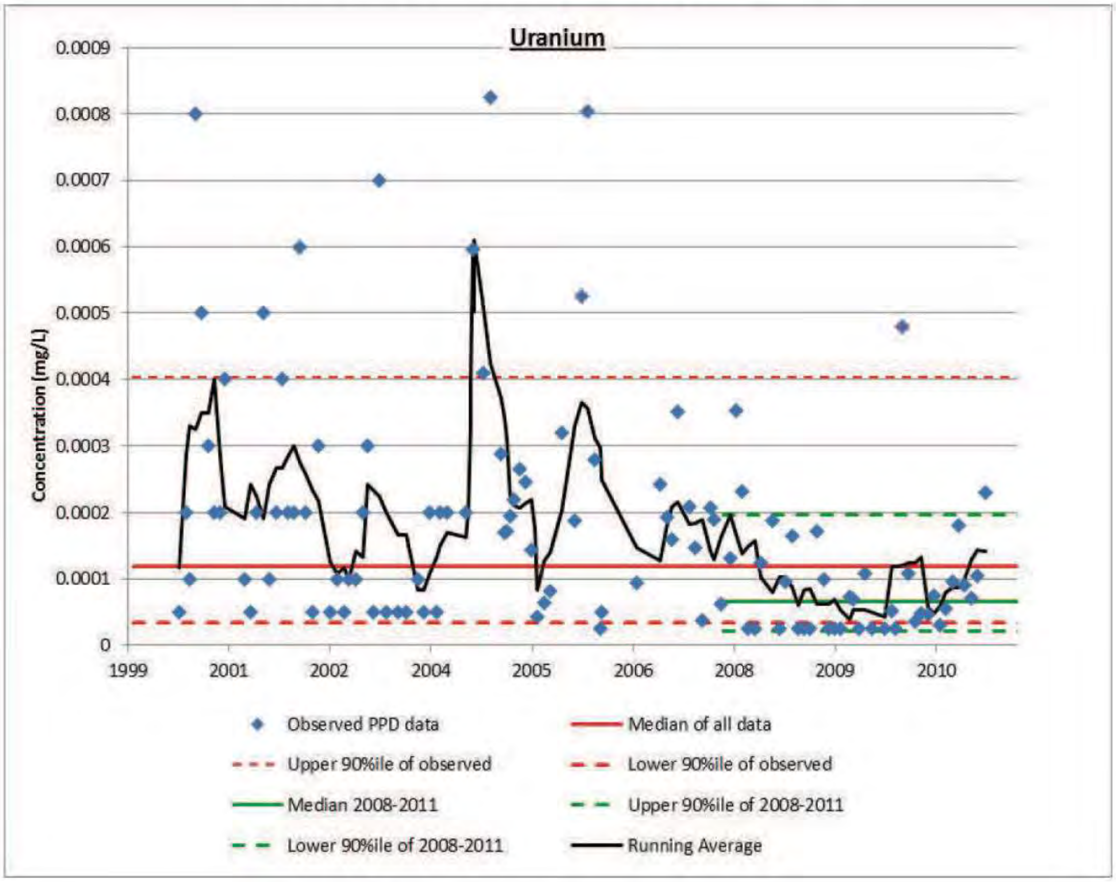
Comment on Model Fit to Observed Data

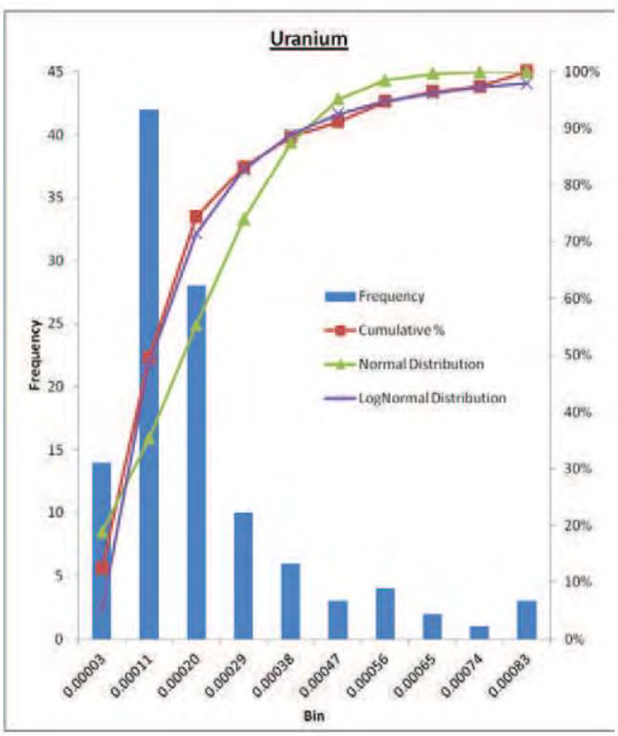
Good fit with observed data in Cell E, Leslie and Moose Lakes. Model over-predicts (slightly) concentrations in Nema and Slipper.

Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Possibly lower PPD concentrations post-2008, but there have been changes in detection limit over time.

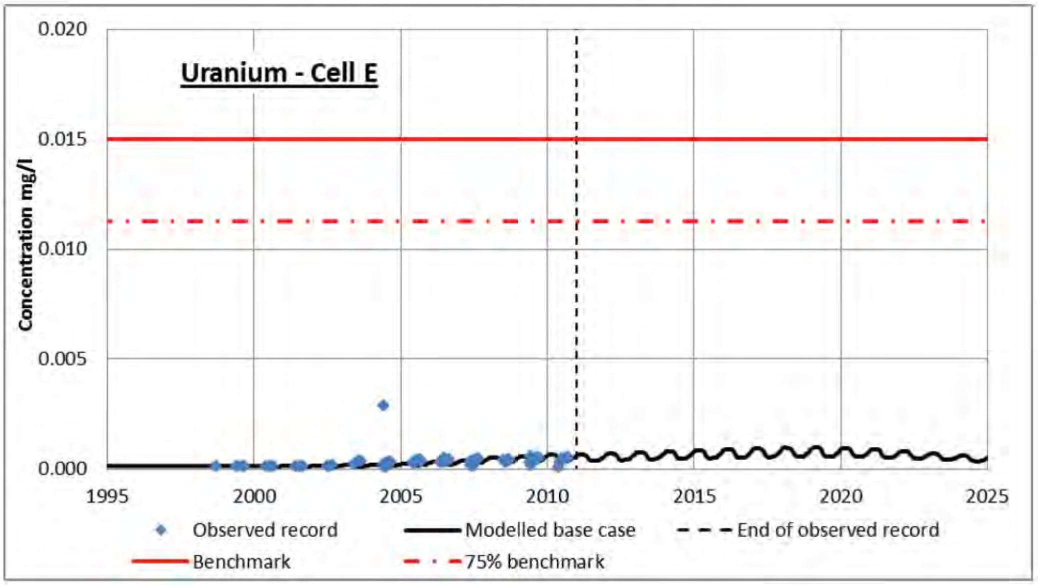
Modelling Approach for Future PPD

Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters

Uranium is correlated to arsenic (0.7)

Figure 2: Model Predictions for LLCF



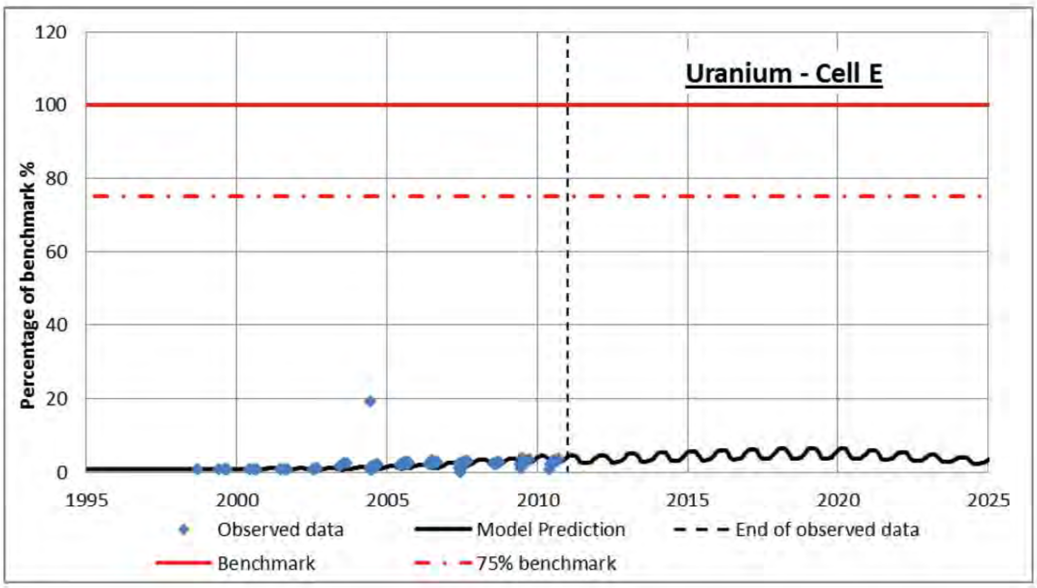


Figure 3: Predictions in Receiving Environment

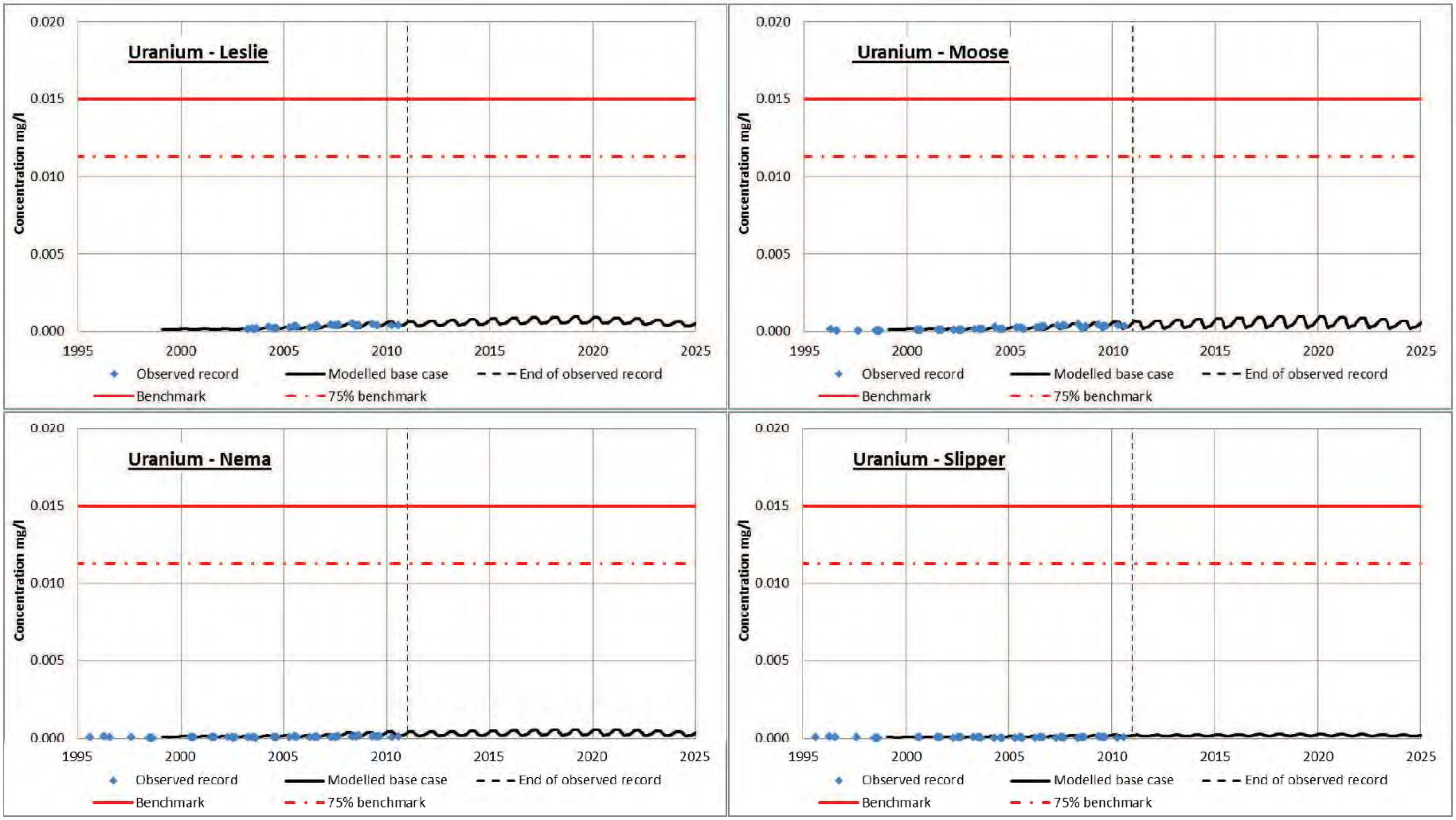
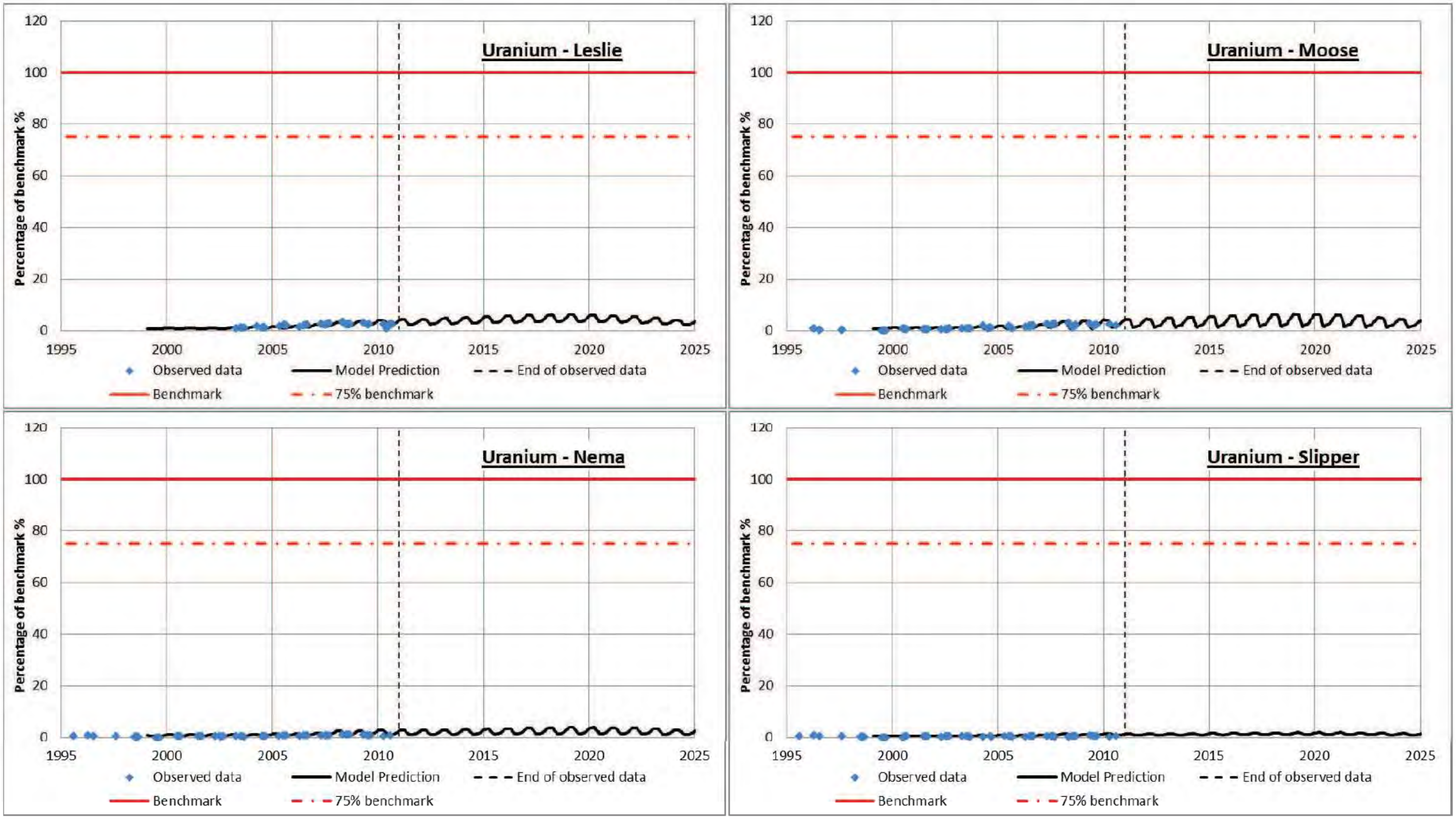


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Vanadium

Sources of Parameter in LLCF

Historical 2000 – end 2010		***Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)***	
Process Plant	87%	Process Plant	72%
Sump	11%	Sump	%
Underground	0%	Underground	0%
Runoff	3%	Runoff	2%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	18%

Key Comments Related to Modelling Work

Nearly all loadings to LLCF are from the Process Plant discharge. Vanadium concentrations have increased substantially in PPD since 2008. The model uses Process Plant discharge observed concentrations from 2008 to 2010, which are higher than in previous years, as the post-2010 Process Plant discharge estimates. The increase in Process Plant discharge concentrations since 2004 may indicate an increase in loadings of Vanadium to LLCF which may continue in the future. However, if the PPD concentrations return to levels seen pre-2008, the model may over-predict future Vanadium concentrations.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.030 mg/L (Site Specific WQO)

<table>
<tr><th colspan="4">Leslie Lake (mg/L)</th><th colspan="4">Slipper Lake (mg/L)</th></tr>
<tr><th colspan="2">Historical Period (incl. Cell E data)</th><th rowspan="2">Best Estimate future peak concentration</th><th rowspan="2">Percentage of Benchmark</th><th colspan="2">Historical Period</th><th rowspan="2">Best Estimate future peak concentration</th><th rowspan="2">Percentage of Benchmark</th></tr>
<tr><th>Highest observed</th><th>Median 2009/2010</th><th>Highest observed</th><th>Median 2009/2010</th></tr>
<tr><td>0.0028</td><td>0.0005</td><td>0.00622</td><td>41%</td><td>0.0038</td><td>0.0001</td><td>0.00148</td><td>10%</td></tr>
</table>

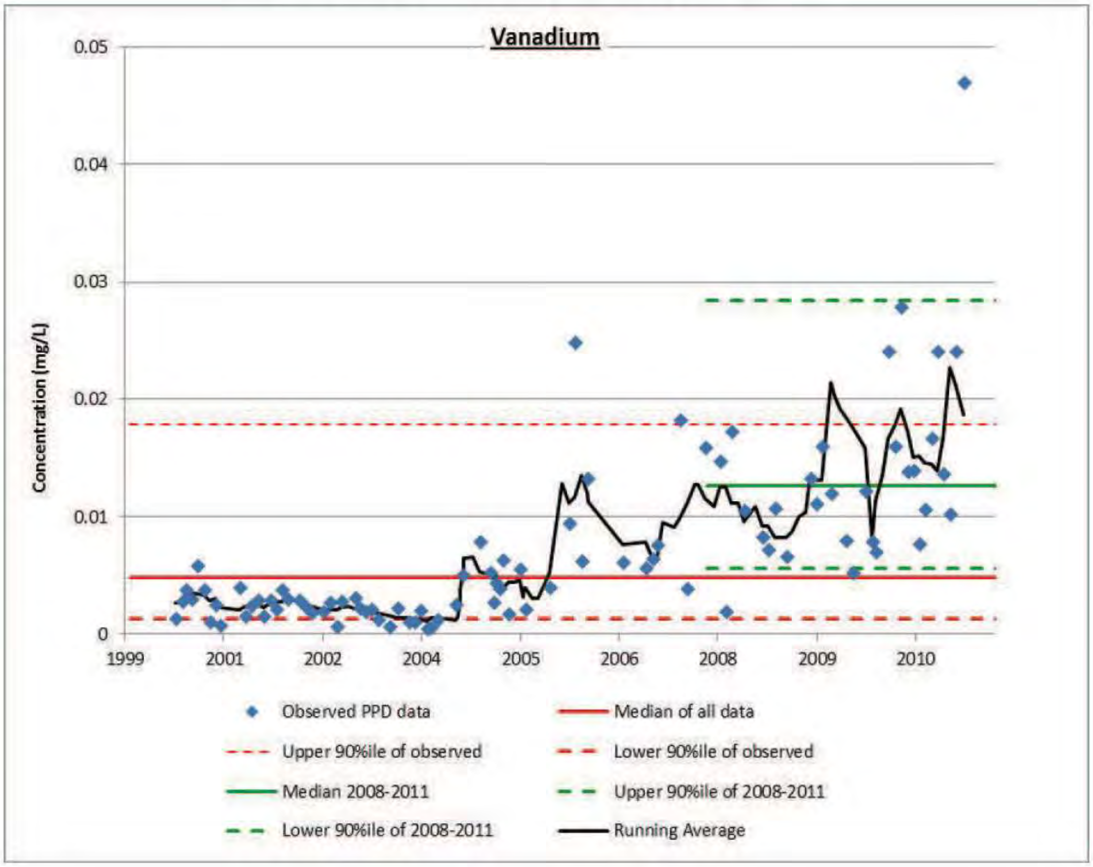
Comment on Model Fit to Observed Data

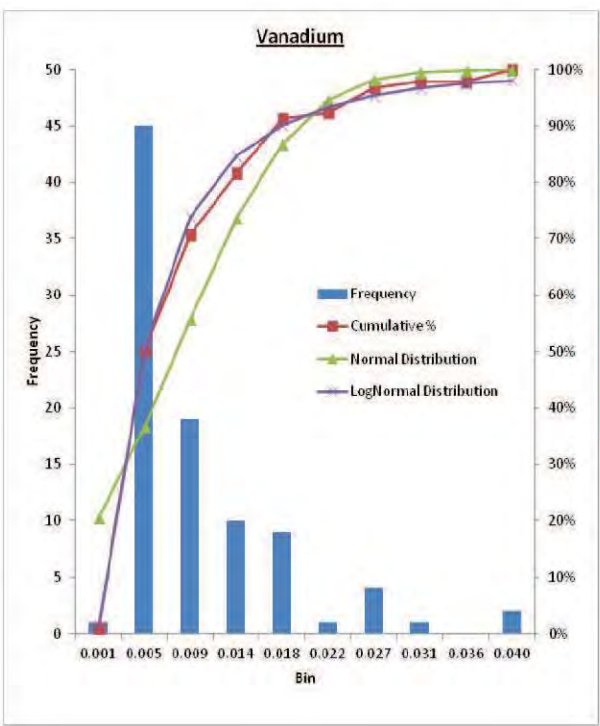
Model over-predicts historical Vanadium concentrations.

Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

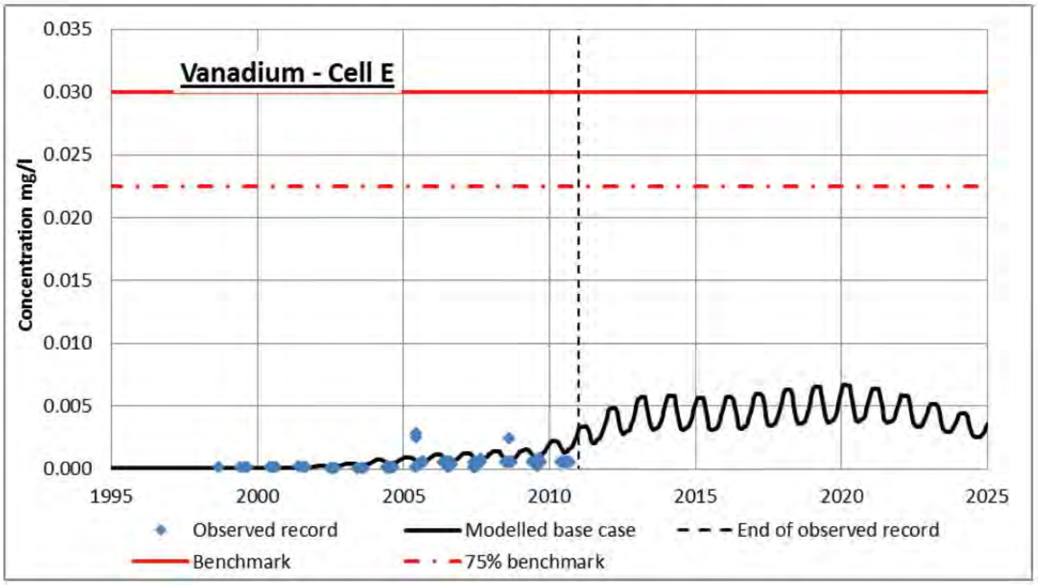
Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD Lower concentrations are observed pre-2004, then rise in concentrations over the period late 2004 to 2008. From 2008 higher average concentrations and higher variability in concentrations than in preceding years.
Modelling Approach for Future PPD Based on lognormal distribution of 2008 - 2010 observed PPD data.
Modelled Correlation between WQ Parameters Vanadium is correlated to aluminium (0.8)

Figure 2: Model Predictions for LLCF



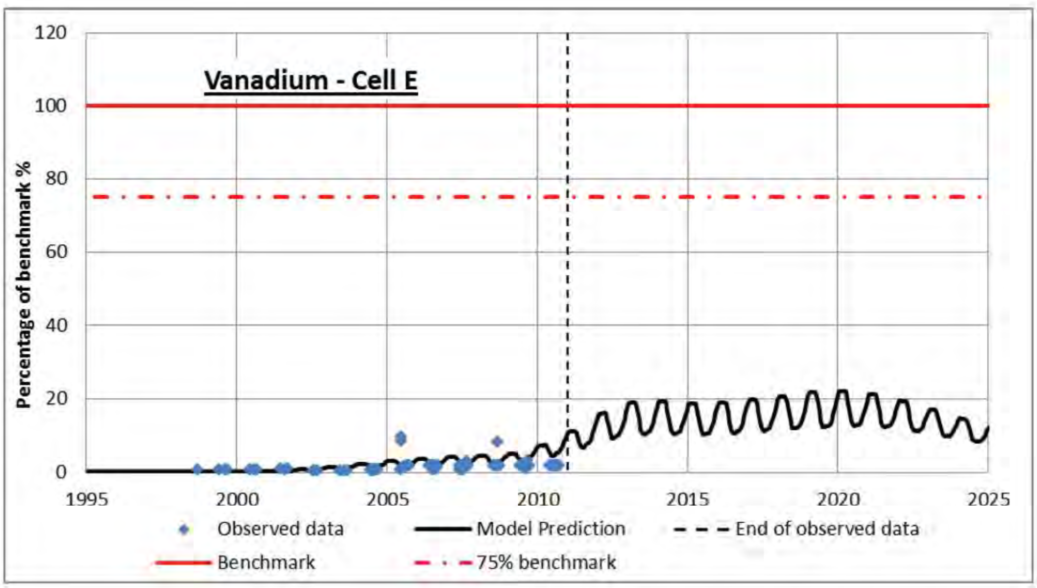


Figure 3: Predictions in Receiving Environment

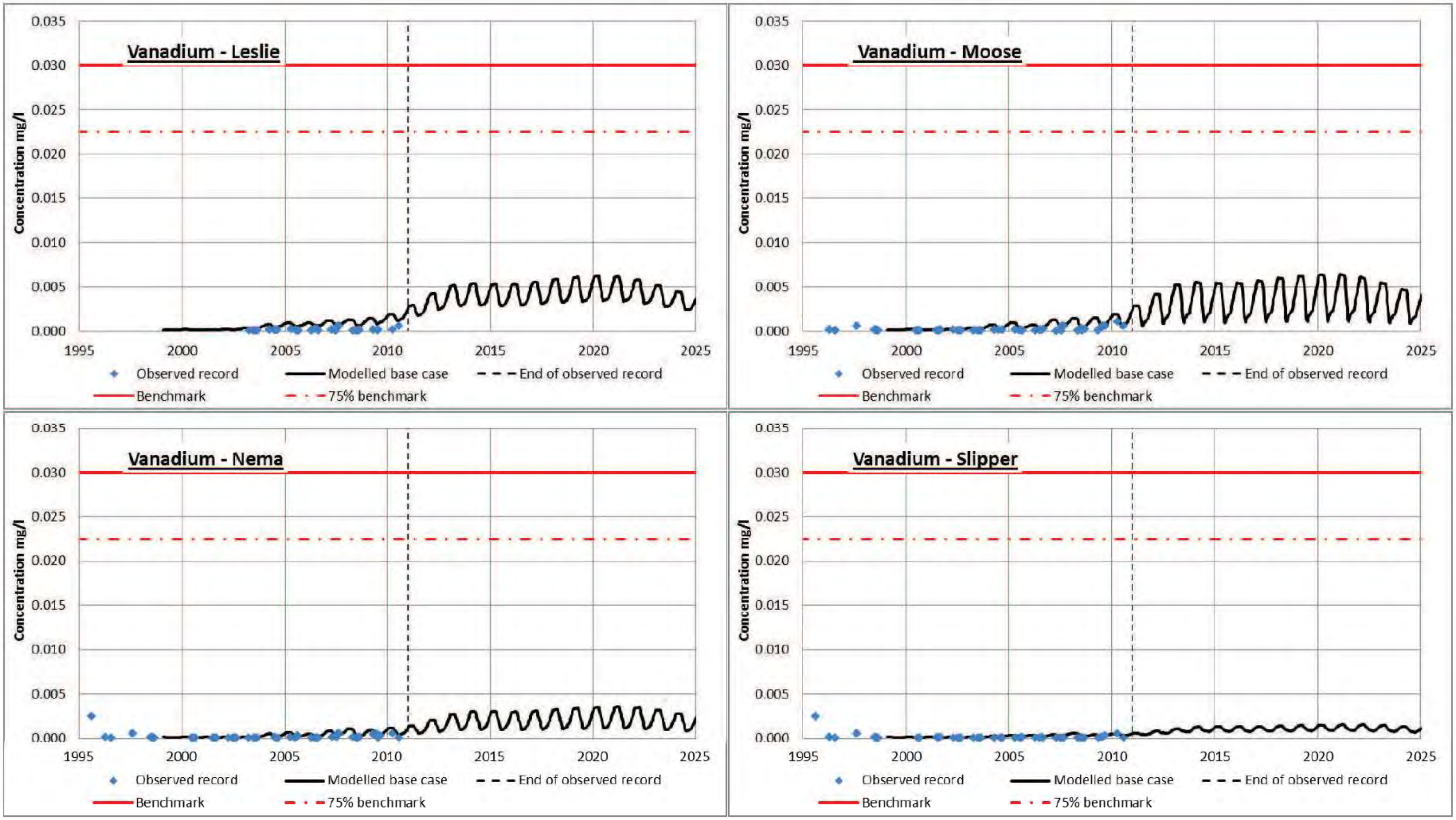
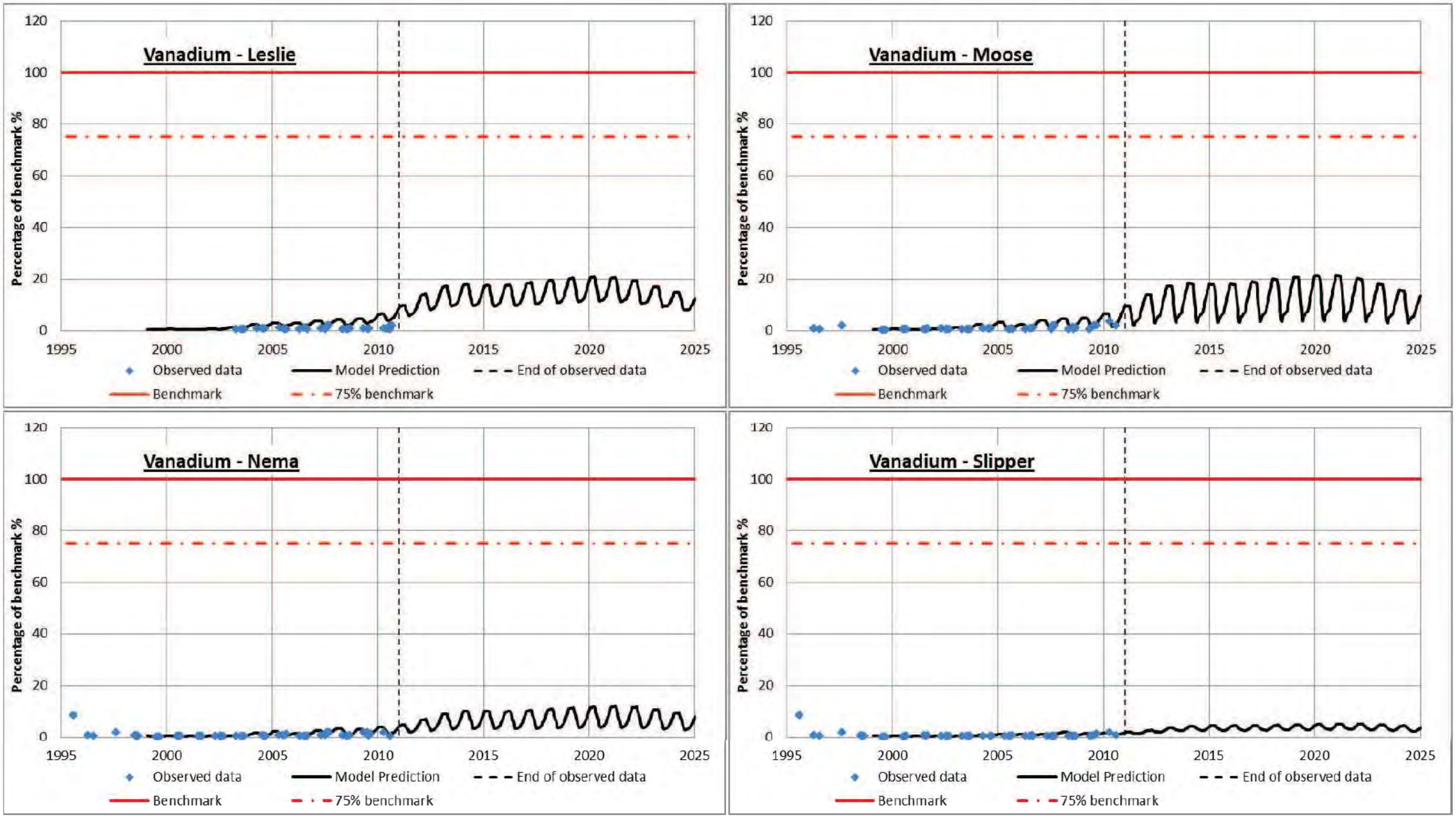


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark



Zinc

Sources of Parameter in LLCF

Historical 2000 – end 2010		*Future Estimated Based on Mine Plan (Jan 2011 – Feb 2020)*	
Process Plant	48%	Process Plant	34%
Sump	11%	Sump	10%
Underground	9%	Underground	0%
Runoff	32%	Runoff	37%
Beartooth Pit Reclaim	0%	Beartooth Pit Reclaim	18%

Key Comments Related to Modelling Work

Zinc concentrations are generally low and most water quality samples from Process Plant discharge are below detection limit.

The Base Case model run includes discharge of underground water to Beartooth pit starting in June 2009 and discharge of FPK slurry to Beartooth pit starting in September 2012. Once Beartooth pit approaches 30 m from spill level, free water is decanted to Process Plant for use as reclaim water.

Water Quality Benchmark

0.03 mg/L (CCME guideline)

Leslie Lake (mg/L)				Slipper Lake (mg/L)			
Historical Period (incl. Cell E data)		Best Estimate future peak concentration	Percentage of Benchmark	Historical Period		Best Estimate future peak concentration	Percentage of Benchmark
Highest observed	Median 2009/2010			Highest observed	Median 2009/2010		
0.016	0.00063	0.00318	11%	0.016	0.0005	0.00258	9%

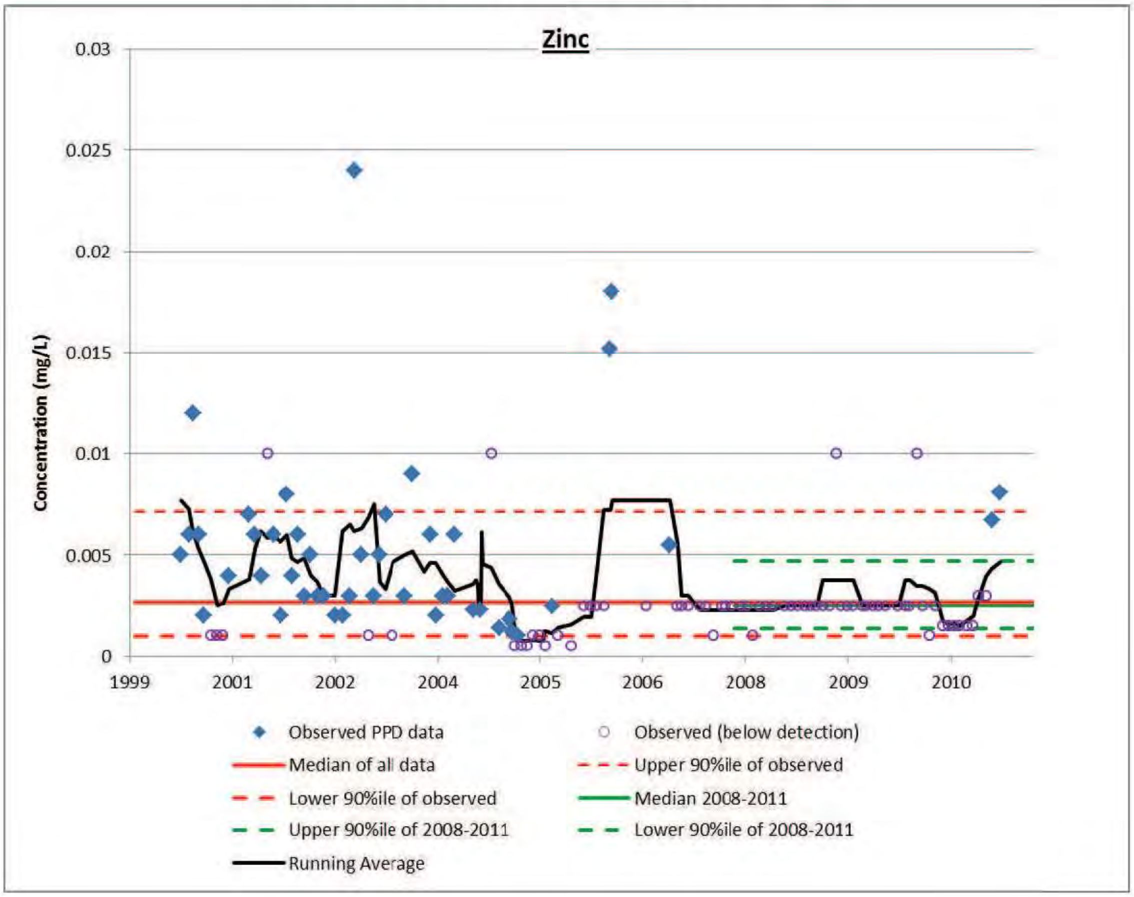
Comment on Model Fit to Observed Data

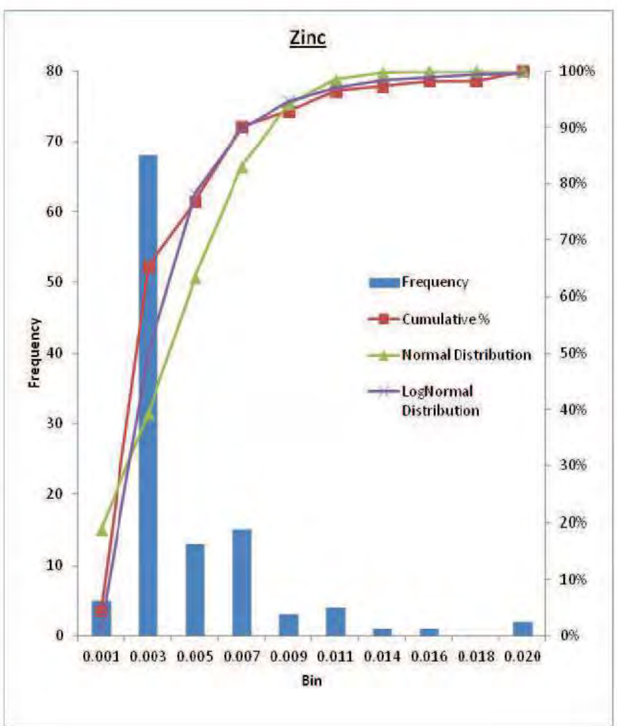
Reasonable fit with observed data, although many observed concentrations are below detection limit.

Summary

Historical concentrations and model predictions for downstream lakes are significantly below 75% of the benchmark.

Figure 1: Process Plant Inputs to LLCF Model





Comment on Historical Trends in PPD

Lower PPD concentrations post-2007/2008, with lower average values and lower variability in data.

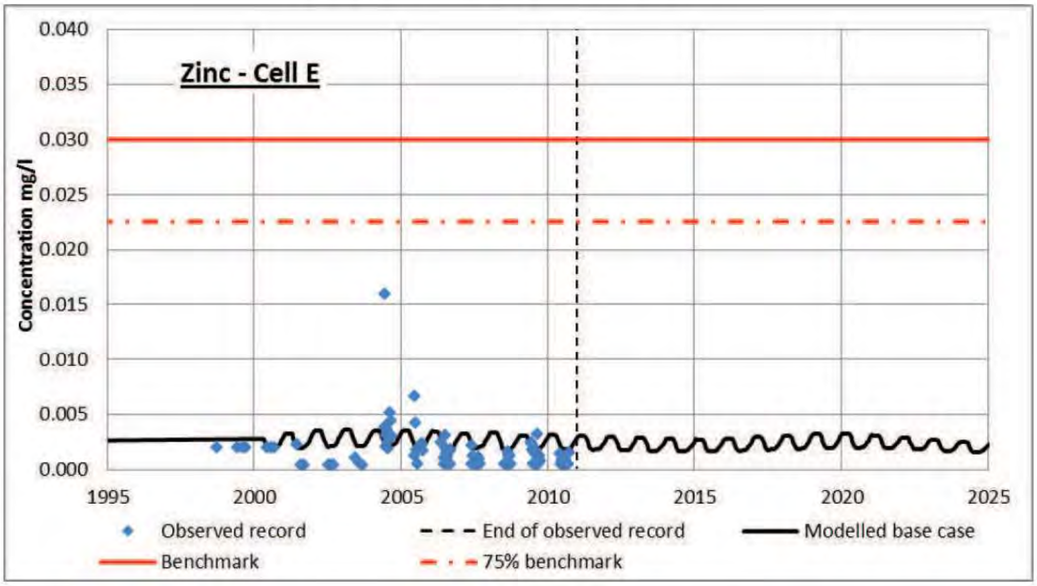
Modelling Approach for Future PPD

Based on lognormal distribution of all observed PPD data.

Modelled Correlation between WQ Parameters

Zinc is uncorrelated to other parameters.

Figure 2: Model Predictions for LLCF



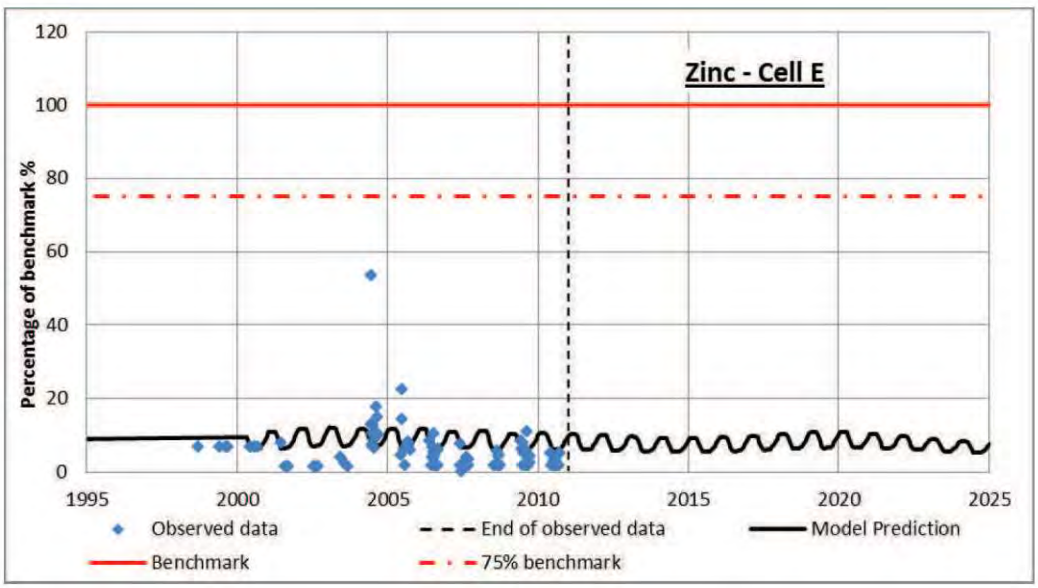


Figure 3: Predictions in Receiving Environment

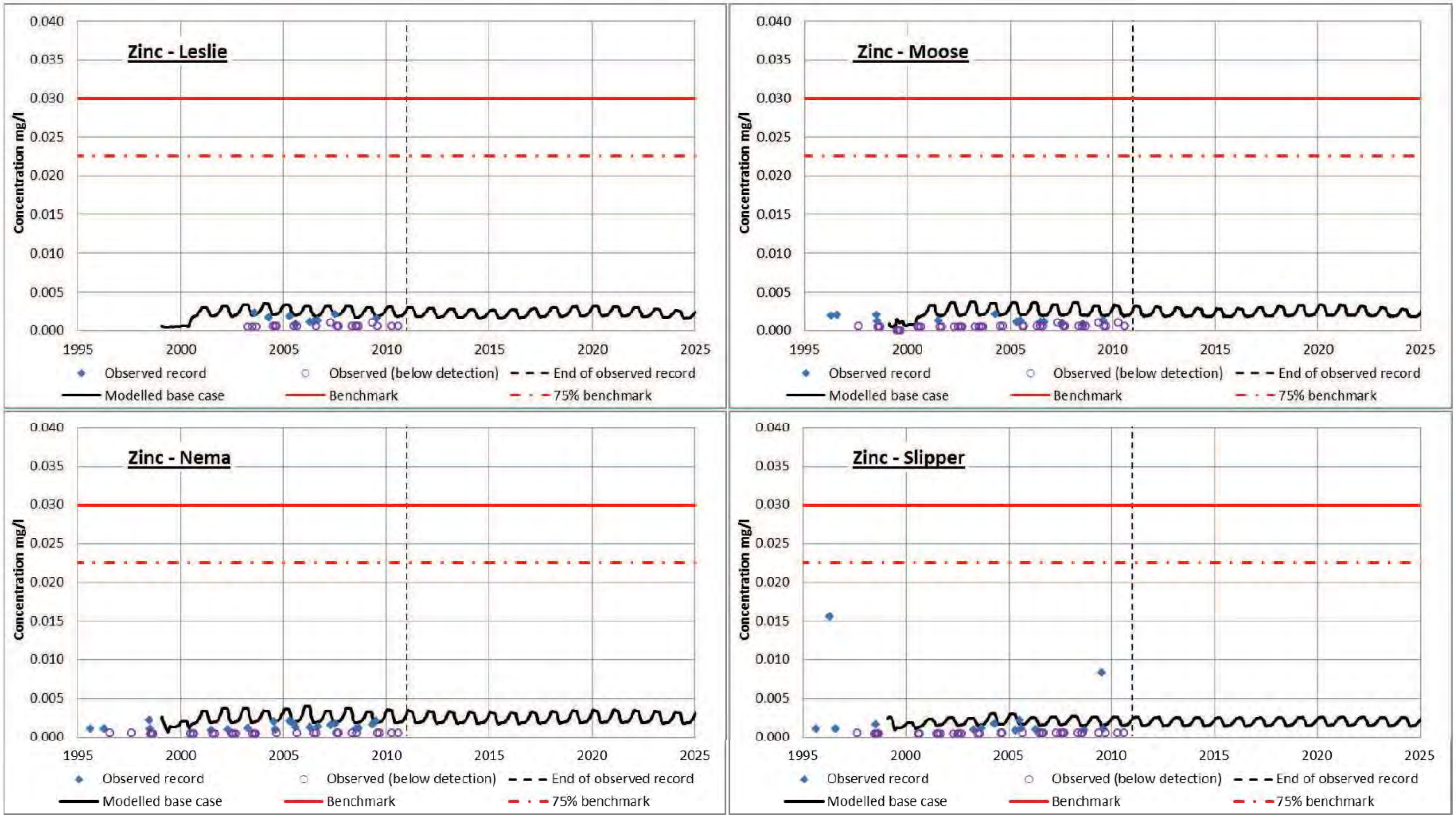


Figure 4: Predictions in Receiving Environment as Percentage of Benchmark